

Predicting acetabular growth in developmental dysplasia of the hip following open reduction after walking age

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Abstract

Background: Acetabular dysplasia of the hip following open reduction can complicate the treatment of developmental dysplasia of the hip (DDH). The purposes of this retrospective study were to investigate the long-term results of open reduction performed via an extensive anterolateral approach for DDH after walking age and to predict acetabular development using postoperative radiographs and arthrograms.

Methods: From 1973 to 2001, we performed open reduction for 131 hips in 119 pediatric patients with DDH after failed closed reduction. Of these, 85 hips of 73 patients who underwent arthrography at 5 years old were followed-up radiologically until skeletal maturity. Mean age at the time of surgery was 17 ± 4.6 months (range, 10-33 months), and mean age at final survey was 19 ± 5.7 years (range, 14-33 years). Mean follow-up time was 17.7 ± 5.8 years (range, 13-32 years). Groups with satisfactory outcomes (66 hips) and unsatisfactory outcomes (19 hips) according to the Severin classification were compared. Factors predicting acetabular development were identified using univariate and multiple logistic analyses.

Results: Univariate analysis showed a significant between-group difference in acetabular index (AI) at 2 months postoperatively, and in center-edge (CE) angle, cartilaginous AI (CAI), and cartilaginous CE angle at 5 years old

18 ($p < 0.05$ each). In multiple logistic regression analysis, CAI at 5 years old represented a predictor of acetabular
19 development after open reduction for DDH (odds ratio, 1.81; 95% confidence interval (CI), 1.04-3.13; $p < 0.05$).
20 Area under the receiver operating characteristic curve for CAI at 5 years old was 0.93 (95%CI, 0.85-1.0), and the
21 optimal cut-off was 10° (81.8% sensitivity, 92% specificity).
22 **Conclusions:** A CAI $\geq 10^\circ$ on hip arthrograms at 5 years old may offer a useful indicator of the need for corrective
23 surgery following open reduction after walking age.

24

25 **Introduction**

26 The incidence of developmental dysplasia of the hip (DDH) has been decreasing, thanks to recent improvements
27 in neonatal examinations and diagnostic techniques. If not detected early and treated correctly, DDH is
28 associated with a high incidence of degenerative hip disease [1]. Achieving stable concentric reduction as early
29 as possible allows normal acetabular development and prevents late acetabular dysplasia [2]. Although children
30 under 1 year old can be managed using closed methods, some dislocated hips fail to respond to this method. If
31 concentric, stable reduction of the hip cannot be achieved, open reduction becomes necessary [3]. Compared to
32 other methods, including Ludloff's method, open reduction via an extensive anterolateral approach for DDH
33 after walking age involves circumferential dissection of the joint capsule and enables good concentric reduction,
34 so additional surgery (such as Salter's innominate osteotomy) is rarely needed [3-6]. We consider that restoration
35 of labral inversion or interposition is essential for obtaining both good postoperative concentric reduction and
36 future acetabular development [7]. Several studies have predicted acetabular development after treatment for
37 DDH [8-11]. However, those reports were conducted using radiography, and thus did not include adequate
38 assessment of the labrum. Arthrography is an invasive technique that requires general anesthesia and is mainly
39 used as a preoperative examination [12], but allows dynamic analysis and assessment of radiolucent structures
40 [3]. The purposes of this study were to investigate the long-term results of open reduction performed via an
41 extensive anterolateral approach for DDH after walking age, and to identify predictors of subsequent acetabular

development using postoperative arthrography.

Materials and Methods

We treated 131 hips of 119 pediatric patients who had undergone open reduction surgery for hip dislocation after walking age between 1973 and 2001, and analyzed patients who were followed-up radiologically to skeletal maturity. This study included patients who were diagnosed as having dislocation of the hip using the Tönnis classification (grades II, III, and IV) [13] after walking age. We excluded cases involving teratologic and paralytic dislocations, and patients who had undergone corrective surgery before bone maturity to ensure that only the results of open reduction were evaluated.

Retrospective radiographic evaluation was performed by orthopedic surgeons trained in radiography of the young adult hip. Anteroposterior (AP) radiographs of hips before and after the operation, at 3 and 5 years old, and at final survey were reviewed for all patients. For postoperative assessment, acetabular index (AI) and center-edge (CE) angle were assessed from AP radiographs of the hip taken at 2 months postoperatively and at 3 and 5 years old. Hip arthrography was performed under general anesthesia for postoperative assessment at 5 years old. Cartilaginous acetabular index (CAI) and cartilaginous CE angle (CCE angle) were examined on AP radiographs via hip arthrography (Fig. 1). Maximum diameter of the capital femoral ossific nucleus in the affected hip (a) was measured, and the ratio of this diameter to that on the unaffected side (a') was measured as a/a' at surgery. At final

examination, we examined CE and sharp angles [14], and radiologic findings were divided in accordance with the classifications of Severin and Kalamchi and MacEwen [15]. Three patients who had undergone osteotomy after bone maturity were evaluated just before osteotomy. All study protocols were approved by the ethics board at our hospital.

Surgical procedure [16]

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 (Fig. 2a). The fibrous adhesion was dissected to thoroughly expose the joint capsule, and the joint capsule was incised circumferentially (Fig. 2b, c). The hypertrophied ligamentum capitis femoris and fibro-fatty tissues in the acetabulum were removed (Fig. 2d, e). We corrected inversion of the labrum manually using Tupfer gauze. We also transected the transverse acetabular ligament, and trimmed the anteroinferior part of the labrum if needed (Fig. 2f). We consider that these steps enabled us to achieve successful concentric reduction. After surgery, a hip spica cast was applied to hold the hip joint in slight flexion, 30° of abduction, and internal rotation. The cast was removed 8 weeks after surgery.

Statistical analysis

Patients were divided into two groups according to outcome: satisfactory, Severin group I or II; and

unsatisfactory, Severin group III or IV. Factors predicting acetabular development were identified using univariate (χ^2 and t tests) and multivariate analyses (multiple logistic regression). Potential predictive variables showing values of $p < 0.20$ in 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 final survey. The variables included in the multivariate model were normally distributed (assessed by Kolmogorov-Smirnov test), therefore parametric correlation coefficients (Pearson's correlation coefficient test, r) were used to study the relationship between variables. 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. The area under the curve (AUC) was calculated with the 95%CI for each ROC curve, with a higher AUC representing greater diagnostic accuracy [17]. Statistical analysis was conducted using PASW Statistics version 18 software (SPSS Japan, Tokyo, Japan).

Results

Eighty-five hips in 73 patients were followed up radiologically to skeletal maturity. Eleven cases involving teratologic and paralytic dislocations, and 5 patients who had undergone corrective surgery before bone maturity were excluded from the current study (**Supplemental Table 1**). The severity of the dislocation was graded using the Tönnis classification as grade II in 54 hips, grade III in 21 hips, and grade IV in 10 hips. Mean age at final

survey was 19 ± 5.7 years (range, 14-33 years). Mean duration of follow-up was 17.7 ± 5.8 years (range, 13-32 years; follow-up rate, 73.3%). Ten hips in 9 boys and 75 hips in 64 girls were included, and mean age at the time of surgery was 17 ± 4.6 months (range, 10-33 months). In total, 31 right hips and 54 left hips were included. Twelve patients had bilateral DDH. Initial treatment with conservative therapy proved unsuccessful in all patients. A Pavlik harness was applied before surgery in 59 hips, overhead traction (OHT) in 6 hips, cast in 5 hips, Pavlik harness and OHT in 6 hips, OHT and cast in 3 hips, Pavlik harness and cast in 2 hips, and Pavlik harness, OHT, and cast in 4 hips. In all cases involving casts, the cast was applied to maintain the hip joint in abduction and flexion.

The Kalamchi and MacEwen classification at final examination was group I in 75 hips, group II in 5 hips, group III in 4 hips, and group IV in 1 hip. The Severin classification at final examination was group I in 52 hips, group II in 14 hips, group III in 17 hips, and group IV in 2 hips, representing 66 hips in the satisfactory group (77.6%) and 19 hips in the unsatisfactory group (22.4%). Univariate analysis showed that the AI at 2 months after surgery was significantly larger in the unsatisfactory group than in the satisfactory group ($p = 0.04$, Table 1). At 5 years old, CE and CCE angles were significantly smaller in the unsatisfactory group than in the satisfactory group ($p = 0.01$ and 0.04 , respectively), while the CAI was significantly larger in the unsatisfactory group than in the satisfactory group ($p < 0.001$). No significant difference in a/a' at surgery was apparent between the two groups ($p = 0.43$).

We investigated correlation coefficients between variables using Pearson's correlation coefficient test.

Moderate positive correlations ($p < 0.01$) were observed between AI and CAI at 5 years of age ($r = 0.62$), and between CE and CCE angle at 5 years of age ($r = 0.50$, Table 2). We examined correlation coefficients by dividing patients into a satisfactory group and an unsatisfactory group, to study the issues in greater detail. In the satisfactory group, low but significant positive correlations were observed between AI and CAI at 5 years of age ($r = 0.49$, $p = 0.01$), and between CE and CCE angle at 5 years of age ($r = 0.41$, $p = 0.049$). In the unsatisfactory group, a very highly significant positive correlation was observed between AI and CAI at 5 years of age ($r = 0.91$, $p < 0.001$), and no significant statistical correlation was not observed between CE angle and CAI at 5 years of age ($r = 0.30$, $p = 0.08$). Multiple logistic regression analysis of the Severin classification at final assessment suggested the CAI at 5 years old as a predictor of poor results after open reduction for DDH, and the OR for satisfactory results compared to unsatisfactory results was 1.81 (95% CI, 1.04-3.13, $p = 0.04$, Table 2). The ROC curve for the CAI at 5 years old showed an optimal cut-off of 10° (81.8% sensitivity, 92% specificity) (Fig. 3).

Discussion

Results from univariate analysis showed significant differences in the AI at 2 months after surgery and CE angle, CAI, and CCE angle at 5 years old between the satisfactory and unsatisfactory groups. Results of multiple logistic regression analysis indicated the CAI at 5 years old as a predictor of unsatisfactory results, and future acetabular dysplasia was predicted with a $CAI \geq 10^\circ$.

Good postoperative results with open reduction using an extensive anterolateral approach in patients with severe hip dislocation have been reported since 1973 [3, 6, 7]. Patients treated after reaching walking age show adhesion of the postero-superior part of the capsular ligament and short external rotators caused by compression under weight-bearing [5]. Tönnis reported an increased incidence of avascular necrosis (AVN) of the femoral head if open reduction was preceded by failed conservative treatment [18]. We used complete release of postero-superior tightness and contraction of the short external rotators under the extensive anterolateral approach to achieve good concentric reduction [3, 4]. In our view, following this procedure represents a first key step to facilitating future acetabular development.

We have used two-directional arthrography of all hips before and after reduction to evaluate the anterior, superior, and posterior portions of the labrum, and have reported a significant correlation between joint stability and shape of the labrum, and that an inverted labrum prevented good concentric reduction [3, 6, 12]. We consider this as a second key point to facilitate future acetabular development. The present study therefore investigated predictors of subsequent acetabular development using postoperative arthrography, in consideration of the potential need for corrective surgery.

Regarding predictors of DDH, Mitani et al. performed multivariate analysis using radiographic findings at 1 and 3 years old in 96 hips that were reduced using a Pavlik harness [19]. Ohmori et al. also investigated 217 hips reduced using a Pavlik harness and reported an ossification-edge angle $<2^{\circ}$ on radiography at 3 years old as a

predictor of unsatisfactory outcomes [20]. However, these examinations were conducted using results from closed reduction. We considered application of these predictors to patients treated by open reduction as inappropriate.

Chen et al. investigated 64 hips with non-open reduction, 4 hips with open reduction, and 7 hips with open reduction and femoral osteotomy (75 hips in total) to determine predictors of open reduction, and reported a center-head distance discrepancy $<6\%$ at 1 year after reduction as indicative of favorable prognosis [21]. Albinana et al. investigated 48 hips with non-open 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 for corrective surgery in these patients [8].

As abundant cartilage, including the labrum, cannot be detected radiographically in early childhood, predicting subsequent acetabular development using radiography alone is not an accurate methodology. We analyzed predictors after open reduction using both radiography and arthrography to determine the cartilaginous acetabular edge. Zamzam et al. reported that the acetabular cartilaginous angle obtained via arthrography offered a good predictor of later acetabular development after successful closed reduction for DDH [22]. The limbus is the labrum that has become hypertrophied with fibrous and fibrocartilaginous overgrowth, representing a potential hindrance to concentric reduction of the dysplastic hip [23]. We consider that assessing the cartilaginous acetabular edge is important in patients after failed closed reduction because the inverted labrum is frequently immobilized in the acetabulum in these patients. The CAI and CCE angle are arthrographic indices that enable assessment of

the lateral margin of the labrum, which cannot be evaluated radiographically. CAI and CCE angle become smaller than normal in patients with an inverted or everted labrum caused by subluxation or coxa magna. In this manner, patients with a deformed labrum (including inverted or everted labrum) may possibly develop acetabular dysplasia caused by instability. Postoperative adhesions make evaluation of the labrum using magnetic resonance imaging (MRI) difficult. However, even in these cases, arthrography enables to high-resolution evaluation of the labrum. We consider this as a key advantage of arthrography.

The acetabulum comprises the ilium, ischium, pubis, and interstitial cartilage complex. The triradiate cartilage, one of the cartilage complexes, is an epiphyseal growth plate [24]. The acetabular epiphysis, within the acetabular cartilage adjoining the iliac bone, forms a good part of the superior wall of the acetabulum [24]. In the present study, we corrected the inverted labrum to achieve concentric reduction. An inverted labrum decreases direct stimulation between the femoral head and acetabular epiphysis, and consequently inhibits favorable lateral acetabular development. Although Somerville et al. recommended excision of the limbus in order to gain concentric reduction [25], this risks unintentional damage to the acetabular articular cartilage. Since the acetabular cartilage is epiphyseal, damage may in turn hinder hip growth and development [23]. We therefore transected the transverse acetabular ligament and trimmed only the anteroinferior part of the labrum to widen the labrum inlet and to correct the inversion of the labrum atraumatically. One more factor facilitating acetabular development is a hip spica cast to hold the hip joint in slight flexion, 30° of abduction, and internal rotation after

surgery, enabling contact between the femoral head and triradiate cartilage. Concavity of the acetabulum then develops in response to the presence of the femoral head and growth of the triradiate cartilage [24].

The results of multiple logistic regression analysis for the Severin classification as a final assessment indicated that the ratio of the maximum diameter of the capital femoral ossific nucleus is not associated with acetabular development. This type of physeal damage is commonly referred to as aseptic necrosis of the femoral head [15, 26, 27] and is assumed to result in poor acetabular development, but generally does not become evident until about 9-10 years of age [15]. As acetabular dysplasia is generally evident before the radiographic changes of physeal arrest [27], growth disturbance of the capital femoral epiphysis is not necessarily associated with poor acetabular development.

We investigated correlation coefficients between variables using Pearson's correlation coefficient test to clarify the correlations between radiographic and arthrographic indices at 5 years old. If such correlations exist, CE and AI could be sufficient to predict future acetabular development. In the unsatisfactory group, very highly significant positive correlations were observed between AI and CAI at 5 years of age. Therefore, AI, which is a radiographic index, could be sufficient to predict future acetabular development in the unsatisfactory group. However, correlations between AI and CAI at 5 years of age ($r = 0.49$) and CE angle and CAI at 5 years of age ($r = -0.48$) were low in the satisfactory group. These results indicate that predicting future acetabular development using radiography only would be difficult. We therefore consider that evaluation of the cartilaginous acetabulum

by hip arthrography as meaningful.

The current study shows various limitations. Hip arthrography has the disadvantage of requiring general anesthesia and hospitalization. This study did not evaluate acetabular development using contrast MRI or ultrasonography. If these tests had been performed, we could have obtained the same information suggesting a radiographically permeable structure derived from hip arthrography without invasion. Although MRI should be performed under sedation, we can conduct ultrasonography under alert, awake conditions. The static technique (Graf) [28] and dynamic technique (Harcke) [29] enable accurate and reliable determination of the anatomic structures and relationships of the hip joint.

Despite these limitations, we were able to investigate factors related to poor results of open reduction for DDH after walking age. Our findings indicate that a CAI $\geq 10^\circ$ on a hip arthrogram at 5 years old represents a predictor of acetabular development after open reduction. We consider that corrective surgery should be performed on patients with CAI $\geq 10^\circ$ at 5 years old to avoid hip dysplasia and improve final outcome. Hip arthrography is a more useful procedure than plain radiography when considering the necessity for corrective surgery.

Conflicts of interest

The authors declare that they have no conflicts of interest.

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279 **Figure legends**

Fig. 1 Radiographic measurements. AI, acetabular index; CE angle, center-edge angle; CAI, cartilaginous acetabular index; CCE angle, cartilaginous center-edge angle.

Fig. 2 A transverse incision is made from the medial border of the sartorius muscle to the greater trochanter 3 cm distal to the anterior superior iliac spine (**a**). The joint capsule is freed from fibrous adhesion and the joint capsule is thoroughly exposed (**b**). The joint capsule is incised circumferentially (**c**). Obstacles in the acetabulum, including the pulvinar, are removed, and the transverse acetabular ligament is transected to widen the labrum inlet (**d, e**). To achieve successful concentric reduction, the inverted labrum is corrected manually, and the anteroinferior part of the labrum is trimmed if needed (**f**).

Fig. 3 Receiver operating characteristic curve of cartilaginous acetabular index for acetabular development at 5 years old. AUC, area under the curve; CI, confidence interval; CAI, cartilaginous acetabular index; y, years.

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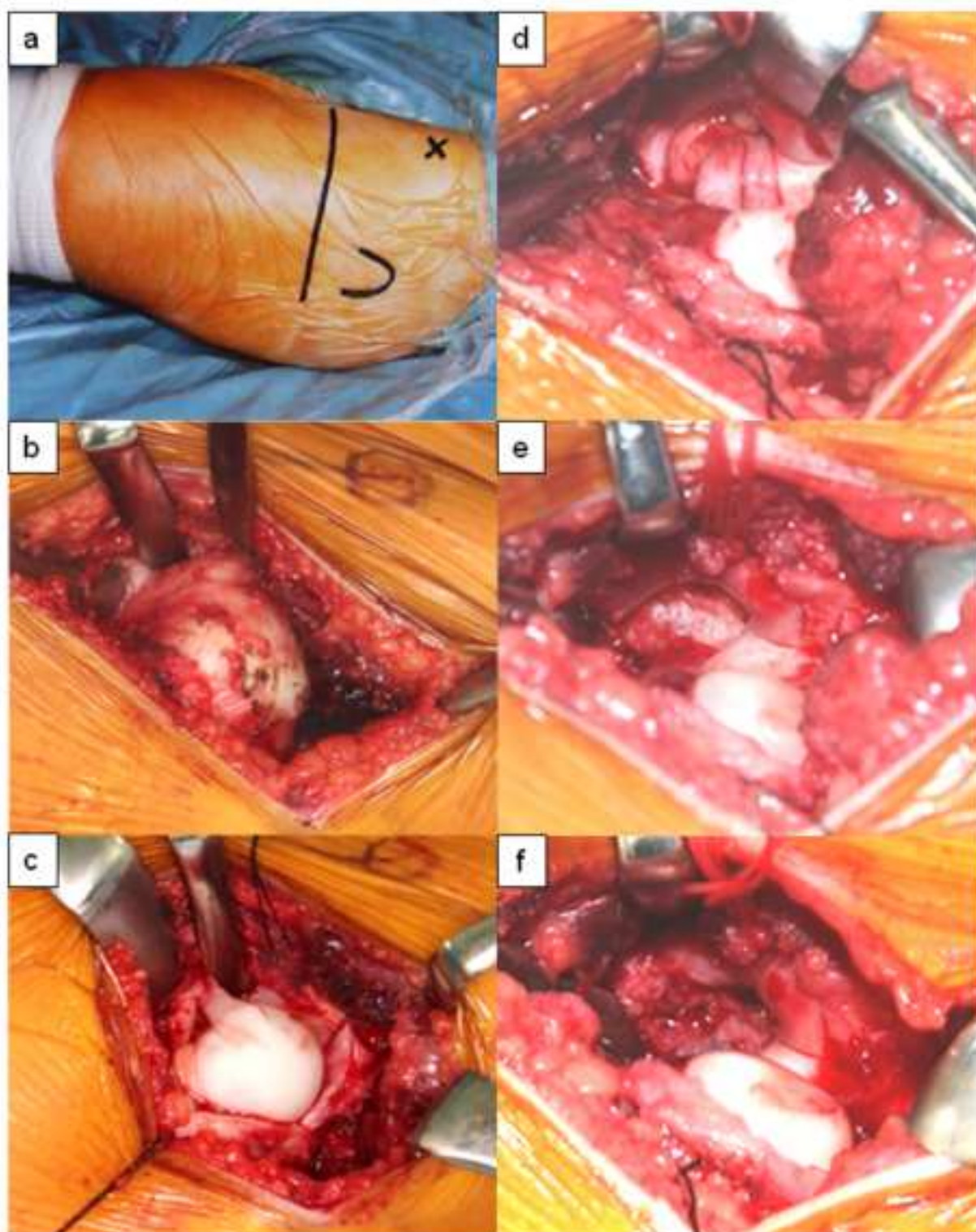


Figure3

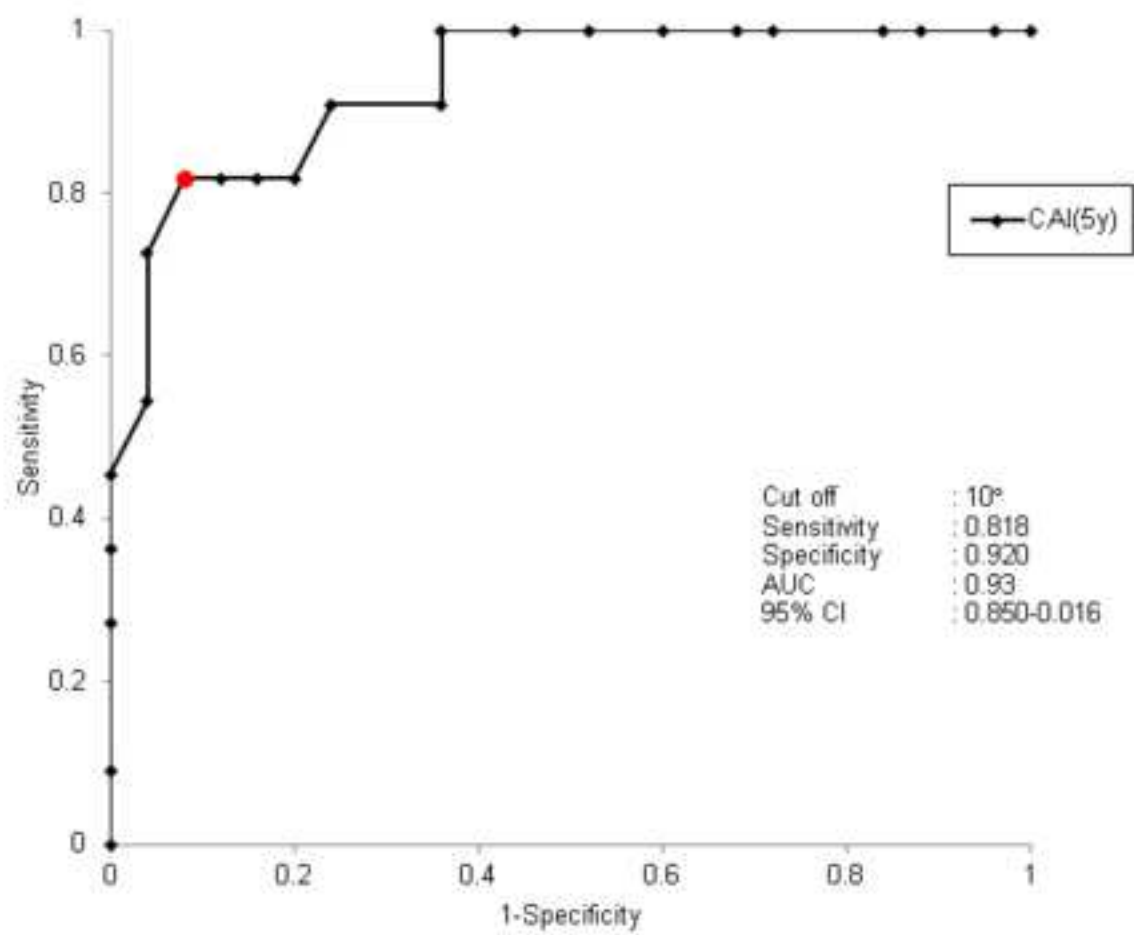


Table 1

Univariate analysis between the satisfactory and unsatisfactory groups with developmental dysplasia of the hip.

	Satisfactory group (n = 66)	Unsatisfactory group (n = 19)	p value
Age (months)	17 \pm 4.4 (10-33)	17 \pm 5.2 (12-33)	0.74
Sex (male:female)	7:59	3:16	0.54
Affected side (Lt:Rt)	40:26	13:6	0.54
At surgery			
AI (°)	34 \pm 6.3 (25-51)	38 \pm 3.9 (29-43)	0.04
CE angle (°)	5.9 \pm 11.1 (-34 to 25)	2.5 \pm 10.6 (-19 to 19)	0.30
a/a'	1.7 \pm 1.1 (0.9-3.3)	2.1 \pm 2.2 (0.8-8)	0.43
3 years of age			
AI (°)	34 \pm 5.6 (21-42)	40 \pm 7.5 (16-40)	0.36
CE angle (°)	37 \pm 8.0 (-7 to 26)	30 \pm 8.2 (-10 to 20)	0.30
5 years of age			
AI (°)	32 \pm 6.8 (10-35)	42 \pm 7.3 (16-41)	0.10
CE angle (°)	38 \pm 8.0 (0-32)	23 \pm 8.0 (0-24)	0.01
CAI (°)	14 \pm 6.9 (-13 to 13)	29 \pm 7.0 (1 to 24)	<0.001
CCE angle (°)	20 \pm 13 (11-71)	12 \pm 7.9 (26-52)	0.04

Data are expressed as mean \pm standard deviation (range). AI acetabular index, CE angle center-edge angle, CAI cartilaginous acetabular index, CCE angle cartilaginous center-edge angle.

Table 2

Pearson's correlation coefficient between the variables.

		AI (op)	AI (5 y)	CE angle (5 y)	CAI (5 y)	CCE angle (5 y)
Total	AI (op)	-	0.27	-0.20	0.28	0.10
	AI (5 y)	*	-	-0.54	0.62	-0.31
	CE angle (5 y)		*	-	-0.55	0.50
	CAI (5 y)	*	*	*	-	-0.70
	CCE angle (5 y)		*	*	*	-
Satisfactory group	AI (op)	-	0.14	-0.15	-0.07	0.20
	AI (5 y)		-	-0.48	0.49	-0.17
	CE angle (5 y)		*	-	-0.48	0.41
	CAI (5 y)		*	*	-	-0.80
	CCE angle (5 y)			*	*	-
Unsatisfactory group	AI (op)	-	0.44	0.17	0.73	0.31
	AI (5 y)		-	-0.48	0.91	-0.64
	CE angle (5 y)			-	-0.30	0.61
	CAI (5 y)	*	*		-	-0.37
	CCE angle (5 y)					-

AI acetabular index, CE angle center-edge angle, CAI cartilaginous acetabular index, CCE angle cartilaginous center-edge angle, op operation, y years. * $p < 0.05$.

Table 3

Multiple logistic regression analysis of the Severin classification at the final assessment.

Variable	Partial regression coefficient	Standard error	OR	95% CI		<i>p</i> value
				Lower	Upper	
AI (5 y)	-0.2	0.16	0.82	0.60	1.11	0.20
CE angle (5 y)	-0.26	0.17	0.77	0.55	1.07	0.12
CAI (5 y)	0.59	0.28	1.81	1.04	3.13	0.04
CCE angle (5 y)	0.20	0.13	1.22	0.95	1.58	0.12
Constant term	-3.60	4.21	0.03	0.00	104.2	0.39

AI acetabular index, CE angle center-edge angle, CAI cartilaginous acetabular index, CCE angle cartilaginous center-edge angle, OR odds ratio, CI confidence interval, op operation, y years.