■ HIP

Development of the osseous and cartilaginous acetabular index in normal children and those with developmental dysplasia of the hip

A CROSS-SECTIONAL STUDY USING MRI

L. Y. Li,
L. J. Zhang,
Q. W. Li,
Q. Zhao,
J. Y. Jia,
T. Huang

From Shengjing Hospital of China Medical University, Shenyang, China

The purpose of this study was to investigate the development of the osseous acetabular index (OAI) and cartilaginous acetabular index (CAI) using MRI. The OAI and CAI were measured on the coronal MR images of the hip in 81 children with developmental dysplasia of the hip (DDH), with a mean age of 19.6 months (3 to 70), and 241 normal control children with a mean age of 5.1 years (1 month to 12.5 years). Additionally the developmental patterns of the OAI and CAI in normal children were determined by age-based cross-sectional analysis.

Unlike the OAI, the normal CAI decreased rapidly from a mean of 10.17° (SD 1.60) to a mean of 8.25° (SD 1.90) within the first two years of life, and then remained constant at a mean of 8.04° (SD 1.65) until adolescence. Although no difference in OAI was found between the uninvolved hips in children with unilateral DDH and normal hips ($p = 0.639$), the CAI was significantly different between them both ($p < 0.001$). The normal CAI has fully formed at birth, and is maintained constantly throughout childhood. The CAI in the unaffected hips in children with unilateral DDH is also mildly dysplastic.

Developmental dysplasia of the hip (DDH) is common and presents as a spectrum, ranging from isolated acetabular dysplasia to subluxation or dislocation.[1] Early diagnosis and treatment can restore a normal relationship of acetabulum and femoral head.[2] Acetabular dysplasia is one of the major pathological deformities in various subtypes of DDH. The acetabular index (AI)[3,4] and the centre-edge (CE) angle[5] have been used to assess acetabular dysplasia and its correction after surgery. The AI is helpful for assessing dysplasia in children aged < eight years, but after this age becomes less useful as Hilgenreiner's line[6,7] is difficult to measure after ossification of the tri-radiate cartilage.[8] The CE angle is useful only in children aged > five years, as the centre of the femoral head is difficult to define in a younger child because of an eccentrically placed ossific nucleus, especially in those with DDH.[8]

Traditionally, the AI is measured on the anteroposterior (AP) pelvic radiograph. However, it provides an imperfect assessment of acetabular development because the cartilaginous development of the acetabulum is not accurately presented. The cartilaginous component of the superior acetabular floor probably plays a major role in stabilising the reduced femoral head and predicting the true potential for acetabular growth, and thus the cartilaginous acetabular index (CAI) has been used more frequently to evaluate the cartilaginous cover of the femoral head in current studies.[9-12] Although Fisher, O'Brien and Davis[13] suggested that the CAI could be accurately reflected by the osseous acetabular index (OAI), most authors believe that the bony development of the acetabulum does not always represent the cartilaginous development, and the cartilaginous anatomy of the acetabulum should be evaluated accurately, directly and separately.[10,14,15]

Ultrasound has provided information about the cartilaginous acetabulum in the younger population,[16] but is often difficult to interpret when imaging all the soft-tissue components of a child's hip.[14] Arthrography of the hip can also be used to measure cartilaginous cover, but is invasive and impractical for frequent investigation.[10] In contrast, magnetic resonance (MR) non-invasively differentiates the osseous margin from the cartilaginous acetabulum in the immature hip, and has been used to assess the osseous and cartilaginous acetabular anatomy.[9,14,17]

■ L. Y. Li, MD, Paediatric Orthopaedic Surgeon, Associate Professor
■ L. J. Zhang, MD, Paediatric Orthopaedic Surgeon, Professor
■ Q. W. Li, MD, Paediatric Orthopaedic Surgeon, Associate Professor
■ Q. Zhao, PhD, MD, Paediatric Orthopaedic Surgeon, Professor
■ J. Y. Jia, MD, Paediatric Orthopaedic Surgeon, Attending Surgeon
■ T. Huang, MM (Master of Medicine), Paediatric Orthopaedic Surgeon, Resident
Shengjing Hospital of China Medical University, Department of Pediatric Orthopaedics, No.36 Sanhao Street, Heping District, Shenyang City, China.

Correspondence should be sent to Professor Q. Zhao; e-mail: zh_qs@sina.com

doi:10.1302/0301-620X.94B12.29958 $2.00

J Bone Joint Surg Br 2012;94-B:1625–31.
Received 29 April 2012; Accepted after revision 5 September 2012

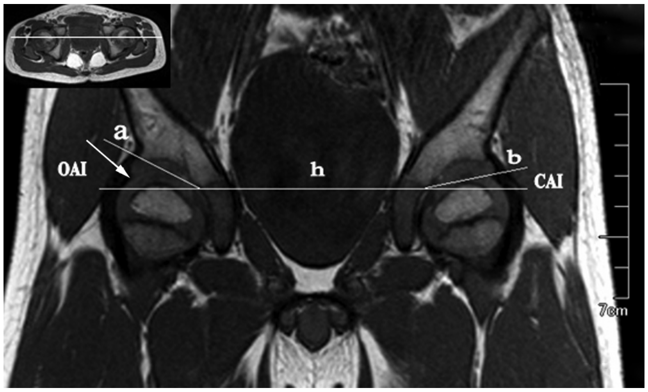

Fig. 1

T_1-weighted coronal MR image showing the measurement of the osseous (OAI) and cartilaginous acetabular index (CAI). The OAI was determined by Hilgenreiner's line (line h) and line 'a' drawn from the most superolateral margin of the ossified acetabulum to the superolateral margin of the tri-radiate cartilage. The CAI was formed by the line 'h' and line 'b' drawn from the lateral margin of the cartilaginous acetabulum at the attachment of the labrum (white arrow) to the superolateral margin of the tri-radiate cartilage.

The morphology of the osseous and cartilaginous acetabulum in children with DDH has been observed qualitatively using MRI,[18-21] but few studies focus on the quantitative measurement of the CAI in dysplastic hips.[13,22] Moreover, unlike the radiologically based AI, the normal development of the CAI has not been established. This information is clearly required in order to understand the development of the acetabulum in normal hips and in children with DDH, and thus to make appropriate decisions when treating this condition surgically.

The aims of this cross-sectional MR study were to identify: 1) how the OAI and CAI develop and evolve in normal children before adolescence; 2) whether the OAI and CAI in children with DDH are associated with the age of the child and the severity of the dislocation according to Tönnis grade[23]; and 3) whether the development of OAI and CAI in the uninvolved hip in children with unilateral DDH are consistent with that in normal children. In addition, the OAI measured by MR was compared with the radiologically based AI in children with DDH.

Patients and Methods

Between January 2006 and November 2010, 85 children with isolated DDH were treated at Shengjing Hospital, Shenyang, China. All were evaluated using MRI and radiographs before treatment by closed or open reduction. Details from the medical records, radiographs and MR images were collected. Four were excluded because of poor quality MR scans, leaving a total of 81 children (16 boys and 65 girls) in the study with a mean age of 19.6 months (3 to 70). Of these, 42 had bilateral DDH, giving a total of 123 affected hips. Of the 39 children with unilateral involvement, 19 were in the left and 20 in the right hip. According to the classification system of Tönnis,[23] based on the level of dislocation of the femoral head on AP pelvic radiographs, 17 hips were grade I, 59 grade II, 30 grade III and 17 grade IV. Dysplasia was diagnosed radiologically if there was increased obliquity and loss of concavity of the acetabulum with an AI of > 30°, when Shenton's line was intact according to Ishida's classification system.[24] Additionally Perkin's line[7] would be lateral to the medial quarter of the proximal metaphysis for the diagnosis to be made.

From January 2006 to December 2010, 241 children required examination by MRI in the authors' institution because of non-neuromuscular and non-skeletal disease. There were 142 boys and 99 girls with a mean age of 5.1 years (1 month to 12.5 years). In order to record the normal development of the acetabulum, an additional protocol was established. All of the 482 hips (from the 241 children) were clinically normal, and the children had no systemic or genetic disorders. A total of 203 children had confirmed Graf type I[25] hips from the neonatal screening programme, and the remaining 38 who had not undergone ultrasound screening had been ruled out from having DDH on the AP pelvic radiograph. The controls included children with benign abdominal or pelvic tumours in 118 cases, cutaneous and subcutaneous lymphangioma or haemangioma in 94 cases, mediastinal benign neoplasms in 29 cases. Informed consent was obtained from the parents of the 241 children before performing an additional MRI. The study was approved by the Medical Ethics Committee of Shengjing Hospital.

All the hips in children with DDH and normal controls were examined with standardised MR scans. The MR scans were performed using a 1.5T Philips Medical System (Philips Achieva, Best, The Netherlands). The children were positioned supine inside the scanner with both legs in a symmetrical neutral position, using a body array coil placed anterior and posterior to the hips. Children aged < four years were sedated before MR examination. T_1- and T_2-weighted images were obtained in the axial and coronal planes using 3 mm slice thickness and 0 mm interslice gap. The parameters setting included TR 4500 ms, TE 120 ms in T_2-weighted fast spin-echo; TR 450 mms, TE 12 ms in T_1-weighted spin-echo; matrix 512×512.

The measurements of radiological AI, MR-based OAI and CAI were completed by Picture Archiving and Communication Systems (PACS; Neusoft, Shenyang, China). The AI was measured using AP pelvic radiographs as described by Tönnis.[26] Coronal T_1-weighted images through the centre of the tri-radiate cartilage were selected to measure the OAI and CAI (Fig. 1). The OAI was determined from Hilgenreiner's line[6] and a line drawn from the most superolateral margin of the ossified acetabulum to the superolateral margin of the triradiate. The Hilgenreiner's line is a horizontal line connecting the inferior margins of the left and right bony ilium at the tri-radiate cartilage. The CAI was the angle formed by Hilgenreiner's line and a line drawn from the lateral margin of the cartilaginous acetabulum at the attachment of the labrum to the superolateral margin of the tri-radiate cartilage (Fig. 1).

Table I. Assessment of intra- and interobserver agreement of osseous acetabular index and cartilaginous acetabular index (ICC, intraclass correlation coefficient; CI, confidence interval)

	Osseous acetabular index		Cartilaginous acetabular index	
Observers	ICC (95% CI)	p-value	ICC (95% CI)	p-value
LYL–LYL	0.9965 (0.9957 to 0.9971)	< 0.001	0.9769 (0.9720 to 0.9810)	< 0.001
LYL–LJZ	0.8809 (0.8569 to 0.9011)	< 0.001	0.8861 (0.8631 to 0.9055)	< 0.001
LYL–QWL	0.9892 (0.9868 to 0.9911)	< 0.001	0.8749 (0.8498 to 0.8961)	< 0.001
LJZ–QWL	0.8933 (0.8716 to 0.9115)	< 0.001	0.9067 (0.8876 to 0.9227)	< 0.001

Table II. Values of osseous (OAI) and cartilaginous acetabular index (CAI) corresponding to age in normal children (CI, confidence interval)

		OAI (°)		CAI (°)	
Age (yrs)	Hips (n)	Mean (SD)	95% CI	Mean (SD)	95% CI
1	84	26.75 (2.57)	26.20 to 27.31	10.17 (1.60)	9.82 to 10.51
2	40	22.24 (2.50)	21.45 to 23.05	8.25 (1.90)	7.65 to 8.86
3	44	19.89 (2.07)	19.26 to 20.52	8.17 (1.48)	7.72 to 8.62
4	46	18.22 (2.26)	17.54 to 18.89	7.91 (1.83)	7.36 to 8.45
5	34	18.51 (1.32)	18.05 to 18.97	8.40 (1.44)	7.90 to 8.90
6	54	17.91 (2.23)	17.30 to 18.52	8.19 (1.74)	7.71 to 8.67
7	32	18.25 (1.97)	17.54 to 18.96	8.05 (1.44)	7.53 to 8.57
8	48	17.64 (2.09)	17.03 to 18.25	8.15 (1.69)	7.66 to 8.64
9	30	16.40 (1.89)	15.69 to 17.10	7.87 (1.34)	7.37 to 8.37
10	30	15.19 (1.75)	14.54 to 15.84	7.52 (1.63)	6.92 to 8.13
11	24	15.56 (2.09)	14.68 to 16.45	8.37 (2.18)	7.45 to 9.29
12	16	14.98 (2.64)	13.57 to 16.38	7.57 (1.44)	6.80 to 8.34

In order to evaluate the interobserver variation of the MR-based measurements, the OAI and CAI were repeatedly measured three times by the first three authors independently (LLY, ZLJ and LQW). In order to determine the intra-observer variation, the measurements were repeated two weeks later by the first author (LLY).

Statistical analysis. Statistical analysis was performed using SPSS v11.5 software (SPSS Inc., Chicago, Illinois). The paired samples *t*-test and Pearson correlation analysis were used to evaluate the relationship between the AI and the OAI, and the independent Student's *t*-test was used to compare the difference in OAI and CAI between normal hips and the uninvolved hips in unilateral DDH. Differences in the OAI and CAI with age and Tönnis classification were assessed with a one-way analysis of variance (ANOVA). A p-value < 0.05 was considered statistically significant.

Intra-observer agreement between the two sets of measurements of an observer (LLY) and interobserver agreements between the three sets of measurements of the observers (LLY, ZLJ and LQW) were analysed using Pearson correlation coefficient and the intra-class correlation coefficient (ICC). An ICC > 0.75 was regarded as excellent, ICC 0.40 to 0.75 was fair to good, and ICC < 0.40 was poor.

Results

The intra- and interobserver agreements with 95% confidence intervals (CI) were assessed by measuring the OAI and CAI repeatedly on the 644 hips, comprising 162 hips in children with DDH (123 affected hips and 39 unaffected hips) and 482 hips in children without DDH (Table I). For all the measurements, the ICCs were > 0.875, indicating excellent agreement.

The mean OAIs and CAIs according to the age in the 482 normal hips are summarised in Table II, and the p-values of multiple comparisons in OAI and CAI with age are indicated in Table III. The normal OAI was mean of 26.75° (SD 2.57) at the age of one year, and progressively decreased during the first four years, reaching a mean of 18.22° (SD 2.26) at the age of four years. After this, it remained unchanged with age until the age of eight. Before adolescence (from eight to ten years), it decreased slightly by approximately 2° to 3°. It then remained constant until adolescence (assumed at 12 years of age) (Fig. 2). Interestingly, the normal CAI had a significantly different pattern of development from the OAI. Within the first two years of life, the CAI decreased rapidly from a mean of 10.17° (SD 1.60) to a mean of 8.25° (SD 1.90), and then stayed at a constant mean level of 8.04° (SD 1.65) until adolescence (Fig. 2).

In the hips with DDH, there was a statistically significant correlation between the AI measured on plain radiographs and OAI measured on MR scans (r = 0.919, p < 0.001), but no significant difference (p = 0.056, paired samples *t*-test). When matching the age of the children with unilateral DDH and normal controls, the uninvolved hips in unilateral DDH were similar to the normal control hips for the measurements of OAI (p = 0.639, independent Student's *t*-test), but they were significantly different for the

Table III. Multiple comparisons of osseous and cartilaginous acetabular index over age in normal children. The data in the table represent the p-values calculated by analysis of variance test. The values in the bottom left semi-part of the table are the multiple comparisons of osseous acetabular index (OAI) by age, and the right upper semi-part are the multiple comparisons of cartilaginous acetabular index (CAI) by age

	CAI by age (yrs)											
OAI by age (yrs)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	-	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	-	0.813	0.333	0.704	0.853	0.606	0.771	0.342	0.069	0.785	0.164
3	0.000	0.000	-	0.455	0.539	0.948	0.762	0.960	0.453	0.102	0.630	0.218
4	0.000	0.000	0.000	-	0.188	0.395	0.706	0.477	0.931	0.326	0.267	0.485
5	0.000	0.000	0.006	0.550	-	0.561	0.392	0.501	0.204	0.035	0.946	0.099
6	0.000	0.000	0.000	0.489	0.211	-	0.708	0.905	0.402	0.078	0.657	0.190
7	0.000	0.000	0.001	0.946	0.627	0.489	-	0.793	0.673	0.212	0.475	0.344
8	0.000	0.000	0.000	0.201	0.075	0.529	0.221	-	0.473	0.105	0.595	0.226
9	0.000	0.000	0.000	0.000	0.000	0.002	0.001	0.015	-	0.415	0.274	0.556
10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.033	-	0.063	0.928
11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.165	0.536	-	0.135
12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.036	0.750	0.406	-

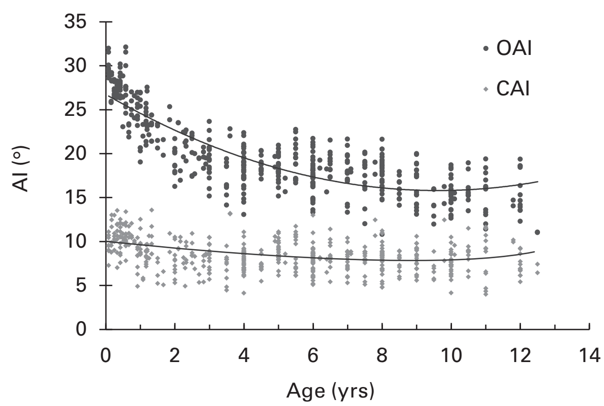

Fig. 2a

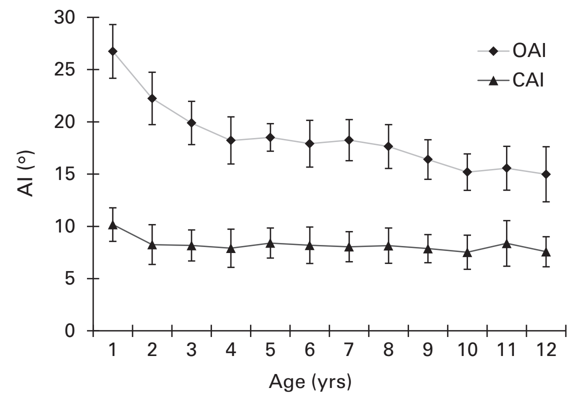

Fig. 2b

Graphs of the values for osseous (OAI) and cartilaginous acetabular index (CAI) *versus* age, in a) a scatter graph of all measurements in normal hips, with trend lines, and b) a graph showing mean values, with the error bars showing the standard error of the mean.

Table IV. The mean (SD) with 95% confidence intervals (CI) of osseous (OAI) and cartilaginous acetabular index (CAI) in children with developmental dysplasia of the hip according to Tönnis classification

		OAI (°)*		**CAI (°)†**	
Tönnis grade	**Hips (n)**	**Mean (SD)**	**95% CI**	**Mean (SD)**	**95% CI**
Grade I	17	31.48 (4.30)	29.27 to 33.69	16.62 (5.44)	13.82 to 19.41
Grade II	59	34.48 (5.38)	33.08 to 35.88	22.20 (4.85)	20.93 to 23.46
Grade III	30	35.14 (4.72)	33.38 to 36.90	22.26 (5.84)	20.08 to 24.44
Grade IV	17	32.45 (2.60)	31.12 to 33.79	16.27 (3.97)	14.23 to 18.31

* comparison of OAI by Tönnis classification: grade I *vs* II, p = 0.012; grade II *vs* III, p = 0.496; grade I *vs* IV, p = 0.511

† comparison of CAI by Tönnis classification: grade I *vs* II, p < 0.001; grade II *vs* III, p = 0.921; grade I *vs* IV, p = 0.718

measurements of CAI (mean 12.01° (SD 3.54) and mean 9.19° (SD 1.91), respectively; p < 0.001, independent Student's *t*-test), indicating that the cartilaginous component of the acetabulum in uninvolved hips seemed to be also dysplastic. Based on the level of dislocation, a notable difference was found between the Tönnis grade in the OAI and CAI (Table IV). Nevertheless, regardless of the grades, the OAI and CAI did not show a notable correlation with age (all p ≥ 0.052), respectively). When the age of the children with DDH was matched with the normal controls, both the OAI and CAI in those with DDH were significantly larger (p < 0.001, independent Student's *t*-test).

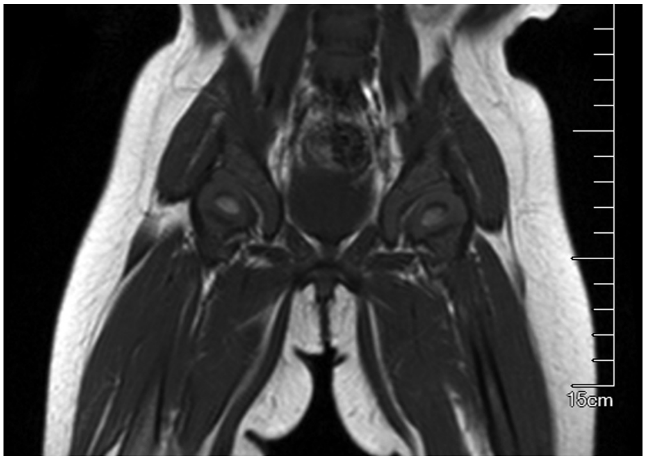

Fig. 3

Coronal T_1-weighted MR image in a 6.5-month-old girl with normal hip development. The osseous acetabular index was 27.37° on the left hip and 24.57° on the right hip. The cartilaginous acetabular index was 10.17° on the left hip and 9.81° on the right, showing the cartilaginous acetabulum has fully formed, and extended to a sufficient coverage over the femoral head.

Discussion

Although expensive, and despite the possibility of requiring additional sedatives, the advantages of MR imaging are considerable in assessing the developing hip, such as avoiding radiation, allowing imaging in several planes and providing high resolution and contrast at the interfaces between the bony and cartilaginous components. The availability and accuracy of MR scans in demonstrating the details of the immature hip have been described and confirmed by comparison with the anatomical preparations in cadavers previously.[27] However, no studies have focused on the reliability of MR imaging in measuring the OAI and CAI during development. In this study, the repeatability was good with excellent agreement between the observers through a large number of measurements.

It is well known that the postnatal development of the acetabulum is by endochondral ossification. The normal growth curves of the acetabular angle on radiographs have been reported by Tönnis.[26] We confirmed the normal ossifying process that he described. The rapidly ossified stage is completed in the first four years of the life, confirming the current view that surgical intervention should be performed if the acetabular dysplasia does not spontaneously correct by four years of age.[28,29] Between the ages of four and eight, the OAI stays at a constant level, indicating that the development of the bony acetabulum in the coronal plane concentrates on an increase in size, but not in angle. The second developmental stage of the OAI is during preadolescence (eight to ten years of age); the change was minor, with a decrease of only 2° to 3°. This development could be attributed to the appearance of the ossification centre on the lateral portion of the acetabulum, starting at about nine years of age and fusing to the ilium at approximately 15 years of age.[30,31]

The CAI has a different pattern of development and remains at a constant mean value of 8.04° (SD 1.65) throughout childhood, except for a small decrease of approximately 2° within the first two years of life, showing that the cartilaginous acetabulum has fully formed at birth when it is extended as far over the femoral head as is the bony acetabulum in the adult (Fig. 3). This finding is supported by Laurenson[32] who observed the development of the acetabular roof in fetal hips, and by Johnson et al[33] who investigated anatomy of the infant hip on MRI. Nevertheless, the postnatal pattern of growth of the cartilaginous acetabular roof has not been reported previously. This age-based cross-sectional data, with detailed mean and standard deviation from the age of one to 12 years, provides the normal standards for the development of cartilaginous acetabular structures in children. After infancy, a hip with a CAI of 12° (> 2 SDs from the mean) should be diagnosed as cartilaginous acetabular dysplasia. Meanwhile, the normal value of CAI gives us a new understanding of the cartilaginous acetabular development. In view of these findings, the term of 'acetabular dysplasia' should be reconsidered. If the acetabular dysplasia was determined radiologically, but with a normal CAI or sufficient cartilaginous acetabular cover, this should be regarded as delayed endochondral ossification. Conversely, cartilaginous acetabular dysplasia with an increased CAI could be true 'dysplasia' (Fig. 4). It is essential to identify these conditions in order to decide whether a second procedure should be performed to correct the dysplasia, particularly as isolated delay of endochondral ossification in the acetabulum following the concentric reduction in DDH can correct spontaneously.[14]

Despite the significant relationship between the values of radiologically- based AI and the need for acetabuloplasty, some hips with high values developed satisfactorily and others with low values required later pelvic osteotomy. Zamzam et al[10] recognised that the importance of radiological AI was to monitor but not predict acetabular development after closed reduction. In contrast they observed that almost all hips with a CAI of < 20° developed satisfactorily and all hips with a CAI > 24° needed acetabuloplasty. The CAI is an early and reliable predictor of acetabular development and can be used to ensure optimal timing for acetabuloplasty and avoid unnecessary surgery in those hips likely to develop satisfactorily if given enough time.

However, despite defining the normal values of the CAI, we have not determined when and to what extent cartilaginous acetabular dysplasia needs to be corrected surgically as whether it also has the potential for spontaneous improvement remains uncertain.

For the hips with developmental dysplasia, the measurements of AI on plain radiographs were significantly correlated with the OAI measured on MR scans, indicating that the AI represents the development of osseous acetabular margins, although the correlation between the two was not found in the study by Duffy et al.[22] Regarding the uninvolved hips in unilateral DDH, the CAI was significantly

Fig. 4a

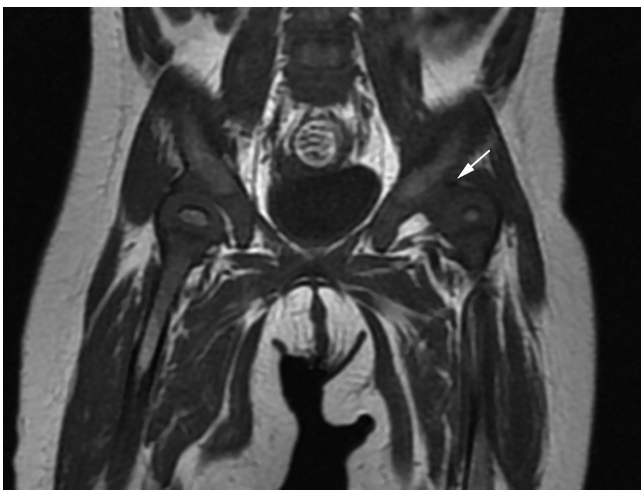

Fig. 4b

Imaging of a nine-month-old girl with bilateral developmental dysplasia of the hip, with a) an anteroposterior plain radiograph, showing the left hip with Tönnis grade II and an acetabular index of 35.19°, and the right hip with Tönnis grade I and an index of 28.23°, and b) coronal T_1-weighted MR image in the same patient. On the left hip, the osseous acetabular index (OAI) was 37.57° and the cartilaginous index (CAI) was 28.77°, indicating that both the OAI and CAI were severely dysplastic. The everted labrum was also seen (arrow). On the right hip, the OAI and CAI were 31.47° and 10.12°, respectively, revealing the cartilaginous acetabular component was near normal, but the ossification on the bony acetabulum was delayed.

increased compared with the normal when age matched, with a mean difference of approximately 3°. This suggests that the uninvolved hips in unilateral DDH are also dysplastic and are not suitable to be used as controls. When compared with the normal hips, as expected, both the OAIs and the CAIs in DDH were increased, which confirms that the delay in ossification and cartilaginous dysplasia in the acetabulum in children with DDH occurs simultaneously. The correlation between the OAI and CAI has been previously discussed. Fisher et al[13] suggested that the bony AI determined by MR imaging could accurately reflect the cartilaginous AI, and a bony AI of 30° corresponded to a cartilaginous AI of 10°. This is further supported by measurements made on seven children by Pirpiris et al.[34] In our opinion, the pathological morphology in the dysplastic acetabulum is complicated and individualised, especially for the cartilaginous components, and thus it may be cursory that the CAI should simply be represented by the OAI. In this study, the extent of acetabular dysplasia in Tönnis grade II and III hips was more severe than that in grade I and IV hips (Table IV), with a difference of 6° in CAI. This can be a result of the increased pressure on the rim of the acetabulum by the laterally positioned femoral head.[31] Although we could not find a correlation between the OAI or CAI and the age of the child in various Tönnis grades, probably because of the small sample size and young age in the subgroup, we still believe that the destructive effect from the abnormal biomechanics to the cartilaginous part of the acetabulum can be increased with an extended period of dislocation.[35] The cartilaginous anlage is a better representative of the final state of the acetabulum than the bony model.[10,22] Therefore, we propose that for children with severe bony dysplasia, the cartilaginous component of the acetabulum should be evaluated by MR imaging, especially when trying to identify the developmental potential of the acetabulum and to plan an acetabuloplasty.

In summary, according to MRI measurements, the cartilaginous part of the acetabulum has a different growth pattern from the osseous part. The CAI has fully formed at birth, nearly extending as far as the bony acetabulum in the adult, and remains constant throughout childhood. However, the OAI reduces rapidly within the first four years of the life, and then remains unchanged until eight years of age, with a difference of approximately 10° from the CAI. Before adolescence, the OAI exhibits a small decrease again, because of the appearance of the ossification centre at the lateral portion of the acetabulum. The cartilaginous acetabular component of the unaffected hips in children with unilateral DDH is also dysplastic, compared with the normal hips and these hips should not be used as a control. The OAI and CAI in DDH are significantly different in different Tönnis grades. Although the plain radiograph remains a common and simple examination for the diagnosis and follow-up of children with DDH, MRI is necessary when the cartilaginous components of the acetabulum require assessment.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

References

1. **Herring JA.** Developmental dysplasia of the hip. In: *Tachdjian's pediatric orthopaedics*. Fourth ed. Philadelphia: Saunders Elsevier, 2008:637.
2. **Albinana J, Dolan LA, Spratt KF, et al.** Acetabular dysplasia after treatment for developmental dysplasia of the hip: implications for secondary procedures. *J Bone Joint Surg [Br]* 2004;86-B:876–886.
3. **Hilgenreiner H.** Zur Frühdiagnose und Frühbehandlung der angeboren Hüftgelenksverrenkung. *Med Klin* 1925;21:1385–1388 (in German).
4. **Kleinberg S, Lieberman HS.** The acetabular index in infants in relation to congenital dislocation of the hip. *Arch Surg* 1936;32:1049–1054.

5. **Wiberg G.** Studies on dysplastic acetabular and congenital subluxation of the hip joint with special reference to the complication of osteoarthritis. *Acta Chir Scand* 1939;83(Suppl 58):1–7.

6. **van der Bom MJ, Groote ME, Vincken KL, Beek FJ, Bartels LW.** Pelvic rotation and tilt can cause misinterpretation of the acetabular index measured on radiographs. *Clin Orthop Relat Res* 2011;469:1743–1749.

7. **McCarthy JJ, Scoles PV, MacEwen D.** Developmental dysplasia of the hip (DDH). *Current Orthopaedics* 2005;19:223–230.

8. **Broughton NS, Brougham DI, Cole WG, Menelaus MB.** Reliability of radiological measurements in the assessment of the child's hip. *J Bone Joint Surg [Br]* 1989;71-B:6–8.

9. **Wakabayashi K, Wada I, Horiuchi O, et al.** MRI findings in residual hip dysplasia. *J Pediatr Orthop* 2011;31:381–387.

10. **Zamzam MM, Kremli MK, Khoshhal KI, et al.** Acetabular cartilaginous angle: a new method for predicting acetabular development in developmental dysplasia of the hip in children between 2 and 18 months of age. *J Pediatr Orthop* 2008;28:518–523.

11. **Chin MS, Shoemaker A, Reinhart DM, et al.** Use of 1.5 Tesla and 3 Tesla MRI to evaluate femoral head reduction in hip dysplasia. *J Pediatr Orthop* 2011;31:633–637.

12. **Desai AA, Martus JE, Schoenecker J, et al.** Spica MRI after closed reduction for developmental dysplasia of the hip. *Pediatr Radiol* 2011;41:525–529.

13. **Fisher R, O'Brien TS, Davis KM.** Magnetic resonance imaging in congenital dysplasia of the hip. *J Pediatr Orthop* 1991;11:617–622.

14. **Douira-Khomsi W, Smida M, Louati H, et al.** Magnetic resonance evaluation of acetabular residual dysplasia in developmental dysplasia of the hip: a preliminary study of 27 patients. *J Pediatr Orthop* 2010;30:37–43.

15. **Kim HT, Kim IB, Lee JS.** MR-based parameters as a supplement to radiographs in managing developmental hip dysplasia. *Clin Orthop Surg* 2011;3:202–210.

16. **Tréguier C, Baud C, Ferry M, et al.** Irreducible developmental dysplasia of the hip due to acetabular roof cartilage hypertrophy: diagnostic sonography in 15 hips. *Orthop Traumatol Surg Res* 2011;97:629–633.

17. **Bos CF, Bloem JL, Verbout AJ.** Magnetic resonance imaging in acetabular residual dysplasia. *Clin Orthop Relat Res* 1991;265:207–217.

18. **Greenhill BJ, Hugosson C, Jacobsson B, Ellis RD.** Magnetic resonance imaging study of acetabular morphology in developmental dysplasia of the hip. *J Pediatr Orthop* 1993;13:314–317.

19. **Nishii T, Sugano N, Sato Y, et al.** Three-dimensional distribution of acetabular cartilage thickness in patients with hip dysplasia: a fully automated computational analysis of MR imaging. *Osteoarthritis Cartilage* 2004;12:650–657.

20. **Kawaguchi AT, Otsuka NY, Delgado ED, Genant HK, Lang P.** Magnetic resonance arthrography in children with developmental hip dysplasia. *Clin Orthop Relat Res* 2000;374:235–246.

21. **Guidera KJ, Einbecker ME, Berman CG, et al.** Magnetic resonance imaging evaluation of congenital dislocation of the hips. *Clin Orthop Relat Res* 1990;261:96–101.

22. **Duffy CM, Taylor FN, Coleman L, et al.** Magnetic resonance imaging evaluation of surgical management in developmental dysplasia of the hip in childhood. *J Pediatr Orthop* 2002;22:92–100.

23. **Tönnis D.** *Congenital dysplasia and dislocation of the hip in children and adults*. Berlin: Springer-Verlag, 1987.

24. **Ishida K.** Prevention of the development of the typical dislocation of the hip. *Clin Orthop Relat Res* 1977;126:167–169.

25. **Graf R.** Classification of hip joint dysplasia by means of sonography. *Arch Orthop Trauma Surg* 1984;102:248–255.

26. **Tönnis D.** Normal values of the hip joint for the evaluation of X-rays in children and adults. *Clin Orthop Relat Res* 1976;119:39–47.

27. **Krasny R, Prescher A, Botschek A, et al.** MR-anatomy of infants hip: comparison to anatomical preparations. *Pediatr Radiol* 1991;21:211–215.

28. **Kasser JR, Bowen JR, MacEwen GD.** Varus derotation osteotomy in the treatment of persistent dysplasia in congenital dislocation of the hip. *J Bone Joint Surg [Am]* 1985;67-A:195–202.

29. **Barrett WP, Staheli LT, Chew DE.** The effectiveness of the Salter innominate osteotomy in the treatment of congenital dislocation of the hip. *J Bone Joint Surg [Am]* 1986;68-A:79–87.

30. **Ponseti IV.** Growth and development of the acetabulum in the normal child: anatomical, histological, and roentgenographic studies. *J Bone Joint Surg [Am]* 1978;60-A:575–585.

31. **Ponseti IV.** Morphology of the acetabulum in congenital dislocation of the hip. Gross, histological and roentgenographic studies. *J Bone Joint Surg [Am]* 1978;60-A:586–599.

32. **Laurenson RD.** Development of the acetabular roof in the fetal hip: an arthrographic and histological study. *J Bone Joint Surg [Am]* 1965;47-A:975–983.

33. **Johnson ND, Wood BP, Noh KS, et al.** MR imaging anatomy of the infant hip. *Am J Roentgenol* 1989;153:127–133.

34. **Pirpiris M, Payman KR, Otsuka NY.** The assessment of acetabular index: is there still a place for plain radiography? *J Pediatr Orthop* 2006;26:310–315.

35. **Bowman KF, Fox J, Sekiya JK.** A clinically relevant review of hip biomechanics. *Arthroscopy* 2010;26:1118–1129.