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ORIGINAL ARTICLE

Anatomical landmarks for acetabular abduction in adult hips: the teardrop vs. the inferior acetabular rim

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Abstract

Purpose The purpose of this study is to compare the acetabular teardrop (the structure located inferomedially in the acetabulum, just superior to the obturator foramen. The medial lip is the interior, and the lateral lip is the exterior of the acetabular wall) with the inferior acetabular rim as anatomical landmarks to measure the acetabular abduction angle (AAD) using coronal CT images from different levels.

Methods Our retrospective study included 120 pelvic CT scans from patients with non-orthopedic pathologies or stress fractures of the proximal femur. The patients included 60 females with a mean age of 48 years (range 40–66) and 60 males with a mean age of 46 years (range 38–65). Each AAD was measured using coronal plane CT slices from five levels: AAD (+ 10) (10 mm anterior to the femoral head center), AAD (+ 5) (5 mm anterior to the femoral head center), AAD (0) (through the femoral head center), AAD (− 5) (5 mm posterior to the femoral head center), and AAD (− 10) (10 mm posterior to the femoral head center). The measurements were then divided into two groups: teardrop-based AADs [AAD (+ 10), AAD (+ 5), and AAD (0)] and rim-based AADs [AAD (− 5) and AAD (− 10)].

Results There were no mean significant differences in AAD within the groups, whereas the difference between the groups was significant. The mean teardrop-based AAD was quite significantly different from the mean rim-based AAD due to the use of different anatomical landmarks. Teardrop-based AADs are lower than rim-based AADs, leading to measurement differences of more than 10°.

Conclusions AAD measurements considering the inferior acetabular rim can be more accurate than those considering the acetabular teardrop because the inferior rim represents the nearly hemispheric acetabulum better than does the teardrop. It is recommended to differentiate between the teardrop and the inferior acetabular rim when measuring AAD to avoid confusion regarding acetabular abduction.

Keywords Acetabular abduction · Teardrop · Inferior acetabular rim

Introduction

The acetabular abduction angle (AAD) and acetabular anteversion angle (AAV) have both been extensively studied. These angles are important for diagnosis of hip diseases such as hip dysplasia and implant positioning in total hip arthroplasty. Malposition of the implant may induce an increased risk for postoperative complications including dislocation, limitation of range of motion, prosthetic impingement, polyethylene wear, early aseptic loosening, and leg length discrepancy [5, 6]. Optimal cup orientation that is essential to reduce postoperative hip dislocation [8] is closely related to AAD and AAV.

Even though discrepancies regarding these angles still exist due to different assessment methods [11], more

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effective measurements of these angles are possible due to advances in computed tomography (CT) technology. Using transverse CT images, the AAV is measured either at the femoral head center level or at the acetabular center level [2, 3, 16, 18, 21]. However, there are as of yet no established techniques to measure AAD using coronal CT images, possibly because AAD is generally measured with radiographs rather than CT images.

The acetabular teardrop (henceforth, the teardrop) is located inferomedially in the acetabulum, just superior to the obturator foramen. The medial lip is the interior, and the lateral lip is the exterior of the acetabular wall. Although AAD measurements using radiographs are convenient and simple, these methods inevitably lead to measurement error because the teardrop does not indicate the peripheral rim of the acetabulum due to the presence of the acetabular notch.

Theoretically, the peripheral rim of the acetabulum (the inferior rim) is more appropriate for measuring the AAD because the acetabulum is nearly hemispheric [10]. With advances in and the increasing availability of CT imaging, the inferior rim can be easily used for measuring AAD on coronal CT images.

Our two hypotheses for this study were as follows: first, using axial CT images, if AAV measurements including the peripheral acetabular rims (anterior and posterior rims) do not vary at different levels near the femoral head center, the acetabulum is almost hemispheric, and any of the AAV measurements near the femoral head center can be used as a measure of acetabular anteversion. If the first hypothesis is correct, we can assume that the acetabulum is nearly hemispheric, and if AAD measurements including the peripheral acetabular rims (superior and inferior rims) do not vary at different levels near the femoral head center on coronal CT images, any of these AAD measurements can be used as a measure of acetabular abduction. The purpose of this study is to compare the teardrop with the inferior acetabular rim as anatomical landmarks for measuring AADs using CTs in adult hips.

Materials and methods

Patient selection and CT preparation

The study was approved by our institutional review board and informed consent was waived because the study involved retrospective evaluation of CTs and records in such a manner that the patients could not be identified. Even though this study is a retrospective case series, clinical and radiographic data were prospectively collected at the beginning of the study. Patients were identified before they were scanned. We performed a retrospective analysis of a prospectively collected data because of the limitations such as sample sizes and patient selection bias.

We gathered acetabular angle measurement data from a database of pelvic CTs that had been performed from March 2010 to February 2017. The CTs had been performed for several reasons, including stress fractures of the proximal femur and pelvic metastases.

Only adequate CTs that were taken in an acceptable position according to the inclusion criteria described below were included. Patients with proximal femoral fractures that resulted from high-energy injuries were excluded because the CT images were inadequate with respect to the patient's position (most likely due to fracture pain). Cases with osteoarthritis of the hip joint (especially with acetabular rim osteophytes) were also excluded to minimize measurement error, especially in the elderly population. Cases with history of previous pelvic trauma or hip disease such as dysplastic hips [9] were all excluded from the study. For statistical independence, the non-injured side of the hip was chosen for cases with stress fractures, while hip side was chosen randomly in non-traumatic cases.

Neutral pelvic tilt in the sagittal plane was defined when the reference plane through the anterior pubic tubercles and the anterior superior iliac spines was parallel to the scanning table [1]. A 1- to 3-cm gap between the superior border of the pubic symphysis and the tip of the coccyx on the CT topogram was regarded as the appropriate pelvic tilt in the sagittal plane [17, 20]. Neutral pelvic tilt in the frontal plane was defined when the interiliac line, drawn between the highest points of the iliac crests, was parallel to the scanning table. Neutral pelvic rotation in the axial plane was defined when vertical line through the center of the symphysis pubis overlaps vertical line through the center of sacrococcyx with symmetrical obturator foramen [7].

Our inclusion criteria for pelvic tilts in the sagittal and frontal planes were 5° (inclination) to − 5° (reclination) and 3° (right side) to − 3° (left side), respectively.

All CTs were reviewed with consensus by two independent observers who had more than 10 years of orthopedic experience. Before completion of enrollment, 55 patients were excluded for the following reasons: previous history of pelvic bone fracture (one patient), hip osteoarthritis (five patients), or a pelvic tilt that was out of range (49 patients). Ultimately, we enrolled 120 patients, comprising 60 females and 60 males with average ages of 48 years (range 40–66) and 46 years (range 38–65), respectively.

All CT scanning was performed according to the pelvic bone CT protocols of our institution. Patients were placed in the supine position parallel to the scanning table in the transverse plane. Both the hip and knee were fully extended, and the lower extremities were secured with pelvic binder to the table after rotational control comparing both limbs.

Coronal, sagittal, and axial views of both hips were taken using a CT scanner (SOMATOM sensation 16; Siemens, Germany). The scanning parameters used were 120 kV, 70 mA average, 1 mm slice collimation, and a bone algorithm.

Measuring AADs and AAVs

AAD and AAV were measured using CT slices in the coronal and transverse planes, respectively. AAD was measured at five levels: + 10 (10 mm anterior to the center of the femoral head), + 5 (5 mm anterior to the center of the femoral head), 0 (through the center of the femoral head), − 5 (5 mm posterior to the center of the femoral head), and − 10 (10 mm posterior to the center of the femoral head) (Fig. 1). AAV was also measured at five levels: + 10 (10 mm superior to the center of the femoral head), + 5 (5 mm superior to the center of the femoral head), 0 (through the center of the femoral head), − 5 (5 mm inferior to the center of the femoral head), and − 10 (10 mm inferior to the center of the femoral head) (Fig. 1). All measurements were performed using the cross-link technique to confirm each proper level. For AAD, the coronal and sagittal planes were cross linked, while for AAV, the transverse and coronal planes were cross linked. AAD and AAV were defined as follows.

- AAD (Topogram): the angle between a line connecting both the acetabular teardrops and a line drawn from the lateral superior acetabular margin to the acetabular teardrop on a CT anteroposterior projection radiograph (Fig. 2) [18].
- Teardrop-based AADs [AAD (+ 10), AAD (+ 5), and AAD (0)]: the angle between a line connecting both the acetabular teardrops and a line drawn from the lateral superior acetabular margin to the acetabular teardrop on the coronal CT image (Fig. 3). Parentheses indicate the level of the coronal CT slice (Fig. 1): AAD (+ 10), AAD (+ 5), and AAD (0). For all three AAD measure-

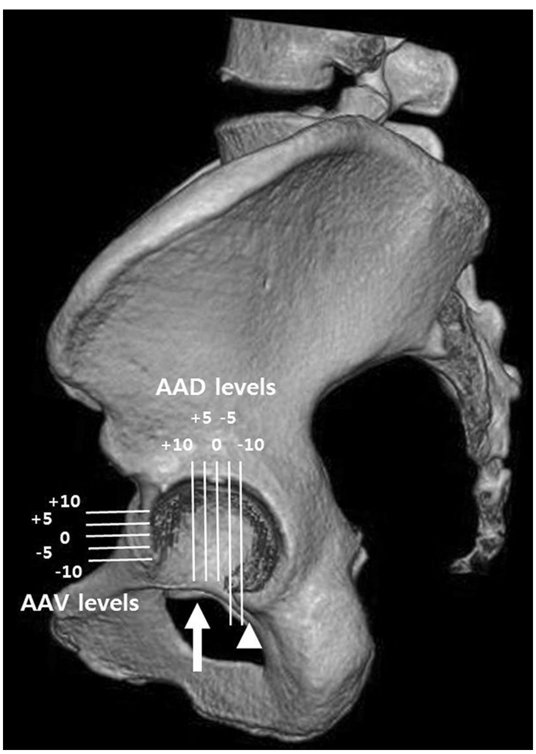

Fig. 1 AAD and AAV are selected at each of the five levels on the sagittal and axial CT images, respectively. Level 0 indicates the slice through the femoral head center. + and − denote the anterior and posterior directions (for AAD) and the superior and inferior directions (for AAV), respectively. The numbers indicate the distance in mm. The acetabular teardrop (arrow) and the inferior acetabular rim (arrow head) are shown near the acetabular notch

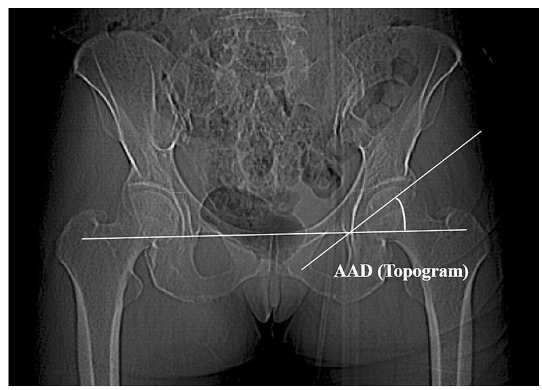

Fig. 2 AAD (Topogram) is measured between a line connecting both the acetabular teardrops and a line drawn from the lateral superior acetabular margin to the ipsilateral acetabular teardrop on the CT topogram

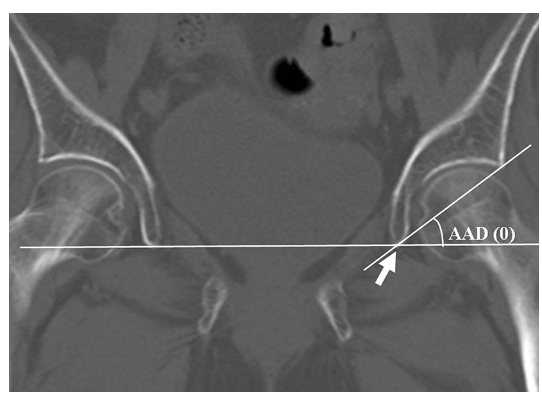

Fig. 3 AAD (0) is measured on the coronal CT image at the femoral head center level in the coronal plane between a line connecting both the acetabular teardrops and a line drawn from the lateral superior acetabular margin to the ipsilateral teardrop (arrow)

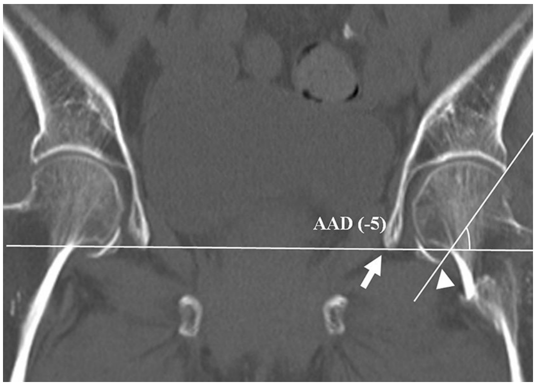

Fig. 4 AAD (−5) is measured on the coronal CT image 5 mm posterior to the femoral head center level in the coronal plane between a line connecting both of the acetabular teardrops (arrow) and a line drawn from the lateral superior acetabular margin to the inferior acetabular rim (arrow head)

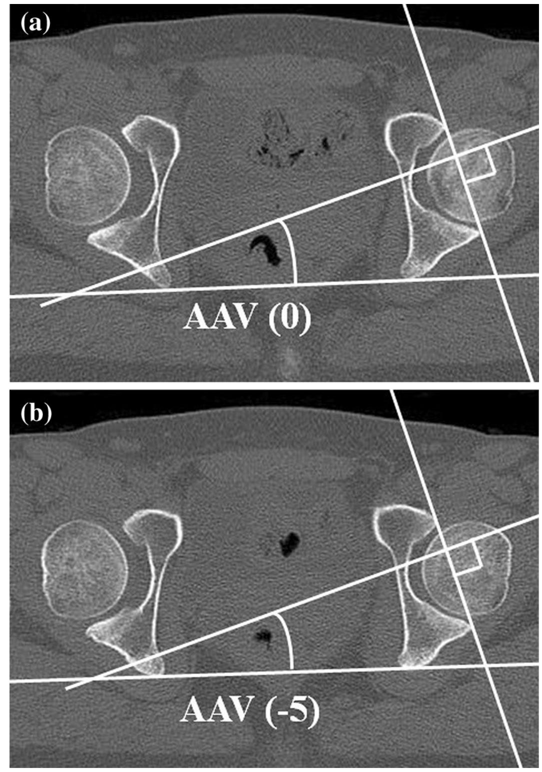

Fig. 5 AAV is measured between a line connecting the posterior pelvic margins and a line perpendicular to that between the anterior and posterior acetabular ridges on the transverse CT image. AAV (0) (**a**) and AAV (−5) (**b**) are measured at the femoral head center level and 5 mm inferior to the femoral head center level in the axial plane, respectively

ments, the acetabular superior peripheral rim was present, whereas the inferior acetabular rim was absent due to the acetabular notch (Fig. 1).

- Rim-based AADs [AAD (−5) and AAD (−10)]: the angle between a line connecting both the acetabular teardrops and a line drawn from the lateral superior acetabular margin to the inferior acetabular margin on the coronal CT image (Fig. 4). Parentheses indicate the selected level of the coronal CT slice (Fig. 1): AAD (−5), AAD (−10). For both AAD measurements, the acetabular superior and inferior peripheral rims were present because there was no acetabular notch (Fig. 1).
- AAVs [AAV (+10), AAV (+5), AAV (0), AAV (−5), and AAV (−10)]: the angle (Fig. 5) between a line connecting the posterior pelvic margins and a line perpendicular to a line between the anterior and posterior acetabular ridges on the transverse CT image. Parentheses indicate the selected level of the axial CT slice (Fig. 1): AAV (+10), AAV (+5), AAV (0), AAV (−5), and AAV (−10). The acetabular peripheral rims (anterior and posterior) are intact for all five AAV measurements.

All angles were measured in the same period by two independent observers (more than 10 years of orthopedic experience), neither of whom knew the findings of the other until all the material had been investigated. These measurements were repeated in the same way 2 weeks later to assure intraobserver reliability. Descriptive statistics are summarized as mean ± SD (Tables 1, 2).

Statistical analysis

The intraclass correlation coefficient (ICC) (2,1) was used to analyze interobserver and intraobserver agreement. Based on the 95% confident interval of the ICC estimate, values less than 0.5, between 0.5 and 0.75, between 0.75 and 0.9, and greater than 0.90 are indicative of poor, moderate, good, and excellent reliability, respectively.

The one-way analysis of variance (ANOVA) test was used to compare the mean difference between all AAD and AAV measurements with Turkey's-b multiple comparison test. Gender differences were analyzed using Student's *t* test. The level of significance was set to $p < 0.05$. SPSS 13.0 (SPSS for Windows; SPSS, Chicago, IL, USA) was used for all analysis.

Results

The ICCs of both the interobserver and intraobserver agreement showed excellent reliability. ANOVA demonstrated that there was no significant difference in means across all five AAV measurements [AAV (+10), AAV (+5), AAV (0), AAV (−5), and AAV (−10)]. The ANOVA test also showed that there was no significant difference in means between the topogram AAD and the teardrop-based AADs [AAD (+10),

Table 1 Measurements of acetabular abduction and anteversion in females

Level of CT slices (mm)[a]	ANOVA[b]		Interobserver agreement[c]		Intraobserver agreement		Measurements (°)		
	p value	*T*	ICC	95% CI	ICC	95% CI	Mean ± SD	Minimum	Maximum
AAD	< 0.001								
AAD (Topogram)		a	0.88	0.81–0.92	0.88	0.84–0.91	36.5 ± 2.8	31.3	43.2
AAD (+ 10)		a	0.88	0.80–0.92	0.90	0.86–0.92	36.8 ± 2.8	30.1	43.2
AAD (+ 5)		a	0.89	0.82–0.93	0.90	0.86–0.93	36.3 ± 2.9	31.5	42.5
AAD (0)		a	0.90	0.88–0.93	0.90	0.85–0.92	36.2 ± 2.6	31.2	43.4
AAD (− 5)		b	0.88	0.82–0.92	0.89	0.83–0.92	54.7 ± 3.5	49.2	65.1
AAD (− 10)		b	0.88	0.81–0.92	0.88	0.81–0.91	54.9 ± 3.6	48.3	64.0
AAV	0.298								
AAV (+ 10)			0.87	0.81–0.90	0.88	0.82–0.91	24.1 ± 6.8	10.3	40.1
AAV (+ 5)			0.88	0.81–0.91	0.89	0.83–0.93	23.3 ± 6.1	11.8	38.2
AAV (0)			0.89	0.85–0.92	0.90	0.87–0.93	23.1 ± 5.5	12.9	33.9
AAV (− 5)			0.87	0.82–0.90	0.90	0.85–0.92	23.2 ± 5.8	15.3	36.2
AAV (− 10)			0.86	0.82–0.91	0.88	0.81–0.91	24.5 ± 5.5	15.4	39.6

[a]AAD, acetabular abduction angle; AAV, acetabular anteversion angle. Parentheses denote the level of measurement; Level 0 was cut through the femoral head center. AAD (Topogram) indicates acetabular abduction that was measured using CT projection radiographs

[b]ANOVA, one-way analysis of variance; T, the same letters indicate non-significant differences between groups based on Tukey's b multiple comparison test

[c]ICC, Intraclass correlation coefficient; CI, confidence interval

Table 2 Measurements of acetabular abduction and anteversion in males

Level of CT slices (mm)[a]	ANOVA[b]		Interobserver agreement[c]		Intraobserver agreement		Measurements (°)		
	p value	*T*	ICC	95% CI	ICC	95% CI	Mean ± SD	Minimum	Maximum
AAD	< 0.001								
AAD (Topogram)		a	0.87	0.80–0.91	0.89	0.82–0.91	38.3 ± 2.8	32.3	49.8
AAD (+ 10)		a	0.87	0.81–0.91	0.89	0.84–0.91	39.4 ± 3.9	32.1	46.2
AAD (+ 5)		a	0.88	0.82–0.92	0.90	0.86–0.92	38.7 ± 3.9	32.5	46.5
AAD (0)		a	0.90	0.87–0.93	0.91	0.88–0.93	38.2 ± 3.8	32.2	44.4
AAD (− 5)		b	0.89	0.83–0.92	0.90	0.85–0.92	51.8 ± 3.8	44.4	58.1
AAD (− 10)		b	0.87	0.82–0.90	0.88	0.86–0.90	52.7 ± 3.8	46.3	59.0
AAV	0.124								
AAV (+ 10)			0.87	0.81–0.90	0.89	0.85–0.91	18.2 ± 4.0	12.3	26.1
AAV (+ 5)			0.89	0.83–0.91	0.90	0.88–0.92	18.1 ± 3.4	13.8	25.2
AAV (0)			0.90	0.88–0.92	0.90	0.88–0.92	17.5 ± 3.1	11.9	24.9
AAV (− 5)			0.88	0.85–0.91	0.89	0.85–0.91	17.5 ± 2.8	12.4	23.6
AAV (− 10)			0.86	0.80–0.90	0.88	0.84–0.90	17.1 ± 3.3	10.5	24.8

[a]AAD, acetabular abduction angle; AAV, acetabular anteversion angle. Parentheses denote the level of measurement; level 0 was cut through the femoral head center. AAD (Topogram) indicates acetabular abduction that was measured using CT projection radiographs

[b]ANOVA, one-way analysis of variance; T, the same letters indicate non-significant differences between groups based on Tukey's b multiple comparison test

[c]ICC, Intraclass correlation coefficient; CI, confidence interval

AAD (+ 5), and AAD (0)] nor was there a significant difference in means between the rim-based AADs [AAD (− 5) and AAD (− 10)].

However, the average of teardrop-based AADs [AAD (+10), AAD (+ 5), and AAD (0)] was quite significantly different from the average of rim-based AADs [AAD (− 5) and AAD (− 10)] due to the use of different anatomical landmarks (the teardrop vs the inferior acetabular rim). The average teardrop-based AAD (0) of the females is 18.5° lower than the average rim-based AAD (− 5) of the females. The average teardrop-based AAD (0) of the males is 13.6° lower than the average rim-based AAD (− 5) of the males.

We detected a significant difference in mean AAV (0) between females (range 12.9°–33.9°) and males (range 11.9°–24.9°) ($p < 0.001$), with females having an AAV (0) 5.6° higher than that of the males. The average AAD (0) was significantly different between females (range 31.2°–43.4°) and males (range 32.2°–44.4°) ($p < 0.001$), with females having an AAD (0) 2.0° lower than that of the males. The average AAD (− 5) was significantly different between females (range 49.2°–65.1°) and males (range 44.4°–58.1°) ($p < 0.001$), with females having an AAD (− 5) 2.9° higher than that of the males.

Discussion

AAD measurements based on the inferior acetabular rim were significantly different from those based on the acetabular teardrop. AAD measurements considering the inferior acetabular rim are higher than those considering the acetabular teardrop. This is because the inferior rim represents the nearly hemispheric acetabulum better than does the teardrop. Accurate AAD measurement is important to prevent postoperative hip dislocation in total hip arthroplasty and to avoid confusion in communication about the abduction angles of the acetabulum.

Acetabular orientation, including AAD and AAV, has been extensively studied in many fields. Although it is well known that transverse CT slices are adequate to measure AAV; there are no established methods for measuring AAD using coronal CT images. The best coronal CT image level for the assessment of AAD is also unknown.

This may be because simple radiographic measurements are considered sufficient to measure AAD. We found no significant difference between teardrop AADs [AAD (+ 10), AAD (+ 5), and AAD (0)] and topogram AAD, indicating that conventional radiographic AAD measurements using the teardrop are consistent with teardrop-based AADs using CT scans. However, measurement errors in radiographic AAD measurements are inevitable because these methods cannot differentiate the inferior acetabular peripheral rim [4, 14] from the acetabular teardrop. Although the teardrop is an attractive anatomical landmark and has been commonly used in pelvic measurements, AAD measurements using the acetabular teardrop instead of the inferior acetabular rim lead to measurement errors because the teardrop only indicates the most medial acetabular notch area, where the acetabular peripheral rim is absent (Fig. 1). Teardrop-based AADs are lower than rim-based AADs (Fig. 3 vs. Fig. 4), leading to measurement differences of more than 10° (Tables 1 and 2).

With the increasing use of CT scans, it has become possible to differentiate between AAD measurements considering the teardrop (using radiographs) and AAD measurements considering the inferior acetabular rim (using CT scans).

Based on our results that none of the five AAV measurements were significantly different on ANOVA, our first hypothesis (acetabulum is nearly hemispheric) is correct, and any AAV measurement near the femoral head center level can be used as a measure of acetabular anteversion. Based on our results that there was no mean significant difference between AAD (− 5) and AAD (− 10), our second hypothesis is correct. Therefore, rim-based AADs [AAD (− 5) and AAD (− 10)] can be used to measure acetabular abduction because the acetabulum is nearly hemispheric.

In addition, based on our results, rim-based AADs can be more accurate than teardrop-based AADs because rim-based AADs consider the peripheral acetabular rim and therefore are a good measure of acetabular abduction on the assumption that the acetabulum is nearly hemispheric.

AAD measurement differences across different anatomical landmarks (the teardrop vs. the inferior acetabular rim) may account for the discrepancies between previous studies that have measured AAD using the teardrop and those that have measured anatomical or geometrical acetabular orientation [8, 12, 13, 18].

The traditional acetabular teardrop cannot be discarded because it is a very important landmark to guide the choice of horizontal plane and to approximate the AAD using radiographs. However, we suggest that teardrop-based AADs should be differentiated from rim-based AADs considering the inferior acetabular rim to avoid confusion between studies and to obtain more accurate AAD measurements. In addition, this concept that the inferior acetabular rim is another useful anatomical landmark for the acetabular abduction measurement can be applied to navigation-assisted hip surgeries [15, 19].

The main limitation of this study is that pelvic tilt and osteophytes of the inferior acetabular rim can introduce measurement errors. Even with the consistent patient positioning with pelvic binder while taking CT scan, we cannot absolutely control pelvic tilt and pelvic rotation. Therefore, we excluded cases with pelvic tilts that were unacceptable, cases with osteoarthritis of the hip joint, and cases with history of previous pelvic trauma or hip disease such as hip dysplasia.

Another limitation of this study includes its retrospective nature. However, it was a relatively large case series performed and clinical and radiographic data were prospectively collected from the start of the study. In addition, a strength of this study is relatively narrow confidence intervals for ICCs that may imply a large sample size and less measurement error.

In the future, a prospective, large-scale, randomized trial with stricter control of pelvic tilt and rotation can provide more accurate information about the differences between teardrop-based AADs and inferior acetabular rim-based AADs.

In conclusion, teardrop-based AADs are lower than inferior acetabular rim-based AADs, leading to the measurement error of more than 10°. Inferior acetabular rim-based AADs can be more accurate than teardrop-based AADs because the inferior rim represents the hemispheric acetabulum better than does the teardrop due to the absence of the acetabular notch. Differentiation between the teardrop and the inferior acetabular rim when measuring AAD is needed to avoid confusion about acetabular abduction.

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Compliance with ethical standards

Conflicts of interest The authors declare that they have no conflict of interest.

Research involving human participants or animals This article does not contain any studies with human participants or animals performed by any of authors.

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