ORIGINAL ARTICLE

Correlation of postoperative magnetic resonance image measurements with persisting acetabular dysplasia in open reduction of developmental hip dysplasia

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Developmental dysplasia of the hip (DDH) is a common disorder that requires early treatment by orthosis or open or closed reduction.[1-4] If left untreated, it causes an abnormal gait pattern, lifelong disability, and hip osteoarthritis in early adulthood.[5-8] The disease spectrum ranges from acetabular dysplasia or subluxation to dislocation.[9] After hip reduction, acetabular dysplasia may persist, and these patients would need further surgery. Ultrasonography (USG) is the gold standard for the evaluation of the concentric reduction of the hip within the first six months,[10] as it is difficult to evaluate the reduction by X-ray as the femoral head is not yet ossified.[9]

ABSTRACT

Objectives: The aim of this study was to evaluate correlation of post-reduction magnetic resonance imaging (MRI)-based parameters with residual acetabular dysplasia in developmental dysplasia of the hip (DDH) patients who underwent open reduction.

Patients and methods: A total of 62 hips of 54 children (5 males, 57 females; mean age: 8.5±3.5 months; range, 0 to 24 months) with a diagnosis of DDH who underwent open reduction between January 2012 and January 2017 were retrospectively analyzed. The acetabular head index (AHI), head coverage index (HCI), sphericity, bony acetabular index (BAI), cartilage acetabular index (CAI), anterior acetabular index (AAI), posterior acetabular index (PAI), abduction angle (AA), and acetabular medial wall thickness were measured by MRI. The correlation between MRI measurements and residual acetabular dysplasia was evaluated.

Results: The mean follow-up was 23.7±10.1 (range, 12 to 56) months. The mean age at the final examination was 47.6±10.4 months. The age at the time of operation (r=0.250, p=0.049), medial wall thickness (r=0.304, p=0.016), AAI (r=0.729, p<0.001), PAI (r=0.590, p<0.001), and early postoperative AI (r=0.900, p<0.001) at the third postoperative month were positively correlated with the last follow-up AI. The AHI (r=-0.512, p<0.001), sphericity (r=-0,661, p<0.001), and HCI (r=-0.554, p< 0.001) were negatively correlated with the last follow-up AI.

Conclusion: Post-reduction MRI parameters can be used to evaluate correlation with persistent acetabular dysplasia in DDH patients.

Keywords: Acetabular dysplasia, hip dysplasia, magnetic resonance imaging, open reduction.

Assessment of a hip reduction after a surgical intervention is technically difficult.[11] Either USG or X-ray cannot be used after closed or open reduction due to spica casting. The concentric reduction of the hip can be evaluated easily and reliably by computed

tomography (CT) after open reduction; however, it has the disadvantage of radiation exposure.[12] Recently, magnetic resonance imaging (MRI) has been used to assess hip reduction to avoid radiation exposure.[13] Chin et al.[12] concluded that MRI was an effective alternative to CT imaging with excellent sensitivity and specificity. Other previous reports described MRI measurements as useful for the evaluation of postoperative hip reduction.[14,15]

In the present study, we hypothesized that medial wall thickness had an association with residual acetabular dysplasia. We, therefore, aimed to evaluate the correlation between post-reduction MRI-based parameters and persisting acetabular dysplasia in DDH patients who underwent open reduction.

PATIENTS AND METHODS

This single-center, retrospective study was conducted at Baltalimani Bone Diseases Training and Research Hospital, Department of Orthopedics and Traumatology, between January 2012 and January 2017. The medical records of the patients who were diagnosed with DDH using the International Classification of Diseases, 10th Revision codes were reviewed. Inclusion criteria were undergoing open reduction for DDH and casting at the age of 3 to 12 months. Exclusion criteria were as follows: a follow-up period of less than one year (n=2), absence of MRI evaluation on the first postoperative day (n=12), low-quality MRI scans on which measurements could not be performed (n=28), having neurological disorder or teratologic hips (n=14), and age less than two years (n=9). Of a total of 119 hips, 62 in 54 children (5 males, 57 females; mean age: 8.5±3.5 months; range, 0 to 24 months) that fulfilled the inclusion criteria were included in the study. A written informed consent was obtained from the parents and/or legal guardians of the patients before surgery. The study protocol was approved by the Health Science University, Baltalimani Bone Diseases Training and Research Hospital Review Board (09.11.2017/17). The study was conducted in accordance with the principles of the Declaration of Helsinki.

The operations were performed by four different surgeons in a single center. The medial open approach was used in all patients. The MRI scans were obtained using a 1.5 T Signa Scanner (General Electric Healthcare, WI, USA). T2-weighted turbo spin-echo hip images were used for evaluation. The MRI scans had a 3-mm slice thickness. All measurements were made using annotation tools on a light picture archiving and communications

system workstation (Koninklijke Philips Electronics, Eindhoven, The Netherlands). The measurements were performed by a pediatric orthopedic surgeon with five years of experience who was blinded to the study design.

On the first postoperative day, the acetabular head index (AHI), head coverage index (HCI), and sphericity were measured, as previously described.[14,16] The bony acetabular index (BAI) and cartilage acetabular index (CAI) were measured, as described by Huber et al.[17] The anterior acetabular index (AAI), posterior acetabular index (PAI), and abduction angle (AA) were measured on axial images.[13] The reliability of the indices measured on infant hip MRI scans was previously evaluated.[14,16-18]

For the measurement of the acetabular medial wall thickness (AMWT), the section in which the femoral head is widest in the axial plane, on the T2 pelvis MRI image, was used. The distance between the deepest point where the femoral head touches the acetabulum and the medial wall of the acetabulum was measured (Figure 1). Two separate observers who were blinded the study measured the AMWT twice.

Tönnis[19] first described the limits of the acetabular index (AI) as normal, mildly dysplastic, or severely dysplastic. The AI was measured on the day of operation, after the spica removal at the third month after surgery (early postoperative AI), and at the last follow-up on X-ray images. According to the last follow-up AI, the hips were divided into three
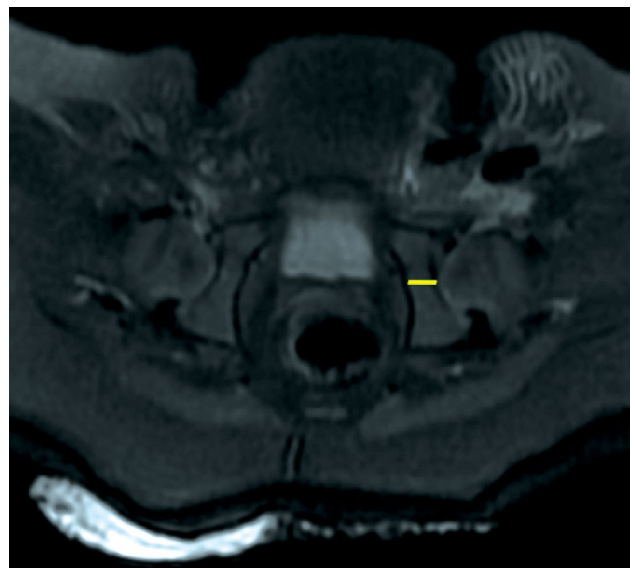
FIGURE 1. Measurement of acetabular medial wall thickness on magnetic resonance imaging.

groups, as described.[19] The correlation between the last follow-up AI and MRI parameters measured on the day after the operation was evaluated.

Surgical technique

The Ludloff approach was used in medial open reduction.[1] After a 4-cm incision was made from the groin, adductor longus tenotomy was performed. It was deepened between the adductor brevis and pectineus muscles. Iliopsoas tenotomy was performed. Following capsule incision, ligamentum teres and pulvinar excision were performed. The transverse acetabular ligament was cut to achieve concentric reduction. After checking the hip stability, the skin was closed without suturing the capsule. After the procedure, a well-molded cast was applied at 90 to 100° of hip flexion.

Statistical analysis

Statistical analysis was performed using the IBM SPSS version 22.0 software (IBM Corp., Armonk, NY, USA). Descriptive data were expressed in mean ± standard deviation (SD), median (min-max) or number and frequency. The Kolmogorov–Smirnov test was used to measure the distribution of the variables. In the analysis of independent quantitative data, the Kruskal-Wallis and Mann-Whitney U tests were used. The Wilcoxon test was used to analyze dependent quantitative data. In the analysis of independent qualitative data, the chi-square test and Fisher exact test were used, when the chi-square test conditions were not met. The Spearman correlation analysis was used to examine the relation of MRI measurements with residual acetabular dysplasia. A p value of <0.05 was considered statistically significant.

RESULTS

At the final follow-up, 23 hips (37%) had a normal AI, 19 (30.6%) had mild dysplasia, and the remaining 20 hips (32.4%) had severe dysplasia. The mean operation age was 8.5±3.5 (range, 3 to 16) months, and the mean follow-up was 23.7±10.1 (range, 12 to 56)

| **TABLE I** | | | | | |
| Demographic characteristics of the patients and MRI parameters | | | | | |
Patient demographics	n	%	Mean±SD	Median	Min-Max
Operation age (month)			8.5±3.5	8.0	3.0-16.0
Follow-up time (month)			23.7±10.1	23.5	12.0-56.0
Sex					
Female	57	91.9			
Male	5	8.1			
Side					
Right	21	33.9			
Left	41	66.1			
Cast exchange					
+	13	21.0			
-	49	79.0			
Previous treatment (Pavlik or other braces)					
+	23	37.1			
-	39	62.9			
Acetabular head index			70.5±1.4	70.8	68.0-73.3
Head coverage index			14.3±0.6	14.3	13.1-15.7
Sphericity			0.8±0.1	0.8	0.6-0.9
Bony acetabular index			37.5±3.9	36.5	30.1-44.8
Cartilage acetabular index			20.3±1.2	20.1	18.0-23.0
Anterior acetabular index			60.3±1.9	60.0	57.0-64.0
Posterior acetabular index			64.7±1.4	65.0	62.0-67.0
Hip abduction angle			58.3±4.8	58.5	43.0-67.0
Acetabular medial wall thickness (mm)			7.5±0.9	7.3	5.9-11.1
Acetabular index			37.7±4.3	37.0	29.0-45.0
Early postoperative acetabular index			29.9±3.2	29.0	18.0-39.0
Last follow-up acetabular index			25.4±3.7	25.0	16.0-34.0
MRI: Magnetic resonance imaging; SD: Standard deviation.					

TABLE II

Comparison of variables in normal AI, mild dysplasia, and severe dysplasia groups

Patient demographics	Normal				Mild dysplasia				Severe dysplasia				p
	n	%	Mean±SD	Median	n	%	Mean±SD	Median	n	%	Mean±SD	Median	
Operation age (months)			7.1±3.1‡	6.0			8.4±3.3	8.0			10.1±3.5	10.5	0.022†
Follow-up time (months)			20.6±9.1	15.0			24.5±11.3	20.0			26.6±9.6	26.5	0.143†
Sex													0.810†
Female	21	91.3			17	89.5			19	95.0			
Male	2	8.7			2	10.5			1	5.0			
Side													0.285†
Right	8	34.8			4	21.1			9	45.0			
Left	15	65.2			15	78.9			11	55.0			
Cast exchange													0.019χ²
-	14	60.9‡			16	84.2			19	95.0			
+	9	39.1			3	15.8			1	5.0			
Previous treatment (Pavlik or other braces)													0.659χ²
-	13	56.5			12	63.2			14	70.0			
+	10	43.5			7	36.8			6	30.0			
Acetabular head index			71.3±0.9*‡	71.4			70.7±1.1‡	70.5			69.4±1.4	68.9	0.000†
Head coverage index			14.7±0.5*‡	14.8			14.2±0.6	14.1			14.0±0.6	14.0	0.001†
Sphericity			0.8±0.1*‡	0.79			0.8±0.1‡	0.75			0.72±0.04	0.71	0.000†
Bony acetabular index			37.3±3.3	37.2			37.2±4.4	36.6			37.9±4.2	36.2	0.880†
Cartilage acetabular index			19.9±0.8‡	19.9			20.0±1.2‡	20.0			21.1±1.2	21.3	0.003†
Anterior acetabular index			59.3±1.6‡	59.0			60.0±1.7‡	60.0			61.9±1.5	61.5	0.000†
Posterior acetabular index			63.7±1.3*‡	64.0			64.8±0.9‡	65.0			65.6±1.3	66.0	0.000†
Hip abduction angle			57.0±6.0	57.0			60.3±3.5	60.0			58.0±3.6	58.5	0.105†
Acetabular medial wall thickness (mm)			7.0±0.7*‡	6.9			7.7±1.0	7.5			7.7±0.7	8.0	0.002†

AI: Acetabular index; SD: Standard deviation; † Kruskal-Wallis (Mann-Whitney U test); * Differences with mild group (p<0.05); ‡ Differences with severe group (p<0.05).
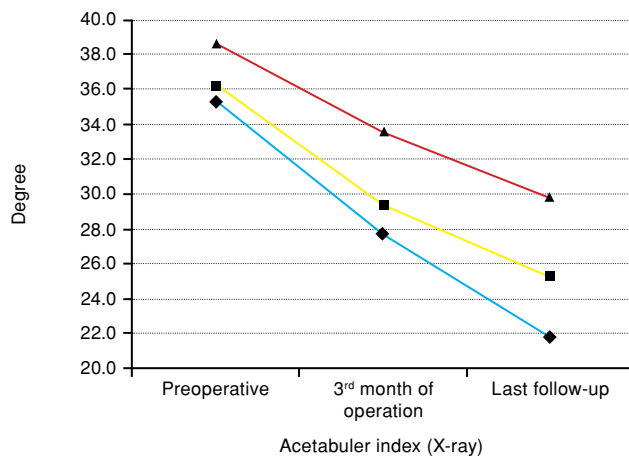
FIGURE 2. Acetabular index change from the beginning to last follow-up in the normal (blue), mild (yellow), and severe (red) dysplasia groups.

months. A cast exchange was needed in 13 of the 62 hips (21%). Demographic characteristics of the patients and MRI-based parameters are summarized in Table I.

The AHI and sphericity scores were significantly lower in the severe dysplasia group than in the mild and normal groups (p<000.1). The sphericity score was significantly lower in the mild dysplasia group than in the normal group (p<000.1). The CAI was significantly higher in the severe dysplasia group than in the mild and normal groups (p=0.003). The

AAI and PAI were significantly higher in the severe dysplasia group than in the mild and normal groups (p<0.001). The HCI was significantly lower in the mild and severe dysplasia groups than in the normal group (p=0.001). The AMWT was significantly higher in the mild and severe dysplasia groups than in the normal group (p=0.002). The results are summarized in Table II. At the time of operation, the AI was not significantly different among the three groups (p=0.88).

The last follow-up AI and third-month AI were significantly higher in the severe dysplasia group than in the mild dysplasia and normal groups (p<0.001). The last follow-up AI and third-month AI were significantly higher in the mild dysplasia group than in the normal group (p<0.001). Figure 2 shows the change of AI from the operation day to the last follow-up in the three groups.

The correlation between the MRI parameters of the patients and last follow-up AI is summarized in Table III. Accordingly, the operation age (r=0.250, p=0.049), AMWT (r=0.304, p=0.016), AAI (r=0.729, p<0.001), PAI (r=0.590, p<0.001), and early postoperative AI (r=0.9, p<0.001) at the third month after the operation were positively correlated with the last follow-up AI. The AHI (r=-0.512, p<0.001), sphericity (r=-0.661, p<0.001), and HCI (r=-0.554, p<0.001) were negatively correlated with the last follow-up AI. The mean AMWT was 7.5±0.9 mm. The AMWT showed excellent intra- and inter-observer

TABLE III					
Correlation between the last follow-up AI and post-reduction MRI-based measurements					
	Operation age (month)	Follow-up time (month)	Acetabular head index	Sphericity	Acetabular indeks
Last follow-up acetabular index					
r	0.250	-0.248	-0.512	-0.661	-0.030
p	**0.049**	0.052	**0.000**	**0.000**	0.819
	Bony acetabular index	Cartilage acetabular index	Acetabular medial wall thickness (mm)	Head coverage index	Hip abduction angle
Last follow-up acetabular index					
r	-0.032	0.462	0.304	-0.554	0.064
p	0.808	**0.000**	**0.016**	**0.000**	0.621
	Anterior acetabular index	Posterior acetabular index	Early postoperative acetabular index		
Last follow-up acetabular index					
r	0.729	0.590	0.900		
p	**0.000**	**0.000**	**0.000**		
AI: Acetabular index; MRI: Magnetic resonance imaging; Spearman correlation.					

reliability: kappa, 0.976; 95% confidence interval (CI), 0.97-0.99; p<0.001; and kappa, 0.958; 95% CI, 0.924-0.986; p<0.001, respectively.

DISCUSSION

The present study attempted to investigate the correlation between postoperative MRI assessment and residual AI in DDH patients who underwent open reduction during infancy. The main finding of this study was that the last follow-up AI was positively correlated with age at the time of operation, CAI, AAI, PAI, early postoperative AI, and medial wall thickness. The last follow-up AI was negatively correlated with AHI, HCI, and sphericity. The relationship between medial wall bone stock and acetabular dysplasia has been previously investigated in an adult population.[20-22] To the best of our knowledge, this is the first study to evaluate medial wall thickness in postoperative hip reduction MRI scans during infancy. We found that the medial wall thickness was significantly higher in the mild and severe dysplasia groups than in the normal group (p=0.002). We hypothesized that, in a shallow acetabulum, the medial wall bone stock would be higher, and by remodeling, the medial wall would become thinner, and the acetabulum would become deeper. Therefore, we consider that shallow acetabula should have thicker medial walls. Our results confirm the hypothesis as these hips had a higher AI at the last follow-up.

Mitchell et al.[23] evaluated MRI parameters obtained immediately after the reduction of the hip as a predictor of long-term acetabular dysplasia. They concluded that they could not predict which hips would remain dysplastic and require pelvic osteotomy based on post-reduction MRI scans. However, they analyzed only 13 hips in their study, which is a very low number to identify the relationship between MRI measurements after reduction and residual acetabular dysplasia. In our study, we included 62 hips, and the correlation between MRI parameters and acetabular dysplasia was documented. We analyzed a higher number of patients and found that the mean age of patients with severe dysplasia was significantly higher than the other normal and mild dysplasia groups (p=0.022), unlike the study of Mitchell et al.[23] We also found that there was a positive correlation between last follow-up AI and operation age (p=0.049). This is an expected finding of the present study, as younger children have a greater remodeling capacity.[23] However, we still need to consider the *p* value very close to the 0.05.

In another study, Duffy et al.[15] investigated 73 hip MRI scans after closed or open reduction. However, they could not find a correlation between the appearance of the bony or cartilaginous MRI scans and the acetabular morphology at the last follow-up. However, they only had a 15-month follow-up time (range, 2 to 36 months), and they suggested that a longer follow-up time was required to show a correlation. The mean follow-up time in our study was 23.7±10.1 months, and we excluded patients with a follow-up time of less than 12 months. Our results provide valuable evidence of the correlation between patient MRI parameters and the AI at the last follow-up. Of note, we only investigated who underwent medial open reduction patients, unlike the study of Duffy et al.[15] Open and closed reduction procedures are completely different from each other, and they should be evaluated separately. Duffy et al.[15] reported significant differences between the normal and dysplastic acetabulum with respect to the PAI (p<0.001) and AAI (p<0.001). According to our results, there was a positive correlation between the PAI (r=0.590, p=0.001), and AAI (r=0.729, p=0.001). Even if this measurement confirms each other to predict secondary intervention, we need further longer-term studies.

The Tonnis classification system is widely used to evaluate the severity of persistent acetabular dysplasia.[24,25] We classified patients according to the last follow-up AI in our study. The patients who needed a cast exchange had a statistically significantly (p=0.007) higher AI at the last follow-up. It is difficult to explain how a cast exchange affects the AI, although it may not be clinically important. In the severe dysplasia group, the operation age was also higher. It may be related to a greater need for cast exchanges in the higher age group, as the operation age is clinically associated with severe acetabular dysplasia.

Nonetheless, this study has some limitations. First, the follow-up time was relatively short, and some of the mild or severe dysplasia patients are still being followed. Some of these patients would require a pelvic osteotomy at a later stage and some of them would have a normal AI as a result of a high capacity for remodeling. The patients need to be monitored up to at least five years of age. Second, osteonecrosis of the femoral head following treatment and intraoperative quality of reduction are the two important factors which directly affect the acetabular development and these factors were not taken into consideration in this study. Third, the sample size is relatively small, as we excluded patients due to artifacts or low-quality

MRIs. As a result, a large number of normal children (n=40) were excluded. It is not possible to determine the extent that this changes the data or conclusions. The variables should be evaluated with multivariate analyses with a higher number of patients. Finally, this was a retrospective study and further prospective studies using high-quality MRI should be designed to provide additional evidence.

In conclusion, even if we cannot predict which patient would require pelvic osteotomy in the future, we can speculate that a trend can be seen in predicting residual dysplasia in patients treated with open reduction for DDH with these MRI parameters.

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