Does This Newborn Have a Dislocated Hip? The Rational Clinical Examination Systematic Review

Abhinav Singh, MSc, MRCS[1]; Ryckie George Wade PhD, MRCS[2]; David Metcalfe PhD, FRCEM[1]; Daniel C Perry PhD, FRCS(Orth)[1,3].

[1] Nuffield Department of Orthopaedics, Rheumatology and Musculoskeletal Sciences, University of Oxford, UK

[2] Academic Department of Plastic and Reconstructive Surgery, University of Leeds, UK

[3] Department of Child Health, University of Liverpool, UK

Corresponding Author: Daniel Perry danperry@liverpool.ac.uk or daniel.perry@ndorms.ox.ac.uk

Author Contributions: Abhinav Singh (AS), Ryckie George Wade (RGW), David Metcalfe (DM) and Daniel Perry (DP) all contributed to the study design, analysis and interpretation of the data. AS and RGW were additionally involved in data acquisition.

Conflict of interest: None

Funding: AS is funded by a National Institute for Health and Care Research (NIHR) Doctoral Research Fellowship (ID301835). RGW is an NIHR Academic Clinical Lecturer (CL-2021-02-002). DM is supported by an NIHR Advanced Fellowship (ID302219). DP is an NIHR Research Professor (ID301655).

Role of the Funder: The funding body did not have any role in the design and conduct of the study nor in the decision to submit the manuscript for publication.

Disclaimer: The views expressed are those of the authors and not necessarily of the UK National Health Service, the NIHR or the Department of Health and Social Care.

Registration: PROSPERO registration ID: CRD42023422122

Level of Evidence: II

Keywords: Developmental dysplasia of the hip, clinical examination, diagnostic test, sensitivity, systematic review

Additional Contributions: We are grateful to Kat Steiner, MSc (Specialist Librarian at the Bodleian Health Care Libraries, University of Oxford) for helping develop the search strategy and choice of databases.

Word Count: 2989 (excluding abstract, clinical scenario and references).

Abstract

Importance: Delayed diagnosis a dislocated hip in newborns can lead to complex childhood surgery, interruption to family life and premature osteoarthritis.

Objective: To evaluate the diagnostic accuracy of clinical examination in identifying dislocated hips in newborns.

Data Sources: Systematic search of CINAHL, Embase, Medline and Cochrane from the inception of each database until October 31st 2023.

Study Selection: Included studies reported the diagnostic accuracy of the clinical examination in newborns up to three months, compared to diagnostic ultrasound scanning. The target condition was defined by the ultrasound Graf classification based on whether the hip was dislocated.

Data Extraction and Synthesis: The Rational Clinical Examination scale assigned levels of evidence and the Quality Assessment of Diagnostic Accuracy Studies tool assessed bias. Data were extracted using the individual hip as the unit of analysis and pooled when the clinical examinations were evaluated by 3 or more studies.

Main Outcomes and Measures: Sensitivity, specificity and likelihood ratios of identifying a dislocated hip.

Results: Among newborns screened with clinical examination and an ultrasound scan the prevalence of a dislocated hip (n= 37,859 hips) was 0.94% (95% CI 0.28-2.0%) of all hips. Eight studies (n= 44,827) evaluated the Barlow and Ortolani maneuvre which dislocates and relocates an unstable hip; the maneuver had a sensitivity of 46% (95% CI 26-67%), specificity 99.1% (95% CI 97.9-99.6%), positive likelihood ratio (LR+) 52 (95% CI 21-127) and negative likelihood ratio (LR-) 0.55 (95% CI 0.37-0.82). Three studies (n= 22,472) evaluated limited hip abduction (LHA) which had a sensitivity of 13% (95% CI 3.3-37%), specificity of 97% (95% CI 87-99%), LR+ of 3.6 (95% CI 0.72-18) and LR- of 0.91 (95% CI 0.76-1.1). One study (n= 13,096) evaluated a clicking sound which had a sensitivity of 13% (95% CI 6.4-21%), specificity of 92% (95% CI 92-93%), LR+ of 1.6 (95% CI 0.91-2.8) and LR- of 0.95 (95% CI 0.88-1.0).

Conclusions and Relevance: In studies where all newborn hips were screened for DDH, the prevalence of a dislocated hip is 0.94% (95% CI 0.28-2.0%). A positive Barlow/Ortolani maneuver (LR 52) was the finding most associated with an increased likelihood of a dislocated hip. Limited hip abduction or a clicking sound has no clear diagnostic utility.

Clinical Scenario

In the following cases, the clinician wants to determine whether the child has a dislocated hip.

Case 1

A 4-week-old baby girl presents to her primary care clinician for a routine history and physical examination. She does not have any relevant family history. On examination, the Barlow and Ortolani maneuvres are abnormal in the right hip.

Case 2

An 11-week-old baby boy was brought to his primary care clinician with stiffness in his left hip and clicking of the right hip, which has been noted during diaper changes. He did not appear to be in pain and was systemically well. He was born by planned caesarean section at term and no prior hip examination has been performed. On examination, there was limited hip abduction on the left and an audible click on the right without restricted movement.

Background

Developmental dysplasia of the hip (DDH) is one of the most common musculoskeletal conditions in newborns, present in 4-23 per 1000 live births.[1,2] DDH encompasses a spectrum of abnormalities from instability of the hip joint to complete dislocation. Risk factors include female sex, first-degree family history and breech presentation, with other risk factors postulated such as foot deformity and oligohydramnios.[3–5]

If DDH is diagnosed before 3 months old, a removable hip brace is an effective treatment in 90% of cases.[6–9] However, delayed diagnosis (e.g. after 4 months of age) frequently requires treatment surgery to restore the position of the hip, along with immobilization of the hip and thigh for up to 6 months in a spica cast. The recovery period after surgery requires medical appointments for cast changes, mobility limitations affecting play, monitoring for ongoing dysplasia and a considerable risk of early degenerative joint disease, which may ultimately necessitate total hip replacement in adolescence or young adulthood.[10–13] In Norway, DDH accounts for nearly 10% of all total hip replacements performed and a third of those performed before 60 years old.[14]

There are different approaches to population screening for DDH, with some countries (such as Austria[15]) conducting repeat hip ultrasound on all babies at 3-5 days and 6-8 weeks after birth, whilst others (such as the United Kingdom[16] and the United States[17]) selectively performing ultrasound scans following an abnormal clinical examination or in the presence of risk factors; such as female sex or a positive family history of DDH.[18] Primary screening by clinical examination is based on limited hip abduction (LHA), a femoral length difference and tests of hip stability, termed the Barlow and Ortolani maneuvers.

Although clinical examination of the hip is the foundation of many screening programs, the reliability and reproducibility of the examination is uncertain.[19–23] Population data from England suggests that the incidence of late-diagnosed DDH did not change after the introduction of systematic screening of all newborns in 1986.[24] This consisted of the identification of risk factors at birth and serial clinical examinations for instability (Barlow and Ortolani) and dislocation (leg length difference, thigh asymmetry, limited hip abduction) at birth and at 6-8 weeks.[25] Given the uncertain utility of clinical examination,[26–28] this review sought to evaluate the diagnostic accuracy of clinical examination in determining a dislocated hip in newborns.

How to elicit the signs of a hip instability or dislocation in newborns

Evaluation of the hip begins with the observation of both lower limbs in a relaxed newborn without a diaper.

The examiner should begin with observation, to prevent upsetiing the child. First, the baby is supine, their feet are brought together and knees flexed to 90 degrees. The length of the femurs can then be compared to identify asymmetry (Galeazzi test). The hips can then be gently abducted, with a restriction of more than 20 degrees in one hip compared to the other considered abnormal.[29] These tests largely rely on identifying asymmetry, however dislocations occur bilaterally in around a third of cases, which may result in symmetrical findings.[30]

To perform the Barlow/Ortolani test, the baby is supine and hips flexed to 90 degrees (see Figure xxx). Each hip should be examined separately while stabilizing the contralateral side. The examiners should place their 2nd and 3rd fingers laterally over the baby's greater trochanter and their thumb medially along the inner edge of the groin crease.[31] For the Barlow test to be positive, a downward force applied to an adducted flexed hip dislocates it posteriorly. The Ortolani test is positive if the hip relocates when gently abducting the hip and applying an upward force to the greater trochanter. The Barlow and Ortolani tests are

paired in routine clinical practice and considered positive when a dislocatable hip can be dislocated (Barlow maneuvre) and then reduced inside the acetabulum (Ortolani maneuvre). The Barlow/Ortolani test will miss a dislocated hip that cannot be reduced within the acetabulum, which may occur with increased tone (i.e. spacticity) or through syndromic manesestation such as arthrogryposis.[32] Whilst performing this test, it is common to hear a click or feel soft tissues 'snapping' over bony prominences during normal hip examination.[32]

[JAMA to create original images - These are placeholders to help with the concept. See for example https://images.app.goo.gl/6eA1fir7mvdyNGy99 or https://images.app.goo.gl/h9wQdWjucnkbAg6P7).]

Methods

This systematic review was reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses of Diagnostic Test Accuracy (PRISMA-DTA) Statement.[33] The protocol was prospectively registered on the PROSPERO database with reference CRD42023422122.

Search Strategy

A medical librarian (KS) searched the CINAHL, Embase, Medline and Cochrane databases from the inception of each database until October 31st 2023, using a combination of MeSH (Medical Subject Headings) terms and keywords (eTable 1). Further items were obtained by searching for articles that referenced known relevant articles, and retrieving relevant articles from included studies.[34] Titles and abstracts and later, full texts of potentially relevant articles were independently screened by two authors (AS and RGW).

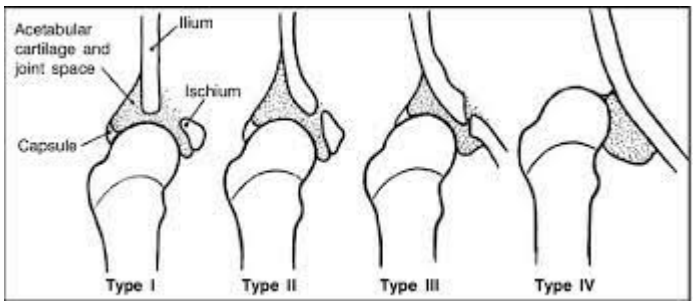
Study Selection

We included studies of newborns (up to three months of age) that reported the findings of clinical examination (index test) and hip ultrasound (reference test). Screening populations were broadly divided into universal (all babies had a clinical examination and ultrasound), selective (only babies with a positive risk factor had the clinical examination and ultrasound, or only those with a positive clinical examination finding underwent the reference tests) and mixed (a universal programme for all infants born at the particular institution but referrals from outside institutions accepted with positive risk factors). Studies were excluded if clinical examination maneuvers and/or severity of ultrasound findings could not be disaggregated to

determine the sensitivity and specificity of clinical findings. Where appropriate, the flow of patients through the study was clarified by contacting the corresponding author.

Target condition

We used the Graf method of ultrasound assessment to define a dislocated hip[35] The Graf method is the most commonly used ultrasound technique used worldwide to classify abnormalities. Broadly hips are ‘centered’ or ‘decentered’, with decentred hips representing those with clinical instability for which the prognosis is worse[36,37] [JAMA ILLUSTRATORS will work with authors to create an illustration. As a placeholder, see this



In centered hips, the socket (acetabulum) is well developed and covers the femoral head. Types 1 and 2 differ based on how well the acetabulum is developed, with Type I considered normal, and Type II showing mild dysplasia. In decentered hips, the bony socket is poorly developed, and the cartilage roof is displaced allowing the femoral head to dislocate. Type 3 and 4 are dislocated joints, distinguished by the morphological features of the acetabulum , with a separate group, Type D, representing the first sign of dislocation. Types D, 3 and 4 are therefore grouped as ‘dislocation’ because they represent instability and have the worst prognosis.

Data Extraction

Two authors (AS and RGW) independently extracted demographic and clinical examination finding results to construct 2 x 2 tables from included studies. When authors presented diagnostic ultrasound data by severity, hips classified as Graf 1 or 2 were grouped as ‘centered’ (i.e. stable), and Graf D, 3 or 4 as ‘decentered’ (i.e. unstable).[35] The minimum standard for the reference test was for the ultrasound to be performed by a trained clinician using a linear probe. This could include sonographers, attending radiologists/paediatricians

and orthopedic surgeons. The Graf method includes an explicit threshold for judging the quality of the obtained image before using it in diagnosis.

Quality Assessment

Study quality was evaluated using a checklist designed for the Rational Clinical Examination series.[38] Level 1 studies required clinical findings to be assessed and categorized independently of the reference test in consecutive patients suspected of having DDH whereas Level 2 had the same requirement in fewer patients (<200). Level 3 studies included non-consecutive patients. We did not retain Levels 4 and 5 studies that had verification bias that could not be adjusted for and undertook non-independent assessment of predictors and outcomes with a reference standard of uncertain validity. The risk of bias and applicability of included studies was assessed by two authors (AS and RGW) using a tailored version of the Quality Assessment of Diagnostic Accuracy Studies 2 (QUADAS-2) criteria[39] with disagreements resolved by discussion among all four authors.

Statistical Methods

A random effects pooled prevalence rate of affected hips was estimated using the meta suite in Stata18 (StataCorp, Texas, USA).[40] Heterogeneity by year of publication was explored using meta-regression. One study[41] was excluded from the prevalence meta-analysis because verification bias resulted in an overestimated prevalence. Verification bias occurred when only a sample of children with particulalr at-risk characteristics, among all children at-risk children of disease, had an ultrasound to verify their hip status.

The unit of analysis was the individual hip. Where data were reported in only 1 or 2 studies, findings are summarised as individual data points or ranges, respectively. For findings reported in 3 or more studies we used MetaDTA to calculate summary sensitivity, specificity and likelihood ratios (LRs).[42] To confirm the integrity of the findings, the primary analysis was repeated in Stata18 via metandi by fitting a bivariate model with the gllamm option (eTable 2).[43] We did a sensitivity analysis on diagnostic accuracy outcomes when studies with verification bias enrolled a random sample of infants with normal clinical findings as opposed to all infants with normal findings. Summary test performance of the clinical screening tests were visually assessed using forest and summary receiver operating characteristic plots (eFigures 1a/b and 2a/b).[44] Zero cells occurring in the 2 x 2 tables were corrected with the addition of 0.5 to all cells.[45]

We planned *a priori* to highlight clinical examination maneuvers with a positive LR ≥3.0 or a negative LR <0.5 and a confidence interval that excludes 1.0 as being most useful in clinical practice.

Results

We identified 378 unique articles of which nine studies satisfied the pre-specified inclusion criteria (Figure 1).[41,46–53] The included studies (Table 1) were conducted between 1992 and 2016 and reported data on 50,579 hips in 27,175 newborns. Information was available for both hips in 85.9% of infants, with one paper only reporting the left hip[53]. Amongst three studies, the clinical examination and sonographic assessment was done in the immediate postnatal period by day four[51–53], with the remainder performed between 4-9 weeks old.

Prevalence of Dislocated Hips

Five studies (n= 37,859 hips) reported data on an undifferentiated universal screening population where all eligible newborns underwent screening.[46,48,50–53] The summary prevalence in this cohort was 0.94% (CI 0.28-2.0%) (eFigure 1) and provides the best possible estimate of the pre-test probability of a dislocated hip for any newborn drawn from the general population. A subgroup analysis for the selective or mixed cohorts was not conducted as prevalence in these studies would be determined by the threshold for referral, which would vary between clinicians and health systems. The observed heterogeneity of prevalence was not explained by the year of publication (eFigure 2).

Quality Assessment and Risk of Bias

The levels of evidence are shown in Table 1 and risk of bias assessments in eFigure 3. Five studies were judged to be level 1 and four level 3 on the Rational Clinical Examination scale[38]. All studies had low applicability concerns across all domains. Six studies had an unclear risk of bias in the reference standard domain as the results may have been interpreted with knowledge of the examination findings.[41,47–51]

Diagnostic Accuracy of Clinical Tests

All studies evaluated physical examination findings that are used in routine clinical practice and reported findings that were most likely associated with a dislocated hip (Graf D/3/4)

(Table 2). Eight studies (n= 44,827) evaluated a positive Barlow and Ortolani maneuver which had a sensitivity of 58% (95% CI 22-87%), specificity 99% (95% CI 94-99.7%), LR+ 43 (95% CI 14-130) and LR- 0.43 (95% CI 0.17-1.1).[41,46–48,50–53] A sensitivity analysis on the summary estimates after adjusting for verification bias in Chang et al (eTable 2) had a sensitivity of 46% (95% CI 26-67%), specificity 99.1% (95% CI 97.9-99.6%), LR+ 52 (95% CI 21-127) and LR- 0.55 (95% CI 0.37-0.82) (Figures 4a/b).

Three studies (n= 22,472) evaluated limited hip abduction (LHA) which had a sensitivity of 13% (95% CI 3.3-37%), specificity of 97% (95% CI 87-99%), LR+ of 3.6 (95% CI 0.72-18) and LR- of 0.91 (95% CI 0.76-1.1) (Figures 5a/b).[47,49,51] One study (n= 13,096) evaluated a clicking sound which had a sensitivity of 13% (95% CI 6.4-21%), specificity of 92% (95% CI 92-93%), LR+ of 1.6 (95% CI 0.91-2.8) and LR- of 0.95 (95% CI 0.88-1.0).[51]

Discussion

This review found that a positive Barlow and Ortolani test or the presence of limited hip abduction were both associated with a much higher likelihood of a dislocated hip compared to infants with normal findings. For every 1000 newborn hips screened with the clinical examination, relying on the Barlow and Ortolani maneuvers will identify 4 dislocations (95% CI 2-6), result in 9 “unnecessary” ultrasound scans (95% CI 1-30) and 5 missed diagnoses (95% CI 3-8). For every 1000 newborn hips screened with limited hip abduction, the system would identify 1 dislocation, result in 33 “unnecessary” ultrasound scans and 8 missed diagnoses per 1000 newborn hips.

These physical examination tests are currently used as the population screening modality in some health systems (such as the United States and the United Kingdom). Whilst other health systems (such as Austria and Germany) have adopted a universal ultrasound strategy in which every child receives an ultrasound scan. Whilst universal ultrasound screening may have appeal as a screening tool, it is expensive and children with minor ultrasound-detected abnormalities, in the absence of abnormal clinical findings, appear unlikely to benefit from treatment.[54] In this study, we considered all centered hips (i.e. Graf 2) as ‘normal’ because the natural history shows a benign course, with 80-97% of Graf 2 hips developing normally without treatment.[55] Universal ultrasound screening is therefore likely to drive overtreatment of children with minor dysplasia.[56] Overtreatment using a brace may lead to complications, such as avascular necrosis and femoral nerve palsy, and may have a negative psychological effect on new parents and inhibit breastfeeding.[57,58]

Screening programs must consider the serious long-term consequences of missing dislocated hips and also consider the infant period, up to 4 months of age, where treatments are most effective. The negative effects of early detection must be balanced against overtreatment. If clinical examination is to be the basis for a screening program, it is important to minimize inter-rater variability.[22] Improved reliability among senior doctors and trainees can be achieved through periodic re-training of skills, with double examinations demonstrating inter-rater Kappa of 0.90.[23]

Limitations

This review has several limitations. First, the review analysed each clinical feature using the individual hip as the unit of analysis. The studies reported data as if each hip was independent but hip pathology can be associated with contralateral abnormalities, which would lead to more uncertainty than is suggested by the confidence intervals presented in this review. Second, the reported examinations were undertaken by clinicians with a specialist interest, so the findings may differ among non-specialists. Third, the reference standard was based on ultrasound scanning, which is an operator-dependent imaging modality with evidence suggesting moderate interrater reliability (0.59 (95% CI 0.32-0.85)) following structured training.[59] Third, sensitivity estimates for clinical examination have been artificially inflated by verification bias, which might have arisen in populations in which ultrasound was reserved for babies with risk factors (Kea 2019). However, this risk was mitigated by performing a sensitivity analysis of the summary estimates after adjusting using the verified fraction. Fourth, whilst the point estimate for the limited hip abduction suggest that that the test may be useful, the confidence interval was wide creating uncertainty and further study to evaluate whether the variance is affected by interobserver variability could be useful. Finally, no study evaluated the combination of Barlow/Ortolani with hip abduction assessment, to see if the combination of findings improved diagnostic accuracy.

Scenario Resolution

Before considering the individual characteristics of the presented cases, there is a pre-test probability of 0.94% that any given newborn hip is dislocated, which is the prevalence of the condition in a non-selected population presenting for initial assessment. This pre-test probability will increase or decrease based on the features of the clinical examination.

Case 1

A 4-week-old girl with a positive Barlow/Ortolani test (sensitivity 46%, specificity 99.1%, LR 52 (95% CI 21-127)) would convert the pre-test probability of a dislocated right hip from 0.94% to 33%, diagnostic ultrasound of the hip should be ordered to determine if the hip is dislocated.

Case 2

An 11-week-old boy with limited hip abduction (sensitivity 13%, specificity 97%, LR 3.6 (95% CI 0.72-18)) in his left hip and clicking (sensitivity 13%, specificity 92%, LR 1.6 (95% CI 0.91-2.8)) of the right hip. The finding of limited hip abduction suggests that the pre-test probability of a dislocated left hip goes from 0.94% to 3.3%, but the confidence interval for the LR is broad. The click adds no further diagnostic information. A diagnostic ultrasound of both hips would resolve uncertainty about the significance of the limited hip abduction.

Clinical Bottom Line

In studies where all newborn hips are screened for DDH, the prevalence of a dislocated hip is 0.94% (95% CI 0.28-2.0%). A positive Barlow/Ortolani maneuver (LR 52) was the finding most associated with an increased likelihood of a dislocated hip. The limited hip abduction or the presence of a clicking sound has no clear diagnostic utility.

References

1. Kuitunen I, Uimonen MM, Haapanen M, Sund R, Helenius I, Ponkilainen VT. Incidence of Neonatal Developmental Dysplasia of the Hip and Late Detection Rates Based on Screening Strategy: A Systematic Review and Meta-analysis. *JAMA Netw Open*. 2022;5(8):E2227638. doi:10.1001/jamanetworkopen.2022.27638

2. Clinical practice guideline: early detection of developmental dysplasia of the hip. Committee on Quality Improvement, Subcommittee on Developmental Dysplasia of the Hip. American Academy of Pediatrics. *Pediatrics*. 2000;105(4 Pt 1):896-905. doi:10.1542/peds.105.4.896

3. Woodacre T, Ball T, Cox P. Epidemiology of developmental dysplasia of the hip within the UK: refining the risk factors. *J Child Orthop*. 2016;10(6):633-642.

doi:10.1007/s11832-016-0798-5

4. Poacher AT, Froud JLJ, Caterson J, et al. The cost effectiveness of potential risk factors for developmental dysplasia of the hip within a national screening programme. *Bone Jt open*. 2023;4(4):234-240. doi:10.1302/2633-1462.44.BJO-2022-0135.R1

5. Paton RW, Hinduja K, Thomas CD. The significance of at-risk factors in ultrasound surveillance of developmental dysplasia of the hip. A ten-year prospective study. *J Bone Joint Surg Br*. 2005;87(9):1264-1266. doi:10.1302/0301-620X.87B9.16565

6. Bradley CS, Verma Y, Maddock CL, Wedge JH, Gargan MF, Kelley SP. A comprehensive nonoperative treatment protocol for developmental dysplasia of the hip in infants. *Bone Joint J*. 2023;105-B(8):935-942. doi:10.1302/0301-620X.105B8.BJJ-2023-0149.R1

7. Ömeroğlu H, Köse N, Akceylan A. Success of Pavlik Harness Treatment Decreases in Patients ≥ 4 Months and in Ultrasonographically Dislocated Hips in Developmental Dysplasia of the Hip. *Clin Orthop Relat Res*. 2016;474(5):1146-1152. doi:10.1007/s11999-015-4388-5

8. Aarvold A, Perry DC, Mavrotas J, Theologis T, Katchburian M. The management of developmental dysplasia of the hip in children aged under three months : a consensus study from the British Society for Children's Orthopaedic Surgery. *Bone Joint J*. 2023;105-B(2):209-214. doi:10.1302/0301-620X.105B2.BJJ-2022-0893.R1

9. Merchant R, Singh A, Dala-Ali B, Sanghrajka AP, Eastwood DM. Principles of Bracing in the Early Management of Developmental Dysplasia of the Hip. *Indian J Orthop*. 2021;55(6):1417-1427. doi:10.1007/s43465-021-00525-z

10. Thomas SRYW. A review of long-term outcomes for late presenting developmental hip dysplasia. *Bone Joint J*. 2015;97-B(6):729-733. doi:10.1302/0301-620X.97B6.35395

11. Gambling TS, Long A. Psycho-social impact of developmental dysplasia of the hip and of differential access to early diagnosis and treatment: A narrative study of young adults. *SAGE open Med*. 2019;7:2050312119836010. doi:10.1177/2050312119836010

12. Engesaeter IØ, Lie SA, Lehmann TG, Furnes O, Vollset SE, Engesaeter LB. Neonatal hip instability and risk of total hip replacement in young adulthood: follow-up of 2,218,596 newborns from the Medical Birth Registry of Norway in the Norwegian Arthroplasty Register. *Acta Orthop*. 2008;79(3):321-326.

doi:10.1080/17453670710015201

13. Furnes O, Lie SA, Espehaug B, Vollset SE, Engesaeter LB, Havelin LI. Hip disease and the prognosis of total hip replacements. *J Bone Jt Surg - Ser B*. 2001;83(4):579-586. doi:10.1302/0301-620X.83B4.11223

14. Engesaeter LB, Furnes O, Havelin LI. Developmental dysplasia of the hip--good results of later total hip arthroplasty: 7135 primary total hip arthroplasties after developmental dysplasia of the hip compared with 59774 total hip arthroplasties in idiopathic coxarthrosis followed for 0 to 15 . *J Arthroplasty*. 2008;23(2):235-240. doi:10.1016/j.arth.2007.03.023

15. Thallinger C, Pospischill R, Ganger R, Radler C, Krall C, Grill F. Long-term results of a nationwide general ultrasound screening system for developmental disorders of the hip: The Austrian hip screening program. *J Child Orthop*. 2014;8(1):3-10. doi:10.1007/s11832-014-0555-6

16. Committee UNS. National Screening Programme- Developmental Dysplasia of the Hip. https://view-health-screening-recommendations.service.gov.uk/developmental-dislocation-of-the-hip/. Accessed October 31, 2023.

17. Mulpuri K, Song KM, Goldberg MJ, Sevarino K. Detection and nonoperative management of pediatric developmental dysplasia of the hip in infants up to six months of age. *J Am Acad Orthop Surg*. 2015;23(3):202-205. doi:10.5435/JAAOS-D-15-00006

18. Biedermann R, Eastwood DM. Universal or selective ultrasound screening for developmental dysplasia of the hip? A discussion of the key issues. *J Child Orthop*. 2018;12(4):296-301. doi:10.1302/1863-2548.12.180063

19. Davies R, Talbot C, Paton R. Evaluation of primary care 6- to 8-week hip check for diagnosis of developmental dysplasia of the hip: a 15-year observational cohort study. *Br J Gen Pract J R Coll Gen Pract*. 2020;70(693):e230-e235. doi:10.3399/bjgp20X708269

20. McAllister DA, Morling JR, Fischbacher CM, Reidy M, Murray A, Wood R. Enhanced detection services for developmental dysplasia of the hip in Scottish children, 1997-2013. *Arch Dis Child*. 2018;103(11):1021-1026. doi:10.1136/archdischild-2017-314354

21. Clarke NMP, Reading IC, Corbin C, Taylor CC, Bochmann T. Twenty years experience of selective secondary ultrasound screening for congenital dislocation of

the hip. *Arch Dis Child*. 2012;97(5):423-429. doi:10.1136/archdischild-2011-301085

22. 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. doi:10.1097/BPO.0000000000001602

23. Roposch A, Protopapa E, Malaga-Shaw O, et al. Predicting developmental dysplasia of the hip in at-risk newborns. *BMC Musculoskelet Disord*. 2020;21(1):442. doi:10.1186/s12891-020-03454-4

24. Broadhurst C, Rhodes AML, Harper P, Perry DC, Clarke NMP, Aarvold A. What is the incidence of late detection of developmental dysplasia of the hip in England? *Bone Joint J*. 2019;101-B(3):281-287. doi:10.1302/0301-620X.101B3.BJJ-2018-1331.R1

25. Standing Medical Nursing and Midwifery Advisory Committee. Screening for the detection of congenital dislocation of the hip. *Arch Dis Child*. 1986;61(9):921-926. doi:10.1136/adc.61.9.921

26. Shorter D, Hong T, Osborn DA. Cochrane Review: Screening programmes for developmental dysplasia of the hip in newborn infants. *Evidence-Based Child Heal*. 2013;8(1):11-54. doi:10.1002/ebch.1891

27. Cheok T, Smith T, Wills K, Jennings MP, Rawat J, Foster B. Universal screening may reduce the incidence of late diagnosis of developmental dysplasia of the hip : a systematic review and meta-analysis. *Bone Joint J*. 2023;105-B(2):198-208. doi:10.1302/0301-620X.105B2.BJJ-2022-0896.R1

28. Harper P, Gangadharan R, Poku D, Aarvold A. Cost Analysis of Screening Programmes for Developmental Dysplasia of the Hip: A Systematic Review. *Indian J Orthop*. 2020;55(6):1402-1409. doi:10.1007/s43465-021-00501-7

29. Jackson JC, Runge MM, Nye NS. Common questions about developmental dysplasia of the hip. *Am Fam Physician*. 2014;90(12):843-850.

30. Loder RT, Skopelja EN. The epidemiology and demographics of hip dysplasia. *ISRN Orthop*. 2011;2011:238607. doi:10.5402/2011/238607

31. Storer SK, Skaggs DL. Developmental dysplasia of the hip. *Am Fam Physician*. 2006;74(8):1310-1316.

32. Sewell MD, Rosendahl K, Eastwood DM. Developmental dysplasia of the hip. *BMJ*. 2009;339:b4454. doi:10.1136/bmj.b4454

33. McInnes MDF, Moher D, Thombs BD, et al. Preferred Reporting Items for a

Systematic Review and Meta-analysis of Diagnostic Test Accuracy Studies: The PRISMA-DTA Statement. *JAMA*. 2018;319(4):388-396. doi:10.1001/jama.2017.19163

34. Haddaway NR, Grainger MJ, Gray CT. Citationchaser: A tool for transparent and efficient forward and backward citation chasing in systematic searching. *Res Synth Methods*. 2022;13(4):533-545. doi:10.1002/jrsm.1563

35. Graf R. Classification of hip joint dysplasia by means of sonography. *Arch Orthop Trauma Surg*. 1984;102(4):248-255. doi:10.1007/BF00436138

36. Chavoshi M, Mirshahvalad SA, Mahdizadeh M, Zamani F. Diagnostic Accuracy of Ultrasonography Method of Graf in the detection of Developmental Dysplasia of the Hip: A Meta-Analysis and Systematic Review. *Arch bone Jt Surg*. 2021;9(3):297-305. doi:10.22038/abjs.2021.55292.2755

37. Peterlein CD, Schüttler KF, Lakemeier S, et al. Reproducibility of different screening classifications in ultrasonography of the newborn hip. *BMC Pediatr*. 2010;10:98. doi:10.1186/1471-2431-10-98

38. Simel DL, Rennie D. A Primer on the Precision and Accuracy of the Clinical Examination. In: *The Rational Clinical Examination: Evidence-Based Clinical Diagnosis*. New York, NY: McGraw-Hill Education; 2016. http://jamaevidence.mhmedical.com/content.aspx?aid=1004218574.

39. Whiting PF, Reitsma JB, Leeflang MMG, et al. QUADAS-2: A Revised Tool for the Quality Assessment of Diagnostic Accuracy Studies. *Ann Intern Med*. 2011;155(4):529-536. https://doi.org/10.7326/0003-4819-155-8-201110180-00009.

40. Nyaga VN, Arbyn M, Aerts M. Metaprop: a Stata command to perform meta-analysis of binomial data. *Arch Public Health*. 2014;72(1):39. doi:10.1186/2049-3258-72-39

41. Chang WC, Hsu KH, Lo IF, Liao KH, Su YP. Interobserver agreement and clinical disparity between the Graf method and femoral head coverage measurement in developmental dysplasia of the hip screening: A prospective observational study of 198 newborns. *Med (United States)*. 2021;100(24):E26291. doi:10.1097/MD.0000000000026291

42. Freeman SC, Kerby CR, Patel A, Cooper NJ, Quinn T, Sutton AJ. Development of an interactive web-based tool to conduct and interrogate meta-analysis of diagnostic test accuracy studies: MetaDTA. *BMC Med Res Methodol*. 2019;19(1):81. doi:10.1186/s12874-019-0724-x

43. Rabe-Hesketh S, Skrondal A, Pickles A. Generalized multilevel structural equation

modeling. *Psychometrika*. 2004;69(2):167-190. doi:10.1007/BF02295939

44. Patel A, Cooper N, Freeman S, Sutton A. Graphical enhancements to summary receiver operating characteristic plots to facilitate the analysis and reporting of meta-analysis of diagnostic test accuracy data. *Res Synth Methods*. 2021;12(1):34-44. doi:10.1002/jrsm.1439

45. Weber F, Knapp G, Ickstadt K, Kundt G, Glass Ä. Zero-cell corrections in random-effects meta-analyses. *Res Synth Methods*. 2020;11(6):913-919. doi:10.1002/jrsm.1460

46. Arti H, Mehdinasab SA, Arti S. Comparing results of clinical versus ultrasonographic examination in developmental dysplasia of hip. *J Res Med Sci*. 2013;18(12):1051-1055.

47. Bialik V, Wiener F. Sonography of Suspected Developmental Dysplasia of the Hip: A Description of 3,624 Hips. *J Pediatr Orthop B*. 1993;2(2). https://journals.lww.com/jpo-b/fulltext/1993/02020/sonography_of_suspected_developmental_dysplasia_of.10.aspx.

48. Chen HW, Chang CH, Tsai ST, et al. Natural progression of hip dysplasia in newborns: A reflection of hip ultrasonographic screenings in newborn nurseries. *J Pediatr Orthop Part B*. 2010;19(5):418-423. doi:10.1097/BPB.0b013e328339ecff

49. Choudry Q, Goyal R, Paton RW. Is limitation of hip abduction a useful clinical sign in the diagnosis of developmental dysplasia of the hip? *Arch Dis Child*. 2013;98(11):862-866. doi:10.1136/archdischild-2012-303121

50. Dogruel H, Atalar H, Yavuz OY, Sayli U. Clinical examination versus ultrasonography in detecting developmental dysplasia of the hip. *Int Orthop*. 2008;32(3):415-419. doi:10.1007/s00264-007-0333-x

51. Falliner A, Hahne HJ, Hassenpflug J. Sonographic hip screening and early management of developmental dysplasia of the hip. *J Pediatr Orthop B*. 1999;8(2):112-117.

52. Rosendahl K, Markestad T, Lie R. Congenital dislocation of the hip: a prospective study comparing ultrasound and clinical examination. *Acta Pædiatrica*. 1992;81(2):177-181. doi:10.1111/j.1651-2227.1992.tb12198.x

53. Rosendahl K, Markestad T, Lie RT. Developmental dysplasia of the hip. A population-based comparison of ultrasound and clinical findings. *Acta Paediatr Int J Paediatr*. 1996;85(1):64-69. doi:10.1111/j.1651-2227.1996.tb13892.x

54. Dwan K, Kirkham J, Paton RW, Morley E, Newton AW, Perry DC. Splinting for the non-operative management of developmental dysplasia of the hip (DDH) in children under six months of age. *Cochrane database Syst Rev*. 2022;10(10):CD012717. doi:10.1002/14651858.CD012717.pub2

55. Sakkers R, Pollet V. The natural history of abnormal ultrasound findings in hips of infants under six months of age. *J Child Orthop*. 2018;12(4):302-307. doi:10.1302/1863-2548.12.180056

56. Perry DC, Paton RW. Knowing your click from your clunk. *Bone Joint J*. 2019;101-B(3):236-237. doi:10.1302/0301-620x.101b3.bjj-2019-0075

57. Theunissen W, van der Steen MC, van Veen MR, van Douveren F, Witlox MA, Tolk JJ. Parental experiences of children with developmental dysplasia of the hip: a qualitative study. *BMJ Open*. 2022;12(9):e062585. doi:10.1136/bmjopen-2022-062585

58. Hoffer A, Chhina H, Mulpuri K, Cooper AP. Early Investigation and Bracing in DDH Impacts Maternal Wellbeing and Breastfeeding. *J Pediatr Orthop*. 2023;43(1):e30-e35. doi:10.1097/BPO.0000000000002274

59. Roposch A, Graf R, Wright JG. Determining the reliability of the Graf classification for hip dysplasia. *Clin Orthop Relat Res*. 2006;447:119-124. doi:10.1097/01.blo.0000203475.73678.be

Figure 1: PRISMA Flow Diagram

Table 1- Characteristics of included studies

Study ID and Author	Year	Location	Study Type	RCE Level	Screening Population	Clinical Tests	Reference Classification	Patients	Male	Female	Hips	Hip dysplasia[a]	No hip dysplasia[b]
1 Arti et al	2013	Iran	Consecutive series, prospective	1	Universal	Barlow and Ortolani	Graf	5701	2518	3183	11402	96	11306
2 Bialik et al	1993	Israel	Consecutive series, temporality unknown	3	Selective	Barlow and Ortolani, hip abduction	Graf	1812	699	1113	3624	148	3476
3 Chang et al	2021	Taiwan	Consecutive series, prospective	3	Mixed	Barlow and Ortolani	Graf / Femoral Head Coverage	248	101	147	338	59	279
4 Chen et al	2010	Taiwan	Consecutive series, temporality unknown	1	Universal	Barlow and Ortolani	Graf	1333	705	628	2666	4	2662
5 Choudry et al	2013	United Kingdom	Consecutive series, prospective	3	Selective	Hip abduction	Graf	2876	-	-	5752	156	5596
6 Dogruel et al	2008	Turkey	Consecutive series, temporality unknown	1	Universal	Barlow and Ortolani	Graf	3541	1626	1915	7082	61	7021
7 Falliner et al	1999	Germany	Consecutive series, prospective	1	Universal	Barlow and Ortolani, hip abduction	Graf	6548	3309	3239	13096	88	13008
8 Rosendahl et al	1996	Norway	Consecutive series, prospective	1	Universal	Barlow and Ortolani	Graf	3613	1846	1767	3613	114	3499
9 Rosendahl et al	1992	Norway	Consecutive series, prospective	3	Selective	Barlow and Ortolani	Graf	1503	212	1291	3006	80	2926
Total (n)								**27175**			**50579**	**806**	**49773**

[a] **Decentered (Graf D,3,4)**

[b] **Centered (Graf 1,2)**

Table 2- Hip examination findings and likelihood of a dislocated hip, with positive and negative likelihood ratios (see eTable 2 for results from individual studies)

Examination Finding	Total Studies	Total number of hips	Number of hips with positive finding (%)	Sensitivity (%, 95$ CI)	Specificity (%, 95% CI)	LR+ (95% CI)	LR- (95% CI)
Barlow and Ortolani	8	44827	650, (1.5)	46 (26-67)[a]	99.1 (97.9-99.6)[a]	52 (21-127)[a]	0.55 (0.37-0.82)[a]
Limited hip Abduction	3	22472	392, (1.7)	13 (3.3-37)	97 (87-99)	3.6 (0.72-18)	0.91 (0.76-1.1)
Click	1	13096	88, (0.67)	13 (6.4-21)	92 (92-93)	1.6 (0.91-2.8)	0.95 (0.88-1.0)

Abbrivviations: LR+, positive likelihood ratio; LR-, negative likelihood ratio

[a] Summary estimates after adjusting Chang et al[41] for verification bias