

Prevalence and morphological features of acetabular dysplasia with coexisting femoroacetabular impingement-related findings in a Japanese population: a computed tomography-based cross-sectional study

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ABSTRACT

The coexistence of acetabular dysplasia (AD) and femoroacetabular impingement (FAI) has not been well discussed. This study was performed to elucidate the prevalence and morphological features of AD with coexisting FAI-related findings in a Japanese population. Computed tomography images were retrospectively evaluated. AD was classified as definite or borderline. The morphological findings that defined cam deformity were an α angle of $\geq 55^\circ$, head–neck offset ratio (HNOR) of < 0.13 , pistol grip deformity positivity and herniation pit positivity. The morphological findings that defined pincer deformity were acetabular index of $\leq 0^\circ$ and a retroverted acetabulum. In total, 128 hips (male, 64; female, 64) were analyzed. The prevalence of coexistence of AD and FAI-related findings was detected in 23.4% of hips (definite AD and FAI, 7.8%; borderline AD and FAI, 15.6%). The percentages of hips with AD containing cam or pincer deformities among all were 54.3% and 4.3%, respectively. The percentage of AD with coexisting cam and that of AD with coexisting combined deformities was significantly higher in men, respectively. On the other hand, the most major morphological feature of FAI detected in hips with AD was a HNOR of < 0.13 . The coexistence of AD and FAI-related findings was common in a Japanese population, and 65.2% of hips with AD had some FAI-related findings. In discussing and managing AD, we recommend paying attention to the coexistence with FAI-related findings, especially in men and in borderline AD. In such hips, the most notable parameter as a morphological feature of FAI is a reduced HNOR.

INTRODUCTION

Acetabular dysplasia (AD) is a well-recognized cause of osteoarthritis (OA) of the hip [1]. In Japan, AD is a major risk factor for OA [2], and the prevalence of AD is higher in Japanese than in Western populations [3]. Furthermore, definite AD and borderline AD are often distinguished in the clinical setting [4, 5]. Femoroacetabular impingement (FAI) has also been highlighted, and an association between FAI and hip OA has been identified [6, 7]. FAI has been thought to be divided into four categories: cam

deformity, pincer deformity, combined deformities and sports impingement, where a hip with normal anatomy impinges in extreme positions in sporting activity.

The anatomical abnormalities associated with AD and FAI have been discussed as independent anatomical features. Several recent reports have described the coexistence of AD and FAI-related findings in patients with symptomatic AD or FAI [8–11]. However, the prevalence and morphological features of the coexistence of AD (especially borderline AD) and FAI-related findings are not well known in

Japanese populations who are generally assumed to have AD rather than Western populations. The aim of this study was to investigate the detailed prevalence and morphological features of AD with coexisting FAI-related findings using multislice computed tomography (CT) images in a Japanese population.

MATERIALS AND METHODS

Patients and parameters

The ethics committee of our institution approved the study protocol. We conducted a retrospective patient-based study of patients who had undergone CT imaging of the chest, abdomen and pelvis. We reviewed all CT data from 1 July 2013–14 August 2013 in our institution. First, we selected the scans that had been ordered by other departments at our institution and confirmed that the CT examination had been performed for conditions unrelated to hip disorders based on the information in the clinical record. Next, we selected 65 consecutive patients irrespective of sex who fulfilled the criteria described below. The inclusion criteria for the present study were as follows: (1) involvement of the whole pelvis and both hip joints, (2) reconstructed axial slice thickness of ≤ 1 mm and (3) normal pelvic rotations and tilt (specified below in the section describing standardization of CT images). The exclusion criteria were as follows: (1) age of < 20 years, (2) inability to clearly detect the center of the femoral head, such as in patients with an elliptical femoral head and (3) inability to correctly measure the parameters, such as clear hip OA that had the osteophyte formation, the loss of joint space and subchondral bone cysts [12].

Both hips were analyzed in each patient. Two male hips were excluded because of a metaphyseal bone tumor in each. As a result, 128 hips (64 male hips and 64 female hips) were evaluated. The examined parameters and findings were age, sex, center-edge (CE) angle [13], Sharp angle [14], acetabular index (AI) [15], acetabular version angle [16], α angle [17], head-neck offset ratio (HNOR) [18], herniation pit (HP) [19] and pistol grip deformity (PGD) [20, 21].

CE angle, Sharp angle and AI were measured on a slice of the femoral head center in the coronal plane (Fig. 1). The acetabular anteversion angle was measured in four axial slices (Fig. 2). We defined an acetabulum with a negative acetabular anteversion angle in any slice (A1, A2, A3 or A4) as a retroverted acetabulum (RA) [22]. RA of these slices was representing crossover sign positive on plain radiograph. The α angle and HNOR were measured in multiple radial slices, namely clockwise system, using previously described methods [23–25] (Fig. 3). We defined an

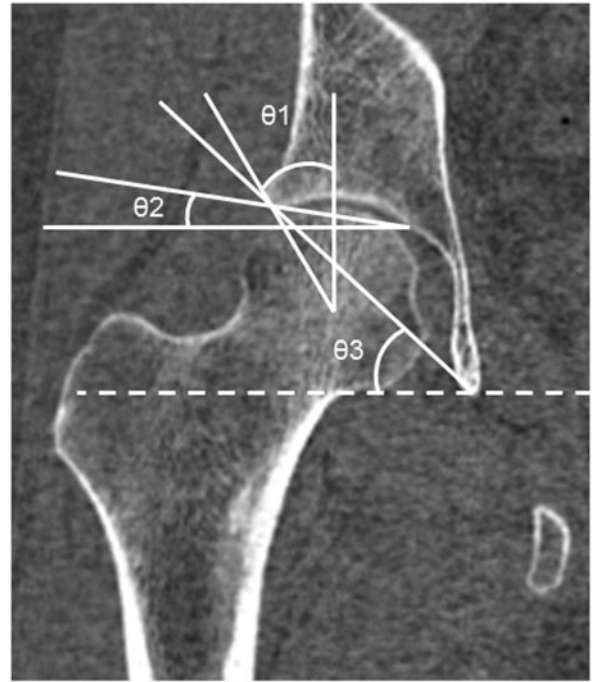


Fig. 1. Measurement of CE angle, Sharp angle and AI. These angles were measured on a slice of femoral head center in the coronal plane. θ_1 , θ_2 , and θ_3 is CE angle, Sharp angle and AI, respectively. CE angle was measured as the angle between the line joining the lateral aspect of the acetabulum and the femoral head center, and the line perpendicular to the line parallel to the transverse axis of the pelvis. Sharp angle was measured as the angle between the line joining the lateral aspect of the weight bearing zone and the inferior point of teardrop, and the line parallel to the transverse axis of the pelvis. AI was measured as the angle between the line joining the medial and lateral aspects of the weight bearing zone, and the line parallel to the transverse axis of the pelvis.

HP as a cystic-like lesion underneath the anterior cortex at the anterosuperior femoral head-neck junction with a clear demarcation [26] and a diameter of > 3 mm [27] (Fig. 4). HP was evaluated at the above-described multiradial slices. The presence of a PGD was subjectively determined using reconstructed three-dimensional CT images (Fig. 5). AD was classified into definite AD and borderline AD. Definite AD was defined as a CE angle of $< 20^\circ$ or a Sharp angle of $> 45^\circ$. Borderline AD was defined as a CE angle of 20° to $< 25^\circ$ or a Sharp angle of $> 42^\circ$ to 45° (hips already defined as definite AD were excluded). We investigated the prevalence of these morphological findings and then determined the prevalence of AD with coexisting radiological FAI. FAI was classified into cam and pincer deformities. Cam deformity was defined as an α angle of $\geq 55^\circ$ [28], HP positivity [29], PGD positivity [29] or

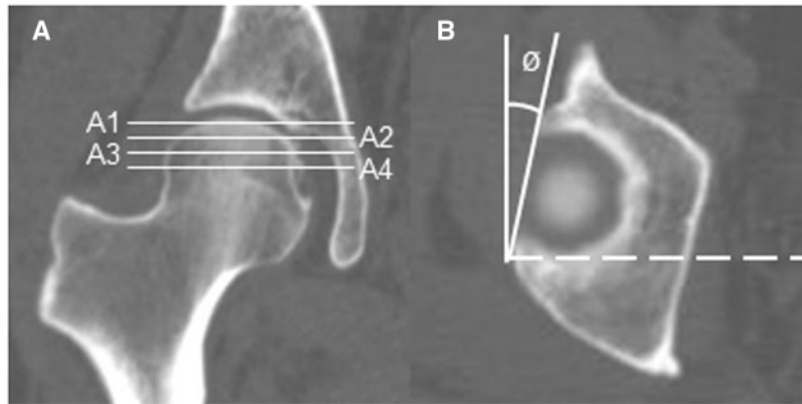


Fig. 2. Measurement of the acetabular version angle in four axial slices. (A) Reference plane for measuring the acetabular version angle. Each line represents one of the four slices; a slice at the level of the superior margin of the femoral head (slice A1), a slice 5 mm below the superior margin of the femoral head (slice A2), a slice 10 mm below the superior margin of the femoral head (slice A3) and a slice 15 mm below the superior margin of the femoral head (slice A4). (B) Axial slice of A1. Angle θ is the acetabular version angle.

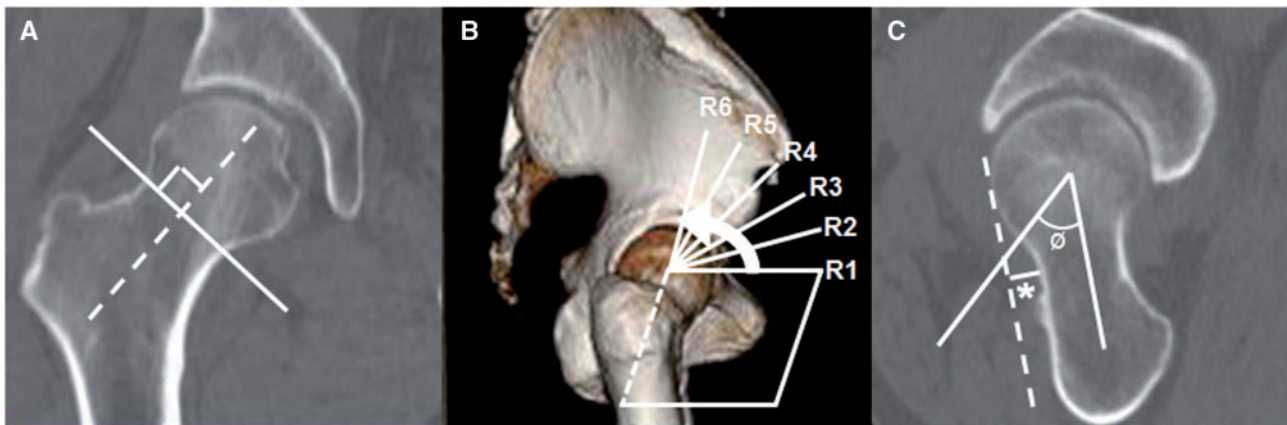


Fig. 3. Measurement of the α -angle and HNOR in multiple radial slices (clockwise system). (A) Reference plane for measuring the α -angle and HNOR. The *dotted line* is the axis through the center of the femoral neck. It is adjusted to be parallel to the femoral neck–shaft angle. The *solid line* is the reference plane for radial angle reconstruction. (B) The reconstructed three-dimensional image demonstrates superimposed radial reference lines at 15° intervals. R1 (3:00 o'clock) is the oblique axial slice (*dotted line* in A). R2 (2:30 o'clock) is a plane rotated 15° from R1. R3 (2:00 o'clock) is a plane rotated 30° from R1. R4 (1:30 o'clock) is a plane rotated 45° from R1. R5 (1:00 o'clock) is a plane rotated 60° from R1. R6 (12:30 o'clock) is a plane rotated 75° from R1. (C) Angle θ is the α -angle. The α -angle is the angle between the line joining the center of the femoral head and the center of the femoral neck, and the line from the center of the femoral head to the point where the spherical image of the femoral head is lost. The HNOR was calculated by dividing the anterior offset (*asterisk*) by the maximum diameter of the femoral head of each slice. The anterior offset is the thickness of the femoral head that lies anterior to a line passing the anterior wall of the femoral neck that is parallel to a line crossing the center of the femoral head and neck.

an HNOR of <0.13 [28]. Pincer deformity was defined as AI of $\leq 0^\circ$ [29] or the presence of an RA. Hips with both cam and pincer deformities were considered to have a combined deformity. Prevalence was defined as the proportion of hips that fulfilled a specific definition among all of the hips in this study.

Radiological examination and standardization of CT images

All CT images were axial and sequential and were obtained in the supine position without gantry tilt (120 kV, 160 mA, 0.5 s) using a Toshiba Aquilion CX (Toshiba Medical Systems Corporation, Tokyo, Japan). The data were



Fig. 4. We defined an HP as a cystic-like lesion underneath the anterior cortex at the anterosuperior femoral head–neck junction with clear demarcation and a diameter of >3 mm. A HP (arrow) was evaluated in multiradial six slices.

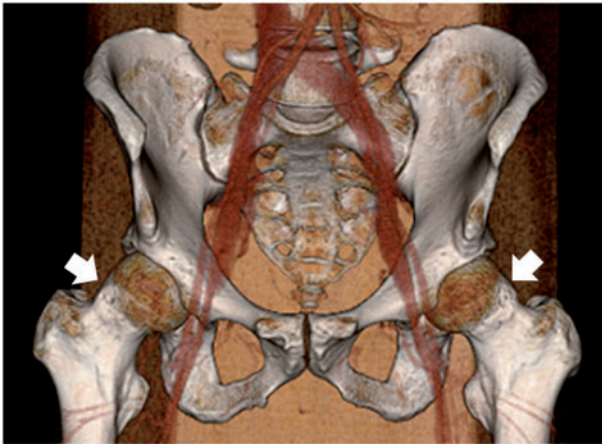


Fig. 5. The presence of a PGD was subjectively judged on reconstructed three-dimensional reconstructed computed tomography images. This case was judged to be PGD-positive bilaterally (arrow).

reconstructed under conditions suitable for bone evaluation using AquariusNet Viewer software (TeraRecon Inc., San Francisco, CA, USA). We used the three-dimensional reconstructed CT images to confirm the pelvic rotation and tilt. We confirmed (1) the rotation in the coronal plane (confirmed whether the teardrop line was horizontal), (2) the rotation in the axial plane (examined whether

any horizontal distance was present between the tip of the coccyx and the pubic symphysis [30]) and (3) the neutral pelvic tilt (investigated the distance between the upper border of the symphysis and the midportion of the sacrococcygeal joint, as described previously [29, 30]). In this study, $32 \text{ mm} \pm 10 \text{ mm}$ in men and $47 \pm 10 \text{ mm}$ in women were considered neutral [30].

Statistical methods

Data are expressed as mean \pm standard deviation. All statistical analyses were performed using StatView version 5.0 (SAS Institute, Cary, NC, USA). The significance of differences between men and women was evaluated using the Wilcoxon rank-sum test and χ^2 test. Values of $P < 0.05$ were considered to indicate statistical significance. The 95% confidence interval (CI) was estimated based on the score test for prevalences. To evaluate the intraobserver reliability and interobserver reliability between the two observers (senior orthopedic surgeons) who were blinded to the each other's results, the intraclass correlation coefficients (ICCs) of the CE angle, Sharp angle, AI, acetabular version angle, α angle and HNOR were evaluated using SPSS statistics 22.0 for Windows (IBM Corp., Armonk, NY, USA) at least 2 weeks apart. Observer agreement was considered unacceptable if the value was less than 0.40, moderate if the value was 0.41–0.60, substantial if the value was 0.61–0.80, and almost perfect if the value was greater than 0.80.

RESULTS

Table I shows the mean age and parameters of all patients and of men and women. Table II shows the prevalence of each type of AD and FAI-related findings in all patients, men and women. Overall, AD was detected in 35.9% of hips (46/128) [29.7% (19/64) in men, 42.2% (27/64) in women; $P = 0.140$] (data not shown). A total of 76.6% of hips (98/128) met at least one criterion of the definition of cam or pincer deformity [89.1% (57/64) in men, 64.1% (41/64) in women; $P < 0.001$] (data not shown).

Table III shows the prevalence of each combination of the coexistence of AD and FAI-related deformities. Figure 6 was the representative case of definite AD with coexisting cam deformity. The prevalence of borderline AD with coexisting FAI (15.6%, 20/128) was times higher than that of definite AD with coexisting FAI (7.8%, 10/128). Altogether, the coexistence of AD and any type of FAI-related deformity was detected in 23.4% (30/128) of all hips. The prevalence of AD with a coexisting cam deformity was higher than that of AD with a coexisting pincer deformity regardless of sex. No significant difference was

Table I. Mean age and data for each parameter in all patients, men and women

	All subjects (128 hips)	Males (64 hips)	Females (64 hips)	P-value
Age (years)	56.3±15.8 (21–84)	57.2±16.1(21–83)	55.5±15.48 (31–84)	0.520*
CE angle (°)	31.6±7.0 (15.4–47.8)	32.3±6.5 (17.6–45.7)	30.9±7.3 (15.4–47.8)	0.315*
Sharp angle (°)	40.1 ± 6.9 (31.8–54.8)	39.3 ± 4.1 (31.8–54.8)	40.9 ± 3.3 (31.9–49.1)	0.003*
Acetabular index (°)	6.7±9.2 (–7.9–22.8)	6.6±11.3 (–7.5–22.8)	6.8±6.4 (–7.9–22.3)	0.195*
Acetabular version				
A1 (°)	9.0±8.6 (–14.9–31.3)	7.8±9.9 (–7.2–29.0)	10.3±8.8 (–14.9–31.3)	0.043*
A2 (°)	12.0±9.0 (–10.6–34.0)	9.9±8.6 (–7.5–34.0)	14.0±8.8 (–10.6–32.7)	0.003*
A3 (°)	16.7±8.7 (–7.5–33.4)	15.1±8.1 (–1.3–33.3)	18.2±9.1 (–7.5–33.4)	0.025*
A4 (°)	19.6±7.8 (–3.8–35.6)	18.2±6.8 (1.51–35.6)	20.9±8.5 (–3.8–35.6)	0.030*
α-angle				
R1 (°)	40.3±5.1 (21.6–55.0)	41.6±5.0 (30.5–55.0)	39.0±5.0 (21.6–48.7)	0.011*
R2 (°)	42.8±5.7 (30.8–60.3)	44.0±6.1 (30.8–60.3)	41.7±4.9 (31.6–52.9)	0.025*
R3 (°)	46.0±5.9 (32.3–64.6)	46.9±6.5 (32.3–64.6)	45.0±5.1 (33.9–58.2)	0.130*
R4 (°)	48.5±5.9 (35.9–68.6)	49.0±6.5 (35.9–68.6)	47.9±5.2 (39.2–63.9)	0.413*
R5 (°)	49.0±6.9 (34.7–75.0)	51.4±7.0 (39.2–75.0)	47.7±5.9 (34.7–72.1)	<0.001*
R6 (°)	46.9±7.4 (33.1–74.7)	49.5±7.4 (34.1–74.7)	44.3±4.9 (33.1–53.7)	<0.001*
HNOR				
R1	0.245±0.03 (0.159–0.371)	0.243±0.03 (0.159–0.333)	0.248±0.04 (0.165–0.371)	0.504*
R2	0.241±0.07 (0.123–0.349)	0.245±0.09 (0.123–0.305)	0.236±0.04 (0.156–0.349)	0.784*
R3	0.205±0.04 (0.080–0.336)	0.211±0.05 (0.080–0.307)	0.200±0.04 (0.115–0.336)	0.099*
R4	0.167±0.05 (0.036–0.323)	0.165±0.05 (0.036–0.306)	0.168±0.04 (0.113–0.323)	0.628*
R5	0.140±0.03 (0.054–0.270)	0.136±0.03 (0.057–0.248)	0.145±0.03 (0.054–0.270)	0.113*
R6	0.141±0.03 (0.056–0.263)	0.132±0.03 (0.056–0.191)	0.150±0.03 (0.065–0.263)	0.002*
HP positive	17.2% (10.6%–23.7%)	24.6% (17.14%–32.06%)	9.2% (6.65%–11.75%)	0.019†
PGD positive	14.0% (7.98%–20.01%)	20.0% (13.07%–26.92%)	12.3% (17.32%–28.68%)	0.041†

Data are presented as mean ± standard deviation (range) or as percentage (95% CI). CE angle, center-edge angle; HNOR, head–neck offset ratio; HP, herniation pit; PGD, pistol grip deformity. A1, axial slice at the level of the superior margin of the femoral head; A2, axial slice 5 mm below the superior margin of the femoral head; A3, axial slice 10 mm below the superior margin of the femoral head; A4, axial slice 15 mm below the superior margin of the femoral head; R1, oblique axial plane through the center of the femoral neck, adjusted to be parallel to the femoral neck–shaft angle (3:00 o'clock); R2, radial plane cranially rotated 15° from R1 (2:30 o'clock); R3, radial plane cranially rotated 30° from R1 (2:00 o'clock); R4, radial plane cranially rotated 45° from R1 (1:30 o'clock); R5, radial plane cranially rotated 60° from R1 (1:00 o'clock); R6, radial plane cranially rotated 75° from R1 (12:30 o'clock).

*Male versus female, evaluated with the Wilcoxon rank-sum test. *P*-values of <0.05 were considered statistically significant.

†Male versus female, evaluated with χ^2 test. *P*-values of <0.05 were considered statistically significant.

Table II. Detailed prevalence of AD and FAI-related findings in all patients, men, and women

	<i>All subjects (128 hips)</i>	<i>Males (64 hips)</i>	<i>Females (64 hips)</i>	<i>P-value*</i>
Definite AD				
CE angle <20°	6.3% (8/128) [3.2%–11.8%]	3.1% (2/64) [0.9%–10.7%]	9.4% (6/64) [4.4%–19.0%]	0.144
Sharp angle >45°	7.8% (10/128) [4.3%–13.8%]	6.3% (4/64) [2.5%–15.0%]	9.4% (6/64) [4.4%–19.0%]	0.439
Total	11.7% (15/128) [7.2%–18.4%]	7.8% (5/64) [3.4%–17.0%]	15.6% (10/64) [8.7%–26.4%]	0.169
Borderline AD				
20° ≤ CE angle <25°	12.5% (16/128) [7.8%–19.3%]	12.5% (8/64) [6.5%–22.8%]	12.5% (8/64) [6.5%–22.8%]	1
42° < Sharp angle ≤45°	21.9% (28/128) [15.6%–29.8%]	15.6% (10/64) [8.7%–26.4%]	28.1% (18/64) [18.6%–40.1%]	0.087
Total	24.2% (31/128) [17.6%–32.3%]	21.9% (14/64) [13.5%–33.4%]	26.6% (17/64) [17.3%–38.5%]	0.536
Cam deformity				
α angle ≥55°	28.9% (37/128) [21.8%–37.3%]	40.6% (26/64) [29.5%–52.9%]	17.2% (11/64) [9.9%–28.2%]	0.003
HNOR <0.13	58.6% (75/128) [49.9%–66.9%]	65.6% (42/64) [53.4%–76.1%]	51.6% (33/64) [39.6%–63.4%]	0.106
PGD positive	14.1% (18/128) [9.1%–21.1%]	20.3% (13/64) [12.3%–31.7%]	7.8% (5/64) [3.4%–17.0%]	0.041
HP positive	17.2% (22/128) [11.6%–24.7%]	25.0% (16/64) [16.0%–36.8%]	9.4% (6/64) [4.4%–19.0%]	0.016
Total	68.0% (87/128) [59.5%–75.4%]	79.7% (51/64) [68.3%–87.7%]	56.3% (36/64) [44.1%–67.7%]	0.004
Pincer deformity				
Acetabular index ≤0°	18.0% (23/128) [12.3%–25.5%]	20.3% (13/64) [12.3%–31.7%]	15.6% (10/64) [8.7%–26.4%]	0.489
RA	12.5% (16/128) [7.8%–19.3%]	17.2% (11/64) [9.9%–28.2%]	7.8% (5/64) [3.4%–17.0%]	0.108
Total	28.9% (37/128) [21.8%–37.3%]	37.5% (24/64) [26.7%–49.7%]	20.3% (13/64) [12.3%–31.7%]	0.031
Combined deformity	20.3% (26/128) [14.3%–28.1%]	28.1% (18/64) [18.6%–40.1%]	12.5% (8/64) [6.5%–22.8%]	0.028

Data are shown as percentage [95% CI]. AD, acetabular dysplasia; FAI, femoroacetabular impingement; CE, center-edge angle; PGD, pistol grip deformity; HP, herniation pit; HNOR, head–neck offset ratio; RA, retroverted acetabulum.

*Male versus female, evaluated with χ^2 test. *P*-values of <0.05 were considered statistically significant.

Table III. Prevalence of each combination of coexistence of AD and FAI-related deformities

	All subjects (128 hips)	Males (64 hips)	Females (64 hips)	P-value*
Definite AD and FAI-related deformities	7.8% (10/128) [4.3%–13.8%]	7.8% (5/64) [3.4%–17.0%]	7.8% (5/64) [3.4%–17.0%]	1
Definite AD + cam deformity	6.3% (8/128) [3.2%–11.8%]	4.7% (3/64) [1.6%–12.9%]	7.8% (5/64) [3.4%–17.0%]	0.465
Definite AD + pincer deformity	0% (0/128) [0%–2.9%]	0% (0/64) [0%–5.7%]	0% (0/64) [0%–5.7%]	–
Definite AD + combined deformity	1.6% (2/128) [0.4%–5.5%]	3.1% (2/64) [0.9%–10.7%]	0% (0/64) [0%–5.7%]	0.154
Borderline AD and FAI-related deformities	15.6% (20/128) [10.3%–22.9%]	20.3% (13/64) [12.3%–31.7%]	10.9% (7/64) [5.4%–20.9%]	0.144
Borderline AD + cam deformity	13.3% (17/128) [8.5%–20.2%]	17.2% (11/64) [9.9%–28.2%]	9.4% (6/64) [4.4%–19.0%]	0.193
Borderline AD + pincer deformity	1.6% (2/128) [0.4%–5.5%]	1.6% (1/64) [0.3%–8.3%]	1.6% (1/64) [0.3%–8.3%]	1
Borderline AD + combined deformity	0.8% (1/128) [0.1%–4.3%]	1.6% (1/64) [0.3%–8.3%]	0% (0/64) [0%–5.7%]	0.315
AD in total (definite and borderline) and FAI-related deformities	23.4% (30/128) [16.9%–31.5%]	28.1% (18/64) [18.6%–40.1%]	18.7% (12/64) [11.1%–30.0%]	0.210
AD in total (definite and borderline) + cam deformity	19.5% (25/128) [13.6%–27.2%]	21.9% (14/64) [13.5%–33.4%]	17.2% (11/64) [9.9%–28.2%]	0.504
AD in total (definite and borderline) + pincer deformity	1.6% (2/128) [0.4%–5.5%]	1.6% (1/64) [0.3%–8.3%]	1.6% (1/64) [0.3%–8.3%]	1
AD in total (definite and borderline) + combined deformity	2.3% (3/128) [0.8%–6.7%]	4.7% (3/64) [1.6%–12.9%]	0% (0/64) [0%–5.7%]	0.079

Data are shown as percentage [95% CI]. AD, acetabular dysplasia; FAI, femoroacetabular impingement.

*Male versus female, evaluated with χ^2 test. P-values of <0.05 were considered statistically significant.

observed in any combination of AD and FAI-related deformity between men and women.

Table IV shows the percentage of each type of AD with coexisting cam, pincer and combined deformities compared with total AD (definite and borderline). The percentage of AD with a coexisting cam deformity (54.3%, 25/46) was much higher than that of AD with coexisting pincer (4.3%, 2/46). The percentage of AD without coexisting FAI-related findings was 34.8% (16/46); in other

words, 65.2% of hips (30/46) with AD had some FAI-related findings.

Table V shows the detailed percentage of each type of AD with coexisting cam, pincer and combined deformities in men and women compared with total AD. There was no combination of AD and FAI-related findings which showed that the corresponding percentage in women was higher than that in men. The percentages of total AD with a coexisting cam deformity and total AD with a coexisting

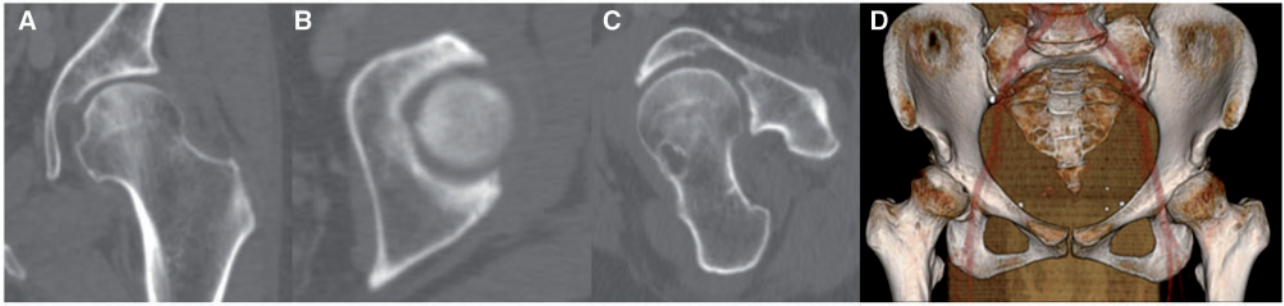


Fig. 6. The representative case of the hip of AD with coexisting FAI-related findings. This case was 50 years old women, left hip was defined as a hip of borderline AD with coexisting cam deformity. (A) CE angle, Sharp angle and AI was 21° , 44° and 20° , respectively. (B) The acetabular version angle was 7° at a slice at the level of the superior margin of the femoral head (slice A1). (C) The α -angle and HNOR at a slice of R4 (1:30 o'clock) was 57° and 0.125, respectively. HP was also positive. (D) PGD was negative. According to the CE and Sharp angle, this hip was defined as a borderline AD. On the other hand, this hip was also defined as a cam deformity due to α -angle $> 55^\circ$, HNOR < 0.13 and HP positive. However, this hip did not coexist with a pincer deformity, because the AI was over 0° and acetabular version angle was not negative.

Table IV. Corresponding percentage of each type of AD with coexisting cam, pincer and combined deformities and without coexisting FAI-related findings compared with all numbers of each type of AD in all patients

	With coexisting cam deformity	With coexisting pincer deformity	With coexisting combined deformity	Without coexisting FAI-related findings
Definite AD ($n = 15$)	53.3% (8/15) [30.1%–75.2%]	0% (0/15) [0%–20.4%]	13.3% (2/15) [3.7%–37.9%]	33.3% (5/15) [15.2%–58.3%]
Borderline AD ($n = 31$)	54.8% (17/31) [37.8%–70.8%]	6.5% (2/31) [1.8%–20.7%]	3.2% (1/31) [0.6%–16.2%]	35.5% (11/31) [21.1%–53.1%]
AD in total (definite and borderline) ($n = 46$)	54.3% (25/46) [40.2%–67.8%]	4.3% (2/46) [1.2%–14.5%]	6.5% (3/46) [2.2%–17.5%]	34.8% (16/46) [22.7%–49.2%]

Data are shown as percentage [95% CI]. AD, acetabular dysplasia; FAI, femoroacetabular impingement.

combined deformity were significantly higher in men than women ($P = 0.0272$ and $P = 0.0327$, respectively). Conversely, the percentages of total AD without coexisting FAI-related findings were significantly higher in women ($P = 0.0004$).

Table VI shows the corresponding percentages of the combinations of the coexistence of each type of AD and each FAI-related finding compared with all hips. The most major features of cam deformities coexisting with definite AD and borderline AD were an HNOR of < 0.13 . On the other hand, the major feature of pincer deformities coexisting with definite AD and borderline AD were RA. No significant differences were found in the corresponding percentages of the coexistence of each type of AD and each FAI-related finding between men and women.

The ICCs of the intraobserver and interobserver reliability of all parameters were almost perfect (≥ 0.80).

DISCUSSION

AD and FAI have been thoroughly discussed as a cause of hip OA [1, 2, 6, 7]. However, the prevalence and morphological features of the coexistence of AD and FAI have not been well discussed. In the present study, we showed the prevalence of AD with coexisting pincer, cam and combined deformities, and also the frequency with which FAI-related findings coexist with definite and borderline AD in asymptomatic Japanese population. To the best of our knowledge, there is scarce literature on this topic.

Several authors have discussed the coexistence of cam deformity and AD in symptomatic populations. Ida *et al.* [9]

Table V. Comparison of corresponding percentage of AD with coexisting cam, pincer and combined deformities and without coexisting FAI-related findings compared with all numbers of each type of AD between men and women

	With coexisting cam deformity		With coexisting pincer deformity		With coexisting combined deformity		Without coexisting FAI-related findings	
	Male	Female	Male	Female	Male	Female	Male	Female
Definite AD (<i>n</i> = 5 in male, <i>n</i> = 10 in female)	60% (3/5)	50% (5/10)	0% (0/5)	0% (0/10)	40% (2/5)	0% (0/10)	0% (0/5)	50% (5/10)
	[23.1%–88.2%]	[23.7%–76.3%]	[0%–43.4%]	[0%–27.8%]	[11.8%–76.9%]	[0%–27.8%]	[0%–43.3%]	[23.7%–76.3%]
	– <i>P</i> =0.7144–		–		– <i>P</i> =0.0317–			– <i>P</i> =0.0528–
Borderline AD (<i>n</i> = 14 in male, <i>n</i> = 17 in female)	78.6% (11/14)	35.3% (6/17)	7.1% (1/14)	5.9% (1/17)	7.1% (1/14)	0% (0/17)	7.1% (1/14)	58.8% (10/17)
	[52.4%–92.4%]	[17.3%–58.7%]	[1.3%–31.5%]	[1.0%–27.0%]	[1.3%–31.5%]	[0%–18.4%]	[1.3%–31.5%]	[36.0%–78.4%]
	– <i>P</i> =0.0032–		– <i>P</i> =0.8869–		– <i>P</i> =0.3113–			– <i>P</i> =0.00276–
AD in total (<i>n</i> = 19 in male, <i>n</i> = 27 in female)	73.7% (14/19)	40.7% (11/27)	5.3% (1/19)	3.7% (1/27)	15.8% (3/19)	0% (0/27)	5.3% (1/19)	55.6% (15/27)
	[51.2%–88.2%]	[24.5%–59.3%]	[0.9%–24.6%]	[0.7%–18.3%]	[5.5%–37.6%]	[0%–12.5%]	[0.9%–24.6%]	[37.3%–72.4%]
	– <i>P</i> =0.0272–		– <i>P</i> =0.7984–		– <i>P</i> =0.0327–			– <i>P</i> =0.0004–

Data are shown as percentage [95% CI]. AD, acetabular dysplasia; FAI, femoroacetabular impingement. *P* values were evaluated with the χ^2 test. *P* values of <0.05 were considered statistically significant.

Table VI. Corresponding percentage of combination of coexistence with each type of AD and each FAI-related finding compared with all hips with coexistence of each type of AD (definite or borderline) and each FAI-related deformity (cam or pincer deformity)

	All subjects	Males	Females	P-value*
Definite AD + cam deformity				
Definite AD + α angle $\geq 55^\circ$	40% (4/10) [16.8%–68.7%]	40.0% (2/5) [11.8%–76.9%]	40.0% (2/5) [11.8%–76.9%]	1
Definite AD + HNOR < 0.13	100% (10/10) [72.2%–100%]	100% (5/5) [56.6%–100%]	100% (5/5) [56.6%–100%]	–
Definite AD + PGD positive	10% (1/10) [1.8%–40.4%]	20% (1/5) [3.6%–62.4%]	0% (0/5) [0%–43.3%]	0.292
Definite AD + HP positive	20% (2/10) [5.7%–51.0%]	20% (1/5) [3.6%–62.4%]	20% (1/5) [3.6%–62.4%]	1
Definite AD + pincer deformity				
Definite AD + acetabular index $\leq 0^\circ$	0% (0/2) [0%–65.8%]	0% (0/2) [0%–65.8%]	(0/0)	–
Definite AD + RA	100% (2/2) [34.2%–100%]	100% (2/2) [34.2%–100%]	(0/0)	–
Borderline AD + cam deformity				
Borderline AD + α angle $\geq 55^\circ$	55.6% (10/18) [33.7%–75.4%]	41.7% (5/12) [19.3%–68.0%]	83.3% (5/6) [43.6%–97.0%]	0.094
Borderline AD + HNOR < 0.13	88.9% (16/18) [67.2%–96.9%]	83.3% (10/12) [55.2%–95.3%]	100% (6/6) [61.0%–100%]	0.249
Borderline AD + PGD positive	27.8% (5/18) [12.5%–50.9%]	25.0% (3/12) [8.9%–53.2%]	33.3% (2/6) [9.7%–70.0%]	0.709
Borderline AD + HP positive	22.2% (4/18) [9.0%–45.2%]	33.3% (4/12) [13.8%–60.9%]	0% (0/6) [0%–39.0%]	0.109
Borderline AD + pincer deformity				
Borderline AD + acetabular index $\leq 0^\circ$	33.3% (1/3) [6.1%–79.2%]	0% (0/2) [0%–65.8%]	100% (1/1) [20.7%–100%]	0.083
Borderline AD + RA	66.7% (2/3) [20.8%–93.9%]	100% (2/2) [34.2%–100%]	0% (0/1) [0%–79.3%]	0.083

Data are shown as percentage [95% CI]. AD, acetabular dysplasia; FAI, femoroacetabular impingement; PGD, pistol grip deformity; HP, herniation pit; HNOR, head–neck offset ratio; RA, retroverted acetabulum.

*Male versus female, evaluated with χ^2 test. P-values of <0.05 were considered statistically significant.

reported the frequency of cam deformity in hips with symptomatic AD. They found that 40% of patients with AD had radiological evidence of cam deformity (α angle of $>55^\circ$) on lateral roentgenograms. On the other hand,

Clohisy *et al.* [8] found that femoral head asphericity was present in 72% and reduced head–neck offset was also presented in 75% of symptomatic AD. Furthermore, Wyles *et al.* [11] reported that patients with coexisting AD and

cam deformity developed hip OA more rapidly rather than patients with AD. From this study, we are agreed to these previous reports showed the high prevalence of coexistence of AD and cam-related findings, and clinical importance of them. However, previous studies have evaluated the coexistence of AD and cam-related findings only using simple plain radiographs. In the present study, we revealed the coexistence of several FAI-related findings and AD (including borderline) using multislice CT images and also compared the results between men and women. We emphasized the prevalence of borderline AD with coexisting cam deformity was 15.6%, which was two times higher than that of definite AD with coexisting cam deformity. Therefore, we consider that more attention should be given to the coexistence of borderline AD and cam deformity. Furthermore, the percentage of hips with AD and a coexisting cam deformity was significantly higher in men than women. Therefore, we also suppose that more attention should be given to the coexistence of AD and cam deformity especially in men. Additionally, we showed that the most major feature of cam-related findings detected in definite and borderline AD in Japanese hips was reduced HNOR.

The percentage of hips with definite AD with coexisting pincer-related findings compared with all hips with definite AD was 0%, and the prevalence of borderline AD with coexisting pincer-related findings compared with all hips with borderline AD was only 6.5%. Fujii *et al.* [10] reported that an RA was observed in 18% of Japanese patients with symptomatic AD. They showed that AD with an RA was associated with an earlier onset of pain than AD with anteversion. However, Troelsen *et al.* [31] reported that an RA was found in one-third of hips with AD when assessed on weight-bearing pelvic radiographs. They also reported that the prevalence of an RA may be underestimated if the evaluated images are obtained from patients in the supine position. Therefore, we might have underestimated the coexistence of AD and pincer-related findings in the present study because we used CT images and excluded the pelvis anteriorly rotated rather than normal range from present study. Although the percentage of AD with coexisting pincer deformity was lower than that of AD with coexisting cam deformity, we had better understand that the coexistence of pincer deformity in men was slightly higher than that in women. In such hips, we should pay more attention to a RA as a morphological finding of pincer deformity.

We employed two parameters for the definition of AD in the present study. As a result, we detected definite AD in 11.7% of the Japanese hip joints in this study, which is relatively higher than in previous Asian studies based on

plain radiograph examination (Inoue *et al.* [3], 8.1%; Umer *et al.* [32], 7.3%). However, direct comparison of our results with their results is difficult because the evaluation methods were different. We recognize that these angles showed discrepancy between CT images and plain radiographs. Actually, Chadayammuri *et al.* [33] reported discrepancies in the CE angle between plain radiographs and CT images. They found that the CE angle measured on CT images was 2.1° larger than that of measured on plain radiographs. Considering these facts, our results might overestimate the prevalence of AD rather than the studies that measured these parameters using plain radiograph. However, we believe that CT images are more suitable than plain radiographs with respect to correct measurement of AD parameters because we can more easily detect the bony morphological features of the acetabulum, especially the lateral point of the acetabular dome, and we can also accurately evaluate the acetabular bony coverage in the center of the femoral head. Furthermore, the ICCs for the interobserver reliability of the CE angle and Sharp angle were 0.83 and 0.94 in this study, respectively. Mast *et al.* [34] and Tan *et al.* [35] reported that the ICCs for the interobserver reliability of the CE angle evaluated on plain radiographs were 0.73 and 0.51, respectively. We believe that CT images allow for calculation of a more accurate prevalence of AD than do plain radiographs.

In the present study, we defined a CE angle of <20° as indicative of definite AD and a CE angle of 20° to <25° as indicative of borderline AD. These cut-off values have been widely utilized in the literature [4, 5]. We also defined a Sharp angle of >45° as indicative of definite AD and a Sharp angle of >42° to 45° as indicative of borderline AD. A Sharp angle of >45° has been widely used to define the presence of definite AD in the literature [5]. However, few reports have described the cut-off of Sharp angle for the definition of borderline AD. Paliobeis and Villar [4] reported that a Sharp angle of >39° to 42° was indicative of borderline AD and that a Sharp angle of >42° was indicative of definite AD. If we had used these definitions in the present study, the prevalence of borderline AD as diagnosed by a Sharp angle of >39° to 42° would have been 28.9%, and that of definite AD as diagnosed by a Sharp angle of >42° would have been 29.7%; the prevalence of total AD would have been 58.6%. However, these prevalences are much higher than those defined using the CE angle in our study and much higher than the previously reported prevalences of definite AD [3, 32]. Sharp [14] originally reported that angles of 39°–42° were within the upper limit of normality. Therefore, we defined a Sharp angle of >45° as indicative of definite AD and a Sharp angle of >42° to 45° as indicative of borderline AD in the

present study. On the other hand, we did not define AD using AI in the present study. Namely, we did not distinguish between 'flat roof (short roof) dysplasia' and 'sloping roof dysplasia' [36, 37]. Brockwell *et al.* [36] suggested that a sloping roof dysplasia was so-called primary dysplasia or classical dysplasia which has instability and a flat roof dysplasia was essentially taking with cam impingement. They described that a flat roof dysplasia was brought by the impingement between iliac acetabular epiphysis and cam deformity in adolescence. In the present study, we did not discuss these morphologies of AD. If we classified and discussed these morphologies of AD, we believed that the results would be different.

This study has some limitations. First, it was not population-based, but patient-based. This is an inescapable limitation of this study. However, our aim in this study was not to simply investigate the prevalence of AD with coexisting radiological FAI but to evaluate its prevalence using detailed multislice and multiplane examinations. Therefore, we investigated the patients' CT images from scans that had been requested by other departments at our institution for evaluation of conditions unrelated to hip disorders. Second, we excluded clear hip OA in order to precisely measure morphological parameters. We understand that AD and FAI are generally thought to be lead to hip OA. Therefore, we recognized that this might lead to potential selection bias and an underestimation of the prevalence of AD or FAI. Third, the sample size was relatively small, and this study was performed in a single hospital. We recognize that it might be incorrect to generalize our results to region throughout Japan. Finally, we employed four parameters to define cam deformity, and we employed two parameters to define pincer deformity. We recognize that the prevalence of AD with coexisting FAI-related findings would be different if we had employed other parameters for definition of FAI-related deformities or altered the number of parameters used to define cam or pincer deformity. For example, a HP is generally thought to be a predictor of FAI [29, 25]. However, Kim *et al.* [27] indicate that a HP may have limited significance as a predictor of FAI. Furthermore, α angle would be naturally more than 55° , if PGD was existed. Therefore, we supposed that the results would be different, if HP and PGD positivity were excluded as a parameter from cam deformity. And then we recalculated the results in that situation. As a result, a total of 74.2% of hips met at least one criterion of the definition of cam or pincer deformity, and the prevalence of coexistence of AD and FAI-related findings was estimated in 22.6% of hips (definite AD and FAI, 7.8%; borderline AD and FAI, 14.8%). And then, 63.0% of the hips with AD had some FAI-related findings. In this manner, the prevalence and other

percentages did not generally change, if HP and PGD positivity were excluded from the parameter of cam deformity.

Although, AD and FAI were originally independent concepts, we consider that simultaneous evaluation of AD and FAI would be informative from the viewpoint of preventing the progression of hip OA. Actually, we found that only 34.8% of hips with AD were free from the coexistence of FAI-related findings when we investigated AD using multislice CT images in Japan. Furthermore, we revealed that the major and notable parameter of a cam deformity detected in hips with AD was a HNOR. We consider that it is important to correctly evaluate the coexistence of AD and radiological FAI-related findings when discussing morphological disorders of the hip joint. However, it still remains unclear what additional procedure (debridement, labral fixation or osteochondroplasty of cam lesion) is needed and suitable when we perform acetabular osteotomy for AD with coexisting FAI [38]. Further research will be needed to indicate how to manage FAI-related findings coexisting with AD.

In conclusion, we found that the coexistence of AD and FAI-related findings was common in Japanese population, and 65.2% of hips with AD had some FAI-related findings. The prevalence of borderline AD with coexisting FAI was much higher than that of definite AD with coexisting FAI, and the percentage of AD with coexisting FAI-related findings in men was higher rather than that in women. We also found that AD with coexisting cam-related findings was considerably more common than AD with coexisting pincer-related findings, and the most notable parameter as a morphological feature of cam deformity detected in such hips was a HNOR.

CONFLICT OF INTEREST STATEMENT

None declared.

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