CLINICAL ARTICLE

Surgical implications for residual subluxation after closed reduction for developmental dislocation of the hip: A long-term follow-up

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Objective: Untreated residual subluxation after early closed reduction for developmental dislocation of the hip (DDH) leads to early degenerative osteoarthritis. The aim of our study was to investigate the role of early surgical timing and its indications.

Methods: Thirty-six patients (48 hips) with untreated residual subluxation after closed reduction who had serial follow-up radiographs until they had reached skeletal maturity were retrospectively reviewed. The average age at closed reduction was 1.6 years and at the last follow-up 13.8 years. The last radiographs were evaluated according to the Severin classification: Severin grades I and II were defined as satisfactory and Severin grades III and IV as unsatisfactory. Several measurements of the acetabular index (AI), Reimer's index (RI), center edge angle of Wiberg (CE angle) and orientation of the sourcil of the acetabulum were evaluated.

Results: The satisfactory group comprised 18/48 hips (37%), whereas the unsatisfactory group comprised 30/48 hips (63%). The average RI in the unsatisfactory group was significantly worse than that in the satisfactory group at the age of ≥ 3 –4 years, as was the average CE angle at the age of ≥ 4 –5 years and AI at the age of ≥ 5 –6 years. As remodeling occurs over time, some subluxations diagnosed at age of 2–3 years developed into normal hips. At 3–4 years, 42 hips were still subluxed; 71% of these had unsatisfactory final Severin grades. At 4–5 years, 30 hips were still subluxed; 87% of these had unsatisfactory Severin grades (III and IV). Very little remodeling after the age of 5 years. Eighteen/18 hips with ($34.4\% \pm 4.5\%$ vs $43.0\% \pm 4.6\%$, $P < 0.00$) $RI > 38\%$ at the age of 3–4 years fell into the unsatisfactory ($21.0^\circ \pm 5.5^\circ$ vs $10.6^\circ \pm 5.2^\circ$, $P < 0.01$) group. In addition, 26/30 hips with $RI > 33\%$ at the age of 4–5 years were in the unsatisfactory group, as were 26/26 hips with upward sourcil orientation.

Conclusion: To avoid early osteoarthritis, surgery correction of residual subluxation is recommended when the $RI > 38\%$ at the age of 3–4 years or the $RI > 33\%$ with the sourcil upward at the age of 4–5 years.

Key words: Congenital; Follow-up studies; Hip dislocation; Prognosis

Introduction

Residual subluxation after closed reduction of developmental dislocation of the hip (DDH) is not infrequent^{1,3}. The resultant abnormal stress distribution between the acetabulum and femoral head creates a high risk of early osteoarthritis^{1,4–11},

and total hip arthroplasty usually needs to be performed for advanced osteoarthritis^{12–15}. Earlier surgical correction is necessary to prevent this complication. Therefore, it is important to explore the indications for surgical management of residual subluxation.

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Fig. 1 Measurements on AP pelvic radiographs. (A) Acetabular index (AI). (B) Center-Edge (CE) angle and Reimers Index (RI).

Because young patients with residual subluxation usually are asymptomatic, the decision to undertake surgical correction during childhood depends more on the radiological characteristics. Schwartz¹⁶ and Tonnies¹¹ have both suggested that surgical

correction of residual subluxation should be performed when the acetabular index (AI) is $>25^\circ$. Terjesen has proposed that osteotomy should be considered when the center edge angle of Wiberg (CE angle) is $<10^\circ$. Wakabayashi *et al.* have reported that their usual criteria for surgery are an AI $>30^\circ$ and CE angle $<5^\circ$. The surgical indications for residual subluxation vary between institutions. More importantly, research on the indications for surgery for residual subluxation is mostly based on the retrospective study of surgical patients and generally lack precision. A concentric and stable reduction is a necessary condition for the dysplastic acetabulum to remodel into normal¹⁹⁻²⁴. It is unstable in a hip of subluxation as the femoral head transfers laterally and superiorly. However, Normal growth and development will occur in part of the hips of subluxation^{25,26}. We presume that if a hip of subluxation is mildly or moderately unstable, it could become stable gradually to get enough remodeling. So the surgical intervention should be performed for the hip of subluxation that is not stable enough. And the surgical indications probably associate with the stability. Wiberg has recommended an interrupted Shenton line as evidence of subluxation⁴; however, this is both difficult to measure in children and not very accurate. We therefore use Reimer's index (RI) to diagnose subluxation when the RI is $>33\%$ ²⁷; this index can also provide a quantitative measure of the severity degree of subluxation and instability. Moreover, Kim *et al.* have reported that the sourcil orientation of the acetabulum is an early predictor of hip development after closed reduction of DDH²⁸, which may also associate with the degree of instability.

A set of predictors for the development of the hips should base on a series without surgical treatment where the

Fig. 2 The sourcil is a curved area of dense bone on the weight-bearing surface of the acetabulum (arrows). (A) The outer side of a normal sourcil orientate horizontal or downward. (B) The outer side of a abnormal sourcil orientate upward.

Fig. 3 Female, residual subluxation was found 4 months after closed reduction for DDH. (A) AP pelvic radiograph of a 2 years and 3 months old girl who had undergone closed reduction at 1 year and 11 months. In the left hip, the AI is 23, the RI 34% and the CE angle 6°; on the right side, the AI is 30°, the RI 38% and the CE angle 5°, she therefore has bilateral residual subluxation. (B) At 4 years and 3 months, the AI is 28°, RI 38% and the CE angle 11° on the left side, whereas the AI is 28°, RI 45% and CE angle 11° on the right side; both sides show upward orientation of the sourcil. (C) At 6 years and 5 months, the AI is 32°, RI 36% and CE angle 8° on the left side; the AI is 28°, RI 37% and CE angle 13° on the right side. (D) The most recent radiograph is at the age of 12 years and 7 months: the triradiate cartilage has achieved closure, the RI is 41% and CE angle 5° on the left side, the RI is 47% and CE angle 0° on the right side; thus both hips are Severin grade IV.

outcomes are not influenced by other events^{1,29,30}. We therefore performed this study to assess the natural history of residual subluxation without any surgical intervention and ascertain what should be done. Because the radiograph characteristics change over time, the timing for surgery also requires discussion. In this study, we retrospectively reviewed patients who had entered reached skeletal maturity with untreated residual subluxation after closed reduction, our aim being to assess the implications of surgical timing and indications for its implementation for residual subluxation.

TABLE 1 Severin grades at maturity of hips with RI >33% at various ages

Age (years)	Total	Unsatisfactory outcome (hips [%])
2–3	48	30 (63)
3–4	42	30 (71)
4–5	30	26 (87)
5–	30	30 (100)

Fig. 4 Changes in RI index according to group and age.

Materials and Methods

Patient Selection

Patients who had been born before January 2000 and undergone closed reduction of DDH, not necessarily in our hospital, were retrospectively reviewed. The study included patients with residual subluxation one year after closed reduction in and triradiate cartilage closure on their most recent latest radiographs. Subluxation was diagnosed when the RI was $>33\%$ ⁸. Patients who had teratologic dislocations, inadequate radiographs, had undergone additional treatment before skeletal maturity or showed severe growth disturbance of the proximal femur were excluded from this study.

Thirty-six patients (48 hips) met the criteria and were included. There were 8 boys and 28 girls. The average age at closed reduction was 1.6 (1.2–2.1) years. The average age at the most recent follow-up was 13.8 (12.3–14.8) years. Unilateral dislocation was present in 24 patients and bilateral dislocation in 12.

Radiograph Evaluation

Anteroposterior (AP) pelvic radiographs had been obtained at least once a year until 6 years of age and then every two years until skeletal maturity in all patients. The following measures were evaluated on the radiographs at each age: AI, RI $[B/(A+B) \times 100\%]$, CE angle (Fig. 1) and orientation of the sourcil of the acetabulum (Fig. 2). All measurements were made using Trauma Cad 2.3 software (Volant Health Company, Israel) by a single observer who was blinded to other results.

The final radiographs were evaluated according to the Severin classification^{8a} and defined as satisfactory if the Severin grades were I or II (CE angle $>15^\circ$ before 13 years of age or $>20^\circ$ after 14 years of age) or unsatisfactory if the Severin grades were III and IV (CE angle $<15^\circ$ before 13 years of age or $<20^\circ$ after 14 years of age). Several measurements were evaluated according to age in the two groups to determine early predictors of Severin grade at maturity.

Statistical Analysis

All data were analyzed using SPSS (Version 13.0, SPSS). Continuous data such as AI, CE angle, RI age and age at closed reduction were compared between the two groups by unpaired Student's *t*-test. Categorical data such as sex and sides were assessed with the χ^2 test. *P* values <0.05 were considered statistically significant.

Results

Severin Classification on Final Radiographs

According to the Severin classification, the satisfactory group comprised 18/48 hips (37%), whereas the unsatisfactory group comprised 30/48 hips (63%) (Fig. 3). There were no statistically significant differences between the two groups in sex, age at closed reduction or bilateral/unilateral. Because remodeling occurs over time, some subluxations after closed reduction of DDH diagnosed at age of 2–3 years developed into normal hips and were assessed as satisfactory according to Severin grade. Severin grades of the hips diagnosed as being subluxed because of RI $>33\%$ were analyzed according to age (Table 1). At 3–4 years, 42 hips were still subluxed; 71% of these had unsatisfactory final Severin grades. At 4–5 years, 30 hips were still subluxed; 87% of these had unsatisfactory Severin grades (III and IV). Very little remodeling after the age of 5 years.

Serial Changes in AI, CE Angle and RI with Age

Figures 4–6 show the serial changes in RI, CE angle and AI, respectively, according to age and group. These graphs show improvement of the measurements with age, especially in the satisfactory group. More importantly, the differences between the two groups in these measurements change with age. The average RI is significantly greater in the satisfactory group than the unsatisfactory group from 3–4 years of age ($34.4\% \pm 4.5\%$ vs $43.0\% \pm 4.6\%$, $P < 0.00$ and the difference between the two groups in CE angle is statistically significant after the age of 4–5 years ($21.0^\circ \pm 5.5^\circ$ vs $10.6^\circ \pm 5.2^\circ$,

Fig. 5 Changes in CE angle according to group and age.

Fig. 6 Changes in AI according to group and age.

$P < 0.01$); however, there is no statistically significant difference between the groups in AI before the age of 5–6 years (Table 2).

Analysis of Severin Classification Based on RI at Early Age

We found that the difference in RI between the two groups became significant earlier than did the difference in CE angle. We therefore selected RI as an early predictor of the Severin grade at maturity. At the age of 3–4 years, 18/18 hips with RI $>38\%$ fell into the unsatisfactory group, whereas 12/30 hips (40%) with $\leq 38\%$ fell into the unsatisfactory group. At the age of 4–5 years, 26/30 hips (87%) with RI $>33\%$ were in the unsatisfactory group, whereas 4/18 hips (22.2%) with RI $\leq 33\%$ were classified as unsatisfactory (Table 3). We then analyzed the correlation between RI and sourcil orientation and found that 26/26 hips with RI $>33\%$ and upward orientation of the sourcil were in the unsatisfactory group (Table 4).

Discussion

Outcome of Untreated Residual Subluxation after Closed Reduction

Because this research aimed to explore the indications for and timing of surgery for residual subluxation, we analyzed the outcome of untreated residual subluxation, using the Severin

TABLE 3 Relationship between Severin grade at maturity and RI at 3–5 years

Age (years)	RI	Satisfactory group	Unsatisfactory group
3–4	$>38\%$	0	18
3–4	$\leq 38\%$	18	12
4–5	$>33\%$	4	26
4–5	$\leq 33\%$	14	4

grade at maturity as an intermediate outcome. Severin grading, which can predict the development of early osteoarthritis, is the most widely used system for evaluating hip development. Malvitz and Weinstein reported the findings of a 44 year follow-up of hips: 46% of Severin grade III and IV hips had severe osteoarthritis, compared with only 3% of Severin grade I and II hips. They also identified a significant relationship between Severin grade and hip function (Iowa hip rating): 17% of Severin I and II hips had poor ratings, compared with more than 80% Severin III and IV hips¹.

In our study, we used RI $>33\%$ as the criterion for diagnosing subluxation rather than the interrupted Shenton line. Our reasons for not using the Shenton line were that it is very difficult to measure in children and there is lack of agreement about its interpretation: some authors consider discontinuity <5 mm as normal³¹, whereas others allow a 10 mm discrepancy³². In contrast, the RI is a quantitative measure of the severity of a subluxation, which may correlate strongly with the outcome in untreated hips. Eklof *et al.* reported that the 98th percentile in normal children aged <4 years is 16% and subluxation should be considered when the RI is $>33\%$ ³³.

In our study, at skeletal maturity the satisfactory group comprised 18/48 hips (37%), whereas the unsatisfactory group comprised 30/48 hips (63%). We found that remodeling occurs in a small proportion of subluxations over time, but rarely in patients aged >5 years. Remodeling of the hips is based on stable concentric reduction of the femoral head^{34,35}, because subluxated hips are usually unstable, most do not achieve successful remodeling. Harris confirmed that the capacity to remodel is stronger before the age of 4 years, and then decreases gradually over time; this may explain why remodeling rarely occurs after 5 years³⁴.

TABLE 2 AI, CE angle and RI at 2–5 years according to group (mean $\pm$ SD)

Group	2–3 years			3–4 years			4–5 years		
	RI (%)	CE (°)	AI (°)	RI (%)	CE (°)	AI (°)	RI (%)	CE (°)	AI (°)
Satisfactory ($n = 18$)	37.6 ± 11.7	7.3 ± 6.4	25.3 ± 8.3	34.4 ± 4.5	13.3 ± 5.0	24.3 ± 5.8	29.3 ± 7.2	21.0 ± 5.5	26.5 ± 10.7
Unsatisfactory ($n = 30$)	42.3 ± 8.3	7.6 ± 2.3	28.4 ± 5.9	43.0 ± 4.6	7.4 ± 4.5	29.8 ± 6.4	40.0 ± 6.2	10.6 ± 5.2	28.4 ± 4.3
<i>t</i> value	0.504	−0.069	−0.615	−5.814	1.988	−1.119	−3.115	3.434	−0.268
<i>P</i> value	0.57	0.95	0.56	<0.001	0.17	0.28	0.01	0.01	0.81

TABLE 4 Relationship between Severin grade at maturity and RI and sourcil orientation at 4–5 years (hips)

Reimer's index	Sourcil orientation	Satisfactory group	Unsatisfactory group
>33%	Upward	0	26
>33%	Horizontal or downward	4	0
≤33%	Upward	6	2
≤33%	Horizontal or downward	8	2

Predictors of the Outcome at Maturity of Untreated Subluxation

We found no statistically significant differences between the satisfactory and unsatisfactory groups in sex, age at closed reduction or bilateral/unilateral. We analyzed the serial changes in the AI, CE angle and RI according to group and with age and found that the differences in average RI, CE angle and AI became significant after the ages of 3, 4 and 5 years, respectively. Kitoh *et al.* found that the AI of 4 years and CE of 5 years after reduction were the earliest predictors of the final outcome at skeletal maturity, which was also later than the RI in our research. We therefore established that the RI is the earliest predictor of these three measurements.

We also found a correlation between the RI and CE angle ($r = -0.96$) and the curves of changes with age of these variables (Figs. 4,5) showed opposite patterns. These findings are similar to those of Terjesen, who reported that a close relationship between the RI and CE angle ($r = -0.973$)⁸. Wiberg was the first to report using CE angle to evaluate the containment of the femoral head by the acetabulum⁴. Reimer reported that the RI reflects lateral migration of the femoral head in the acetabulum²⁷. Actually, these two measurements both reflect the reduction of the femoral head in the acetabulum, the difference is that the RI focuses on the part of femoral head outside the acetabulum whereas the CE angle focuses on the inside part. Remodeling of subluxation correlates with the reduction position of the femoral head, which, in our opinion, is more directly reflected by the RI.

Implications for the Indications for and Timing of Surgery for Subluxation

In our study, 18/18 hips with the RI >38% at the age of 3–4 years fell into the unsatisfactory group, whereas when the RI

was >33% at the age of 4–5 years, 26/30 hips had unsatisfactory outcomes. These findings suggest that the RI is a reliable means of helping clinicians decide between surgery and observation. Our research firstly used the RI to predict the outcome of untreated residual subluxation; no other published research has explored this. Kim *et al.* used center-head distance discrepancy (CHDD) to predict the Severin grade at skeletal maturity and reported that CHDD ≥6% at the age 4–5 years correlated significantly with poor outcomes²⁸. The CHDD is similar to the RI: they both reflect the lateral migration of the femoral head; however, the CHDD can only be used in unilateral cases. Kitoh *et al.* concluded that, after closed reduction, the CE angle at age 5 years is the earliest predictor of the final outcome³⁶; the CE angle indirectly reflects the lateral migration of the femoral head.

Kim *et al.* concluded that the sourcil orientation of the acetabulum is an early predictor of the final outcome of hip dysplasia²⁸. We found that 26/26 hips with RI >33% and upward orientation of the sourcil at age 4–5 years had unsatisfactory outcomes at maturity. The normal orientation of the sourcil, a curved area of dense bone on the weight-bearing surface of the acetabulum visible on AP pelvic radiographs, is horizontal or downward with a 3–4° discrepancy³⁷; its orientation, in part, reflects the previous biomechanical environment of the hip. A combination of this measurement and morphology is a good means of predicting the final outcome of the development of the subluxation hips.

The limitations of our study include that it was a small, retrospective study and, because we included patients who had undergone closed reduction of DDH in other institutions, we were unable to assess the relevant variables before reduction. However, our research does evaluate the natural history of residual subluxation and the changes with age, our findings therefore do have some implications for timing of and indications for surgery for residual subluxation.

In conclusion, remodeling can occur in some residual subluxations after closed reduction of DDH. Secondary surgery for residual subluxation is recommended for prevention of early osteoarthritis when the RI is >38% at the age 3–4 years or >33% with upward sourcil orientation at the age of 4–5 years.

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