Original Article

Avascular necrosis predictive factors after closed reduction in patients with developmental dysplasia of the hip

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Background: Developmental dysplasia of the hip (DDH) is a common pediatric orthopedic condition. Closed reduction (CR) is the conservative treatment approach with high success rates for DDH. However, avascular necrosis (AVN) is a severe potential complication after this procedure. This study retrospectively assessed the potential risk factors for AVN occurrence after CR and Spica cast immobilization. **Materials and Methods:** In a retrospective observational study, 71 patients (89 hips) with DDH aged 6–24 months old undergoing CR were enrolled. All patients were followed up for 3 years, and their demographic data, initial Tönnis grade, pre-reduction procedures, abduction angle in the Spica cast, and the AVN presence (based on Bucholz and Ogden classification [3rd–4th class]) were documented. **Results:** Of 71 patients (89 hips) with a mean age of 12.5 ± 3.9 months, 13 patients (18 hips) developed AVN. The mean age of patients in the AVN and non-AVN groups was 14.3 ± 4.9 and 12.2 ± 3 months ($P = 0.07$); also, the mean abduction angle in patients with and without AVN was 51.86 ± 3.66 and 58.46 ± 3.91 ($P < 0.001$) in univariate analysis. The distribution of initial Tönnis grade, and previous conservative procedures, adductor tenotomies during the CR were comparable between the two groups ($P > 0.05$). We found age 12 months and 54° in abduction angle as the best cutoff values for differentiating AVN patients from non-AVN and the risk of experiencing AVN for patients older than 12 months was odds ratio (OR) =4.22 ($P = 0.06$) and patients with abduction angle greater than 54 was OR = 34.88 ($P < 0.001$). **Conclusion:** In this study, older age at the time of intervention and larger abduction angle in the hip Spica cast were two predictors of experiencing AVN in DDH patients after undergoing CR treatment approach. Performing CR at a younger age and keeping the abduction angle lower than 54° in the hip Spica cast could help to have the best possible prognosis. **Level of Evidence:** IV, retrospective, observational, cross-sectional study.

Key words: Closed reduction, congenital hip dislocation, developmental dysplasia of the hip, femur head necrosis, hip

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INTRODUCTION

Developmental dysplasia of the hip (DDH) has a broad spectrum of definitions, from mild dysplasia to very severe dislocations, and it is one of the most common pediatric deformities.[1-4] Female sex, genetics, breech presentation, and incorrect swaddling are introduced as predisposing factors for DDH occurrence.[4-7] Different treatment protocols based on patients' age and severity of dysplasia have been introduced for this condition.[8,9]

If DDH remains untreated or maltreated, it could lead to complications, including subluxation, residual acetabular dysplasia, arthritis, coxa valga, and avascular necrosis (AVN) in older ages.[1,4,10-12] Furthermore, untreated and maltreated DDH is the most common cause of arthritis in women younger than 40 years.[4]

The conservative approach toward DDH in children usually starts with an abduction tool-like Pavlik harness (if the patient is younger than 6 months old), followed by closed reduction (CR) if it remains unreduced.[1] Tenotomy of adductors could also be done if soft-tissue limits the proper abduction needed for a successful reduction.

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Although CR is successful in 95% of the cases, AVN of the femoral head can happen as a serious complication.[13] The reported incidence rate of AVN after CR has been reported to be between 4% and 60% in the literature.[14] Moreover, factors affecting the AVN incidence rate after the CR of patients with DDH are controversial in the literature.[15-17]

In this study, we evaluated the potential risk factors for AVN after CR during a 3-year follow-up. We hypothesized that the Post-CR AVN could be minimized if risk factors of this condition are identified.

MATERIALS AND METHODS

Study design and participants

Ethical approval for this study was obtained from the University's Ethics Committee (code: IR.MUI.MED.REC.1399.283). This retrospective cohort study was conducted on 71 patients (89 hips) with DDH who fulfilled the following inclusion criteria in Kashani Hospital affiliated with Isfahan University of Medical Sciences, Isfahan, Iran. Inclusion criteria were: (1) 6–24 months of age at the time of CR, (2) at least 36 months of follow-up. Exclusion criteria were: (1) teratologic or neuromuscular dysplastic hips (2) closed/opened reduction in other centers before, (3) nonconcentric reduction after CR, and (4) incomplete clinical data.

Study procedures and variables assessment

One skilled pediatric orthopedic surgeon did all the procedures, evaluations, and documentations to prevent potential operator bias.

Tönnis classification system was used to measure the initial severity of the dysplasia as it has been proved to be an acceptable grading system of the pelvic radiograph of DDH based on the ossification of the femoral head.[18] In this classification, DDH grading is based on the position of the femoral proximal ossific nucleus relative to the Perkin line (P-line), which is a perpendicular line from the superior acetabular rim, and the superolateral margin of the acetabulum line (SMA-line). In Grade I, the ossific nucleus is medial to the P-line, while in Tönnis Grade II, the ossific nucleus is lateral to the P-line and below the SMA-line. In Tönnis Grade III, the ossific nucleus is at the level of SMA-line, and in Tönnis Grade IV, the ossification center is above the SMA line.

Intervention

CR was performed by one expert pediatric orthopedic surgeon for all the patients in 90°–100° of hip flexion and neural rotation under general anesthesia and on the Spica frame. The minimal amount of abduction necessary to maintain a stable hip reduction was sustained. The quality of CR was evaluated with arthrography and Ramsey's safe zones definition (more than 35°).[19] Adductor release was performed based on the positivity of the adductor contracture test.

Postoperative protocol

After successful reduction, the hips were immobilized by Spica cast [Figure 1]. Then, the abduction angle in the cast (in 90°–100° of hip flexion and neutral rotation) was measured by one fellowship-trained attending pediatric orthopedic surgeon using goniometer. Measuring the abduction angle in the Spica cast is hard for untrained people as in addition to the normal two axes which constitute the angle itself, it is also affected by the flexion of the hip in the Spica cast. Moreover, it is crucial that this angle be measured within fixed amount of flexion for all of the patients; therefore, we specifically chose to measure the abduction angle with goniometer in the operating room (OR). In addition, to insure that a concentric reduction, without subluxation is achieved, and to prevent further clinical errors, all of the patients underwent a single-section (axial cut) computed tomography scan as well.

Follow-up evaluations

The hips remained immobilized in the cast for 6 weeks. Then, the cast was removed, and hip stability was gently evaluated in the OR using C-arm, while the patient was under general anesthesia. Then, the hips went immobilized by another Spica cast in human position for another 6 weeks.

In the 12th week after reduction, the cast were removed under general anesthesia, and if the hips had enough stability, Petrie casts were located. We insisted on maintaining 45° of abduction during the Petri cast application process. The casts were removed in the 18th week after CR.

Figure 1: Hip Spica cast after closed reduction. The angle shown between two lines is the abduction

After 3–6 months of follow-up, the hips were re-evaluated by anteroposterior radiographs, then patients got followed up every 6 months in the 1st year and then yearly until 3 years after the first admission. In these follow-up sessions, hips were checked for post-reduction complications, including AVN clinical and radiographic evidence based on Bucholz and Ogden classification (3rd–4th class).[20]

Participant's basic demographic and clinical variables assessment

Suffering from AVN in included DDH patients was documented as our study outcomes and number of joints involved in the dysplasia (unilateral/bilateral), age at the time of CR, initial Tönnis grade, initial abduction angle in the Spica cast [Figure 1], previous conservative procedures, adductor tenotomies during the CR were evaluated as potential predictors.

Statistical analysis

Continuous and categorical data were reported as mean ± standard deviation and frequency (percentage), respectively. The normality of continuous data was evaluated using Kolmogorov–Smirnov test and Q-Q plot. Continuous and categorical data were compared between two groups using independent samples *t*-test and Chi-squared test, respectively. Logistic regression analysis was used for evaluating the predictive role of those variables showed association at $P < 0.1$ in univariate analysis. The results of logistic regression were reported as odds ratio (OR) and 95% CI for OR. Receiver operating characteristic curve (ROC) was used to find the best cutoff values for age and abduction angle for differentiating AVN and non-AVN patients by maximizing the Yuden index. The results of ROC analysis were reported as area under the curve (AUC) along with counterpart sensitivity, specificity, and accuracy indices. The data were analyzed by SPSS 22.0 (IBM SPSS, Chicago, IL, USA), and $P < 0.05$ was considered statistically significant.

RESULTS

The mean age of the patients was 12.5 ± 3.9 months old (range, 6–12 months). There were eight males (11.3%) and 63 (88.7%) females. Fifty-three hips (59.6%) had unilateral dysplasia, and 36 hips (40.4%) had bilateral dysplasia. Of the 89 total hips, 17 (19.1%) had undergone previous bracing. In 65 hips (73%), the adductor tenotomy was performed during the CR. There were no unplanned changes of Spica casts for the patients. During the 3 years of follow-up, 18 hips (20.2%) (13 patients) experienced postreduction AVN.

Table 1 presents the distribution of basic demographic and clinical predictors of experiencing AVN. The mean age of CR in patients who experienced AVN and who did not experienced AVN were 14.3 ± 4.9 and 12.2 ± 3 months, respectively ($P = 0.07$), also the mean abduction angle in patients with and without AVN were 51.86 ± 3.66 and 58.46 ± 3.91° ($P < 0.001$) in univariate analysis. Other variables including initial Tönnis grade, and previous conservative procedures, adductor tenotomies during the CR were comparable between two groups ($P > 0.05$).

The results of ROC analysis led to 12 months (AUC: 0.62 [95% CI: 0.48–0.82; $P = 0.05$]) as the best cutoff value for differentiating AVN from non-AVN patients with the highest sensitivity, specificity, and accuracy. Furthermore, 54° was found as the best cutoff value for abduction angle which could significantly differentiate AVN from non-AVN patients (AUC: 0.88 [95% CI: 0.79–0.97; $P < 0.001$]) [Table 2 and Figure 2].

We included two above variables associated with AVN occurrence in univariate analysis into multivariable logistic regression and found a dramatic significant predictive role for abduction angle in which patients with abduction angle larger than 54° had odds of experiencing AVN as OR = 38.44 ($P < 0.001$) and higher risk of AVN in patients older than 12 months OR = 4.22 ($P = 0.051$) [Table 3].

DISCUSSION

Our results confirmed that age and abduction angle in the Spica cast are related to AVN incidence. Furthermore, to

Table 1: Basic demographic and clinical characteristics of patients with and without avascular necrosis

Variables	AVN (%)	Non-AVN (%)	$P^§$
Age	14.3±4.9	12.2±3.7	0.07
Gender			
Male	2 (15.4)	7 (9.2)	0.50
Female	11 (84.6)	69 (90.8)	
Number of joints involved in the dysplasia			
Unilateral	8 (61.5)	45 (59.2)	0.87
Bilateral	5 (38.8)	31 (40.8)	
Previous abduction tools			
No	11 (84.6)	61 (80.3)	0.71
Yes	2 (15.4)	15 (19.7)	
Adductor tenotomy			
No	3 (23.1)	21 (27.6)	0.73
Yes	10 (76.9)	55 (72.4)	
Tönnis grade			
I	0	0	0.15
II	9 (11.8)	1 (7.7)	
III	24 (31.6)	1 (7.7)	
IV	43 (56.6)	11 (84.6)	
Abduction angle	51.86±3.66	58.46±3.91	<0.001

§Resulted from independent samples *t*-test for continuous and Chi-squared test for categorical data. Continuous and categorical data are represented as mean±SD and frequency (%), respectively. SD=Standard deviation; AVN=Avascular necrosis

Table 2: Receiver operating characteristic curve analysis results for differentiating avascular necrosis versus nonavascular necrosis based on age and abduction angle

Variable	Cutoff value	Sensitivity	Specificity	Accuracy	AUC	95% CI for AUC		*P*
						Lower limit	Upper limit	
Age	12 months	0.74	0.57	0.62	0.65	0.48	0.82	0.051
Abduction angle	54°	0.92	0.70	0.76	0.88	0.79	0.97	<0.001

AUC=Area under the curve; CI=Confidence interval

Table 3: Multivariable association of age and abduction angle with the risk of avascular necrosis

Variable	OR	95% CI for OR		*P*
		Lower	Upper	
Age				
≤12 (Ref)	1			
>12	4.22	0.92	19.33	0.06
Abduction angle				
≤54 (Ref)	1			
>54	38.44	4.14	293.74	<0.00

Results are OR and 95% CI for OR obtained from logistic regression. Ref=Reference category; OR=Odds ratio; CI=Confidence interval

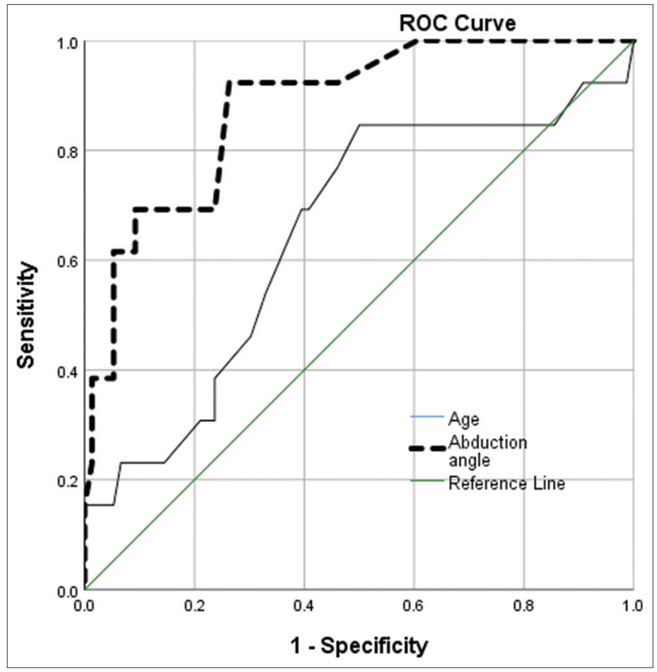

Figure 2: Area under the curve of age and abduction angle for differentiating avascular necrosis and nonavascular necrosis patients. ROC = Receiver operating characteristic

omit the confounding effects of the mentioned variables, we used multivariable logistic regression, and it was demonstrated that abduction angle in the Spica cast, and age had the most significant effects on AVN occurrence, respectively. Based on the calculated ORs for these variables, patients with abduction angles in the Spica casts of more than 54° were at 38.44 times higher risk for experiencing AVN than patients whose abduction angles in their Spica casts were ≤54°. Furthermore, patients who were older than 12 months of age at the time of CR were at 4.22 times higher risk for experiencing AVN than patients who were younger than 12 months old at the time of CR; therefore, in our study, abduction angle was a more important contributor in predicting AVN than other variables. In addition, interestingly, the initial Tönnis grade was not related to AVN incidence. This could suggest that if patients are admitted soon enough after DDH diagnosis, they can have good prognosis regardless of the initial severity of their dysplasia.

There have been controversies on the effect of the number of joints involved in the dysplasia (unilateral/bilateral), using pre-reduction braces and adductor tenotomy on the AVN occurrence.[10,15,17,21-24] In our analysis, there was no significant relationship between any of these factors and AVN incidence.

Sibiński *et al*. reported that age and initial Tönnis grade are AVN risk factors after CR, while in their study, the use of pre-reduction tools (including Pavlik harness, Frejka pillow, tractions, and hip-abduction braces) did not affect AVN incidence.[25] Gregosiewicz and Wośko reported a higher AVN risk in patients using abduction tools, including the Frejka pillow,[26] while Brougham *et al*. followed up with 210 hips treated by CR for a minimum follow-up of 2 years and found no relations between previous abduction orthosis usage and AVN occurrence.[23] Segal *et al*. studied 57 hips with DDH, which underwent CR and open reductions, and also reported no relation between neither Pavlik harness usage nor traction application and the AVN risk.[24] In our study, we only included patients undergoing CR, and as mentioned, no relationship between pre-reduction brace usage and the AVN occurrence was noted.

Furthermore, age has been shown to play a controversial role in DDH prognosis.[8,15,16,23,27,28] It has been reported that CR is better to be delayed until after the ossification center's appearance.[29] Schur *et al*. reported that patients older than 6 months of age at the time of CR were more likely to experience AVN than patients younger than this age; they also used 6 months as the cutoff point for calculating the proper abduction angle in the Spica cast to have the least AVN occurrence.[10]

In addition, abduction angle in the Spica cast has been suggested to be an important prognostic factor for AVN as even slight deviations from the correct angle could lead to partial or complete occlusion of the blood vessels around the femoral head.[10] Schur *et al*. suggested the abduction angle in patients younger than 6 months to be <50°.[10] While in our results with cutoff value of 54°, for the abduction angle in the Spica cast, 92% of the patients who showed AVN and 70% of those who did not demonstrate any signs of AVN could be predicted. In addition, high AUC of this ROC curve suggested that the reported cutoff point of the abduction angle could be properly used for AVN predictions.

This study has multiple limitations. A longer follow-up period, at least until the time for physeal closure, could reveal the AVN rate more accurately. However, in our referral orthopedic hospital, patients with DDH are strictly being followed up in the first 3 years after CR due to high AVN and other complications incidence during this period; therefore, the number of patients attending all of the follow-up sessions during the first three years after reduction were higher for performing this retrospective research.

The retrospective nature of this research was another limitation of this study, we probably had unwanted selection bias or missed some of the confounding factors; however, we decided to overcome this limitation by choosing patients who were exclusively treated and followed up by the most expert pediatric orthopedic surgeon in the city.

CONCLUSION

In our study, age and abduction angle within the Spica cast played essential roles in AVN prediction. Based on our results, we recommend that the abduction angle in the Spica cast (as the most important contributor in AVN prediction) to be <54° to prevent further pressure on the hip joint and have the best possible reduction prognosis in the future. Further studies on a higher number of patients and longer durations of follow-up under more controlled circumstances are essential to approve our results.

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Conflicts of interest
There are no conflicts of interest.

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