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Misinterpretation of cup anteversion in total hip arthroplasty using planar radiography

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Abstract
Introduction Anteroposterior pelvic radiographs are routinely used to monitor cup orientation in total hip arthroplasty (THA). Analysis of planar radiographs leads to a certain degree of measurement error for the cup anteversion (AV). With the current study, we wanted to clarify whether planar radiography can be used for accurate evaluation of the THA position.
Materials and methods The postoperative orientation of pelvic implants in 42 patients was analyzed according to five documented mathematical algorithms using planar radiographs. Postoperative computed tomography (CT) pelvis scans were available for all patients. A CT-based navigation system was used to determine AV.
Results The comparison showed that all five formulas presented substantial variations for the AV angle. Of these, Widmer's algorithm presented the smallest difference compared to the CT. Misinterpretation of postoperative planar radiographs is a common problem in THA.
Conclusion Planar radiographs are too imprecise for exact evaluation of the correct cup AV after THA. CT-based analysis may be necessary if exact values are required.

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Introduction

Planar radiography is routinely used to monitor the correct orientation of implants after total hip arthroplasty (THA). To interpret the three-dimensional orientation of implants on radiographs, both patient and X-ray beam have to be in an ideal position. The pelvis of the patient has to be plane on the radiography table. Tilting, rotation, and obliqueness of the pelvis must either be prevented or properly corrected by computations.

There are various definitions for cup inclination and anteversion (AV) to describe the acetabular implant position: These can be classified as surgical, anatomical, and radiological evaluation methods [18, 25, 26]. The radiological inclination is the angle between the longitudinal axis and the acetabular axis projected onto the coronal plane [11, 14, 18, 21, 25]. The radiological AV is the angle between the acetabular axis and the projection of the acetabular axis onto the coronal plane [11, 18, 25].

Different methods of analyzing postoperative planar radiographs have been published by various authors [1, 10, 16, 21, 28]. Different algorithms help to calculate the orientation of the implant based on the projection of the cup as an ellipse on the film.

In contrast, newer technologies use computed proceedings to perfect surgical accuracy in hip surgery [3, 6, 12, 13, 19, 22, 23]. These procedures can be used to analyze the quality of surgical treatment [3, 22, 23, 25, 26].

Ideal implant position is essential to achieve low wear, minimize the risk of dislocation, and ensure longstanding of the implant. These three objectives are documented in the literature as the criteria for achieving an optimal outcome after THA [2, 4, 14, 15, 17, 20, 29] and are defined standards in modern hip surgery. For a reasonable follow-up after THA, the implant's position must be exactly determined post-operatively in order to preclude implant malposition as a cause of early failure.

There are several hypotheses for this study: Is planar radiography a successful tool for verifying cup position after THA? Do measurement errors occur frequently and do conventional radiographs lead to incorrect judgment of implant position? When the published mathematical algorithms are used to calculate the cup AV in planar radiographs, is one of the formulae superior to the other calculation methods or are all versions too imprecise to serve as a basis for an accurate opinion?

Materials and methods

We retrospectively reviewed the planar radiographs and CT scans of 42 patients who had undergone THA at two institutions (the University of Duisburg-Essen and the University of Bochum). Eighteen patients were operated in Essen and 24 at the Orthopaedic Department in Bochum. There were 11 men and 31 women. In 24 cases, a hemispheric cup was implanted, in 14 cases a screw cup, and in 4 cases a cemented implant. All operations had been planned using a computed tomography (CT)-based computer-assisted navigation system and were performed between May 1999 and July 2004. We consecutively included only patients who already had a THA of the contralateral side. In all cases, symphysis-centered radiography was performed with the patients lying flat on the radiography table. No extra caliper was used.

Both departments used the computer-assisted cup placement module of the SurgiGATE©-System (Praxim AG, Bern, Switzerland; formerly Medivision, Oberdorf, Switzerland) introduced by Langlotz et al. [13].

All patients underwent a CT scan of the pelvis. The scan protocol had a 2-mm slice distance. The patients were positioned supine on the CT table. No extra positioning guide was used. The whole pelvis was scanned to determine the orientation of the anterior pelvic plane defined by both anterior superior iliac spines and the pubic tubercles. A three-dimensional model of the pelvis was constructed. The position of the cups was measured relative to this reference plane using the planning part of the CT-based hip module. A virtual cup was superimposed onto the implanted cup and the exact AV of the component could be measured with the computer navigation system (Fig. 1). This procedure was performed by one observer (A.M.) who was familiar with the system.

All radiographic methods used the ellipse of the acetabular implant rim to calculate the AV (Fig. 2). A line at the maximum diameter of the ellipse of the acetabular implant (D) was marked. The investigation was performed by one observer (A.M.) using the Medicad II-System (Hectec GmbH©, Altfraunhofen, Germany). The five following algorithms to assess the cup AV were included:

(1). Pradhan [21]:

$$\text{Anteversion} = \arcsin\left(\frac{p}{0.4D}\right) \tag{1}$$

where D is the maximum diameter of the ellipse of the acetabular implant (Fig. 2). A line is drawn perpendicular to the cup rim after one-fifth of the diameter. The distance along this line between the diametrical line and the rim of the cup is p.

(2). McLaren [16, 25]:

$$\text{Anteversion} = \arcsin\left(\frac{a}{b}\right) \tag{2}$$

A right angle is drawn at the center of the diameter a/b of the acetabular implant ellipse (Fig. 2). The distance to the intersection with the cup rim is a/b:

(3). Hassan [10, 25]:

$$\text{Anteversion} = \arcsin\left[\frac{x/D}{\sqrt{(x/D - x^2/D^2)}}\right] \tag{3}$$

where D is the maximum diameter of the acetabular implant ellipse. An arbitrary tangent is drawn at a right angle to the diameter. The distance of this tangent between the diametrical line and the rim of the cup is $y/2$ (Fig. 2). X is the distance from the end of the ellipse to the cross-section between the tangent and the diametrical line.

(4). Ackland [1, 25]:

$$\text{Anteversion} = \arcsin\left[\frac{2y}{2\sqrt{2ax - x^2}}\right] \tag{4}$$

A right angle is drawn at the center of the diameter of the ellipse $a/2$ (Fig. 2). The distance to the intersection

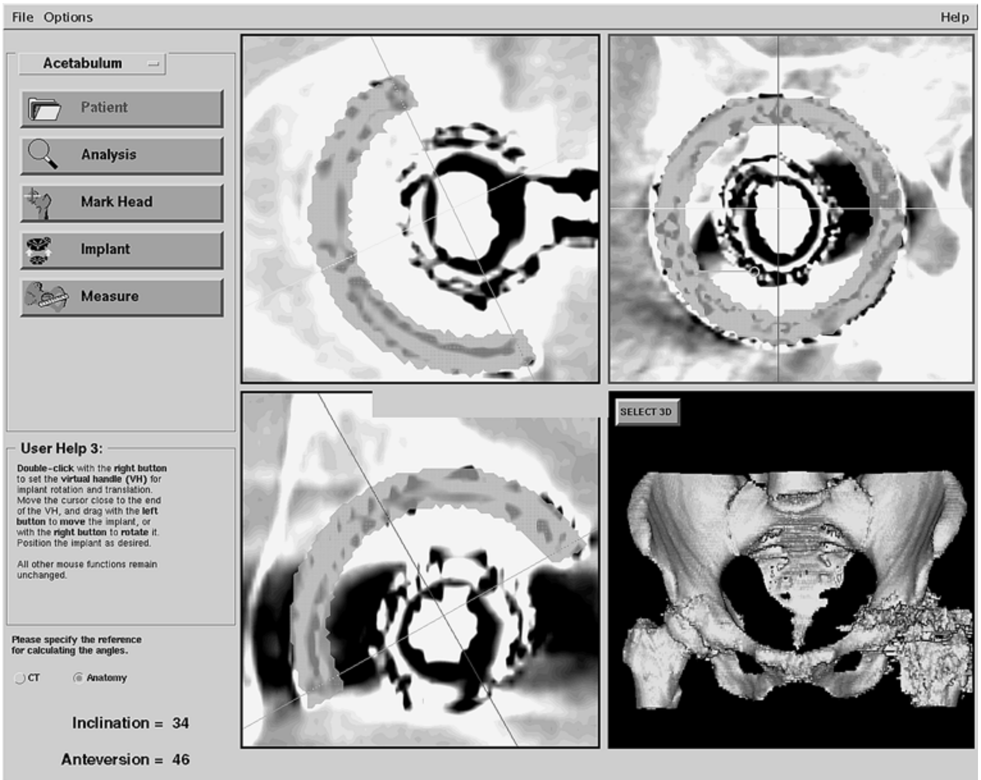

Fig. 1 The SurgiGATE© computer planning system shows superimposition of the virtual cup onto the implant

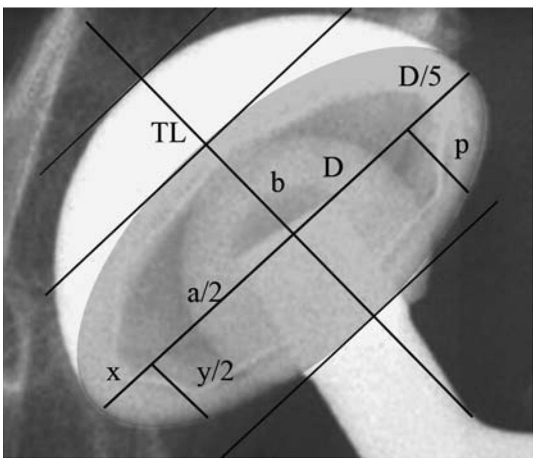

Fig. 2 An analysis of the planar radiography is shown using the ellipse of the cup rim and various algorithms to determine the cup *AV*

with the cup rim is *b*/2. An arbitrary tangent is drawn at a right angle to the diameter. The distance from the two-cup rims along this tangent is *y*. *X* is the distance from the end of the ellipse to the cross-section between the tangent and the diametrical line.

(5). Widmer [28]:

$$\text{Anteversion} = \arcsin\left(\frac{b}{TL}\right) \quad (5)$$

where *D* is the maximum diameter of the ellipse of the acetabular implant (Fig. 2). A line is drawn perpendicular to *D* from the proximal top of the cup to the distal intersection with the cup rim. Along this line, the distance from the top of the cup to the distal cup rim intersection is *TL*. The distance along this line between the two-cup rim intersections is *b*.

The gold standard for our investigation was the data set obtained by the CT-based navigation system. As analyzed by Bernsmann et al. [3], these values can be obtained with an accuracy of about 1°. For comparison, we calculated the difference (Δ angle) between the AV angle of the planar radiography for all five formulas and the CT-based angle. A negative value meant a lower AT angle for planar radiography compared to CT-based measurement.

Descriptive statistics for the Δ angles were calculated for all five algorithms with means and standard deviations. Normal distribution was checked using the Shapiro–Wilks test. We used box plots for the visual presentation according to Der and Everitt [5]. The box included the interquartile range. The cross marked the medium and the whiskers comprised outliers up to one-and-a-half interquartile ranges. We used Student's paired *t* tests for comparison of planar and CT-based AV angles. Using a Pearson's regression, we determined the relation of the Δ angle and increasing AV and inclination angles at the CT measurements. We determined significant differences between the five planar algorithms using a one-way analysis of variance (ANOVA) with an *F* test for a significant deviation. For multiple pairwise comparisons, we used the Ryan–Einot–Gabriel–Welsch *F* test and the Scheffé test [5]. For all tests, we used a significance level of alpha = 0.05. For multiple testing, we conducted post hoc testing using the Bonferroni transformation. All tests were two-sided. All statistics were performed with SPSS 12.0.

Results

Nearly all measurements for the planar AV angles were lower (69–88%) than the CT-based AV angles (Table 1). Widmer's AV formula had Δ angles of mean –6.4, the other four AV formulas presented means at nearly the same level, ranging from –14.3 to –14.5 for all tests. For all tests, the standard deviations were remarkable (10.2–10.8). Post hoc testing confirmed differences between the planar and CT-based AV values.

Only Widmer's formula resulted in a larger (31%) group of Δ values near or above zero (Fig. 3). For the others, only outliers reached positive values (11–14%).

A correlation of the Δ angles and CT-based AV values showed uniformly increasing deviations with increasing AV values for all five formulas (Fig. 4a). Regression analysis showed slopes of –0.52 to –0.65. The level of the deviations was lower for Widmer's formula, but similarly high for the other four. The correlation measure (R^2) for Widmer was moderate (0.38), and for the others it was between 0.56 and 0.63. This demonstrates that the increasing error with increasing AV angles is more random and smaller for Widmer's formula, but more interrelated and larger for the other four formulas.

A similar situation was found for the correlation of the Δ AV angle and the CT-based inclination angle (Fig. 4b). For decreasing inclination, the deviation of all five AV formulas increased similarly with a

Table 1 AV angles and Δ angles of the five AV formulas*

AV formula	AV angle		Δ Angle				*P* value (*t* test)
	Mean	SD	Mean	SD	Min	Max	
McLaren [16]	15.4	7.7	-14.5	10.5	-36.1	3.7	< 0.0001
Ackland et al. [1]	15.6	8.2	-14.3	10.3	-33.8	5.5	< 0.0001
Pradhan [21]	15.4	8.4	-14.5	10.2	-33.9	5.2	< 0.0001
Widmer [28]	23.5	10.5	-6.4	10.8	-26	17.9	< 0.0001
Hassan et al. [10]	15.5	8.3	-14.4	10.2	-34.2	5	< 0.0001
$AV_{CT\text{-}based}$	29.9	8.7	–	–	–	–	–
$Incl_{CT\text{-}based}$	43.1	6.9	–	–	–	–	–

SD standard deviation, *Incl* inclination, *Min/Max* ranges of the Δ angle

*Paired *t* tests compared plain and CT-based AV angles; $p < 0.01$ were significant

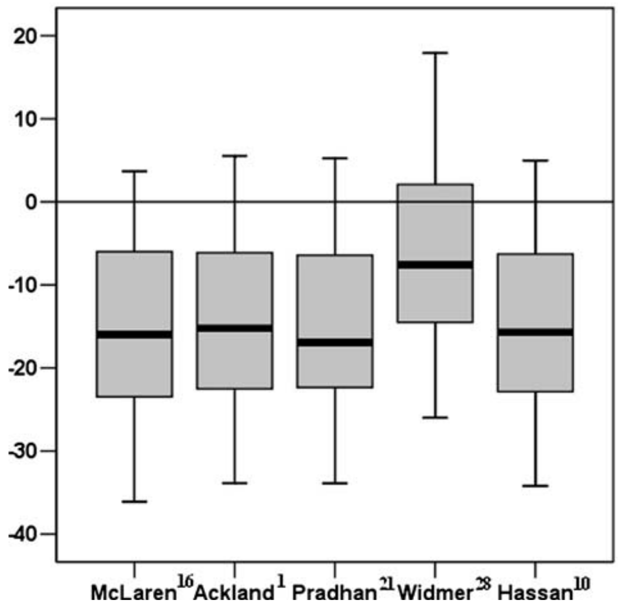

Fig. 3 A box and whisker plot diagram shows the Δ angles for all five *AV* formulas

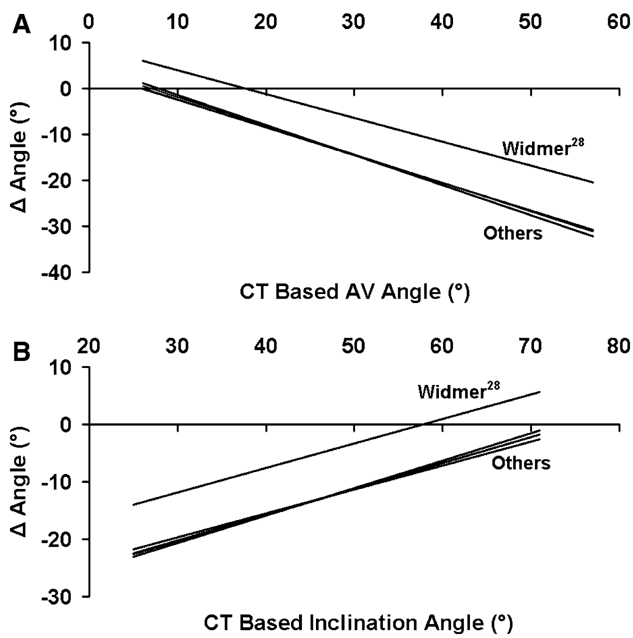

Fig. 4 Graphs showing the correlation of Δ values for all five *AV* formulas with the **a** *CT*-based *AV* angle and the **b** *CT*-based inclination angle

regression slope of 0.42–0.48. Only the error level of Widmer's algorithm was lower, with no relevant differences between the other four algorithms. However, the correlation measure (R^2) was poor for all five formulas (0.12–0.15). We did not observe a relevant relation between the Δ AV angles and the CT-based inclination angle.

The Δ values for all hips using the five algorithms were normally distributed. The means of the Δ values differed significantly ($F = 4.93$, $p = 0.0008$), but only the Widmer algorithm produced values different from the four others (which were similar).

Discussion

We are aware of the ideal implant position in THA from laboratory and clinical testings [2, 4, 14, 17, 29] The correct values have to be assured for scientific, comparative analysis. The AV angle is probably a risk factor for dislocation and mechanical loosening [3, 14, 15, 23]. In our study, we compared five mathematical algorithms for calculating cup AV using planar radiographs. We ascertained that all five algorithms had significant and clinically relevant differences to the gold standard and showed large variations due to measurement errors. This was a measurement bias and would mask a risk factor. For all five AV formulas, the error increased as the AV angles of the cup increased.

Of the five formulas, Widmer's had the lowest values. Furthermore, Widmer's Δ values had the lowest interrelation with the AV angle. Comparison of all five algorithms showed that Widmer's formula was different from the others.

In many cases, only anteroposterior pelvic radiographs are performed as a routine measure. Pelvic orientation during radiography cannot be accurately standardized. Flexion contraction of the operated hip, simultaneous disease of the contralateral side, or disorders of the lower spine can lead to an unbalanced position during the radiological procedure [11, 26]. Measures to optimize the patient's position during radiography cannot achieve perfect conditions [7, 8, 10]. Tannast et al. [26] showed that in most cases the pelvic tilt (rotation along the pelvic horizontal axis) cannot be prevented in planar radiographs of the hip.

Retroversion of the acetabular implant cannot be identified with certainty on planar films. Adjustments are necessary to detect incorrect cup placement [1, 24].

As seen in the literature, a computer navigation system ensures a high degree of accuracy for implant positioning and information about orientation of the components. This so-called ''anterior pelvic plane'' is the basis for the calculation of the correct inclination and AV of the cup [3, 6, 12, 13, 19, 22, 23, 25, 26]. CT scanning or new fluoroscopic techniques [9, 27, 30] help to define a reference co-ordinate system. The analysis is therefore independent of the patient's orientation during the imaging process. There are further limitations in the design of our study.

The investigation of the planar radiographs and the CT data sets requires reasonable care to achieve exact data. The analysis was performed by a single observer and no interobserver or intraobserver analysis was executed. Various types of implants were included in this study. Besides hemispheric cups, screw-in and cemented polyethylene cups were analyzed. There was no low image quality.

Furthermore, these techniques have limitations for orthopedic surgeons in everyday practice. A standardized postoperative CT scan is inefficient regarding costs and radiation dosage for patients. Our arrangement can therefore only be used for scientific research.

Symphysis-centered radiographs were analyzed in this study. Varying the X-ray beam certainly influences the mathematical algorithms. We found consistently lower AV values for all algorithms. According to basic geometrical knowledge, hip-centered images should lead to somewhat larger values, but no exact values for these statements are available [1, 21]. Even Hassan's analysis found that AV angles based on hip-focused X-rays were too low [10]. Ackland and Pradhan suggested a general correction by adding 5° for all symphysis-centered radiographs, but presented no evidence to support this proposal. However, as seen in the analysis, the error is not linear. The study showed that the errors increase as the AV angles increase. The outcome is also affected by the inclination angle. There is therefore no simple general correction factor that may lead to correct data. In our next study, we will investigate the relationship between hips and symphysis-centered radiography analysis.

When these five algorithms are used to analyze cup AV by planar radiography, a certain amount of error has to be expected. We found differences to the gold standard of up to –36°. In many situations, the influence on results of the patient's position during radiography cannot be controlled sufficiently. For scientific or clinical reasons, CT-based analysis may be necessary if exact values are required. Of all algorithms, only Widmer's formula had a smaller error rate and can be recommended for approximations of analyses based on planar radiography.

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