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Original Article

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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HipCOMPASS, a mechanical intraoperative support device used in total hip arthroplasty (THA), improves the cup-alignment accuracy. However, the alignment accuracy achieved by HipCOMPASS has not been specifically examined in obese patients. In this study, we retrospectively evaluated the relation between alignment accuracy and several obesity-related parameters in 448 consecutive patients who underwent primary THA using HipCOMPASS. We used computed tomography (CT) to measure the preoperative soft-tissue thickness of the anterior-superior iliac spine (ASIS) and pubic symphysis and the differences between preoperative and postoperative cup angle based on the cup-alignment error. We found significant correlations between the absolute value of radiographic anteversion difference and body mass index ($r=0.205$), 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 receiver operating characteristic 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. Our results indicate that methods other than HipCOMPASS, including computed tomography-based navigation systems, might be preferable in obese patients.

Key words: HipCOMPASS, total hip arthroplasty, cup-alignment accuracy, body mass index, soft-tissue thickness

In total hip arthroplasty (THA), malalignment of the implants has been reported to lead to increased dislocation rates and polyethylene wear associated with impingement [1,2]. Therefore, accurate implantation is important. In recent years, mechanical intraoperative support devices or navigation systems have been used to assist in the accurate placement of implants [3,4].

Previous studies have reported that dislocation after THA occurs more often in obese patients due to difficulties in the accurate implantation of the acetabular component [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 increased by ≥0.2 for each 5 kg/m^2 increase in BMI.

To increase the accuracy of cup alignment, and especially to reduce the cup-alignment error to <5°, a

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mechanical intraoperative support device, HipCOMPASS [8], was developed in 2012. This device 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 the cup radiographic inclination and radiographic anteversion, according to Murray's definition [9], was better in a HipCOMPASS group compared to a non-HipCOMPASS group, where conventional non-navigation techniques were used [8]. However, the same study included a patient with high BMI for whom accurate cup implantation was difficult even when using HipCOMPASS (which was still in the developmental stage at the time). The authors suggested that, since this device is placed on the skin, the implantation may be impaired in patients with high soft-tissue thickness [8]. However, cup-alignment errors caused by high BMI and soft-tissue thickness have not been specifically examined.

The purpose of this study was to clarify the errors of acetabular-cup positioning caused by high BMI and soft-tissue thickness in THA using a HipCOMPASS. Moreover, we also aimed to calculate the cutoff values of ASIS- and PS-thickness for error values of ≥5° in anteversion and inclination, because a previous study stated that the implantation errors 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°. We hypothesized that cup alignment errors would tend to be large in the case of obese patients, because it is difficult to maintain a constant inclination of the HipCOMPASS on the skin and difficult to identify the ASIS and PS in patients with thick subcutaneous tissue.

Materials and Methods

Participants. Four hundred and sixty-two patients who underwent primary THA using the HipCOMPASS (LEXI, Tokyo) in the supine position between April 1, 2012 and March 31, 2017 at Niigata University Medical and Dental Hospital were included in this retrospective analysis. None of the patients had undergone other hip surgeries before the THA, and none had been included in the aforementioned study [8]. HipCOMPASS was used only in Crowe group I or II cases [10]. We attempted placement of the acetabular component to restore the original hip joint center position. A bulk bone graft was used if the cup center edge angle was <0°. We excluded 14 cases: 6 that required an additional bulky bone graft because the cup center edge angle was <0° and 8 that were deprioritized side of the 8 cases required simultaneous bilateral procedures because the setting of HipCOMPASS had a bilateral effect. Consequently, 448 consecutive cases were retrospectively evaluated in this study.

The patients underwent THAs with a purely cementless acetabular component, while the femoral component was cemented or cementless. All the THAs were performed using the anterolateral supine approach. One of seven senior orthopedic surgeons performed the procedures. We inserted the acetabular cup using HipCOMPASS as an alignment guide. After press-fit fixation of the acetabular cup, we routinely inserted 1-3 cancellous screws (AESCLUP, Tuttlingen, Germany) as additional fixation. Plasmacup MSC or Plasmafit (AESCLUP), a hemispherical titanium plasma-sprayed cup, was used as the acetabular component. All patients were allowed to get out of bed and start rehabilitation without restriction of load or movement on the first day after surgery.

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

Mechanical intraoperative support device: HipCOMPASS. HipCOMPASS consists of a T-plate with three legs of equal 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 the legs on the ASIS and PS. However, this method may cause an 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). We therefore measured the thickness of the bilateral ASISs and the PS using a special depth gauge (LEXI) having the same shape as the legs of the HipCOMPASS (Fig. 3). These measurements were performed as follows. After anesthesia, the bilateral ASISs and the PS were punctured using a wire, and the depth gauge was pressed on the skin to measure soft tissue thickness at all three points. The difference in soft-tissue thickness between the PS and the average value of the bilateral ASISs was calculated. The error between the inclination of the APP and the T-plate was corrected by shortening the leg on the PS by the amount of the difference in soft-tissue thickness. An angle indicator was adjusted to point to the angle obtained by converting radiographic inclination and radiographic anteversion, relative to the functional pelvic plane, to the APP [9]. The angle indicator 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 [8].

Preoperative planning. Preoperative planning was conducted by entering preoperative computed tomography (CT) into ZedHip® three-dimensional (3D) THA planning software (LEXI). We set the cup radio-

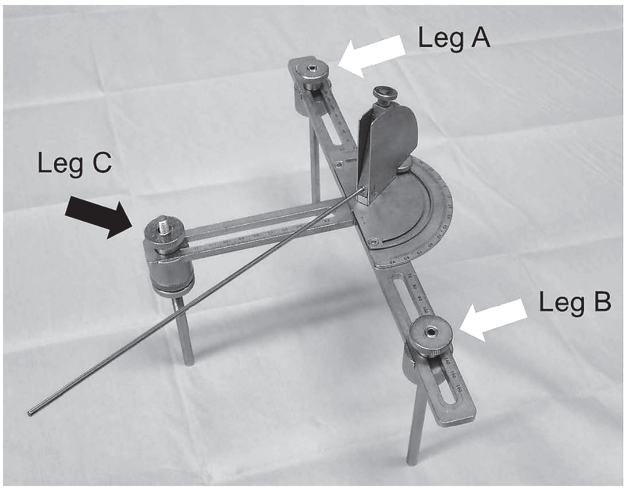

Fig. 1 Placement of HipCOMPASS legs. The two legs placed on the bilateral ASISs (legs A and B) are hollow to allow the insertion of K-wires for fixation. The length of the leg on the PS can be changed.
ASIS, anterior-superior iliac spine; PS, pubic symphysis.

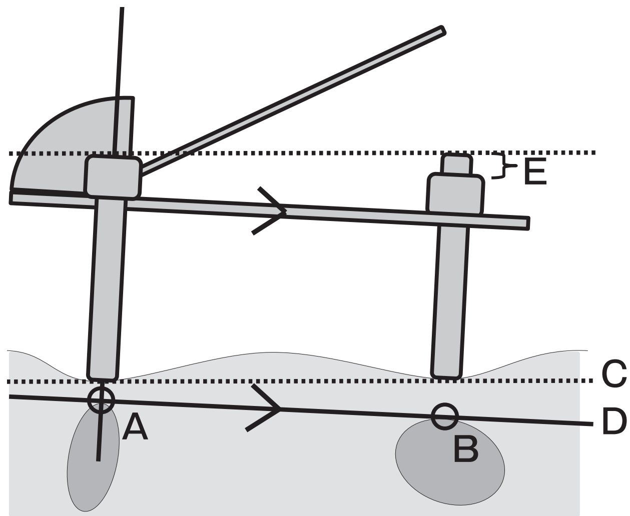

Fig. 2 APP comparison. A, ASIS; B, PS; C, APP on the skin; D, True APP; E, Difference between soft-tissue thickness on the ASIS and on the PS.
ASIS, anterior-superior iliac spine; PS, pubic symphysis; APP, anterior pelvic plane.

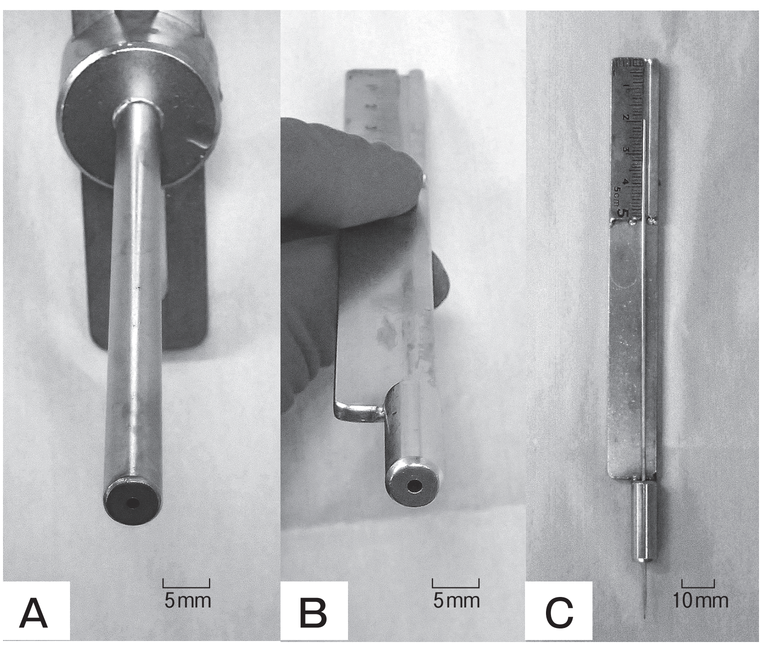

Fig. 3 Special depth gauge. A, A leg of HipCOMPASS; B, The tip of the depth gauge having the same shape and diameter as the leg of HipCOMPASS; C, After anesthesia, both the ASISs and PS were punctured using a wire and the depth gauge was pressed into the tissue to measure the thickness of the soft tissue at both points.
ASIS, anterior-superior iliac spine; PS, pubic symphysis.

graphic inclination at 40° relative to the functional pelvic plane in all patients. The cup radiographic anteversion was adjusted in the range of 10-20°, usually 15°, relative to the functional pelvic plane [11] with consideration for the stem anteversion, according to the "combined anteversion theory" [12, 13].

Measurements of the soft-tissue thickness. If the cup-placement error increased, even with the use of HipCOMPASS, we had to preoperatively prepare other methods for accurate cup implantation. If the soft-tissue thickness had been measured after anesthesia, as described above, other methods were not considered. 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, in a similar manner as for the preoperative planning plane described above, and measured the PS thickness as the length from the PS to the skin surface at a right angle to the PS (Fig. 4B). Similarly, we measured the length from the bilateral ASISs to the skin surface at a right angle to each ASIS, and the average value of the right and left lengths was expressed as the ASIS-thickness (Fig. 4A). 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, the 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 one week after the THA for postoperative evaluation of the positioning of both the acetabular and femoral components using ZedHip® software (LEXI) [14-16]. The cup-placement angle was evaluated using the ZedHip postoperative evaluation system as described previously [17]. 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. And 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 (Version 24; IBM Corp., Armonk, NY, 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 $\geq 5°$ 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) influencing the implantation error of $\geq 5°$ in radiographic inclination and radiographic anteversion, as 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 the ROC curves, and the cutoff values deter-

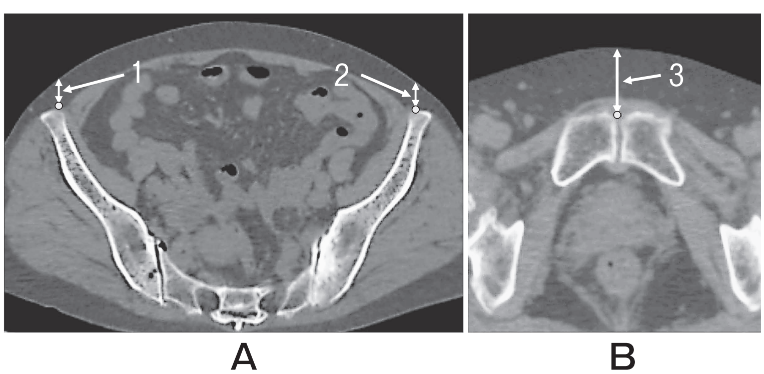

Fig. 4 CT images adjusted to the functional pelvic plane. A, Measurement of ASIS-thicknesses; B, Measurement of PS-thicknesses. 1, ASIS-thickness on right side; 2, ASIS-thickness on left side; 3, PS-thickness.
ASIS, anterior-superior iliac spine; PS, pubic symphysis; CT, computed tomography.

mined the point where the sensitivity + 1-specificity was maximum according to the Youden index [18, 19]. In addition, we examined the statistical power (type II (β) error) as a post-hoc analysis and a desirable power value of at least 0.8 [20]. 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 the intra-observer reliability with intraclass correlation coefficients (ICCs), and two-sided 95% confidential intervals (CIs) were calculated to evaluate the validation accuracy. One observer conducted 2 measurements with an interval of more than one week on 56 randomly selected patients. In addition, we compared the measurements to assess the inter-observer reliability using a single measurement from two observers, using the same 56 patients as above. The statistical significance of the *p*-value was set at 0.05.

Results

In total, 448 THAs were performed in this study on 72 males and 376 females with a mean age of 65.9 (standard deviation [SD]: 10.6; range: 55-75) years. Among them, 255 THAs were performed on the right side and 193 on the left side, and the mean BMI was 23.6 (SD: 4.0; range: 14.5-39.0) 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° (SD: 3.2; range: 31.1-51.8), and radiographic anteversion was 15.8° (SD: 3.5; range: 6.1-27.6) in the preoperative functional pelvic plane coordinate system. The differences in radiographic inclination and radiographic anteversion between preoperative planning and postoperative cup alignment in all participants were 0.8° (SD: 3.7; range: -9.5 to 10.9) and 1.5° (SD: 3.8; range: −9.6 to 11.6), respectively, and the absolute values were 3.1° (SD: 2.1; range: 0-10.9) and 3.3° (SD: 2.4; range: 0-11.6), respectively. Among the THA cases, 71.9% (322/448) were implanted with a difference of < 5° between preoperative planning and postoperative cup alignment in both radiographic inclination and radiographic anteversion, and 4.7% (21/448) were implanted with a difference of ≥ 5° in both radiographic inclination and radiographic anteversion simultaneously (Fig. 5). There were significant correlations between the absolute values of the radiographic anteversion difference and BMI (r = 0.205), ASIS-thickness (r = 0.419), and PS-thickness (r = 0.434). The absolute values of the radiographic inclination difference were significantly correlated with ASIS-thickness (r = 0.257) and PS-thickness (r = 0.202) (Table 1).

There were significant differences in the BMI, ASIS-thickness, and PS-thickness between patients whose

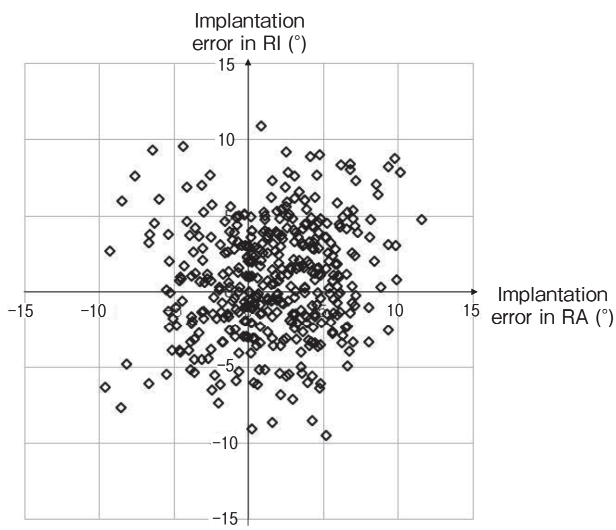

Fig. 5 HipCOMPASS cup-implantation errors. Of the total THA cases, 71.9% were implanted within 5° of both radiographic inclination and anteversion, and 4.7% were implanted with a ≥ 5° error in radiographic inclination and anteversion simultaneously.
THA, total hip arthroplasty.

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 coefficients (*P*-value)
BMI, body mass index; ASIS-thickness, anterior-superior iliac spine thickness; PS-thickness, pubic symphysis; THA, total hip arthroplasty.

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; the results showed that ASIS-thickness was a significant independent risk factor of a ≥ 5° implantation error in radiographic inclination, and PS-thickness was a significant independent risk factor for a ≥ 5° implantation error in radiographic anteversion and in both radiographic anteversion and radiographic inclination simultaneously (Table 3).

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.

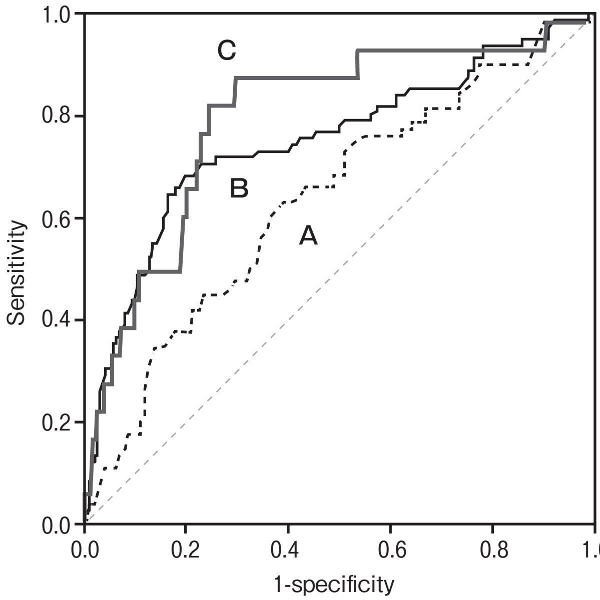

Fig. 6 Receiver operating characteristic curve. **A**, ASIS-thickness with a radiographic inclination difference ≥5°; **B**, PS-thickness with a radiographic anteversion difference ≥5°; **C**, PS-thickness with both radiographic inclination and anteversion differences ≥5°. ASIS, anterior-superior iliac spine; PS, pubic symphysis.

According to the ROC curve, an ASIS-thickness of 16.8 mm was the cutoff value for a ≥5° implantation error in radiographic inclination, while a PS-thickness of 35.0 mm was the cutoff value for a ≥5° implantation error in radiographic anteversion. A PS-thickness of 37.2 mm was the cutoff value for a ≥5° implantation error in both radiographic inclination and radiographic anteversion simultaneously (Fig. 6) (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, the power values were 0.97 and 0.99, respectively. With regard to intra-observer validity, a high ICC of >0.9 was obtained for both intra-observer and inter-observer reliabilities for each parameter (Table 5). No dislocation occurred during the follow-up period of one year in these 448 patients.

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

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

Table 5 Intra- and inter-observer reliabilities

	Intra-observer reliability		Inter-observer 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; ICC, intraclass correlation coefficients; 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.

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). Moreover, we found that PS-thickness and ASIS-thickness were independent risk factors for an 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 strongly related owing to the installation error of HipCOMPASS. Since the HipCOMPASS is placed on the skin during use, it is difficult to keep the inclination of HipCOMPASS constant if the subcutaneous tissue is thick. Moreover, it seemed that the thicker the soft tissue under the skin, the more difficult it was to identify the ASISs and PS over the skin. Consequently, the position of HipCOMPASS was misaligned from the ASISs and PS in patients with thick subcutaneous tissue. This accounted for the poor cup installation accuracy in patients with thick subcutaneous tissue. Tsukada *et al.* [21] reported that errors of cup anteversion placed using imageless navigation were larger in patients with a BMI ≥ 25 kg/m^2 than in others. Similarly, Parratte *et al.* [22] reported that cup anteversion placed using an imageless computer-assisted surgical system, as 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. However, BMI alone did not give a cutoff value. This was thought to be because body composition, such as muscle and fat mass, differs depending on the person, and a 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 on the bearing surface, and instability of the components [1, 23-26]. If 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 for dislocation due to the malpositioning of the acetabular component when using non-navigation technique [5, 6]. It has been previously reported that THA with a CT-based navigation system was not affected by obesity, even though patients' BMIs were ≥ 30 kg/m^2 [17].

In the 448 consecutive cases in this study, no dislocation was observed during the one-year follow-up period. However, age-related changes in the spinal pelvic alignment over time [27, 28] may lead to instances of dislocation in the future. In addition, malpositioning of the acetabular component leads to an increased risk of dislocation and wear damage on bearing surfaces and instability of components [1, 2].

This study has several limitations. First, this was a retrospective study with a small sample size. Second, the power value of a $\geq 5°$ implantation error in both radiographic inclination and radiographic anteversion simultaneously was 0.72 according to the unpaired *t*-test, while a desirable power value is 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, 17, 29-31]. Moreover, according to our findings, the surgeons could predict the risk of a $\geq 5°$ 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 used by correcting for the difference between the soft tissue thickness of PS and the average soft tissue thickness of the bilateral ASISs; therefore, if the difference between the soft tissue thickness of the left and right ASIS is large, it can affect the cup installation angle. However, in the present cohort the differences in soft tissue thickness between the left and right ASIS were ≤ 1 mm in most cases. Hence, their effect was not considered to be significant. HipCOMPASS is an alignment guide and has the disadvantage of not being able to actually determine the location of implantation in the manner of the CT-based navigation systems. In addition, HipCOMPASS can only be used for THA in the supine position and cannot be used in the lateral decubitus position. However, HipCOMPASS has the advantage of being less expensive than CT-based navigation systems. The accuracy of the cup alignment placed using HipCOMPASS was previously reported to be approximately 3° [8], which is slightly inferior to the accuracy of 2° obtained by CT-based navigation systems [17]; nevertheless, an accuracy of 3° is sufficiently acceptable.

In this study, we showed that the cup-alignment error in patients with a large PS-thickness tends to be larger than that in the previous study [8] during THA using HipCOMPASS. 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.

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