Original Article

Predictors of residual hip dysplasia in 12–18-month-old *vs.* over 18-month-old DDH patients after closed reduction and the reliability of one residual hip dysplasia criterion: a retrospective cohort study

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Background: The diagnostic and prediction criteria of residual hip dysplasia (RHD) remains controversial. There were no studies that focused on the risk factors of RHD after closed reduction (CR) in children with developmental dislocation of the hips (DDH) over 12 months of age. In this study, we assessed the percentage of RHD in DDH patients aged 12 to 18 months *vs.* that in DDH patients aged over 18 months after CR and determine the predictors of RHD. Meanwhile, we tested the reliability of our RHD criteria compared with Harcke standard.

Methods: Patients over 12 months of age who underwent successful CR from October 2011 to November 2017 and followed up for at least 2 years were enrolled. Gender, affected side, age at CR and follow-up time were recorded. Acetabular index (AI), horizontal acetabular width (AWh), center-to-edge angle (CEA), and femoral head coverage (FHC) were measured. The cases were divided into two groups according to whether older than 18 months. RHD was determined according to our criteria.

Results: A total of 82 patients (107 hips) were included, including 69 females (84.1%), 13 males (15.9%), 25 patients (30.5%) with bilateral DDH, 33 patients (40.2%) with left side, 24 patients (29.3%) with right side, 40 patients (49 hips) with age 12–18 months, and 42 patients (58 hips) with age >18 months. At a mean follow-up of 47.8 [24–92] months, the percentage of RHD was higher in patients >18 months of age (58.6%) than patients 12–18 months of age (40.8%), but the difference was not statistically significant. Binary logistic regression analysis showed that pre-AI, pre-AWh, and improvement in AI and AWh (P=0.025, 0.016, 0.001, 0.003, respectively) had significant difference. The sensitivity and specialty of our RHD criteria were 81.82% and 82.69%, respectively.

Conclusions: For patients with DDH over 18 months, CR is still a choice. We documented four predictors of RHD, suggesting that we should focus on the developmental potential of an individual's acetabulum. Our RHD criteria may be one of the reliable and useful tools in clinical practice to help determine whether to perform continuous observation or surgery, but further research is needed due to limited sample size and follow-up time.

Keywords: Developmental dislocation of the hip (DDH); residual hip dysplasia (RHD); acetabulum development; closed reduction (CR)

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Introduction

Closed reduction (CR) is one of the most common procedures for treating late-detected developmental dislocation of the hips (DDH) (1), considering a marked trend toward spontaneous improvement of the hips after reduction (2-4). However, CR or open reduction (OR) for DDH during walking age remains controversial and the upper age limit for CR is unclear (1,5,6). The proponents of CR believed that OR as a more invasive procedure may cause hip movement limitation, and the most important thing is that hip at this stage still has potential for development (7). The opponents of CR insisted that the high incidence of re-dislocation and the need for secondary surgery caused by residual hip dysplasia (RHD) (8). Although it is well accepted that CR is preferred over OR in children under 18 months, it might be subjective that concerns of the possibility of RHD lead to recommend OR in older 18 months children (7-9). Based on this, we used 18 months as a threshold to see if there was a difference between the two age groups.

RHD represents one of the most frequent causes of secondary osteoarthritis of the hip and it happens when the interaction between the natural remodeling forces of the hip and initial treatment fails (10). Although RHD is not rare, there is no consensus on the diagnostic criteria of RHD (11,12). In fact, the current definition itself relies on old concepts and ideas on the basis of pelvic radiographs that reflect only parts of the anatomic reality and are not treatment oriented (10). Harcke (11) and Severin (13) criteria are commonly used to determine RHD, but both of them had limitations. In our institution, we defined RHD with an acetabular index (AI) greater than or equal to 28° and/or a femoral head coverage (FHC) less than or equal to 70% at 4–5 years old and pelvic osteotomy is indicated if RHD diagnosed.

RHD prediction before osseous acetabular maturity is an accurate evaluation of acetabular remodeling and growth potential (10). To establish early and reliable predictors of RHD, several radiographic parameters have been investigated such as AI, center-to-edge angle (CEA), centre-head distance discrepancy (CHDD) and teardrop and sourcil line (TSL) (12-17). However, prediction of RHD remains controversial, because these parameters have some limitations and RHD on radiographs alone may underestimate the residual growth potential, leading in some cases to overtreatment (10). Recent study has shown a high incidence of RHD after CR in children older than 12 months (18), and there is no research focus on the risk factors of RHD after CR who are older than 12 months old specifically.

In this study, we compared the percentage of RHD in 12–18-month-old *vs.* over 18-month-old DDH patients after CR and evaluated acetabular development and limbus improvement. Furthermore, we attempted to determine correlated factors and predictors of RHD in walking-age patients and the reliability of our RHD criteria. We present the following article in accordance with the STROBE reporting checklist (available at https://tp.amegroups.com/article/view/10.21037/tp-22-299/rc).

Highlight box

Key findings

- The potential of individual acetabulum development is the key point for avoiding RHD after CR in DDH patients over one year old.

What is known and what is new?

- The percentage of RHD was no statistical difference in patients >18 months of age compared with patients 12–18 months of age.
- There were four predictors of RHD after CR in DDH patients over one year old, including preoperative AI, preoperative AWh, and improvement in the AI and AWh.
- It might be a reliable criterion to evaluate RHD after CR that is AI ≥28° and/or a FHC ≤70% at 4–5 years old.

What is implication, and what should change now?

- The individual development of acetabulum index and width before and after CR should be monitored to evaluate the optimal timing of secondary surgery for RHD in DDH patients.

Methods

The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Children's Hospital of Fudan University Ethics Committee (No. 2015181), and informed consent for this retrospective analysis was waived by the ethics

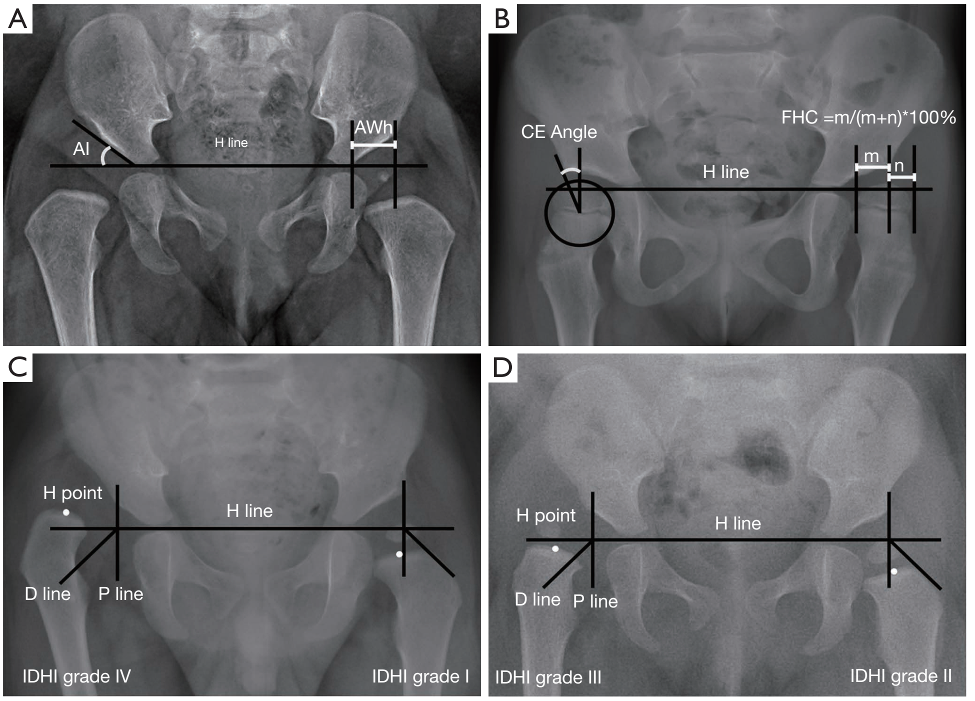

Figure 1 Radiographic measurement on pelvic anteroposterior view. The measurement of AI, AWh, CEA and FHC (A and B); the IHDI classification grades severity from Grade I as the mildest type to Grade IV as the most severe type of hip dislocation (C and D). AI, acetabular index; AWh, horizontal acetabular width; CEA, center-to-edge angle; FHC, femoral head coverage; IHDI, International Hip Dysplasia Institute.

committee. One hundred and forty-nine patients over 12 months of age who underwent CR for DDH in our hospital between October 2011 and December 2017 were retrospectively reviewed. The exclusion criteria were as follows: (I) CR failure (8 cases), (II) follow-up <2 years (16 cases), (III) avascular necrosis of femoral head (31 cases), (IV) under 48 months of age at last follow-up (11 cases), (V) neuromuscular diseases (1 case). Finally, a total of 82 patients (107 hips) were included, and gender, affected side, age at CR and follow-up time were recorded. The cases were divided into two groups based on whether they were older than 18 months.

CR procedure

In brief, no traction was performed before surgery. CR was achieved under general anesthesia by gentle manipulation after bilateral percutaneous adductor tenotomy. The reduced hips were maintained at hip flexion 90° to 100° and abduction 40° to 50° by a spica cast for three months, and an abduction brace was then used for another three to six months.

MRI evaluation

All MRI scans were performed on the same digital scanner (SimensAvanto 1.5T MRI, Germany). After sedative administration, the scan was performed in either the supine position with neutral lower extremities before reduction or in a hip-spica cast within 72 hours post-reduction and three months in the spica at the end of cast treatment.

Follow-up

After the CR, each patient was followed up at a fixed time points (1.5, 3, and 6 months after reduction, then once per year). Bilateral hip motion and lower extremity length were assessed at each visit. We performed standard anteroposterior (AP) pelvic radiographs at each follow-up time.

Radiographic assessment

Retrospective medical images were derived from the picture archiving and communication system (PACS; GE Healthcare RIS/PACS, USA). The AI, horizontal

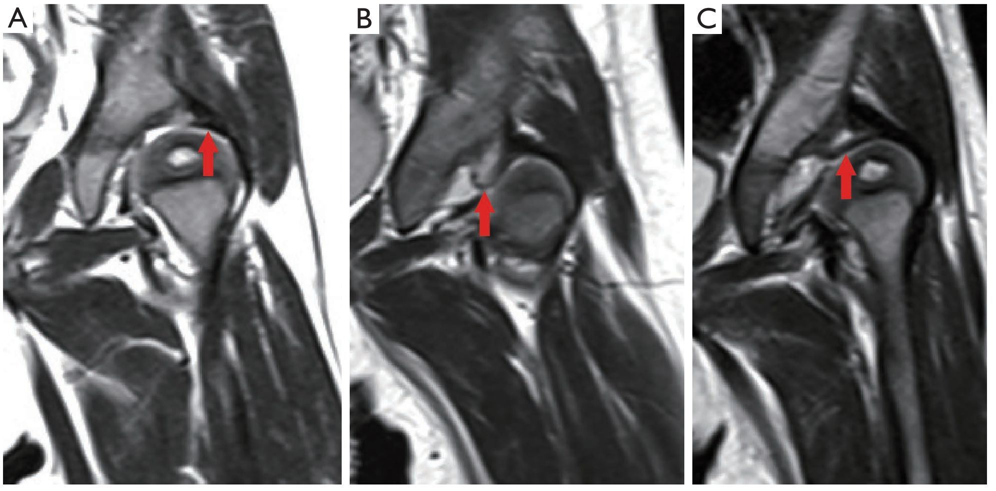

Figure 2 Classification of limbus. Limbus was analyzed on coronal T2 weighted MRI image and classified as inverted (A); everted (B); and mixed (C). The red arrows pointed out limbus.

acetabular width (AWh), CEA and FHC were measured on AP pelvic radiographs (*Figure 1A,1B*). Hip dislocation was categorized according to the International Hip Dysplasia Institute (IHDI) classification (*Figure 1C,1D*). Limbus was analyzed on coronal T2 weighted MRI and classified as inverted, everted, or mixed (*Figure 2*). RHD was determined according to our criteria (AI ≥28° and/or a FHC ≤70% at 4–5 years old). Measurements and imaging review were performed three times with a two-week interval by one orthopedic surgeon blinded to the patient history. The mean value was taken as final result.

Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics (version 26.0; IBM, USA). Student's *t*-test was used for comparing continuous variables, and the chi-squared test was used for comparing categorical variables. Correlation analysis was performed by the Spearman method. Binary logistic regression was used to determine the predictive variables. These variables were included to the model one at a time, and P<0.1 were included in the multivariate regression analysis using Enter method. Odds ratios and 95% CIs from the binary logistic regression models were used to identify predictors of RHD. The level of agreement in the diagnostic indicators for RHD was assessed by kappa coefficients; values ≤0.40 represented poor agreement; values between 0.41–0.60 represented moderate; values between 0.61–0.80 represented good agreement; and values over 0.80 represented excellent agreement. The level of significance was set at P≤0.05.

Results

Cohort characteristics

A total of 82 patients (107 hips) with a mean age of 18.8±3.8 months (range, 12–32 months). Sixty-nine patients were girls (84.1%), and 13 (15.9%) were boys. Twenty-five patients (30.5%) had bilateral DDH, 33 patients (40.2%) on the left side, and 24 patients (29.3%) on the right side. The mean follow-up was 47.8±16.6 months (range, 24–92 months). According to the IHDI classification, there were 4 hips of type II (3.7%), 45 hips of type III (42.1%), and 58 hips of type IV (54.2%).

Demographic and radiographic characteristics and percentage of RHD in the two groups

The 82 patients were divided into two groups: 12–18 months of age (40 patients with 49 hips) and >18 months (42 patients with 58 hips). There were no significant differences in sex, involved side, or pre-operative AI (pre-AI) between the two groups. However, there were significant differences in the pre-operative AWh (pre-AWh). The 12–18 months group primarily had IHDI grade III (8.2% grade II, 63.3% grade III, and 28.6% grade IV), while the majority of grade IV hips were in >18 months group (24.1% grade III and

Table 1 Demographic and radiographic characteristics of two groups

Characteristics	12–18 months	>18 months	P value
Patients, n	40	42	
Hips, n	49	58	
Gender, n			0.316
Female	32	37	
Male	8	5	
Side, n			0.179
Left	16	17	
Right	15	9	
Bilateral	9	16	
Pre-AI (mean ± SD, degree)	36.1±4.4	35.9±3.6	0.819
Pre-AWh (mean ± SD, cm)	1.2±1.8	1.3±1.8	0.026
IHDI, n			<0.001
II	4	0	
III	31	14	
IV	14	44	
Follow-up (mean ± SD, months)	50.99±16.89	44.82±15.85	0.092

Pre-AI, pre-operative acetabular index; Pre-AWh, pre-operative horizontal acetabular width; IHDI, International Hip Dysplasia Institute; SD, standard deviation.

75.9% grade IV). Chi-squared testing revealed a significant difference in IHDI grade classification between the two groups (P<0.001) (*Table 1*).

At the last follow-up, the mean improvement in the AI was approximately 11° (11.2°±5.2°) in patients 12–18 months *vs.* 10° (9.9°±5.5°) in patients >18 months. The difference between the two groups was not significant (P=0.106) (*Figure 3A*). The mean improvement in the AWh was 1.4 cm (1.4±0.3 cm) in patients 12–18 months *vs.* 1.3 cm (1.3±0.3 cm) in patients >18 months, and the difference was significant (P=0.008) (*Figure 3B*). There was no significant difference in the incidence of RHD (P=0.066) between patients aged 12–18 months (40.8%) and in patients aged >18 months (58.6%) (*Figure 4*).

Limbus observation in the patients before and after CR

We defined improvement of limbus as a change of inverted limbus to mixed or everted. Full serial MRI images were obtained for a total of 51 patients (65 hips) during follow-up. The IHDI classification of the 65 hips was 3 grade II, 28 grade III, and 34 grade IV. Initially, limbus was inverted in 52 hips (80.0%), mixed in 7 (10.8%), and everted in 6 (9.2%). Within 48 h after CR, there were 33 cases of inverted (50.8%), 25 cases of mixed (38.5%), and 7 cases of everted limbus (10.8%); three months later, MRI showed 8 inverted (12.3%), 20 mixed (30.8%), and 37 everted cases (56.9%) (*Table 2*).

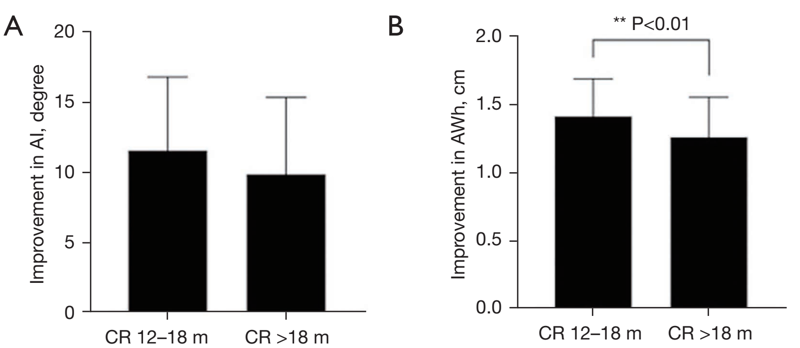

Figure 3 Acetabular development in two groups after CR. The improvement of AI showed no significant difference between two groups (A). However, the improvement of AWh was better in patients 12–18 months compared with patients >18 months (B). CR, closed reduction; AI, acetabular index; AWh, horizontal acetabular width.

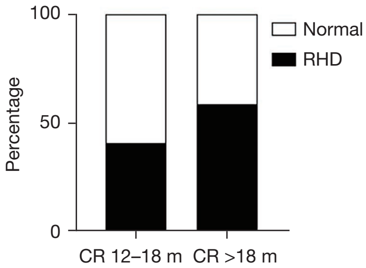

Figure 4 The incidence of RHD after CR in two groups. The percentage of RHD was no significant difference between two groups based on our criteria. RHD, residual hip dysplasia; CR, closed reduction.

Table 2 Limbus observation on MRI (51 patients, 65 hips)

IHDI	Inverted	Mixed	Everted
Pre-CR			
II	0	0	3
III	20	5	3
IV	32	2	0
Within 48 hours after CR	33	25	7
3 months after CR	8	20	37

Pre-CR, pre-operative closed reduction; IHDI, International Hip Dysplasia Institute.

Correlated factors of RHD in DDH patients at aged over 12 months after CR

Several factors were involved in correlation analysis of RHD, including age, sex, involved side, IHDI classification, pre-AI, pre-AWh, and improvement in the AI, AWh and limbus. The results showed that RHD was significantly related to pre-AI (P=0.04), pre-AWh (P=0.031), IHDI classification (P=0.004), improvement in AI (P=0.000) and AWh (P=0.000), specifically. There was no relationship between RHD and limbus improvement (P=0.926) (*Table 3*).

Predictors of residual acetabular dysplasia

We identified age at CR [P=0.044, 1.117 (1.003–1.244)], pre-AI [P=0.015, 1.146 (1.027–1.28)], pre-AWh [P=0.029, 0.079 (0.009–0.767)], IHDI classification (P=0.088), and improvement in AI [P=0.000, 0.837 (0.764–0.917)] and AWh [P=0.002, 0.074 (0.015–0.371)] as potential predictors of RHD. Furthermore, multiple binary logistic regression analysis was used to determine the relationship between the significant univariate predictors of RHD. Lastly, four significant predictors, pre-AI [P=0.025, 1.225 (1.025–1.464)], pre-AWh [P=0.016, 0.006 (0.000–0.384)], and improvement in AI [P=0.001, 0.795 (0.698–0.906)] and AWh [P=0.003, 0.026 (0.002–0.296)], remained as statistical significance factors.

Table 3 Correlation analysis between various parameters and RHD

	P value	Correlation coefficient
Improvement in limbus	0.926	0.012
Age at CR (months)	0.056	0.186
Gender	0.564	–0.056
Side	0.780	–0.027
Pre-AI (degree)	0.040	0.199
Pre-AWh (cm)	0.031	–0.209
IHDI	0.004	0.274
Improvement in AI (degree)	0.000	–0.395
Improvement in AWh (cm)	0.000	–0.336

RHD, residual hip dysplasia; CR, closed reduction; Pre-AI, pre-operative acetabular index; Pre-AWh, pre-operative horizontal acetabular width; IHDI, International Hip Dysplasia Institute.

Reliability of our RHD criteria

We determined the sensitivity, specificity, positive and negative predictive value of our RHD criterion with respect to the Harcke evaluation (10) (*Figure 5*). The kappa coefficient showed good agreement between the Harcke standard and our RHD criteria (Kappa coefficient =0.645). There was no significant difference between the two kinds of RHD criteria (P=1.00).

Discussion

The acetabulum has the potential to recover and continue to develop after a concentric and stable reduction in DDH (19-22). CR is generally attempted as the first line of treatment prior to OR in patients between 6–24 months old in our institution. Recent studies have shown high rates of RHD following CR of between 35% and 58%, especially in older than 12 months old (18,23,24). Therefore, our goal was to review the children over 12 months old treated with CR and analyze the possible related factors and predictors

A

Harcke RHD criteria

Age (y)	AI (°)	CEA (°)
4–8	–	<15

Our RHD criteria

Age (y)	AI (°)	and & or	FHC (%)
4–5	≥28		≤70

B

Reliability of our RHD criteria

		95% CI
Sensitivity	0.8182	0.6865–0.9048
Specificity	0.8269	0.6918–0.9131
PPV	0.8333	0.7021–0.9164
NPV	0.8113	0.6759–0.9011

Figure 5 The reliability of our RHD criteria compared with Harcke standard. Harcke standard and our criteria to define RHD (A). Comparing with Harcke evaluation, we showed the sensitivity, specificity, positive and negative predictive value of our RHD criterion (B). RHD, residual hip dysplasia; AI, acetabulum index; CEA, center-to-edge angle; FHC, femoral head coverage; PPV, positive predictive value; NPV, negative predictive value.

of RHD, to further evaluate the reliability of our RHD criteria.

Our results did not show that the AI was significantly different between 12–18-month-old patients (mean 36.1°) and >18-month-old patients (mean 35.9°) before CR. Terjesen *et al.* (4) reviewed 49 patients (52 hips) in the age range of 3–33 months and showed that the mean AI at the time of diagnosis was lower in children younger than 18 months (36.3°) than in older children (40.1°). This difference might be explained by the enrollment of patients younger than 12 months old in their study. After CR, the acetabulum showed development, and the mean improvement in AI was similar in the two groups at the last follow-up (mean 11.6° for patients aged 12–18 months and mean 9.9° for patients aged >18 months). Consistent with the data of Terjesen *et al.* (4,25), they documented a pronounced reduction during the first year, with no significant difference between age at reduction for the 12–18 months and >18 months groups (12.4° *vs.* 13.4°).

In addition to the decrease in the AI, the AWh also increased after CR. Although the AWh was deeper in patients aged >18 months (mean 1.3 cm) than in those aged 12–18 months (mean 1.2 cm) before CR, the improvement in AWh was greater in the latter group (mean improvement 1.4 *vs.* 1.3 cm). The majority of authors measured acetabular width by a line connecting the superolateral and inferomedial edges of the acetabulum (26,27). However, the inferomedial edge is not easily identified in radiographs from younger children. In our institution, we draw two vertical lines, one line passing through the lateral edge of the acetabulum and one passing the medial edge of the acetabulum, to measure so-called AWh. Our data indicate that the improvement in AWh was greater in younger walking-age patients.

We found that only 3.7% of patients had IHDI grade II hips, and most of the patients had grade III or IV hips in our study. Ramo *et al.* (28) showed similar results in patients with walking-age DDH. In our study, the majority of IHDI grade IV hips were seen in patients >18 months, which might have been caused by walking duration.

The percentage of RHD was higher in patients >18 months of age (58.6%) than patients 12–18 months of age (40.8%), but the difference was not statistically significant. Terjesen *et al.* (4) reported that the frequency of RHD was higher in children aged >18 months at reduction than in children younger than 18 months; however, as stated above, their study included patients younger than 12 months old. The results from Albinana *et al.* (12) indicated that the age of patients determines the subsequent remodeling in the AI. We did not observe a difference in the improvement in the AI after CR in the two walking-age groups. The probable prognosis of CR in patients >18 months could be similar to that in patients 12–18 months.

Limbus can become inverted and then interposed between the femoral head and acetabular surface and obstruct concentric reduction of dislocated hips (29-32). Some authors recommended OR if inverted limbus prevents concentric reduction during arthrography-guided CR. However, Severin stated that OR is not necessary, as serial arthrograms demonstrated remodeling of the soft tissue

(11,33). We observed serial spontaneous improvement of limbus after CR in 65 hips. One-third of inverted limbus cases improved to mixed or everted within 72 hours after CR. Almost 85% of inverted limbus cases spontaneously improved three months after CR. Studer *et al.* (29). Found that 37% of the hip remained in subluxated reduction, and limbus was interpreted as inverted and acted as the main obstacle; however, the authors did not perform MRI of the hip before CR. Our data revealed evidence confirming the suggestion of Studer *et al.* (29), who believed that inverted limbus might resolve with time. In the study by Hattori *et al.* (34), inverted limbus disappeared in 71% of patients by the age of five years. Our results suggested that inverted limbus could improve even earlier.

Furthermore, we attempted to determine the relationship between various parameters and RHD. Our results showed that RHD could be expected in patients with a larger AI or a shorter AWh before CR but avoided in patients with greater improvement in AI and AWh after CR, and the severity of dislocation was related with RHD either. Some authors (35-37) considered it necessary to correct inverted limbus to improve outcome; however, our data did not show a relationship between RHD and improvement in limbus.

Different predictors for residual dysplasia have been reported (12,14-16). A multicenter study (38) showed that AI was one of the best predictors of RHD after CR. Terjesen *et al.* (4) considered high AI and reduced FHC the first years after reduction to be predictors. Kawamura *et al.* (37) documented that acetabular depth was a predictor at walking age. Our results showed that pre-AI, pre-AWh, and improvement in AI and AWh after CR in patients at walking age were predictors of RHD.

If development of the acetabulum is unsatisfactory after reduction, subsequent surgery such as pelvic osteotomy and/or femoral osteotomy can be used to correct RHD, but the indications and timing of such operations differ considerably (4). Albinana *et al.* (12) suggested that the younger a child at the time of osteotomy, the less complicated the procedure and recovery would be. Morris *et al.* (18) performed secondary surgery on patients between 3 and 7 years old. We preferred to perform a secondary procedure when the potential of remodeling mostly remained stable, based on the marked spontaneous improvement of the acetabulum after reduction (12,37).

Kim *et al.* (39) reported that these radiographic parameters (such as AI, FHC, CEA, etc.) alone have at least a 20% error in predicting patient prognosis. We considered that the FHC and AI might together represent the congruity of the hip joint. Severin (13) and Harcke (11) criteria are commonly used to determine RHD, and CEA is measured in these two criteria. Both CEA and FHC reflect the coverage of femoral head, in contrast to CEA, FHC does not require identification of the exact point at the center of the femoral head especially in patients suffer from avascular necrosis of femoral head. Meanwhile, Severin criteria only applies to children over 6 years old. In this study, we defined RHD with an AI ≥28° and/or an FHC ≤70% at 4–5 years old in our institution, and our RHD criteria show good agreement and reliability compared to Harcke criteria.

The current study had limitations due to its retrospective nature, its comparison between two groups at one tertiary center, and its limited follow-up time. Secondly, it is assumed that the larger the sample size, the better the binary logistic regression is. However, patients with DDH older than 12 months had lower performance after early screening for DDH. Thirdly, follow-up bias may influence the data on the improvement in the AI and AWh. Finally, consensus has yet to be reached on indicators for RHD and secondary corrective surgery.

Conclusions

In conclusion, we showed similar percentage of RHD in 12–18-month-old *vs.* over 18-month-old DDH patients after CR. Inverted limbus could be improved after CR, but this improvement was not related to RHD. We documented four predictors of RHD, including pre-AI, pre-AWh, and improvement in the AI and AWh, which might indicate that we should focus on potential of individual acetabulum development. These predictors are easy to measure and could be available for DDH patients at any age in clinical practice. We also introduced a reliable RHD criterion and it might be an indicator of further osteotomy surgery; however, additional prospective studies are necessary to validate our RHD criteria in the future.

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Footnote

Reporting Checklist: The authors have completed the

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Data Sharing Statement: Available at https://tp.amegroups.com/article/view/10.21037/tp-22-299/dss

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://tp.amegroups.com/article/view/10.21037/tp-22-299/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Children's Hospital of Fudan University Ethics Committee (No. 2015181) and informed consent for this retrospective analysis was waived by the ethics committee.

References

1. Shipman SA, Helfand M, Moyer VA, et al. Screening for developmental dysplasia of the hip: a systematic literature review for the US Preventive Services Task Force. Pediatrics 2006;117:e557-76.
2. Jadhav SP, More SR, Shenava V, et al. Utility of immediate postoperative hip MRI in developmental hip dysplasia: closed vs. open reduction. Pediatr Radiol 2018;48:1096-100.
3. Schoenecker PL, Dollard PA, Sheridan JJ, et al. Closed reduction of developmental dislocation of the hip in children older than 18 months. J Pediatr Orthop 1995;15:763-7.
4. Terjesen T, Horn J. Management of late-detected DDH in children under three years of age: 49 children with follow-up to skeletal maturity. Bone Jt Open 2020;1:55-63.
5. Cooper AP, Doddabasappa SN, Mulpuri K. Evidence-based management of developmental dysplasia of the hip. Orthop Clin North Am 2014;45:341-54.
6. Sharpe P, Mulpuri K, Chan A, et al. Differences in risk factors between early and late diagnosed developmental dysplasia of the hip. Arch Dis Child Fetal Neonatal Ed 2006;91:F158-62.
7. Tomlinson J, O'Dowd D, Fernandes JA. Managing Developmental Dysplasia of the Hip. Indian J Pediatr 2016;83:1275-9.
8. Kotlarsky P, Haber R, Bialik V, et al. Developmental dysplasia of the hip: What has changed in the last 20 years? World J Orthop 2015;6:886-901.
9. Race C, Herring JA. Congenital dislocation of the hip: an evaluation of closed reduction. J Pediatr Orthop 1983;3:166-72.
10. Mansour E, Eid R, Romanos E, et al. The management of residual acetabular dysplasia: updates and controversies. J Pediatr Orthop B 2017;26:344-9.
11. Zhang ZL, Fu Z, Yang JP, et al. Intraoperative Arthrogram Predicts Residual Dysplasia after Successful Closed Reduction of DDH. Orthop Surg 2016;8:338-44.
12. Albinana J, Dolan LA, Spratt KF, et al. Acetabular dysplasia after treatment for developmental dysplasia of the hip. Implications for secondary procedures. J Bone Joint Surg Br 2004;86:876-86.
13. Ward WT, Vogt M, Grudziak JS, et al. Severin classification system for evaluation of the results of operative treatment of congenital dislocation of the hip. A study of intraobserver and interobserver reliability. J Bone Joint Surg Am 1997;79:656-63.
14. Lindstrom JR, Ponseti IV, Wenger DR. Acetabular development after reduction in congenital dislocation of the hip. J Bone Joint Surg Am 1979;61:112-8.
15. Kitoh H, Kitakoji T, Katoh M, et al. Prediction of acetabular development after closed reduction by overhead traction in developmental dysplasia of the hip. J Orthop Sci 2006;11:473-7.
16. Gotoh E, Tsuji M, Matsuno T, et al. Acetabular development after reduction in developmental dislocation of the hip. Clin Orthop Relat Res 2000;(378):174-82.
17. Huang P, Wang D, Mo Y, et al. Teardrop and sourcil line (TSL): a novel radiographic sign that predicts residual acetabular dysplasia (RAD) in DDH after closed reduction. Transl Pediatr 2022;11:458-65.
18. Morris WZ, Hinds S, Worrall H, et al. Secondary Surgery and Residual Dysplasia Following Late Closed or Open Reduction of Developmental Dysplasia of the Hip. J Bone Joint Surg Am 2021;103:235-42.

19. Forlin E, Choi IH, Guille JT, et al. Prognostic factors in congenital dislocation of the hip treated with closed reduction. The importance of arthrographic evaluation. J Bone Joint Surg Am 1992;74:1140-52.
20. Noritake K, Yoshihashi Y, Hattori T, et al. Acetabular development after closed reduction of congenital dislocation of the hip. J Bone Joint Surg Br 1993;75:737-43.
21. Pemberton PA. Pericapsular osteotomy of the ilium for the treatment of congenitally dislocated hips. Clin Orthop Relat Res 1974;(98):41-54.
22. Zionts LE, MacEwen GD. Treatment of congenital dislocation of the hip in children between the ages of one and three years. J Bone Joint Surg Am 1986;68:829-46.
23. Bolland BJ, Wahed A, Al-Hallao S, et al. Late reduction in congenital dislocation of the hip and the need for secondary surgery: radiologic predictors and confounding variables. J Pediatr Orthop 2010;30:676-82.
24. Luhmann SJ, Bassett GS, Gordon JE, et al. Reduction of a dislocation of the hip due to developmental dysplasia. Implications for the need for future surgery. J Bone Joint Surg Am 2003;85:239-43.
25. Terjesen T, Halvorsen V. Long-term results after closed reduction of latedetected hip dislocation: 60 patients followed up to skeletal maturity. Acta Orthop 2007;78:236-46.
26. Ayanoglu T, Ataoglu MB, Tokgöz N, et al. Assessing the risk of asymptomatic dysplasia in parents of children with developmental hip dysplasia. Acta Orthop Traumatol Turc 2019;53:346-50.
27. Maranho DA, Ferrer M, Kalish LA, et al. The acetabulum in healed Legg-Calvé-Perthes disease is cranially retroverted and associated with global reduction of femoral head coverage: a matched-cohort study. J Hip Preserv Surg 2020;7:49-56.
28. Ramo BA, De La Rocha A, Sucato DJ, et al. A New Radiographic Classification System for Developmental Hip Dysplasia is Reliable and Predictive of Successful Closed Reduction and Late Pelvic Osteotomy. J Pediatr Orthop 2018;38:16-21.
29. Studer K, Williams N, Studer P, et al. Obstacles to reduction in infantile developmental dysplasia of the hip. J Child Orthop 2017;11:358-66.
30. Landa J, Benke M, Feldman DS. The limbus and the neolimbus in developmental dysplasia of the hip. Clin Orthop Relat Res 2008;466:776-81.
31. Rosenbaum DG, Servaes S, Bogner EA, et al. MR Imaging in Postreduction Assessment of Developmental Dysplasia of the Hip: Goals and Obstacles. Radiographics 2016;36:840-54.
32. Drummond DS, O'Donnell J, Breed A, et al. Arthrography in the evaluation of congenital dislocation of the hip. Clin Orthop Relat Res 1989;(243):148-56.
33. SEVERIN E. Congenital dislocation of the hip; development of the joint after closed reduction. J Bone Joint Surg Am 1950;32-A:507-18.
34. Hattori T, Ono Y, Kitakoji T, et al. Soft-tissue interposition after closed reduction in developmental dysplasia of the hip. The long-term effect on acetabular development and avascular necrosis. J Bone Joint Surg Br 1999;81:385-91.
35. Fujii M, Mitani S, Aoki K, et al. Significance of preoperative position of the femoral head in failed closed reduction in developmental dislocation of the hip: surgical results. J Orthop Sci 2004;9:346-53.
36. Takagi T, Mitani S, Aoki K, et al. Three-dimensional assessment of the hip joint by two-directional arthrography. J Pediatr Orthop 2002;22:232-8.
37. Kawamura Y, Tetsunaga T, Akazawa H, et al. Acetabular depth, an early predictive factor of acetabular development: MRI in patients with developmental dysplasia of the hip after open reduction. J Pediatr Orthop B 2021;30:509-14.
38. Li Y, Guo Y, Li M, et al. Acetabular index is the best predictor of late residual acetabular dysplasia after closed reduction in developmental dysplasia of the hip. Int Orthop 2018;42:631-40.
39. Kim HT, Kim IB, Lee JS. MR-based parameters as a supplement to radiographs in managing developmental hip dysplasia. Clin Orthop Surg 2011;3:202-10.

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