Can Medialization of Acetabular Rim Be a Prognostic Factor in Treatment of Developmental Dysplasia of Hip?

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Objectives—To investigate if acetabular rim medialization (ARM) can be used as a new parameter in determining the treatment choice and duration in Graf type III and IV hips.

Methods—Among the 12,300 infants who underwent hip ultrasound (US) according to Graf's method between 2015 and 2019, 26 infants (9 had bilateral pathology hence 35 hips) with type III and IV hips, whose follow-up data could be obtained were included in the study. Age of the infants at the initial diagnosis, ARM measurement, the duration of harness treatment, and the treatment results were noted. To determine the extent of ARM, distance between a line that is drawn tangential to the iliac wing and acetabular rim was measured.

Results—In cases with poor prognosis, ARM measurement was 6 to 8.5 mm on the right hip and 4 to 9 mm on the left hip. Bilaterality or unilaterality, left or right pathology, and gender did not have a significant effect on the prognosis ($P > .05$). Age at the initial diagnosis and ARM had significant effects on treatment success ($P = .04$, $P = .00$, respectively). In predicting the prognosis, ARM was found to be more successful than age (AUC = 0.95 versus AUC = 0.68). When these two variables were evaluated together, the success in predicting the prognosis significantly increased (AUC = 0.98).

Conclusions—ARM measurement may have an important role in determining the treatment method and duration in Graf type III and IV hips. It can be used as a prognostic factor alone or in combination with treatment initiation time. When the two factors are combined, prognostic value significantly increases.

Key Words—developmental dysplasia of the hip; dysplasia metrics; Graf's classification; hip ultrasound

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Abbreviations

ARM, acetabular rim medialization; DDH, developmental dysplasia of hip; LACD, late acetabular dysplasia; ROC, receiver operating characteristic; US, ultrasound

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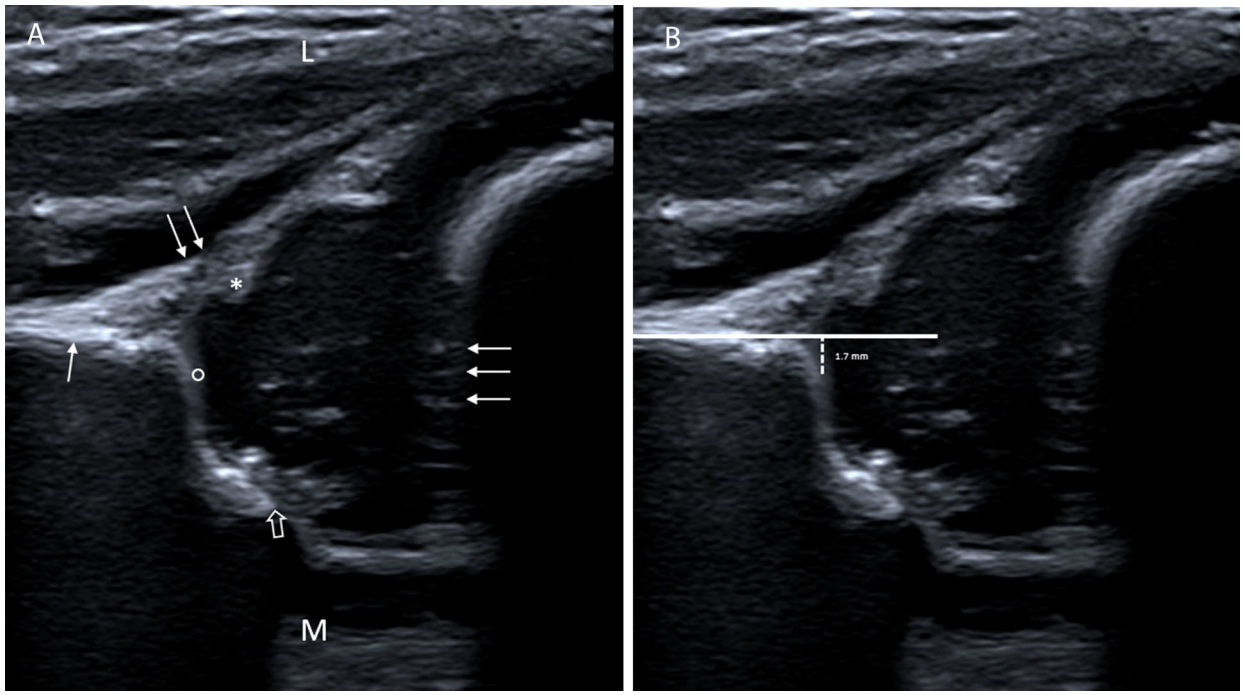
Hip ultrasound (US) is widely used as a method of diagnosis and screening of developmental dysplasia of hip (DDH). US has several advantages such as being widely available and lack of ionizing radiation, which makes it safe to use in infants.[1,2] However, it is an operator-dependent modality and standardization of hip US is difficult. As the hip joint is mostly cartilaginous in the neonatal period, it is easier to visualize its components with US; however, it is difficult to perform hip US properly, and the method has strict rules that must be followed carefully.[3] The method of hip US has been standardized by Graf.[4] Graf has defined a standard coronal plane with three reference points including acetabular labrum, bony acetabular rim, and lower iliac margin. Acetabular labrum is a fibrocartilaginous structure

Figure 1. Type I hip. **A**, Standard coronal plane of Graf is seen. L and M indicate the lateral side and medial side of the image, respectively. Circle shows the bony rim (concavity of the bony roof meets the convexity of the iliac promontory), arrow shows the iliac wing, double arrow the joint capsule, asterisk the labrum, triple arrow chondro-osseous junction, and open arrow shows the lower iliac margin. **B**, Measurement of the distance between the line that is parallel to the iliac wing (straight solid line) and bony rim is seen as a small dashed line. The distance is 1.7 mm in this type I hip.

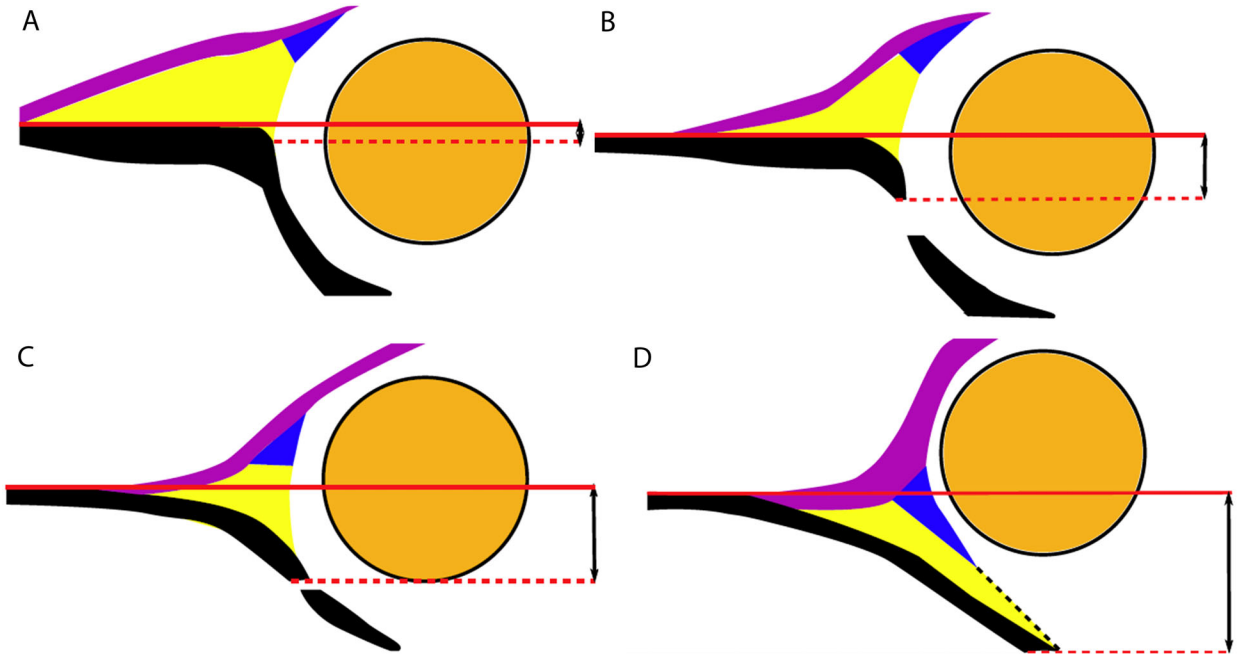


seen as a small echogenic triangle situated at the periphery of the cartilaginous roof. In the coronal plane, lower iliac margin is the most inferior tip of the acetabular bony roof that is adjacent to triradiate cartilage, and if we are in the correct scanning plane at the deepest portion of acetabulum, then it is seen as a sharp point.[5] Bony acetabular rim is the ring where bony acetabulum intersects the cartilaginous acetabulum. In the standard coronal plane, it is seen as the point where concavity of the bony roof meets the convexity of the iliac promontory.[6] Although in the normal hip bony acetabular rim is close to the iliac contour and can be clearly distinguished in the standard coronal plane, it gets rounded and displaces medially in pathological hips. This situation is due to under development of bony acetabular roof and indicates that acetabulum is mostly cartilaginous. As the relation between femoral head and acetabulum is disrupted, medial displacement of the acetabular rim increases. Graf's method enables to determine the patient that needs treatment for DDH; however, it does not give any prognostic information. Pavlik harness that is widely used in the treatment of DDH is not devoid of complications; hence, any method that will predict its success in treatment on a patient basis in addition to diagnosing DDH will make the patient management more successful and prevent unnecessary treatment efforts. In the present study, acetabular rim medialization (ARM) is measured in hips classified as Graf type III and 4 by US, and it is investigated whether this measurement may have a prognostic value in the treatment of these hips.

Materials and Methods

This retrospective study is approved by the intuitional review board. Informed consent was obtained from the parents. The hip US examinations performed within the framework of DDH scanning protocol

Figure 2. Drawing in **A** demonstrates type I hip and drawings in **B** to **D** demonstrate the gradual medial displacement of the acetabular rim (bony rim) as the dysplasia of the bony roof worsens. Compare them with the image in Figure 1, the dashed line that represents the location of the acetabular rim is in the medial side, and the distance between the solid line (iliac line) and dashed line represents the extent of acetabular rim medialization (ARM). **A**, Type I (normal) hip, **B**, type II (a/b) hip, **C**,- the hip is decentered, labrum (blue triangle) is displaced cranially, dysplasia of the bony roof is more marked than the hip in **B**, as is the increase in the distance between the solid and dashed lines. **D**, Type IV hip, labrum (blue triangle) is displaced caudally and the distance between the solid and dashed lines (ARM) is markedly increased when compared to the hips in **B** and **C**.



between 2015 and 2019 in our center were retrospectively reviewed. Graf's technique is standard in our institution. During this period 12,300 infants underwent hip US examination, of these 2337 (19%) infants who were under follow-up US were excluded, and 9963 infants (19,926 hips) who had their initial US examination were included in the study. Among these 9963 infants, 83% (16538 hips) were classified as type I, 12% (2390 hips) as type IIa, 2.4% (498 hips) as type IIb, 0.9% (179 hips) as type IIc, 0.8% (157 hips) as type D, and 0.9% (164 hips) as type III and IV hips. One hundred nineteen infants had type III and IV hips of which 74 had unilateral pathology while 45 had bilateral pathology. Among these 119 infants, we could get the follow-up results and treatment records in only 26 from the hospital data record system. Consequently 26 infants among whom 9 had bilateral pathology (35 hips) were included in the study. The age of the infant at the time of initial diagnosis, ARM measurement, the duration of harness treatment, and the treatment results were noted. To determine the extent of ARM, standard coronal plane defined by Graf is used (Figure 1A), a line that is parallel to the iliac wing was drawn in the standard coronal plane and the distance between this line and acetabular rim was measured (Figure 1B). As the dysplasia of bony roof worsens, the bony rim is displaced away from the iliac wing (Figure 2). Measurement in type III hip is shown in Figure 3. In type IV hips, it is difficult to locate the acetabular rim due to caudal displacement of labrum, in these hips the location of the acetabular rim was decided according to the continuity of cartilaginous roof (Figure 4). Measurement of ARM was done on the images of the initial US examinations that were retrieved from the scanners' picture archive. Measurements are rounded to the nearest 10th. Failure of Pavlik harness treatment, need for closed reduction, open reduction and pelvic osteotomy, and development of aseptic necrosis due to treatment were accepted as negative

Figure 3. ARM measurement in Graf type III hip is shown. It is 4.5 mm.

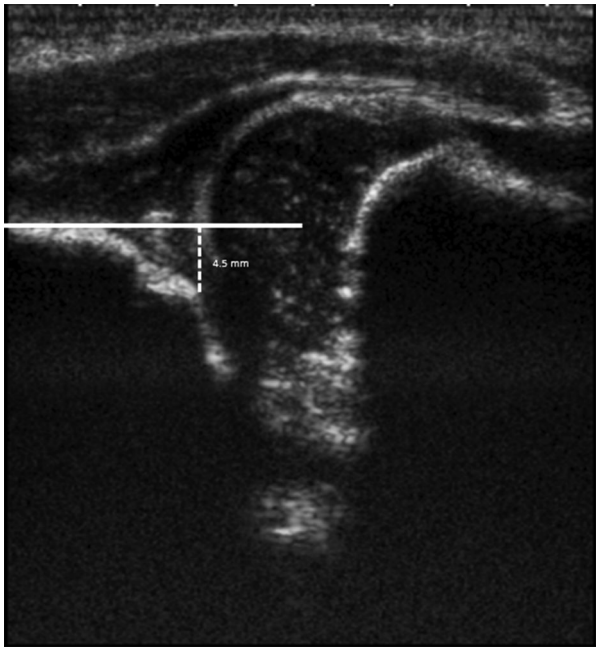
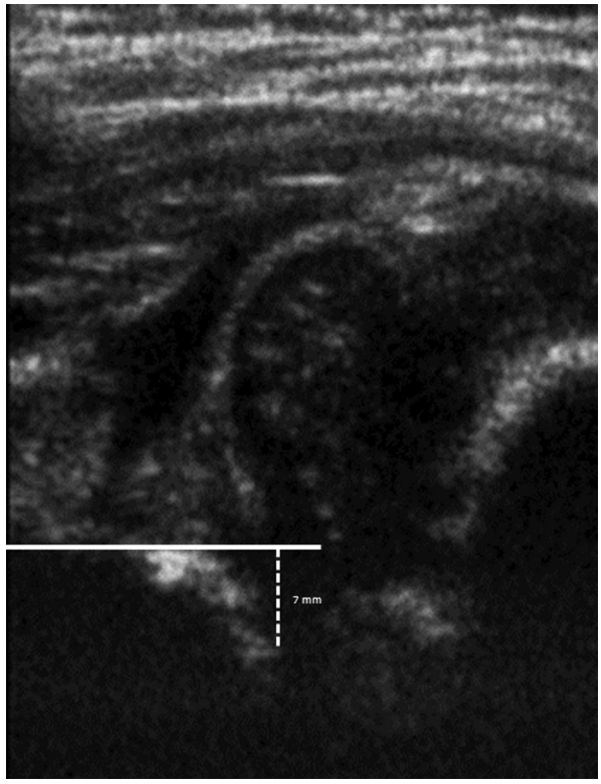


Figure 4. Measurement of ARM in Graf type IV hip. It is 7 mm.



prognostic factors. Successful treatment with Pavlik harness in duration shorter than 8 months was considered as a positive prognostic factor.

The hip US examinations were performed by three radiologists (Pınar Nercis Koşar, Elif Ergün, Dilek Gökharman) with 20 years of experience in pediatric hip US. US was performed with Toshiba Xario, 7.5-MHz linear transducer, Toshiba Aplio 500, 10-MHz linear transducer and Siemens Acuson S3000 (Siemens Healthcare Erlangen, Germany), and 10-MHz linear probe. Images were obtained in coronal planes through a lateral approach to the hip while the infant lie in a lateral decubitus position with the leg either in neutral position or flexed at the hip and the knee.

Statistical Analysis

Statistical analysis was performed using STATA/SE 15.1. The significance levels are shown with asterisks, with * referring to P <.1, ** referring to P <.05, and *** referring to P <.01. Continuous variables were compared with unpaired t test and categorical variables were compared by χ^2. The performance of different variables in predicting the prognosis is evaluated using receiver operating characteristic (ROC) curve analysis, specifically using the AUC measure (area under the curve). This statistic is commonly used in the ROC curve analysis and measures the area under the ROC curve, which plots the true positive rate to false positive rate for different classification thresholds. The AUC measure (as the area under the ROC curve) varies between 0 and 1, where a model with 100% wrong predictions would have an AUC of 0 and a model with 100% right predictions would have an AUC of 1. We believe this is a proper measure for analyzing a model with different specifications as in our setting because it is both scale invariant and classification-threshold invariant.

Results

Twenty-six infants (35 hips) who underwent hip US and had type III and IV hips according to Graf's classification were included in the study. Among them, 20 cases (73%) were female while 6 (27%) were male. Seventeen cases (65.4%) had unilateral

Table 1. Distribution of Cases According to Age, Gender, ARM Measurements, Treatment Methods, and Prognosis

Case	Gender	Age Weeks	R	L	RARM, mm	LARM, mm	Treatment	Prognosis	Comorbidity
1	F	10	+		3		Pavlik harness	+	
2	F	11		+		4	Aseptic necrosis	−	
3	F	12	+	+	6	8	[a]	−	Ch
4	F	8	+	+	5	5	Pavlik harness	+	
5	M	10	+	+	5	3	Pavlik harness	+	
6	F	7		+		7.5	Closed reduction	−	
7	F	7	+		4		Pavlik harness	+	
8	F	8	+		7		Closed reduction	−	Ch
9	F	11		+		7	Closed reduction	−	
10	F	16		+		6	Closed reduction	−	
11	F	6		+		4	Pavlik harness	+	
12	M	8	+	+	6	4	Closed reduction/Pavlik	−/+[b]	
13	F	10	+		6		+	+	
14	F	8	+	+	8	3.5	Open reduction/Pavlik	−/+[b]	
15	F	4	+		4		Pavlik harness	+	
16	M	6	+	+	8	3	R aseptic necrosis	−/+[b]	
17	F	8		+		4	Pavlik harness	+	
18	F	8		+		7	Pavlik harness	+	
19	F	8	+	+	8	7	Bl open reduction	−	
20	F	12		+		9	Open reduction	−	
21	M	8		+		3.5	Pavlik Harness	+	Ch
22	M	11	+		6.5		Closed reduction	−	
23	M	10		+		9	Pelvic osteoyomy	−	RS
24	F	4	+	+	2.5	4	Pavlik harness	+	
25	F	8	+		3.5		Pavlik harness	+	
26	F	5	+	+	8.5	9	Bl pelvic osteotomy	−	

R, right hip; L, left hip; Bl, bilateral; RARM, right acetabular rim medialization; LARM, left acetabular rim medialization; OT, pelvic osteotomy; Ch, Chiari 2 malformation; RS, Robinow syndrome.
[a]Ex at eighth month before the completion of treatment.
[b]Bilateral cases with different treatment duration and process for right hip and left hip.

Table 2. Distribution of Right and Left Hip Pathologies in Unilateral and Bilateral Cases According to Prognosis

Prognosis	R hip (R UL+ R BL)	L hip (L UL+ L BL)	Total
Good	5 + 3	1 + 9	18
Poor	2 + 6	6 + 3	17
Total	16	19	35

UL, unilateral; BL, bilateral.

pathology, of these the pathology was on the right hip in 7 (7/17, 41%) and it was on the left hip in 10 (59%) cases. 9 cases (34.6%) had bilateral pathology. At the time of the initial US, the age of the cases ranged between 4 and 16 weeks (mean 8 weeks of age). Following the US diagnosis, the first 2 to 3 follow-ups were done by US with an interval of 1 month, then follow-ups continued by orthopedic evaluation and pelvic radiographs. Four cases had coexisting abnormalities, of which 3 (1 had bilateral pathology) had Chiari 2 malformation and 1 had Robinow syndrome.

Eighteen of the 35 hips were successfully treated with Pavlik harness. The remaining 17 hips were in the group of poor prognosis. Among them, 6 had closed reduction, 4 had open reduction and iliopsoas tenotomy, and 3 had pelvic osteotomy. Aseptic necrosis occurred in 2 cases (1 with unilateral and 1 with bilateral DDH) as a complication of the harness therapy and both remained in splint treatment for more than 8 months. In the case with

Table 3. Differences in Positive and Negative Prognosis Subsamples

Variables	Test Statistic	*P*-Value	Significance
Gender	0.0826	.774	
Unilateral or bilateral	0.0303	.862	
Left hip	1.4011	.237	
Right hip	0.7372	.392	
Calendar age (weeks)	2.1231	.041	*
ARM measurement (mm)	7.6596	.000	**

Test statistic refers to a χ^2 test for the gender, unilateral or bilateral, left hip, and right hip rows, while it refers to an unpaired *t*-test for age and ARM measurement rows. The significance levels are shown in asterisks.
*Referring to $P < .05$.
**Referring to $P < .01$.

Table 4. Variables' Predictive Performance of a Positive Prognosis

	AUC
Gender	0.5212
Unilateral or bilateral	0.5147
Left hip	0.5801
Right hip	0.5654
Calendar age (weeks)	0.6781
ARM measurement (mm)	0.9510
ARM + age	0.9804

AUC refers to "area under the curve" of the ROC curve associated with each model as indicated by the variables in each row.

bilateral type IV hip and Chiari 2 malformation, ARM was measured 6 mm on right hip and 8 mm on left hip (Table 1, case 3). This case died in the eight month of treatment due to fungal infection of the lung and was classified in the poor prognosis group because treatment was not completed in 8 months. One of the other 2 infants with Chiari 2 malformation had closed reduction and 1 was treated with Pavlik harness in 6 months. The case with Robinow syndrome had pelvic osteotomy.

In the whole study population, ARM measurements were found to be between 2.5 and 8.5 mm on the right hip and 3 and 9 mm on the left hip. Among the cases that were successfully treated by Pavlik harness in <8 months, ARM measurements were 2.5 to 6 mm on the right hip and 3 to 7 mm in the left hip. In cases with poor prognosis, ARM measurements were 6 to 8.5 mm on the right hip and 4 to 9 mm on the left hip.

Distribution of right and left hip pathology in unilateral and bilateral cases according to the prognosis is shown in Table 2.

The difference between groups with negative and positive prognosis according to various features such as gender, presence of unilateral or bilateral type III and IV hips, age, and ARM measurements is presented in Table 3. Effect of various variables (such as unilaterality, bilaterality, ARM measurement, age) on the prognosis is shown in Table 4.

Discussion

US is a safe method that can be used in screening, diagnosis, and follow-up of DDH.[7,8] The hip US technique was first introduced by Graf.[9] Graf's technique minimized the disadvantages of US such as operator dependency and subjective interpretation through defining a standard examination plane obtained by using fixed anatomical landmarks and measurement of alpha and beta angles in addition to morphological analysis.[10] Amid the three anatomical landmarks used in this method, acetabular rim can be easily identified in normal hips. However, its shape and location changes in pathological hips and the extent of this change depend on the severity of the pathology. In addition, in type III and IV hips due to the great extent of dysplasia of bony roof, measurement of alpha and beta angles becomes harder.[11] To overcome this difficulty, we searched for an alternative measurement that will make the subjective interpretation more objective in severely dysplastic hips. For this purpose, we measured the distance of medial displacement of the acetabular rim and investigated its effect on treatment and follow-up procedure in DDH.

Bilaterality or unilaterality of involvement or gender was not found to show significant effect on the prognosis. However, ARM measurement was found to be an independent significant prognostic factor.

Gender did not cause a difference in treatment and follow-up regime in type III and IV hips in the present study ($P = .77$). There are studies stating that male infants are more resistant to treatment and treatment period is longer in them.[12–14] However according to our findings, gender is not a prognostic factor regarding the success of the treatment. Having unilateral or bilateral hip abnormality did not affect the treatment response ($P = .86$). Of the 9 cases with bilateral pathology, in 3 cases prognosis was poorer in the right hips. In 3 cases (Table 1, cases 12, 14, and 16) with bilateral type III and IV hips and different ARM measurements in the right and left hips, we observed that treatment response of each side and prognostic factors have changed in line with ARM values. In unilateral cases, poor prognosis was observed in 28.5% (2/7) of right hips and 60% (6/10) of left hips (Table 2 laterality of hips with poor prognosis, right 8/17, left 9/17). Right or left hip pathologies were only found to have limited power on predicting the prognosis (AUC: 0.56 and 0.58, respectively) (Table 4). Bilaterality is commonly considered as a risk factor of failure of Pavlik harness treatment. This is explained by the intrauterine environment that applies more pressure to the hips and long treatment period in these infants. However, in the present study in line with the study of Palocaren et al,[15] bilaterality was not found to be a significant poor prognostic factor.

Early diagnosis and proper treatment affect the prognosis of DDH.[2,3,9,16,17] However, the optimal time of the treatment to achieve success is not clear. The common opinion is that starting the treatment before 7 weeks of age has a positive effect on the treatment duration and success. For instance, Atalar et al[18] found that the rate of treatment success was higher in infants <7 weeks of age when compared to the infants >8 weeks of age ($P = .038$). According to Harding et al[19] for a successful Pavlik harness treatment, the treatment initiation age is the second most important factor following the initial type of dysplasia. Another study showed that the rate of residual dysplasia was higher in infants in whom treatment initiation age was >8 weeks of age regardless of the initial US hip type (Graf type D, type III, type IV). The authors recommend long-term follow-up of even the successfully treated cases to detect deterioration following initial normal radiographs.[16] However, one study, which included infants with dislocated irreducible (D/I) 59 hips, reported 56.3% rate of treatment success with Pavlik harness. They added that treatment was successful until 4 months, and no correlation between treatment success and treatment initiation age was found.[12] In the present study, the mean age of treatment initiation was 8 weeks of age (4–16 weeks), and treatment success rate was 51%. Among the negative and positive prognostic factors, age and ARM had significant effects on treatment success ($P = .04$, $P = .00$, respectively). In predicting the prognosis, ARM was found to be more successful than age (AUC = 0.95 versus AUC = 0.68). When these two variables were evaluated together, the success in predicting the prognosis significantly increased (AUC = 0.98).

Pavlik harness has been used in the treatment of DDH since 1946.[20] The duration of the treatment depends on whether the joint reduction is completed or not. Treatment duration in dislocated hips is reported to be 43 to 106 days in 1 study and another study stated it as 51 to 169 days in bilateral dislocation and 68 to 189 days in unilateral dislocation.[12,15] In the present study, in the cases who were treated successfully with Pavlik harness, the duration of treatment was 60 to 120 days. In two cases, aseptic necrosis occurred as a late complication of the treatment. Femoral nerve palsy (85% occurs in the first week of treatment) has also been reported as a complication of Pavlik harness treatment.[21] This complication generally occurs in large infants. We did not observe this complication in our study population.

Acetabular roof cartilage hypertrophy (acetabular bulge) is stated among the reasons for failure of Pavlik harness treatment by Treguier et al.[22] Authors defined acetabular roof cartilage hypertrophy (acetabular bulge) as a factor in treatment failure besides inversion of the labrum, interposition of the psoas, narrowing of the capsular isthmus, thickening of the ligamentum teres, and thickening of the fibrofatty pulvinar. They recommend that if acetabular bulge is detected by US examination through external frontal scan, treatment procedures other than Pavlik harness should immediately be performed. Alexiev et al[20] investigated the value of various morphological features and the extent of laxity in the initial US examination as a predictor of residual acetabular dysplasia (late acetabular dysplasia [LACD]). Three findings including femoral head coverage rate (<%22), alpha angle (<43′), and echogenicity of cartilaginous

roof (abnormal echogenicity) were evaluated. Among these, transformation of the cartilaginous roof was found to be the most valuable factor in predicting LACD. In the present study, we did not evaluate these features. However, we have shown that ARM measurement is a valuable prognostic factor in Graf type III and IVhips and is reliable in determining the treatment method and duration.

This study has various limitations. First, owing to the retrospective nature of the study, measurements were carried out on hard copy images, and we believe if they were carried out on real-time images, then they would be more accurate. Second, most of our patients with Graf type III and IV hips were not included in the study because we could not obtain their follow-up data, which led to a limited study group. Yet, the results of the study supported our prediction that ARM may be a prognostic factor in DDH patients.

In conclusion, ARM measurement is valuable in predicting the prognosis of DDH patients and can be used as a criterion in follow-up on them.

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