The Egyptian Journal of Hospital Medicine (July 2025) Vol. 100, Page 4028-4033

Role of Ultrasound in Evaluation of Infantile Developmental Hip Dysplasia: A Cross-Sectional Observational Study

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ABSTRACT
Background: Ultrasonography (USG) is now widely recognized as a reliable imaging tool for the early diagnosis of developmental dysplasia of the hip (DDH).
Objectives: This study aimed to assess the diagnostic utility of ultrasonography (USG) in infants with developmental DDH.
Patients and Methods: In this cross-sectional observational study, 30 infants at risk of DDH were examined using USG, with Graf alpha (α) and beta (β) angles measured. The study was conducted at Mansoura University Children's Hospital and the Radiology Department, Mansoura University Hospitals, Egypt, during the period from October 2023 to September 2024.
Results: Breech delivery (36.7%) was the predominant risk factor, while female sex (30%) and oligohydramnios (16.7%) were less common. Most hips were classified as Graf type I (33.3% right, 36.7% left), with Graf type II accounting for 16.7% of right and 23.3% of left hips. The alpha (α) was markedly decreased in dysplastic hips compared with normal hips. A statistically significant strong correlation was observed between right hip α angle and right hip D ratio.
Conclusion: This study demonstrated that US evaluation using α and β angles in addition to the D ratio, is an effective and non-invasive method for diagnosing developmental DDH in neonates. The findings support using the α angle as the primary diagnostic parameter, with the degree of femoral–acetabular coverage considered a complementary indicator, especially in atypical cases.
Keyword: Developmental Hip Dysplasia, Graf classification; Ultrasound.

INTRODUCTION
In infancy, developmental dysplasia of the hip (DDH) represents a continuum of abnormalities, ranging from minimal joint laxity to overt dislocation. The underlying pathology may involve acetabular shallowness, delayed maturation of the femoral head, or a combination of both, resulting in a smaller, aspherical femoral head [1]. Typical risk factors for DDH include firstborn order, female sex, increased birth size, and breech presentation. A family history confers a nearly 12-fold elevated risk, and the disorder is generally identified during infancy or early childhood [2]. The contribution of genetic factors and specific cytokines has been explored in several studies, demonstrating their association with disease occurrence [3].

Ultrasound (US) assessment of DDH in neonates was developed by Graf, who designed it as a tool for classification and therapeutic decision-making. His method requires positioning the infant laterally to obtain coronal hip views, from which α and β angles are measured [4]. Hips with an α angle ≥60° are classified as mature (type Ia or Ib depending on the β angle). Those with an α angle of 50–59° are considered immature and are designated type IIa or IIb depending on the infant's age. An α angle ≤49° signifies pathological development, classified as type IIc, D, IIIa, IIIb, or IV [5].

Graf ***et al.*** introduced a classification system based on hip morphology, which involves calculating two angles: the α angle, formed between the ilium and the bony acetabular roof, and the β angle, between the ilium and the cartilaginous acetabular labrum [6].

Other sonographic techniques for assessing DDH exist, including the method introduced by Morin ***et al.***, which evaluates the percentage of femoral head coverage by the acetabular bone rather than relying on Graf angles [7]. A dynamic approach was described by Harcke ***et al.***, involving movement of the hip joint throughout the ultrasonographic assessment [8]. Suzuki and colleagues developed a frontal ultrasonographic approach that captures both hip joints at once, facilitating identification of femoral head position [9].

This study aimed to assess the diagnostic accuracy of USG in evaluating developmental DDH among infants.

PATIENTS AND METHODS
This cross-sectional observational study included 30 infants at high risk for developmental DDH, who attended the Department of Radiology, Mansoura University Hospitals, after referral from Mansoura University Children's Hospital and pediatric outpatient clinics, Egypt. This study was conducted over a one-year period (October 2023–September 2024).

The infants were selected based on risk factors including breech presentation, female sex, positive family history, firstborn birth order, and oligohydramnios.

Received: 30/04/2025
Accepted: 30/06/2025

Inclusion criteria: Infants aged 0 to 6 months, of either sex, with clinically diagnosed DDH. **Exclusion criteria:** Infants who had received prior non-surgical or surgical therapy for DDH; those with secondary hip dislocation; a history of hip infection or septic arthritis in infancy; and those with neuromuscular disorders.

All participants were assessed by the same radiological team following a standardized protocol.

1) History: personal history, presenting symptoms and their duration, and history of trauma were recorded.
2) Clinical examination: general assessment included pulse, blood pressure, and temperature; local hip examination involved joint evaluation using the Barlow and Ortolani maneuvers, performed with and without stress [10].
3) Ultrasonography (USG): bilateral hip joints were examined using Graf's technique [4].

Technique of hip ultrasonography

Ultrasonographic assessment of 30 infants was carried out by an experienced pediatric radiologist using 12-MHz linear transducers on GE Healthcare GE-S6 and Philips iU22 scanners. Neonates were positioned laterally, supported with pads if available, to allow high-quality coronal and transverse visualization. Parameters measured included α and β angles as well as femoral head coverage, according to Graf's technique.

The measurement technique employed four anatomical landmarks—the perichondrium–periosteum junction, acetabular bone margin, lower iliac border, and midpoint of the labrum—to construct three reference lines. Two angles were calculated: **the α angle**, or bony coverage angle, measured between the iliac baseline and acetabular roof line, and **the β angle**, or cartilaginous coverage angle, measured between the baseline and the labral line. As per Graf's classification, normal hips demonstrate α angles above 60° and β angles below 55°.

As described by **Morin *et al.*** [7], femoral head coverage was quantified as a percentage by dividing acetabular width by femoral head diameter. Acetabular width was defined as the distance from the iliac line to the medial edge of the acetabulum, while femoral head diameter was the distance between two lines parallel to the iliac line tangential to the medial and lateral femoral head margins. The formula used was (acetabular width / femoral head diameter) × 100.

Ethical Considerations

This study was ethically approved by Mansoura Faculty of Medicine Institutional Research Board (MFM-IRB; Code No. MS.22.02.1858) and the local ethics committee. Written informed consent was obtained from all participants guardians, with assurances of confidentiality. The study protocol conformed to the Helsinki Declaration, the ethical norm of the World Medical Association for human subjects.

Statistical Analysis

Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS, version 27; IBM/SPSS Inc., Chicago, IL, USA). The Monte Carlo test was applied to assess associations between categorical variables when more than 20% of cells had an expected count less than five. For continuous variables, ANOVA was used to compare more than two normally distributed groups, after verifying assumptions of normality and homogeneity of variance using Shapiro–Wilk and Levene's tests, respectively. When these assumptions were not met, the non-parametric Kruskal–Wallis test was applied for comparing more than two groups of skewed data. Post hoc analyses included Tukey's honestly significant difference (Tukey-HSD) test after significant ANOVA results, and the Bonferroni test after significant Kruskal–Wallis results, to adjust for multiple comparisons and identify intergroup differences. Student's t-test was used to determine statistical significance between two independent groups with parametric data, while Mann–Whitney U test was used for non-parametric data. Agreement between two quantitative variables was examined using the intraclass correlation coefficient (ICC), and inter-method agreement between assessment modalities was evaluated using the kappa coefficient. Statistical significance was set at P<0.05.

RESULTS

A total of 30 infants at risk for DDH were included, with a mean age of 3.11 ± 1.53 months. Of these, 19 (63.3%) were female and 11 (36.7%) were male. The most common risk factors associated with DDH were breech delivery (36.7%), female gender (30%), oligohydramnios (16.7%), positive family history (6.7%), weight (6.7%) and congenital anomaly (3.3%) **Table (1)**.

Table 1. Demographic data and risk factors of studied cases.

Variables	Study cases (*n* = 30)
Gender	N (%)
Males	11 (36.7)
Females	19 (63.3)
Age (Months) Mean ± SD	3.11 ± 1.53
Risk factors	N (%)
Breech	11 (36.7)
Female gender	9 (30.0)
Oligohydramnios	5 (16.7)
Family History	2 (6.7)
Weight	2 (6.7)
Congenital anon	1 (3.3)

Data are presented as mean ± SD or frequency (%).

For the right hip, the mean α angle measured 53.87 ± 9.65°, whereas for the left hip it was 55.17 ± 7.16°. The mean β angle was 53.87 ± 11.16° in the right hip and 53.93 ± 8.08° in the left hip. **Table 2**

Table 2. Mean value of alpha and beta angles in both sides.

Angle	Side	Mean ±SD
Alpha (α)	Right hip	53.87 ± 9.65
	Left hip	55.17 ± 7.16
Beta (β)	Right hip	53.87 ± 11.16
	Left hip	53.93 ± 8.08

Data are presented as mean ± SD

According to Graf's classification, the most frequent hip type was type I, observed in 33.3% of right hips and 36.7% of left hips, followed by type IIb in 16.7% and 23.3%, respectively **(Table 3)**.

Table 3. Graf types in both sides in the studied cases.

Type	Right side (*n* = 30) N (%)	Left side (*n* = 30) N (%)
Type 1	10 (33.3)	11 (36.7)
Type II a+	4 (13.3)	2 (6.7)
Type II a–	4 (13.3)	4 (13.3)
Type II b	5 (16.7)	7 (23.3)
Type II c	3 (10)	4 (13.3)
Type III	3 (10)	2 (6.7)
Type IV	1 (3.3)	0

Data are presented as frequency (%).

Concerning the D ratio, the mean right hip D ratio in the studied cases was 47.4 ± 14.64 % and there were 15 cases (50%) with dysplasia according to this right hip D ratio. While the mean left hip D ratio in the studied cases was 50.87 ± 10.99 % and there were 11 cases (36.7%) with dysplasia according to this left hip D ratio. According to diagnosis of DDH by US in the right, 50% of babies were diagnosed to have a degree of DDH while in the left side, 36.7% only had dysplasia **(Table 4)**.

Table 4. The hip D ratio in the right and left sides in the studied cases.

Variables	Study cases (*n* = 30)
Right hip D ratio	
Mean ± SD	47.4 ± 14.64
Median (Range)	49 (0 - 70)
Diagnosis	
Normal	15 (50)
Dysplasia	15 (50)
Left hip D ratio	
Mean ± SD	50.87 ± 10.99
Median (Range)	55 (8 - 61)
Diagnosis	
Normal	19 (63.3)
Dysplasia	11 (36.7)

Data are presented as mean ± SD or frequency (%).

There was strong significant agreement between right hip α and right hip D ratio and moderate significant agreement between left hip α and left hip D ratio. On the other hand, there was no significant agreement between the hip β (right or left) and the D ratio **(Table 5)**.

Table 5. Agreement analysis of interclass correlation between alpha (α), beta (β) angles and D ratio on the both sides (right and left).

Agreement (Interclass correlation coefficient = ICC)		95% CI	P value
Right hip α and right hip D ratio	0.862	0.710: 0.934	< 0.001*
Right hip β and right hip D ratio	- 0.714	- 0.853: - 0.481	0.999
Left hip α and left hip D ratio	0.394	0.046: 0.657	0.014*
Left hip β and left hip D ratio	- 0.213	- 0.528: 0.154	0.053

CI: Confidence interval; ICC: Interclass correlation coefficient; *: Statistically significant ($p < 0.05$)

About relation between the diagnosis according to D ratio with hip alpha and hip β on the both sides, the hip α was markedly lower in cases with dysplasia as compared to the normal cases. On the other hand, the hip β on the right side was substantially higher in the cases with dysplasia as compared to normal cases. And there was no substantial variation between the dysplasia and normal cases regarding the hip β on the left side **(Table 6)**.

Table 6. Relation between the diagnosis according to D ratio with hip beta and hip alpha on the right side.

Variable	Normal (*n*= 10)	Dysplasia (*n*= 7)	Test of significance
Right hip α	59.33 ± 6.94	48.40 ± 8.99	t = 3.729 P = 0.001*
Right hip β	47.60 ± 7.93	60.13 ± 10.54	t = -3.680 P = 0.001*
Left hip α	57.53 ± 7.37	51.09 ± 4.70	t = 2.597 P = 0.015*
Left hip β	52.89 ± 7.32	55.73 ± 9.34	t = - 0.923 P = 0.364

Quantitative data are expressed as mean ± SD; t: Independent samples t-test; *: Statistically significant ($p \leq 0.05$).

CASE PRESENTATION

Case No: 1

Male case aged 4 months; USG of Left hip was showed as following (fig 1):

α angle: 44°, β angle :55°, Graft type: IIc, Femoral head coverage (d: D ratio) :30%, Eccentric hip dislocation according to Graf classification and d:D ratio is significantly reduced indicating poor femoral head coverage and supporting the diagnosis of dysplastic hip.

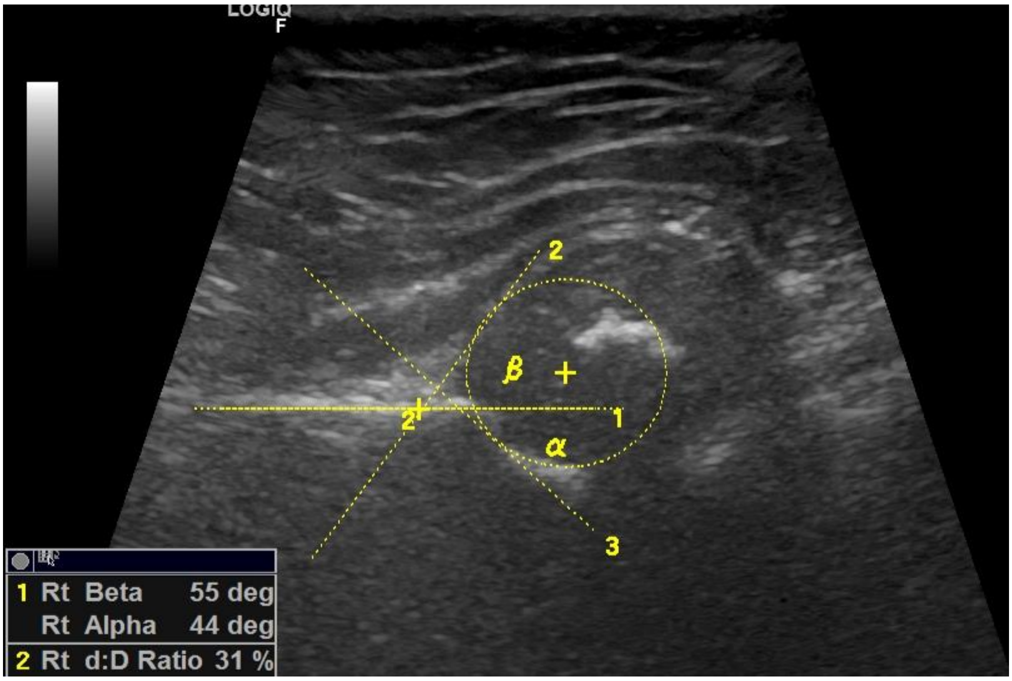

Figure 1: Ultrasound evaluation of 2 months male with eccentric hip dislocation.

Case No: 2

Male case aged 2 months; USG of Left hip was showed as following (fig 2):

α angle: 43°, β angle :69°, Graft type: IV, Femoral head coverage (d: D ratio): 8%, Dislocation according to Graf classification and d:D ratio is significantly reduced indicating poor femoral head coverage and supporting the diagnosis of dysplastic hip.

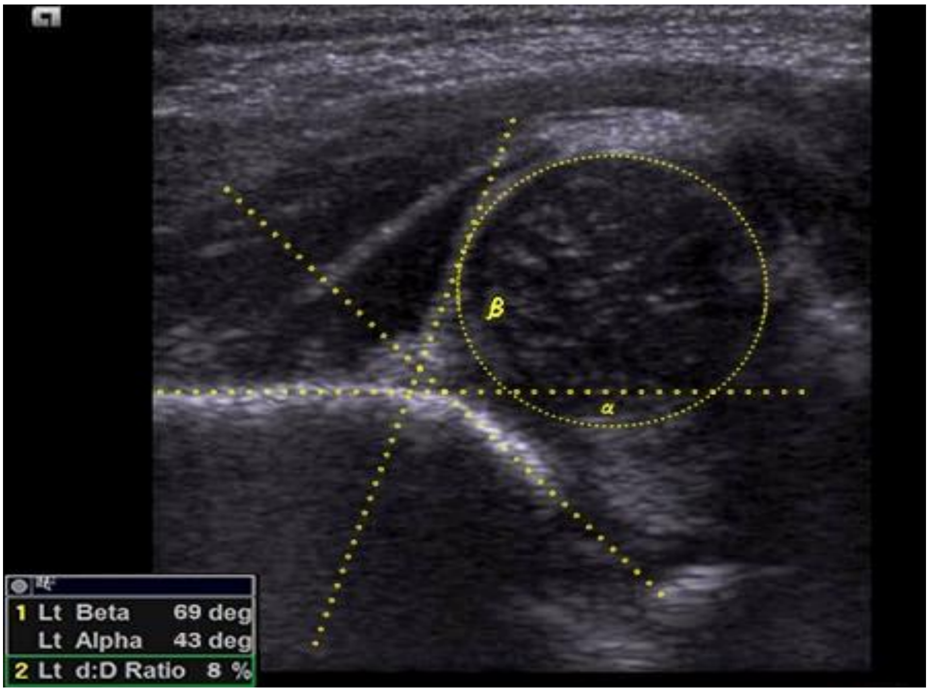

Figure 1: Ultrasound evaluation of 2 months male with left hip dislocation.

DISCUSSION

The present study demonstrated a higher prevalence of DDH in females compared to males. This finding was consistent with **Amer *et al.*** [11], who reported that 66% of infants with DDH under 6 months of age were female. Additionally, **Gyurkovits *et al.*** [12] showed that out of 55 newborns with DDH, 81.8% were females. This was explained by estrogen circulating from both maternal and fetal sources probably caused ligamentous laxity and increased a woman's risk of developing DDH. The significance of hormones in the development of DDH is supported by the fact that DDH cases have more estrogen receptors than normal [13].

Breech presentation in the third trimester is regarded as the principal risk factor for DDH [14]. Our results of the present study supported the mechanical constraint theory, which implicated prolonged knee extension in frank breech, maternal pelvic compression, and rapid fetal growth in generating excessive forces that compromised hip development [15, 16]. A recent meta-analysis further corroborated these findings, demonstrating that breech presentation, family history, female sex, macrosomia, and oligohydramnios were significantly linked to increased DDH risk [17].

In the present study, the mean α angle measured 53.87 ± 9.65° in the right hip and 55.17 ± 7.16° in the left hip, while the mean β angle was 53.87 ± 11.16° and 53.93 ± 8.08° for the right and left hips, respectively. Slightly higher values were reported in the literature. **Amer *et al.*** [11] documented mean α angles of 60.04 ± 7.71° (right) and 57.42 ± 7.30° (left), with β angles of 56.08 ± 10.51° (right) and 58.24 ± 9.95° (left). Similarly, **El Sheikh *et al.*** [18] reported mean α angles of 58.42 ± 7.57° (right) and 56.08 ± 9.11° (left), alongside β angles of 59.32 ± 8.76° (right) and 61.04 ± 7.54° (left).

The present study demonstrated that Graf type I (normal) was the most prevalent hip morphology on both sides, followed by type IIb (immature/abnormal). These findings are consistent with those of **Jacobino *et al.*** [19], who reported predominance of type I hips, with type Ia observed in 78.38% of right hips and 72.07% of left hips. Similarly, **Amer *et al.*** [11] documented Graf type I in 52% of right hips and 50% of left hips, followed by type II in 44% and 46%, respectively. **El Sheikh *et al.*** [18] stated that Graf type I was most common in their study (82%) followed by Type II (16%).

Furthermore, our findings showed a strong and statistically significant correlation between D ratio and α angle which is consistent with **Fan *et al.*** [20], who reported that there was a strong positive correlation between femoral head coverage and the α angle. The lack of significant correlation with β angle reinforces its limited diagnostic value. Other study revealed that a D ratio < 40% had a sensitivity of 79–83% and specificity of 100% for diagnosing DDH and it is positively correlated with the α angle [21]. **Liu *et al.*** [22] found a moderate positive correlation between α angle and FHC (r = 0.594, p < 0.001), in agreement with our results. Since the α angle reflects acetabular roof ossification and FHC denotes the proportion of femoral head coverage, this relationship indicates coordinated hip development during the first 6 months of life [23]. Such correlation is valuable for detecting early DDH and monitoring recovery after treatment [24, 25].

Compared with these studies, the current findings, D ratio ~47–51%, and DDH detection in 36–50% of hips were consistent with borderline to mild dysplastic categories. Our population, selected based on risk factors, likely explained the relatively high rate of dysplasia observed.

In this study, the hip α angle was significantly lower and the hip β angle was substantially higher in cases with dysplasia as compared to normal cases.

Previous clinical and imaging studies demonstrated that α angle was markedly lower in infants with DDH compared to healthy peers. In a large cohort of 3,067 normal infants under 6 months of age, the mean α angle measured approximately 62–63° (62.4° ± 3.6 on the left hip and 63.2° ± 3.5 on the right hip) [22]. In contrast, an investigation of 264 hips in infants with a positive Ortolani sign (clinical indicator of hip dislocation) reported a median α angle of only 43° (IQR: 37–49°), with the 90th percentile at 54° [26]. These findings clearly indicated that α angles in DDH cases were significantly lower than in unaffected infants, underscoring their diagnostic value as a primary sonographic parameter for assessing hip development in early childhood.

Our findings demonstrated that there was strong significant agreement between right hip α and right hip D ratio (ICC= 0.862) and moderate significant agreement between left hip α and left hip D ratio (ICC= 0.394). On the other hand, there was no significant agreement between the hip β (right or left) and the D ratio. Similarly, **Chang *et al.*** [27] reported ICCs of 0.71 for FHC and 0.63 for the α angle, indicating substantial agreement, whereas the β angle showed only moderate reliability (ICC = 0.47). They further noted that FHC ratio provided greater sensitivity and similar specificity to the Graf method for detecting unstable hips. Our findings are consistent with **Simon *et al.*** [28], who observed higher ICCs for the α than for the β angle, a trend also confirmed by later studies [28, 29]. The reduced reliability of the β angle has been linked to difficulty in consistently locating the iliac rim transition landmark [27].

CONCLUSION

This study demonstrated that US evaluation using α and β angles in addition to the D ratio, is an effective and non-invasive method for diagnosing developmental DDH in neonates. The findings support using the α angle as the primary diagnostic parameter, with the degree of femoral–acetabular coverage considered a complementary indicator, especially in atypical cases. The D ratio is found to be a valuable complementary indicator, especially in borderline or unclear cases, highlighting its role in enhancing diagnostic accuracy.

Conflict of interest
None.
Funding: None.

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