

Original Article

Evaluating acetabular version through MRI and CT in 55 children of untreated DDH and 222 normal children

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Abstract: The aim of this study was to determine if computed tomography (CT) can accurately evaluate acetabular version despite its poor visualization of the cartilaginous component of the acetabulum in children with developmental dysplasia of the hip (DDH); if increasing acetabular anteversion (AA) can spontaneously its recover normal alignment after the reduction of the femoral head into the acetabulum in DDH; and if children with untreated DDH have acetabular retroversion. AA was measured in 55 children with DDH using between CT and magnetic resonance imaging. We also compared AA before and after the reduction of the femoral head into the acetabulum in 19 of the 55 children with DDH. A total of 55 children with DDH and 222 normal children were observed for acetabular retroversion. Although CT measurement underestimated the true AA, a mean difference of 4 has no clinical significance. CT remains a helpful tool in evaluating AA in children with DDH because of its lower cost, shorter scan time, and three-dimensional image and it does not require sedative. The AA on the affected hips was larger than that on the unaffected hips in unilateral DDH before the reduction of the femoral head into the acetabulum. However, the increasing AA recovered to normal range after reduction during the final follow-up, which suggests that correcting excessive AA through lateral rotation of the distal fragment during pelvic osteotomy seems unnecessary. No acetabular retroversion was observed in children with DDH or in normal children. Surgeons should avoid excessive rotation of the distal fragment toward the lateral during Salter's osteotomy in children with DDH to prevent iatrogenic complication (acetabular retroversion).

Keywords: Acetabular anteversion, acetabular retroversion, children with developmental dysplasia of the hip, nuclear magnetic resonance, computed tomography

Introduction

Developmental dysplasia of the hip (DDH) is a common deformity in childhood [1-4]. As conservative treatment fails in DDH, surgical intervention is required [5]. The purpose of surgical intervention is to recover normal alignment and improve the abnormal biomechanics due to DDH. Therefore, accurate evaluation of the morphologic deficit of the acetabulum in each individual with DDH is necessary for a satisfactory outcome and to avoid iatrogenic complications. According to previous studies, increasing acetabular anteversion (AA) is a universal pre-operative finding in children with DDH and is responsible for the hip instability [6-10]. However, an 18% incidence of acetabular retroversion was reported in adults with DDH who did not undergo surgery [11-13]. A couple of

studies have pointed out that acetabular retroversion was closely associated with pain and osteoarthritis of the hips [14-17].

Upon careful review of the above-mentioned literatures, we divided them into two groups according to the result of measurement: increasing AA [6-10] and acetabular retroversion [11-13]. An interesting finding was that the average age of patients was 18 months (range, 6-60 months) in the group with increasing AA [6-10]. In contrast, the average age of patients in the group with acetabular retroversion was 30 years (range, 12-61 years) [11-13]. Notably, acetabular version was mainly evaluated by computed tomography imaging (CT) and antero-posterior radiographs of the pelvis in all studies [6-13]. Although CT can accurately evaluate the AA in adults with DDH (in the group with acetab-

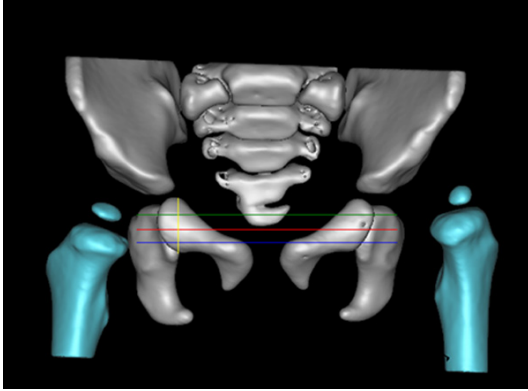


Figure 1. The yellow line represents the height of pubis head. Herein, the lateral one third of the pubis was considered as the pubis head. The green line, red line and blue line equally divided the yellow line into four parts.

ular retroversion), the strategy does not appear to be completely suitable for children with DDH (in the group with increasing AA). During childhood, the acetabulum consists of cartilaginous and osseous components. However, CT evaluation can only reveal osseous AA. Cartilaginous AA (i.e., true AA) is not completely demonstrated by CT in children. In fact, magnetic resonance imaging (MRI) is the most helpful tool for evaluating the cartilaginous component of the acetabulum in children. However, it could not be widely employed in clinical practice due to its higher cost, longer scan time, and need for sedative.

The aim of this study was to determine if CT can accurately evaluate acetabular version during childhood despite its poor visualization of the cartilaginous component of the acetabulum, if children with untreated DDH and normal children have acetabular retroversion, and if increasing AA can spontaneously recover its normal alignment after the femoral head is reduced into the acetabulum in DDH.

Materials and methods

Patients and controls

We retrospectively reviewed the medical records, plain anteroposterior pelvic radiographs, and CT and MRI images of 103 patients with a primary diagnosis of DDH at our institution between 2012 and 2016. Since non-operative or operative treatment can alter acetabular

anatomy, patients with prior treatment were excluded. Finally, 55 patients were included in the present study (female, 33; male, 12; average age, 19 months; range, 6-60 months). Thirty-seven patients had bilateral hip involvement, including 18 patients with bilateral hip dislocation, 4 patients with left hip dysplasia and right hip dislocation, 6 patients with left hip dislocation and right hip dysplasia, 4 patients with left hip subluxation and right hip dislocation, and 5 patients with left hip dislocation and right hip subluxation. Eighteen patients had unilateral DDH involvement, including 18 hip dislocation and 18 unaffected hips. In total, 73 dislocated hips, 9 subluxated hips, 10 dysplasia hips, and 18 unaffected hips were enrolled in the present study. Dysplasia was defined as a direct radiographic finding of increased obliquity and loss of concavity of the acetabulum and increased acetabular index ($> 30^\circ$) with intact Shenton line according to Ishida's classification system [18]. In addition, the Perkin line is lateral to the medial quarter of the proximal metaphysis. Subluxation was characterized by a lack of full contact of the femoral head with the acetabulum, a widened teardrop-femoral head distance, a reduced center-edge angle, a break in the Shenton line, and the Perkin line within the medial quarter of the proximal metaphysis. In the dislocated hip, the femoral head is not in contact with the acetabulum, the metaphysis lies lateral to the Perkin line, and the Shenton line is broken [6].

Of the 55 children with DDH, 26 (47.3%) were treated with closed reduction under general anesthesia. The hip was immobilized with a cast for 3 months. As we intended to use three-dimensional (3D) CT to observe whether the excessive AA could spontaneously recover the normal angle after the femur head is reduced into the acetabulum, an additional CT scan was needed at the end of the follow-up. Finally, 19 patients with DDH were voluntarily enrolled in the study (female, 14; male, 5); the mean age was 20 months (range, 14-48 months) before closed reduction and 47 months (range, 28-83 months) at the end of follow-up. The follow-up time ranged from 10 to 59 months. Unilateral and bilateral hips were involved in 10 and 9 cases, respectively.

To observe the incidence of acetabular retroversion and developmental evolution in normal

Acetabular version in untreated DDH

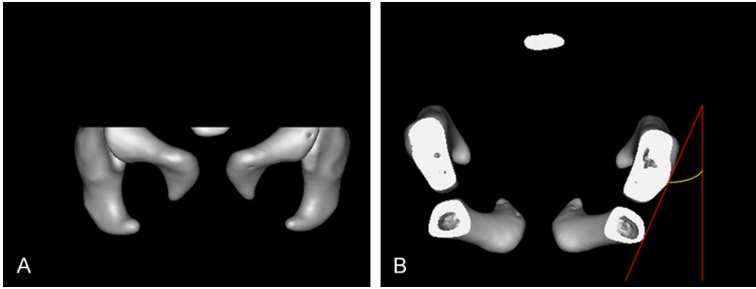


Figure 2. The acetabulum was cut on the transverse plane according to green line (A). Then, the upper acetabular anteversion was measured on the inferior view of pelvis (B).

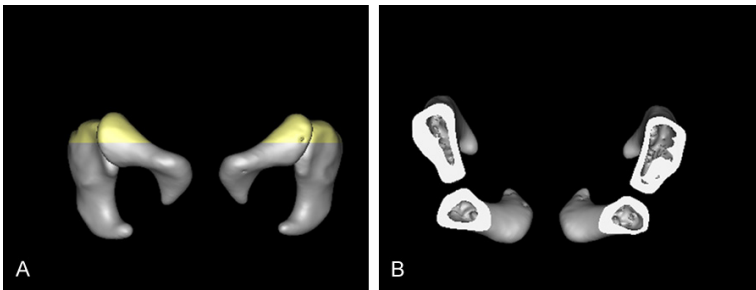


Figure 3. The acetabulum was cut on the transverse plane according to red line (A). Then, the middle acetabular anteversion was measured on the inferior view of pelvis (B).

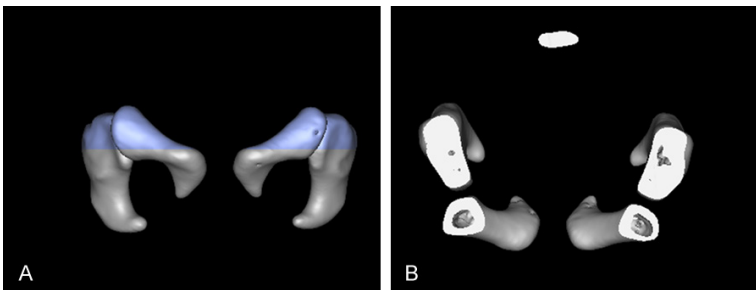


Figure 4. The acetabulum was cut on the transverse plane according to blue line (A). Then, the inferior acetabular anteversion was measured on the inferior view of pelvis (B).

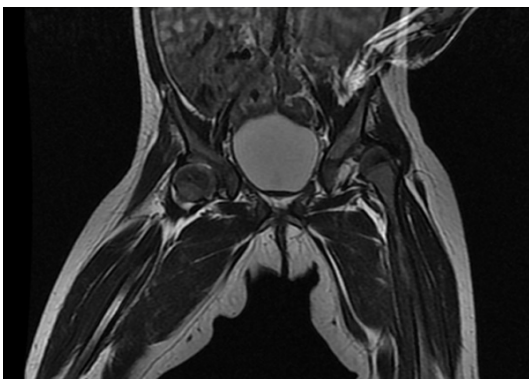


Figure 5. Like the 3D-CT observation, the MRI image also shows the left dislocated hip in the patient.

children, 222 cases that required magnetic resonance (MR) examination in our institution for non-neuromuscular and non-skeletal diseases and whose hips were simultaneously scanned were included (male, 132; female, 90; mean age, 6.2 years; range, 3 months to 15 years). All the cases had been clinically confirmed to have normal hip joints and no systemic or genetic disorders. The diagnosis included benign tumor of the abdomen or pelvic cavity in 108 cases, cutaneous and subcutaneous lymphangioma or hemangioma in 89 cases, and benign mediastinal neoplasms in 25 cases. The 444 hips in the 222 cases comprised the normal MRI controls. Approval and informed consent were obtained from the parents of the 222 children before additional MR scanning was performed. This research had been approved by the Medical Ethics Committee of the Second Affiliated Hospital of Nanchang University, and informed consent was obtained from all patients.

CT and MRI scanning and measurements

The 3D-CT scans were performed using a Philips Brilliance 64 scanner (Marconi Medical Systems, Netherlands). The scanning technique used was 120 kV, 70-120 mA (depending on the patient's size), and 0.5-s rotation time. Contiguous slices (1.5 mm) were obtained from the anterior superior iliac spine to the level of the lesser trochanter in DDH and from 11 thoracic vertebrae to the inferior margin of the pubic symphysis in the normal control group. The patients were placed in supine position with hips extended and thighs horizontal and

Acetabular version in untreated DDH

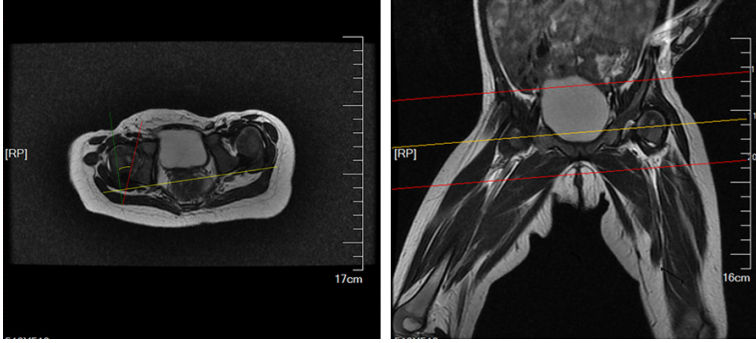


Figure 6. The coronal T2-weighted images that could show the pubis to the greatest extent were regarded as localizer. Like the 3D-CT measurement, the upper cartilaginous acetabular anteversion was measured on the transverse plane of T2-weighted images. The region between the two red lines on sagittal MRI represents the scan range of MRI in the patient. It is notable that if the pelvis presents rotation around the longitudinal axis, the cartilaginous AA is formed by the red line and green line on the transverse plane, and the green line is perpendicular to the yellow line. If the pelvis presents obliquity on the coronal plane, the MRI scan also is identical with the posture.

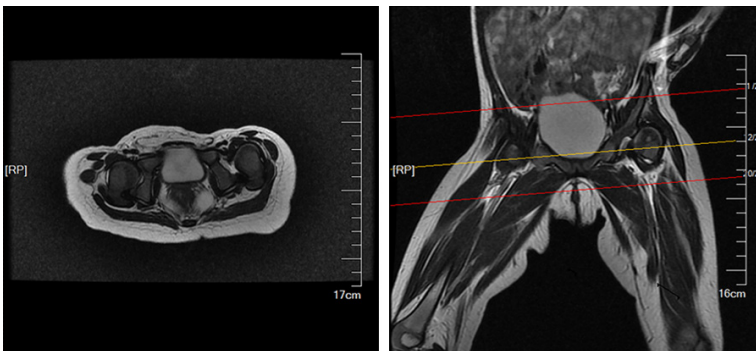


Figure 7. The middle cartilaginous acetabular anteversion was measured on the transverse plane of T2-weighted images.

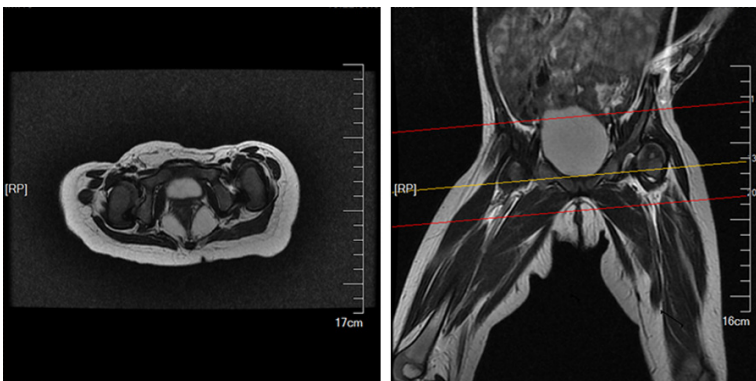


Figure 8. The inferior cartilaginous acetabular anteversion was measured on the transverse plane of T2-weighted images.

parallel. The MR scans were performed using the 1.5-T Philips Medical System (Philips

images according to the localizer, like the osseous AA, on the basis of the 3D-CT (Figures 5-8).

Achieva, Best, the Netherlands). The patients were placed supine inside the scanner with both limbs in symmetrical neutral position, using a body array coil placed anterior and posterior to the hip joints. The child who was younger than 4 years was sedated before MR examination. T1- and T2-weighted images were obtained in the axial and coronal planes using 3-mm slice thickness and 0-mm interslice gap. The parameters were TR of 4500 ms and TE of 120 ms in T2-weighted fast spin-echo, TR of 450 ms and TE of 12 ms in the T1-weighted spin-echo, and a 512 × 512 matrix.

The CT images were retrospectively reconstructed at a CT workstation (Extended Brilliance™ Workspace version 3.5.0.2250) to produce the 3D images. For more exact assessment of the osseous AA, the authors measured the osseous AA of the cross section based on 3D-CT. After the pelvic inclination was corrected by the software of the 3D-CT workstation, the upper, middle, and inferior acetabular anteversion (UAA, MAA, and IAA, respectively) were measured on the inferior view image (Figures 1-4). The cartilaginous AA were measured performed by the Picture Archiving and Communication Systems (PACS; Neusoft). First, the coronal T2-weighted images that showed the pubis to the greatest extent were regarded as the localizer. Then, the upper, middle, and lower cartilaginous AA were measured on the transverse plane of the T2-weighted

Acetabular version in untreated DDH

Table 1. Comparison of intra-observer and inter-observer agreement in the measurement of osseous and cartilaginous UAA, MAA and IAA as calculated by the intra-class correlation coefficient (ICC)

Observer	Osseous UAA		Osseous UAA		Osseous UAA		Cartilaginous UAA		Cartilaginous UAA		Cartilaginous UAA	
	ICC	P-Value	ICC	P-Value	ICC	P-Value	ICC	P-Value	ICC	P-Value	ICC	P-Value
Jia-Jia	0.913	0.000	0.925	0.000	0.898	0.000	0.922	0.000	0.903	0.000	0.903	0.000
Jia-Liu	0.814	0.000	0.837	0.000	0.844	0.000	0.876	0.000	0.857	0.000	0.808	0.000
Jia-Li	0.836	0.000	0.855	0.000	0.821	0.000	0.811	0.000	0.804	0.000	0.825	0.000
Liu-Li	0.808	0.000	0.812	0.000	0.842	0.000	0.836	0.000	0.825	0.000	0.837	0.000

Table 2. Differences in the UAA, MAA or IAA between the dislocated hips, subluxated hips, dysplasia hips and unaffected hips were evaluated with a one-way analysis of variance (ANOVA) based on the CT measurement

	Upper AA	Middle AA	Inferior AA
Dislocated hips (N = 73)	16.05 ± 3.59 (6.19-23.78) ^{Di}	16.71 ± 3.55 (8.19-27.77) ^{Di}	18.43 ± 4.18 (10.81-30.00) ^{Di}
Subluxated hips (N = 9)	14.28 ± 3.42 (8.77-18.00) ^{Su}	15.29 ± 3.31 (10.19-19.00) ^{Su}	16.28 ± 2.49 (13.00-19.22) ^{Su}
Dysplasia hips (N = 10)	12.64 ± 4.15 (7.19-19.00) ^{Dy}	13.67 ± 5.36 (8.00-26.00) ^{Dy}	14.73 ± 4.14 (9.23-21.00) ^{Dy}
Unaffected hips (N = 18)	10.39 ± 4.06 (3.00-20.00) ^{Un}	10.89 ± 3.81 (2.17-19.21) ^{Un}	12.88 ± 4.11 (3.82-23.00) ^{Un}

Upper AA: F = 12.395 P 0.000 Di/Su 0.180, Di/Dy 0.008, Di/Un 0.000; Su/Dy 0.338, Su/Un 0.012; Dy/Un 0.127. Middle AA: F = 12.258 P 0.000 Di/Su 0.288, Di/Dy 0.018, Di/Un 0.000; Su/Dy 0.351, Su/Un 0.005; Dy/Un 0.064. Inferior AA: F = 10.369 P 0.000 Di/Su 0.136, Di/Dy 0.008, Di/Un 0.000; Su/Dy 0.407, Su/Un 0.042; Dy/Un 0.249.

Table 3. Differences in the UAA, MAA or IAA between the dislocated hips, subluxated hips, dysplasia hips and unaffected hips were evaluated with a one-way analysis of variance (ANOVA) based on the MRI measurement

	Upper AA	Middle AA	Inferior AA
Dislocated hips (N = 73)	21.56 ± 5.12 (6.56-32.09) ^{Di}	21.77 ± 4.91 (7.05-31.54) ^{Di}	21.31 ± 4.69 (9.67-31.81) ^{Di}
Subluxated hips (N = 9)	19.88 ± 4.68 (11.21-26.22) ^{Su}	21.37 ± 4.31 (14.31-26.11) ^{Su}	20.35 ± 2.97 (15.00-24.32) ^{Su}
Dysplasia hips (N = 10)	17.32 ± 4.37 (12.00-23.05) ^{Dy}	17.77 ± 5.13 (8.00-23.10) ^{Dy}	17.85 ± 6.02 (7.13-23.63) ^{Dy}
Unaffected hips (N = 18)	14.18 ± 5.57 (4.05-25.83) ^{Un}	14.59 ± 5.09 (4.12-23.48) ^{Un}	15.67 ± 5.72 (2.90-26.21) ^{Un}

Upper AA: F = 10.946 P 0.000 Di/Su 0.354, Di/Dy 0.015, Di/Un 0.000; Su/Dy 0.277, Su/Un 0.007; Dy/Un 0.122. Middle AA: F = 11.287 P 0.000 Di/Su 0.821, Di/Dy 0.018, Di/Un 0.000; Su/Dy 0.114, Su/Un 0.001; Dy/Un 0.103. Inferior AA: F = 7.115 P 0.000 Di/Su 0.579, Di/Dy 0.038, Di/Un 0.000; Su/Dy 0.268, Su/Un 0.021; Dy/Un 0.261.

To evaluate interobserver variation, all measurements were taken by three experts, including one orthopedic surgeon, one pediatrician, and one radiologist. To determine intraobserver variation, the measurement was repeated 2 weeks later by one of the orthopedic surgeons.

Statistical analysis

Statistical analysis was performed with SPSS version 13.0 (IBM Corp., Armonk, NY, USA). Intraobserver agreement between the two sets of measurements by one orthopedic surgeon and interobserver agreements among the three sets of measurements by the orthopedic surgeon, pediatrician, and radiologist were analyzed using the Pearson's correlation coefficient and the intraclass correlation coefficient (ICC). An ICC > 0.75 was regarded as excellent; 0.40-0.75, fair to good; < 0.40, poor.

To analyze whether CT-based AA was a good proxy of MR-based AA, the paired sample t-test was used to assess the difference between CT- and MR-based AAs. Meanwhile, Pearson correlation analysis was performed to observe whether the CT-based AA has positive correlation with the MR-based AA.

To evaluate if the increasing AA was the cause or effect of DDH, the authors compared the AA between the hips with dysplasia and the unaffected hips. We also compared the AA before and after the reduction of the femoral head into the acetabulum using independent Student t-test.

The incidence of acetabular retroversion was recorded on the basis of CT and MRI measurement in children with DDH and normal children. The correlation of AA with age was also assessed using Pearson correlation analysis in

Acetabular version in untreated DDH

Table 4. The mean, standard deviation (SD) and 95% confidence interval (95% CL) of UAA, MAA and IAA at the different age on the basis of the MRI measurement

Age	Hips	Upper AA		Middle AA		Inferior AA	
		Mean \pm SD (Range)	95% CL	Mean \pm SD (Range)	95% CL	Mean \pm SD (Range)	95% CL
1	22	13.48 \pm 5.86 (5.21 to 26.35)	10.88 to 16.08	13.61 \pm 4.25 (7.11 to 25.22)	11.72 to 15.49	14.66 \pm 4.44 (8.07 to 26.21)	12.70 to 16.63
2	28	13.95 \pm 4.69 (6.80 to 25.39)	12.13 to 15.77	13.51 \pm 4.00 (4.39 to 21.08)	11.96 to 15.05	14.65 \pm 3.12 (8.39 to 19.32)	13.44 to 15.86
3	26	15.01 \pm 4.26 (8.48 to 24.50)	13.29 to 16.73	15.58 \pm 3.14 (9.52 to 21.17)	14.32 to 16.85	15.01 \pm 3.79 (9.40 to 22.12)	13.48 to 16.54
4	44	13.74 \pm 3.58 (2.06 to 19.21)	12.65 to 14.83	14.95 \pm 3.12 (6.94 to 20.61)	14.00 to 15.89	15.09 \pm 4.04 (5.89 to 23.93)	13.87 to 16.32
5	32	13.84 \pm 2.55 (8.23 to 18.07)	12.92 to 14.76	15.52 \pm 2.92 (9.67 to 22.20)	14.47 to 16.57	16.22 \pm 3.06 (11.26 to 23.70)	15.12 to 17.33
6	54	13.85 \pm 3.08 (6.67 to 19.78)	13.01 to 14.69	15.24 \pm 3.36 (7.53 to 23.52)	14.33 to 16.16	16.03 \pm 4.08 (6.70 to 26.90)	14.91 to 17.21
7	30	13.45 \pm 4.25 (5.12 to 21.88)	11.86 to 15.03	15.47 \pm 3.26 (7.81 to 21.00)	14.25 to 16.69	15.89 \pm 3.53 (10.23 to 22.75)	14.57 to 16.63
8	30	13.46 \pm 3.57 (4.25 to 22.71)	12.13 to 14.79	13.23 \pm 3.22 (7.81 to 20.87)	11.80 to 14.66	15.26 \pm 2.64 (9.34 to 19.76)	14.27 to 16.24
9	22	12.90 \pm 3.18 (5.43 to 18.46)	10.49 to 13.31	14.06 \pm 3.76 (7.49 to 21.87)	12.86 to 15.26	13.40 \pm 3.71 (8.02 to 19.99)	11.75 to 15.04
10	40	13.86 \pm 4.21 (7.25 to 21.37)	12.52 to 15.21	12.82 \pm 3.84 (7.10 to 21.33)	10.91 to 14.73	14.82 \pm 4.48 (4.98 to 23.63)	13.39 to 16.25
11	18	12.14 \pm 3.23 (5.95 to 16.74)	10.53 to 13.75	13.65 \pm 3.42 (7.92 to 20.44)	12.45 to 14.84	13.00 \pm 2.99 (6.52 to 18.54)	11.51 to 14.48
12	34	12.28 \pm 3.96 (4.28 to 21.37)	10.90 to 13.67	15.32 \pm 3.73 (6.93 to 23.22)	13.97 to 16.66	14.24 \pm 3.74 (7.19 to 23.65)	12.94 to 15.55
13	32	14.75 \pm 3.78 (7.90 to 22.62)	13.39 to 16.11	12.94 \pm 4.13 (6.26 to 20.50)	10.89 to 15.00	16.27 \pm 4.27 (8.97 to 25.19)	14.73 to 17.82
14	18	12.41 \pm 4.12 (4.45 to 21.29)	10.36 to 14.45	13.11 \pm 4.75 (6.49 to 20.07)	10.37 to 15.85	12.82 \pm 4.31 (3.51 to 19.66)	10.68 to 14.97
15	17	12.58 \pm 4.34 (6.32 to 22.44)	10.08 to 15.09			12.57 \pm 3.91 (4.50 to 18.72)	10.31 to 14.83

Acetabular version in untreated DDH

Table 5. The AA on the affected hips was higher than that on the unaffected hips in the children of unilateral DDH without prior treatment

	Affected hips	Unaffected hips	P Value
Upper AA	16.75 ± 4.33 (6.00-22.00)	11.11 ± 4.31 (4.00-19.00)	0.001
Middle AA	18.29 ± 4.85 (6.21-23.00)	12.70 ± 4.28 (5.17-22.00)	0.001
Inferior AA	20.18 ± 4.20 (14.00-25.79)	13.35 ± 5.33 (7.00-27.00)	0.000

Table 6. The difference of AA was not observed between the affected hips and the unaffected hips in the children of unilateral DDH after reduction of femoral head into acetabulum

	Affected hips	Unaffected hips	P Value
Upper AA	12.14 ± 2.39 (6.00-15.00)	11.48 ± 3.64 (6.81-19.00)	0.560
Middle AA	13.95 ± 2.58 (8.18-17.00)	12.98 ± 3.27 (8.00-20.00)	0.250
Inferior AA	13.59 ± 3.99 (7.00-21.80)	13.50 ± 4.46 (9.00-24.00)	0.920



Figure 9. A 17 months children with unilateral DDH presented dislocation of left hip. The AA in the dislocated hip is 20° before close reduction.

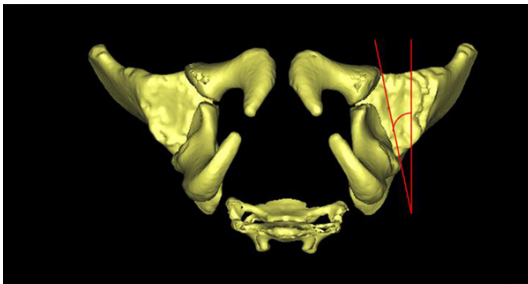


Figure 10. The AA of the dislocated hip recovered from 20 (at the age of 17 months) to 12 (at the age of 41 months), after the children (same **Figure 9**) was performed close reduction and immobilization of hip cast for 3 months.

the normal children to observe whether AA could spontaneously evolve to acetabular retroversion with aging.

Results

The 3D-CT and MRI-based measurement of UAA, MAA, and IAA revealed excellent intra-

observer and interobserver agreement across the three observers (**Table 1**).

The CT-based AA was smaller than the MRI-based AA in children with DDH (**Tables 2** and **3**), which suggested that CT measurement underestimated the true AA. However, the mean difference between CT- and MRI-based AAs was only 4°, which is not clinically significant. A positive correlation was observed between CT- (UAA, MAA, and IAA) and MRI-

based AAs (UAA, MAA, and IAA) in DDH ($r = 0.582, P = 0.000$; $r = 0.681, P = 0.000$; and $r = 0.640, P = 0.000$, respectively).

No acetabular retroversion was observed in our study of 55 DDH (110 hips) (**Tables 2** and **3**) and 222 normal children (444 hips) (**Table 4**) using CT and MRI evaluation. No correlation of UAA, MAA, and IAA with age was noted in normal children with ages 3 months to 15 years ($r = -0.075, P = 0.268$; $r = -0.055, P = 0.418$; and $r = -0.126, P = 0.07$, respectively; **Table 4**).

Although the AA on the affected hips was larger than that on the unaffected hips in unilateral DDH before the reduction of the femoral head into the acetabulum ($P < 0.05$, **Table 5**), the increasing AA recovered to a normal range after the reduction of the femoral head into the acetabulum at the final follow-up ($P > 0.05$, **Table 6**; **Figures 9** and **10**). Meanwhile, the increasing AA also improved significantly after the reduction of the femoral heads into the acetabulum in the bilateral DDH ($P < 0.05$, **Table 7**).

In addition to those, the authors found that as the AA of the dislocated and subluxated hips was larger than that of the unaffected hips ($P < 0.05$, **Tables 2** and **3**), no significant difference on AA was noted between the hips with dysplasia and the unaffected hips ($P < 0.05$, **Tables 2** and **3**). We noted that the increasing AA can spontaneously recover to a normal range after the reduction of the femoral head into the acetabulum. Furthermore, if the dislocated hips are not reduced into the acetabulum in children with DDH, the AA angle will further increase (**Figures 11** and **12**).

Table 7. The preoperative UAA, MAA and IAA were compared with the postoperative UAA, MAA and IAA in the bilateral DDH group

	Pre-operation	Post-operation	P Value
Upper AA	18.26 ± 3.16 (12.00-23.00)	14.48 ± 2.79 (7.00-18.79)	0.000
Middle AA	18.26 ± 3.08 (12.00-23.18)	14.76 ± 3.99 (6.00-23.00)	0.000
Inferior AA	19.44 ± 3.76 (13.00-29.00)	15.48 ± 3.78 (9.00-25.00)	0.000

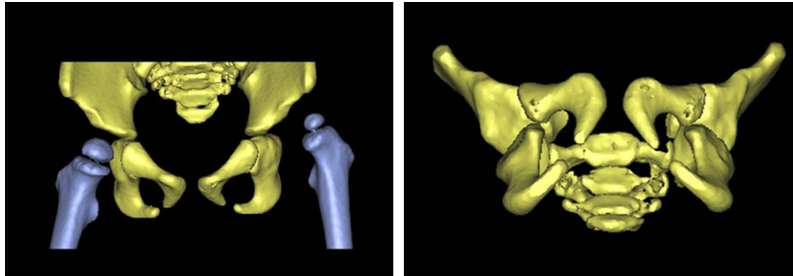


Figure 11. The children of unilateral DDH presented dislocation of left hip. The AA in the dislocated hip is 22 at the age of 18 months.

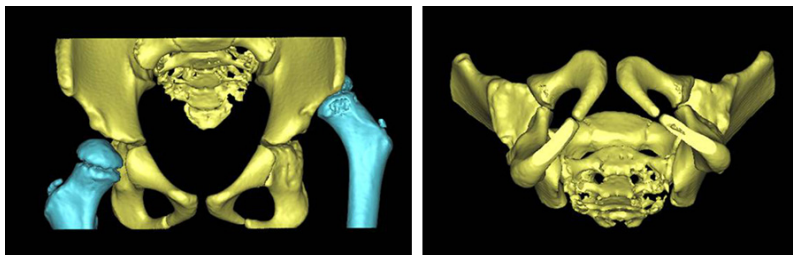


Figure 12. The children (same **Figure 11**) was not performed any treatment. The AA of the dislocated hip progressed from 22° to 27° after 33 months.

Discussion

Reasonable presurgical planning is largely based on the accurate understanding of the morphologic deformity of the acetabulum in DDH. If the increasing AA in DDH was not corrected during surgery, the hip joint would be unstable. If the AA in DDH was excessively corrected at operation, acetabular retroversion may present after operation. Acetabular retroversion was closely associated with hip pain and osteoarthritis of the hip [14-17]. Therefore, preoperatively identifying whether patients of DDH have excessive AA or acetabular retroversion is necessary to avoid iatrogenic complications.

However, it was a contradictory finding on AA in DDH. Sarbana et al. [6] compared the difference in AA between 44 affected hips (25 dislocated hips, 15 subluxated hips, and 4 dysplas-

tic hips) and 10 unaffected hips in DDH using 2D-CT (mean age, 32.3 months; range, 18-48 months), and they found an AA of 19.8° ± 2.5° on the dislocated group and 13.4° ± 2.8° on the unaffected group (P < 0.05). Meanwhile, Li et al. [7] evaluated AA using 3D-CT on the inferior view of the 3D pelvis in 66 patients with DDH (mean age, 35.4 months; range, 4-132 months), which revealed that AA was still significantly increasing in the dislocated hips compared with the unaffected hips (18.44° ± 3.82° and 13.92° ± 3.95°, respectively, P < 0.05). Jia et al. [8] also measured the AA using 3D-CT in 90 patients with unilateral DDH (average age, 18 months; range, 6-60 months) and observed that the AA in the dislocated hips was larger than that in the unaffected hips (17.02° ± 3.44° and 12.22° ± 3.22°, respectively, P < 0.05). Accumulating

evidence indicated that increasing AA, as an anatomical abnormality component, seems to be a universal finding in DDH.

In contrast, several studies [11-13] could not confirm previous findings and discovered acetabular retroversion in patients with DDH. Li et al. [11] assessed the AA using anteroposterior radiographs of the pelvis of patients with DDH (average age, 30 years) and found that one in six patients with acetabular dysplasia has retroversion. Ezoë [12] observed an 18% prevalence of acetabular retroversion (13/74 hips) using anteroposterior radiographs of the pelvis of patients with DDH (average age, 36.1 years; range, 14-54 years). Meanwhile, Fujii [13] also noted acetabular retroversion in 18% (17/96 hips) of 59 patients with DDH using 2D-CT and anteroposterior radiographs of the pelvis (average age, 40.1 years; range, 15-60 years).

Notably, the average age of patients is 18 months (range, 6-60 months) in the group with increasing AA [6-10]. However, the average age of patients is 30 years (range, 12-61 years) in the group with acetabular retroversion. Currently, acetabular version in children with DDH was mainly evaluated by CT imaging and anteroposterior radiographs of the pelvis in most studies because of its lower cost, shorter scan time, and 3D images [6-13]. Cong Shang et al. [19] study combined the clinical evaluation of DDH patients through 3D-CT with experimental observation of rat DDH models, aiming at finding out the features of spatial change in the ischium in DDH. The acetabulum consists of cartilaginous and osseous components during childhood. Therefore, it is not controversial for the fact that CT could exactly evaluate the AA in the adult with DDH. However, it was uncertain whether CT could accurately represent the true AA in children with DDH. In present study, we found that although CT measurement underestimated the true AA, the mean difference was only 4°, which has not clinical significance in our views. Moreover, the CT-based AA was positive correlation with MRI-based AA. This indicated that the CT-based AA was still a good proxy of MRI measurement in children with DDH. The CT was still a helpful tool on evaluating AA in children with DDH due to its lower cost, shorter scan time, and 3D images and it does not require a sedative. As children with DDH sometimes have accompanying pelvic tilt and deformity, AA measurement using 2D-CT and anteroposterior radiographs of the pelvis likely presents variable outcomes. For example, Van [20] found that pelvic obliquity and tilt could lead to variances in AA measurements using CT. Wassilew et al. [21] and Zaltz et al. [22] pointed out that variable morphology, location, and size of the anterior inferior iliac spine can result in an inaccurate evaluation of acetabular version. Therefore, we reconstructed the 3D images of the pelvis and corrected the pelvic tilt at a CT workstation. Subsequently, multilevel AAs (UAA, MAA, and IAA) were assessed. Inconsistent with the results of Ezoë et al. [11-13], no acetabular retroversion was detected on patients with DDH using CT and MRI in our study. Moreover, acetabular retroversion was not observed either in the 222 normal children. AA has fully formed at birth and did not present any obvious change along with the increase in age in the normal children. In our

opinion, the incidence of acetabular retroversion may be overestimated by pelvis 2D-CT and anteroposterior radiographs because of pelvic tilt and deformity.

In the present study, we observed that excessive AA was a universal finding in the affected hips of patients with DDH. However, excessive AA spontaneously recovered to a normal range after the femoral head was reduced into acetabulum at the final follow-up in patients with unilateral DDH. This suggests that correcting excessive AA through lateral rotation of the distal fragment during pelvic osteotomy seems to be unnecessary. Surgeons should avoid excessive rotation of the distal fragment toward the lateral side on Salter's osteotomy in children with DDH to prevent iatrogenic complication (acetabular retroversion). Claudio et al. [23] has reported acetabular retroversion in 27% and averaged -15° in patients with DDH after Salter's osteotomy. Lv et al. [24] observed a mean preoperative AA of 18.7°, which decreased to 11.03° after Salter's osteotomy ($P < 0.05$). Akiyama et al. [25] reported that acetabular retroversion was present in 37.5% of the hips that underwent Pemberton osteotomy after skeletal maturity in DDH.

Our study found that no significant difference on AA was noted between the hips with dysplasia and the unaffected hips ($P > 0.05$). However, after dislocation or subluxation of the femoral head from acetabulum, the AA obviously increased. Such as, the AA of the dislocated and subluxated hips was larger than that of the unaffected hips ($P < 0.05$). In addition to those, we also observed that the increasing AA can spontaneously recover to a normal range after the reduction of the femoral head into the acetabulum. More importantly, if the dislocated hips are not reduced into the acetabulum in children with DDH, the AA angle will further increase. Therefore, we speculate that the increased AA maybe a result, and not a cause, of hip dislocation. Due to a single-center study and smaller sample size in the present study, multicenter study ought to be considered in diverse populations using larger sample size in order to support or refute our finding.

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Disclosure of conflict of interest

None.

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