Pubofemoral distances correlate to acetabular morphology and sonological instability in screening for hip dysplasia

Cite this article:
Bone Jt Open 2024;5(1):
3–8.

DOI: 10.1302/2633-1462.
51.BJO-2023-0134

Correspondence should be sent to H-C. Husum h.husum@rn.dk

H-C. Husum,[1,2] M. B. Hellfritzsch,[2,3] R. D. Maimburg,[2,4] B. Møller-Madsen,[2,5] M. Henriksen,[2,3] N. Lapitskaya,[2,3] S. Kold,[1,2] O. Rahbek[1,2]

[1]Interdisciplinary Orthopaedics, Aalborg University Hospital, Aalborg, Denmark
[2]Danish Paedatric Orthopaedic Research, Aarhus University Hospital, Aarhus, Denmark
[3]Department of Radiology, Aarhus University Hospital, Aarhus, Denmark
[4]Department of Children's Orthopaedics, Aarhus University Hospital, Aarhus, Denmark
[5]Department of Midwifery, University College of Northern Denmark, Aalborg East, Denmark

Aims
The present study seeks to investigate the correlation of pubofemoral distances (PFD) to α angles, and hip displaceability status, defined as femoral head coverage (FHC) or FHC during manual provocation of the newborn hip < 50%.

Methods
We retrospectively included all newborns referred for ultrasound screening at our institution based on primary risk factor, clinical, and PFD screening. α angles, PFD, FHC, and FHC at follow-up ultrasound for referred newborns were measured and compared using scatter plots, linear regression, paired *t*-test, and box-plots.

Results
We included 2,735 newborns, of whom 754 received a follow-up hip ultrasound within six weeks of age. After exclusion, 1,500 hips were included for analysis. Sex distribution was 372 male and 380 female, and the mean age at examination was 36.6 days (4 to 87). We found a negative linear correlation of PFD to α angles (p < 0.001), FHC (p < 0.001), and FHC during provocation (p < 0.001) with a 1 mm increase in PFD corresponding to a -2.1° (95% confidence interval (CI) -2.3 to -1.9) change in α angle and a -3.4% (95% CI -3.7 to -3.0) change in FHC and a -6.0% (-6.6 to -5.5) change in FHC during provocation. The PFD was significantly higher with increasing Graf types and in displaceable hips (p < 0.001).

Conclusion
PFD is strongly correlated to both α angles and hip displaceability, as measured by FHC and FHC during provocation, in ultrasound of newborn hips. The PFD increases as the hips become more dysplastic and/or displaceable.

Take home message
- The pubofemoral distance (PFD) strongly correlates to traditionally used ultrasound metrics in developmental dysplasia of the hip (DDH) diagnostics.
- Primary PFD screening may be a viable candidate for selective screening for DDH, as it predicts acetabular morphology and hip stability upon follow-up hip ultrasound.

Introduction
Multiple ultrasound metrics have been proposed in screening for developmental dysplasia of the hip (DDH), with the most commonly used being the α angle proposed by Graf in 1983,[1] which describes the morphological conditions of the acetabulum, by measuring the slope of the acetabular roof. In the following years, Harcke et al[2] and Terjesen et al[3] proposed the femoral head

Bone & Joint Open

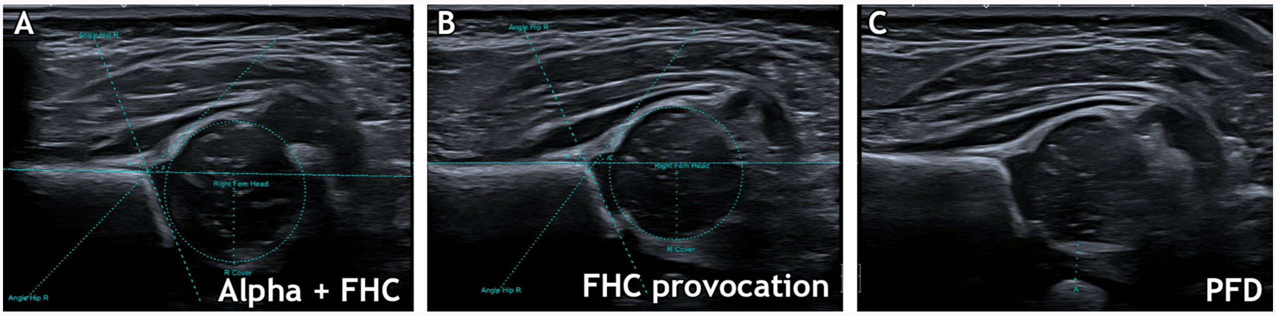

Fig. 1

Three ultrasound images of one paediatric hip examination. a) Graf standard plane with added annotated α angles and femoral head coverage (FHC) values. b) Ultrasound image captured during hip provocation with annotated FHC values. c) Ultrasound image captured during hip provocation with annotated pubofemoral distance (PFD) values.

coverage (FHC), defined as the percentage of the cartilaginous femoral head covered by the bony acetabular roof while the hip is at rest, and while applying lateralizing stress.

In 2013, the pubofemoral distance (PFD) ultrasound method was first published.[4] PFD measures the minimum distance between the medial epiphysis of the femoral head and the most lateral part of the ossified pubic bone while applying lateralizing stress to the hip joint. It is a dynamic stress test similar to the FHC method, but rather than being measured in relative units (percentages) it is measured in millimetres and thus does not account for individual differences in the size of the examined anatomy. The PFD method has been proven to be a reliable and accessible ultrasound screening tool for DDH,[5,6] and has since been implemented as a universal screening tool for female newborns in the original authors' region of France, which has reportedly reduced the rate of late diagnoses of hip dysplasia to zero in a catchment area of one million inhabitants.[4] However, the diagnosis of DDH was not made using the gold-standard Graf method. Rather, it relied on an assessment of clinical stability and acetabular morphology in ultrasound using the PFD measurement and FHC.[4]

The PFD has been proven to be sensitive in detecting ultrasound-positive DDH hips per the Graf method,[7] and therefore must correlate to the α angle measurement of the Graf method, although the degree of correlation is not known.

No studies have examined how the PFD correlates to traditionally used ultrasound metrics in DDH diagnostics, including the gold-standard Graf method. The aim of the current study is therefore to evaluate the correlation of PFD to α angles and hip displaceability, as measured by the FHC at rest and during lateralizing stress, in newborns undergoing ultrasound screening for DDH.

Methods

Design and setting

This was a retrospective observational study of newborns referred for DDH ultrasound screening at Aarhus University Hospital (AUH), Denmark, during a one-year period from October 2021 to October 2022. Annually, 5,000 newborns are born at AUH, a tertiary hospital including the only maternity ward in the municipality of Aarhus. Reporting follows the STROBE guidelines for reporting on observational studies.[8]

Participants

The newborns in the present retrospective study participated in the Danish Hip Screening Project (DHP). In the DHP, primary early PFD screening was added to the traditional selective referral criteria for follow-up Graf hip ultrasound. A newborn was included in the DHP, and the present retrospective study, once written parental consent for participation and data collection had been obtained.

The clinical examination and risk factor identification were performed by a midwife at the post-partum clinic at AUH. The primary PFD ultrasound examination was performed by a secondary midwife trained in the PFD method on the same weekday or, in the case of the newborn being screened in the post-partum clinic on a weekend, during the following week. All primary examinations, including clinical, risk factor, and primary PFD screening, were performed within the first ten days after birth.

We included newborns referred for follow-up hip ultrasound in this hybrid selective screening programme for DDH at AUH where primary clinical examination, risk factor identification, and primary PFD ultrasound examination had been performed. Referral criteria were: a positive clinical examination, presence of a risk factor (family history of DDH, breech presentation, oligohydramnios, twins, clubfeet, or musculoskeletal syndromes) a primary PFD ≥ 5.1 mm, or a PFD difference ≥ 1.5 mm between hips.

The exclusion criteria were age at follow-up ultrasound examination by radiologist above three months, and follow-up ultrasound examination missing PFD measurements.

The referred newborns received a follow-up hip ultrasound examination ideally before six weeks of age or, in the case of clinical instability or a primary PFD above 8.0, before two weeks of age. Follow-up hip ultrasound was performed by one of three musculoskeletal radiologists (MBH, MH, NL) experienced in paediatric ultrasound using a combination of the Graf, Harcke, and PFD methods (Figure 1).[1,2,4,9] α angles and FHC were measured in the frontal standard plane with the child fixed in a cradle in the lateral decubitus examination position, the hip flexed to 90°, and the knees gently adducted. Additionally, the FHC during provocation and PFD were measured in the same lateral examination position while the hip was stressed laterally in a Barlow equivalent manoeuvre. FHC during provocation was routinely

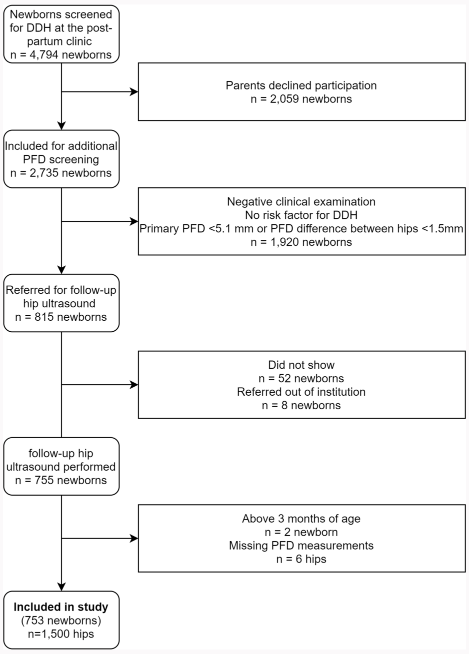

Fig. 2

Consort diagram of inclusion process and distribution of hips according to the Graf classification and displaceability criteria. DDH, developmental dysplasia of the hip; PFD, pubofemoral distance.

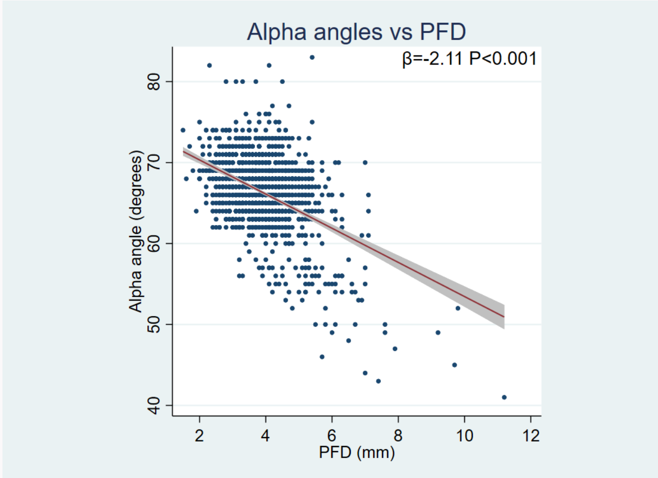

Fig. 3

Scatter plot of pubofemoral distance (PFD) and α angles with fitted regression line, 95% confidence intervals, and regression coefficients.

reported in all scans by one of three radiologists, while the remaining two only reported it if they observed lateralization on ultrasound, i.e. FHC decreased below 50% after applying lateralizing stress to the hip.

As both clinical stability testing and FHC during provocation evaluates the degree of laxity of the paediatric hip joint, to avoid any confusion in terms, we have chosen to use the term ‘displaceability’ when referring to hips able to be provoked laterally during hip ultrasound, i.e. a FHC < 50% in situ or during provocation, while ‘instability’ refers to clinical instability.

All measurements were performed using a high-frequency (10 MHz) linear transducer (Canon Aplio i800; Canon Medical Systems, Japan). The parents were present during all examinations of the newborns.

Statistical analysis

The performed analyses use α angles, FHC, and FHC during provocation as dependent variables, and PFD as obtained at the follow-up hip ultrasound examination as an independent variable. The primary PFD measurement was only used in the referral of patients, not for subsequent correlation analysis.

We examined the correlation and impact of increasing PFD values on α angles, FHC, and FHC during provocation using linear regression, scatter plots, and box plots. Regression results are presented as intersections and β-coefficients with accompanying p-values. Scatter plots are presented with fitted lines and 95% confidence intervals (CIs) and linear regression coefficients. To further illustrate the correlation, mean PFD values were calculated stratified by Graf classification and hip displaceability status, and compared using *t*-test as well as box plots with median values and 25% and 75% centiles, with whiskers representing upper and lower adjacent values. A sensitivity analysis was performed using a mixed effect model to account for any bias introduced by the bilaterality of observations.[10] As no bias was detected in the sensitivity analysis, independence between bilateral observations was assumed. PFD measurements were used as a referral criterion, when performed by a midwife in primary screening, and as an independent variable in the regression analysis, when performed by the radiologist at the follow-up hip ultrasound. To investigate any selection bias introduced to the correlation analysis of PFD to α angles and displaceability status, by selecting patients using primary PFD screening, a secondary sensitivity analysis was performed by linear regression stratified by referred/not referred by primary PFD screening. No significant difference in regression coefficients between these two groups was detected. Normality of data was inspected using QQ-plots for continuous data and a significance level of 5% was used. All statistical analyses were performed using Stata version 17.0 (StataCorp, USA).

Results

In the present study, 4,794 newborns were born during the study period. Of these, consent for data collection was obtained from the parents of 2,735 newborns. A total of 815 newborns were referred for follow-up hip ultrasound, 52 missed their screening appointments, eight were referred to another institution, six hips had no PFD ultrasound measurements, and two newborns were older than three months at ultrasound examination, which left 753 newborns for inclusion (1,500 hips) (Figure 2). Sex distribution was 372 males and 380 females, and mean age at examination was 36.6 days (4 to 87; 95% CI 36.1 to 37.2). Distribution of patients according to highest Graf classification was type I: 696 (92.5%), type IIa: 48 (6.4%), type IIc: 7 (0.9%), and type III: 1 (0.1%). Distribution of hips according to Graf classification were type I: 1.416, type IIa: 74, type IIc: 9, and Type III: 1. Overall, 78 hips were classified as displaceable and 1,422 were non-displaceable (Table I).

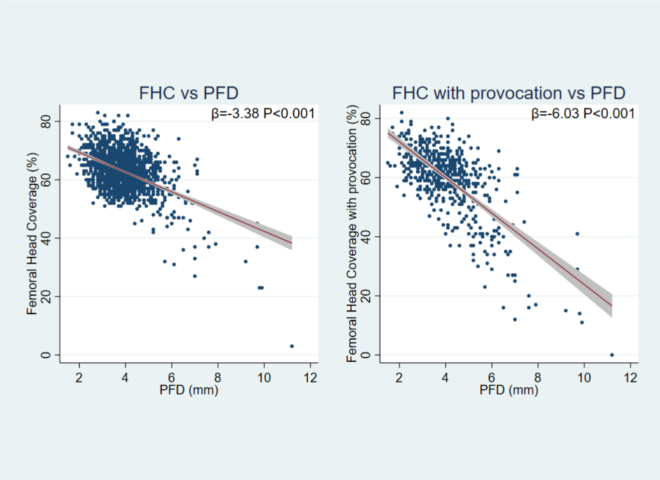

Fig. 4

Scatter plot of pubofemoral distance (PFD), femoral head coverage (FHC), and FHC with provocation with fitted regression lines, 95% confidence intervals, and regression coefficients.

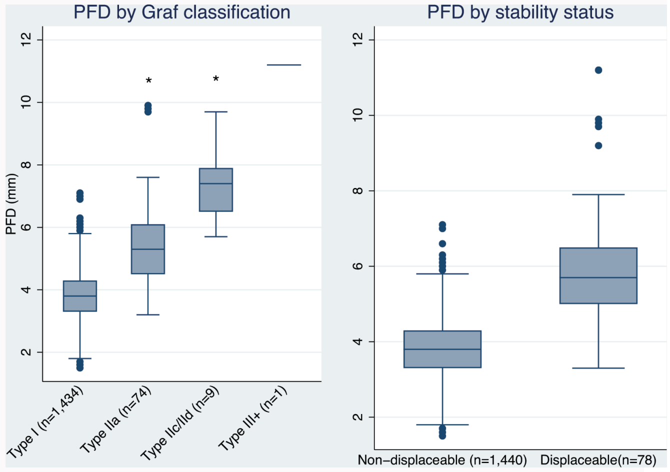

Fig. 5

Box plots of pubofemoral distance (PFD) values stratified by Graf classification and hip displaceability status. Boxes represent 25%, median, and 75% percentiles with whiskers representing upper and lower adjacent values. Displaceable = femoral head coverage (FHC) or FHC during provocation < 50% * = statistically significant result.

Table I. Distribution of hips according to Graf types and hip displaceability status with accompanying mean pubofemoral distance values.

Graf classification (no. hips)	PFD (mean 95% CI)	p-value*
Type I (n = 1,416)	3.8 (3.8 to 3.9)	
Type IIa (n = 74)	5.4 (5.1 to 5.7)	< 0.001
Type IIc (n = 9)	7.4 (6.4 to 8.5)	< 0.001
Type III+ (n = 1)	11.2 (N/A)	N/A
Hip displaceability		
Non-displaceable = FHC > 50% (n = 1,422)	3.8 (3.8 to 3.9)	
Displaceable = FHC < 50% (n = 78)	5.9 (5.6 to 6.2)	< 0.001

*Paired *t*-test.
CI, confidence interval; FHC, femoral head coverage; N/A, not applicable; PFD, pubofemoral distance.

Table II. Results of linear regression of α angles, femoral head coverage, and femoral head coverage during provocation with pubofemoral distance as independent variable.

Variable	Intersection	β-coefficient (95% CI)	p-value
α angle	74.5°	2.1 (-2.3 to -1.9)	< 0.001*
FHC	76.0%	3.4 (-3.7 to -3.0)	< 0.001*
FHC during provocation	84.1%	6.0 (-6.6 to -5.5)	< 0.001*

CI, confidence interval; FHC, femoral head coverage.

Inspection of scatter plots and linear regression revealed a negative linear correlation of PFD to α angles ($p < 0.001$), FHC ($p < 0.001$), and FHC during provocation ($p < 0.001$) with a 1 mm increase in PFD corresponding to a -2.1° (95% CI -2.3 to -1.9) change in α angle, a -3.4% (95% CI -3.7 to -3.0) change in FHC, and a -6.0% (95% CI -6.6 to -5.5) change in FHC during provocation (Table II, Figure 3, Figure 4). Further, PFD was significantly higher with increasing Graf types and in displaceable hips ($p < 0.001$) (Figure 5, Table I).

Discussion

Key results

PFD was significantly correlated to both acetabular morphology and hip displaceability. An increase in PFD was seen with both shallowing of the acetabulum and an increase in hip displaceability.

Interpretation

There is no universal consensus on what constitutes true DDH. Graf proposed a treatment plan according to his classification system, which relies on hip morphology.[11] Surgeons, when deciding which hips to treat, rely on a combination of radiological findings and hip stability assessment, with the latter being the guiding factor for a majority of surgeons, as they are more likely to opt for nonoperative management of children showing no signs of hip instability.[12] Hip instability is clinically assessed using the Barlow and Ortolani manoeuvres, and the Galeazzi test, but the value of these examinations is questionable. The Barlow and Ortolani manoeuvres have a combined sensitivity of 60%.[13] While they are more sensitive in the hands of experienced orthopaedic surgeons,[14] in a study from 2020, Harper et al[15] demonstrated that 14% of dislocated hips, as detected on ultrasound, were incorrectly classified as being reduced upon clinical examination by experienced orthopaedic surgeons. Further, the positive predictive value of clinical hip examinations in detecting hip dysplasia, defined as ≥ Graf IIc type hips, is 33% among experienced orthopaedic surgeons,[16] and as low as 4% among primary screeners.[17]

In evaluating the correlation of PFD to hip stability, we therefore chose to define it as displaceability using the

FHC, which has a high degree of agreement when classifying dysplastic hips (Kappa > 0.7).[18] Terjesen et al[3] originally described a cut-off value for FHC of 44% for females and 47% for males for hip dysplasia with some age variation. Others describe a cut-off of 50% for both sexes,[19] which is also used routinely at AUH and consequently in this study.

In terms of reliability and accessibility, the PFD method outperforms both the Graf and FHC methods,[4,5,18] but, as demonstrated in this study, is strongly correlated to both. The PFD method may therefore be a viable candidate for predicting α angles and displaceability status in primary DDH screening.

Limitations

Both the PFD and FHC methods rely on a Barlow equivalent hip provocation manoeuvre. As the application of force may not be equal between the examiners when performing the examinations, the obtained measurements may, to a minor extent, be affected in precision. This uncertainty can affect the precision of the correlation coefficients of our regression analyses. However, the impact may not have any clinical influence when classifying the hips as displaceable using the 50% FHC threshold, as a significantly increased PFD when compared to stable hips was found.

As there was a limited number of pathological hips in our study population, both in terms of FHC and α values, the calculated regression coefficients for the PFD in the regression analyses are less impactful (i.e. less negative) than what the data in the scatter plots seem to suggest. The inclusion of more pathological hips would likely further lower the regression coefficients.

The present study only evaluated the correlation of PFD to Graf's α angles and hip displaceability status. An assessment of the effectiveness of primary PFD screening on DDH detection cannot be made on the present results.

Generalizability

Participants for the current study were selected through a unique selective screening programme for DDH using primary PFD as a referral criterion for follow-up Graf hip ultrasound. As such, all newborns included in this study were selected based on the presence of a risk factor for DDH, positive clinical examination, or primary PFD screening. However, as the prevalence of Graf types are comparable to those reported in universal screening programmes,[20] we believe the present results to be representative of a general population.

In conclusion, PFD is strongly correlated to both α angles and hip displaceability, as measured by FHC and FHC during provocation, in ultrasound of hips at six weeks of age. The PFD increases as the hips become more dysplastic and/or displaceable.

References

1. **Graf R**. New possibilities for the diagnosis of congenital hip joint dislocation by ultrasonography. *J Pediatr Orthop*. 1983;3(3):354–359.
2. **Harcke HT**, **Clarke NM**, **Lee MS**, **Borns PF**, **MacEwen GD**. Examination of the infant hip with real-time ultrasonography. *J Ultrasound Med*. 1984;3(3):131–137.
3. **Terjesen T**, **Bredland T**, **Berg V**. Ultrasound for hip assessment in the newborn. *J Bone Joint Surg Br*. 1989;71-B(5):767–773.
4. **Tréguier C**, **Chapuis M**, **Branger B**, **et al**. Pubo-femoral distance: an easy sonographic screening test to avoid late diagnosis of developmental dysplasia of the hip. *Eur Radiol*. 2013;23(3):836–844.
5. **Husum H-C**, **Bach Hellfritzsch M**, **Maimburg RD**, **et al**. Pubo-femoral distances measured reliably by midwives in hip dysplasia ultrasound. *Children (Basel)*. 2022;9(9):1345.
6. **Teixeira SR**, **Dalto VF**, **Maranho DA**, **Zoghbi-Neto OS**, **Volpon JB**, **Nogueira-Barbosa MH**. Comparison between Graf method and pubo-femoral distance in neutral and flexion positions to diagnose developmental dysplasia of the hip. *Eur J Radiol*. 2015;84(2):301–306.
7. **Husum H-C**, **Hellfritzsch MB**, **Hardgrib N**, **Møller-Madsen B**, **Rahbek O**. Suggestion for new 4.4 mm pubo-femoral distance cut-off value for hip instability in lateral position during DDH screening. *Acta Orthop*. 2019;90(1):88–93.
8. **von Elm E**, **Altman DG**, **Egger M**, **et al**. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. *J Clin Epidemiol*. 2008;61(4):344–349.
9. **Couture A**, **Baud C**, **Prodhomme O**, **Saguintaah M**, **Veyrac C**. Ultrasound of the neonatal hip: initial evaluation and follow-up. *J Radiol*. 2011;92(2):142–165.
10. **Ranstam J**. Problems in orthopedic research: dependent observations. *Acta Orthop Scand*. 2002;73(4):447–450.
11. **Graf R**. *Hip Sonography. Diagnosis and Management of Infant Hip Dysplasia*. 2nd ed. London, UK: Springer, 2006.
12. **Omeroğlu H**, **Ağuş H**, **Biçimoğlu A**, **Tümer Y**. Evaluation of experienced surgeons' decisions regarding the need for secondary surgery in developmental dysplasia of the hip. *J Pediatr Orthop*. 2012;32(1):58–63.
13. **Jones D**. An assessment of the value of examination of the hip in the newborn. *J Bone Joint Surg Br*. 1977;59-B(3):318–322.
14. **el-Shazly M**, **Trainor B**, **Kernohan WG**, **et al**. Reliability of the Barlow and Ortolani tests for neonatal hip instability. *J Med Screen*. 1994;1(3): 165–168.
15. **Harper P**, **Joseph BM**, **Clarke NMP**, **et al**. Even experts can be fooled: reliability of clinical examination for diagnosing hip dislocations in newborns. *J Pediatr Orthop*. 2020;40(8):408–412.
16. **Husum H-C**, **Ghaffari A**, **Rytoft LA**, **et al**. Positive predictive values in clinical screening for developmental dysplasia of the hip. *Acta Paediatr*. 2021;110(8):2430–2434.
17. **Choudry QA**, **Paton RW**. Neonatal screening and selective sonographic imaging in the diagnosis of developmental dysplasia of the hip. *Bone Joint J*. 2018;100-B(6):806–810.
18. **Quader N**, **Schaeffer EK**, **Hodgson AJ**, **Abugharbieh R**, **Mulpuri K**. A systematic review and meta-analysis on the reproducibility of ultrasound-based metrics for assessing developmental dysplasia of the hip. *J Pediatr Orthop*. 2018;38(6):e305–e311.
19. **Omeroğlu H**. Use of ultrasonography in developmental dysplasia of the hip. *J Child Orthop*. 2014;8(2):105–113.
20. **Biedermann R**, **Riccabona J**, **Giesinger JM**, **et al**. Results of universal ultrasound screening for developmental dysplasia of the hip. *Bone Joint J*. 2018;100-B(10):1399–1404.

Author information

H-C. Husum, MD, Research Fellow
S. Kold, PhD, Orthopaedic Surgeon
O. Rahbek, MD, PhD, Professor, Orthopaedic Surgeon
Interdisciplinary Orthopaedics, Aalborg University Hospital, Aalborg, Denmark; Danish Paedatric Orthopaedic Research, Aarhus University Hospital, Aarhus, Denmark.

M. B. Hellfritzsch, MD, Consultant Radiologist
M. Henriksen, MD, Consultant Radiologist
N. Lapitskaya, MD, PhD, Resident Radiologist
Danish Paedatric Orthopaedic Research, Aarhus University Hospital, Aarhus, Denmark; Department of Radiology, Aarhus University Hospital, Aarhus, Denmark.

R. D. Maimburg, MPH, PhD, Associate Professor, Midwife, Danish Paedatric Orthopaedic Research, Aarhus University Hospital, Aarhus, Denmark; Department of Children's Orthopaedics, Aarhus University Hospital, Aarhus, Denmark.

B. Møller-Madsen, MD, DMSC, Professor, Consultant Orthopaedic Surgeon, Danish Paedatric Orthopaedic Research, Aarhus University Hospital, Aarhus, Denmark; Department of Midwifery, University College of Northern Denmark, Aalborg East, Denmark.

Author contributions

H-C. Husum: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Project administration, Funding acquisition.
M. B. Hellfritzsch: Conceptualization, Investigation, Writing – review & editing.
R. D. Maimburg: Conceptualization, Writing – review & editing, Supervision, Project administration.
B. Møller-Madsen: Conceptualization, Writing – review & editing, Project administration.
M. Henriksen: Conceptualization, Investigation, Writing – review & editing.
N. Lapitskaya: Conceptualization, Investigation, Writing – review & editing.
S. Kold: Conceptualization, Writing – review & editing.
O. Rahbek: Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Supervision, Project administration, Funding acquisition.

Funding statement

The authors disclose receipt of the following financial or material support for the research, authorship, and/or publication of this article: this study was funded by The Danish Arthritis Foundation, the Dagmar Marshall Fund and the Independent Research Fund Denmark Grant no. 1030-00366B.

ICMJE COI statement

R. D. Maimburg is the programme leader for the PhD school at Aarhus University.

Data sharing

The datasets generated and analyzed in the current study are not publicly available due to data protection regulations. Access to data is limited to the researchers who have obtained permission for data processing. Further inquiries can be made to the corresponding author.

Ethical review statement

Ethical approval for the present study and written parent information was obtained from the Danish National Committee on Health Research Ethics (Registration number N-20200051). The project and data management plan were approved by the regional Department of Research Data and Statistics at Aarhus University Hospital (Project ID 2021-043).

Open access funding

The authors confirm that the open access fee for this study was self-funded.