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Effectiveness of incorporating the graf method into a universal neonatal ultrasound screening program for early diagnosis of developmental dysplasia of the hip in the Taiwanese population

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Abstract

Purpose This study evaluated the effectiveness of integrating Graf method into the universal neonatal screening program for detecting developmental dysplasia of the hip (DDH) in Taiwanese population.

Methods A total of 4,667 neonates screened between May 2014 and November 2019 were enrolled in this study. Hip ultrasound scans were performed three days after birth, and hips were classified based on their morphology and stability. The incidence rates of early diagnosis, late diagnosis, and surgical interventions for DDH were assessed. Risk factors and treatment measures for DDH were documented.

Results During the initial examination, 95.95% of hips were classified as Graf type I, while a small proportion were classified as types IIa, IIc (stable/unstable), or III. By the second examination at 4 weeks, all type IIa hips had matured to type I. A total of 35 hips (0.37%) were diagnosed with DDH and treated with a Pavlik harness before 12 weeks, resulting in an early diagnosis rate of 0.37%, with no cases of late diagnosis reported. The incidence of DDH-related surgeries was 0.04%. Multivariable logistic regression identified female sex (OR = 2.41, 95% CI: 1.05–5.52, $p = 0.038$) and breech presentation (OR = 6.54, 95% CI: 2.22–19.32, $p < 0.001$) as significant risk factors for DDH.

Conclusion Universal neonatal ultrasound screening using the Graf method is simple and beneficial in the early detection and intervention of DDH. Additionally, it significantly reduces the rates of late diagnosis and the need for surgical intervention.

Keywords Developmental dysplasia of the hip, Hip ultrasound, Universal screening, Neonatal screening

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Background

Developmental dysplasia of the hip (DDH) is the most common musculoskeletal condition in newborns. It encompasses a spectrum of anatomical abnormalities of the hip, ranging from mild flattening of the acetabular cavity to complete dislocation of the femoral head. Given the critical importance of early and accurate diagnosis for timely intervention and optimal outcomes, various hip screening methods have been developed and proposed [1–5].

Different screening policies, including selective and universal screening programs, have been implemented. Recent systematic reviews and meta-analyses indicate a trend toward a lower prevalence of late-diagnosed DDH with universal screening compared to selective screening [6]. The global incidence of DDH ranges from 0 to 22.66%. The average prevalence rate was 1.4%, varying based on geographical and ethnic factors [7]. However, there is currently no available data on the incidence, early diagnosis rate, or late diagnosis rate of DDH in the Taiwanese population.

No consensus exists regarding the most appropriate method for hip screening. Sonographic diagnosis of hip dysplasia in newborns, first described by Graf, is the most widely used method in European countries [8–10]. This method classified hips into four primary types based on morphological characteristics, with further subtypes according to additional parameters [8]. For type IIc hips, supplementary instability testing ("stress test" according to Graf's terminology) further subdivides type IIc hips (which are heavily dysplastic hips) into stable or unstable. Our clinical practice incorporates provocative maneuvers across all Graf types to evaluate hip stability. This study assesses the incidence of DDH, associated risk factors, and the effectiveness of the Graf method in universal DDH screening for Taiwanese infants, comparing the results with earlier population-based cohort studies.

Methods

Since 2014, our hospital has implemented a universal neonatal ultrasonographic (US) hip screening program based on the Graf method. This single-center retrospective observational study was conducted after obtaining ethical approval from the institutional review board (IRB No. 2021064). A total of 4,963 consecutive neonates were screened between May 2014 and November 2019. Premature neonates and those with congenital deformities were screened but excluded from the study.

The Graf method

In the standard Graf method, the infant is positioned in a lateral decubitus position with the hips slightly flexed, adducted, and internally rotated [8, 11]. A 7.5-MHz linear array transducer captured a standard mid-acetabular coronal plane image. The baseline, cartilage roof line, and bony acetabular roof line were drawn on the screen. The α angle (bony roof angle) and β angle (cartilage roof angle) were measured according to the Graf method.

We applied a stress test to all Graf types in neonates. After measuring the α and β angles, an assistant manually applied a posterior-directed force to the hip (Fig. 1). The examination report included acetabular dysplasia grading and hip stability assessment. Examined hips in our study were classified as follows (according to the α/β angle, hip morphology and age): Type I hips (α angle ≥ 60°, mature hips), type IIa hips (50° ≤ α angle < 60°, age < 12 weeks), Type IIc hips (43° ≤ α angle < 50° and β angle < 77°, any age / stable or unstable), Type D hips (43° ≤ α angle < 50° and β angle > 77°, any age), and Type III / Type IV hips (α angle, if measurable, < 43° - decentered hips: type III hips show upward displacement of the cartilage roof, while Type IV hips exhibit downward displacement).

In Type IIc hips, stability was assessed based on the β angle during the stress test. If the β angle remained < 77° under cranial pressure on the femur, the hip was classified as a Type IIc stable hip. However, if the β angle increased to > 77° with cranial pressure on the femur, the hip was classified as a Type IIc unstable hip.

It is important to discriminate between elastic whipping and pathological instability: Elastic whipping reflects a well-formed bony socket (α angle ≥ 50°), whereas pathological instability indicates a poorly formed socket prone to joint decentering under stress (α angle < 50°). This distinction is essential to prevent overdiagnosing hip instability, thus leading to overtreatment.

Screening and treatment protocols

Graf method ultrasound examination was typically performed on the 3rd day (range 1–7 days) by the same trained orthopedic specialist in the Neonatology Ward. Alongside the ultrasound screening, routine physical examinations, including the Ortolani maneuver and Barlow tests, were conducted on every neonate. In our study, DDH was defined to encompass all classifications more severe than type IIa hips, which are considered physiologically immature. With the exception of the infants with Type I hips, all other infants underwent reassessment at 4 weeks of age through physical examination and ultrasound imaging. Parents were then asked to return for further clinical and radiological assessment until the age of 1 year. All newborns with abnormal ultrasound findings and clinical signs of DDH were treated according to our national protocol. Graf type IIa hips were re-evaluated at two weeks of age, and a harness was prescribed if no progress was observed. Type IIc stable, IIc unstable, D, III and IV hips were immediately treated with a Pavlik harness. Patients who exhibited persistent instability upon physical examination and X-ray assessment after

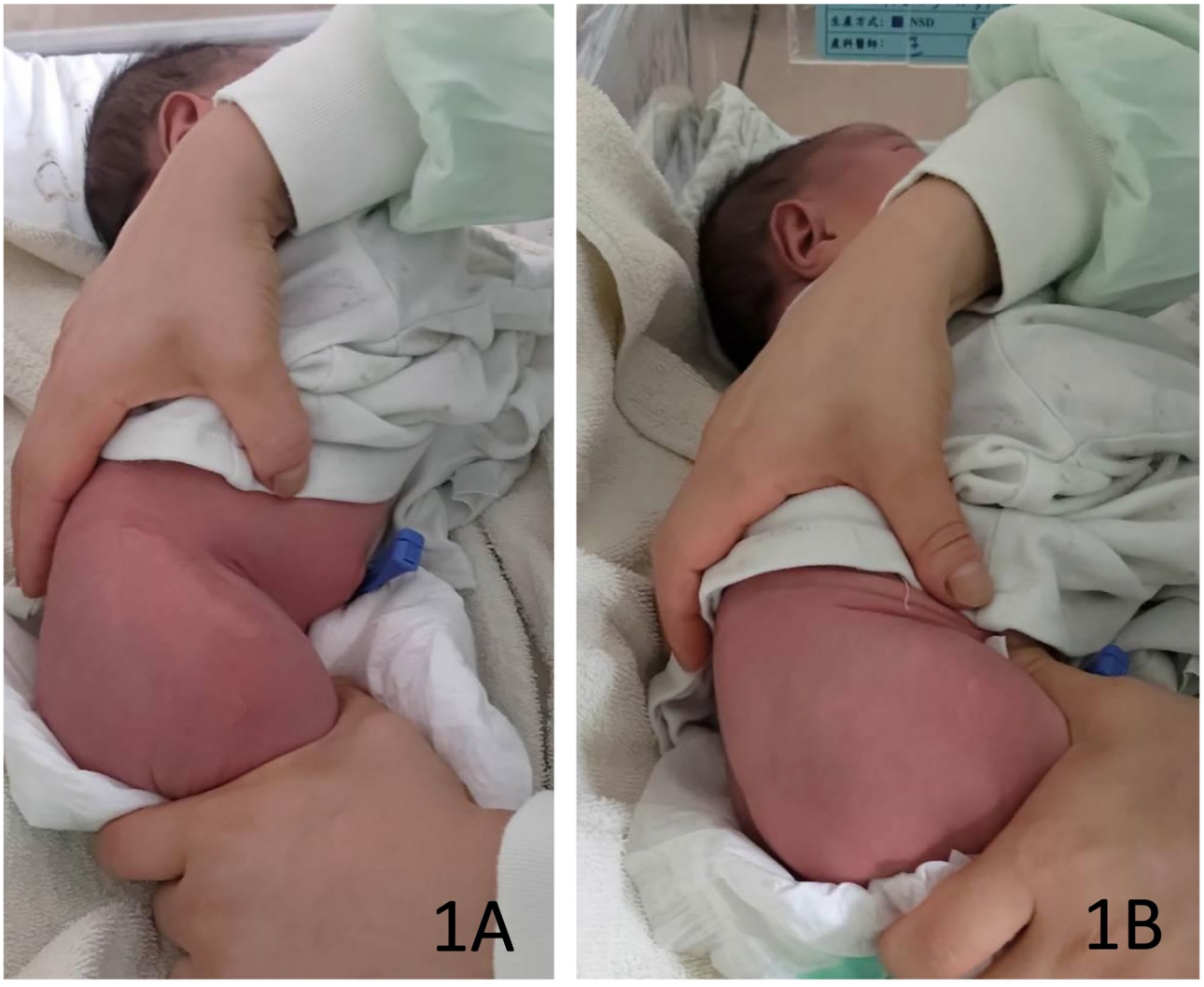

Fig. 1 Demonstration of the stress-test **(A)** The baby is positioned in the lateral decubitus position with the hip slightly flexed, adducted, and medially rotated. **(B)** Under sonographic monitoring, a cranially directed stress is applied to the examined hip

six months of age underwent closed reduction followed by spica cast application. If the hip was not reducible, open reduction followed by spica cast application was performed.

Outcome measures

Early diagnosis was defined as any diagnosis made within the age of 12 weeks, and late diagnosis was defined as any diagnosis made after the age of 12 weeks [2]. The incidence of early DDH diagnosis was calculated by dividing the cumulative number of hips diagnosed before the age of 3 months by the total number of hips examined. The incidence of late diagnosis and surgical intervention was calculated using the same formula. The age at first surgery for DDH was recorded. Risk factors, including the female sex, positive family history for DDH, breech presentation, and macrosomia (birth weight > 4,000 g), were also recorded [12].

Statistical analysis

Categorical variable differences between the DDH and non-DDH groups were evaluated using either the chi-square test or Fisher's exact test, based on expected cell counts. Multiple logistic regression was used to calculate the odds ratios (ORs) and 95% confidence intervals (CIs) to assess the risk factors in the two groups. The models were adjusted for sex, breech presentation, and macrosomia. Statistical significance was set at $p < 0.05$. All analyses were performed using SPSS (version 28.0.1.0; IBM Corporation, Armonk, NY, USA).

Results

A total of 4,963 consecutive neonates were screened between May 2014 and November 2019. After excluding those with prematurity and other congenital anomalies, 4,667 neonates were included in the study. In total, 9,334 hip sonograms were evaluated using the Graf method.

Table 1 Patient characteristics of the DDH and Non-DDH groups

	Non-DDH	DDH	*p*-value
Number of patients	4640	27	
Number of hips	9299	35	
Bilateral DDH (patients)	—	8	
Female (*n*, % of patients)	2300(49.6%)	19(70.4%)	0.031
Positive family history (*n*, % of patients)	—	2(7.4%)	—
Breech presentation (n, % of patients)	122(2.6%)	4(14.8%)	0.005[a]
Macrosomia (*n*, % of patients)	51(1.1%)	1(3.7%)	0.262[a]
Final Graf classification (hips)			
I	9299(100%)	0(0.0%)	—
IIc stable	0(0.0%)	13(37.1%)	
IIc unstable	0(0.0%)	14(40%)	
D	0(0.0%)	0(0.0%)	
III	0(0.0%)	8(22.9%)	
After treatment			
Well developed	—	31(88.6%)	
Hip spica	—	2(5.7%)	
Surgical osteotomy	—	2(5.7%)	

[a] Fisher's exact test; DDH: Developmental dysplasia of the hip

Table 2 Comparing factors associated with the DDH and non-DDH groups

	Crude OR (95% CI)	*p*-value	Adjusted OR[a] (95% CI)	*p*-value
Sex				
Male	ref		ref	
Female	2.416 (1.056–5.531)	0.037	2.407 (1.05–5.517)	0.038
Breech presentation	6.44 (2.194–18.907)	< 0.001	6.54 (2.215–19.315)	< 0.001
Macrosomia	3.461 (0.461–25.992)	0.228	4.181 (0.551–31.733)	0.167

[a] This model was adjusted by sex, breech presentation, and macrosomia

During the initial examination, 8,956 hips (95.95%) were classified as Graf type I. Additionally, 343 hips were identified as type IIa, 13 as type IIc stable, 14 as type IIc unstable, and 8 as type III. By the second examination at 4 weeks of age, all type IIa hips had fully matured into type I hips. Overall, 35 hips (0.37%) were diagnosed with developmental dysplasia of the hip (DDH) and treated with a Pavlik harness before 12 weeks of age, resulting in an early diagnosis rate of 0.37%.

Table 1 presents the patient characteristics for both the DDH and non-DDH groups. A total of 4,640 patients (9,299 hips) were included in the non-DDH group, whereas 27 patients (35 hips) were classified as having DDH. A significantly higher proportion of females was observed in the DDH group compared to the non-DDH group (70.4% versus 49.6%, $p = 0.031$), and breech presentation was also more prevalent in the DDH group (14.8% versus 2.6%, $p = 0.005$). No association was found between macrosomia and DDH. A positive family history was reported in 7.4% of the DDH group. Family history data were not routinely collected for patients in the non-DDH group, and thus, this information is only available for the DDH cohort. Associations between the incidence of DDH and patient characteristics were determined using a logistic regression model and are presented as crude and adjusted ORs in Table 2. Female sex was associated with a 2.41-fold (95% CI: 1.05–5.52, $p = 0.038$) higher risk of DDH compared to male sex. Breech presentation carried the highest risk, with a 6.54-fold (95% CI: 2.22–19.32, $p < 0.001$) increased risk compared to those without breech presentation. No significant association was observed between macrosomia and DDH risk.

The final Graf classification for the DDH group revealed varying degrees of dysplasia: type IIc stable (37.1%), type IIc unstable (40.0%), and type III (22.9%). Post-treatment, the majority of hips (88.6%) demonstrated satisfactory development, while a smaller proportion required a hip spica (5.7%) or surgical osteotomy (5.7%). In our cohort, two hips initially classified as Type III failed Pavlik harness treatment and underwent closed reduction followed by spica cast immobilization at seven months of age.

Additionally, two hips initially graded as Type IIc unstable required Pemberton acetabuloplasty for residual hip dysplasia at 2.5 years of age. The overall incidence of surgery for DDH was 0.04%, with open surgery incidence at 0.02%. Notably, no cases of DDH were diagnosed after 12 weeks of age, leading to a late diagnosis incidence of 0%.

Discussion

Universal neonatal US screening based on the Graf method has been implemented in our hospital, and we evaluated its effectiveness in this study. We retrospectively analyzed a total of 9,334 hip sonograms acquired during a 5-year period. We observed that the incidence rates of early diagnosis, late diagnosis, surgery, and open surgery for DDH were 0.37%, 0%, 0.04%, and 0.02%, respectively. Notably, only four (0.04%) hips with early detection underwent surgery for DDH. Chang et al. conducted a retrospective population-based cohort study using the Taiwan National Health Insurance (NHI) database. They reported the overall DDH incidence as well as the incidence of early diagnosis, late diagnosis, and surgical intervention for the period from 2000 to 2005 [2]. Specifically, they revealed that the average DDH incidence was 0.15% (range 0.14–0.18%); the incidence of early diagnosis before the age of 6 months ranged from 0.071 to 0.092%, that of late diagnosis after the age of 1 year ranged from 0.046 to 0.067%, and that of surgical intervention ranged from 0.049 to 0.071%. Although retrospective studies using the NHI database may encounter several limitations, including unverified diagnostic coding and miscoding of surgical procedures, Chang et al. provides the most comprehensive investigation of the incidence of DDH and surgery in the Taiwanese population. The present study is the first to provide statistics under the universal ultrasound screening program for the Taiwanese population. We noted a nearly twofold higher incidence of DDH under universal screening program. All patients received a diagnosis before the age of 12 weeks. We also observed a reduction in the incidence of surgery for DDH. Accordingly, integrating the Graf method with the neonatal hip screening program might be beneficial.

Globally, numerous studies have investigated the incidence of DDH and its necessary surgical intervention under the universal ultrasound screening program based on the Graf method [9, 13]. The reported DDH incidence ranged from 0.24 to 2.5%. A 19-year retrospective study conducted by Schams et al. evaluated 11,820 neonates in Switzerland and reported that 2.5% of the hips were pathological [13]. Kolb et al. evaluated 5,356 consecutive hips in Austria retrospectively and identified that only 0.24% were pathological [14]. In the past 3 years, two extensive cohort studies conducted by Biedermann et al. and Treiber et al. have demonstrated similar DDH incidence rates (0.8% and 0.6%, respectively) [15, 16]. Regarding the incidence of surgical intervention for DDH, Thallinger et al. conducted a 17-year retrospective study using the Austrian Health Institute database [17]. Since the application of the nationwide general US screening program, the surgical intervention rate has decreased by 46% (from 0.13 to 0.07%). Our results are comparable to those of previous studies, supporting our proposal to incorporate the Graf method into the neonatal hip screening program.

The optimal DDH screening strategy remains debatable. Although numerous studies have demonstrated the cost-effectiveness of the universal ultrasound screening strategy [15–18], other studies have opposed universal screening because of concerns about overdiagnosis, which could lead to overtreatment and the potential development of osteonecrosis of the femoral head (ONFH) [19, 20]. Laborie et al. reported the long-term follow-up outcome of a randomized controlled trial comparing three newborn screening strategies. They reported that the universal ultrasound screening strategy was not associated with a higher rate of ONFH [21]. The treatment rates under the universal ultrasound screening strategy ranged from 0.26 to 3.4% [15, 16, 19, 21]. Similar to the results reported by Treiber et al., our study revealed a low treatment rate (0.37%) [16]. Early universal ultrasound screening does not necessarily lead to overdiagnosis or overtreatment of DDH. Defining hip morphology and sonographic stability can standardize DDH screening procedures and render them more practical in medical education for primary care physicians, pediatricians, and orthopedic surgeons.

It is important to note that secondary hip dysplasia or dislocation may occur in extensively swaddled babies. At our institution, caregivers were instructed on healthy hip swaddling techniques before discharge. In our series, no cases of late or secondary dysplasia or dislocation were observed. However, the sensitivity of hip ultrasound screening performed in the first week of life is not 100%. According to Biedermann et al., deterioration was observed in 125 patients (0.4%), with an increasing incidence in higher Graf types. Among 25,093 Graf type I hips, 48 deteriorated during the observation period. Only one patient was misdiagnosed as type I initially, indicating that Graf type I hips diagnosed in the first week of life had a 99.8% likelihood of not worsening and a 99.94% likelihood of not requiring treatment upon later evaluation.

This study has several limitations. First, the data were collected retrospectively from a single medical center without a control group, which may limit the generalizability of the findings, as the study cohort may not fully represent the general population. Nevertheless, the relatively large sample size helps to mitigate this potential

bias to some extent. Another limitation is the absence of long-term follow-up, which restricts the ability to evaluate the sustained effectiveness of the interventions, the natural progression of DDH, and potential long-term outcomes, such as residual dysplasia or the development of osteoarthritis in later life. Future studies with larger, more diverse cohorts and extended follow-up periods are necessary to validate these findings and provide a more comprehensive understanding of the long-term implications of early DDH diagnosis and treatment.

Conclusion

The Graf method is a straightforward technique for assessing hip morphology and stability. Compared with findings from previous population-based cohort studies in our region, our results demonstrate that incorporating the Graf method into the DDH universal screening program led to a higher rate of early diagnosis and a lower rate of late diagnosis and DDH-related surgeries. Additionally, our study identified female gender and breech presentation as significant prognostic factors correlated with an increased risk of DDH. These findings underscore the value of the Graf method as a reliable tool for orthopedic surgeons and pediatricians in the universal screening and early detection of DDH.

Author contributions

JH-Wang, CH-Chen and TM-Wang contribute to conceptualization and methodology. JH-Wang, SH-Yao, CH-Lin perform formal analysis and investigation. JH-Wang was a major contributor in writing the manuscript. Writing - review and editing was done by TM-Wang, CJ-Lin and CH-Chen. All authors read and approved the final manuscript.

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Data availability

The dataset used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This study was performed in accordance with the guidelines of the Declaration of Helsinki. The study design was approved by Ditmanson Medical Foundation Chia-Yi Christian Hospital institutional review board (approval no.: 2021064), and the institutional review board waived the requirement to obtain the informed consent due to the retrospective design.

Consent for publication

All authors have read and agreed to the published version of the manuscript.

Competing interests

The authors declare no competing interests.

Clinical trial number

Not applicable.

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