



Intraoperative measurement of cup inclination using fluoroscopy requires a correction factor

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Abstract

Introduction Malpositioning of the cup in total hip arthroplasty (THA) is associated with dislocation, early polyethylene wear, and impingement. The direct anterior approach (DAA) THA allows for intraoperative fluoroscopy imaging (IF). The current study investigates the following research hypotheses: (1) intraoperative measurements of radiographic cup inclination (RI) are reliable and reproducible. (2) A correction factor can compensate for the complex parallax effects when using IF.

Methods In 2016, 100 consecutive hips underwent primary THA utilizing DAA and IF for cup placement. RI was measured on intraoperative fluoroscopy images and postoperative AP pelvis radiographs.

Results Determination of RI on IF images is reliable and reproducible (ICC 0.851–0.950). RI measurement on IF images had a good correlation with the corresponding postoperative RI on AP pelvis radiographs ($r=0.538$, $p<0.001$). However, intraoperative RI measurements are on average 4.9° lower compared to postoperative measurements (SD 2.5°).

Conclusion Intraoperative fluoroscopy is a reliable tool to measure RI during DAA THA. The surgeon needs to apply a 5° correction factor to the intraoperative measurements to adjust for parallax.

Keywords THA · Cup positioning · Intraoperative fluoroscopy · Inclination

Introduction

Correct positioning of the acetabular component is essential for successful total hip arthroplasty (THA). Malpositioning is related to dislocation, early polyethylene wear, and impingement [6, 10, 12]. High-volume surgeons hit the target zone for inclination and anteversion in up to 86% during posterior approach THA [23]. The use of intraoperative fluoroscopy (IF) during the direct anterior approach (DAA) does improve the accuracy of acetabular component positioning [1]. Unlike MR- and CT-based 3-dimensional navigation techniques [7, 18], IF images can be easily obtained. However, stereometric effects (parallax) in two-dimensional projections can alter angle measurements [16,

17]. IF measurements might, therefore, not resemble postoperative measurements on standardized plain radiographs [9, 11, 20]. While the intraoperative measurement of cup anteversion has been validated [1] this is not the case for the measurement of cup inclination (RI). The current study investigates the following research hypotheses: (1) intraoperative measurements of radiographic cup inclination (RI) are reliable and reproducible. (2) A correction factor can compensate for the complex parallax effects when using IF.

Materials and methods

In 2016, the senior author and high-volume surgeon performed 121 consecutive THA in 113 patients using the DAA and intraoperative standardized c-arm imaging. All patients were diagnosed with osteoarthritis, except one patient was s/p hip fusion. 21 hips were excluded because of inappropriate images (18 hips, 14.9%), the use of dual-mobility cups (2 hips, 1.7%) or missing follow-up images (1 hip, 0.8%). Of those included, all patients underwent DAA THA utilizing an uncemented acetabular component (Pinnacle, DePuy

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Synthes, Warsaw, IN), and an uncemented stem (7 TRI-LOCK, 81 CORAIL, 2 ACTIS, DePuy Synthes, Warsaw, IN and 10 ANTHOLOGY, Smith&Nephew, Memphis, TN). The study included 68 females and 27 males. At the time of surgery, the patients had a mean age of 62.3 years (range 26–84) and a BMI of 24.8 kg/m² (range 17–34). There were 50 left and 50 right hips, including 5 patients underwent two-staged bilateral THA.

Radiographic evaluation

Intraoperative c-arm images were obtained using a 12-inch GE 9900 elite C-arm (GE Healthcare, Chicago, IL). The patient was in a supine position and the detector of the c-arm was placed as close to the patient as possible. The pelvis position was corrected based on size of the obturator foramen and the alignment between sacrum and symphysis. The c-arm was tilted around the patient's horizontal axis until the height-to-width ratio matched the corresponding preoperative AP pelvic radiograph to eliminate vertical pelvic tilt and tilted around its longitudinal axis until the extension of the tip of the sacrum projected to the symphysis and the height-to-width ratio of the obturator foramen was equal to eliminate malrotation (Fig. 1). Images were taken centered over the symphysis including both hips.

All patients underwent standardized preoperative and 4-week postoperative weight-bearing anterior to posterior (AP) pelvic radiographs with the x-beam centered on the symphysis (source-to-film distance (SID) of 100 cm) [19] (Fig. 1).

In the current paper, inclination is defined as radiographic inclination (RI) [16]. Radiographic inclination (RI) was defined as the angle ρ between the long axis of the projected ellipse of the cup opening and a line through both tear drops. ρ was measured in both the intra-IF images and postoperative AP pelvis radiographs [11, 16] (Fig. 1).

Distances were measured on calibrated digital radiographs. Pre- and postoperative AP pelvis views were calibrated with a 25-mm magnification ball, positioned in the acetabular plane. Intraoperative images were calibrated with a best fitting circle surrounding the acetabular component utilizing its known diameter to correct image magnification. The actual calibration was performed by Sectra PACS software package IDS7 (Sectra AB, Linköping, Sweden). To anticipate differences in pelvic tilt, the distance between a horizontal line connecting the lower end of the sacroiliac joints and its perpendicular line through the upper border of the symphysis (SySi distance) was measured [21]. According to Tannast et al., pelvic tilt δ can be calculated as

$$\delta = \frac{\text{SySi} - \text{distance} - 2.4565}{0.119}$$

with a correlation strength of $r = 60$ [21].

Radiographic measurements were performed by three observers (two residents and a senior attending). Measurements of RI were repeated in all, intra- and postoperative radiographs for intra-observer reliability (intraclass correlation coefficient, ICC 0.905–0.950) and inter-observer correlation (ICC 0.851–0.920). All radiographic measurements were performed with the orthotool-box, Sectra PACS software package IDS7.

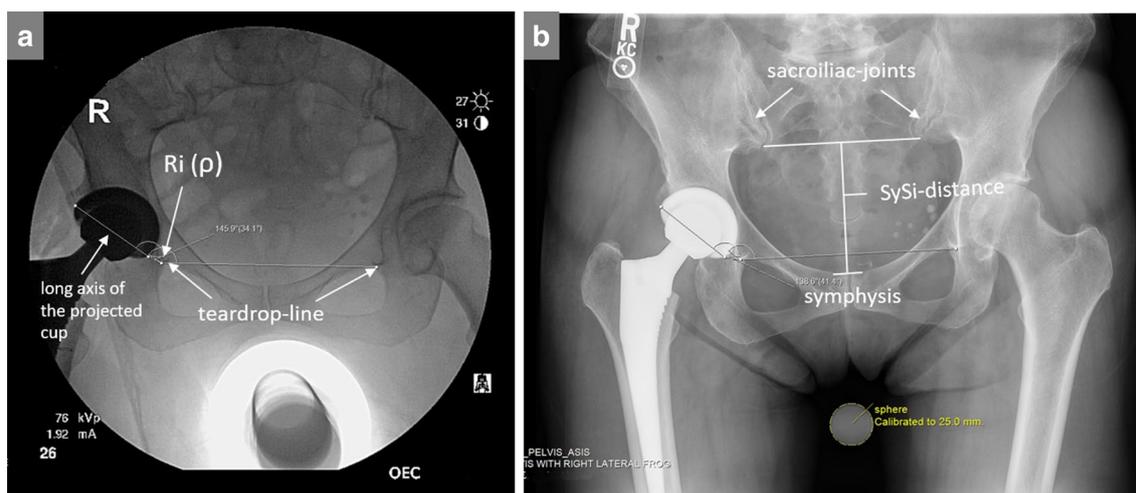


Fig. 1 Intraoperative fluoroscopic image (a) and postoperative AP pelvis image (b). Radiographic inclination (RI) was defined as angle ρ between the long axis of the projected ellipse of the cup opening

and the tangent on the tear drop (a) [11, 16]. Pelvis tilt was determined utilizing the SySi-distance (b)

Statistical methods

Descriptive statistics were performed to describe means, medians and range for all variables. Kolmogorov–Smirnov, Shapiro and Welch tests were used to identify normal distribution of variables. The “intraclass correlation coefficient” (ICC) was used to measure inter- and intra-observer reliability. r was interpreted as “poor” below 0.3, “fair” from 0.31 to 0.5, “moderate” from 0.51 to 0.6, “moderately strong” from 0.61 to 0.8, and “very strong” from 0.81 to 1.0 [2]. Paired t test (for parametric, normal-distributed values) or the Wilcoxon-rank-sum test (for nonparametric values) was performed to identify significance. Statistical analysis was performed for a 95% confidence interval. Results with $p < 0.05$ were considered as statistically significant results with $p < 0.01$ considered as highly significant.

For bivariant correlation analyses (eg. pelvic tilt, teardrop distance, hip rotation, BMI, gender and intra- or postoperative RI) Pearson’s correlation r was used. Correlation was defined weak for $0.1 < r < 2.9$, medium for $3.0 < r < 4.9$ and strong for $0.5 < r < 1$ [3].

To detect a significant difference in RI of 5° with a SD of 10 in dependent groups, power calculation for an alpha failure of $\alpha = 0.05$, an effect size of 0.5 and an aimed power ($1 - \beta$) of 95% yield a required sample size of 54 patients in total. All statistical analyses were performed using IBM SPSS® Statistics software version 23.0.0.0 (SPSS Inc.,

Chicago, IL, USA). Power calculation was performed with G*Power, version 3.1.9.2 [8].

Results

The mean intraoperative RI was 35.2° (range $28.5\text{--}41.0^\circ$, SD 2.81) compared to 40.1° (range $34.1\text{--}45.0^\circ$, SD 2.26) on postoperative AP pelvis radiographs (Fig. 2). The measurements had a “very strong” ICC for intra-observer (0.91 intraoperative RI, 0.92 postoperative RI) and inter-observer (0.85 intraoperative RI, 0.85 postoperative RI) correlation. The difference in means between intra- and postoperative RI was $\Delta\rho = 5^\circ$ ($p < 0.001$) with a strong correlation ($r = 0.538$).

The mean distance between the symphyses and a line, connecting the lower border of the sacroiliac joints (SySi distance), was 73.1 mm (range $40.0\text{--}107.0$, SD 15.2) pre-, 86.7 mm (range $66.0\text{--}105.0$, SD 9.9) intra- and 70.4 mm (range $32.5\text{--}106.5$, SD 15.3) postoperatively. Regression analysis for the dependent variable “intraoperative RI” or “postoperative RI” showed no correlations with demographic, anatomic or functional parameters (i.e. gender, body mass index (BMI), age, pelvic incidence, SySi distance, obturator foramina AP diameter ratio, or cup size) (Table 1).

56 cups had an intraoperative RI of $35.0^\circ\text{--}40.0^\circ$. 29 cups had a higher RI (range $40.5^\circ\text{--}46.0^\circ$) and 15 had a lower RI

Fig. 2 The boxplot shows intraoperative (white) and postoperative (blue) RI. The hatched boxes display mathematical results of different corrections ($+4^\circ$, $+5^\circ$, $+6^\circ$) added to the measured intraoperative RI. When applying a correction factor of $+5^\circ$. For intraoperative RI, there is no significant difference between intraoperative and postoperative RI measurements

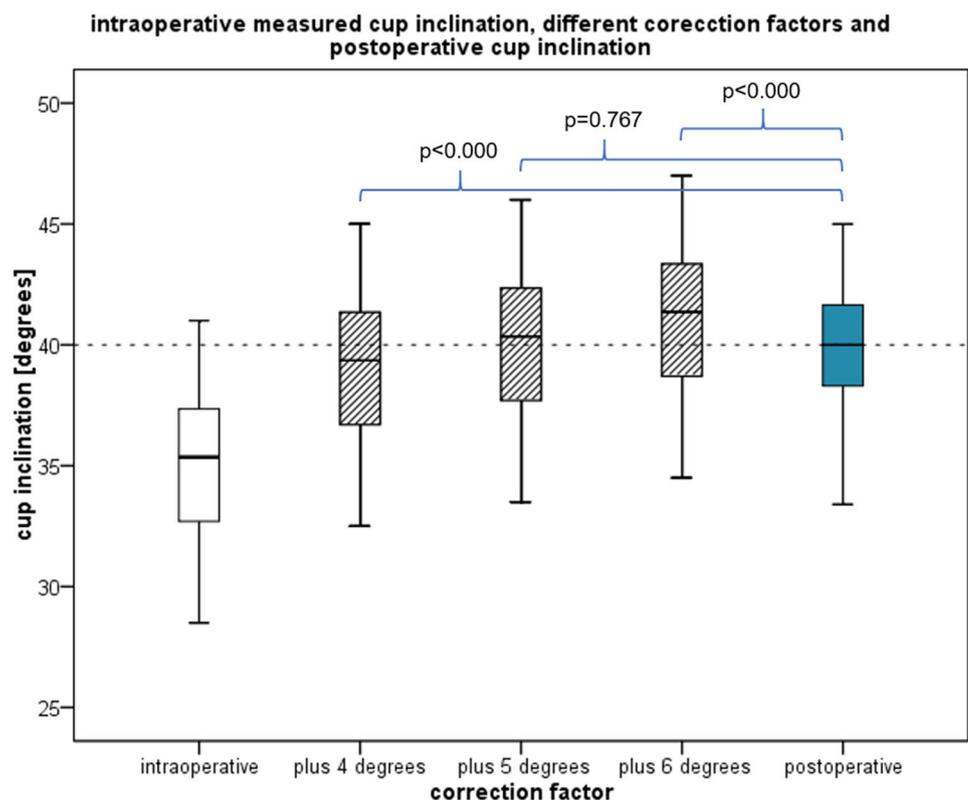


Table 1 Regression analysis for the dependent variable “intraoperative RI” or “postoperative RI” shows no correlations with demographic, anatomic or functional patterns

Independent variable	Level of correlation	
	Intraoperative RI	Postoperative RI
Gender	0.38	0.33
Age at date-of-surgery	0.99	0.17
BMI	0.87	0.19
Pelvic incidence	0.93	0.16
SiSy distance	0.91	0.44
Obturator-foramina AP diameter ratio	0.39	0.84
Cup size	0.09	0.51

(range 34.5°–32.0°). All 56 cups with an intraoperative RI within the range of 35.0°–40.0° (mean 37.0°, SD 1.23) had a postoperative RI between 37.5° and 45.0° (mean 40.8°, SD 1.87) (Figs. 2, 3).

Discussion

The current study suggests that the intraoperative determination of cup inclination using fluoroscopic imaging is reliable and reproducible; however, to predict postoperative inclination a correction factor of 5° needs to be added to

intraoperative measurements. All cups placed intraoperatively between 35.0° and 40.0° (SD 1.23) of inclination showed RI values between 37.5° and 45.0° (SD 1.87) on postoperative radiographs.

To meet realistic clinical conditions, all measurements are based on plain radiographs. Due to its nature, two-dimensional projections are exposed to various stereometric effects that influence measurement:

1. Pelvic orientation

Inaccuracy in vertical pelvic rotation influences anteversion and inclination of the acetabular component. Thoren et al. measured an increased inclination of 1.8°–2.7° (e. g. 45.0°–46.8°) for every 5° of pelvic rotation [22]. Regression analyses ruled out any relation between the measured RI and pelvic rotation in the sagittal plane in the current study.

Horizontal pelvic rotation influences both cup anteversion (RA) and RI. Thoren et al. proposed a change of 2.8 mm in SySi distance equals 1° of pelvic tilt [22]. Based on a computer model, Maratt et al. calculated a positive correlation between increased pelvic tilt and RI.

In the present series, the intraoperative image of the pelvis tended to be projected with some degrees of anterior tilt (86.7 mm, SD 9.9) compared to the pre- (73.1 mm, SD 15.1) or postoperative (70.4 mm, SD 15.3) radiographs (Fig. 4). The resulting Δ SySi distance = 13.6 mm equals a pelvic tilt of 4.9° [22]. Bivari-

Fig. 3 The boxplot shows the intraoperative RI (white), the corrected intraoperative RI (empiric correction factor $\psi=5^\circ$, hatched) and the postoperative RI (blue, hatched) for patients with an intraoperative RI in our target zone, between 35° and 40°. Postoperatively, no cup had a RI of more than 45° or less than 35° (gray area); all cups were placed within the Lewinnek safe zone

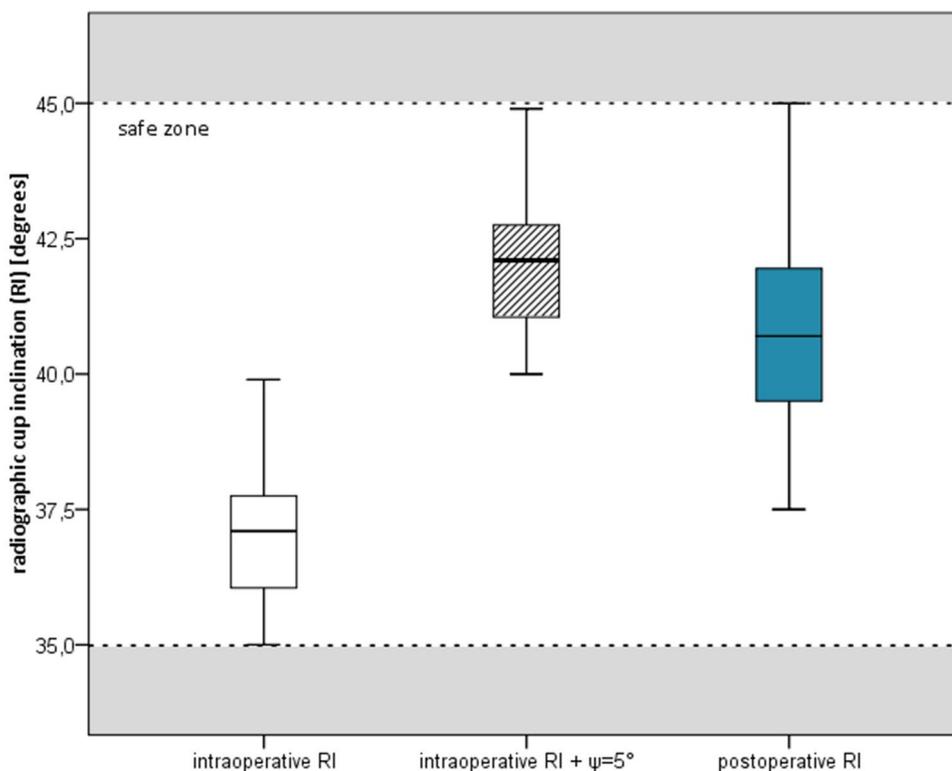
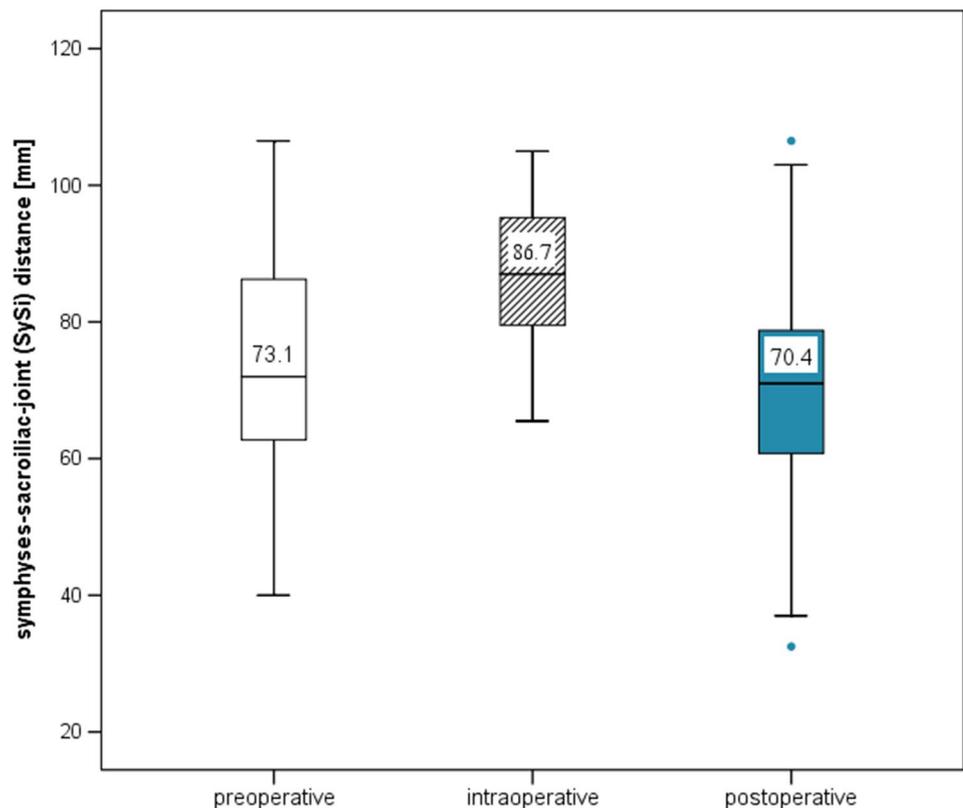


Fig. 4 Difference in pre-, intra-, and postoperative distance between symphysis and a line connection the lower edges of the sacroiliac joint (SySi distance) in mm. On relevant difference in means between the pre- and postoperative image can be seen, whereas there is a highly significant difference between intra- and postoperative view ($\Delta\text{SySi} = 16.4 \text{ mm}$, $p < 0.001$)



ant correlation analysis showed a moderate correlation ($r = 0.301$, $p = 0.001$) between difference in pelvic tilt and difference in measured intra- and postoperative RI. However, for a difference of pelvic tilt of less than 20° , the influence on RI is clinically irrelevant and can be ignored [14].

2. Cup anteversion

Increased cup *anteversion* impacts the measurement of RI [5, 20]. Derbyshire et al. developed a mathematic relation to proof this effect [5].

In the current study, RA was determinate using a standardized technique [1]. All patients had RA between 15° and 25° and RA, therefore, had a minimal effect on the RI measurements.

3. Central beam effect

Moving the object away from the central X-ray beam causes changes in RI and RA [5, 20, 24]. With 50 mm off center placement, Schwarz et al. reported a mean error of measurement of 3.9° for RA and 0.7° for RI for vertical or horizontal offset. However, the absolute effect for RI was less ($1.3^\circ - 0.1^\circ$) [20]. As a result of the smaller source-to-film distance, the X-ray-beam used in c-arm imaging is more divergent than in postoperative radiographs. Because of the decreased field of view, the cups are projected at the very outer boarder of the image (Fig. 5). Compared to the postoperative image

a distortion of the projected cup was observed in the c-arm image (Fig. 5). As result, the cup is displayed as an eclipse. This effect changes horizontal offset and reduces intraoperative RI measurements in comparison to postoperative images (Fig. 3).

As result of the combination of these stereometric effects (parallax), our data suggest a mean difference of intra- and postoperative RI of 4.9° for the c-arm used in the current study (Figs. 2, 3).

This study has the following limitations: (1) the reported correction factor is calculated for a 12-inch GE 9900 elite c-arm and correction factors will vary between different c-arm models. (2) All patients were operated by one high-volume surgeon who performs more than 250 THAs per year at a specialized orthopedic hospital which might eliminate outliers and therefore the current correction factor can only be applied for measurements in the range reported here. (3) Measurement of RI on plain AP pelvic radiographs is a valid method with repeatedly reported excellent intra- and inter-observer correlation (ICC 0.94–0.99) comparable to accuracy of CT can measurements [4, 13, 15, 24]. Consistently, ICC was “very strong” (0.85–0.92) and measurement was reliable and reproducible in the current study.

While some parallax effects result from technical limitations, correct orientation of the pelvis is mandatory for

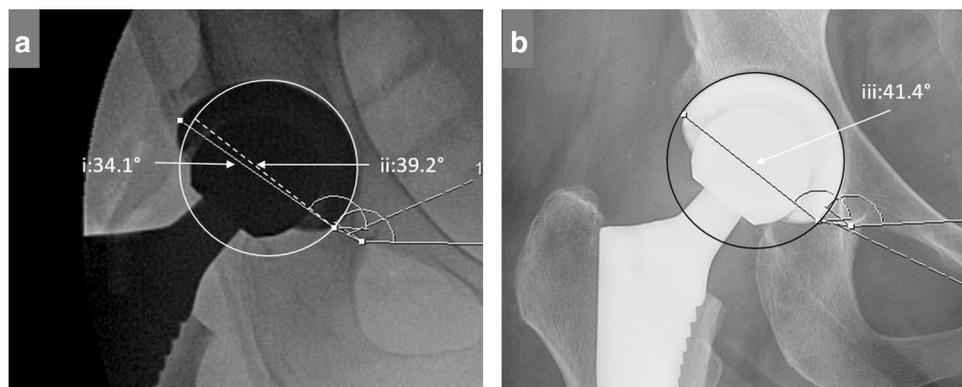


Fig. 5 Intra- and postoperative radiographic imaging of the same patient with a left THA. **a** A magnification of the intraoperative fluoroscopic image. The image of the cup shows a horizontal distraction compared to a perfect circle (white line). **b** The postoperative view without any distraction of cup or head. The drawn circles (white line) perfectly fit the image of the cup/head. RI is determined as the angle

ρ between the long axis of the projected ellipse of the cup opening and the tear drop tangent line, for **a** $\rho = 34.1^\circ$ (i) is measured. To better display the effect of distraction, a fictive measurement (ii) to the point of intersection with the perfect circle results in $\rho = 39.2^\circ$ RI (dotted line). Within measurement accuracy this equals the postoperative measurement of $\rho = 41.4^\circ$ (iii) for image (**b**)

correct radiographic cup orientation. First, the central beam should project over the symphysis. Second, the obturator foramen should project symmetrically to avoid rotation error. Third, the pelvic tilt should match the preoperative image by aiming for the same SySi distance.

Conclusion for clinical practice

A standardized technique for IF-based measurement of cup inclination is described for patients undergoing DAA THA. To adjust for various stereometric effects on IF images, a correction factor of 5° needs to be added to the intraoperative measurements and RI on IF images should target 35° – 40° inclination.

Compliance with ethical standards

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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