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Evaluation of iliac morphology and innominate bone rotation in unilateral developmental dysplasia of the hip

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Three-dimensional assessments of unilateral developmental dysplasia of the hip (DDH) have not been performed yet. Using computed tomography scanning, this study aimed to determine the morphological and rotational abnormalities of the innominate bone in female patients with unilateral DDH.
Patients with unilateral and bilateral DDH were compared with healthy patients. The distances between two points along each anatomical part of the pelvis and femur in the coronal plane were measured. The angles of each measurement line for the anterior pelvic plane (APP) and its perpendicular axis were investigated in the sagittal and horizontal planes.
The distance between the acetabular centre and anterior inferior iliac spine was longer on both sides in the unilateral DDH group than in the bilateral DDH group. Values of several angles measured on the APP in the horizontal or sagittal plane differed between the unilateral DDH and bilateral healthy groups. The distance between the centres of the femoral head was longer in the unilateral DDH group than in the bilateral healthy group. The distance between the femoral head and middle of the pelvis was longer on the affected side than on the unaffected side in the unilateral DDH group.
The iliac bone morphology was similar in both unilateral DDH and bilateral healthy groups; the rotation of the innominate bone was comparable to that in bilateral DDH. The femoral head on the affected side was shifted more laterally than that on the unaffected side in unilateral DDH.

Keywords: Hip joint, developmental dysplasia of the hip, computed tomography, X-ray.

INTRODUCTION

Previous studies have reported on developmental dysplasia of the hip (DDH) with acetabular dysplasia[1-6]. DDH with acetabular dysplasia shows osteogenic abnormalities in the acetabulum and entire pelvis[1]. These detailed anatomical findings led to more appropriate implant placement for total hip arthroplasty, including the establishment of a more accurate pelvic axis than the anterior pelvic plane tilt (APPt). However, these previous findings were from research on patients with bilateral DDH.

Whether DDH develops independently or as a gradual change during normal bone development remains unclear. In clinical practice, patients often present with unilateral DDH. Characterising the pelvic anatomy in patients with unilateral DDH may help understand the relationship between healthy bone development and DDH and determine whether the anterior pelvic plane (APP) in unilateral DDH is comparable to that in healthy individuals and those with bilateral DDH. Jacobsen et al.[7] found that the unaffected side in patients with unilateral DDH had lower anterior femoral coverage than those in healthy individuals. The iliac morphology of the affected and unaffected sides of unilateral Crowe type IV DDH with severe femoral head dislocation has been reported[8,9]. However, the most prevalent clinical cases of acetabular dysplasia are Crowe type I or II, with a near-normal femoral head position. Since many patients with Crowe type I or II have not been treated for DDH in childhood, DDH Crowe type I or II and dislocated hip dysplasia in Crowe IV cannot be excluded as belonging to the same category[10,11].

Iliac bone hypoplasia or deformity might be present in either bilateral or unilateral DDH[6,7]. However, no studies have provided three-dimensional measurements of the morphology and rotation of the innominate bone, including distances and angles from the coronal, sagittal, and horizontal planes to rotation in unilateral DDH. Therefore, this study aimed to determine the iliac morphology characteristics and innominate bone rotation values in patients with unilateral DDH using three-dimensional CT scanning, and to compare them with the characteristics of patients with bilateral healthy hips and bilateral DDH.

MATERIALS AND METHODS

This retrospective study was approved by institutional review board of Oita University (No. 1052; June 17, 2016). All participants provided informed consent before undergoing CT scanning. This study was conducted in accordance with the ethical standards of the 1964 Declaration of Helsinki and its subsequent amendments or comparable ethical standards.

The DDH group included women aged 25-65 years who presented with complaints of hip pain or discomfort and radiographic evidence of bilateral acetabular dysplasia. As the hip bone, specifically, the pubic bone, continues to grow until the age of 25 years, the lower age limit was set to 25 years[12]. Furthermore, patients with Crowe type I or II were in the early stages of DDH with a round femoral head and normal joint space. The centre-edge (CE) angle was measured in all patients; a CE angle of <20° was defined as DDH, and an angle of >25° was defined as “healthy”. Based on this classification, 30 patients with unilateral DDH and 30 patients with bilateral DDH were included. For the healthy group, 30 individuals with bilateral CE angles of >25° were recruited from among trauma patients without pelvic fractures who had undergone CT scanning between 2004 and 2021. The groups were age-matched.

The CT images obtained at our hospital were imported into a surgical planning software ZedHip (LEXI Co. Ltd., Tokyo, Japan) for three-dimensional reconstruction and measurement. All three-dimensional CT images were acquired using a helical CT scanner (Aquilion CX; Toshiba Medical Systems Corp., Tokyo, Japan) with 1-mm slice thickness.

The anterior inferior iliac spine (AIIS), posterior superior iliac spine (PSIS), posterior inferior iliac spine (PIIS), iliac crest (IC), and centre of the acetabulum were determined, and the anterior superior iliac spine (ASIS) and length between two points were measured as a three-dimensional linear distance (Fig. 1a and b). The IC was determined as the most lateral point of the crest. The acetabular centre (AC) was defined at the point where a perpendicular line intersects the acetabulum rim from the circle centre (Fig. 2)[13].

The pelvic three-dimensional model was corrected using the APP. Four straight lines were set up in the model: ASIS to PSIS, AIIS to PIIS, pubic symphysis (PS) to the ischial spine (IS), and PS to the ischial tuberosity (IT) (Fig. 3). Each line was set as follows: the straight line from the ASIS to the PSIS was designated as Line A; from the AIIS to the PIIS, as Line B; from

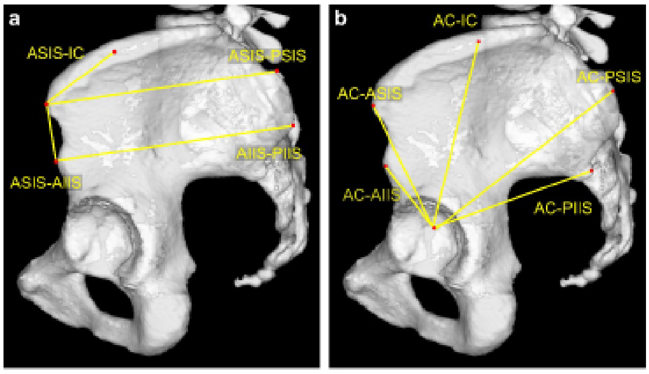

Figure 1. — Distance measurement between two points. The most elevated area on the three-dimensional model was used. The distance between each ridge and the distance from the acetabular centre to the ridge was measured.

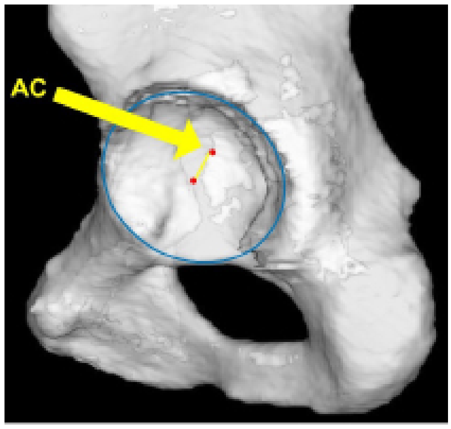

Figure 2 . — Defining the acetabular centre (AC) using the method by Köhnlein et al.[13]

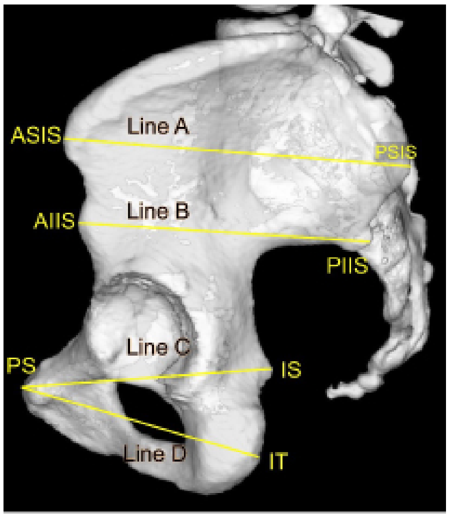

Figure 3 . — Determination of the four measurement axes. The pelvic model was corrected using the anterior pelvic plane to draw four straight lines between each ridge.

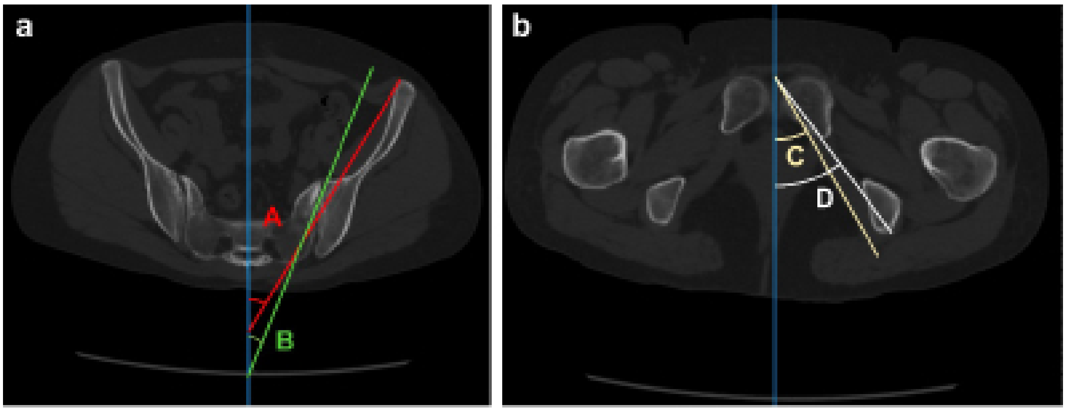

Figure 4 . — Measurement of angles A, B, C, and D. The angles between the vertical axis of the anterior pelvic plane and Line A to Line D in the horizontal plane were measured as A, B, C, and D.

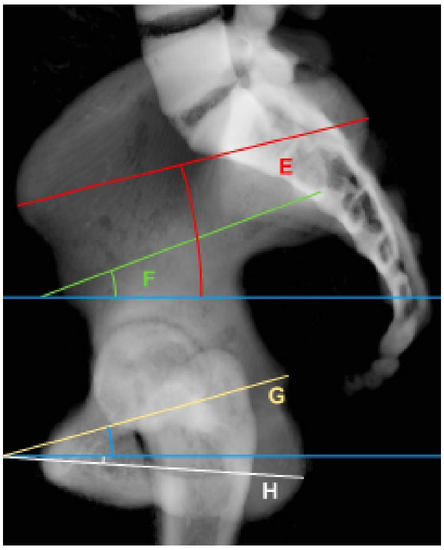

Figure 5 . — Measurement of angles E, F, G, and H. In the sagittal plane, the angles between the horizontal axis of the anterior pelvic plane and Line A to Line D were measured as E, F, G, and H.

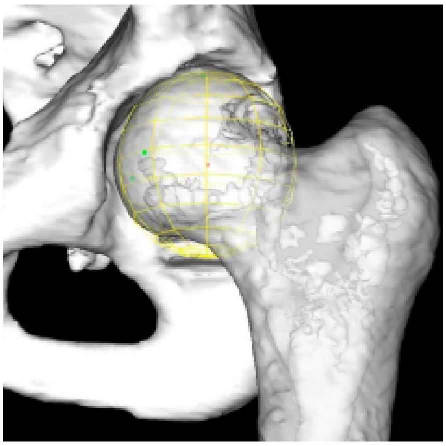

Figure 6 . — Determination of the femoral head centre. The software automatically detected the femoral head centre.

the PT to the IS, as Line C; and from the PT to the IT, as Line D.

The angles between the vertical axis of the APP and Lines A to D in the horizontal plane were measured as A, B, C, and D, respectively (Fig. 4a and b). Similarly, in the sagittal plane, the angles between the horizontal axis of the APP and lines A to D were measured as E, F, G, and H, respectively (Fig. 5). The subtraction and addition equations were used on measured angles to investigate the relationship between the respective lines. The distances between the bilateral ASISs and bilateral femoral head centres and acetabulum were measured. In unilateral DDH, the distance from the PS to the DDH side and opposite side was divided by the APP perpendicular line. The femoral head centre was plotted using ZedHip, which automatically created a sphere and indicated the femoral head centre by plotting one point at the apex of the femoral head on the bone surface and three points at the slice where the diameter of the femoral head was greatest in the horizontal section (Fig. 6).

All measurements were acquired by one person who was blinded to other case data. This process was repeated with the same person after at least 1 month. The intra-observer reliability of the measurements evaluated using the intraclass correlation coefficient was good (0.96-0.98). The reproducibility of the measurements was also assessed using the intraclass correlation coefficient, with two independent observers blinded to the measurements of 30 randomly selected joints. The inter-observer reliability was also good (range, 0.90-0.98). We compared the four (affected side group and unaffected side group in unilateral DDH; bilateral DDH group and bilateral healthy group) groups using the Kruskal-Wallis test; subsequently, two groups were compared using the Steel-Dwass method. Comparisons were performed using EZR (Saitama Medical Centre, Jichi Medical University, Japan), a graphical user interface of R (The R Foundation for Statistical Computing, Vienna, Austria, version 3.6.2)[14]. P-values of < 0.05 were considered statistically significant.

RESULTS

The patients' characteristics were comparable among the groups, except the CE angle (Table I). No significant differences were found among the groups in terms of the distance between the two points, which did not include the AC (Table II). The distances between the two points, including the AC, in the unilateral DDH group were significantly longer than the same distances in the bilateral DDH group at AC to AIIS (Fig. 7). No parameter differed between the affected and unaffected sides in unilateral DDH.

Regarding A-H angle measurements (Table II), the horizontal plane angle A was significantly smaller in the unilateral DDH group than that in the bilateral healthy group (Fig. 8). The unaffected and affected sides were not significantly different in the unilateral DDH group.

In the sagittal plane, angles E, F, and H in the unilateral DDH group were significantly smaller than those in the bilateral healthy group, and their angles were close to those in the bilateral DDH group (Table II, Fig. 9). The values were comparable between the unaffected and affected sides in the unilateral DDH group.

Angle C-A, used to compare the iliac and ischiopubic bones, was significantly larger on both sides in the unilateral DDH group than in the bilateral healthy group. In contrast, angle D-A was significantly larger on the affected side in the unilateral DDH group than

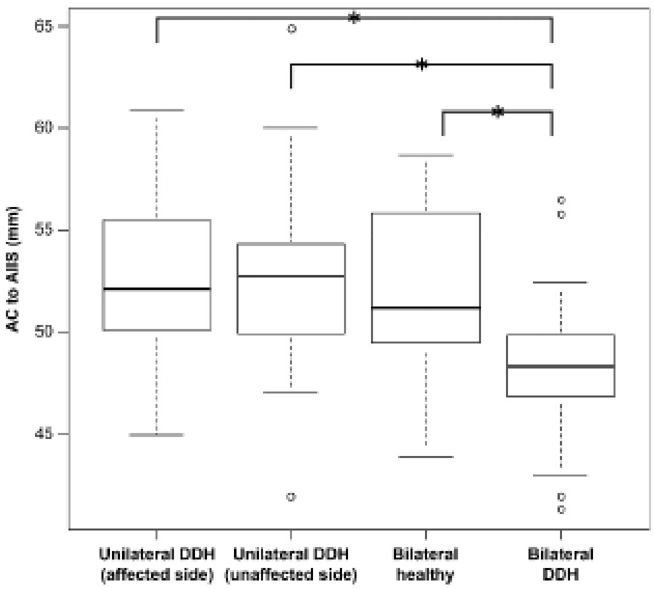

Figure 7. — Comparison of distances between AC and AIIS. Bilateral distances in the unilateral DDH group were significantly longer than those in the bilateral DDH group. AC, acetabular centre; AIIS, anterior inferior iliac spine; DDH, developmental dysplasia of the hip.

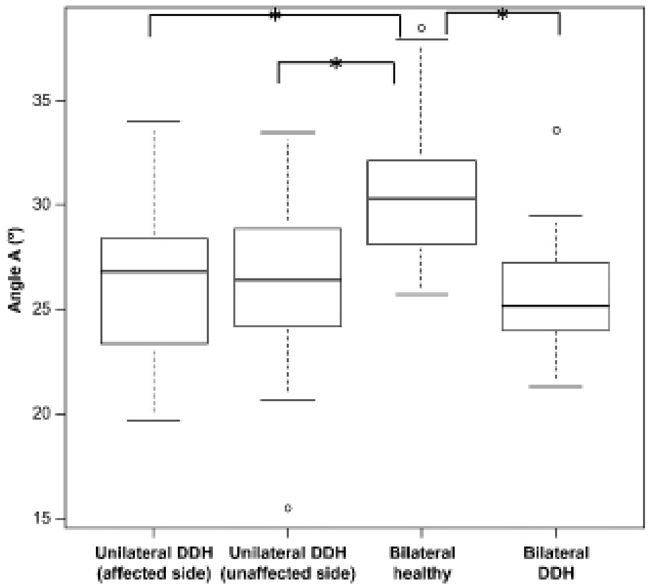

Figure 8. — Comparison of angle A. Unilateral DDH group angle was smaller than the bilateral healthy group angle. DDH, developmental dysplasia of the hip.

Table I. — Patients' demographic characteristics

	Bilateral DDH	Bilateral healthy	Unilateral DDH (Affected side)	Unilateral DDH (Unaffected side)	p-value
Age (years)	43.5± (8.7)	49.9± (12.5)	43.9± (9.13)		0.0421
Height (cm)	156.9± (6.0)	155.5± (6.5)	156.8± (7.9)		0.6845
Body weight (kg)	58.0± (9.8)	57.6± (10.7)	56.1± (11.2)		0.8124
BMI (kg/m^2)	23.5± (3.5)	24.0± (5.0)	22.8± (3.8)		0.6181
Centre-edge angle (°)	10.1± (8.7)	33.6± (5.7)	15.7± (4.9)	29.8± (5.4)	<0.001
DDH, developmental dysplasia of the hip; BMI, body mass index.					

Table II. — Comparison of distances between two points

	Unilateral DDH (Affected side)	Unilateral DDH (Unaffected side)	Bilateral DDH	Bilateral healthy	p-value	p-value between affected side and bilateral DDH	p-value between affected side and bilateral healthy	p-value between unaffected side and bilateral DDH	p-value between unaffected side and bilateral healthy	p-value between bilateral DDH and bilateral healthy
ASIS-AIIS (mm)	39.2± (6.1)	38.8± (5.6)	41.6± (4.8)	40.9± (4.3)	0.0965	—	—	—	—	—
ASIS-PSIS (mm)	153.3± (7.8)	154.2± (6.5)	153.9± (7.9)	153.4± (7.5)	0.927	—	—	—	—	—
ASIS-IC (mm)	58.1± (9.0)	56.9± (8.9)	61.1± (7.8)	60.2± (9.6)	0.346	—	—	—	—	—
AIIS-PIIS (mm)	122.1± (7.1)	121.6± (9.1)	123.3± (7.7)	122.4± (9.7)	0.853	—	—	—	—	—
AC-ASIS (mm)	87.7± (5.9)	87.3± (6.6)	85.0± (4.5)	87.4± (65.5)	0.203	—	—	—	—	—
AC-AIIS (mm)	52.3± (4.1)	52.6± (4.5)	48.2± (3.5)	52.1± (3.9)	<0.001	<0.001	0.9792	<0.001	0.9243	<0.001
AC-PSIS (mm)	113.6± (7.6)	114.7± (7.6)	114.0± (6.0)	113.1± (6.6)	0.822	—	—	—	—	—
AC-PIIS (mm)	86.0± (9.1)	86.9± (10.4)	89.3± (7.3)	85.4± (8.7)	0.191	—	—	—	—	—
AC-IC (mm)	108.5± (6.1)	107.5± (7.5)	103.8± (6.1)	108.4± (6.0)	0.0223	0.051	0.9988	0.2897	0.9101	0.0316
A (°)	26.1± (3.7)	26.5± (3.9)	25.8± (2.6)	30.8± (3.5)	<0.001	0.9520	<0.001	0.7908	<0.001	<0.001
B (°)	23.1± (2.7)	23.2± (2.6)	22.0± (2.5)	24.9± (2.8)	<0.001	0.2317	0.0837	0.0704	0.0512	<0.001
C (°)	29.7± (3.4)	29.9± (2.6)	31.0± (2.0)	29.6± (2.3)	0.0926	—	—	—	—	—
D (°)	34.3± (3.6)	34.1± (3.6)	36.1± (3.0)	32.5± (2.8)	<0.001	0.1477	0.2525	0.2251	0.3591	<0.001
E (°)	13.1± (4.4)	12.0± (4.7)	12.7± (4.4)	19.5± (6.9)	<0.001	0.9029	0.0014	0.9887	<0.001	<0.001
F (°)	15.1± (5.0)	15.0± (5.5)	15.3± (4.6)	20.8± (5.6)	<0.001	0.9842	0.0019	0.9437	0.0016	0.0018
G (°)	15.3± (5.6)	15.6± (6.2)	12.6± (4.0)	17.0± (4.6)	0.0117	0.2122	0.6769	0.2352	0.8274	0.0026
H (°)	7.2± (4.2)	7.0± (3.7)	7.1± (3.7)	4.0± (2.7)	0.0011	0.9998	0.0090	0.9852	0.0052	0.0071
C-A (°)	3.58± (5.9)	3.36± (5.7)	5.18± (3.4)	-1.20± (3.8)	<0.001	0.4505	0.0033	0.1877	0.0046	<0.001
D-A (°)	8.14± (6.3)	7.55± (6.7)	10.28± (4.6)	1.69± (4.6)	<0.001	0.2091	<0.001	0.1909	0.0646	<0.001
D-C (°)	4.56± (3.7)	4.18± (2.6)	5.11± (1.7)	2.89± (2.0)	0.0013	0.8745	0.0233	0.6862	0.1335	<0.001
A-B (°)	3.03± (2.7)	3.39± (3.6)	3.88± (2.6)	5.89± (3.3)	0.0017	0.3419	0.0015	0.7425	0.0433	0.0525
E+H (°)	20.29± (6.5)	19.02± (6.4)	19.80± (4.3)	23.49± (7.7)	0.0423	0.9982	0.1738	0.7289	0.0903	0.1106

Only groups with significant differences (p-value <0.05) by the Kruskal–Wallis test were further compared using the Steel-Dwass test and listed in the table. ASIS, anterior superior iliac spine; AIIS, anterior inferior iliac spine; PSIS, posterior superior iliac spine; IC, iliac crest; PIIS, posterior inferior iliac spine; AC, acetabular centre; DDH, developmental dysplasia of the hip.

in the bilateral healthy group. Angle A-B, comparing the superior and inferior parts of the iliac bone, was significantly smaller on the affected side in the unilateral DDH group than in the bilateral healthy group. Angle D-C was significantly greater on the affected side in the unilateral and bilateral DDH groups than in the bilateral healthy group. In the sagittal plane, the E + H angle values were comparable between the groups.

There was no significant difference in the ASIS or AC distances between the unilateral DDH group and the other two groups. However, the femoral head centre-to-centre distance was significantly longer in the bilateral healthy group (Table III). When divided into DDH and healthy sides by the vertical axis of the APP from the PS, no significant differences were found in the bilateral ASIS and AC distances (p = 0.709 and

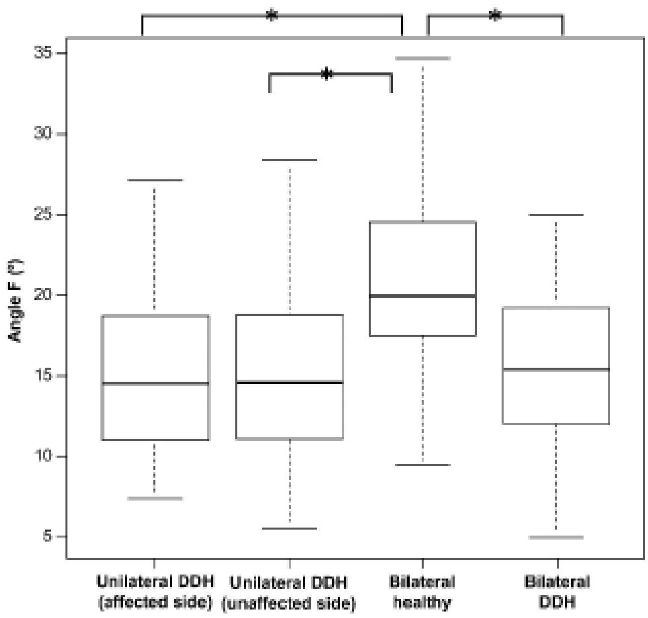

Figure 9. — Comparison of angle F. Unilateral DDH group angle was smaller than the bilateral healthy group angle. DDH, developmental dysplasia of the hip.

0.058, respectively); however, the distance between the bilateral femoral heads centres was significantly longer on the affected side than on the unaffected side in unilateral DDH (p=0.037) (Table IV).

DISCUSSION

Our study showed that the iliac morphology in unilateral DDH was comparable to that in normal bilateral hips. However, the rotation abnormalities in the horizontal and sagittal planes were comparable to those in bilateral DDH; the ilium is rotated posteriorly, and the pubis is rotated anteriorly in the sagittal plane; there was relatively less rotation near the acetabulum in the horizontal and sagittal planes. In the coronal plane, the distance between the femoral heads was significantly longer in unilateral DDH than in bilateral normal hips. The distance between the femoral head and middle of the pelvis was significantly longer on the affected side in unilateral DDH.

In measuring the distance at the iliac bone, only the distances between the AC and AIIS on both sides in the unilateral DDH group were significantly different from those in the bilateral DDH group. The results in this study contradict the findings of a study in which a small pelvic size was associated with severe dislocation of the hip[8,9]. Furthermore, the distance between the AC and the AIIS is reportedly significantly shorter in patients with bilateral DDH than in healthy individuals[15]. Therefore, the iliac morphology in patients with unilateral DDH was close to that of healthy individuals.

Our findings indicate that 1) the superior part of the iliac bone was more internally rotated than the inferior part in the unilateral DDH group compared to the bilateral healthy group; 2) the inferior part of the ischiopubic bones on the affected side in unilateral DDH was more internally rotated than the superior part compared with the bilateral healthy bones, and 3) the iliac bone is more internally rotated than the ischiopubic

Table III. — Comparison of distances in the coronal plane

	Unilateral DDH	Bilateral DDH	Bilateral healthy	p-value	p-value between unilateral and bilateral DDH	p-value between unilateral DDH and bilateral healthy	p-value between bilateral DDH and bilateral healthy
Femoral heads (mm)	179.0± (8.6)	183.6± (11.2)	171.8± (8.6)	<0.001	0.3780	0.0163	<0.001
ACs (mm)	141.3± (7.4)	140.6± (7.9)	136.8± (7.4)	0.0433	0.9994	0.0943	0.0682
ASISs (mm)	231.2± (19.0)	223.2± (14.4)	238.7± (15.7)	0.0011	0.4341	0.0681	<0.001
DDH, developmental dysplasia of the hip; AC, acetabular centre; ASIS, anterior superior iliac spine.							

Table IV. — Comparison of distances between the affected and unaffected sides*

	Unilateral DDH (Affected side)	Unilateral DDH (Unaffected side)	p-value
Distance between femoral heads (mm)	91.6± (4.4)	89.7± (4.0)	0.0374
Distance betwe;en ACs (mm)	72.43± (3.8)	70.18± (3.7)	0.0580
Distance between ASISs (mm)	112.77± (8.5)	11.77± (8.7)	0.7093
*Divided in a plane perpendicular to the anterior pelvic plane through the pubic symphysis. DDH, developmental dysplasia of the hip; AC, acetabular centre; ASIS, anterior superior iliac spine.			

bone in patients with unilateral DDH, and this rotation is more pronounced on the affected side than on the non-affected side. Although the APP in unilateral DDH should be comparable to that in bilateral DDH and unlike that in bilateral healthy hips, the APP differs in three-dimensional measurements between unilateral and bilateral DDH due to the difference in iliac rotation between the affected and the non-affected side in unilateral DDH.

In the sagittal plane, although angles E, F and H on both sides in unilateral DDH were significantly different than those in the bilateral healthy hips, these findings may be due to differences in the APPt[16,17]. The angle E + H, formed between the line connecting ASIS and PSIS and the line connecting PS and IT, is not affected by APPt because it is not based on the APP vertical axis. The p-values compared with the healthy group were 0.174 and 0.09 in the affected and unaffected side of unilateral DDH, respectively, which were substantially smaller than those in bilateral DDH (0.998 and 0.729, respectively). Therefore, the iliac bone in unilateral DDH tended to rotate posteriorly and the ischiopubic bone to rotate anteriorly or both, as in the previous report with bilateral DDH[16].

In addition, the distance between the bilateral ACs tended to be longer on the affected side ($p = 0.058$) than on the unaffected side, despite no statistically significant differences between bilateral ASISs. Furthermore, the acetabulum and femoral head seemed to be shifted laterally on the affected side compared with the unaffected side.

Our results show that unilateral DDH has anatomical characteristics that are intermediate between those of bilateral healthy hips and bilateral DDH. Assuming that unilateral DDH is a precursor of bilateral DDH, it is suggested that DDH is preceded by abnormal rotation of the innominate bone rather than by pelvis deformity itself. However, one cannot rule out that unilateral DDH is an entirely different category characterized only by rotational abnormalities of the innominate bone without deformity of the bone itself.

The most significant limitation of this study was that only female patients were included because DDH is more common in women. Identifying DDH by the CE angle alone was another limitation of this study. Further, if the femoral head instability is independent of the DDH pelvic morphology, it becomes difficult to find detailed anatomical features of unilateral DDH. This study did not include comparisons between patients with subluxation or dislocation of the femoral head, such as Crowe types III and IV. Moreover, differences between various APPs may cause errors in the horizontal plane angle measurements. Finally, statistical comparisons of multiple groups that involve few cases are statistically underpowered and may not detect differences.

CONCLUSION

Although this study clarified some anatomical features attributed to unilateral DDH, it did not elucidate the anatomical relationship between bilateral DDH and bilateral healthy hips. Further studies are needed to clarify the anatomical relationship between bilateral DDH or bilateral healthy hips and to determine the true pelvic axis. These findings would facilitate preoperative planning and intraoperative navigation and improve total hip arthroplasty accuracy.

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