Measurement of Pubofemoral Distance in the Diagnosis of Developmental Dysplasia of the Hip

Sensitivity and Specificity

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Objectives—To evaluate the accuracy of measurement of the pubofemoral distance (PFD) for the diagnosis of developmental dysplasia of the hip (DDH), using the Graf method as the reference standard.

Methods—This was a prospective diagnostic accuracy study evaluating 1980 hips in at-risk neonates. The PFD measurement and the Graf method were performed at the same opportunity, with the hips in the same position (slightly flexed, adducted, and medially rotated).

Results—In our sample, the prevalence of DDH, defined as Graf type IIb or higher, was 15.6%. The mean PFD for dysplastic hips was 3.5 mm (median, 3.3 mm), whereas it was 3.0 mm (median, 2.9 mm) for nondysplastic hips. In both groups, there was a significant overlap between the PFD measurements and the Graf classifications. The PFD cutoff with the largest area under the receiver operating characteristic curve was 3.0 mm, which was found to have a sensitivity and specificity of 63.6 and 62.2%, respectively, with positive and negative predictive values of 31.2 and 71.4%, respectively, for the diagnosis of DDH.

Conclusion—Measurement of the PFD shows good overall accuracy for the diagnosis of DDH. However, given its low-positive predictive value, it should not be considered to be a replacement for the Graf method.

Key Words—diagnosis; hip dislocation; congenital; infant; newborn; ultrasonography

Received March 16, 2021, from the Department of Evidence-Based Health, Federal University of the State of São Paulo, São Paulo, Brazil (G.G.B.M., M.L.D., W.I.); Department of Ultrasonography, Ultrasonography Improvement and Research Center Prof. Dr. Giovanni Guido Cerri (DASA), São Paulo, Brazil (G.G.B.M., A.R.S.C., E.D.C., W.I.); Department of Pediatric Orthopedics, São Paulo University, São Paulo, Brazil (A.F.L., M.S.T.); and Department of Pediatric Orthopedics, São Paulo Municipal Civil Servant Hospital, São Paulo, Brazil (N.V.M.R.). Manuscript accepted for publication July 11, 2021.

All of the authors of this article have reported no disclosures and no financial relationships relevant to this article.

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Abbreviations

DDH, developmental dysplasia of the hip; PFD, pubofemoral distance; ROC, receiver operating characteristic

doi:10.1002/jum.15811

Introduction

Developmental dysplasia of the hip (DDH) is the name given to a spectrum of structural changes in the developing hip, ranging from mild dysplasia in a stable, well-centered hip to marked dysplasia or dislocation.[1] The incidence of DDH is highly region dependent, mainly due to regional differences in ethnicity, customs, and the availability of neonatal screening.[1] Many studies have been carried out in various populations, reporting incidences ranging from 0.06 to 76.1 cases per 1000 live births.[1] One recent study, conducted at a maternity hospital in the city of São Paulo, Brazil, found the prevalence of DDH to be 5.5%.[2]

Ideally, DDH should be diagnosed in the neonatal period, because earlier initiation of treatment increases the chance that conservative treatment will be successful and decreases the risk of sequelae such as arthrosis, abnormal gait, apparent femoral shortening, limb deformity, scoliosis, and low back pain.[3–5]

Although clinical screening for DDH is part of the routine evaluation of all newborns, it is not very sensitive or specific in isolation.[6–8] Therefore, many experts suggest that all newborns, or at least those with abnormalities on physical examination or risk factors, undergo ultrasound assessment in order to increase the rate of detection of the condition and help prevent future complications.[6–8]

Among the various methodologies employed for the diagnosis of DDH, the one that is the most widely accepted and commonly used is the Graf method,[9,10] which consists of a qualitative and quantitative ultrasound assessment of the hip.[11] The alpha angle is a measure of acetabular depth and is the angle formed between the acetabular roof and vertical cortex of the ilium. The beta angle is the angle formed between the vertical cortex of the ilium and triangular labral fibrocartilage.[10,12,13] Figure 1 shows the difference between a normal hip and a dysplastic hip, in terms of the lines employed to determine the alpha and beta angles.[9] Although relatively simple and with good reproducibility, the Graf method requires that the ultrasound image of the hip be acquired in a specific spatial plane and that anatomical landmarks be properly identified.[10] That can be challenging, especially for less experienced examiners.[10]

The pubofemoral distance (PFD) is defined as the distance between the most medial aspect of the femoral head and the most lateral aspect of the pubis.[14] The PFD should be measured in an image obtained in the coronal plane, which includes the largest circumference of the femoral head and the most lateral aspect of the pubis.[14] Figure 2 demonstrates the relative simplicity of measuring the PFD. The technique was first proposed in 2013 by Tréguier et al, who emphasized the potential advantage of increasing the number of cases of DDH diagnosed, through the use of a technique that is more accessible to less experienced examiners.[14] In a retrospective study, Teixeira et al found that the measurement of the PFD is also not significantly affected by

Figure 1. Standardized images showing the measurement of the alpha and beta angles. Measurement of the alpha angle in a normal hip, **A**, and in a dysplastic hip, **B**. Measurement of the beta angle in a normal hip, **C**, and in a dysplastic hip, **D**.

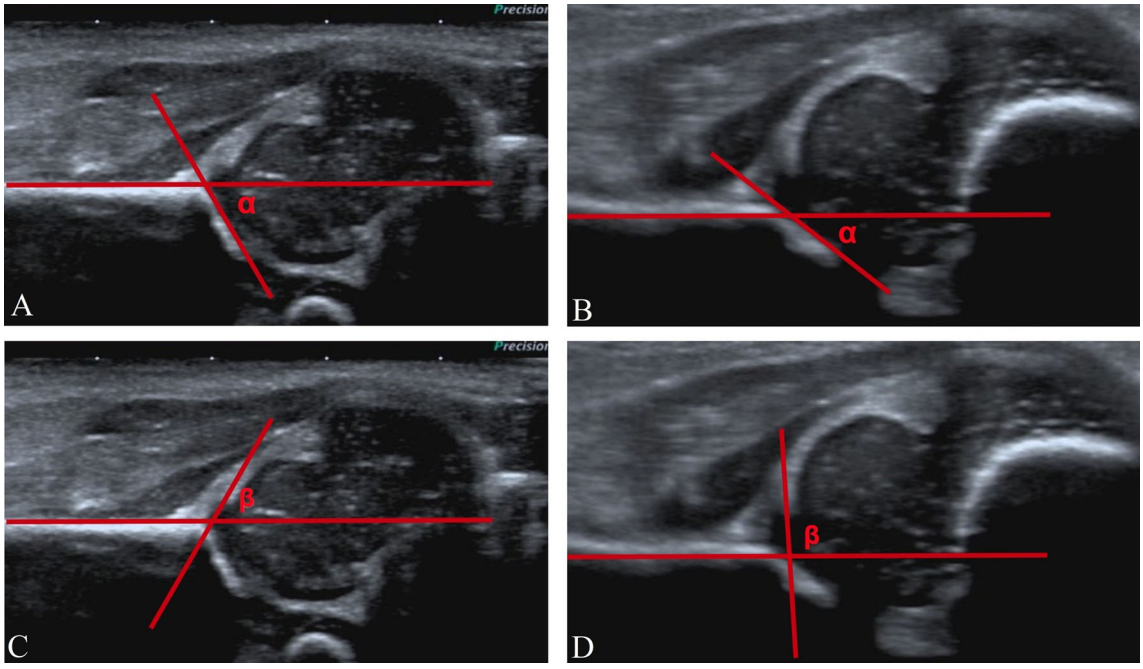
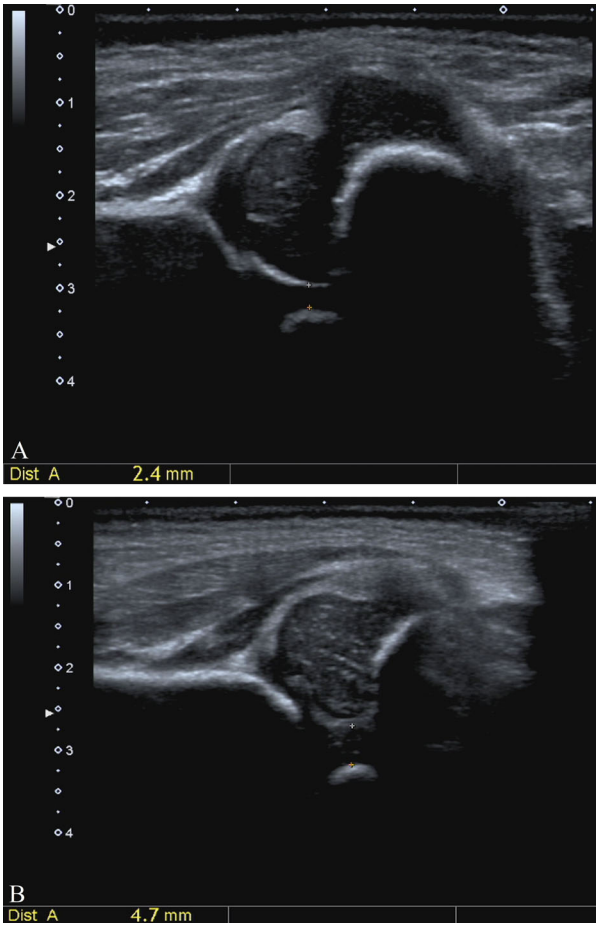


Figure 2. Demonstration of the pubofemoral distance, as measured with the technique described by Tréguier et al,[14] in a normal hip, **A**, and in a dysplastic hip, **B**.



the hip position (flexion or neutral) for dysplastic hips.[15] The authors found that, for the diagnosis of DDH, the technique had a sensitivity of 94% and a specificity of 89%.

According to Tréguier et al, hip instability can exist before acetabular changes occur and measurement of the PFD alone can identify such instability.[14] The authors also stated that measurement of the PFD is a simple technique and could therefore be utilized by sonographers with no experience in performing ultrasound of the hip in pediatric patients.[14]

The aim of this study was to determine the accuracy of PFD measurement in the diagnosis of different degrees of DDH. For comparison, we used the Graf classification.

Figure 3. Illustration demonstrating the correct (lateral) positioning of the patient, with the side to be examined upwards, and the correct positioning of the transducer. The examined limb is in a neutral position, and the transducer is positioned perpendicular to the bed, to obtain an image of the hip in the coronal plane.

Materials and Methods

This study was approved by the local research ethics committee. Prior to any procedure, written informed consent was obtained from the parents or legal guardians of all of the infants evaluated. This manuscript was prepared in accordance with the Standards for Reporting of Diagnostic Accuracy Studies statement.[16]

This was a prospective study of 1980 infant hips evaluated by ultrasound between October 2019 and May 2020, in the city of São Paulo, Brazil. In all hips, the Graf method and PFD measurement were applied with an Aplio 300 ultrasound system (Toshiba Medical Systems, Tokyo, Japan) and a linear transducer with a frequency range of 7.0–14.0 MHz. The infants evaluated ranged in age from 3 days to 6 months. All of the infants were referred by a pediatrician or a pediatric orthopedist; most were referred to our facility because they had 1 or more risk factors for DDH (female gender, breech presentation, primiparous mother, twinning, or a family history) or had tested positive for the condition by clinical examination (with the Ortolani or Barlow test). Infants with an ossific nucleus were excluded because that precludes the visualization of the pubis and therefore the measurement of the PFD.

For each hip, the PFD was measured prior to classification by the Graf method. Each hip was

Figure 4. Anatomy of a normal hip, without and with the landmarks indicated, **A** and **B**, respectively. BR, bone roof; Ca, cartilage; FH, femoral head; GT, greater trochanter; IB, iliac (bone) border; JC, joint capsule; La, labrum; SF, synovial fold; TC, triradiate cartilage.

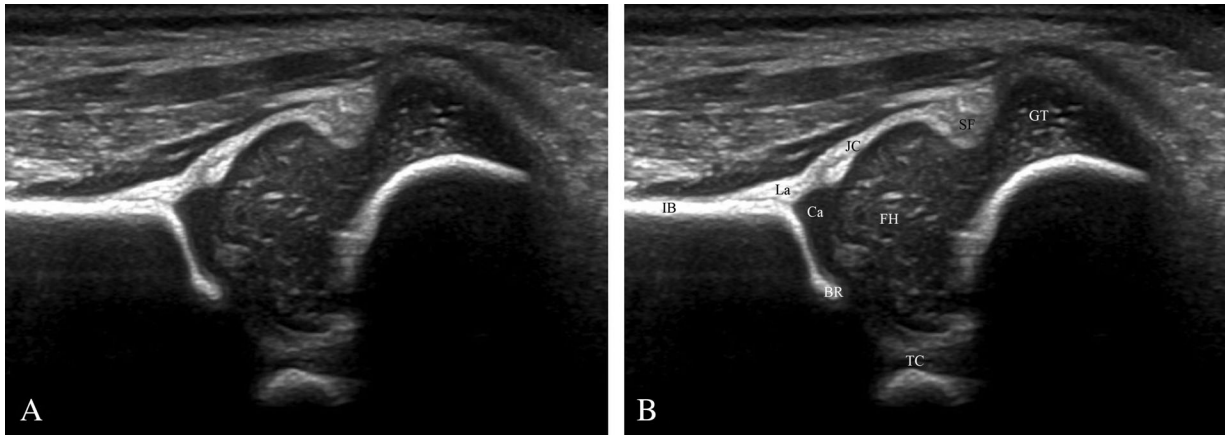


Figure 5. Sample selection flow chart.

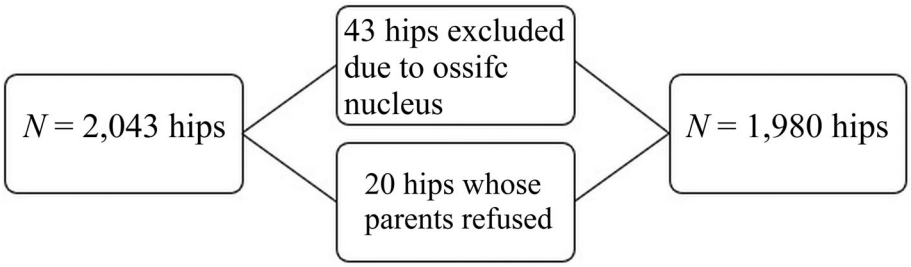


Table 1. Graf Types in Our Sample of Infant Hips (n = 1980)

Graf Type	*n* (%)
Ia	1228 (62.0)
Ib	140 (7.0)
IIa	302 (15.2)
IIb	4 (0.2)
IIc	27 (1.4)
IId	188 (9.5)
IIIa	67 (3.4)
IIIb	8 (0.4)
IV	16 (0.8)

assessed independently by the Graf method and PFD measurement, both of which were performed by the same ultrasound physician, with more than 20 years of experience in pediatric ultrasound, who was blinded to all patient information, including the final diagnosis before the test in question.

Each infant was placed in the lateral position, with the side to be examined upward. The target limb was placed in a neutral position, and the transducer was positioned perpendicular to the bed, in order to obtain an image of the hip in the coronal plane (Figure 3). That view allows the identification of anatomical landmarks (osteochondral border, femoral head, synovial fold, joint capsule, labrum, cartilage, bone roof, and iliac bone border), as depicted in Figure 4, as well as the evaluation of the anatomical pattern (the inferior aspect of the iliac, midpoint of the acetabular roof, and labrum). The hip was then classified by each method. The PFD was measured in the acetabular cavity, after which the hip was classified according to the Graf method. Lines were drawn to outline the alpha and beta angles for classification. Hips classified as Graf type Ia, Ib, or IIa were considered normal, whereas those classified as Graf type IIb, IIc, IId, IIIa, IIIb, or IV were considered dysplastic. The PFD measurements and Graf classifications were transformed into categorical data and entered into a Microsoft Excel spreadsheet.

Figure 6. Histogram of pubofemoral distances in our sample of 1980 infant hips.

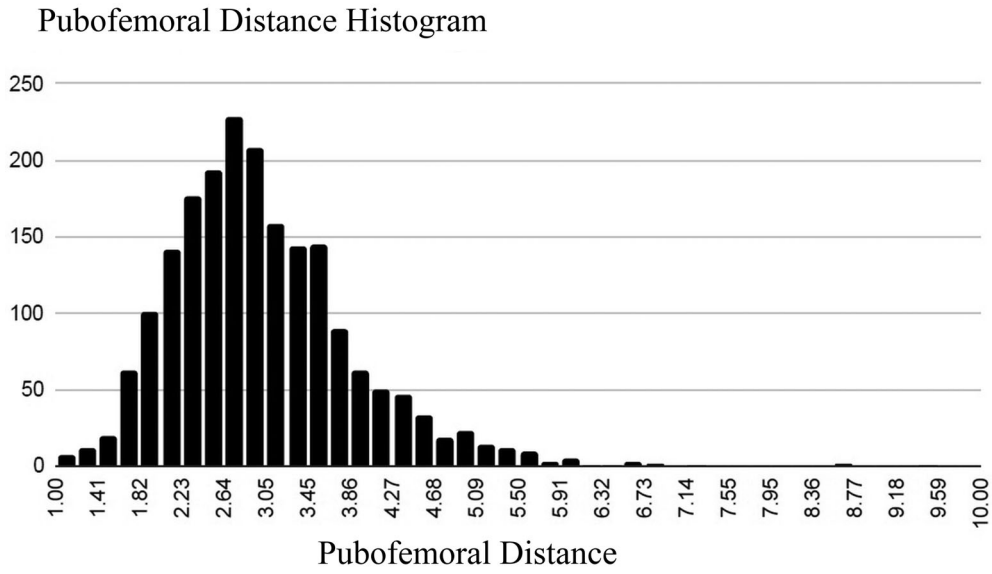
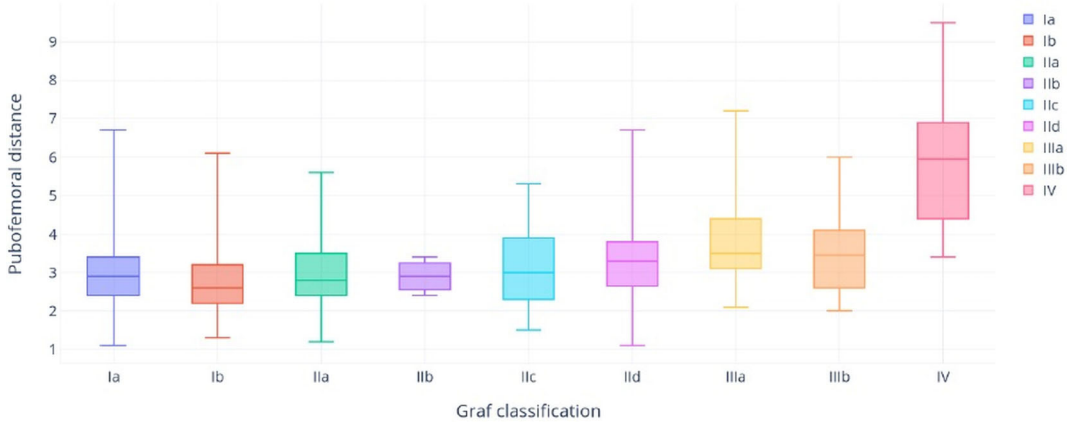


Figure 7. Box plot of the measures of the pubofemoral distance by Graf type.



For the accuracy analysis, we calculated the sensitivity, specificity, positive predictive value, negative predictive value, positive likelihood ratio, and negative likelihood ratio, together with the respective 95% confidence intervals, for each diagnostic method. A type I error less than 5% that was verified by Pearson's chi-square test. The 95% confidence intervals for the proportions were obtained using the binomial distribution.

The statistical analysis was performed with the IBM SPSS Statistics software package, version 19.0 (IBM Corporation, Armonk, NY). Continuous variables are expressed as mean and standard deviation or as median and range, whereas categorical variables are expressed as absolute and relative frequencies. We used 2×2 tables to organize the data and to improve the visualization of bar graphs that were produced in the SPSS software or in Excel.

For statistical analysis, the data were exported to the website www.jrocfit.org for data analysis and construction of a receiver operating characteristic (ROC) curve.[17] We identified the PFD cutoff with the largest area under the ROC curve for the diagnosis of hip

Figure 8. Box plot of the distribution of pubofemoral distance measurements in relation to dysplastic and nondysplastic groups.

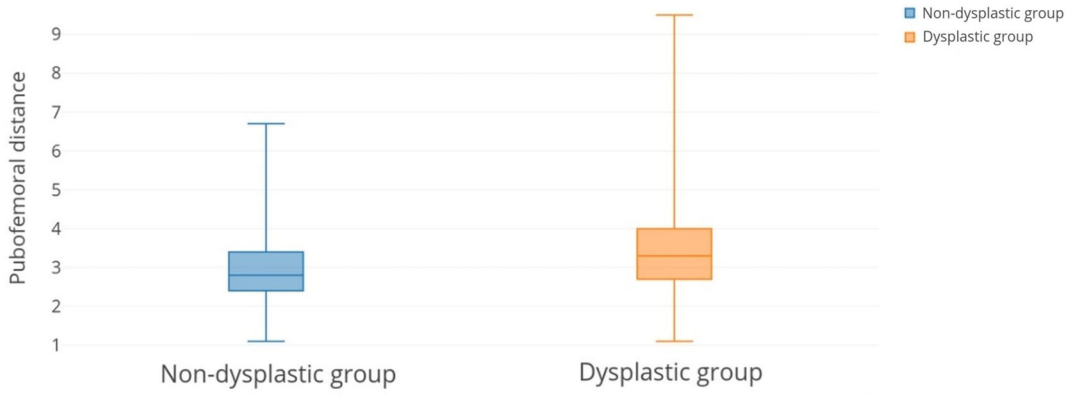


Figure 9. Receiver operating characteristic (ROC) curve of the pubofemoral distance cutoff values.

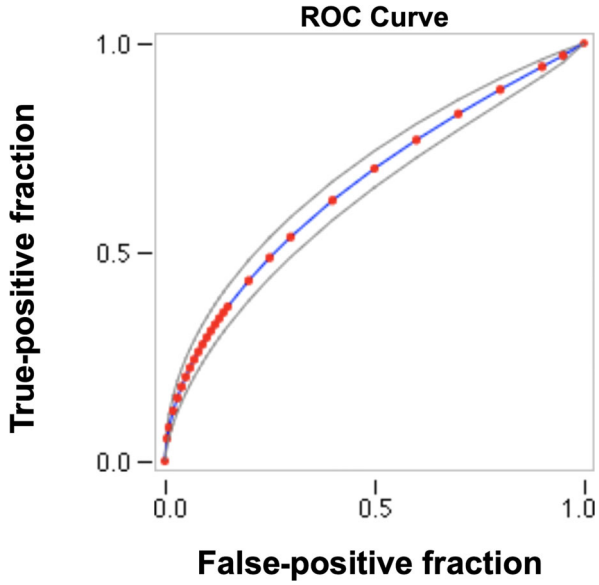
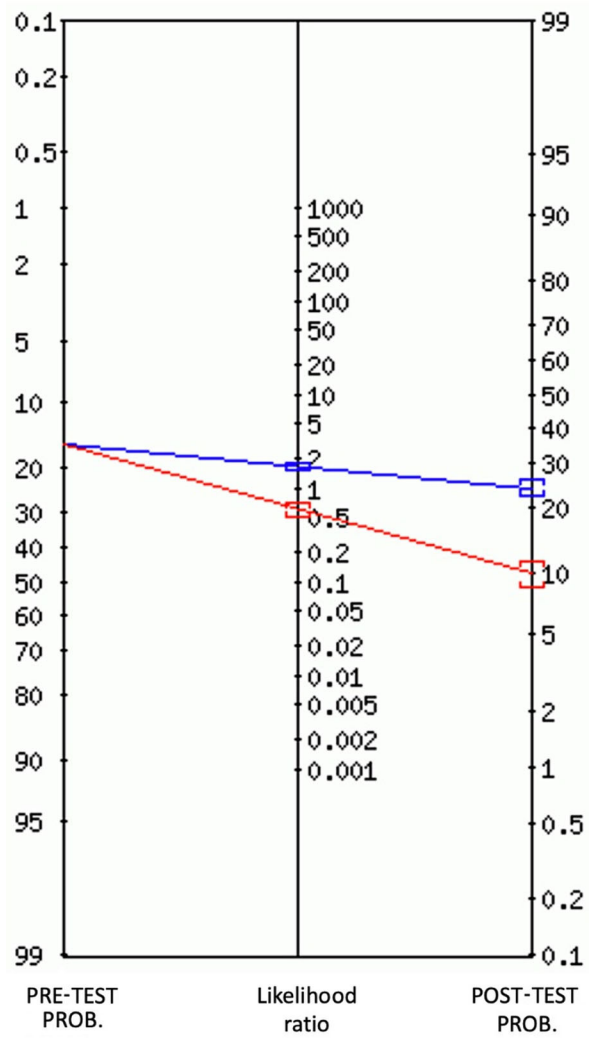


Figure 10. Fagan nomogram for pubofemoral distance measurement. PROB., probability.



dysplasia with a Graf classification of type IIb or higher, calculating its sensitivity, specificity, positive predictive value, negative predictive value, positive likelihood ratio, and negative likelihood ratio.

Results

We initially assessed 2023 hips for eligibility. Figure 5 shows the flow of the patients (hips) through the study. A total of 1980 hips were included in the final

analysis. The median age of the infants evaluated was 30 days, and the female:male ratio was 5:1. The mean age at ultrasound evaluation was 40 days. The main risk factors were breech presentation and being a first-born child.

Of the 1980 hips evaluated, 310 (15.6%) were classified as dysplastic on the basis of the Graf type (≥IIb). The proportional distribution of the hips by Graf type is shown in Table 1.

The mean PFD was 3.02 mm (median, 2.9 mm; range, 1.1–9.5 mm). The distribution of PFD values is shown in Figure 6. The overlap between the PFD measurements and the Graf classifications is shown in Figure 7, and the comparison between hips with and without DDH is shown in Figure 8.

The PFD cutoff deemed ideal for the diagnosis of DDH was 3.0 mm, which had an area under the ROC curve of 0.657 (Figure 9). At that cutoff, PFD measurement was found to have a sensitivity of 63.6%, a specificity of 62.2%, a positive predictive value of 31.2%, a negative predictive value of 71.4%, a positive likelihood ratio of 1.68, and a negative likelihood ratio of 0.58.

Discussion

Ultrasound measurement of the PFD requires little operator experience to quickly classify patients,[14] as well as not being significantly affected by the hip position (flexion or neutral) for dysplastic hips.[15] In contrast, the Graf method can be complex and difficult to perform for sonographers and radiologists with little specific training.[18,19]

Since 2013, when the method for measuring PFD was proposed by Tréguier et al,[14] there have been few studies of its accuracy and application, making it unclear how to use it correctly, use even regarding the cutoff value that should be used. In 2019, Husum et al[20] suggested that the PFD cutoff of 6.0 mm proposed by Tréguier et al[14] should be lower (4.4 mm) to achieve 100% sensitivity. In 2005, Teixeira et al[15] also suggested using a lower threshold (4.6 mm) in the lateral position with adducted flexion. In 2011, Couture et al[21] demonstrated the usefulness of PFD measurement in the assessment of DDH, although the technique employed by those authors was different from the one proposed in our study and that employed by Teixeira et al.[15] Husum et al[20] evaluated the PFD cutoff of 4.4 mm and the Graf method (according to international guidelines), comparing a group of infants under treatment for DDH with another group of untreated infants screened for DDH, and found that placing infants in the lateral position favors the study of the hip in both methods. In the present study, the position proposed by Graf was used and the Graf method was compared with the PFD measurement technique in the same patients. The accuracy values for PFD measurement were not sufficiently relevant to lead us to suggest that it should replace the Graf method. At the cutoff of 3.0 mm, PFD measurement had a positive predictive value of 31%, only slightly higher than the 28% reported by Kowalczyk et al.[22] Given that the positive and negative likelihood ratios for PFD measurement were 1.68 and 0.58, respectively, and that the prevalence of DDH in our sample was 15.6%, the probability of DDH increases to 24.0% after a positive test and decreases to 10.0% after a negative test, as can be seen in the Fagan nomogram (Figure 10).

It should be borne in mind that, in the present study, the index test (PFD measurement) and the reference standard (Graf classification) were performed by the same sonographer. It is noteworthy that the technique used in order to obtain the image for the measurement of PFD was performed in the same way as in the study conducted by Teixeira et al[15] and not as in the study conducted by Tréguier et al.[14] The prevalence of DDH in our study does not reflect that seen in the general population, because our sample comprised infants referred by specialists, who likely identified some risk factor or abnormality on the physical examination. The prevalence in the general population should be lower, making the change in the posttest probability even smaller.

Conclusion

Measurement of the PFD shows good overall accuracy for the diagnosis of DDH. However, given its low-positive predictive value, it should not be considered to be a replacement for the Graf method.

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