Prediction of the requirement of open reduction for developmental dysplasia of the hip

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Abstract

Objective: Closed reduction (CR) is a noninvasive treatment for developmental dysplasia of the hip (DDH), and this treatment is confirmed intraoperatively. This study aimed to develop a preoperative estimation model of the probability of requiring open reduction (OR) for DDH.

Methods: The study design was cross-sectional by screening all patients younger than 2 years who had attempted CR between October 2012 and July 2016 by a single surgeon. Potential diagnostic determinants were sex, age, side, bilaterality, International Hip Dysplasia Institute (IHDI) grade, and acetabular index (AI). An intraoperative arthrogram was the reference standard. A logistic regression equation was built from a reduced model. Bootstrapping was performed for internal validity.

Results: A total of 164 hips in 104 patients who met the inclusion criteria were analysed. The prevalence of CR was 72.2%. Independent factors for OR were older age, higher IHDI grade, and lower AI. The probability of OR = 1/[1 + exp (−2.753 + 0.112 × age (months) + 1.965 × IHDI grade III (0 or 1) + 3.515 × IHDI grade IV (0 or 1) − 0.058 × AI (degrees))]. The area under the curve was 0.79.

Conclusion: This equation is an objective tool that can be used to estimate the requirement for OR.

Keywords

Hip dysplasia, congenital hip dislocation, arthrography, closed reduction, children, International Hip Dysplasia Institute (IHDI) grade

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Introduction

In developmental dysplasia of the hip (DDH), closed reduction (CR) in the operating room continues to be a useful procedure up to the age of 18–24 months.1 Splinting may be first applied to dysplastic
or mildly subluxated hips. However, open reduction (OR) is performed if splinting and CR fail. The long-term outcomes of both treatment modalities are comparable. Because of concerns related to adequacy of acetabular remodelling in older children, only a few centres perform CR after the age of 2 years.

There are several intra- and postoperative aids for decision-making that are mainly based on arthrographic and axial images. Recently, ultrasonography has been used. One or more of these modalities are used to confirm the success of CR. There is limited information available in the literature regarding the added value of preoperative plain radiographs in predicting achievable CR.

The operative time varies considerably between CR and OR. Moreover, parents often seek to be enlightened about the invasiveness of the proposed intervention. This study aimed to develop an objective diagnostic tool to predict the type of reduction for DDH that is based on readily available clinical information.

**Patients and methods**

**Selection of patients**

A cross-sectional study was performed. The study was approved by the institutional review board at King Fahad Medical City (log number: 14-245) and patients’ consent was waived. Data were collected from a single surgeon’s practice. Consecutive patients with DDH who underwent attempted CR between October 2012 and July 2016 were enrolled. Inclusion criteria were the diagnosis of DDH, age younger than 2 years, and International Hip Dysplasia Institute (IHDI) grade II or higher (Figure 1).

In the CR group, there was clear evidence of successful reduction besides an initial intraoperative arthrogram. We performed post-reduction computed tomography (CT) and / or an arthrogram showing concentric reduction during cast change. In the OR group, all of the patients were screened for evidence of attempted CR before inclusion. Patients with preoperative ultrasound and no plain films were excluded. We did not include teratological or neuromuscular hips.

**Treatment**

CR was performed under general anaesthesia with the aid of a standard arthrogram. The arthrogram was performed by injecting 2–3 mL of contrast material (diluted 1:1) inferior to or through the adductor longus tendon. The adequacy of CR was determined based on whether the limbus was simply obstructive. Only a thin line of dye pooling was accepted, where the femoral head was under the limbus. After the CR procedure, percutaneous adductor tenotomy was performed. CR was abandoned if the safe zone of Ramsey remained noticeably narrow after adductor release or if the Ortolani manoeuvre was felt to be forceful. The reduction was followed by...
application of a hip spica cast in the human position with a gentle posterior mold at the greater trochanteric region. Fluoroscopy images were obtained before the patients left the operating room. Only two patients (four hips) needed Kirschner wires to maintain concentric reduction, with one in each diagnostic group. The cast was used for 3–4 months and was changed at least once under general anaesthesia. All of the patients wore a Craig abduction splint full-time for 6 weeks and overnight after this time. None of the patients had preoperative overhead traction. In cases in which CR failed, the patient underwent OR during the same operative session. Adequacy of reduction was based on the equivalent of Shenton’s line as observed on axial images.

**Potential predictors**

Charts were reviewed for information on the patient’s age, sex, side, bilaterality, operative details, and complications. Preoperative anteroposterior pelvic radiographs were examined electronically (Centricity PACS; GE Medical Systems, Slough, United Kingdom) to determine the acetabular index (AI) and IHDI grade. Post-reduction images were reviewed to confirm the intraoperative findings.

As a more direct measure of acetabular dysplasia, the AI was measured using the lateral end of the acetabular lip rather than the lateral bony margin of the acetabular roof (Figure 2).17 Reliability of this measurement was reported by Agus et al.18 Predictors that were impractical to obtain in the ambulatory care setting or those that had a subjective interpretation were excluded from this study.

**Statistical analysis**

Data analysis was performed using R software for statistical analysis, version 3.3.1 (R Foundation for Statistical Computing, Vienna, Austria). Pearson’s chi-squared test was used when comparing proportions. For continuous data, normality was assessed visually. Bartlett test used to confirm the homogeneity of variance. The two-sample t-test was then performed. Two-tailed P values of <0.05 were considered to be significant. For development of the prediction model, we used the backward stepwise binary logistic regression model. The final model was chosen manually based on clinical importance, P values, and Akaike’s information criterion. The variance inflation factor (VIF) was added to quantify multicollinearity. The performance of the fitted model was then analysed with the receiver operating characteristic (ROC) curve. A calibration curve was computed.

**Results**

A total of 164 hips in 104 patients (90 girls and 14 boys) were eventually included.
The intervention was bilateral in 60 and unilateral in 44 patients. The left side was reduced in 92 hips and the right side in 72 hips. The mean age was 15.62 ± 5.16 months (range: 5–24 months). CR was achieved in 119 of the 164 hips (72.2%). Three of the bilateral cases had OR on one side and CR on the other side. Table 1 shows univariate analysis of the subgroups. In contrast to age and IHDI grade, sex, bilaterality, side, and AI were not associated with the probability of having CR or OR.

In multivariate analysis (Table 2), the stepwise logistic regression model retained age, IHDI grade, and AI as significant diagnostic variables. An example of this model is that with each month increase in age, there was a 1.12 increase in the odds ratio for OR, and the odds for OR in IHDI grade IV compared with IHDI grade II was 33.61. The odds of requiring OR decreased by 6% for each degree increase in the AI as measured from the lateral end of the acetabular lip.

The highest VIF in the model was 1.09 (Table 2), which is below the accepted higher limit of 2.5. This finding indicated a stable model and no significant multicollinearity. The area under the ROC was 0.79 (Figure 3a). This area ranged between 0.5 to 1.0, and the closer to 1.0, the better the overall discriminative value of the model. Reasonable calibration was observed (Figure 3b), but there was overestimation of the probability of OR for higher values, which we believe is clinically desirable.

Based on the coefficients of independent predictors (Table 2), the derived prediction equation for calculating the probability of OR was determined as follows:

\[
\frac{1 + \exp\left(-2.753 + 0.112 \times \text{age(months)} + 1.965 \times \text{IHDI grade III (absent = 0, present = 1)} + 3.515 \times \text{IHDI grade IV (absent = 0, present = 1)} - 0.058 \times \text{AI (degrees)}\right)}{1 + \exp\left(-2.753 + 0.112 \times \text{age(months)} + 1.965 \times \text{IHDI grade III (absent = 0, present = 1)} + 3.515 \times \text{IHDI grade IV (absent = 0, present = 1)} - 0.058 \times \text{AI (degrees)}\right)}
\]

There were no complications related to the diagnostic tests. One eligible patient had redislocation that occurred after an arthrogram and CR. This redislocation was confirmed in postoperative CT. The patient was treated the following day by OR and

| Table 1. Univariate analysis for potential predictors of open reduction |
|-----------------------------|-------------------|-----------------|-------------|
| Sex                         | Total             | CR (n = 119)    | OR (n = 45) | P value |
| Female                      | 144               | 107             | 37          | 0.28    |
| Male                        | 20                | 12              | 8           |         |
| Age (months)                | 15.62 ± 5.16 (5–24) | 14.96 ± 5.25 (5–24) | 17.38 ± 4.51 (6–23) | 0.004 |
| Side                        |                   |                 |             |         |
| Right                       | 72                | 53              | 19          | 0.93    |
| Left                        | 92                | 66              | 26          |         |
| Bilaterality                |                   |                 |             |         |
| Bilateral                   | 120               | 91              | 29          | 0.18    |
| Unilateral                  | 44                | 28              | 16          |         |
| IHDI grade                  |                   |                 |             |         |
| II                          | 24                | 23              | 1           | <0.001  |
| III                         | 56                | 49              | 7           |         |
| IV                          | 84                | 47              | 37          |         |
| Acetabular index            | 47.76 ± 8.83 (18–72) | 47.94 ± 8.42 (18–72) | 47.27 ± 9.91 (22–63) | 0.68    |

IHDI, International Hip Dysplasia Institute; CR, closed reduction; OR, open reduction.
analysed in the OR group. None of the hips in this study were subluxated or dislocated during the routine follow-up visit; 6 weeks after cast removal.

**Discussion**

This study provides an equation to calculate the probability of the type of reduction required. An older age, high IHDI grade, and low AI were independent predictors for OR. Failed CR and the potential requirement for secondary procedures are probably less detrimental to the long-term outcome than failure of OR. In the present study, CR was attempted in children aged up to 2 years.

Tönnis initially quantified hip displacement into four categories on the basis of the location of the femoral head ossific nucleus. His classification was later modified, reducing the number of classes to three. Because the ossific nucleus is not always present in patients with DDH aged older than 6 months, IHDI classification was used in our study. Several investigations have used femoral head displacement as a prognostic factor, but only a small number of studies have documented its association with successful CR. Bicimoglu et al. performed a study of 137 hips that underwent CR after lengthening of the adductor longus tendon and iliopsoas in patients aged younger than 18 months. They documented an increased rate of OR with higher femoral head displacement in 30% of patients for Tönnis grade 2 and 87% for Tönnis grade 4. They reported no increase in the requirement for OR with age. In the present study, almost all patients with IHDI grade II, 89% with IHDI grade III, and 56% with IHDI grade IV had CR. Luhmann et al. showed that OR procedures were directly associated with age. Recently, Bolland et al. reported more ORs with increased age and Tönnis

| Table 2. Multivariate analyses for predictors of open reduction |
|---------------------------------------------------------------|

| Regression coefficient | 95% CI of the coefficient | Odds ratio | P value | VIF |
|------------------------|---------------------------|------------|---------|-----|
| Intercept (constant)    | -2.753                    |            |         |     |
| Age (months)           | 0.112                     | 0.02 to 0.21| 1.12    | 0.01| 1.08|
| IHDI grade III vs II   | 1.965                     | 0.06 to 4.97| 7.13    | 0.08| 1.03|
| IHDI grade IV vs II    | 3.515                     | 1.78 to 6.47| 33.61   | 0.001| 1.03|
| Acetabular index       | -0.058                    | -0.11 to -0.01| 0.94    | 0.02| 1.09|

IHDI, International Hip Dysplasia Institute; CI, confidence interval; VIF, variance inflation factor.

Figure 3. (a) Receiver operating characteristic (ROC) curve of the model. (b) Calibration curve.
grade. In the present study, patients with hips that required OR showed a significantly older age and higher IHDI grade than those with hips treated with CR. Arthrographic CR of IHDI grade II hips in this age group is controversial. Guidelines of this situation are lacking in the literature, and the choice of CR in the operating room or application of abduction splinting requires clinical judgment. Based on the current findings, we are now performing more abduction splinting and less CR for IHDI grade II.

Despite technological advances in the imaging of dysplastic hips, conventional radiography remains important. Measuring the AI of the lateral end of the acetabular lip was reported by Kim et al. and later examined by Agus et al. Both of these studies resulted in observers’ agreements that were similar to conventional AI. However, the interclass correlation was not reported in these two studies. In the present study, multivariate analysis showed that the higher the AI, the greater the chance of CR. This finding could be partially explained by the possibility that patients with a lower radiographic acetabular lip have a larger overlying fibrocartilaginous ridge. Ponseti described this finding in an autopsy study and suggested that this ridge is formed by pressure of the femoral head on the outer acetabular margin. Because the shape of the labrum was not determined in the present study, the author could not draw a conclusion about its effect on the rate of OR.

In this study cohort, postoperative CT was feasible for confirming the adequacy of hip reduction. Chin et al. reported 100% sensitivity for magnetic resonance imaging (MRI) and CT in detecting postoperative hip displacement, but MRI is more specific. Because of concerns related to ionizing radiation exposure, MRI is becoming the imaging method of choice. Additionally, the follow-up period does not extend beyond the first follow-up visit; however, the incidence of redislocation after this point in time is low. Case et al. found no redislocation in 67 hips 2 months after reduction.

The prediction equation presented here is not intended to replace the reference standard, namely an intraoperative arthrogram by which the adequacy of CR is confirmed. The prior probability calculated from the formula needs to be updated after an arthrogram. Limitations of this study are potential information bias, the sensitivity of the AI to subtle rotation and tilt, and possible differences in the appearance of femoral head migration between supine and standing radiographs. The outcome of the reduced hips in both groups needs to be determined by a future prognostic study.

Determining the probability of needing to perform OR will enable clinicians to perfect the treatment strategy and plan efficient operative care. More research focussing on confirming the association between pre-operative plain radiographic findings and the type of intervention is required.

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Declaration of conflicting interest
The Author declares that there is no conflict of interest.

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References
1. Salter RB. Role of innominate osteotomy in the treatment of congenital dislocation and subluxation of the hip in the older child. J Bone Joint Surg Am 1966; 48: 1413–1439.
2. Severin E. Congenital dislocation of the hip; development of the joint after closed reduction. J Bone Joint Surg Am 1950; 32-A: 507–518.
3. Terjesen T, Horn J and Gunderson RB. Fifty-year follow-up of late-detected hip dislocation: clinical and radiographic outcomes for seventy-one patients treated with traction to obtain gradual closed reduction. J Bone Joint Surg Am 2014; 96: e28–e28.
4. Thomas SR. Outcome at forty-five years after open reduction and innominate osteotomy for late-presenting developmental dislocation of the hip. J Bone Joint Surg Am 2007; 89: 2341.
5. 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: 876–886.
6. Lindstrom JR, Ponseti IV and Wenger DR. Acetabular development after reduction in congenital dislocation of the hip. J Bone Joint Surg Am 1979; 61: 112–118.
7. Samuelson KM, Nixon GW and Morrow RE. Tomography for evaluation of congenital dislocation of the hip while in a Spica cast. J Bone Joint Surg Am 1974; 56: 844–845.
8. Smith BG, Kasser JR, Hey LA, et al. Postreduction computed tomography in developmental dislocation of the hip: part I: analysis of measurement reliability. J Pediatr Orthop 1997; 17: 626–630.
9. Bos CF, Bloem JL, Obermann WR, et al. Magnetic resonance imaging in congenital dislocation of the hip. J Bone Joint Surg Br 1988; 70: 174–178.
10. van Douveren FQ, Pruijis HE, Sakkers RJ, et al. Ultrasound in the management of the position of the femoral head during treatment in a Spica cast after reduction of hip dislocation in developmental dysplasia of the hip. J Bone Joint Surg Br 2003; 85: 117–120.
11. Biçimoglu A, Agus H, Omeroglu H, et al. Six years of experience with a new surgical algorithm in developmental dysplasia of the hip in children under 18 months of age. J Pediatr Orthop 2003; 23: 693–698.
12. 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: 676–682.
13. Narayanan U, Mulpuri K, Sankar WN, et al. Reliability of a new radiographic classification for developmental dysplasia of the hip. J Pediatr Orthop 2015; 35: 478–484.
14. Race C and Herring JA. Congenital dislocation of the hip. J Pediatr Orthop 1983; 3: 166–172.
15. Ramsey PL, Lasser S and MacEwen GD. Congenital dislocation of the hip: use of the Pavlik harness in the child during the first six months of life. J Bone Joint Surg Am 1976; 58-A: 1000–1004.
16. Smith BG. Closed reduction for developmental dislocation of the hip in infants. Tech Orthop 1995; 10: 36–42.
17. Kim HT, Kim JI and Yoo CI. Diagnosing childhood acetabular dysplasia using the lateral margin of the sourcil. J Pediatr Orthop 2000; 20: 709–717.
18. Agus H, Biçimoglu A, Omeroglu H, et al. How should the acetabular angle of Sharp be measured on a pelvic radiograph? J Pediatr Orthop 2002; 22: 228–231.
19. Tang H-C, Lee W-C, Kao H-K, et al. Surgical outcomes of developmental dysplasia of the hip with or without prior failed closed reduction. J Pediatr Orthop 2015; 35: 703–707.
20. Zionts LE and 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: 829–846.
21. 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-A: 239–243.
22. Ponseti IV. Morphology of the acetabulum in congenital dislocation of the hip. Gross, histological and roentgenographic studies. J Bone Joint Surg Am 1978; 60: 586–599.
23. Chin MS, Betz BW and Halanski MA. Comparison of hip reduction using magnetic resonance imaging or computed tomography in hip dysplasia. J Pediatr Orthop 2011; 31: 525–529.
24. 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: 840–854.

25. Case RD, Gargan MF, Grier D, et al. Confirmation of the reduction and containment of the femoral head with CT or MRI scans in DDH: The need for repeated scans. *Hip International* 2000; 10: 118–122.