Accuracy of acetabular cup implantation, as a function of body mass index and soft-tissue thickness, with a mechanical intraoperative support device: A retrospective observational study

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Research article

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Abstract

Background

HipCOMPASS, a mechanical intraoperative support device used in total hip arthroplasty (THA), improves the cup-alignment accuracy. However, alignment accuracy in obese patients has not been examined. We aimed to compare the cup-alignment accuracy, using HipCOMPASS, between patients with and without obesity.

Methods

We retrospectively evaluated 448 consecutive patients who underwent primary THA using HipCOMPASS. We measured the soft-tissue thickness of the anterior-superior iliac spine (ASIS) and pubic symphysis using preoperative computed tomography (CT) images and the difference in cup angle pre- and postoperatively based on the cup-alignment error on CT. We used Pearson coefficients to determine the correlation of body mass index (BMI) and soft-tissue thickness with cup-alignment error. We created receiver operating characteristic (ROC) curves to determine the cutoff value for statistically significant cup-alignment error factors in radiographic inclination and anteversion of ≥ 5°.

Results

There were significant correlations between the absolute value of radiographic anteversion difference and BMI ($r = 0.205$), ASIS thickness ($r = 0.419$), and pubic symphysis thickness ($r = 0.434$). The absolute value of radiographic inclination difference was significantly correlated with ASIS ($r = 0.257$) and pubic symphysis thickness ($r = 0.202$). The ROC curve showed a pubic symphysis thickness of 37.2 mm for a ≥ 5° implantation error in both radiographic inclination and anteversion simultaneously. The cup-alignment error for HipCOMPASS was large in patients whose pubic symphysis thickness was ≥ 37.2 mm on preoperative CT.

Conclusion

We recommend using methods other than HipCOMPASS, including computed tomography-based navigation systems, in obese patients.

Background

In total hip arthroplasty (THA), malalignment of implants reportedly leads to increased dislocation rates and polyethylene wear associated with impingement [1, 2]. Therefore, accurate implantation is very important. In recent years, mechanical intraoperative support devices or navigation systems have been used to place implants accurately [3, 4].

Previous studies have reported that dislocation after THA occurs more often in patients with obesity because accurate implantation of the acetabular component is difficult in these patients [5, 6]. Barrack et al. [7] conducted a multivariate regression analysis of 1549 THA cases and found that a body mass index (BMI) ≥ 30 kg/m^2 increased the risk of malpositioning of the acetabular cup. They also found that the odds of malpositioning of the acetabular cup increased by ≥ 0.2 for each 5 kg/m^2 increase in BMI.

To increase the accuracy of cup alignment, especially to reduce a cup-alignment error of < 5°, a mechanical intraoperative support device, HipCOMPASS [8], was developed in 2012. This is placed on the skin with the anterior-superior iliac spine (ASIS) and pubic symphysis (PS) as reference points. A previous study reported that the accuracy of cup radiographic inclination and radiographic anteversion, according to Murray's definition [9], was more improved in the HipCOMPASS group compared to that in the group without HipCOMPASS, which used conventional non-navigation techniques [8]. However, another study encountered a high-extremity BMI case in which accurate cup implantation was difficult even when using HipCOMPASS at the developmental stage. Because this device is placed on the skin, there is a possibility that implantation may be impaired in patients with high soft-tissue thickness [8]. However, cup-alignment errors caused by BMI and soft-tissue thickness have not been examined.

The purpose of this study was to clarify the errors of acetabular-cup positioning caused by BMI and soft-tissue thickness in THA using a mechanical intraoperative support device, HipCOMPASS. Moreover, we also aimed to calculate the cutoff for the error values of ≥ 5° for anteversion and inclination, because a previous study stated that the implantation error in radiographic anteversion and radiographic inclination were 2.9 ± 2.3° and 2.9 ± 2.1°, respectively, using HipCOMPASS [8], and the total value of the average and standard deviation was almost 5° for BMI and soft-tissue thickness on the ASIS and/or PS.

Methods

Participants

From April 1, 2012 to March 31, 2017, HipCOMPASS (LEXI, Tokyo, Japan) was used in the supine position in 462 patients who underwent primary THA and had not undergone other hip surgeries before the THA. These participants were completely different from those of a previous report [8]. We excluded 14 cases; six that required an additional bulky bone graft for severe dysplasia and eight simultaneous bilateral procedures. Therefore, we included only cases where the ipsilateral side was prioritized because the setting of HipCOMPASS had a bilateral effect. Consequently, 448 consecutive cases were included in this study, and we evaluated them retrospectively. They underwent THAs with a purely cementless acetabular component, while the femoral component was cemented or cementless. All THAs were performed using the anterolateral supine approach. Seven senior orthopedic surgeons performed the procedure in these participants. We inserted the acetabular cup according to HipCOMPASS. After press-fit fixation of the acetabular cup, we routinely inserted 1–3 cancellous screws (AESCLUP, Tuttlingen, Germany) as an additional fixation. Plasmacup MSC or Plasmafit (AESCLUP, Tuttlingen, Germany), a hemispherical titanium plasma-sprayed cup, was used as the acetabular component.

We conducted this study with approval from the ethics committee of the Niigata University Medical and Dental Hospital (No. 2019 – 0177), and it was performed in accordance with the Declaration of Helsinki. Since this was a retrospective study, informed consent was waived as the patient data were kept confidential.

Mechanical intraoperative support device: HipCOMPASS

HipCOMPASS consists of a T-plate with three legs of the same length and an angle indicator that can be installed on the plate (Fig. 1). The three legs can be slid over the plate, and the T-plate can be made parallel to the anterior pelvic plane (APP) by pressing each leg on both the ASIS and PS. However, this method causes error in the inclination of the T-plate and APP due to the difference in soft-tissue thickness between the ASIS and PS (Fig. 2). After anesthesia, both the ASIS and PS were punctured, and a special depth gauge (LEXI, Tokyo, Japan) was pressed into the tissue to measure the thickness of the soft tissue on both the ASIS and PS. The difference in soft-tissue thickness between average values of both the ASIS and PS was calculated. The error between the inclination of the APP and the T-plate were corrected by shortening the leg on the PS by the amount of difference. An angle indicator was adjusted to point to the angle that converted radiographic inclination and radiographic anteversion, planned relative to the functional pelvic plane, to the APP and was placed on the T-plate that was made parallel to the APP to indicate the planned cup-implantation angle. During the operation, the cup was placed at the planned angle by placing the cup holder and the indicator parallel to each other [9].

Preoperative planning

Preoperative planning was performed using preoperative computed tomography (CT) data installed using ZedHip® three-dimensional (3D) THA planning software (Lexi, Tokyo, Japan). We set the cup radiographic inclination at 40° relative to the functional pelvic plane in all patients. The cup radiographic anteversion was adjusted in the range of 10–20°, mainly 15°, relative to the functional pelvic plane [10] considering the stem anteversion, according to the “combined anteversion theory” [11, 12].

Measurements of the soft-tissue thickness

If the cup-placement error increased, even with the use of HipCOMPASS, we had to prepare other methods for accurate cup implantation before the operation. In the above-mentioned method of measuring the soft-tissue thickness after anesthesia just before the surgery, other methods were not prepared. Therefore, we measured the soft-tissue thickness on both the ASIS and PS using preoperative CT images. We adjusted the 3D pelvis model according to the functional pelvic plane, the same as the preoperative planning plane stated above, and measured the length from the PS to the skin surface at a right angle to the PS as PS-thickness (Fig. 3b). In a similar manner, we also measured the length from bilateral ASISs to the skin surface at a right angle to each ASIS, and the average value of the right and left length was expressed as ASIS-thickness (Fig. 3a). The values of these soft-tissue thickness measurements using CT images were different from the soft-tissue thickness measured when HipCOMPASS was placed on the skin intraoperatively. Therefore, measurements obtained from CT images were not used for intraoperative adjustment of the leg using HipCOMPASS.

Measurements of the alignment of the acetabular component

The CT scans were examined in patients 1 week after THA for postoperative evaluation of the positioning of both the acetabular and femoral components using ZedHip® software (Lexi, Tokyo, Japan) [13, 14, 15]. The cup-placement angle was evaluated using the ZedHip postoperative evaluation system as described previously [16]. In this system, the contour of the 3D pelvic model, created from preoperative CT data, was automatically superimposed on a 3D pelvic model created from postoperative CT data, so that the postoperative cup radiographic inclination and anteversion relative to the preoperative functional pelvic plane could be determined. Thus, the errors between the preoperative planning and postoperative cup radiographic inclination and anteversion were calculated.

Statistical analysis

Statistical calculations were performed using SPSS statistical software (SPSS version 24, Inc., Chicago, IL, USA). The correlations between BMI and the differences in radiographic inclination and radiographic anteversion were evaluated using Pearson's correlation coefficients. The unpaired Student's t-test was performed to compare quantitative data, such as age and BMI. Multiple logistic regression analysis was conducted to determine which factor contributed to the presence of an implantation error ≥ 5° in radiographic inclination, radiographic anteversion, and both radiographic inclination and radiographic anteversion simultaneously. Moreover, we created receiver operating characteristic (ROC) curves to determine the cutoff values for statistically significant factor(s) of implantation error in radiographic inclination and radiographic anteversion of ≥ 5°, determined by multiple logistic regression analysis, for BMI and soft-tissue thickness on the ASIS and/or PS. We also calculated the area under the curve (AUC) from ROC curves, and cutoff values determined the point where the sensitivity + 1-specificity was maximum according to the Youden index [17, 18]. Furthermore, we examined statistical power (type II (β) error) as a post-hoc analysis and a desirable power value of at least 0.8 [19]. We defined 0.5 as the effect size (d) and 0.05 as a type Ⅰ (α) error in the t-test and 0.3 as the effect size (d) and 0.05 as a type Ⅰ (α) error in the correlation analysis and multiple logistic regression analysis. We confirmed intraobserver reliability with intraclass correlation coefficients (ICCs), and two-sided 95% confidential intervals (CIs) were calculated to evaluate validations. One observer conducted two measurements with an interval of more than 1 week on 56 randomly selected patients. Furthermore, we compared the measurements to assess the interobserver reliability using a single measurement from two observers, using the same 56 patients as above. Statistical significance of the *P*-value was set at .05.

Results

In total, the 448 THAs in this study included 72 males and 376 females, with a mean age of 65.9 ± 10.6 years. Among them, 255 THAs were performed on the right side and 193 on the left side, and the mean BMI was 23.6 ± 4.0 kg/m^2. Preoperative diagnoses were osteoarthritis of the hip in 388 cases, osteonecrosis of the femoral head in 42, hip fracture in 6, rapidly destructive arthropathy of the hip in 7, and rheumatoid arthritis in 5 patients. The average cup radiographic inclination was 41.0 ± 3.2°, and radiographic anteversion was 15.8 ± 3.5°. Radiographic inclination and radiographic anteversion differences in all participants were 1.5 ± 3.8° and 0.8 ± 3.7°, respectively, and the absolute values were 3.3 ± 2.4° and 3.1 ± 2.2°, respectively. Among the THA cases, 71.9% (322/448) were implanted within 5° of both the radiographic inclination and radiographic anteversion, and 4.7% (21/448) were implanted within ≥ 5° of both radiographic inclination and radiographic anteversion simultaneously (Fig. 4). There were significant correlations between absolute values of radiographic anteversion difference and BMI (r = 0.205), ASIS-thickness (r = 0.419), and PS-thickness (r = 0.434). Absolute values of radiographic inclination difference were significantly correlated with ASIS-thickness (r = 0.257) and PS-thickness (r = 0.202) (Table 1).

There were statistical differences in BMI, ASIS-thickness, and PS-thickness between patients whose implantation error was < 5° and those with a ≥ 5° error in radiographic inclination and radiographic anteversion (Table 2). Multiple logistic regression analysis was conducted with these parameters; ASIS-thickness was considered a significant independent risk factor of a ≥ 5° implantation error in radiographic inclination, and PS-thickness was considered a significant independent risk factor of a ≥ 5° implantation error in radiographic anteversion and in both radiographic anteversion and radiographic inclination simultaneously (Table 3).

According to the ROC curve, an ASIS-thickness of 16.8 mm was considered the cutoff value for a ≥5° implantation error in radiographic inclination, while a PS-thickness of 35.0 mm was considered the cutoff value for a ≥5° implantation error in radiographic anteversion. Furthermore, a PS-thickness of 37.2 mm was considered the cutoff value for a ≥5° implantation error in both radiographic inclination and radiographic anteversion simultaneously (Fig. 5) (Table 4).

Regarding the post-hoc analysis, power values were 0.99 for a ≥5° implantation error in radiographic inclination, 0.99 for a ≥5° implantation error in radiographic anteversion, and 0.72 for a ≥5° implantation error in both radiographic inclination and radiographic anteversion simultaneously according to the unpaired t-test. In terms of the correlation analysis and multiple logistic regression analysis, power values were 0.97 and 0.99, respectively. With regard to intraobserver validity, a high ICC of >0.9 was obtained for both intraobserver and interobserver reliabilities for each parameter (Table 5). No dislocation occurred during the follow-up period of 1 year in these 448 patients.

Discussion

In this study, BMI was associated with radiographic anteversion errors, while PS-thickness and ASIS-thickness were associated with both radiographic anteversion errors and radiographic inclination errors

(Table 1). Furthermore, we found that PS-thickness and ASIS-thickness were independent risk factors for implantation error of the acetabular component in THA using HipCOMPASS. PS-thickness and ASIS-thickness were considered to be more precise influencing factors because they were more related owing to the installation error of HipCOMPASS. Tsukada et al. reported that errors of cup anteversion were larger in patients with a BMI ≥ 25 kg/m^2 than in others [20]. Similarly, Parratte et al. reported that cup anteversion, measured by postoperative CT, was significantly different from cup anteversion displayed intraoperatively on the navigation screen in patients with a BMI ≥ 27 kg/m^2 [21]. However, BMI alone did not give a cutoff value. It is thought that this is because body composition, such as muscle mass and fat mass, differs depending on the person, and the decrease in height due to poor posture affects the BMI. The decrease in height owing to poor posture may affect the progression of hip disease; it can significantly affect BMI, especially in patients undergoing THA. Malpositioning of the acetabular cup increases the risk of dislocation, wear of the bearing surface, and instability of components [1, 22, 23, 24, 25]. If the surgeons are able to identify patients whose acetabular components are likely to be malpositioned, they should pay special attention to the implantation. It is well-known that obesity is one of the risk factors of dislocation due to the malpositioning of the acetabular component [5, 6]. It was previously reported that THA with a CT-based navigation system was not affected by obesity, even though patients' BMIs were ≥ 30 kg/m^2 [16].

In the 448 consecutive cases in this study, no dislocation was observed during the 1-year follow-up period. However, Widmer et al. [11] confirmed that the optimal cup-positioning angle to reduce the risk of dislocation was 40–42° of radiographic inclination and 20–28° of radiographic anteversion relative to the APP for considering maximum range of motion (ROM) by using 3D computer simulation. Further age-related changes in the spinal-pelvis alignment over time [26, 27] may lead to later instances of dislocation.

This study has several limitations. First, this was a retrospective study with a small sample size. Second, the power value of a ≥ 5° implantation error in both radiographic inclination and radiographic anteversion simultaneously was 0.72 according to the unpaired t-test while a desirable power value was at least 0.8. However, we could evaluate the soft-tissue thickness with high reliability with a high ICC value of > 0.9, similar to previous studies [9, 16, 28, 29, 30]. Moreover, according to our findings, the surgeons could predict the risk of a ≥ 5° implantation error by the CT images taken before surgery. We are convinced that this is a strong point of the current study. Third, HipCOMPASS itself has several limitations. HipCOMPASS is an alignment guide and has the disadvantage of not being able to guide the location of implantation, which can be performed using CT-based navigation systems. Additionally, HipCOMPASS can be used only for THA in the supine position and cannot be used in the lateral decubitus position. However, HipCOMPASS has the advantage of being inexpensive compared to CT-based navigation systems. The accuracy of cup alignment placed using HipCOMPASS was approximately 3° (Suda et al., 2016); it is slightly inferior to the accuracy of 2° obtained by CT-based navigation systems (Imai et al., 2019); although, it is sufficiently acceptable.

In this study, we showed that the cup-alignment error tends to be large, especially in patients with a large PS-thickness, when HipCOMPASS is used in THA. Therefore, we recommend the use of other methods, such as CT-based navigation systems, in cases of a PS-thickness ≥ 37.2 mm on preoperative CT images, because a ≥ 5° implantation error is likely to occur in both radiographic inclination and radiographic anteversion simultaneously.

Abbreviations

APP: anterior pelvic plane

ASIS: anterior-superior iliac spine

AUC: area under the curve

BMI: body mass index

CI: confidence interval

CT: computed tomography

ICC: intraclass correlation coefficient

PS; pubic symphysis

ROC: receiver operating characteristic

THA; total hip arthroplasty

Declarations

Ethics approval and consent to participate

The study was approved by the ethics committee of the Niigata University Medical and Dental Hospital (No. 2019-0177). Since this was a retrospective study, informed consent was waived as the patient data were kept confidential.

Consent for publication

Not applicable

Availability of data and materials

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

Competing interests

The authors declare no conflict of interest.

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No funding was received for this study.

Authors’ contributions

HS and NI contributed to study conception, design and drafting of manuscript. YH and HS were involved in acquisition, analysis and interpretation of data. NE critically revised the data. All authors read and approved the final manuscript.

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Tables

Table 1. Correlation between BMI, ASIS-thickness, PS-thickness, and THA acetabular cup radiographic inclination difference and radiographic anteversion difference with the HipCOMPASS system

	BMI (kg/m^2)	ASIS-thickness (mm)	PS-thickness (mm)
Radiographic inclination difference (°)	0.110 (.240)	0.257 (<.001)	0.202 (<.001)
Radiographic anteversion difference (°)	0.205 (<.001)	0.419 (<.001)	0.434 (<.001)

Data are expressed as correlation coefficient (*P*-value)

BMI, body mass index; ASIS-thickness, anterior-superior iliac spine thickness; PS-thickness, pubic symphysis; THA, total hip arthroplasty.

Table 2. Univariate analysis of BMI, ASIS-thickness, and PS-thickness between the patients whose THA acetabular cup-implantation errors with the HipCOMPASS system were <5° and those that were ≥5° in acetabular cup radiographic inclination and radiographic anteversion

	Radiographic inclination difference <5°	Radiographic inclination difference ≥5°	*P*-value
Number	322	116	
BMI (kg/m^2)	23.5 ± 3.7	24.7 ± 4.3	.017
ASIS-thickness (mm)	17.4 ± 11.8	24.2 ± 15.6	<.001
PS-thickness (mm)	30.0 ± 11.0	35.0 ± 13.2	.001
	Radiographic anteversion difference <5°	Radiographic anteversion difference ≥5°	*P*-value
Number	347	101	
BMI (kg/m^2)	23.4 ± 3.6	25.0 ± 4.3	<.001
ASIS-thickness (mm)	15.9 ± 10.1	28.3 ± 16.3	<.001
PS-thickness (mm)	28.4 ± 9.6	39.6 ± 13.6	<.001
	At least radiographic inclination or radiographic anteversion difference <5°	Both radiographic inclination and radiographic anteversion difference ≥5°	*P*-value
Number	427	21	
BMI (kg/m^2)	23.6 ± 3.8	24.9 ± 4.9	.045
ASIS-thickness (mm)	17.9 ± 12.1	34.6 ± 17.2	<.001
PS-thickness (mm)	30.2 ± 11.0	44.9 ± 14.1	<.001

Continuous values are expressed as average ± standard deviation

BMI, body mass index; ASIS-thickness, anterior-superior iliac spine thickness; PS-thickness, pubic symphysis; THA, total hip arthroplasty.

Table 3. Multiple logistic regression analysis of BMI, ASIS-thickness, and PS-thickness between the patients whose THA acetabular cup-implantation errors with the HipCOMPASS system were <5° and those that were ≥5° in radiographic inclination and radiographic anteversion

		Odds ratio	*P*-value	95% CI
radiographic inclination difference ≥5°	BMI (kg/m^2)	0.985	.439	0.899-1.080
	ASIS-thickness (mm)	1.045	.002	1.002-1.090
	PS-thickness (mm)	0.992	.077	0.944-1.039
radiographic anteversion difference ≥5°	BMI (kg/m^2)	0.847	.754	0.762-1.043
	ASIS-thickness (mm)	1.039	.076	0.996-1.084
	PS-thickness (mm)	1.085	.039	1.030-1.143
Both radiographic inclination and radiographic anteversion difference ≥5°	BMI (kg/m^2)	0.913	.300	0.768-1.085
	ASIS-thickness (mm)	1.024	.146	0.962-1.091
	PS-thickness (mm)	1.067	<.001	1.038-1.097

BMI, body mass index; ASIS-thickness, anterior-superior iliac spine thickness; PS-thickness, pubic symphysis; THA, total hip arthroplasty; CI, confidence interval.

Table 4. Area under curve and cutoff values by receiver operating characteristic curves

Implantation error	Factor	AUC	Cutoff value (mm)	Sensitivity	1-Specificity	95% CI	*P*-value
≥5° in radiographic inclination	ASIS-thickness	0.645	16.8	0.643	0.390	0.573-0.718	<.001
≥5° in radiographic anteversion	PS-thickness	0.756	35.0	0.693	0.186	0.684-0.818	<.001
≥5° in both radiographic inclination and radiographic anteversion simultaneously	PS-thickness	0.808	37.2	0.833	0.248	0.703-0.913	<.001

ASIS-thickness, anterior-superior iliac spine thickness; AUC, area under the cureve; PS-thickness, pubic symphysis; CI, confidence interval.

Table 5. Intra- and interobserver reliabilities

	Intraobserver reliability		Interobserver reliability	
	MAD ± SD	ICC	MAD ± SD	ICC
Radiographic inclination	0.59 ± 0.71	0.972	0.66 ± 0.73	0.952
Radiographic anteversion	0.68 ± 0.72	0.962	1.07 ± 1.11	0.932
ASIS-thickness	0.50 ± 0.43	0.999	0.88 ± 0.78	0.999
PS-thickness	0.53 ± 0.45	0.999	0.73 ± 0.52	0.999

MAD, mean absolute difference; SD, standard deviation; ASIS-thickness: soft-tissue thickness of anterior superior iliac spine, PS-thickness: soft-tissue thickness of pubic symphysis. All ICCs had a P-value < 0.05.

Figures

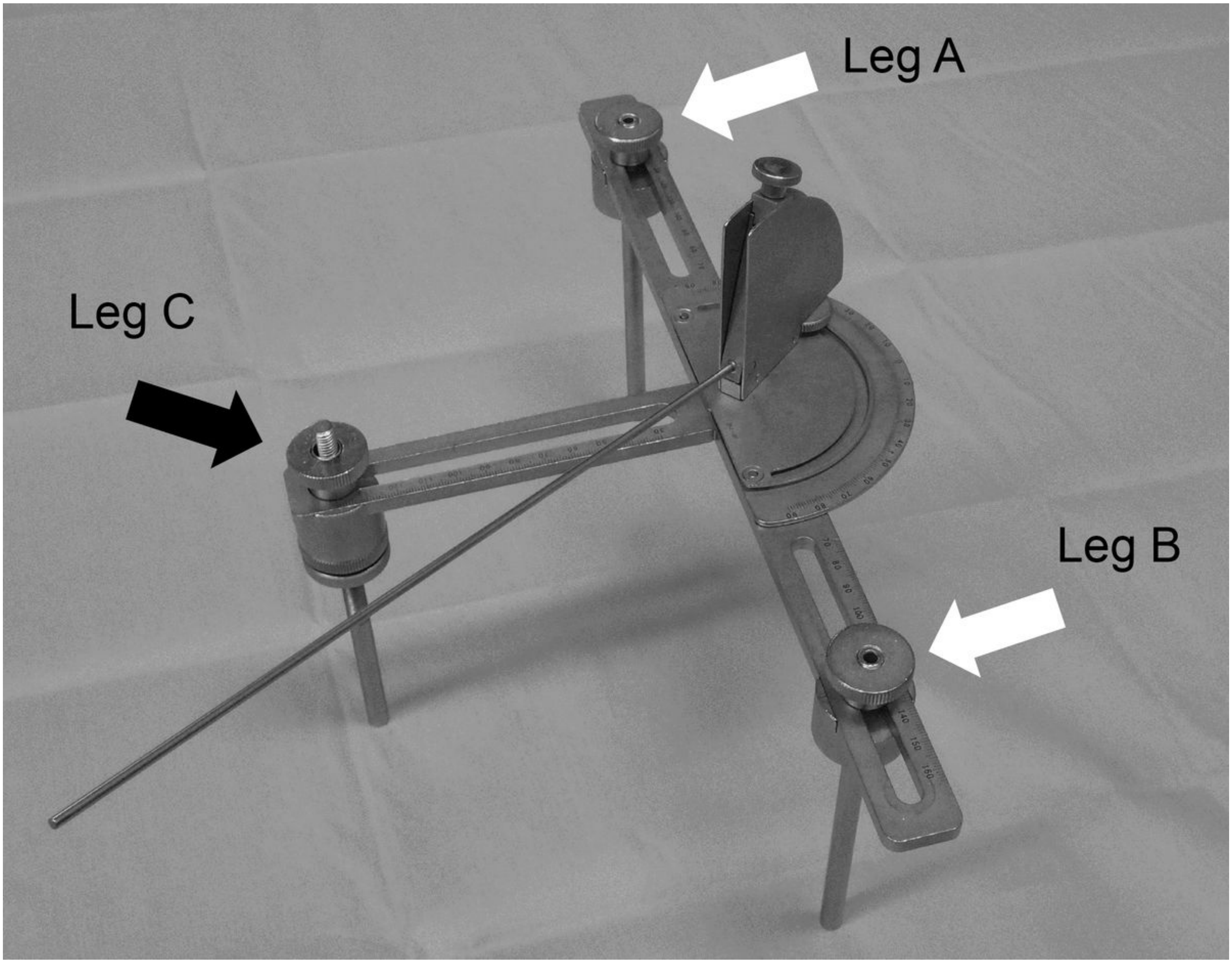

Figure 1

Placement of HipCOMPASS legs. Two legs placed on both ASISs (leg A and B) are hollow for fixation inserting K-wires. The length of the leg on the PS can be changed. ASIS, anterior-superior iliac spine; APP, anterior pelvic plate; PS, pelvic symphysis

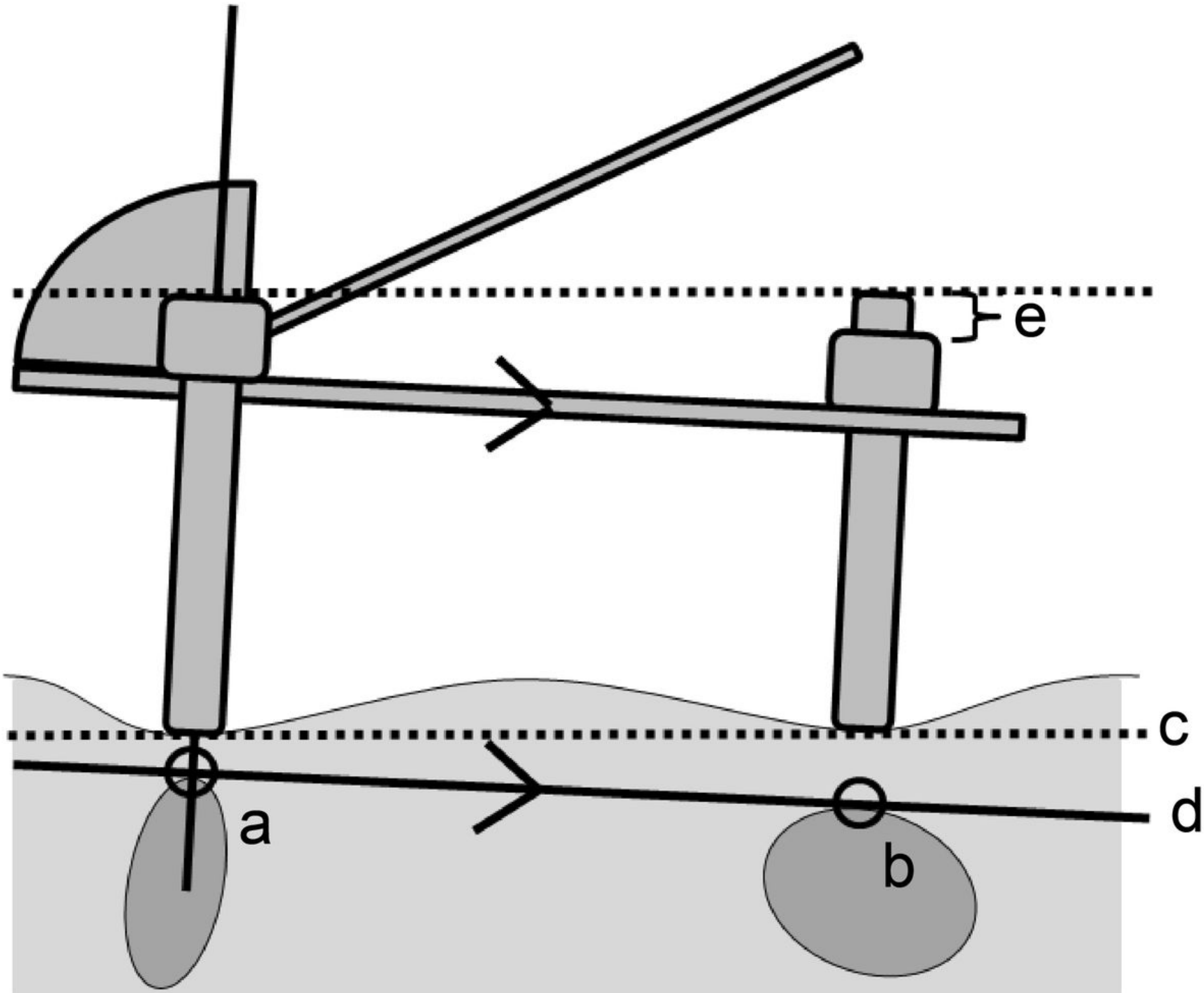

Figure 2

APP comparison. a: ASIS, b: PS, c: APP on the skin, d: true APP, e: difference between soft-tissue thickness on the ASIS and on the PS. ASIS, anterior-superior iliac spine; APP, anterior pelvic plate; PS, pelvic symphysis

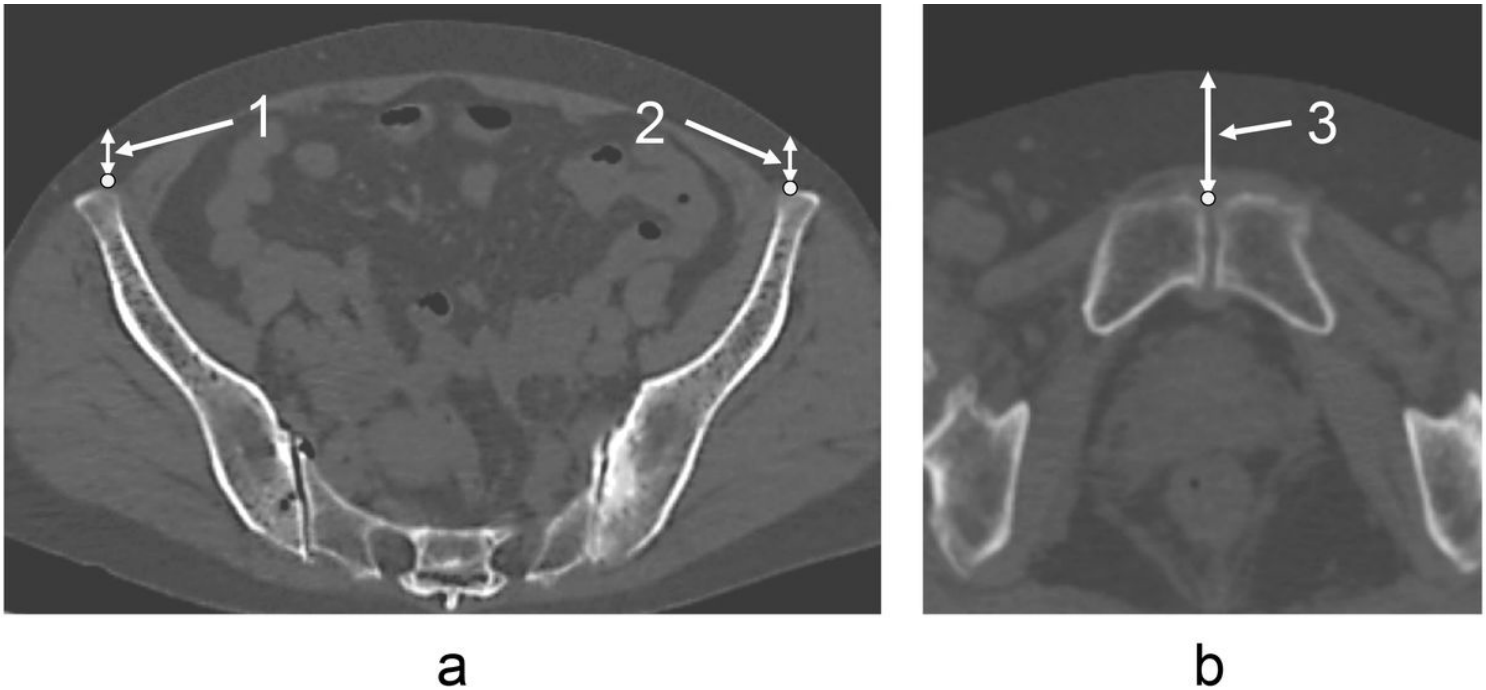

Figure 3

CT images adjusted to functional pelvic plane. a Measurement of ASIS-thicknesses, b Measurement of PS-thicknesses 1: ASIS-thickness on right side, 2: ASIS-thickness on left side, 3: PS-thickness ASIS, anterior-superior iliac spine; PS, pelvic symphysis; CT, computed tomography

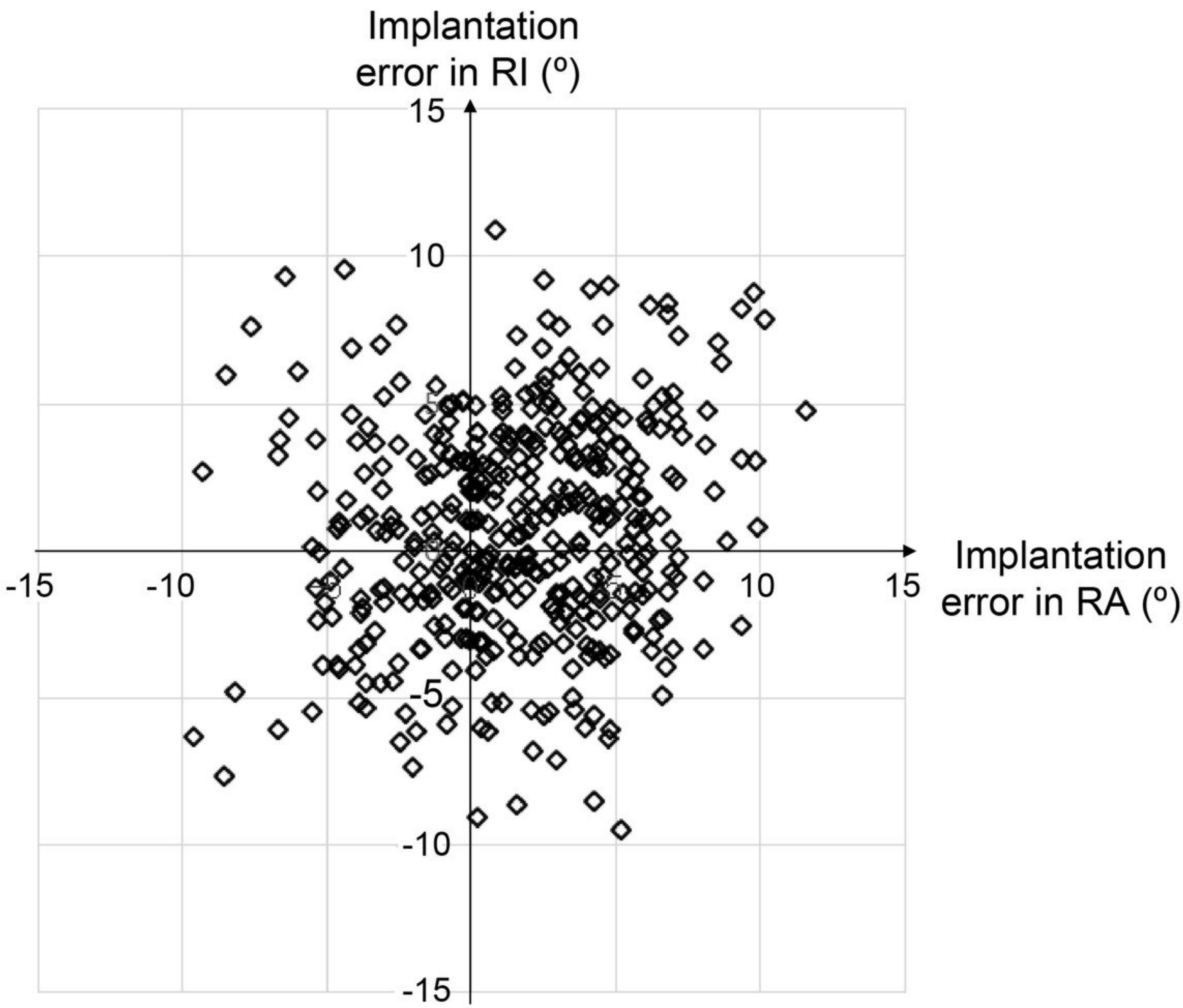

Figure 4

HipCOMPASS cup-implantation errors. Of the total THA cases, 71.9% are implanted within 5° of both radiographic inclination and anteversion, and 4.7% are implanted with a ≥5° error in radiographic inclination and anteversion simultaneously. THA, total hip arthroplasty

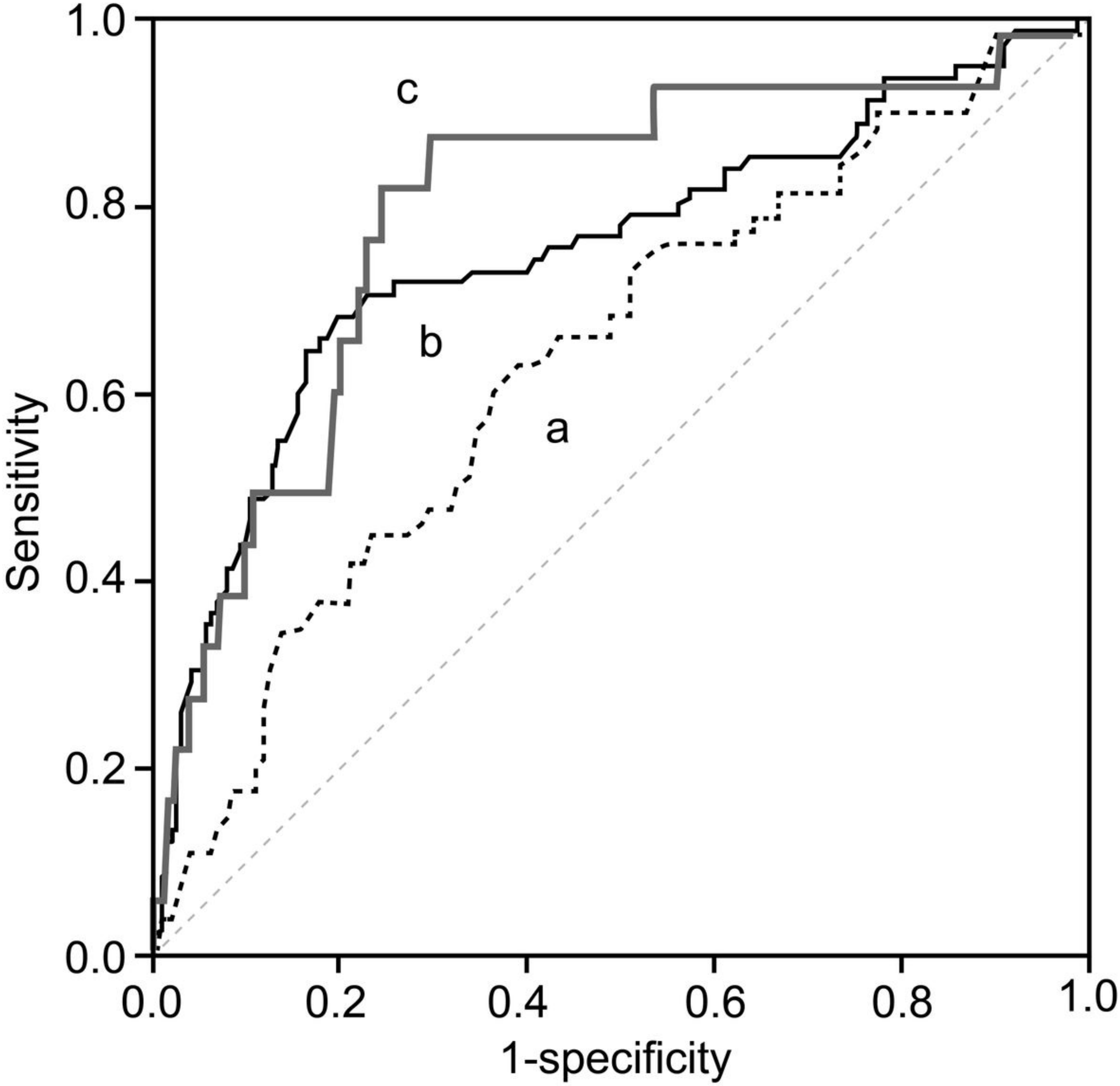

Figure 5

Receiver operating characteristic curve. a: ASIS-thickness with a radiographic inclination difference ≥5°, b: PS-thickness with a radiographic anteversion difference ≥5°, c: PS-thickness with both radiographic inclination and anteversion differences ≥5°. ASIS, anterior-superior iliac spine; PS, pelvic symphysis