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A combination of acetabular coverage and femoral head–neck measurements can help diagnose femoroacetabular impingement

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ABSTRACT

This study aimed to evaluate the relationship between the radiographical features of combination of the acetabular coverage and the femoral head-neck shape and the occurrence of femoroacetabular impingement (FAI). In this study, 114 patients who had FAI with or without labral tear and mild osteoarthritis were analyzed. Plain radiographs and computed tomography (CT) were taken for evaluation of acetabular coverage and femoral head-neck measurements. The relationship between the combination angle of acetabular coverage and femoral head-neck measurements and the occurrence of FAI was evaluated. The prevalence of FAI patients with the combination angle of CT-anterior CE + α angle $\geq$100° was 6.1% (7/114 patients). Receiver operator characteristic curve analysis demonstrated a higher area under the curve for combination of CT-anterior center edge angle (ACEA) with the α angle at 0.94 (CT-ACEA +α angle). A threshold for the occurrence of FAI was determined using the combination CT-ACEA + α angle at 100°. The frequency of FAI surgery was significantly higher in patients with a combination angle $\geq$100° than in those with a smaller angle. The average modified Harris hip score was significantly lower in patients with a combination angle $\geq$100° than in those with a smaller angle. We suggest that the combination of lateral center edge angle $\geq$40°, α angle $\geq$50° and combined angles of CT-ACEA and α angle $\geq$100° may help diagnosis of FAI. Level of evidence III: retrospective cohort study.

INTRODUCTION

Femoroacetabular impingement (FAI) occurs due to recurrent impingement of the anterolateral femoral head-neck junction against the anterior rim of the acetabulum and causes articular cartilage delamination, labral disease and secondary osteoarthritis [1–3]. Two mechanisms of FAI have been reported [1, 4]. Pincer type impingement is due to acetabular overcoverage of the femoral head and is associated with acetabular retroversion, coxa profunda, protrusio acetabuli and periacetabular osteotomy overcorrection [4–7]. Cam-type impingement is due to a relative prominence or reduced head-neck offset at the anterolateral femoral head-neck junction associated with the deformity of aspherical femoral head, such as Legg-Calve-Perthes disease [2, 8–10]. Recently, acetabular and femoral version and tibial torsion have been reported to play a role in FAI [11–13]. A significantly higher mean femoral anteversion in patients with symptomatic cam FAI was found compared with healthy controls [11]. Shin *et al.* demonstrated a significant correlation between the combined index of acetabular and femoral version with both internal and external rotation of the hip [12]. Lerch *et al.* demonstrated that abnormal tibial torsion was found in 42% of patients with FAI [13].

Acetabular coverage of the femoral head is measured using the lateral center edge angle (LCEA) [14], and an LCEA over 40° is a good predictor of pincer-type FAI [15].

The cam-type FAI was first observed on anteroposterior radiographs as a pistol grip deformity [16]. Notzli *et al.* reported, based on a magnetic resonance imaging study, that the majority of cam-type FAI occurs at the anterolateral femoral head-neck junction [8]. Various radiographic diagnoses of cam-type FAI such as cross-table lateral radiographic view and Dunn 45° projection have been reported [17, 18]. Recently, Smith *et al.* compared magnetic resonance imaging, computed tomography (CT) and the Dunn 45° and Dunn 90° α angle measurements; they concluded that the Dunn 45° α angle is the most sensitive evaluation for cam-type deformity [19].

Beck *et al.* reported that most patients have a combination of radiographic features of pincer and cam impingement called mixed-type FAI; a minority of patients actually had the pure forms of pincer or cam impingement [1]. In contrast, a Japanese

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population-based study reported that the prevalence of isolated pincer, cam or mixed-type FAI is not predominant in Japan [20]. However, we often see patients who have anterior impingement without having radiographic features of isolated pincer, cam or mixed-type FAI. We hypothesized that the occurrence of FAI may be affected by the elements of both acetabular coverage and femoral head-neck shape.

Therefore, this study aimed to answer the following question: do the radiographical features of combined acetabular coverage and femoral head-neck shape affect the occurrence of FAI?

METHODS

Patients and surgery

In this retrospective cohort study, data from patients treated for hip symptoms at our hip joint clinic for the first time between January 2015 and June 2020 were included.

Patients who had lateral center edge angle (CE) of acetabulum $< 20^\circ$ the following characteristics were excluded from our study: those older than 60 years, those who had undergone a previous hip surgery or previous trauma and those who had osteoarthritis ($\geq$grade 2 according to the Tönnis classification), osteonecrosis, DDH (lateral center edge (CE)$< 20^\circ$), borderline DDH with periacetabular osteotomy ($20^\circ \leq$ lateral CE$<25^\circ$) or any other hip disease (e.g. inflammatory joint disease, subchondral insufficiency, fracture of the femoral head or transient osteoporosis of the hip). Patients lacking CT examination were also excluded. Finally, 114 patients were analyzed in this study (Fig. 1). In this study, FAI diagnosis was made by two experienced surgeons (SH and YK) based on symptoms that were predominantly caused by FAI (hip pain due to daily activities of sitting and hip flexion). Moreover, this diagnosis was established by physical examination showing positive anterior impingement sign (hip pain caused by flexion, adduction and internal rotation), as previously described [4]. The patients having symptoms predominantly caused by FAI were considered for FAI surgery even without radiographic features of isolated or mixed FAI such as LCEA $\geq 40^\circ$ and/or α angle $\geq 50^\circ$. Thirty-eight patients underwent arthroscopic FAI surgery. In all patients, intra-articular impingement was confirmed during arthroscopic surgery. A total of 76 patients who presented with hip pain that was not predominantly caused by FAI were classified as non-FAI patients. Therefore, four patients were classified as patients with non-FAI even with having an α angle $\geq 50^\circ$.

Clinical evaluation

Hip function was evaluated using the modified Harris Hip Score (mHHS) [21]. The initial mHHS (91 points) was normalized to 100 by multiplying the raw scores by 1.1. Scores $\geq$90 were defined as excellent mHHS [21]. The mHHS was evaluated preoperatively.

Imaging evaluation

The LCEA was defined as described in a previous report [22]. In anteroposterior view of the radiographs, the center of the femoral head was estimated from a circle encompassing the medial and inferior contour of the femoral head, and the longitudinal axis of the body was estimated perpendicular to a line connecting the inferior ischial tuberosities. The LCEA was measured between a line from the center of the femoral head parallel to the longitudinal axis and a line from the center of the femoral head to the most lateral aspect of the acetabular sourcil edge [22]. In false-profile views, the anterior center edge angle (ACEA) was measured between a vertical line through the center of the femoral head and a second line from the center of the hip to the anterior-most aspect of the acetabulum [23].

All analyzed patients were positioned on the CT table in the supine position, and preoperative scans were taken from the pelvis to the knee joint using a 64-row multislice CT system. The obtained image data sets were then transferred to a 3D template software package (ZedHip; LEXI Co., Tokyo, Japan). The CT-LCEA and CT-ACEA were measured from the coronal and sagittal views through the femoral head center to quantitatively evaluate acetabular coverage in multiple directions. Acetabular CT-LCEA was measured in the coronal view through the center of the femoral head according to the functional pelvic plane

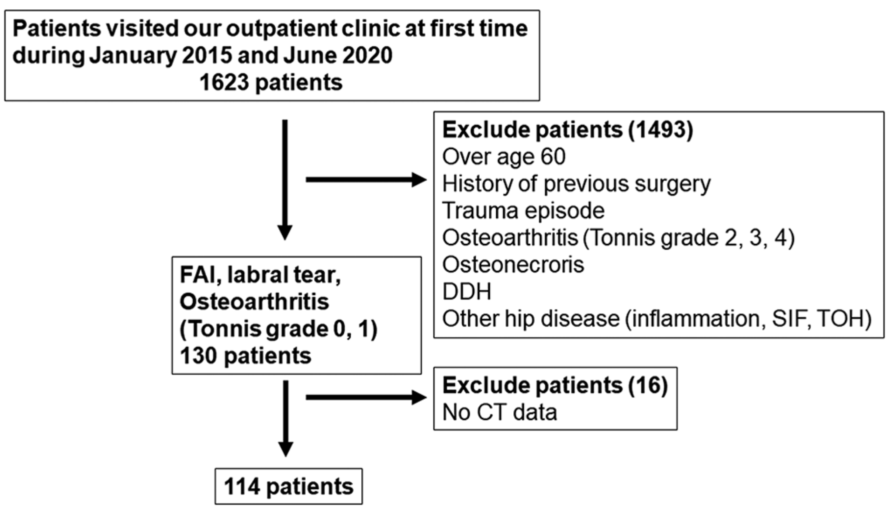

Fig. 1. Flowchart showing the patient selection process. SIF, subchondral insufficiency fracture of femoral head; TOH, transient osteoporosis of hip.

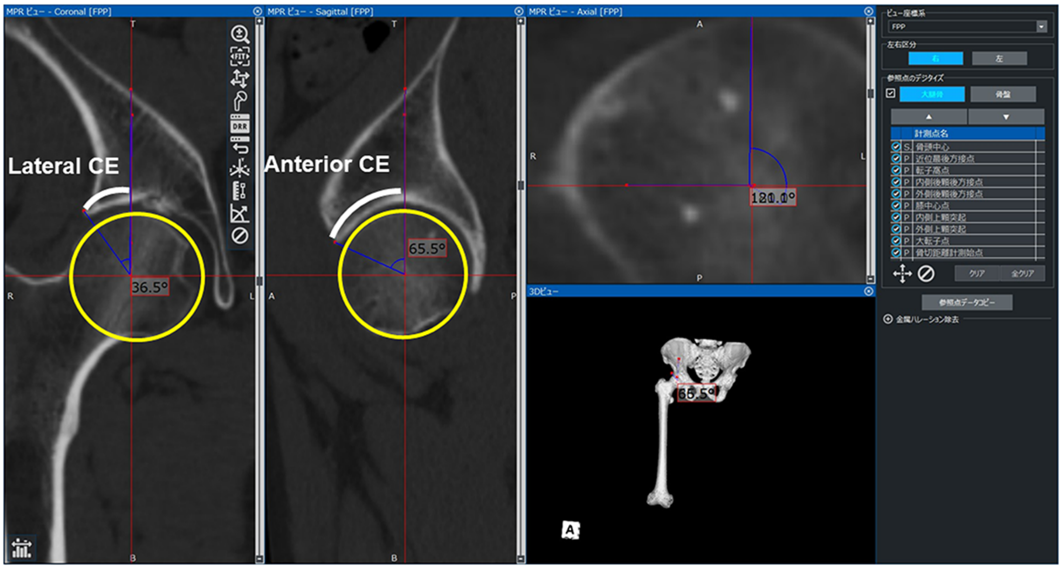

Fig. 2. Image of the 3D template software measuring the postoperative lateral (36.5°, left panel) and anterior (65.5°, second left panel) center edge angles.

Table I. Patient demographics

	FAI patients	*Non-FAI patients*	*P-value*
Number of hips	38	76	
Male/female	28/10	35/41	<0.001
Age (years)	35.6 ± 12.1	36.9 ± 13.0	0.938
mHHS	72.0 ± 12.4	67.5 ± 14.9	0.068

on the 3D template, and CT-ACEA was measured in the axial view through the center of the femoral head (Fig. 2). The α angle was determined by Dunn 45° view of the radiograph according to previous reports [19].

Briefly, the α angle was the angle between a line from the center of the femoral head through the middle of the femoral neck and a line through a point where the contour of the femoral head-neck junction exceeds the radius of the femoral head. All measurements of images were performed by two observers who were blinded to patient data.

Statistical analysis

All data are expressed as the means ± standard deviations, unless otherwise indicated. The numbers of male and female patients between FAI and non-FAI patients were compared using Fisher's exact test (Table I). The difference between continuous variables of patients' backgrounds (age and mHHS) or radiographic parameters (LCEA, ACEA, α angle and combination angle with CEs) between FAI and non-FAI patients was analyzed using the Mann–Whitney U test (Tables I and II). To assess the degree of significance between radiographic parameters and the occurrence of FAI, thresholds of LCEA, ACEA, α angle and combination angle with CEs for the occurrence of FAI were calculated utilizing a receiver operator characteristic (ROC). The ROC allows for graphical representation of a binary model and provides the ability to determine a discriminatory threshold

Table II. Characteristics of radiographic parameters

	FAI patients (n = 38)	*Non-FAI patients (n = 76)*	*P-value*
Lateral CE angle (plain Xp)	30.2 ± 7.1	24.4 ± 4.9	<0.001
Anterior CE angle (plain Xp)	35.7 ± 9.2	29.5 ± 10.2	0.012
Lateral CE angle (CT)	28.5 ± 6.9	24.4 ± 6.2	<0.001
Anterior CE angle (CT)	57.9 ± 8.3	47.8 ± 10.0	<0.001
α angle (plain Xp)	57.3 ± 11.9	42.1 ± 8.4	<0.001
Combination angle with lateral CE and α angle (plain Xp)	87.6 ± 14.5	66.4 ± 10.6	<0.001
Combination angle with anterior CE and α angle (plain Xp)	93.9 ± 15.5	71.5 ± 13.5	<0.001
Combination angle with lateral CE (CT) and α angle	85.9 ± 13.7	66.6 ± 10.7	<0.001
Combination angle with anterior CE (CT) and α angle	115.2 ± 14.2	90.0 ± 13.0	<0.001

(Figs 3 and 4). This methodology has been previously utilized in the literature for determining the patient acceptable symptomatic state—a threshold that approximates patient satisfaction as a binary response [24]. The area under the curve (AUC) measured the accuracy of classifying the outcome based on the model. An AUC of 0.50 was equated with random assignment, an AUC between 0.7 and 0.8 was equated with acceptable discrimination, an AUC >0.80 was equated with excellent discrimination, and an AUC of 1.0 was equated with perfect assignment [25]. The Youden index—the point on the curve

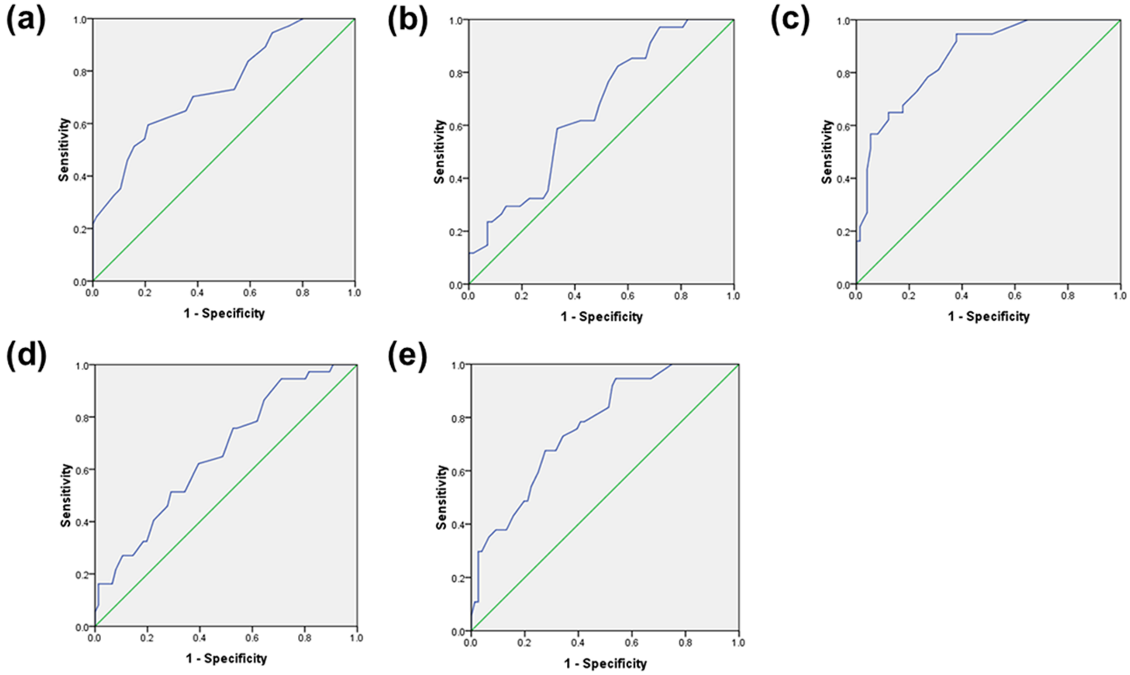

Fig. 3. The ROC curve for the occurrence of FAI. (a) LCEA, (b) ACEA, (c) α angle, (d) CT-LCEA and (e) CT-ACEA. LCEA, lateral center edge angle; ACEA, anterior center edge angle.

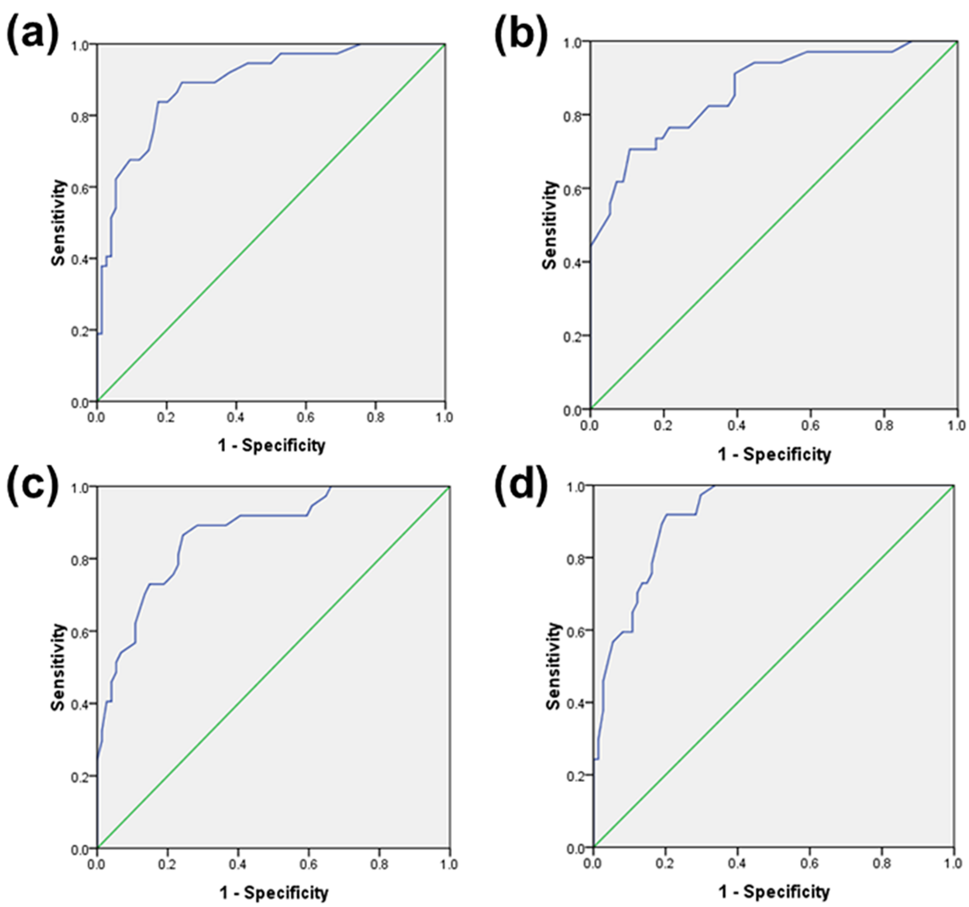

Fig. 4. The ROC curve for the occurrence of FAI. (a) LCEA + α angle, (b) ACEA+ α angle, (c) CT-LCEA + α angle and (d) CT-ACEA+ α angle.

that achieves the highest sensitivity and specificity—was used to set the optimal threshold value [25]. The prevalence of FAI and mHHS between the patients with lateral CE (CT) ≥40° and the angle <40°, α angle ≥50° and the angle <50°, both features having lateral CE ≥40° and α angle ≥50° and not having both features of the angles, or combination angle of CT-anterior CE + α angle ≥100° and the angle <100° were analyzed using the Mann–Whitney *U* test (Table III). The database was analyzed using SPSS version 16.0 (IBM Corp., Armonk, NY, USA), and *P*-values <0.05 were considered statistically significant. To validate the measurement method for CT-LCEA, CT-ACEA and α angle, interobserver variabilities were validated by two blinded observers who were not operating surgeons for the first ten cases; each observer validated three times for intra-observer variabilities.

A post hoc power analysis was performed using G*Power 3. For a sample size of 38 vs. 76 elements in two groups and a type-I error (α) of 0.05 (Mann–Whitney *U* test), the study was expected to provide a power (1-β) of 0.79 for detecting an effect size of 0.5.

Ethics

The study protocol was approved by the institutional review board of the authors' affiliated institution, and informed consent for participation in the study was obtained from all participants.

RESULTS

Patient characteristics and clinical outcomes

The background characteristics of the patients in our study are summarized in Table I. The mean values of age and mHHS were not significantly different between the FAI and non-FAI patients (Table I). However, the number of male patients was significantly higher among FAI patients (Table I).

Combination angle with acetabular coverage and femoral head-neck measurements were larger in FAI patients

The means of the LCEA, ACEA and α angle were significantly higher in the FAI group than in the non-FAI group (Table II). Combination angles of the LCEA or ACEA and α angle were also significantly higher in the FAI group than in the non-FAI group (Table II). Intraclass correlation coefficients of the intra-observer CT-LCEA, CT-ACEA and α angle were 0.972, 0.977 and 0.951. Intraclass correlation coefficients of the interobserver measurement in the CT-LCEA, CT-ACEA and α angle were 0.921, 0.928 and 0.901. These data confirmed the reproducibility of this method.

The combination of lateral or anterior CE and alpha angles predicted the occurrence of FAI

The ROC curve for CT-LCEA and CT-ACEA demonstrated acceptable discrimination. Additionally, regarding the α angle, excellent discrimination was demonstrated between the patients with and without FAI with an AUC of 0.66 (LCEA), 0.66 (ACEA), 0.74 (CT-LCEA), 0.77 (CT-ACEA) and 0.86 (α angle) (Fig. 3). However, a higher AUC was demonstrated by the ROC curve for the combination of either LCEA or ACEA and the α angle with 0.87 (LCEA + α angle), 0.87 (ACEA + α angle), 0.89 (CT-LCEA + α) and 0.92 (CT-ACEA + α) (Fig. 4). The highest AUC was 0.92 CT-ACEA + α angle. Using the Youden index, a threshold for the occurrence of FAI of the combination angle of CT-anterior CE + α angle was 100°.

Table III. Characteristics of radiographic parameters for FAI prediction

		Number of patients	*Frequency of FAI patients*	*mHHS*
Lateral CE (CT) angle	≥40°	7	100%	60.3 ± 14.7
	<40°	107	29%	71.6 ± 13.5
	P-value		<0.001	0.072
α angle	≥50°	32	89%	61.5 ± 13.3
	<50°	82	7.3%	76.5 ± 10.7
	P-value		<0.001	<0.001
Both features having lateral CE ≥40° and α angle ≥50°	Yes	5	100%	54.4 ± 12.4
	No	109	29%	71.7 ± 13.4
			<0.001	0.018
Combination angle with anterior CE (CT) and α angle	≥100°	39	92%	65.5 ± 13.9
	<100°	75	3%	76.0 ± 11.8
	P-value		<0.001	<0.001

Cut-off values of the combination angle with acetabular coverage and femoral head-neck measurements can predict the occurrence of FAI

The prevalence of FAI patients with lateral CE (CT) ≥40°, α angle ≥50°, both features having lateral CE ≥40° and α angle ≥50°, and combination angle of CT-anterior CE + α angle ≥100° were 6.1% (7/114 patients), 28.1% (32/114 patients), 4.4% (5/114 patients) and 34.2% (39/114 patients) of all the patients (Table III). The predominance of patients with FAI was high in those with lateral CE (CT) ≥40° (100%, 7/7 patients); α angle ≥50° (89%, 28/32 patients) (sensitivity, 0.81; specificity, 0.92); and both features having lateral CE ≥40° and α angle ≥50° (100%, 5/5 patients); in addition, this predominance was higher in patients with the combination angle of CT-anterior CE + α angle ≥100° (92%, 36/ 39 patients) (sensitivity, 0.95; specificity, 0.96) than in patients with smaller angles (Table III). Both sensitivity and specificity in identifying patients with FAI were higher in those with the combination angle of CT-anterior CE + α angle ≥100° than with α angle ≥50°. The average mHHS was lower in patients with the α angle ≥50°, both features having lateral CE ≥40° and α angle ≥50°, and the combination angle of CT-anterior CE + α angle ≥100° than in the patients with smaller angles.

DISCUSSION

In this study, our findings demonstrated that the combination angles of acetabular coverage and α angle may help predict the occurrence of FAI than may do the LCEA, ACEA or α angle alone. Moreover, the combination of CT-ACEA and α angle may be predictive measurement that could help screening for occurrence of mixed-type FAI.

Dandachli *et al.* demonstrated that the means of CT-LCEA and CT-ACEA were significantly higher in pincer FAI patients than in non-FAI patients [26]. Higher α angles were associated with cam-type FAI as measured by an increased offset α angle and were correlated with increased chondral damage, labral injury and decreased range of motion [27, 28]. Notzli *et al.* reported that the mean α angles of normal and symptomatic FAI were 42° and 74°, respectively [8]. These previous reports supported our finding that the means of CEAs and α angle were significantly higher in FAI patients than in non-FAI patients. We used the ROC curve analysis for calculating thresholds of LCEA, ACEA, CT-LCEA, CT-ACEA and α angle for determining occurrence of FAI. However, the AUC of these angles was lower than that of the combination angle of acetabular coverage and the α angle. In addition, sensitivity and specificity in identifying patients with FAI were higher in those with the combination angle of CT-anterior CE + α angle $\geq$100° than in patients with the α angle $\geq$50°. These results indicated that the occurrence of FAI varied with changes in acetabular coverage and the shape of the head-neck junction of the femur.

Furthermore, we demonstrated that CT-LCE $\geq$30° or α angle $\geq$50° was associated with the occurrence of FAI and worse mHHS compared with smaller angles. Ibrahim *et al.* reported that anterior coverage had a negative correlation with the improvement of functional score in cam-type FAI patients [29]. Chandrasekaran *et al.* reported a poor improvement in patient outcomes and pain at the 2-year follow-up of patients with acetabular overcoverage undergoing arthroscopic surgery compared with matched controls with normal acetabular coverage; they also reported a higher incidence of conversion to total hip arthroplasty in the acetabular overcoverage group. These reports were in line with our findings. We also demonstrated that the combined angles of CT-anterior CE + α $\geq$100° were significantly associated with the occurrence of FAI and worse mHHS. Therefore, the combination angle may help predict the occurrence of FAI and worse mHHS.

Bouma *et al.* demonstrated that the omega zone was a CT-based drawing of the femoral head surface and represented the area of impingement. They also showed that this omega zone integrated five main parameters affecting occurrence of FAI: alpha and center edge angles, acetabular and femoral version and neck-shaft angle [30, 31]. The omega zone could differentiate between patients with cam-type FAI and patients with non-FAI with alpha angles $\geq$55°, who could not be distinguished using the alpha angle alone. Our current study also evaluated the relationship between radiographical features and occurrence of FAI [30–32]. The combination of the new radiographical indicator for occurrence of FAI such as the omega zone and combination angle may help better diagnose FAI.

Limitations

This study had some limitations. First, our study was not a randomized, but a retrospective cohort study. Second, the number of patients included in the study was too small to completely analyze all parameters. Third, there are only three angles regarding CT analysis. We need further information about acetabular version and/or femoral version to fully understand the occurrence of FAI. However, we focused on the FAI due to combined acetabular coverage and femoral head-neck shape in this study. Fourth, acquisition of CT images causes disadvantages in terms of cost and radiation exposure to the patients. However, we routinely take CT images preoperatively to confirm the three-dimensional acetabular coverage. Finally, mHHS has a ceiling effect in the FAI population and may not best represent the outcomes. Patient-reported outcome measurement will be better to understand than clinical outcomes in FAI populations. Fifth, the classification of FAI and non-FAI in this study may have induced bias of patients with false negatives who had intra-articular impingement but were classified as the non-FAI group.

CONCLUSION

We suggest that the combination with LCEA $\geq$40°, α angle $\geq$50° and the combined CT-ACEA and α angle $\geq$100° may help diagnosis of FAI.

DATA AVAILABILITY

All data generated or analyzed during this study are included in this published article.

ACKNOWLEDGEMENTS

Not applicable.

FUNDING

No funding was received for this study.

CONFLICT OF INTEREST STATEMENT

None declared.

AUTHOR CONTRIBUTIONS

SH participated in the study design, drafting of the manuscript and data collection. YK carried out data collection and drafting of the manuscript. NN participated in the data collection and drafting of the manuscript. TMat participated in the study design and helped to revised the manuscript. TK participated in the data collection and drafting of the manuscript. TMae carried out data collection and drafting of the manuscript. RK participated in the study design and helped to revised the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study protocol was approved by our institutional ethics committee on 8 September 2011 (No. 1219), and informed consent for participation in the study was obtained from all participants.

CONSENT FOR PUBLICATION

Not applicable.

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