An analysis of the best method for evaluating anteversion of the acetabular component after total hip replacement on plain radiographs

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Abstract

Several radiological methods of measuring cup anteversion after total hip arthroplasty (THA) have been described. Different definitions and reference planes have been used when comparing methods in previous studies, causing misinterpretation of cup position. We compared the reliability and accuracy of five current methods using plain radiographs (Lewinnek, Widmer, Liaw, Pradhan, and Woo and Morrey) with CT measurements, using the same definition and reference plane. We retrospectively studied the plain radiographs and CT scans in 84 hips of 84 patients who underwent primary THA. Intra-and interobserver reliability was nearly perfect for cup inclination and anteversion measurements with all methods on plain radiographs and CT scans. Cup inclination measurements on plain radiographs were similar to CT measurements ($p = 0.043$). The mean difference between CT measurements was 0.6° (range, −5.9° to 6.8°). Measurements using Widmer's method was the most similar to CT measurements ($p = 0.088$), with a mean difference between CT measurements of only −0.9° (range, −10.4° to 9.1°), whereas the other four methods significantly differed from CT measurements ($p < 0.001$). Our study showed that Widmer`s method was the best for evaluating cup anteversion on plain radiographs.

Introduction

Accurate assessment of cup position is important to obtain a good long-term outcome after total hip arthroplasty (THA).[1-5] Plain radiographs and CT scans have been used to evaluate cup position after THA. Previous studies [6-9] have shown that cup position can be evaluated accurately using CT scans. However, plain radiographs are widely used for postoperative evaluation of cup position because CT scans are expensive and expose patients to considerable radiation.

Cup position has been defined as radiographic, operative, and anatomical inclination and anteversion.[10] The two reference planes for measuring cup position are the anterior pelvic plane (APP)[11] and the functional coronal plane (FCP) (Fig. 1). Cup inclination can easily be measured on anteroposterior (AP) radiographs, whereas cup anteversion is more difficult to measure.

Several radiological methods for measuring cup anteversion after THA have been described,[1,12-18] but few studies have compared the reliability and accuracy of different methods using plain radiographs.[19,20] In the previous literature,[19,20] different definitions and reference planes have been used in the same study. The mixed use of definitions and reference planes causes misinterpretation of cup position.

Our purpose in this study was to evaluate the reliability of five current methods of anteversion assessment (Lewinnek,[12] Widmer,[17] Liaw,[15] Pradhan,[16] and Woo and Morrey[1]) and to compare the accuracy of these methods to CT measurements using the same definition and reference plane.

Patients and Methods

We performed 268 primary THAs between August 2010 and December 2012. We excluded 163 patients with a clinical history of lumbar disease and/or contralateral hip disease to prevent any errors in measurement on cross-table lateral radiographs that may be caused by these entities. We also excluded 21 patients with no postoperative CT scans. The remaining 84 patients were included in this study.

We retrospectively studied AP radiographs, cross-table lateral radiographs and CT scans in 84 hips of 84 patients. This study was approved by our institutional review board and informed consent was obtained from all patients. There were 63 female and 21 male patients with a mean age of 66.3 years (range, 36 to 84 years) at the time of surgery. Preoperative diagnosis was osteoarthritis in 79 hips and osteonecrosis of the femoral head in five hips. All arthroplasties were performed by two experienced orthopaedic hip surgeons(MN and YN)through a posterolateral approach. In all cases, a cementless cup was implanted: 44 Trilogy cups (Zimmer, Warsaw, IN, USA), 31 TNH cups (Nakashima Medical, Okayama, Japan), and nine Pinnacle cups (Depuy, Warsaw, IN,

USA). The mean cup size was 51.1 mm (range, 48 mm to 54 mm). The articulation was metal-on-polyethylene in all cases.

One week after surgery, the same group of radiology technicians performed AP radiographs, cross-table lateral radiographs, and CT scans of the pelvis. AP radiographs of the pelvis were obtained in the supine position with hips in a neutral position. The radiation beam was centered on the superior aspect of the pubic symphysis and was perpendicular to the patient. The film-focus distance was 110 cm and no extra positioning guide was used. Cross-table lateral radiographs of the hip were taken with the contralateral hip flexed at 90°. The direction of the radiation beam was parallel to the examination table and 45° cephalad to the long axis of the body. X-ray film was held perpendicular to the examination table using a cassette holder.

CT scans were obtained in the supine position with hip joints in a neutral position. We used a 64-channel multi-detector CT system (Aquilion 64-slice CT scanner; Toshiba, Tokyo, Japan). The scan protocol had a 0.5 mm slice distance. All images were digitally acquired using the Picture Archiving and Communication System (PACS). The volume data were stored on a server at our hospital in Digital Imaging and Communications in Medicine (DICOM) format for later analysis.

Measurement of cup inclination on AP radiographs

Cup inclination is the angle between a line through the long axis of the cup ellipse and the inter-teardrop line on AP radiographs.

Measurement of cup anteversion on AP radiographs

Lewinnek's method[12]

$$\textit{Cup anteversion} = \arcsin(D1/D2)$$

D1 is the distance across the short axis of an ellipse drawn perpendicular to the long axis of the acetabular component. D2 is the distance across the long axis, which is the maximal diameter of the implant (Fig. 2a).

Widmer's method[17]

$$Cup\ anteversion = \arcsin(\text{short axis (S)}/\text{total length (TL)})$$

$$= 48.05 \times (S/TL) - 0.3,\ if\ 0.2 < S/TL < 0.6$$

S is the short axis of the ellipse and TL is the total length of the projected cross-section of the cup along the short axis. This method shows linear correlation for values of S/TL between 0.2 and 0.6 (Fig. 2b).

Liaw's method[15]

$$Cup\ anteversion = \sin^{-1}\tan\beta$$

β is the angle formed by the long axis of the component (AB) and the line connecting the top point of the ellipse and the end-point of the long axis (AC) (Fig. 2c)**.**

Pradhan's method[16]

$$Cup\ anteversion = \arcsin(P/0.4D)$$

D is the maximum distance across the long axis of the ellipse of the acetabular implant. A line is drawn perpendicular to the line of the long axis and intersecting the cup rim, beginning at a point one-fifth the total distance of the longitudinal line. P is the distance along this perpendicular line from the longitudinal line to the cup rim (Fig. 2d).

Measurement of cup anteversion on cross-table lateral radiographs

Woo and Morrey's method[1]

On cross-table-lateral radiographs, cup anteversion is measured as the angle formed by the long axis of the ellipsoid projection of the cup base and a vertical line (Fig. 2e).

Measurement of cup inclination and anteversion on CT scan

We used the following methods, borrowed from Murray's concept,[10] to measure cup position. We used a three-dimensional (3-D) workstation (Ziostation, version 1.17t ; ZAIOSOFT Inc, Tokyo, Japan) to reformat the image. We corrected malposition of the pelvis in rotation and abduction/adduction but maintained pelvic tilt relative to the CT table (the FCP). Pelvic images were re-sliced parallel to the FCP. In this plane, the angle between the line connecting the two points of the cup edge and the inter-teardrop line was measured as the radiographic inclination.

To evaluate radiographic anteversion, we created the plane orthogonal to a line drawn from the most medial point of the cup to the most lateral point of the cup. In this plane, the angle between a line perpendicular to the FCP and a tangential line across the open face of the cup was measured as radiographic anteversion (Fig. 3). Measurements of cup anteversion and inclination on CT scans were regarded as the reference standard.

Assessment of reliability and accuracy

Reliability was defined as consistency of measurements, and accuracy was defined as proximity to CT measurements. Four examiners (TN, TK, TS, and HS) performed all measurements independently, using the same protocols. To assess the intraobserver reliability of each method, one examiner (TN) measured all hips three times, with a three-week interval between measurements, without comparison to the previous measurements. The interobserver reliability of each method was assessed by comparing results of the four examiners. All measurements were made without knowledge of the patient's clinical information or of the measurements assigned by the other examiners. Plain radiographs and CT scans were presented to each examiner in random order by a research assistant who did not participate in the reliability and accuracy sessions.

To assess the accuracy of measurements on plain radiographs, we compared the average of measurements on plain radiographs with the average of CT measurements. We calculated the difference between measurements on plain radiographs and CT measurements.

Statistical analysis

The intraclass correlation coefficient (ICC) and 95% confidence interval (CI) were calculated for intra-and interobserver reliability. We used the two-way random-effects intraclass correlation model and absolute agreement to calculate the ICC. An ICC of 1 means perfect reliability, and an ICC of 0 means the opposite.

Paired *t*-tests were used to compare the accuracy of each plain radiograph method relative to CT measurements. Statistical analyses were conducted using SPSS for Windows, version 20.0 (SPSS Inc., Chicago, IL, USA) and statistical significance was set at $p < 0.01$.

Results

Reliability

All measurements on plain radiographs and CT scans had nearly perfect intra-and interobserver reliability.

The ICCs for measurements on CT scans ranged from 0.971 (95% CI, 0.959 to 0.980) for the intraobserver reliability of cup anteversion to 0.985 (95% CI, 0.979 to 0.990) for the interobserver reliability of cup inclination.

The ICCs for measurements on plain radiographs ranged from 0.913 (95% CI, 0.879 to 0.940) for the intraobserver reliability of Pradhan's methods[16] to 0.981 (95% CI, 0.973 to 0.987) for the interobserver reliability of Woo and Morrey's methods[1] (Table I).

Accuracy

Cup inclination measurements on AP radiographs were similar to CT measurements ($p = 0.043$). The mean difference in cup inclination between measurements on AP radiographs and CT measurements was 0.6° (range, −5.9° to 6.8°).

In terms of cup anteversion measurements, measurements made using Widmer's method[17] were not significantly different from CT measurements ($p = 0.088$) and the mean difference with Widmer's method[17] was −0.9° (range, −10.4° to 9.1°), whereas the other four methods were significantly different from CT measurements ($p < 0.001$) (Table II).

Discussion

Cup position is one of the most important factors in obtaining good long-term outcomes after THA. Malposition of the cup is reported to cause impingement, dislocation, limited range of motion, and increased polyethylene wear.[1-5] Previous studies have shown that cup position can be measured accurately using CT scans.[6-9] However, CT scans are expensive and involve considerable radiation exposure to the patient. Accordingly, plain radiographs are an important and widely used tool for assessing cup position after THA.[1,12,14,15,17,21]

Cup inclination can be directly and easily measured on AP radiographs. Our study showed that measurements of cup inclination on AP radiographs were reliable and accurate compared with CT measurements.

Cup anteversion is more difficult to measure and many methods using plain radiographs have been described.[1,12-18] However, few studies have compared the reliability and accuracy of different methods using plain radiographs.[19,20] Our study showed that measurements of cup anteversion using five plain radiograph methods (Lewinnek,[12] Widmer,[17] Liaw,[15] Pradhan,[16] and Woo and Morrey[1]) were reliable. Our findings are similar to those of previous studies.[20,22-24] Our study showed that of the five methods, only Widmer's method[17] was accurate. However, previous studies reported different results.[19,20] Marx et al.[19] compared the accuracy of five plain radiograph methods (Pradhan,[16] Mclaren,[25] Hassan,[14] Ackland,[13] and Widmer[17]) with CT measurements and concluded that Widmer's method[17] had a smaller error rate than the other four methods, but that measurement of cup anteversion using plain radiographs was inaccurate because of a variety of errors. Nho et al.[20] compared the accuracy of six different plain radiograph methods (Lewinnek,[12] Widmer,[17] Hassan,[14] Ackland,[13] Liaw,[15] and Woo and Morrey[1]) with CT measurements and reported that measurements obtained using Widmer's[17] and Ackland's[13] methods were significantly different from CT measurements, whereas the other methods were not. They concluded that the methods of Lewinnek,[12] Hassan,[14] Liaw,[15] and Woo and Morrey[1] were accurate.

Previous studies[19,20] used different definitions and reference planes, resulting in different results from our study (Table III). The APP was determined by three reference points: the two anterosuperior iliac spines and the anterior surface of the pubic symphysis.[11] The FCP was based on the longitudinal axis of the body. The APP deviates from the FCP because of pelvic tilt in almost all patients and varies up to 20°more from the FCP in some patients.[26] Malik et al.[27] reported that an AP pelvic tilt of 1° led to a change of approximately 0.8° in cup anteversion. Thus, a difference of 20° or more in pelvic tilt causes a corresponding difference in cup anteversion of 16° or more. Because of pelvic tilt, measurements of cup position on the FCP cannot be compared with those on the APP.[22,27,28]

In placing the acetabular component, recent studies have highlighted the concept of functional orientation of the acetabular component, which is based on the FCP.[27-30] These studies reported that the APP is not useful when it is used without considering the pelvic tilt, and could lead to

complications. Miki et al.[29] reported that the FCP is adequate for cup planning whether the pelvic tilt is small or large.

In general, on either the FCP or APP, anatomical inclination and anteversion are always greater than radiographic inclination and anteversion, anatomical inclination is always greater than operative inclination, and operative anteversion is always greater than radiographic anteversion. If a difference exists (depending on the combination of inclination and anteversion), the difference in inclination is small, whereas the difference in anteversion may be large.[10]

Cup position on plain radiographs has been defined as radiographic inclination and anteversion relative to the FCP. Cup position on CT scans must be measured using the same definition and reference plane to compare the accuracy of different plain radiography methods. Previous studies recommended using the radiographic definitions and the FCP[22,27,28] when comparing measurements of cup position on plain radiographs with those on CT scans. Mixed use of definitions and reference planes prevents direct comparison of reported methods.

Only a few studies have evaluated the accuracy of plain radiograph measuring methods by comparing them with CT measurements using the same radiographic definition on the same FCP.[22,23] Lu et al.[22] evaluated Lewinnek's method[12] and concluded that it was accurate and reliable. Nishino et al.[23] compared the accuracy and precision of Lewinnek's method[12] with that of Woo and Morrey[1] and concluded that Lewinnek's method[12] was more accurate and precise for measuring cup anteversion. To our knowledge, this is the first study comparing the accuracy of several plain radiographic methods with CT measurements using the same definition and reference plane.

Our study had several limitations. First, there is no gold standard for the accuracy of radiographic- or CT-based values in vivo. However, previous studies [6-9] have shown that cup position measurements using CT scans can be considered an acceptable standard for measurement. The principles of our methods are similar to those reported in the literature. Second, retroversion cannot be identified on AP radiographs. To identify ante-or retroversion, we need oblique or cross-table lateral radiographs.[13] In this study, there were no hips with retroversion according to CT measurements. Third, it is difficult to identify the apex of the ellipse on AP radiographs when a ceramic or metal liner is used.[20] Finally, the patient's position during radiography influences the measurements.[19] These limitations must be taken into consideration when our results are applied in clinical practice.

Our study found that Woo and Morrey's method[1] was inaccurate. However, Woo and Morrey's method[1] directly evaluates cup anteversion without complicated calculations and identifies ante- or retroversion. Cross-table lateral radiographs were taken with the contralateral hip flexed at 90°. Stiffness of the lumbar spine and/or contralateral hip joint might cause error in cup anteversion measurements on cross-table lateral radiographs because they influence the pelvic tilt when the contralateral hip is flexed. [31] Therefore, we excluded patients with a clinical history of lumbar

disease and/or contralateral hip disease. If the flexion angle of the contralateral hip was less than 90°, measurements of cup anteversion using cross-table lateral radiographs might be more accurate. McArthur et al.[32] reported that modification of the cross-table lateral radiograph by adjusting the beam angle to match the cup inclination angle improves accuracy and reliability. If the flexion angle of the contralateral hip is less than 90° and the X-ray beam angle matches the cup inclination angle, the measurement of cup anteversion using cross-table lateral radiographs may be more accurate and reliable. We plan to study this possibility in the future.

We found that Widmer's method[17] had some small errors in analysing cup anteversion. Considering the advantages of plain radiographs, including low cost, low radiation level, convenience for clinical follow-up and assessment of cup position, the errors were within a clinically acceptable range. Our study showed that Widmer`s methods was the best for evaluating cup anteversion on plain radiographs.

Table I Intra- and interobserver reliability of measurements on plain radiographs and CT.

Methods	Intra-observer reliability		Inter-observer reliability	
	ICC	95%CI	ICC	95%CI
Cup inclination				
CT	0.983	0.976 to 0.988	0.985	0.979 to 0.990
AP radiograph	0.973	0.961 to 0.982	0.982	0.975 to 0.987
Cup anteversion				
CT	0.971	0.959 to 0.980	0.975	0.966 to 0.983
Lewinnek[12]	0.930	0.899 to 0.952	0.946	0.926 to 0.962
Widmer[17]	0.925	0.873 to 0.953	0.944	0.921 to 0.962
Liaw[15]	0.922	0.890 to 0.946	0.929	0.903 to 0.950
Pradhan[16]	0.913	0.879 to 0.940	0.923	0.894 to 0.945
Woo and Morrey[1]	0.976	0.966 to 0.984	0.981	0.973 to 0.987

ICC=intraclass correlation coefficient; CI=confidence interval

Table II Accuracy of measurements on plain radiographs compared with CT measurements using paired *t*-tests.

Methods	Mean(range)	Difference Mean(range)	p-value (*t*-test)
Cup inclination(°)			
CT	38.4(25.1 to 54.3)	-	-
AP radiograph	39.0(24.3 to 55.1)	0.6(-5.9 to 6.8)	0.043
Cup anteversion(°)			
CT	23.8(8.6 to 38.7)	-	-
Lewinnek[12]	19.2(7.3 to 32.8)	-4.6(-14.9 to 5.4)	< 0.001
Widmer[17]	22.9(10.1 to 40.4)	-0.9(-10.4 to 9.1)	0.088
Liaw[15]	19.7(7.6 to 33.9)	-4.1(-14.5 to 4.1)	< 0.001
Pradhan[16]	18.5(6.6 to 37.0)	-5.3(-15.3 to 5.2)	< 0.001
Woo and Morrey[1]	27.7(8.8 to 43.7)	3.9(-4.9 to 15.2)	< 0.001

Table III Reported accuracy of plain radiographic measurements compared with CT measurements for anteversion using paired *t*-tests.

Study	Methods for measuring cup anteversion	Definition of anteversion /Reference plane of CT	Anteversion ±SD(°)	Mean error ±SD(°)	p-value (*t*-test)
Marx et al.[19]	CT	Radiographic / APP	29.9±8.7	-	-
	McLaren[25]		15.4±7.7	-14.5±10.5	< 0.0001
	Ackland[13]		15.6±8.2	-14.3±10.3	< 0.0001
	Pradhan[16]		15.4±8.4	-14.5±10.2	< 0.0001
	Widmer[17]		23.5±10.5	-6.4±10.8	< 0.0001
	Hassan[14]		15.5±8.3	-14.4±10.2	< 0.0001
Nho et al.[20]	CT	Anatomical / FCP	26.8±7.9	-	-
	Lewinnek[12]		26.9±6.2	Not Known	0.901
	Widmer[17]		19.1±3.3		< 0.001
	Hassan[14]		26.1±5.3		0.425
	Ackland[13]		15.7±3.5		< 0.001
	Liaw[15]		28.5±6.3		0.058

Woo and Morrey[1]	28.1±6.3	0.171

SD = standard deviation

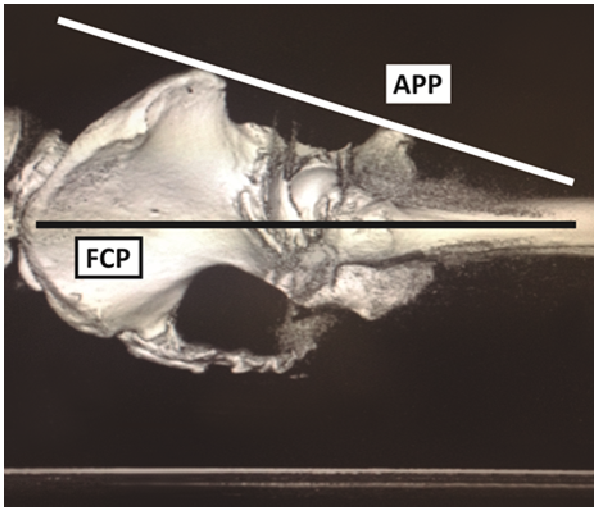

Fig. 1 Reference planes for measuring cup position.

APP: anterior pelvic plane, FCP: functional coronal plane

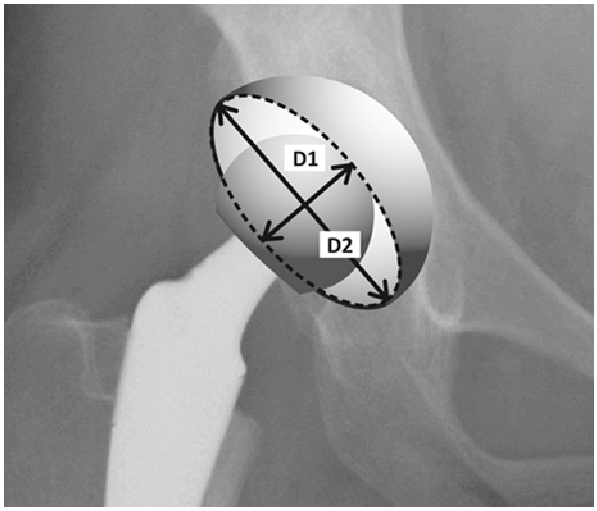

Fig. 2a

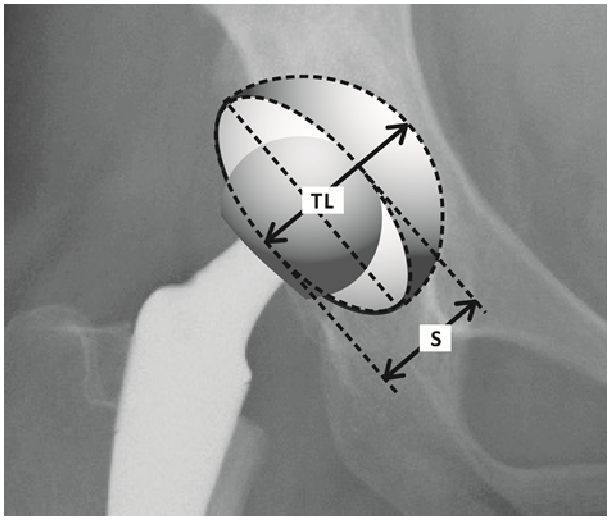

Fig. 2b

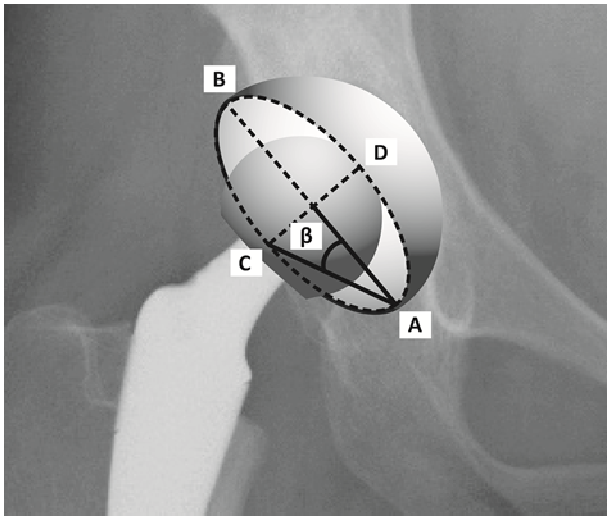

Fig. 2c

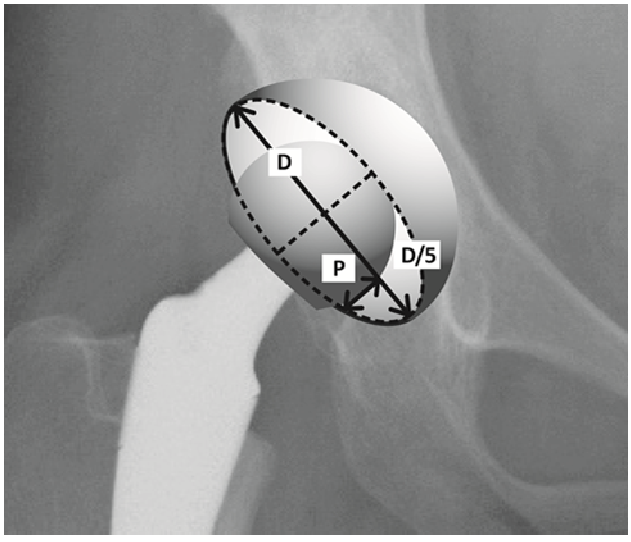

Fig. 2d

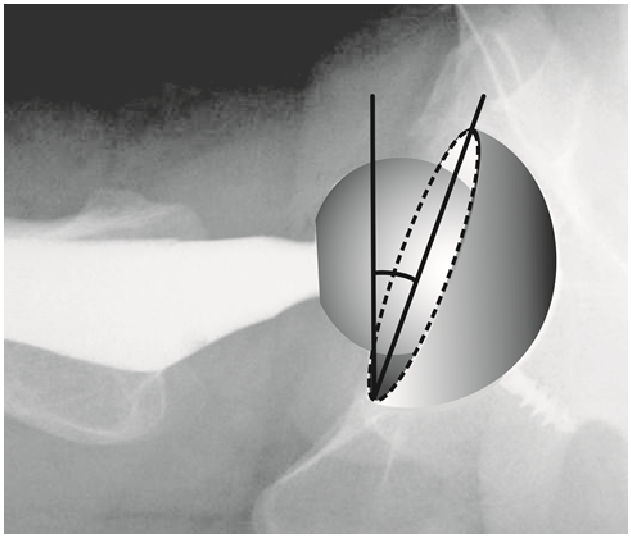

Fig. 2e

Methods for measuring cup anteversion on plain radiographs.
a) Lewinnek[12] b) Widmer[17] c) Liaw[15] d) Pradhan[16] e) Woo and Morrey[1]

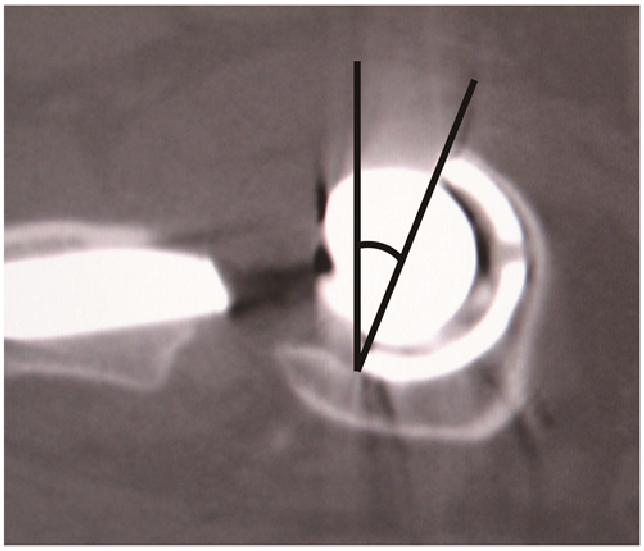

Fig. 3 Method for measuring cup anteversion on CT scans

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