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Original article

RELATIONSHIP BETWEEN GRAF ANGLES AND FEMORAL HEAD COVERAGE IN HIP ULTRASOUND SCREENING FOR DEVELOPMENTAL HIP DYSPLASIA

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Abstract

Introduction: Ultrasound examination is a widely accepted method for developmental hip dysplasia screening, diagnosis and treatment monitoring. The Graf technique, routinely used in the Republic of North Macedonia is reliable and reproducible when performed in a precise and standardized manner, but it can be challenging when used by inexperienced ultrasonographers. We analyzed the relationship between findings of ultrasound scans obtained by the Graf method and femoral head coverage (FHC), in order to examine its usefulness in infant hip screening.

Material and methods: Hip sonograms of 105 infants aged 0 to 6 months were examined. Measurements of alpha and beta angles according to Graf were performed and FHC was calculated as d*/D ratio. Multiple regression analysis was performed to examine the relationship between FHC, alpha and beta angles and infant age.

Results: Two hips in a single patient were abnormal (grade 2c and D) according to Graf technique, with incidence of 0.95%. Seven hips (3.3%) had FHC below 50%, including the 2c and D hips and five hips with Ib grade according to Graf. FHC increased for 0.71% for each degree increase of alpha angle and decreased for 0.68% for each degree increase of beta angle. Infant age did not influence FHC.

Conclusion: There was a positive correlation between alpha angle and FHC and negative correlation between beta angle and FHC. FHC above 50% is strongly indicative of normal hip morphology. FHC can be used in addition to the Graf method for assessment of infant hips.

Keywords: hip ultrasonography, Graf classification, femoral head coverage

Introduction

Ultrasound examination is a widely accepted method for developmental hip dysplasia screening, diagnosis and treatment monitoring. It is relatively cheap, accessible, easily repeated as often as necessary compared to other radiodiagnostic options. There are differences between countries and regions regarding screening scope and screening technique used. In the Republic of North Macedonia universal screening is performed, where every infant is subjected to hip ultrasound. The Graf technique[1,2] with dynamic testing for borderline cases is the gold standard. Other screening techniques, such as femoral head coverage, transinguinal ultrasound,

pubofemoral distance and dynamic ultrasound techniques are used in different parts of the world alone or as an adjunct to the Graf technique[3-5].

The Graf technique is reliable and reproducible when used according to strict rules where sonograms are obtained by appropriate equipment in a standard coronal plane with all the anatomical landmarks present and the measurement performed in a precise and standardized manner[6]. However, despite the efforts for standardized training and screening facilities, the fact remains that in different parts of the world ultrasound screening is performed by ultrasonographers with different levels of experience and with equipment with different levels of sophistication. Interpretation of the results varies also significantly across different geographical regions[7]. In order to lower the incidence of both false positive and false negative results, especially overtreatment of healthy infant hips, we looked for indices that might help achieving correct diagnosis in cases that might be unclear for the examiner.

In this study we examined the relationship between findings of sonograms obtained by the Graf method[2] and femoral head coverage (FHC) introduced by Morin *et al*.[8].

Materials and methods

We analyzed hip sonograms of 105 infants aged 0 to 6 months that were screened for developmental hip dysplasia at the University Clinic for Orthopedic Surgery in Skopje, North Macedonia since the beginning of 2023. All infants with appropriate age were enrolled, regardless of risk factors or comorbidities until the desired number was reached.

Age, sex and risk factors (breach position, twin pregnancy, sibling with DDH, family history of DDH) were recorded. A standard physical examination with Ortolani and Barlow maneuvers was performed and abnormal findings were recorded.

Ultrasonography was performed by a single experienced orthopedic surgeon, with the baby positioned in a cradle. The right hip was examined first and then the left hip, without the use of a probe-guiding system, according to the method of Graf.[2] The scan was recorded and then the most appropriate image in the "standard plane" with all anatomical landmarks (straight os ilium, lower limb of os ilium, acetabular labrum and chondro-osseous border) visible was used for analysis (Figure 1).

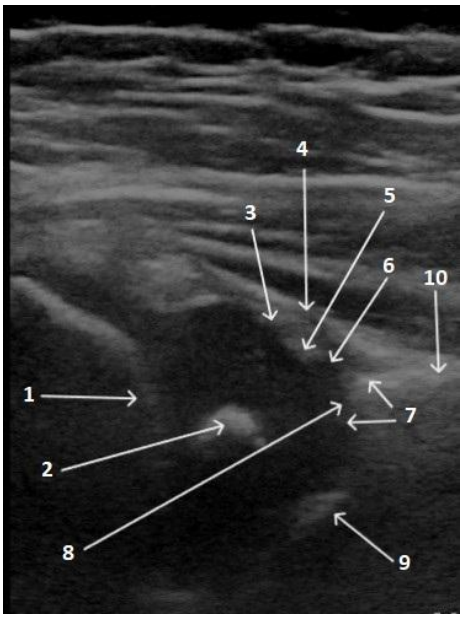

Fig. 1. Anatomic structures in the standard plane of hip ultrasound according to Graf: 1-chondro-osseous border, 2-femoral head (with ossific nucleus in this case), 3-synovial fold, 4-joint capsule, 5-labrum, 6-cartilaginous roof, 7-bony roof, 8-bony rim, 9-iliac wing, 10-lower limb of os ilium

In this image, alpha and beta angles were measured according to the Graf method (Figure 2). FHC was measured using the d*/D ratio, where D is the diameter of the cartilaginous femoral head and d* is the distance from baseline to parallel line going through the deepest point of the femoral head in the acetabulum, and not the acetabular depth itself (Figure 3).

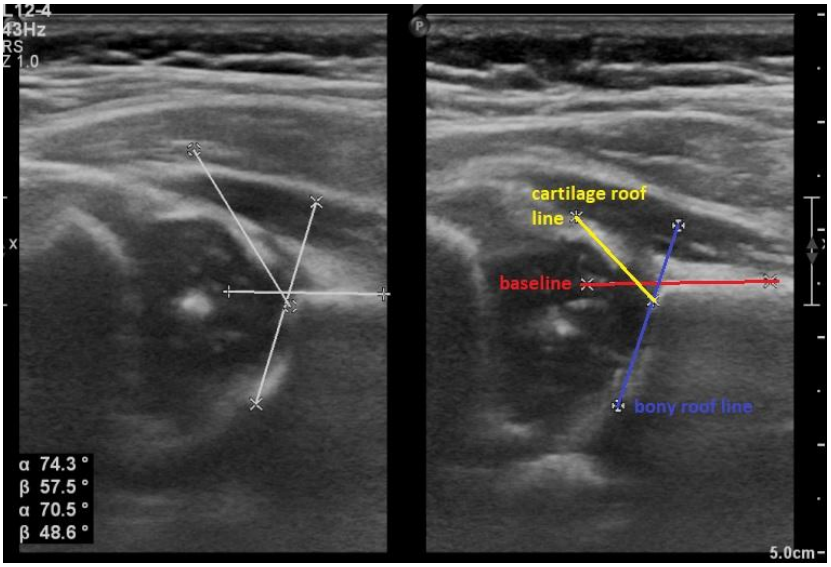

Fig. 2. Measurement of alfa and beta angles.
Left: Graf type 1b. Right: Graf type Ia

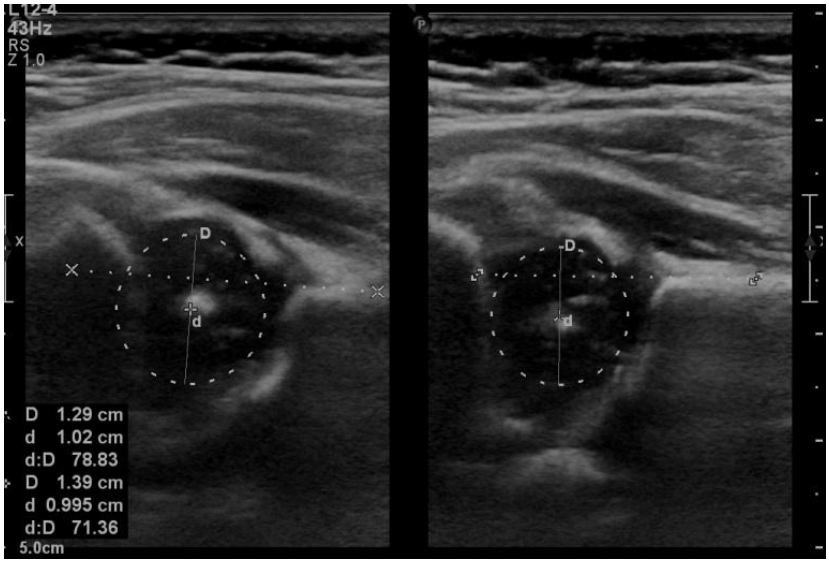

Fig. 3. FHC measurement. D-femoral head diameter, d-part of the diameter inside the acetabulum

Results

A total of 105 infants. aged 11 to 180 days (average 110 days). were screened for hip dysplasia. Fifty-eight (55.2%) were male and 47 were female. Only one child (male) had mother diagnosed with hip dysplasia. Forty-one infants (39%) were born via cesarean. The reasons for cesarean section were not analyzed. There were no breech position deliveries, although breech position may have influenced the decision to perform some of the cesarean sections. There were no twin infants in this series.

One female child (0.95%) had positive Ortolani sign bilaterally. One child had left-sided adductor contracture and 2 infants had bilateral adductor contracture, totaling to 3.8% of

infants with abnormal findings on hip clinical examination. One infant (aged 11 days) had *pes equinovarus*.

Distribution according to Graf classification of all 210 hips is shown in Table 1. There were no hips in the grades omitted in the Table (2a-, 2b, IV). One female child had Graf grade D left and grade 2c of the right hip, with the incidence of developmental hip dysplasia or dislocation in this cohort being 0.95%.

Table 1. Graf classification

Graf grade	Number of hips	Relative frequency per category (%)
Ia	142	67.6
Ib	49	23.3
2a+	17	8.1
2c	1	0.5
D	1	0.5

The values for alpha and beta angles according to the Graf and femoral head coverage (d*/D, %), their range and average values are shown in Table 2. Seven hips had femoral head coverage lower than 50%. Two of them were hips grade 2c (43.5%) and D (49.4%). The five remaining hips with coverage <50%, including the minimum coverage of 35.7%, belonged to the 1b group according to the Graf classification.

Table 2. Values for alpha, beta and d*/D

Statistic	Alpha	Beta	d*/D
Number of hips	210	210	210
Minimum	46.2	26.9	35.7
Maximum	86.6	76.7	99.6
1st Quartile	69.7	44.0	65.9
Median	73.4	49.8	73.2
3rd Quartile	77.3	56.2	78.9
Mean	73.0	50.0	72.5
Standard deviation (n-1)	5.8	9.4	11.4

Multiple regression analysis was performed in order to examine the relationship between femoral head coverage, Graf angles and infant age in days.

The Shapiro-Wilk test substantiated the normality of the residuals (W = .99, p = .059), thereby satisfying the normality criterion. The Durbin-Watson statistic was 1.74, showing acceptable positive autocorrelation among residuals and attesting to the independence of errors. The Variance Inflation Factor (VIF) for each predictor was well below the threshold of 5 (alpha 1.43, beta 1.70, age 1.24), dispelling multicollinearity concerns.

A significant regression equation was found ($F(3,206)=118.870$, $p<.0001$), with an R^2 value of .63. Relative femoral head coverage was equal to 56.61+0.71*Alpha-0.68*Beta-0.01*Age, where alpha and beta are measured in degrees and age is measured in days. Femoral head coverage increased for 0.71% for each degree increase of alpha angle and decreased for 0.68% for each degree increase of beta angle. Based on the type III sum of squares, both alpha ($SS=2461.7$, $F=51.12$, $p<.0001$) and beta ($SS=5026.04$, $F=104.37$, $p<.001$) angles were significant predictors of femoral head coverage, while age ($SS=53.73$, $F=1.12$, $p=.292$) did not have significant influence, with beta angle being the most influential.

Discussion

The prevalence of developmental dysplasia of the hip (DDH) varies greatly between regions and this discrepancy is attributed to both population differences and differences in diagnostic methods and criteria[7]. When using ultrasonography as a diagnostic tool, the

prevalence is reported to be 40 to 60 per 1000, as opposed to 1.4 to 20 per 1000 when employing diverse methodology[7,9,10]. Overtreatment has been a major concern when engaging an universal screening strategy with ultrasound, with numerous studies and subsequent meta analyses showing conflicting or inconclusive results regarding recommendations for screening strategy and treatment tresholds[3,11-13]. In our study, one child had two pathologic hips, translating to prevalence of 9.5 per 1000.

The standardized hip sonography was introduced by Graf in the 1980s and has contributed significantly to the reduction of cases of adults requiring surgery due to severe hip dysplasia in our country as well as across Europe. However, this method has faced criticism regarding inter- and intraobserver reliability and concerns about overtreatment. It is generally accepted that Graf IIa hips are expected to mature into type I without intervention and Graf type III and IV hips need to be treated to prevent severe dysplasia in adults[6]. In a study from 2018, Sakkers *et al.* reviewed the natural history of abnormal hip ultrasound findings in infants under 6 months of age and found that for Graf 2A to 2C hips, 80-97% normalized without treatment, as well as more than 50% of Graf 3 hips. Less than 50% of Graf 4 hips normalized without treatment. They concluded that the natural history of DDH is relatively benign in well-centered hips[14]. A more recent systematic review by Zomar *et al*. found that most mild-to-moderate DDH can resolve without treatment in early infancy, especially in physiologically immature (Graf 2A) hips; however they did not find quality evidence to support spontaneous resolution of greater Graf grades[15].

There are multiple studies examining interobserver reliability and reproducibility of this method, with differing but not contradictory results. Simon *et al.* found significant interobserver differences in values of alpha (0-16º) and beta angle (0-26º), with the least agreement between the most experienced and the least experienced observer[16]. The authors concluded that less experienced examiners tend to assess sonograms as more pathological in order to avoid missing pathological hips. However, true pathological findings were generally identified as such by all examiners. Other studies also attribute poor interobserver reliability to insufficient proficiency in the Graf technique. In a review by Walters *et al*. analyzing studies referring to the Graf method, a large percentage (48.1%) of these studies did not fulfill basic criteria for performing the Graf method[6].

Another ultrasound method in use is the d/D ratio introduced by Morin. This technique uses the lateral coronal view with the hip slightly flexed, similar to the Graf technique. It also determines the percentage of the femoral head lying medial to the lateral iliac border, also known as the femoral head coverage (FHC)[8]. In this technique, d is the acetabular depth and D femoral head diameter. However, hip dysplasia manifests with dynamic as well as morphologic changes and with displaced femoral head d/D ratio may be normal. Therefore, d*/D ratio, where d* is the part of the femoral head diameter seated in the acetabulum is proposed[4]. This measurement was used in our study. Regarding the FHC method, Harcke *et al*. proposed the 50% rule, stating that hips with 50% or higher FHC are normal[4]. They supported this recommendation by findings from their studies, as well as by a study by Gunay *et al*., who found that FHC coverage of 51% or greater was always related to alpha angle equal to or greater than 60º, while FHC lower than 39% was always found in dysplastic hips[17].

In our study, we examined the alpha and beta angles influence on FHC. We found that both alpha and beta angles correlate with FHC, with the beta angle being more influential. One degree increase of alpha angle is expected to increase FHC by 0.71%, while beta angle is negatively correlated, and a single degree decrease results in 0.68% increase of FHC. Overall, 3.3% of hips had FHC below 50% and the dysplastic hips 2c and D belonged to this group. However, this finding is contradictory to the findings obtained by Gunay *et al*, since the FHC for these hips was 43.5% and 49.4% respectively and was well above the threshold of 39% they set. The remaining 5 hips with less than 50% FHC belonged to the 1b group, indicating

the relationship between FHC and beta angle. A single hip was with FHC lower than 39% and it was a normal hip belonging to the 1b group.

From a sonographer's perspective, the combination of analysis of findings from the Graf method and FHC gives a slightly more complete image of the hip morphology, where the relationship between the femoral head and the acetabular labrum can be more closely observed. Studies show that the labrum plays an important stabilizing role in the infant hip and undergoes changes of size and vascularization with treatment of dislocated hips.[18] The negative correlation between beta angle and FHC should be further investigated and may prove to be a useful tool for estimating hip stability.

The limitation of our study is the relatively small sample with a small number of pathological hips included. Although our results show a consistent relationship between alpha and beta angles and FHC in normal hips, and clearly indicate that this relationship is present in pathological hips, the magnitude of the correlation between FHC and Graf angles in pathological hips cannot be clearly established.

Conclusion

FHC can be used in addition to the Graf method for assessment of infant hips. It may be particularly useful for less experienced sonographers. FHC above 50% is strongly indicative of normal hip morphology. This cutoff may be useful in borderline cases, where there is a dilemma regarding the need for treatment helping to avoid overtreatment in patients where spontaneous normalization is expected. It should be noted that the FHC should also be measured in a standard coronal plane with all landmarks necessary for the Graf method present. We do not recommend using the 50% rule as the sole method for classifying infant hips as abnormal.

Conflict of interest statement. None declared.

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