Original Article
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Three-Dimensional Evaluation of Innominate Bone Rotation in Female Patients with Developmental Dysplasia of the Hip

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Background: Patients with developmental dysplasia of the hip (DDH) are known to have abnormal pelvic morphologies; however, rotation of innominate bone features remains unclear. Thus, we investigated innominate bone rotation in patients with DDH by measuring the associated angles and distances using three-dimensional (3D) computed tomography.

Methods: We defined four straight lines in pelvic 3D models: from the anterior superior iliac spine to the posterior superior iliac spine, from the anterior inferior iliac spine to the posterior inferior iliac spine, from the pubic tubercle to the ischial spine, and from the pubic tubercle to the ischial tuberosity. Similarly, we measured the angles formed by these lines using the vertical axis of the anterior pelvic plane on the horizontal plane and the horizontal axis on the sagittal plane. Additionally, we measured the distances between the femoral head centers and the acetabular centers in the coronal plane.

Results: The difference in internal rotation angle between the superior and inferior parts of the iliac bone was significantly lower, by approximately 1.7°, in the DDH group than in the control group ($p = 0.007$); the difference between the inferior and superior parts of the ischiopubic bone was significantly higher, by approximately 1.5°, in the DDH group ($p < 0.001$). In the sagittal plane, the sum of the superior aspect of the iliac bone and the inferior aspect of the ischium was significantly lower in the DDH group ($p = 0.001$) than in the control group. The distances between the femoral heads and the acetabula were significantly greater in the DDH group than in the control group ($p = 0.03$, $p < 0.01$, respectively).

Conclusions: Patients with DDH had a more internally rotated ilium and ischiopubic bone than normal individuals; however, it should be emphasized that internal rotation was reduced near the acetabulum, and the acetabulum was shifted laterally. Similarly, it was shown that patients with DDH had different rotations of the ilium and ischiopubic bone in the sagittal plane.

Keywords: *Pelvic bone, Rotation, Developmental dysplasia of the hip, Tomography, Total hip arthroplasty*

Patients with developmental dysplasia of the hip (DDH) reportedly have morphological bone abnormalities in the acetabulum and the entire pelvis.[1-4] In the horizontal plane, morphological abnormalities of the bone include internal rotation of the entire ilium and superior pubic ramus and increased distal pelvic diameter.[1-3] Further, it has been suggested that there are abnormal bone morphologies, such as a steeper shape of the pelvis in the coronal plane.[4] Additionally, studies have been conducted on angles related to the pelvis, pelvic incidence, or acetabular angle compared with the sacrum, spine, and femoral anteversion.[5-8] However, there is no report of a three-dimensional (3D) evaluation, including the sagittal plane for pelvic morphological abnormalities in patients with DDH.

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In 1986, Kumeta et al.[1] reported that the ilium of patients with DDH was rotated internally and formed the so-called inward wing. The ischiopubic bone was internally rotated along with the internal rotation of the ilium, and Fujii et al.[3] reported that the internal rotation of the ilium exceeded that of the ischiopubic bone. Similarly, Kumeta et al.[1] reported that the distance between the femoral heads was greater in patients with DDH than normal individuals. When the ilium is internally rotated, the acetabular position should be internally rotated, and the distance between the femoral heads should equally be shortened. However, the distance between the femoral heads is, in fact, greater, contrary to reasoning. This may be due to the lateral subluxation of the femoral head in patients with DDH; therefore, measurement of the bilateral-acetabular distance, which has not been investigated in previous studies, is required to identify anatomical details. We hypothesized that the iliac bone of patients with DDH would be internally rotated, while the area near the acetabulum would be shifted laterally with subluxation of the femoral head. As DDH is predominantly found in female patients and it was difficult to collect a substantial number of male patients with DDH,[9] most of these past studies included only female participants. However, a study of DDH based on women alone is more reliable for determining the accurate anatomical characteristics than a comparison using measurements including a low number of men with differences in the size and anatomical characteristics of the pelvis.[10]

The most common method for measuring pelvic morphology with computed tomography (CT) is to use the anterior pelvic plane (APP) as the basic axis in a 3D model. When measuring with the APP as the basic axis, each value depends on the anterior pelvic plane tilt (APPt). Ueno et al.[11] reported that the APP tilted anteriorly in patients with DDH with greater internal rotation of the acetabulum due to the abnormal position of the anterior superior iliac spine (ASIS). Therefore, the coordinate axes of the APP should differ between patients with DDH and those without.

Accurate estimation of the coordinate axis is highly clinically significant for determining appropriate cup placement in total hip arthroplasty (THA).[12,13] However, if the APP axes are different between patients with DDH and those without, these differences will similarly affect the error in the APP set by CT-free navigation, which contains several data from patients with primary osteoarthritis. In fact, it has been reported that the accuracy of cup installation with CT-free navigation is inferior to that of CT-based navigation in THA for patients with DDH.[14] A detailed assessment of the pelvic anatomical features of DDH patients compared to normal patients could facilitate the establishment of a true 3D pelvic axis (that is not on the APP), which should ensure cup installation with an optimum cup angle without variation.

From the report by Ueno et al.[11] that APPt changes with acetabular rotation, the difference in APPt is considered greatly influenced by the rotation of the acetabulum. However, there are no reports comparing the rotation of the innominate bone in patients with DDH to evaluate the reference plane, which is a basic technique for anatomical measurement and preoperative planning. Moreover, to understand 3D deformation of the bone in more detail, it is important to investigate the horizontal and sagittal planes. However, there have been no reports including the sagittal plane. This study aimed to measure the angle between the horizontal and sagittal planes using a 3D model, measure the distance between the femoral heads and acetabula on the coronal plane, and clarify the characteristics of rotation and position of the innominate bone in patients with DDH.

METHODS

This retrospective study was performed in accordance with the ethical standards of the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. This study was approved by the Institutional Review Board of Oita University (IRB No. 1052), and all study participants provided informed consent before undergoing the CT scan.

Images from CT scans performed at our hospital were uploaded to the 3D preoperative planning software ZedHip (LEXI Co., Tokyo, Japan) and constructed in 3D, and we measured the parameters on this using the same software. All 3D CT images were acquired using a helical CT scanner (Aquilion CX; Canon Medical Systems Corporation, Otawara, Japan) with a 1-mm slice thickness.

The DDH group included 72 pelvises of female patients admitted to the hospital with hip pain from 2004 to 2019 with findings of bilateral acetabular dysplasia on X-ray images. Of the 72 patients, 44 patients underwent rotational acetabular osteotomy and 28 underwent THA during or after conservative treatment. None of these patients had previously undergone hip surgery. At the time of examination, we measured the hip joint, wherein osteoarthritis of the acetabulum had not progressed. Therefore, all acetabula were in the early stages of DDH with a circular head, and the joint space was almost maintained. The control group included a total of 72 patients who visited our hospital from 2004 to 2019, including 29 cases of osteonecrosis of the femoral head in stage 2 or lower with no lesions on the pelvic side and 43 cases without fracture of the pelvis or femoral head who were referred to our hospital due to trauma. None of these cases had a history of treatment for impingement syndrome or adhesive capsulitis. Men were excluded from this study, as mentioned in the introduction. We excluded patients with one-sided acetabular dysplasia, male sex (for the reasons outlined in the introduction), obvious narrowing of the joint space with a deformity of the femoral head observed on the radiograph (as this made obtaining the exact measurements needed for this study impossible), a history of hip joint disease in childhood, any skeletal system disease, or age > 65 years who may have had the typical degenerative anatomical changes associated with aging. Since the acetabulum, especially the pubic aspect, grows until approximately the age of 25 years, the lower limit of the age measurement was set to 25 years.[6)]

CT images were taken for all patients, and the center edge (CE) angle was measured in all patients of the DDH and control groups. On the coronal plane of the 3D CT, the CE angle was formed on the software by the perpendicular line passing from the line between the tear scars to the center of the femoral head and the line connecting the center of the femoral head and the lateral end of the acetabulum. After re-examination, it was clear that certain CE angles could not maintain the confidence interval deemed necessary; therefore, we excluded any hip with a CE angle of 20° to 25° from the DDH group and a CE angle of < 25° from the control group. The CE angle was < 20° in 55 cases in the DDH group and > 25° in 57 cases in the control group. In total, 112 pelvic bones were measured on the left side and compared between groups. The mean age was 43.7 years (range, 25–62 years) in the DDH group and 48.3 years (range, 26–65 years) in the control group (Table 1). There were no significant differences observed between the groups in any demographic data, including items related to body habitus, such as height and weight.

The pelvic 3D model was corrected using the APP. We described four straight lines: from the ASIS to the posterior superior iliac spine (PSIS), from the anterior inferior iliac spine (AIIS) to the posterior inferior iliac spine (PIIS), from the pubic tubercle (PT) to the ischial spine (IS), and from the PT to the ischial tuberosity (IT) in pelvic 3D models and measured the 3D straight-line distances (Fig. 1). We set each line as follows: the straight line from the

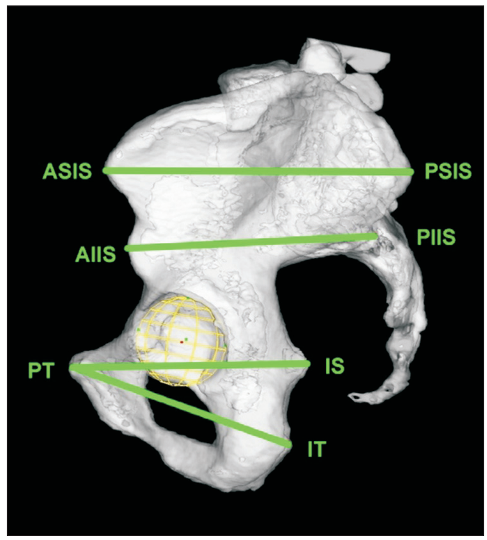

Fig. 1. The three-dimensional pelvic model was corrected with the anterior pelvic plane, and four straight lines were drawn and measured as follows: from the anterior superior iliac spine (ASIS) to posterior superior iliac spine (PSIS) (designated as line A); from the anterior inferior iliac spine (AIIS) to the posterior inferior iliac spine (PIIS) (designated as line B); from the pubic tubercle (PT) to the ischial spine (IS) (designated as line C); and from the PT to the ischial tuberosity (IT) (designated as line D).

Table 1. Subject Demographics

Variable	DDH group (n = 55)	CR group (n = 57)	*p*-value*
Age (yr)	43.7 ± 7.67 (25–62)	48.3 ± 11.9 (26–65)	0.019
Height (cm)	156.2 ± 5.43 (143–169)	155.5 ± 6.56 (141–169.5)	0.570
Body weight (kg)	57.4 ± 10.3 (40–82.6)	55.3 ± 10.6 (37.4–82.4)	0.326
Body mass index (kg/m^2)	23.5 ± 3.77 (17.1–32.5)	23.0 ± 4.82 (17.2–35.8)	0.557
CE angle (°)	10.5 ± 8.4 (–17.6–19.9)	32.6 ± 5.2 (25.0–47.5)	< 0.001

Values are presented as mean ± standard deviation (range).
DDH: developmental dysplasia of the hip, CR: control, CE: center edge.
**p*-value obtained using Student *t*-test.

ASIS to the PSIS was designated as line A; from the AIIS to the PIIS, line B; from the PT to the IS, line C; and from the PT to the IT, line D.

The angles formed by the intersections (vertical axes) of the APP and lines A to D on the horizontal plane were designated as angles A, B, C, and D, respectively (Fig. 2). Similarly, the angles formed by the intersections (horizontal axes) of the APP and lines A to D on the sagittal plane were designated as angles E, F, G, and H, respectively (Fig. 3). The addition or subtraction of the measured angles was calculated to investigate the relationships between the straight lines. The pelvis of one patient was also tilted 5°, and each angle was measured and compared with the angles in patients without pelvic tilt to investigate the effects of the pelvic tilt.

The center of the femoral head was determined by the ZedHip software as the center of a sphere created by plotting one point at the apex of the bony surface of the femoral head and three points in the slice where the diameter of the femoral head was maximized in the horizontal section (Fig. 4A). To determine the center of the acetabulum, we used the method by Kohnlein et al.[15] Using the software, the acetabulum was defined with a rough circle. Next, the intersection of a perpendicular line from the center of the circle, passing through the acetabular margin, to the acetabulum and the circle of the acetabulum itself was defined by the software as the center of the acetabulum (Fig. 4B). The distance between the femoral heads and the distance between the acetabula were measured by the software.

All measurements were performed by one observer (NS) and repeated with the cases blinded to the observer over the course of two sessions, which were at least one month apart. Intraobserver reliability, evaluated using intraclass correlation coefficients (ICCs), was excellent (range, 0.95–0.98). The reproducibility of the measurement was tested by two independent observers who performed measurements for 30 randomly selected hips in a blinded manner (YK and YK). Interobserver reliability, evaluated using ICCs, was also excellent (range, 0.93–0.98).

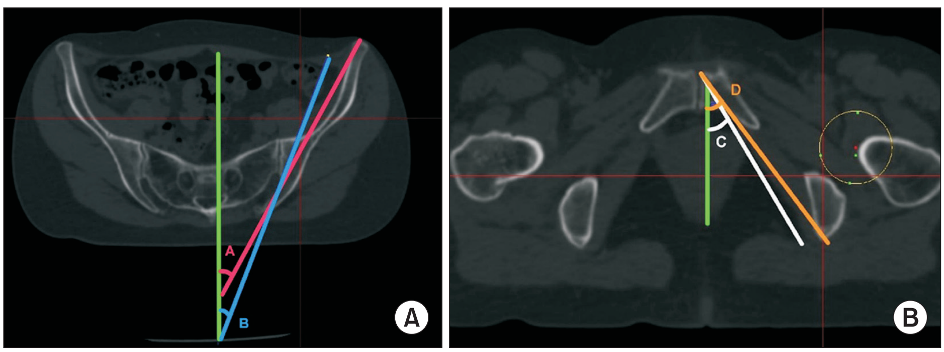

Fig. 2. The angles formed by the intersections (vertical axes) of the anterior pelvic plane and lines A to D on the horizontal plane were measured as angles A, B (A), C, and D (B). Definitions of lines A to D are provided in Fig. 1.

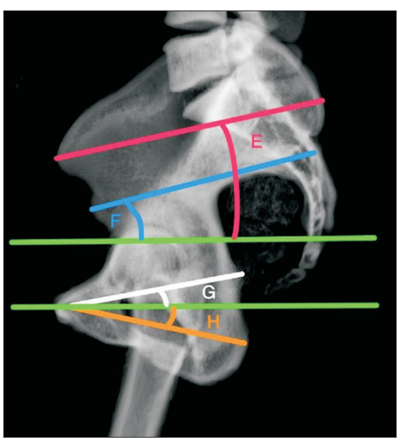

Fig. 3. The angles formed by the intersections (horizontal axes) of the anterior pelvic plane and lines A to D on the sagittal plane were measured as E, F, G, and H, respectively. Definitions of lines A to D are provided in Fig. 1.

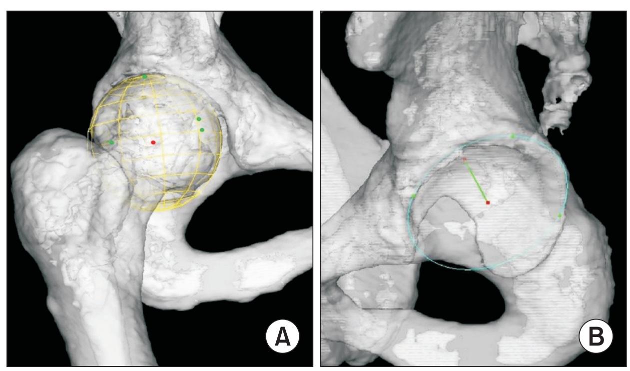

Fig. 4. (A) The ZedHip software determined the center of the femoral head by plotting four points on the bony surface in a horizontal section. (B) The center of the acetabulum was defined as the intersection between the acetabular outline and a perpendicular line drawn from the center of the circle and passing through the margin of the acetabulum.

The values of the distances and angles were compared using Student's t-test. Comparisons were performed using EZR (ver. 1.54; Saitama Medical Center, Saitama, Japan), which is a graphical user interface for R (ver 3.6.2; R Foundation for Statistical Computing, Vienna, Austria).[16] More precisely, EZR is a modified version of R commander (ver. 2.6-2; John Fox, Hamilton, Canada) that was designed to include the statistical functions frequently used in biostatistics. A $p < 0.01$ was considered to indicate statistical significance in all analyses.

RESULTS

The lengths of lines A to D did not differ significantly between the two groups (Table 2). There was a significant difference in all measured angles from A to H (range, $p <$ 0.001 to 0.009) (Table 3). In the horizontal plane, the DDH group had smaller values than the control group did for angles A and B and larger values for angles C and D. In the sagittal plane, the DDH group had smaller values than the control group did for angles E, F, and G, and a larger H angle.

On the values calculated using these angles, both C–A and D–A comparisons of the ilium and the ischiopubic bone were significantly larger in the DDH group than in the control group (both $p < 0.001$). The A–B comparison of the superior and inferior iliac bones was significantly smaller, by approximately 1.7°, in the DDH group than in the control group ($p = 0.007$). The D–C comparison of the inferior and superior ischiopubic bones was significantly larger, by approximately 1.5°, in the DDH group than in the control group ($p < 0.001$). In the sagittal plane, E + H was significantly smaller in the DDH group than in the control group ($p = 0.001$) (Table 4). Additionally, measurements were performed using the pelvis of all patients in the DDH group with a varying pelvic tilt (Table 5). When the pelvis was tilted posteriorly from 0° to 5° in the sagittal plane, the change in angles of A–B was within 0.3°. The angle calculated using D–C changed by approximately 0.7°.

The average distance between the femoral heads was 174.21 ± 8.74 mm (median, 172.98 mm) in the control group and was significantly greater in the DDH group

Table 2. Differences between Developmental Dysplasia of the Hip Group and Control Group

Variable	DDH group	CR group	p-value
Line A (mm)	152.3 ± 8.1	153.5 ± 7.3	0.410
Line B (mm)	122.0 ± 7.3	123.3 ± 9.0	0.405
Line C (mm)	111.8 ± 6.2	113.4 ± 5.3	0.147
Line D (mm)	119.5 ± 6.1	120.8 ± 5.6	0.258

Values are presented as mean ± standard deviation.
DDH: developmental dysplasia of the hip, CR: control.

Table 3. Comparison of Acetabular Angles in Developmental Dysplasia of the Hip Group and Control Group

Variable	DDH group (°)	CR group (°)	p-value
A	23.5 ± 3.6	27.7 ± 4.9	< 0.001
B	21.1 ± 2.6	23.5 ± 3.0	< 0.001
C	32.0 ± 2.1	30.7 ± 2.6	0.006
D	36.9 ± 3.1	34.1 ± 3.4	< 0.001
E	10.9 ± 4.3	16.4 ± 7.2	< 0.001
F	14.1 ± 4.7	18.2 ± 5.9	< 0.001
G	12.5 ± 3.6	14.8 ± 4.8	0.005
H	7.5 ± 3.8	5.6 ± 3.9	0.009

Values are presented as mean ± standard deviation.
DDH: developmental dysplasia of the hip, CR: control.

Table 4. Comparison of Bony Angles between Developmental Dysplasia of the Hip Group and Control Group

Variable	DDH group (°)	CR group (°)	*p*-value
C–A	8.45 ± 4.8	3.02 ± 6.0	< 0.001
D–A	13.41 ± 5.4	6.46 ± 7.1	< 0.001
D–C	4.95 ± 1.9	3.44 ± 2.1	< 0.001
A–B	2.44 ± 3.1	4.23 ± 3.7	0.007
E + H	18.45 ± 4.8	22.03 ± 6.6	0.001

Values are presented as mean ± standard deviation.
DDH: developmental dysplasia of the hip, CR: control.

Table 5. Angles in the Developmental Dysplasia of the Hip group with Pelvic Posterior Tilt of 5° from the Anterior Pelvic Plane Standard

Variable	A	B	A–B	C	D	D–C
Posterior tilt of 5°	23.5 ± 3.2	20.9 ± 2.5	2.7 ± 3.1	31.6 ± 2.3	37.2 ± 3.3	5.61 ± 2.8

Values are presented as mean ± standard deviation.

with 184.13 ± 10.16 mm (median, 182.1 mm) ($p = 0.03$). The average bilateral-acetabular distance was 138.25 ± 7.64 mm (median, 138.25 mm) in the control group, while it was significantly greater in the DDH group with 142.16 ± 7.76 mm (median, 142.60 mm) ($p < 0.01$).

DISCUSSION

Patients with DDH are known to have a different pelvic morphology from the norm. Many studies have measured pelvic distances and angles to investigate pelvic morphology in patients with DDH. Kumeta et al.[1] investigated the bilateral ASIS distance and femoral head distance using CT and reported that the ASIS and femoral head distances were short and long, respectively, in patients with DDH. Additionally, Kumeta et al.[1] reported that the anterior iliac wing opening angle increased in patients with DDH. Fujii et al.[3] compared the angle between the iliac dilatation angle and the ischiopubic bone at the ASIS level and described the characteristics of the internal rotation of the iliac wings and the ischiopubic bone. As described above, the ilium in patients with DDH is particularly internally rotated; however, the details of other innominate bone rotation are unclear. Additionally, when the ilium is internally rotated, the distance between the femoral heads is greater. As mentioned in the introduction, this may be due to superolateral subluxation of the femoral head in patients with DDH, and the characteristics, angles, and distances of the pelvis could be accurately understood by measuring the bilateral distance of the center of the acetabula instead of using the femoral heads.

In the horizontal plane, patients with DDH had significantly smaller values for angles A ($p < 0.001$) and B ($p < 0.001$) and significantly larger values for angles C ($p = 0.006$) and D ($p < 0.001$) than did the controls. This result indicated that the ilia were internally rotated, and the ischiopubic bones were equally internally rotated according to the rotation of the ilia. As the differences in the average values of angles A, C, and D were 4.2°, 1.3°, and 2.8°, respectively, between DDH patients and controls, when expressed in absolute values, that of A was larger than those of C and D despite the small angle A and large angles C and D. Therefore, we think that the ilium is more internally rotated than the ischiopubic bone in DDH patients. In addition, the angle of A–B, comparing the superior and inferior ilia, was significantly smaller in DDH patients, by approximately 1.8°, than in the control group ($p = 0.007$). This indicates that the superior aspect of the ilium was more internally rotated than the inferior aspect in patients with DDH. The angle of D–C, compared to the inferior and superior parts of the ischiopubic bone, was significantly larger in DDH patients than in control patients, by approximately 1.5° ($p < 0.001$). This indicates that the inferior aspect of the ischiopubic bone was more internally rotated than the superior aspect in patients with DDH. That is, it was shown that in patients with DDH, the ilia and the ischiopubic bones were internally rotated; however, the rotation was reduced near the acetabulum rather than at the superior and inferior parts of the pelvis. Additionally, the DDH group had a significantly greater acetabular distance than the control group ($p < 0.01$); although the bilateral femoral head distance was not significantly greater ($p = 0.03$), it might become significant if the sample size were increased. Since the acetabular opening angle was greater in the DDH group than in the control group, the acetabular center that was determined using Kohnlein et al.'s measurement method[15] in this study should have been located closer to the acetabular fossa in the DDH group than in the control group. Even if there was an error in the measurement of the acetabular center, the acetabular distance should be shorter in the DDH group than the control group. However, the results showed that this distance was conversely still longer in the DDH group even under such a condition. From the present study results, it was expected that both the ilium and ischiopubic bones of patients with DDH would be internally rotated; however, the acetabulum, which involves the inferior ilium and superior ischiopubic bone, experienced traction from the femoral head and was shifted laterally, which resulted in reduced internal rotation of the acetabulum (Fig. 5).

In the sagittal plane, the angles E and F were significantly smaller in DDH patients than in controls. This was considered to be due to the difference in APPt between patients with DDH and patients without. Ueno et al.[11] reported that the advancement of the ASIS caused the APP to tilt anteriorly in patients with DDH, and the APPt increased in patients with DDH. Therefore, when the sagittal axis was corrected with the APP and measured in this study, the entire pelvis tilted posteriorly in patients with DDH, in whom the ilium was internally rotated. We considered that the angles E and F were smaller in patients with DDH in this study due to differences in APPt. Similarly, angle G decreased, and angle H increased in patients with DDH. These results were similarly considered to be generated by the difference in APPt. However, the angle E + H, which is not affected by APPt, was significantly smaller in DDH patients than in control patients, by approximately 3.6°. This indicates that the relationship between the ilium and the ischiopubic bone in the sagittal plane differed between patients with and without DDH. Specifically, patients with DDH may have had either a posteriorly tilted ilium or an anteriorly tilted ischiopubic bone or both (Fig. 6). However, since these angles in the sagittal plane also changed depending on the degree of internal rotation of the innominate bone, there was limited proof of the hypothesis above. However, even when the innominate bone is rotated in DDH, as shown in Fig. 5, angular differences between the normal and DDH groups can be seen in the sagittal plane, similar to the results of our study. Therefore, our assumption concerning Fig. 5 seems appropriate from the point of the 3D view.

The following points can be mentioned as the limitations of this study: first, the APP was used as the refer-

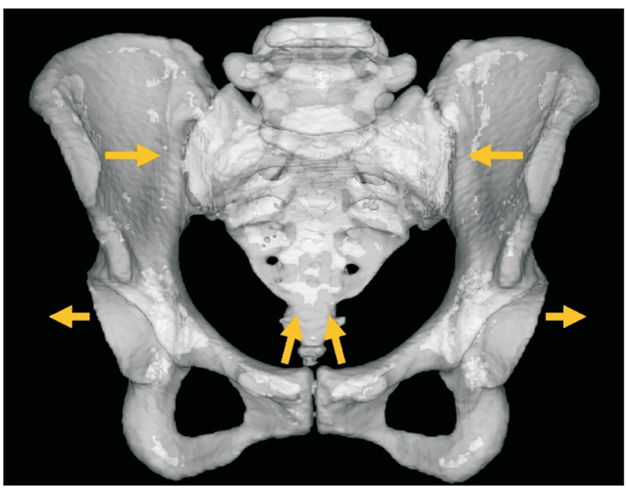

Fig. 5. Compared to the norm, the pelvis of patients with developmental dysplasia of the hip (DDH) had great internal rotation of the ilium and ischiopubic bone, and the internal rotation of the ilium was larger than that of the ischiopubic bone. However, the internal rotation was reduced near the acetabulum, and the acetabulum was shifted laterally. Arrows indicate the direction of bone rotation or shift in patients with DDH compared to the norm in the view of coronal plane.

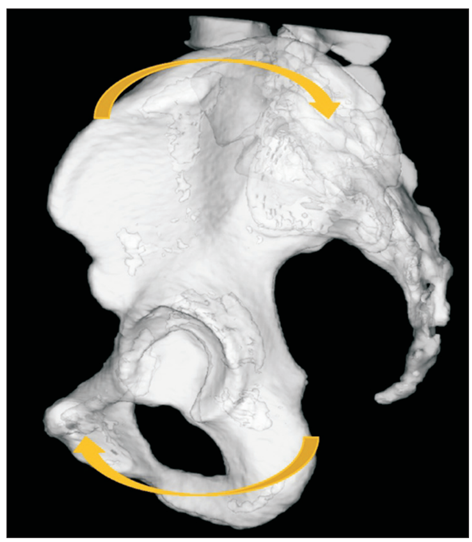

Fig. 6. Our results show the possibility of a posteriorly tilted ilium or an anteriorly tilted ischiopubic bone or both. In any of the cases above, although the position of the rotational axis of the innominate bone cannot be clarified in the sagittal plane, it should exist near the acetabulum. Arrows indicate the direction of bone rotation in patients with developmental dysplasia of the hip compared to the norm in the view of sagittal plane.

ence plane for measurement. As described above, APPt changes according to the internal rotation of the ilium; as such, there is a possibility that the axial plane cannot be measured in the same plane when using APP as the reference plane. In other words, in patients with DDH whose ilium is more internally rotated, measurement is performed in a state of posterior pelvic tilt. From the results in Table 4, when the pelvis was tilted posteriorly by 5° from the APP standard, the change in angles A to B was within 0.3°. In other words, the anterior-posterior tilt of the pelvis may hardly be involved in the angle measurement, and the angle difference observed in the present study may be considered too significant. However, as the angle of D−C changed by approximately 0.7° when the pelvis was tilted posteriorly by 5° from the APP standard, further investigation of the anatomical significance of this difference is warranted. Another limitation is that all the patients were female. Since DDH is more common among female patients, it was difficult to enroll the same number of male patients. It is known that pelvic morphology differs between male and female patients and also in patients with DDH.[10] Hence, it appears necessary to include male patients in future studies.

For the pelvises of patients with and without DDH, we measured the angle of each parameter in the horizontal and sagittal planes, the distance between the femoral heads, and the bilateral-acetabular distance in the coronal plane and compared both groups. We found that patients with DDH had internal rotation of the ilium, ischiopubic bone, and acetabulum; however, the internal rotation was reduced near the acetabulum, which was shifted laterally. Similarly, it was suggested that different rotations of the ilium and ischiopubic bone may be observed in patients with DDH in the sagittal plane. Patients with DDH may have had a posteriorly tilted ilium or an anteriorly tilted ischiopubic bone or both. Due to these 3D rotational differences in the innominate bone between groups, the axes of APP probably differed between DDH patients and normal patients. We hope that our study will help establish the true 3D pelvic axis and facilitate more accurate preoperative planning or intraoperative navigation for THA in the future. Nevertheless, further studies are needed to clarify the etiology and functional/clinical significance of the morphological abnormalities identified in the present study.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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REFERENCES

1. Kumeta HK, Funayama S, Miyagi S, et al. Inward wing ilium of adult hip dysplasia: a characteristic cross sectional pelvic anatomy visualized by CT. Rinsho Seikeigeka. 1986;21(2): 67-75.
2. Kojima S, Kobayashi S, Saito N, Nawata M, Horiuchi H, Takaoka K. Morphological characteristics of the bony birth canal in patients with developmental dysplasia of the hip (DDH): investigation by three-dimensional CT. J Orthop Sci. 2001;6(3):217-22.
3. Fujii M, Nakashima Y, Sato T, Akiyama M, Iwamoto Y. Pelvic deformity influences acetabular version and coverage in hip dysplasia. Clin Orthop Relat Res. 2011;469(6):1735-42.
4. Tannast M, Pfannebecker P, Schwab JM, Albers CE, Siebenrock KA, Buchler L. Pelvic morphology differs in rotation and obliquity between developmental dysplasia of the hip and retroversion. Clin Orthop Relat Res. 2012;470(12):3297-305.
5. Akiyama M, Nakashima Y, Fujii M, et al. Femoral anteversion is correlated with acetabular version and coverage in Asian women with anterior and global deficient subgroups of hip dysplasia: a CT study. Skeletal Radiol. 2012;41(11): 1411-8.
6. Anda S, Terjesen T, Kvistad KA, Svenningsen S. Acetabular angles and femoral anteversion in dysplastic hips in adults: CT investigation. J Comput Assist Tomogr. 1991;15(1):115-20.
7. Imai N, Miyasaka D, Tsuchiya K, et al. Evaluation of pelvic morphology in female patients with developmental dysplasia of the hip using three-dimensional computed tomography: a cross-sectional study. J Orthop Sci. 2018;23(5):788-92.
8. Imai N, Suzuki H, Nozaki A, Hirano Y, Endo N. Correlation

of tilt of the anterior pelvic plane angle with anatomical pelvic tilt and morphological configuration of the acetabulum in patients with developmental dysplasia of the hip: a cross-sectional study. J Orthop Surg Res. 2019;14(1):323.

9. Jingushi S, Ohfuji S, Sofue M, et al. Multiinstitutional epidemiological study regarding osteoarthritis of the hip in Japan. J Orthop Sci. 2010;15(5):626-31.

10. Tomohiro K, Masatoshi N, Yoshinari N, et al. Sex-related differences in pelvic morphology in acetabular dysplasia. Med Bull Fukuoka Univ. 2015;42(2):241-6.

11. Ueno T, Kabata T, Kajino Y, et al. Anterior pelvic plane tilt poorly estimates the sagittal body alignment due to internal rotation of innominate bone. J Orthop Res. 2021;39(3):580-9.

12. Renner L, Janz V, Perka C, Wassilew GI. What do we get from navigation in primary THA? EFORT Open Rev. 2017; 1(5):205-10.

13. Beckmann J, Luring C, Tingart M, Anders S, Grifka J, Kock FX. Cup positioning in THA: current status and pitfalls. A systematic evaluation of the literature. Arch Orthop Trauma Surg. 2009;129(7):863-72.

14. Kaku N, Tagomori H, Tsumura H. Comparison of cup setting angle accuracy between computed tomography-based and computed tomography-free navigation in the same patients with Crowe's classification I or II hip dysplasia. Clin Orthop Surg. 2021;13(2):144-51.

15. Kohnlein W, Ganz R, Impellizzeri FM, Leunig M. Acetabular morphology: implications for joint-preserving surgery. Clin Orthop Relat Res. 2009;467(3):682-91.

16. Kanda Y. Investigation of the freely available easy-to-use software 'EZR' for medical statistics. Bone Marrow Transplant. 2013;48(3):452-8.