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Original Article

Acetabular development after open reduction to treat dislocation of the hip after walking age

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ABSTRACT

Background: Treatment of hip dislocation diagnosed after walking age is often difficult. We report the surgical treatment of these patients by open reduction with a soft tissue surgical procedure without osteotomy.

Methods: Thirty-eight children (43 hips) diagnosed with complete dislocation of the hip after walking age were included in this study. We radiographically analysed postoperative hip joint development up to 6 years of age. To assess the predictors of acetabular development, we evaluated the radiographs, using an acetabular index of $\leq 35°$ and a centre-edge angle of $>5°$ at 6 years of age as satisfactory outcomes, and evaluated the advance of acetabular development over time.

Results: AI on the affected side was improved with time after open reduction. The diameter of the capital femoral ossific nucleus on the affected side was almost equivalent to that on the unaffected side at 6–12 months after surgery, after which the centre-edge angle improved gradually from one year after surgery. We compared hips classified as satisfactory to unsatisfactory at 6 years of age, and found that the centre-edge angle at one year after open reduction was significantly associated with acetabular development ($P = 0.044$). The cut-off value was $-2°$ with sensitivity of 0.909 and specificity of 0.677.

Conclusions: The results of the current study suggest that initial development of the capital femoral ossific nucleus after open reduction would be followed by improved joint congruity, and that this would facilitate acetabular development. The centre-edge angle at one year after surgery could be regarded as a potential predictor of acetabular development in open reduction surgery for late-diagnosed developmental dysplasia of the hip cases.

1. Introduction

When treating the dislocated hip, it has been reported that favourable acetabular development is best promoted by either closed reduction (CR) or open reduction (OR), with additional surgery for residual dysplasia such as Salter's innominate osteotomy [1,2]. To clarify the need for and the timing of additional surgery to prevent dysplastic hip and to avoid unnecessary further surgery, it is important to predict acetabular development after reduction of the dislocated hip. Patients diagnosed with dislocation of the hip after walking age sometimes need to undergo additional surgery after CR, or one-stage OR with combined osteotomy [3–5]. In our institute, we perform an OR procedure to dissect the joint capsule circumferentially and produce a good concentric reduction, a procedure introduced by Tanabe in 1973 [6]. Tanabe's procedure is known to produce favourable outcomes without additional surgery, in contrast to other methods such as Ludloff's method [7–11]. However, coxa magna has been recognized in several patients treated by this method [12]. We consider that coxa magna is responsible for poor acetabular origin and incongruity. There are only a few reports describing acetabular development over time after reduction to correct developmental dislocation of the hip [4,13], and the relationship between coxa magna and acetabular development is unclear [12,14]. The purpose of the present study was to evaluate acetabular development following treatment by OR alone, in children who were diagnosed with dislocated hips after walking age. And we attempted to find early and reliable

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radiographic predictors of acetabular development and to reveal the relationship between the growth of the femoral head and the acetabular development. We collected and investigated radiographs of patients treated at our hospital to test two hypotheses: (1) Acetabular development is more favourable in patients treated at a younger age, and (2) sufficient concentric reduction of the femoral head in the acetabulum facilitates growth of the femoral head at first, leading to secondary improvement in acetabular development.

2. Materials and methods

The common term developmental dysplasia of the hip (DDH) includes acetabular dysplasia, subluxation and dislocation of the hip joint. In this study, we investigated only radiographically completely dislocated hips (Tönnis Grade 3 or 4) [15], and excluded dysplasia or subluxation and teratologic dislocation. To evaluate the outcome of OR alone, the present study enrolled only untreated patients over walking age, to exclude the effects of other conservative treatments.

Of 1441 DDH children (1690 hips) who were treated at our institution between 1974 and 2007, 862 cases (982 hips) were diagnosed with dislocation of the hip. In these cases, OR was performed in 204 cases (233 hips). Three patients (four hips) were excluded because of combined operation with pelvic or femoral osteotomy. All of these three patients were early cases, and we do not perform the combined surgery since 1986. The remaining 46 patients (51 hips) were diagnosed after walking age and received OR alone. Thirty-eight patients (43 hips) were followed radiographically to at least 6 years of age (follow-up rate, 83%) and were enrolled in the current study. The average follow-up periods were 51.5 months (range, 13–65), and the final follow-up periods were 13.9 years (range, 4.7–26.1). Thirty-three patients had unilateral dislocations and five patients had bilateral dislocations. There were 34 girls and four boys, with a mean age at the time of surgery of 24 months (range, 13–67). Based on their age at the time of surgery, the patients were divided into three groups: group A (age 1 to <2 years; 30 hips); group B (2 to <3 years; 6 hips), and group C (age ≥3 years; 7 hips) (Table 1).

Anterior–posterior radiographs of the hip were obtained up to the age of 6 years. We measured acetabular index (AI) [16] and centre-edge angle (CE-A; measured at the anterior acetabular edge according to the method of Ogata et al.) [17,18]. The longest diameter of the capital femoral ossific nucleus on the affected hip was measured, and we evaluated its ratio to that on the unaffected side as a/a′ (only available in the unilaterally affected children) (Fig. 1). According to the criteria described by Imatani et al. [12], a femoral head with a diameter greater than 120% of the unaffected side was defined as coxa magna. Each item was evaluated preoperatively and at 2, 4, 6, and 12 months after surgery, and subsequently each year up to 6 years of age. To evaluate the predictive factors of acetabular development, in this study, an AI of ≤35° and a CE-A of >5° at 6 years of age were defined as good acetabular development, according to Albinana et al. [4] and Akagi et al. [13]. Using these criteria, we divided the patients into four groups as

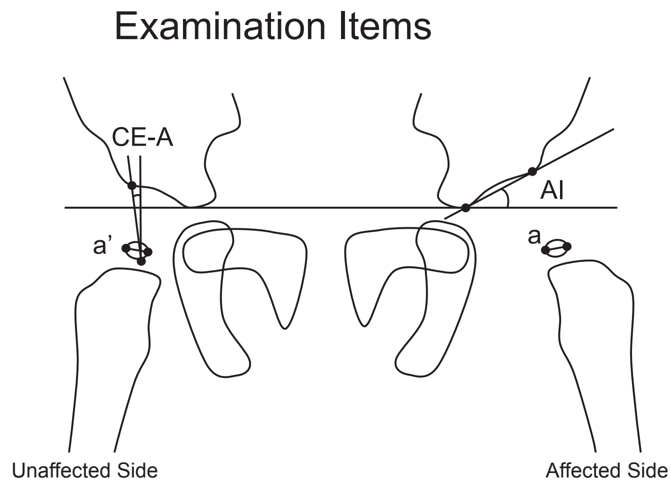

Fig. 1. Acetabular index, centre-edge angle, and the ratio of the capital femoral ossific nucleus were measured on anterior–posterior radiographs taken preoperatively and at 2, 4, 6, and 12 months after surgery, then each year up to 6 years of age.

listed in Table 2. Patients with both an AI of ≤35° and a CE-A of >5° were regarded as having a satisfactory outcome (22 hips). Other patients were regarded as unsatisfactory (21 hips). We compared hips classified as satisfactory to those classified as unsatisfactory by analysing age at surgery, sex, AI, CE-A and a/a′. All statistical analyses were performed using SPSS, version 17.0 (SPSS Inc., Chicago, IL, USA) and a P value of <0.05 was regarded as significant. All measurements and statistical calculations were performed by a single observer who was not involved in the clinical care of participants and was blind to the final outcome. The approval was given by the institutional review board (IRB).

3. Results

There was no re-dislocation after surgery, and AI decreased from one year after surgery in all groups (Fig. 2). However, the difference between the affected and unaffected sides was significant even at 6 years of age. The AI in group A at 6 years of age was significantly lower than that in group C ($P < 0.05$). In group A, the CE-A increased consistently throughout the follow-up period (Fig. 3). In contrast, the CE-A in groups B and C did not change during the first year after surgery, but increased thereafter. Postoperative changes in a/a′

Table 2
Acetabular development at 6 years old.

		CE-A (degrees)	
		≤5	>5
AI (degrees)	>35	Unsatisfactory (11 hips)	Unsatisfactory (6 hips)
	≤35	Unsatisfactory (4 hips)	Satisfactory (22 hips)

The patients who had AI of ≤35° and CE-A of >5° are divided into satisfactory group. The others are divided into unsatisfactory group.
AI indicates acetabular index; CE-A, centre-edge angle.

Table 1
Patients demographics.

Groups (operation age)	Number of patients	Hips	Sex (girls:boys)	Timing for operation (months)
A (<2 y.o.)	29	30	25:4	18.5 (13–23)
B (<3 y.o.)	6	6	6:0	26.7 (24–33)
C (≥3 y.o.)	6	7	6:0	45.7 (36–67)

All patients were untreated dislocation of the hip diagnosed after walking age.
y.o. indicates years old.

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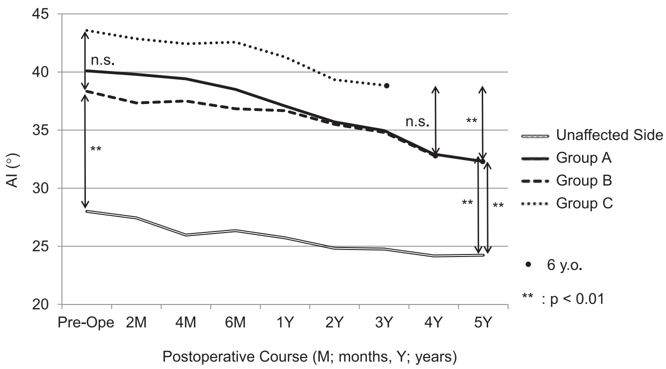

Fig. 2. Acetabular index improved from one year after open reduction in all groups. However a significant difference was observed between the affected and unaffected sides even at 6 years of age.

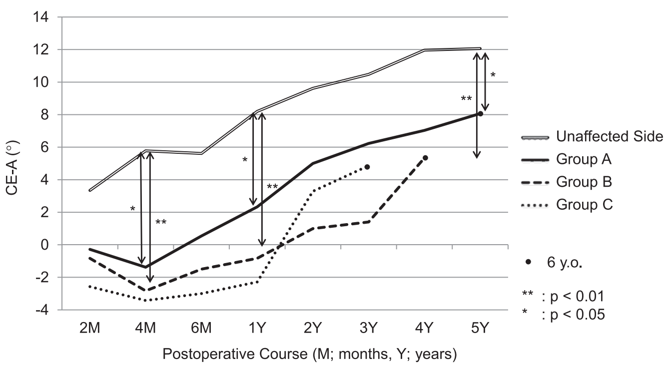

Fig. 3. The centre-edge angle (CE-A) in group A changed at 4 months after surgery, whereas the CE-A in groups B and C remained unchanged during the first year after surgery but improved more rapidly thereafter.

were comparable among the three groups (Fig. 4). The diameter of the capital femoral ossific nucleus on the affected side was almost equal to that on the unaffected side at 6–12 months after surgery in all groups. The mean a/a′ remained constant at around 115% after 3 years postoperatively in group A. At 6 years of age, the mean values of a/a′ were 115%, 118%, and 119% in groups A, B, and C, respectively. Coxa magna was identified in 8/25 hips (32%), 1/3 (33%), and 1/5 (20%) in groups A, B, and C, respectively, and thus in 10/33 hips (30%) overall. We evaluated the predictive factors affecting acetabular development by comparing the two groups (satisfactory and unsatisfactory) at 6 years of age. The postoperative courses of AI and CE-A in the two groups are shown in Figs. 5 and 6. AI in satisfactory group was gradually close to that of unaffected side, but there were significant differences between two groups (Fig. 5). CE-A in satisfactory group remained at a high level nearly equal to that of unaffected side, in total contrast to that of unsatisfactory group which remained minus level during the first year after surgery (Fig. 6). The significant difference between affected and unaffected groups at 2 months after surgery might be attributed to individual differences caused by cast removal for radiography. The operative techniques were standardized as previously reported and were not problematic. However, unfavourable concentricity at that timing might have led to poor outcomes. Analysis of the demographic variables indicated that AI and CE-A differed significantly between the two groups (Table 3). No significant differences were found with respect to age at surgery, sex, or a/a′. Multiple logistic regression analysis was used to assess factors affecting acetabular development. The CE-A at one year after OR was significantly associated with acetabular development ($P = 0.044$) (Table 4). From a receiver operating characteristic (ROC) curve, we determined that the CE-A at one year after OR affects acetabular development at 6 years of age, with a cut-off value of $-2°$, with sensitivity of 0.909 and specificity of 0.677 (Fig. 7).

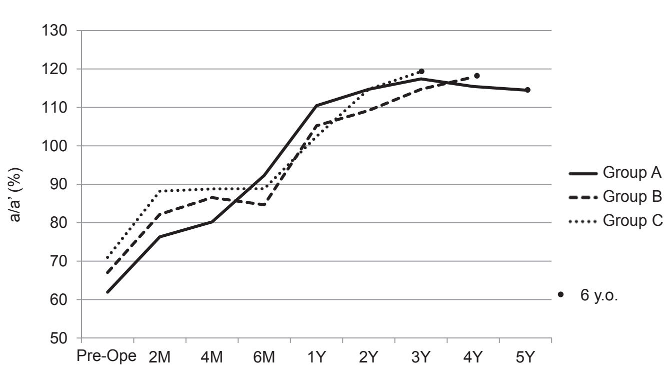

Fig. 4. The postoperative ratio of the longest diameter of the capital femoral ossific nucleus (a/a′) in the three groups increased similarly, and reached 100% at 6–12 months after surgery in each group.

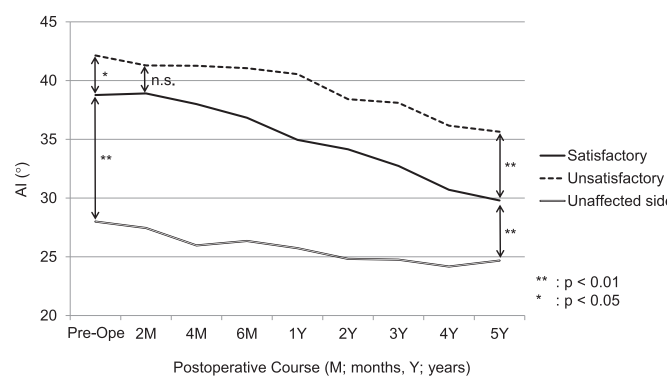

Fig. 5. There were significant differences between satisfactory and unsatisfactory groups except for 2 months after open reduction. And significant differences were observed between satisfactory and unaffected side groups at all time of postoperative course. Each satisfactory or unsatisfactory group included patients from groups A to C, their number varying according to the follow-up period: satisfactory group (≤2 years, $n = 22$; 3 years, $n = 21$; 4 years, $n = 20$; 5 years, $n = 12$) and unsatisfactory group (≤2 years, $n = 21$; 3 years, $n = 18$; 4 years, $n = 15$; 5 years, $n = 5$).

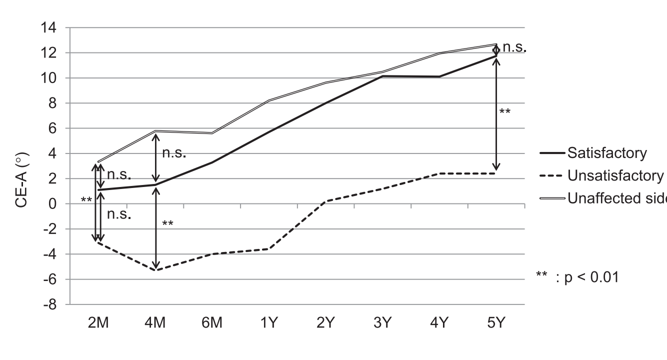

Fig. 6. Significant differences were observed between satisfactory and unsatisfactory groups since 4 months after surgery. And there was no significant difference between satisfactory and unaffected side groups at all time of postoperative course. The satisfactory group vs the unsatisfactory group consisted of different numbers of patients by postoperative follow-up duration (≤2 years, 22 vs 21; 3 years, 21 vs 18; 4 years, 20 vs 15; 5 years, 12 vs 5).

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Table 3
Comparison of good and poor groups.

Variables	Satisfactory (22 hips)	Unsatisfactory (21 hips)	*P*
Age at surgery (months)	21.5 (13–52)	26.8 (15–67)	0.063
Sex (girls:boys)	20:2	19:2	0.48
AI (degrees)			
Pre-operation	38.8 (32–49)	42.0 (34–52)	0.007**
2 months after OR	38.9 (31–49)	41.7 (34–46)	0.011**
1 year after OR	34.8 (27–45)	40.6 (33–47)	0.00003**
CE-A (degrees)			
Pre-operation	−58.0 (−89 to −25)	−69.6 (−30 to −115)	0.035**
2 months after OR	0.9 (−19 to 12)	−4.0 (−17 to 5)	0.011**
1 year after OR	5.5 (−6 to 15)	−3.5 (−14 to 13)	0.00002**
a/a′ (%)			
Pre-operation	63.4 (41–86)	64.2 (0–83)	0.45
2 months after OR	76.7 (56–111)	79.7 (34–102)	0.28
1 year after OR	110.5 (81–136)	107.0 (91–127)	0.22
6 years old	112.9 (96–126)	116.8 (103–132)	0.09

**Statistically significant.
AI indicates acetabular index; CE-A, centre-edge angle; a/a′, the ratio with unaffected side in longest diameter of the capital femoral ossific nucleus; OR, open reduction.

Table 4
Association of variables with the acetabular development by multiple logistic regression analysis.

Variables	Odds ratio	95% CI	Std. error	*P*
AI (pre-operation)	1.14	0.894–1.455	0.12	0.291
AI (1 year after OR)	1.02	0.783–1.338	0.14	0.866
CE-A (pre-operation)	1.14	0.880–1.485	0.13	0.317
CE-A (2 months after OR)	1.02	0.869–1.188	0.08	0.843
CE-A (1 year after OR)	0.84	0.701–0.995	0.09	0.044**

**Statistically significant.
AI indicates acetabular index; CE-A, centre-edge angle; OR, open reduction.

4. Discussion

The goal of treatment for DDH is to achieve and maintain sufficient concentric reduction, thereby promoting favourable acetabular development. Many authors have reported that good and rapid acetabular development can be expected in hips reduced by CR at an early age [19–21]. On the other hand, treatment for DDH in older children is difficult because they have high displacement of the femoral head, contracted soft tissues, dysplastic acetabulum, and increased anteversion of the femoral head [22,23]. Ertürk et al. [24] reported a study of 49 children with DDH between two and five years old who were treated successfully with one-stage treatment (OR combined with Salter's innominate osteotomy, femoral shortening, or femoral de-rotation osteotomy). At our hospital, children who are diagnosed after walking age or who have undergone failed CR are evaluated by two-directional arthrography. Any unreduced hips or hips with inverted limbus are treated by Tanabe's methods [8,25]. Any preoperative conservative treatment would increase the risk of avascular necrosis of the femoral head and deformity of the labrum. Thus, in this study, only patients diagnosed after walking age and untreated were enrolled to assess the true development of the hip joint after OR alone.

Few reports have evaluated the outcomes of OR in children who were diagnosed after walking age [22,23], apart from a few reports describing acetabular development treated by OR alone. Previous reports concerning acetabular development in DDH are listed in Table 5. Brougham et al. [3], in a study of 30 DDH patients treated by CR, emphasized that 77% continued to develop for up to 4 years after reduction. Albinana et al. [4] reported that acetabular development continued up to 4 years after reduction in a study involving more than 7-year follow-up of 72 DDH cases (CR; 48 hips, OR; 24 hips). In contrast, Gholve et al. [5] studied 49 cases of DDH diagnosed after walking age and treated by OR with or without osteotomy, with a minimum follow-up of 5 years, and concluded that maximum acetabular development was obtained in the first 4 years after surgery. Although 76% of patients underwent OR combined with osteotomy, 49% of the patients required secondary surgery for dysplasia at a mean age of 3.2 years (range, 3 months to

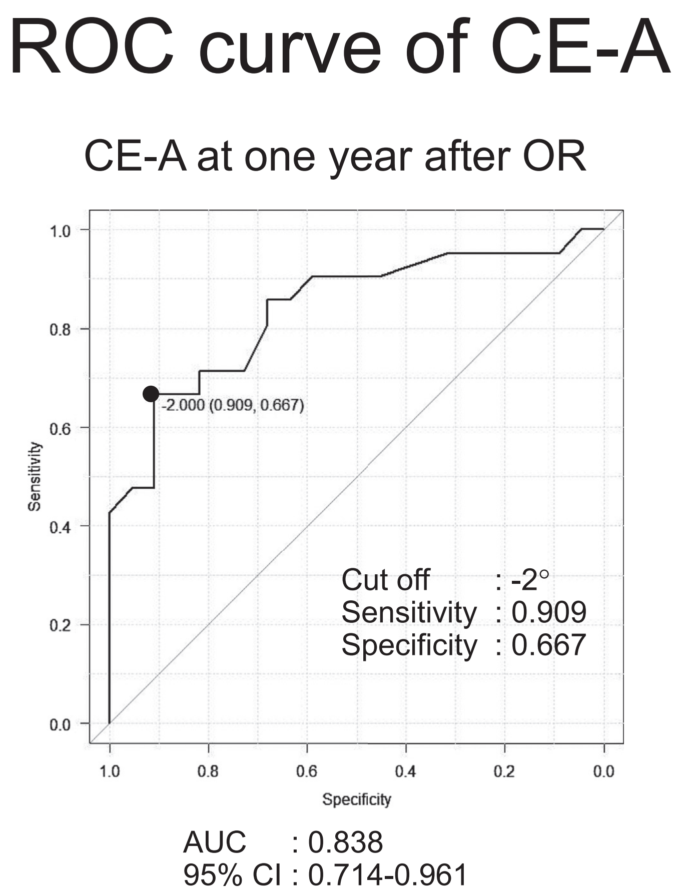

Fig. 7. From a receiver operating characteristic curve, the cut-off value for the centre-edge angle at one year after open reduction was calculated as −2°; with sensitivity of 0.815; specificity of 0.875; and area under the curve of 0.872.

Table 5
Comparison of previous reports and this study about acetabular development in DDH.

Author (year)	Treatment	Hips	Treatment periods (months)	Follow-up periods (years)	Acetabular development
Brougham (2003)	CR	63	15 (1–44)	11 (7–18)	Improve up to 4 years after CR
Albinana (2005)	CR, OR	48, 24	16 (1–46)	At least 7	Improve up to 4 years after treatment
Gholve (2008)	OR with or without osteotomy	49	31 (15–92)	9.7 (5–16.9)	Improve within 4 years after OR
This study (2016)	OR	43	24 (13–67)	4 (1–5)	Improve 1 year after OR Maybe more than 6 y.o.

CR indicates closed reduction; OR, open reduction; y.o., years old.

11.6 years) after index surgery. In these reports, the treatment was not OR alone and there was the influence of a secondary procedure, therefore the intrinsic acetabular development was unclear. In the present study, all hips were treated by OR alone, and we found that acetabular development was facilitated from 6 months after surgery in group A, and improved from one year after OR in groups B and C. The changes in AI and CE-A at 6 years of age on the treated side had a positive slope, thus the development of the acetabulum might continue beyond 6 years of age (Figs. 2 and 3).

With regard to age at treatment, controversy remains over whether treatment at a young age is necessary for a satisfactory outcome. Brougham et al. [3] emphasized that age at reduction did not influence the length of time over which the acetabulum continued to develop in 30 DDH patients treated by CR. Forlin et al. [26] reported that there were no significant differences in outcome with regard to age at the initial reduction, treating 72 hips by CR. In contrast, Zadeh et al. [27] treated 95 cases of DDH by OR combined with osteotomy and concluded that age $\leq$2 years at surgery is associated with a favourable outcome. Cıtlak et al. [28] reported that acetabular development was better in patients treated before the age of 18 months, based on their evaluation of 110 hips treated by medial OR, while additional operations were performed on 32 hips (29%). In this study, the AI improved over time after OR and was equivalent to that on the unaffected side in the young group. However, univariate analysis revealed no meaningful relationship between age at surgery and acetabular development.

To identify predictors of acetabular development, we defined satisfactory or unsatisfactory outcomes of acetabular development at 6 years of age according to AI and CE-A. Albinana et al. [4] used an AI of 35° at two years after reduction as a cut-off value for acetabular development until skeletal maturity. Akagi et al. [13] reported that acetabular development was poor in patients with a CE-A $\leq$ 5° at 6–8 years of age. On the basis of these cut-off values, in the current study, AI and CE-A were significantly associated with acetabular development in univariate analysis. By using multiple logistic regression analysis to assess the factors affecting acetabular development, we identified the CE-A at one year after OR ($P = 0.044$) as the related factor that influenced postoperative acetabular development at 6 years of age (Table 4). According to the ROC curves, a CE-A of −2° at one year after surgery might be a predictor of postoperative acetabular development (Fig. 7).

Several studies have suggested that osteonecrosis primarily affects the proximal femur and compromises acetabular development [3,29,30], but the relationship between femoral head deformity and acetabular development is unclear. Coxa magna has been identified in approximately 34–36% of cases after OR [12,14], but there is no recommendation of the relationship between coxa magna and acetabular development. In the current study, the diameter of the capital femoral ossific nucleus on the affected side became equal to that on the unaffected side at one year after surgery in all groups. Coxa magna was found in 10 (30%) of the 33 hips at 6 years of age, equivalent to the incidence reported from previous studies [12,14]. The a/a′ ratio did not show any significant correlation with the AI or the CE-A, and had no direct effect on acetabular development.

The hypotheses tested in this study were confirmed as follows. AI was improved in all groups and was superior in the youngest group. However, by univariate analysis, there was no meaningful relationship between age at surgery and acetabular development. At one year after surgery, the diameter of the capital femoral ossific nucleus on the affected side had increased to equal that on the unaffected side, after which the CE-A tended to improve. We considered that concentricity was maintained, femoral head remodelling occurred, and joint congruity improved, all of which may have facilitated acetabular development (Figs. 3 and 4). In the radiographs of all patients taken at 6 years of age, almost half of our series (22 of the 43 hips) were indicated for additional surgery according to the criteria (AI of $\leq$35° and a CE-A of >5°). However, in a previous report, Fujii et al. [10] reported that outcomes of Tanabe's procedure were favourable (Groups I and II in Severin's classification) in 79% of patients once the bone had matured. This suggests that maintenance of good concentricity after OR could lead to continuous improvement in acetabular development even after 6 years of age. Further evaluation of radiographic final outcomes at skeletal maturity will be required to confirm this.

The limitations of this study include its retrospective design, the small number of patients, and the fact that surgeries were not performed by a single surgeon, and the radiographs could not exceed completely the influence of the pelvic inclination. Further studies involving a larger number of patients and longer follow-up are needed. In addition, multimodality evaluation is desirable, involving not only outpatient conventional radiography (as conducted in this study) but also ultrasonography and computed tomography, with keen attention to radiation exposure.

Conflict of interest

The authors declare that they have no conflict of interest.

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