

# Acetabular depth, an early predictive factor of acetabular development: MRI in patients with developmental dysplasia of the hip after open reduction

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Early prediction of future acetabular development is important to determine an additional surgery for developmental dysplasia of the hip (DDH). The purpose of this study was to investigate the predictive factors of acetabular development using MRI. We retrospectively investigated dislocated 40 hips and 34 normal hips in 37 pediatric patients (9 males and 28 females) with DDH who underwent open reduction after walking age. We evaluated the cartilaginous acetabulum and labrum of the patients using coronal MRI T2\*-weighted images at 5 years of age. The mean age at the time of surgery was 22 months, and the mean age at the final survey was 19 years. We divided patients into two groups in accordance with the Severin classification at the final follow-up. Groups with good outcomes (affected 26 hips and unaffected 27 hips) and poor outcomes (14 hips and 7 hips) were compared using the MRI parameters on each side. Predictive factors of acetabular development were identified using univariate and multiple logistic regression analyses. Using multiple logistic regression analysis, labral acetabular roof depth and labral hip center distance at 5

years of age represented predictors after open reduction (odds ratio 0.27,  $P = 0.035$ ; odds ratio 3.4,  $P = 0.028$ , respectively) on the affected side, and bony hip center distance represented a predictor on the unaffected side (odds ratio 2.6,  $P = 0.049$ ). Acetabular development in the unaffected side could be predicted by bony assessment, while acetabular development in the affected side had to be assessed by labrum using MRI. *J Pediatr Orthop B* 30: 509–514 Copyright © 2020 The Author(s). Published by Wolters Kluwer Health, Inc.

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## Introduction

Unidentified and untreated developmental dysplasia of the hip (DDH) can lead to serious consequences, such as premature osteoarthritis [1–3]. Therefore, screening during early infancy is essential. Most DDH cases before walking age can be managed using closed methods, with stable concentric reduction of the hip. On the contrary, an open reduction becomes necessary in some patients with DDH after walking age [4].

There are many radiologic parameters, such as the acetabular index (AI) [5–8], the center–edge (CE) angle [2], the center–head distance discrepancy [9] and the amount of femoral head coverage [10]. However, predicting acetabular development accurately using these parameters is difficult. To overcome these shortcomings of this modality,

it seems reasonable to evaluate soft tissue and/or cartilaginous structures for clues to other avenues of treatment [11].

The acetabular labrum increases the depth of the acetabulum and enhances joint stability [12]. We consider that correction of labral inversion or interposition is essential for good postoperative concentric reduction and future acetabular development [13,14]. In DDH treatment, it has been reported that it is useful to evaluate the cartilage acetabulum and labrum by MRI and arthrography during childhood to predict future hip morphology [15–20]. The current study evaluated the cartilaginous acetabulum and the labrum with a new parameter that measures the cartilaginous and labral landmarks on postoperative MRI images in patients at 5 years of age to identify predictors of subsequent acetabular development.

## Materials and methods

This study included 40 dislocated hips and 34 unaffected hips in 37 pediatric patients who were diagnosed with DDH and treated by open reduction after walking age at

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our institution between 1996 and 2001. Cases involving teratologic and paralytic dislocations were excluded. We had five patients who underwent osteotomy with open reduction during this time period. Four cases were combined with Salter innominate osteotomy and one case with femoral derotational osteotomy. We excluded these five cases from this study. All patients were followed up radiologically to skeletal maturity. Three patients had bilateral DDH. There were 10 dislocated hips and eight unaffected hips in nine boys and 30 dislocated hips and 26 unaffected hips in 28 girls, with a mean age of 22 months (range, 12–68 months) at the time of surgery. The mean age at the latest follow-up was 19 years (range, 17–27 years; follow-up rate, 100%). Before surgery, a Pavlik harness in 14 hips, overhead traction in five hips and cast in four hips were applied. All study protocols were approved by the ethics board at our hospital.

Patients were divided into two groups according to Severin classification [21]: good group, Severin group I and II; and poor group, Severin group III and IV. All children underwent postoperative MRI at 5 years of age, excluding one patient who received open reduction after 5 years of age. This patient was evaluated by MRI at 6 years of age. Sedation was administered for the MRI scan using Tricloryl Syrup 10% (20–80 mg/kg, Alfresa Pharma Corporation, Osaka, Japan) or Escre Suppositories (30–50 mg/kg, Hisamitsu Pharmaceutical Co., Inc., Tokyo, Japan). MRI was performed in the supine position with the hip extended and legs in a neutral position. A pelvic phased-array coil was placed anterior and posterior to the pelvis. MRI examinations were performed on a 1.5-Tesla Magnetom H15

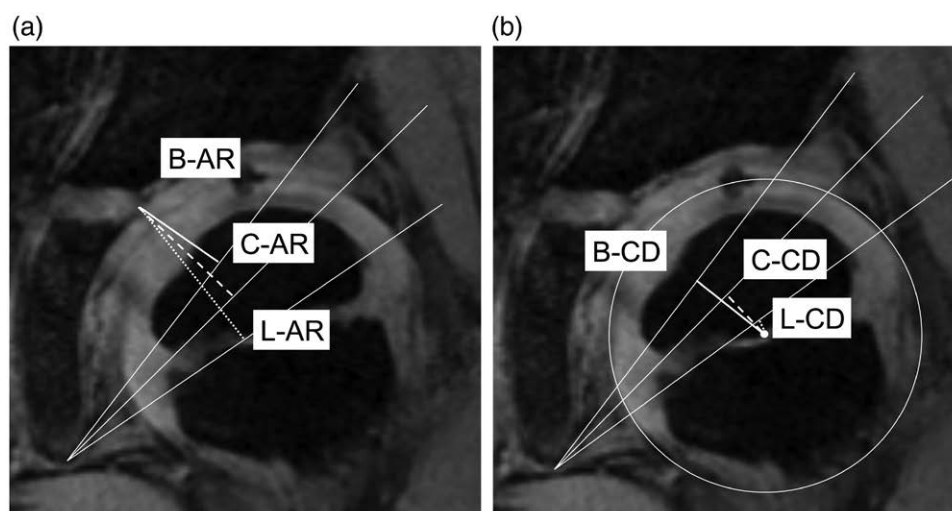
(Siemens, Erlangen, Germany) for the standard examination including the whole pelvis and proximal femur. MR images without contrast material were acquired; T2-star weighted (TR 360 ms, TE 12 ms) images in the coronal and axial planes were obtained. All sequences used a  $22 \times 22 \text{ cm}^2$  field of view, 3 mm slice thickness, and two for the number of excitations.

Each parameter was defined in the coronal plane. The bony acetabular roof depth (B-AR) was defined by the distance from the Y cartilage at the bottom of the acetabulum to the line drawn between the bony acetabular edge and the tear drop, and that distance was divided by the distance between the bilateral tear drops (Fig. 1a). The cartilaginous (C-AR) and labral acetabular roof depth (L-AR) were defined in a manner similar to that used for B-AR. The bony hip center distance (B-CD) was defined by the distance between the line drawn from the bony acetabular edge to the tear drop and hip center divided the distance between the bilateral tear drops (Fig. 1b). In addition, the cartilaginous (C-CD) and labral hip center distance (L-CD) were defined in a manner similar to that used for B-CD.

#### Surgical procedure

A transverse incision was made from the medial border of the sartorius muscle to the greater trochanter 3 cm distal to the anterior superior iliac spine. The fibrous adhesion was dissected thoroughly to expose the joint capsule. The joint capsule was incised circumferentially. The hypertrophied ligamentum capitis femoris and fibro-fatty tissues in the acetabulum were removed. Inversion of the labrum was corrected manually using Tupper gauze, to

Fig. 1



Bony, cartilaginous and labral acetabular roof depth (B-AR, C-AR, L-AR) are defined by the perpendicular line from the line between the tear drop and each edge to the bottom of acetabulum (a). Bony, cartilaginous and labral hip center distance (B-CD, C-CD, L-CD) are defined by the perpendicular line from the line between the tear drop and each edge to the hip center (b).

gain successful concentric reduction. A hip spica cast was applied to hold the hip joint in slight flexion, abduction and internal rotation. The cast was removed 8 weeks after surgery.

**Statistical analysis**

Factors predicting acetabular development were identified using univariate (Mann–Whitney U test) and multivariate analyses (multiple logistic regressions). Potential predictive variables showing values of  $P < 0.05$  on univariate analysis were included in the multivariate model. Odds ratios (ORs) and 95% confidence intervals (CIs) from multiple logistic regression models were used to identify predictors of Severin classification at the final survey. All differences were considered statistically significant for values of  $P < 0.05$ . Optimal cut-off values were also determined from receiver operating characteristic (ROC) curves for the identified factors. Area under the curve (AUC) was calculated with 95% CI for each ROC curve, with higher AUC considered as representing greater diagnostic accuracy. Statistical analysis was performed using PASW Statistics version 22 software (SPSS, Tokyo, Japan).

**Results**

Severin classification of the dislocated hips at final examination was group I in 16 hips, group II in 10 hips representing 26 hips in the good group (65%) and group III in 14 hips in the poor group (35%). Severin classification of the unaffected hips was group I in 27 hips in the good group (79.4%) and seven hips in the poor group (20.6%). Univariate analyses showed no significant differences in age at the surgery ( $P = 0.94$ ), sex ( $P = 0.59$ ) and affected side ( $P = 0.49$ ) between the good and poor groups in the dislocated hips. There were no significant differences with respect to age at surgery ( $P = 0.35$ ), sex ( $P = 0.52$ ) and affected side ( $P = 0.08$ ) in the unaffected hips (Table 1). On the dislocated side, a Pavlik harness was applied in nine

cases with good outcomes (64.3%) and in five cases with poor outcomes (35.7%). Overhead traction was applied in four cases with good outcomes (80.0%) and in one case with poor outcomes (20.0%). Cast was applied in four cases with good outcomes (100%). No significant differences were observed between each prior treatment on the dislocated side ( $P = 0.88$ ). On the unaffected side, a Pavlik harness was applied in seven cases with good outcomes (58.3%) and in five cases with poor outcomes (41.7%). Overhead traction was applied in five cases with good outcomes (100%). Cast was applied in three cases with good outcomes (75.0%) and in one case with poor outcomes (25.0%). No significant differences were observed between each prior treatment on the unaffected side ( $P = 0.12$ ).

The results of MRI analyses are shown in Tables 2 and 3. In dislocated hips, all the AR parameters of the poor group were significantly smaller than those in the good group, and all the CD parameters in the poor group were significantly larger than those in the good group ( $P < 0.05$ ). In the unaffected hips, the B-CD in the poor group was significantly larger than that in the good group ( $P = 0.032$ ).

Multiple logistic regression analysis for Severin classification at final assessment suggested L-AR and L-CD at 5 years of age as predictors of poor results after open reduction for DDH, and the ORs for good results compared to that for poor results were 0.27 (95% CI: 0.077–0.910;  $P = 0.035$ ) and 3.4 (95% CI: 1.146–10.38;  $P = 0.028$ , Table 4). In the unaffected hips, the B-CD was a predictor of poor results, and the OR for good results compared to that for poor results was 2.6 (95% CI: 1.004–6.683;  $P = 0.049$ , Table 5). The ROC curve for L-AR and L-CD of the dislocated side at 5 years of age showed an optimal cut-off of 23.1 (83.3% sensitivity, 62.5% specificity)

**Table 1 Background of patients with dislocated and unaffected sides**

Dislocated side	Good (n = 26)	Poor (n = 14)	P value
Age (months)	22.2 (12–42)	21.9 (15–68)	0.94
Sex (male:female)	6:20	2:12	0.59
Affected side (Lt:Rt)	20:6	11:3	0.49
Prior treatment			
Pavlik harness	9	5	0.88
Over head traction	4	1	
Cast	4	0	
None	9	8	
Unaffected side	Good (n = 27)	Poor (n = 7)	P value
Age (months)	21.2 (12–68)	20.1 (16–24)	0.35
Sex (male:female)	7:20	1:6	0.52
Affected side (Lt:Rt)	19:8	7:0	0.08
Prior treatment			
Pavlik harness	7	5	0.12
Over head traction	5	0	
Cast	3	1	
None	12	1	

All values are representative of the mean (range) value. Lt, left; Rt, right.

**Table 2 MRI parameters of dislocated sides**

	Good (n = 26)	Poor (n = 14)	P value
B-AR (%)	12.8	10.4	0.038*
C-AR (%)	18.4	15.5	0.003**
L-AR (%)	22.5	19.0	<0.001**
B-CD (%)	16.2	20.7	0.041*
C-CD (%)	10.4	14.4	0.012**
L-CD (%)	5.7	9.8	<0.001**

All values are representative of the mean value; \* $P < 0.05$ , \*\* $P < 0.05$ . AR, acetabular roof depth; B, bony; C, cartilaginous; CD, hip center distance; L, labral.

**Table 3 MRI parameters of unaffected sides**

	Good (n = 27)	Poor (n = 7)	P value
B-AR (%)	15.0	14.7	0.487
C-AR (%)	19.4	19.2	0.889
L-AR (%)	23.1	22.9	0.802
B-CD (%)	13.3	16.0	0.032*
C-CD (%)	8.7	11.1	0.055
L-CD (%)	4.0	4.4	0.802

All values are representative of the mean value; \* $P < 0.05$ . AR, acetabular roof depth; B, bony; C, cartilaginous; CD hip center distance; L, labral.

**Table 4 Multiple logistic regression analysis for Severin classification of dislocated sides**

Variables	Partial regression coefficient	Standard error	OR	95% CI		P value
				Lower	Upper	
L-AR	-1.330	0.630	0.27	0.077	0.910	0.035**
L-CD	1.238	0.562	3.4	1.146	10.38	0.028*
constant term	16.33	10.71	12.1	0.001	161.6	0.127

All values are representative of the mean value; \* $P < 0.05$ , \*\* $P < 0.01$ .

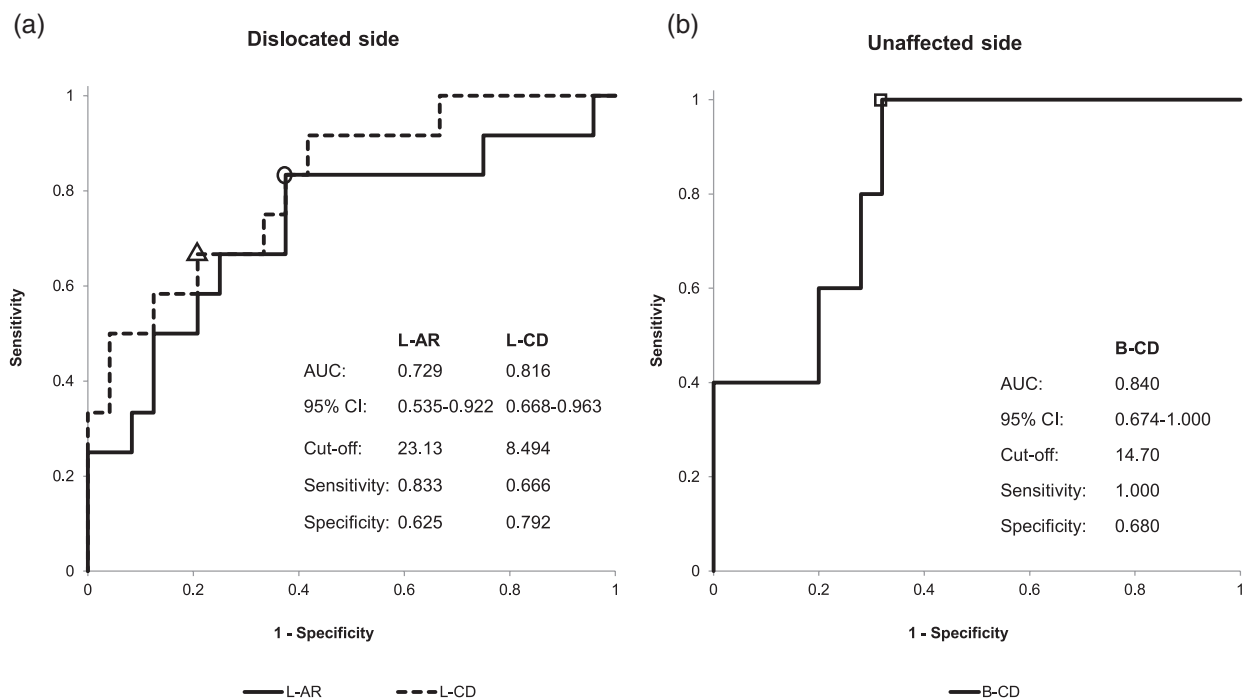
CI, confidence interval; L-AR, labral acetabular roof depth; L-CD, labral hip center distance; OR, odds ratio.

**Table 5 Multiple logistic regression analysis for Severin classification of unaffected sides**

Variables	Partial regression coefficient	Standard error	OR	95% CI		P value
				Lower	Upper	
B-CD	0.952	0.484	2.6	1.004	6.683	0.049*
Constant term	-15.72	7.499	0.0	0.000	0.362	0.036*

\* $P < 0.05$ .

CI, confidence interval; B-CD, bony hip center distance; OR, odds ratio.

**Fig. 2**

Receiver operating characteristic curve for acetabular development at 5-years-old on dislocated (a) and unaffected sides (b). AUC, area under the curve; CI, confidence interval; L-AR, labral acetabular roof depth; L-CD, labral hip center distance; B-CD, bony hip center distance.

and 8.5 (66.7% sensitivity, 79.2% specificity), respectively (Fig. 2a). The ROC curve for B-CD of the unaffected side at 5 years of age showed an optimal cut-off of 14.7 (100% sensitivity, 68.0% specificity, Fig. 2b).

## Discussion

The present study investigated the predictors of acetabular development in pediatric patients who underwent open reduction for DDH after reaching the walking age using MRI. On the contrary, the acetabular depth,

including the labrum, was a better predictor than the bony or cartilaginous acetabular depth in the dislocated hips. The future acetabular development of the unaffected hips can be predicted with the bony acetabular depth.

Duffy *et al.* reported MRI evaluation of surgical management in patients with DDH [22]. Persistent difference could be observed in the coronal plane AI between the dysplastic and normal sides for the cartilaginous angle and the bony model of the acetabulum. Radiographic evaluation using sharp angle, AI and CE angles is common in

patients with DDH. Albinana *et al.* investigated 48 hips with nonopen reduction and 24 hips with open reduction (72 hips in total) and noted that an AI  $> 35^\circ$  at 2 years after reduction was predictive of poor outcomes, with an indication of corrective surgery in these patients [1]. Li *et al.* also reported that AI was one of the best predictors of final radiographic outcomes in DDH treated by closed reduction [23]. However, Kim *et al.* reported that these radiographic parameters alone have at least a 20% error in prognosis prediction [16]. Vahedi *et al.* showed the usefulness of radiographic acetabular depth and that acetabular coverage was low in low-volume acetabula [24]. In recent years, cartilaginous acetabulum and labrum have been advocated their importance on the prognosis of acetabular development, and the usefulness of MRI has been reported [12,18,25]. Shirai *et al.* evaluated the labral eversion with a new method that measured the MRI beta angle using landmarks of the Graf method as a reference [19]. The MRI beta angle was significantly greater in the poor-outcome group than in the normal- and good-outcome groups [19]. Arthrography is also a useful procedure to evaluate cartilage or labral condition. Zamzam *et al.* reported that the acetabular cartilaginous angle was a reliable arthrographic measurement to identify hips with DDH that would later need acetabuloplasty after undergoing successful closed reduction [20]. Despite the benefits of arthrography, we chose MRI because arthrography could not clearly distinguish between cartilage and labrum, and it is associated with a risk of radiation exposure and infection due to joint puncture. We considered that the depth of acetabulum and distance between the acetabulum and femoral head could represent the congruity of the hip joint more directly than angular parameters. In this study, there were significant differences between the two groups for all parameters accessing acetabular depth on the affected side. These parameters have been shown to be useful in assessing concentric reduction.

MRI was performed at 5 years of age because the depth of the acetabulum can change until the age of 4–5 years, and thereafter it mostly remains constant [26]. In addition, we considered that 5 years of age was the time limit for the corrective surgery after open reduction. In this study, only one patient had an open reduction after the age of 5 because no abnormalities were pointed out in the medical examination during early childhood, and he was asymptomatic for up to 60 months and was overlooked. This particular patient was evaluated at 6 years of age.

The limbus and the neolimbus are both pathological lesions that form in response to a developmentally dislocated hip [27]. We consider that it is necessary to correct the varus of the labrum to improve the treatment outcome. Mitani *et al.* performed two-directional arthrography before and after reduction to evaluate the anterior, superior and posterior portions of the labrum and reported a significant correlation between joint stability and the shape of the labrum, and an inverted limbus prevented good

concentric reduction [18,28,29]. The acetabular labrum in children significantly increases the coverage of the femoral epiphysis as well as the stability of the acetabulum [30]. However, predicting acetabular development using radiography alone has limitations. Miyake *et al.* reported that a cartilaginous AI  $\geq 10^\circ$  on hip arthrograms at 5 years of age might offer a useful indicator of the need for corrective surgery following open reduction after walking age [31]. In this study, the parameters related to the labrum were significant as prognostic predictors on the affected side. It has been reported that the labrum plays a more important role than bone or cartilage in the pathogenesis of DDH, and the significance of reducing inverted limbus by surgery has been demonstrated. On the contrary, the future acetabulum formation on the unaffected side could be predicted with only bony index. This was because the unaffected side had less individual differences in the cartilaginous acetabulum or labral morphology than the affected side.

The current study has some limitations. First, we performed MRI at 5 years of age to determine the necessity for corrective surgery in patients with DDH. However, waiting until 5 years of age for this test is not desirable. We consider that MRI evaluation at younger age is preferable with the limited time for corrective surgery in mind. Second, MRI performed in early infancy and childhood needs sedation. Ultrasonography might provide a less invasive alternative without sedation to obtain the same results of the radiographic permeable structure derived from MRI. The static technique (Graf) [32] and dynamic technique (Harcke) [33] enable accurate and reliable determination of the anatomic structures and relationships of the hip joint. Although ultrasonography can also reveal the inside composition of an immature hip joint at 5 years of age, the ossification of the epiphyseal nucleus of the femoral head was so large that a complete observation of the bottom of the acetabulum was probably not possible. Third, we analyzed unaffected hip in patients with unilateral DDH as the normal control. However, it is unknown whether this group accurately reflects the normal group, because this group contains a certain number of primary acetabular dysplasia [34]. Finally, five out of seven patients with poor results on the unaffected side were treated with a Puvlik harness and might be affected by the avascular necrosis of the femoral head.

Despite these limitations, we have obtained the predictive factor related to poor results of open reduction for DDH after walking age. Our findings indicated that L-AR and L-CD on MRI at 5 years of age represents an early predictor of acetabular development after open reduction. MRI is a useful tool to evaluate the necessity for corrective surgery.

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## Conflicts of interest

There are no conflicts of interest.

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