

## Sex-related Differences in Pelvic Morphology in Acetabular Dysplasia

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### Abstract

Acetabular dysplasia occurs more commonly in female than in male subjects. Although sex differences in pelvic morphology of subjects with acetabular dysplasia and without advanced osteoarthritis might be expected, there is little published information to support this contention. We retrospectively investigated sex differences in morphologic features of the pelvises of patients with acetabular dysplasia. We reviewed CT scans of 73 hips in 67 patients (17 male, 50 female subjects; mean age 38 years, range 13–66) with acetabular dysplasia to evaluate rotational alignment of the innominate bone in the axial plane and measure the acetabular sector angles to evaluate acetabular coverage of the femoral head. Male pelvises were narrower than female ones at the level of the greater pelvis through the inferior pelvic aperture. In female pelvises, internal rotation of the innominate bone correlated negatively with the anterior direction and positively with the posterior direction whereas in male pelvises, it correlated negatively with superior direction. Sex differences in pelvises with acetabular dysplasia are characterised by the rotational alignment of the innominate bone and direction of dysplasia.

**Key words:** Acetabular dysplasia, Sex difference, Pelvic morphology, Acetabular sector angle

### Introduction

Acetabular dysplasia, which occurs more commonly in female than in male subjects and is often associated with deficient anterior or global coverage of the femoral head, has an increased prevalence of osteoarthritis.<sup>1),2)</sup> Previous studies have reported differences not only in the morphologic features of the hips of patients with this condition, but also in the morphologic features of their entire pelvises.<sup>3)-6)</sup> However, there are few reports on the morphologic features of the entire pelvis in patients with acetabular dysplasia, especially regarding differences between the sexes.

The purpose of this study was to investigate sex differences in morphologic features of the pelvis in patients with acetabular dysplasia using three-dimensional computed tomography (3D CT).

### Patients and Methods

Of 291 patients who had undergone curved periacetabular osteotomy (CPO)<sup>7)</sup> at our institution from February 2005 to March 2012, 23 patients (27 hips) were male. We excluded six of the hips of male patients from the study because they had severe morphologic abnormalities of the femoral head. This left 21 hips in 17 male patients. We randomly selected 52 hips in 50 age-matched female patients who had undergone surgery during the same period. Therefore, the cohort study group included 17 male (21 hips) and 50 female subjects (52 hips). Sixty-one patients had unilateral involvement and six bilateral involvement.

Inclusion criteria were as follows: radiographic evidence of acetabular dysplasia with centre-edge angle of Wiberg<sup>8)</sup> <20° on anteroposterior radiographs, Crowe type-I subluxation<sup>9)</sup>, no radiographic evidence of joint space narrowing or extreme femoral head deformity such as Legg–Calve–Perthes disease (to eliminate secondary

**Table 1.** Relevant patient data

	total	male	female	p-value
No. of patients (No. of hips)	67 (73)	17 (21)	50 (52)	
Mean Age (yrs)	38.4 (13 to 66)	38.6 (26 to 60)	38.4 (13 to 66)	0.642
Mean Height (cm)	160.3 (145 to 179)	168.8 (160 to 179)	157.1 (145 to 168)	<0.001
Mean Weight (kg)	60.3 (42 to 89)	70.7 (52 to 89)	53.7 (42 to 86)	<0.001
Mean BMI (kg/m <sup>2</sup> )	23.3 (18 to 33)	24.8 (20 to 31)	21.8 (18 to 33)	<0.006

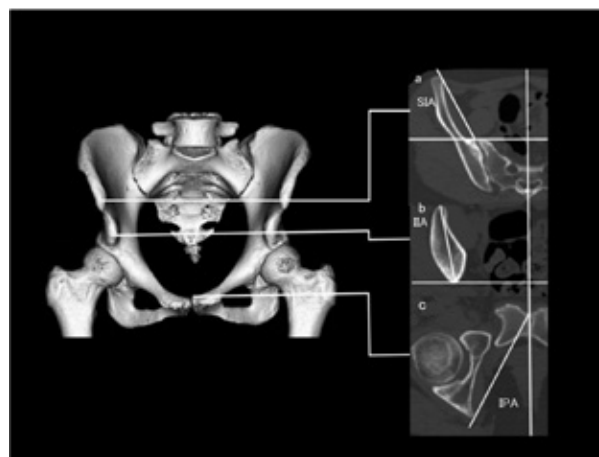
\* BMI, body mass index

changes caused by osteoarthritic involvement); and no previous injury and surgery involving the femur and pelvis.

The overall mean age of the patients was 38.4 years (range 13–66). The mean age of the 17 male subjects (21 hips) was 38.6 years (26–60) and of the 50 female subjects (52 hips) 38.4 years (13–66). There was no significant age difference between male and female patients. The mean body mass index (BMI) was 24.8 (20–31) kg/m<sup>2</sup> in male patients and 21.8 (18 to 33) kg/m<sup>2</sup> in female patients. This difference is significant, as were the differences in weight and height between the two groups (Table 1).

We used a 64-channel multi-detector CT system (Aquilion 64-slice CT scanner; Toshiba, Tokyo, Japan). CT scans was taken with a contiguous thickness of 0.5 mm, from the superior margin of the iliac crest to below the lesser trochanter of the femur with the patients in a supine position with hip and knee fully extended and thighs horizontal and parallel. We acquired all images digitally using the Picture Archiving and Communication System (PACS) and converted the CT data digitally to Digital Imaging and Communications in Medicine (DICOM) format images.

We performed measurements on the pelvic CT images after correcting for pelvic tilt. We reconstructed pelvic CT scans based on the anterior pelvic plane defined by both anterior superior iliac spines (ASIS) and pubic tubercles. From the anterior pelvic plane, we established axial and coronal planes and measured the following three angles<sup>3)</sup> to evaluate the rotational alignment of the innominate bone in the axial plane (Fig. 1). 1) The superior iliac wing angle (SIA), which is formed by the intersection of a line connecting the medial edge of the ASIS and the anterior margin of the sacroiliac joint plus a horizontal line. 2) The inferior iliac wing angle (IIA), which is formed by a line connecting the anterior aspect of the anteroinferior iliac spine (AIIS) and the posterior aspect of the ilium plus a horizontal line. 3) The ischiopubic angle (IPA), which is a projection angle formed by the intersection of a line connecting the anterosuperior edge of the pubic symphysis and the ischial spine and a sagittal line on the axial plane.



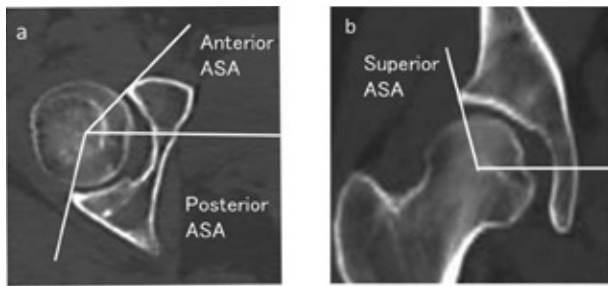
**Fig. 1a** The superior iliac wing angle (SIA) is formed by the intersection of a line connecting the medial edge of the ASIS and the anterior margin of the sacroiliac joint with a horizontal line.

**Fig. 1b** The inferior iliac wing angle (IIA) is formed by a line connecting the anterior aspect of the anteroinferior iliac spine (AIIS) and the posterior aspect of the ilium with a horizontal line.

**Fig. 1c** The ischiopubic angle (IPA) is a projection angle formed by the intersection of a line connecting the anterosuperior edge of the pubic symphysis and the ischial spine with a sagittal line on the axial plane.

and the ischial spine and a sagittal line on the axial plane. To make this measurement, we superimposed the sections that passed through the ischial spine and the pubic symphysis. We evaluated the opening angles by measuring the SIA at the level of the ASIS and the IIA at the level of the AIIS. We evaluated the closing angle by measuring the IPA at the level of the inferior pelvic aperture.

We evaluated acetabular coverage of the femoral head by measuring the superior, anterior, and posterior acetabular sector angles (ASAs) (Fig. 2).<sup>3), 10)</sup> The ASA is formed by the intersection on a line connecting the femoral head centre and the acetabular edge. We measured the anterior and posterior ASAs on a reformatted axial plane passing through the centre of the femoral head and the superior ASA on a reformatted coronal plane passing through the



**Fig. 2a** The anterior ASA and Posterior ASA (angles between the intercapital centreline and lines from the centre point of the heads to the anterior and posterior rims of the acetabulum, respectively) were measured on a reformatted axial plane passing through the centre of the femoral head.

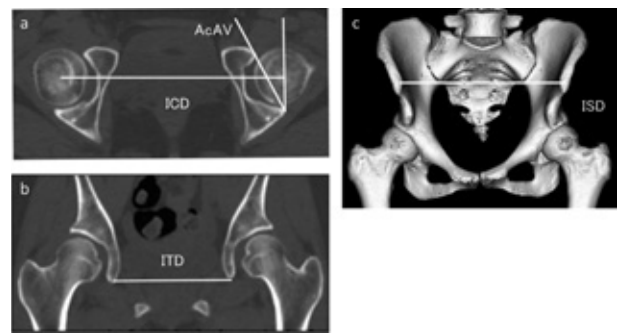
**Fig. 2b** The Superior ASA (the angle between the intercapital centreline and a line from the centre point of the head to the superior rim of the acetabulum) was measured on a reformatted coronal plane at the same line.

centre of the femoral head.

We measured the acetabular anteversion (AcAV) angle and inter-capital distance (ICD) on a reformatted axial plane passing through the centre of the femoral head (Fig. 3a) the inter-teardrop distance (ITD) on a reformatted coronal plane passing through the centre of the femoral head (Fig. 3b) and the inter-spinous distance (ISD) on a reconstructed 3D CT image (Fig. 3c). We then analysed these variables to clarify any between-sex differences.

Three of the authors (TK, NT and DK), who were blind to the sexes, each performed all measurements on the CT images three times on different occasions. We then calculated the average values and analysed the measurements for intraobserver and interobserver reliability. The intraclass correlation coefficients of these measurements were 0.97–0.99 for intraobserver variances and 0.90–0.98 for interobserver variance.

We used the Mann–Whitney U test to compare the two groups and the Pearson linear correlation coefficient ( $r$ ) to assess correlations among various measurements. We considered a probability value less than 0.05 significant. We used SPSS software, version 20.0 (SPSS Inc., Chicago, IL, USA) to perform the statistical analyses.



**Fig. 3a** The acetabular anteversion (AcAV) angle (the angle between the lines connecting the anterior and superior edges of the acetabulum) and inter-capital distance (ICD) were measured on a reformatted axial plane passing through the centre of the femoral head.

**Fig. 3b** The inter-teardrop distance (ITD) was measured on a reformatted coronal plane passing through the centre of the femoral head.

**Fig. 3c** The inter-spinous distance (ISD) was measured on a reconstructed 3D CT image.

## Results

The SIA in male patients was  $57.6^\circ$  ( $47^\circ$ – $64^\circ$ ), which is significantly greater than in female patients ( $54.9^\circ$  [ $43^\circ$ – $63^\circ$ ];  $p = 0.046$ ); thus, the male ilium is rotated more internally at the ASIS level. The IPA in male patients was  $24.7^\circ$  ( $16^\circ$ – $33^\circ$ ), which is significantly smaller than in female patients ( $29.7^\circ$  [ $24^\circ$ – $37^\circ$ ];  $p < 0.001$ ), indicating that the male pelvis tended to be narrower than the female pelvis at the inferior pelvic aperture level. In contrast, the IIA did not differ significantly between male and female patients ( $p = 0.567$ ) (Table 2).

Men had a significantly larger ASA in the anterior direction ( $p = 0.006$ ) and significantly smaller ASA in the superior direction ( $p = 0.041$ ). The difference was not significantly different in the posterior direction (Table 3). Because of there is a whole pelvic deformity in acetabular dysplasia, we sought to evaluate correlations between the SIA and ASA. In female pelvises, the SIA correlated negatively with the anterior ASA and positively with the posterior ASA. There was no SIA–superior ASA correlation.

**Table 2.** Three rotational alignment of the innominate bone

	total	male	female	p-value
No. of patients (No. of hips)	67 (73)	17 (21)	50 (52)	
SIA ( $^\circ$ )	55.7 (43 to 64)	57.6 (47 to 64)	54.9 (43 to 63)	0.046
IIA ( $^\circ$ )	70.1 (61 to 88)	70.8 (63 to 88)	69.8 (61 to 78)	0.567
IPA ( $^\circ$ )	28.2 (16 to 37)	24.7 (16 to 33)	29.7 (24 to 37)	<0.001

\* SIA, superior iliac angle; IIA, inferior iliac angle; IPA, ischiopubic angle

**Table 3.** Acetabular morphometric data and sex-related variations

	total	male	female	p-value
Anterior ASA (°)	46.1 (25 to 61)	51.8 (41 to 61)	47.7 (25 to 63)	0.006
Posterior ASA (°)	90.6 (71 to 103)	89.5 (77 to 100)	90.5 (71 to 103)	0.367
Superior ASA (°)	103.9 (85 to 109)	100.1 (87 to 109)	106.7 (85 to 109)	0.041

\* ASA, acetabular sector angle

**Table 4.** Pelvic morphometric data and sex-related variations

	total	male	female	p-value
AcAV (°)	21.7 (9 to 35)	18.9 (12 to 29)	21.8 (9 to 35)	0.006
ICD (cm)	181.3 (162 to 203)	180.9 (165 to 191)	181.6 (162 to 203)	0.642
ISD (cm)	218.5 (189 to 263)	216.4 (194 to 263)	225.3 (189 to 259)	0.037
ITD (cm)	112.5 (100 to 109)	104.6 (100 to 109)	115.4 (101 to 162)	<0.001

\* AcAV, acetabular anteversion; ICD, inter-capital distance; ISD, inter-spinous distance; ITD, inter-teardrop distance

In male pelvises, the SIA correlated negatively with the superior ASAs (no correlation between SIA and anterior or posterior ASA).

The AcAV angle in male patients was 18.9° (12°–29°), which is significantly smaller than in female patients (21.8° [9°–35°];  $p = 0.006$ ). There was no significant difference between the two groups in the ICD; however, the ISD and ITD were shorter in male than in female patients (Table 4).

### Discussion

There are morphological differences between the sexes throughout the pelvis: the pelvic cavity is generally cylindrical in female subjects from the viewpoint of the birth canal and therefore the pelvic inlet is wider and more oval-shaped and the subpubic angle greater in female than in male subjects.<sup>4),11)</sup> In the present study of subjects with acetabular dysplasia, we found similar differences between the sexes throughout the pelvis.

Previous reports have described the relationship between the morphologic features of the entire pelvis and acetabular dysplasia.<sup>3)-6)</sup> However, none of these studies have measured differences between the sexes in the pelvises of subjects with acetabular dysplasia. Our study is the first to report sex differences throughout the pelvis in relationship to acetabular dysplasia.

Fujii et al.<sup>3)</sup> reported that the SIA and IPA are larger in patients with acetabular dysplasia than in normal subjects. Suzuki<sup>6)</sup> used MRI to assess the morphologic features of the whole pelvis in eight infants with developmental dysplasia of the hip (DDH) and found that the most fundamental deformity was a medial twist of the pelvis on

the side of the affected hip in the transverse plane. Kojima et al.<sup>4)</sup> observed that the hallmark features of the pelvises in subjects with DDH group were shorter transverse diameters of the pelvic inlet, longer transverse diameters of the pelvic outlet, and a higher incidence of the anthropoid type pelvis. These morphological features were similar to those found in the present study. In addition, in subjects with acetabular dysplasia, the male pelvis is narrower than the female one at the level of the greater pelvis through the inferior pelvic aperture. These structural differences may influence the amount of bleeding, the precise surgical field and difficulty in the movement of rotation of during osteotomy. Further investigations are needed to assess the influences of these differences on clinical results and surgical procedures.

In female pelvises, we found that the SIA correlates negatively with the anterior ASA and positively with the posterior ASA, whereas there is no SIA–superior ASA correlation. In male pelvises, the SIA correlates negatively with the superior ASA but there is no correlation between the SIA and anterior or posterior ASA. In other words, these relationships indicate that the medially rotated pelvises of female subjects have less anterior and greater posterior coverage than in male subjects, whereas superior coverage is less in male than in female subjects. Thus, in acetabular dysplasia there are morphological differences between the sexes throughout the pelvis. Ezoe et al.<sup>12)</sup> reported a higher prevalence of acetabular retroversion in acetabular dysplasia than in the normal hip. Our study indicates that in subjects with acetabular dysplasia, pelvic structural abnormalities are not confined to local dysplasia around the hip but occur throughout the pelvis. In particular,

acetabular retroversion in the wide pelvis of subjects with acetabular dysplasia should be noted.

Normal values for the AcAV angle are reportedly 21.3° for female and 18.5° for male subjects.<sup>13)</sup> Similarly, other studies of normal hips have reported that the AcAV angle is greater in female than in male subjects.<sup>14)-16)</sup> We found a similar difference between the sexes in the AcAV angle in our study of subjects with acetabular dysplasia. In addition, we found no significant difference between the two groups in the ICD; however, the ITD was shorter in male than in female subjects even though men are generally larger than women. These findings indicate that acetabular dysplasia may result in geometrically greater stress loading on the hip joint in female subjects.

Radiographs are considered accurate enough to differentiate dysplastic from normal hips. However, when surgical procedures are being considered, 3D CT images can provide important additional information.<sup>17)-19)</sup> Three-dimensional CT scans can easily provide the necessary information concerning the transverse plane and, in some cases, reveal small and shallow acetabula. When undertaking preoperative planning of pelvic osteotomies, surgeons should take the important variations in hip morphology between male and female subjects into account.

This study had several limitations. First, it included relatively few subjects. Second, we did not include measurements on plain radiographs because these are subject to inaccuracies and variability depending on individual observer interpretations regarding acetabulum version.<sup>20)</sup> We decided to limit our evaluation to CT data to permit a purer analysis of the bony morphology. Third, we did not take the femoral component into consideration and excluded patients with obvious proximal femoral deformity from this study. However, further investigations are needed to address the relationship between proximal femoral morphology and direction of dysplasia.

Male pelvises with acetabular dysplasia are narrower than female ones throughout the pelvic cavity. When performing periacetabular osteotomy on male subjects, it may be necessary to pay attention to the direction of rotation and the direction of the osteotomy because these pelvises are narrower than those of female subjects. Moreover, male pelvises tend to be oriented more vertically. In such cases, the external rotation reduces the contact area of the osteotomy surfaces when performing periacetabular osteotomy. Medialisation of osteotomised bone to increase the contact surface should be considered.

In conclusion, the pelvic deformity seen in subjects with acetabular dysplasia involves morphologic differences throughout the pelvis, not just in the acetabulum. Male pelvises with acetabular dysplasia are narrower than those of female subjects throughout the pelvic cavity. We have identified differences between male and female subjects in medial rotational deformity of the pelvis and directions of acetabular defects.

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[The authors declare no conflict of interest.]