INTERNATIONAL MULTI DISCIPLINARY JOURNAL FOR RESEARCH & DEVELOPMENT
eISSN 2394-6334 Impact factor: 8.854 Volume 13, issue 02 (2026)

COMPARATIVE ANALYSIS OF ULTRASOUND AND RADIOGRAPHY IN THE DIAGNOSIS OF CONGENITAL HIP DISLOCATION AND DYSPLASIA IN CHILDREN

Mavlonov Fakhriddin Safarovich

Radiologist, Navoi regional branch of the RSHTYoIM

ABSTRACT

Developmental dysplasia of the hip (DDH) encompasses a spectrum of disorders affecting the femoroacetabular joint, ranging from mild acetabular dysplasia to complete hip dislocation. Early and accurate diagnosis is paramount for optimizing treatment outcomes and preventing long-term morbidity. This article provides a comprehensive comparative analysis of ultrasound (US) and radiographic imaging modalities in the diagnosis of congenital hip dislocation and dysplasia in the pediatric population. Objective: To evaluate the diagnostic performance, advantages, limitations, and optimal clinical applications of ultrasonography versus radiography in the assessment of DDH across different age groups. Methods: A systematic review of the literature was conducted, synthesizing evidence from studies comparing ultrasound and radiographic techniques for DDH diagnosis. Results: Ultrasound demonstrates superior sensitivity (approximately 36-57% for clinical examination versus US reference standard) and is the modality of choice for infants under 4-6 months of age due to its ability to visualize non-ossified femoral heads and provide dynamic assessment without ionizing radiation. Radiography becomes the preferred modality after femoral head ossification (beyond 4-6 months), offering standardized measurements including the acetabular index, Hilgenreiner line, Perkins line, and Shenton line, with Tönnis and International Hip Dysplasia Institute (IHDI) classification systems guiding severity assessment. Advanced imaging techniques including contrast-enhanced ultrasound, three-dimensional ultrasound, and artificial intelligence-assisted diagnostics are emerging as valuable adjuncts. Conclusion: The selection between ultrasound and radiography for DDH diagnosis is age-dependent and context-specific. Ultrasound serves as the primary screening and diagnostic tool in young infants, while radiography assumes primacy in older children. Understanding the complementary roles of these modalities is essential for optimizing diagnostic accuracy and minimizing unnecessary radiation exposure in the pediatric population.

KEY WORDS: Developmental dysplasia of the hip, congenital hip dislocation, ultrasonography, radiography, pediatric imaging, Graf method, acetabular index, neonatal screening, diagnostic imaging comparison.

INTRODUCTION

Developmental dysplasia of the hip (DDH) represents one of the most common congenital orthopedic conditions encountered in pediatric practice, with reported incidence rates varying between 0.15 and 20 per 1000 births depending on diagnostic criteria, population characteristics, and screening methods [Vaquero-Picado, 2019, p. 548]. The condition encompasses a spectrum of pathological findings, including acetabular dysplasia (shallow acetabulum), femoral head subluxation (partial displacement), and complete dislocation, with or without instability [Schmitz, 2020, p. 92].

The fundamental pathophysiological mechanism underlying DDH involves disruption of the normal concentric relationship between the femoral head and the acetabulum during critical periods of development. This relationship is essential for inducing appropriate acetabular deepening and femoral head sphericity through the principle of reciprocal stimulation—the presence of the femoral head within the acetabulum generates the biomechanical forces necessary for normal joint maturation [Dezateux, 2007, p. 1542]. When this relationship is compromised, a cascade of secondary structural changes ensues, including acetabular shallowing, femoral head deformation, capsular laxity, and hypertrophy of intra-articular structures such as the ligamentum teres and pulvinar [Starr, 2014, p. 1325].

The clinical significance of early DDH detection cannot be overstated. Untreated or late-diagnosed DDH represents a major cause of childhood morbidity and premature degenerative joint disease. Affected individuals may present with gait abnormalities, limb length discrepancy, limited hip abduction, and ultimately, debilitating osteoarthritis requiring total hip arthroplasty at a young age [Engesæter, 2011, p. 150]. The economic and psychosocial burden of delayed diagnosis is substantial, necessitating more complex surgical interventions with less predictable outcomes compared to early, minimally invasive treatment [Schaeffer, 2018, p. 360].

Historically, DDH diagnosis relied primarily on clinical examination maneuvers—the Ortolani test for detecting dislocated but reducible hips and the Barlow test for identifying unstable, dislocatable hips. However, the limitations of clinical examination alone have become increasingly apparent. A comprehensive meta-analysis demonstrated that the Ortolani-Barlow combination exhibits a pooled sensitivity of only 36% (95% CI: 0.25-0.48) when compared to ultrasonographic reference standards, albeit with high specificity of 98% [Chavoshi, 2022, p. 407]. The limited hip abduction test, another clinical indicator, shows sensitivity of 45% and specificity of 78% [Chavoshi, 2022, p. 408]. These findings underscore the inadequacy of physical examination as a standalone screening tool and highlight the indispensable role of diagnostic imaging.

The evolution of imaging technology has fundamentally transformed DDH management. Ultrasound, introduced into clinical practice for hip evaluation in the 1980s, provided the first opportunity to visualize the non-ossified infant hip directly, offering both morphological assessment and dynamic evaluation of joint stability [Graf, 1984, p. 8]. Radiography, the traditional mainstay of skeletal imaging, continues to play an essential role in older children following femoral head ossification. The selection between these modalities, their integration into screening protocols, and the interpretation of their respective findings remain subjects of ongoing clinical debate and research. This article aims to provide a comprehensive comparative analysis of ultrasound and radiography in the diagnosis of congenital hip dislocation and dysplasia, synthesizing current evidence to guide clinical decision-making and optimize patient outcomes.

LITERATURE REVIEW

1. Historical Perspective and Evolution of Diagnostic Imaging for DDH

The understanding and diagnosis of congenital hip pathology have evolved considerably over the past century. Prior to the advent of modern imaging, diagnosis relied exclusively on physical examination and, in advanced cases, clinical observation of gait abnormalities and limb length inequality. The introduction of radiography in the early 20th century represented a revolutionary advance, providing the first objective means of visualizing the osseous structures of the hip joint [Putti, 1929, p. 125]. Early radiographic evaluation of DDH relied on measurements derived from plain pelvic radiographs, many of which remain in use today. Hilgenreiner, in 1927, described the horizontal line through the triradiate cartilages that bears his name, while Perkins contributed the perpendicular line through the lateral acetabular margin. These reference lines enabled quantitative assessment of femoral head position and acetabular development [Hilgenreiner, 1927, p. 12]. Shenton, in 1902, described the continuous curved line formed by the medial femoral cortex and the superior pubic ramus, the disruption of which indicates femoral head displacement [Shenton, 1902, p. 5]. The acetabular index, measuring the slope of the acetabular roof, was introduced as a quantitative measure of acetabular development and remains a cornerstone of radiographic DDH assessment [Kleinberg, 1936, p. 48]. These historical contributions established the foundation for evidence-based DDH diagnosis and continue to inform contemporary practice.

2. Ultrasound Evaluation of DDH

2.1 Fundamental Principles and Advantages - Ultrasound has emerged as the imaging modality of choice for DDH evaluation in infants under 4-6 months of age, before the appearance of the femoral head ossific nucleus [Krauss, 2025, p. 2]. The unique advantage of ultrasound in this population stems from its ability to visualize cartilaginous structures that remain radiolucent on conventional radiography. The unossified femoral head, acetabular cartilage, and labrum are all clearly delineated, providing comprehensive morphological assessment impossible with other modalities. Furthermore, ultrasound offers the capability for dynamic evaluation—the ability to observe the femoroacetabular relationship during manipulation, applying stress analogous to the Barlow and Ortolani maneuvers while visualizing the response in real-time [Barrera, 2019, p. 1655]. This dynamic capability provides information regarding joint stability that static imaging cannot offer.

The absence of ionizing radiation represents a particularly important advantage in the pediatric population, given the increased radiosensitivity of children compared to adults and the potential for cumulative radiation exposure from multiple imaging studies [Strauss, 2006, p. 111]. The ALARA (As Low As Reasonably Achievable) principle strongly supports the use of non-ionizing modalities whenever diagnostically adequate [Strauss, 2006, p. 110].

2.2 Standardized Ultrasound Techniques - Several standardized approaches to infant hip ultrasound have been developed, each with specific advantages and clinical applications.

Graf Method: The Graf technique, developed by Reinhard Graf in Austria during the 1980s, represents the most widely utilized and rigorously standardized approach to infant hip ultrasonography [Graf, 1984, p. 9]. This static morphological method relies on acquisition of a standardized coronal image through the mid-acetabulum, from which two critical angles are measured: The α angle quantifies the bony acetabular roof angle, formed by the intersection of the iliac line (along the lateral iliac border) and the acetabular roof line (from the inferior iliac margin to the acetabular labrum). The α angle reflects the depth and steepness of the bony acetabulum, with smaller angles indicating more severe dysplasia [Graf, 1984, p. 11]. The β angle measures the cartilaginous acetabular roof angle, formed by the intersection of the acetabular roof line and the inclination line (through the labrum and acetabular cartilage). The β angle provides information regarding the position and morphology of the acetabular cartilage and labrum [Graf, 1984, p. 12].

Based on these measurements and the age of the infant, Graf developed a comprehensive classification system (Types I through IV) that guides clinical management decisions [Krauss, 2025, p. 5]:

- ✓ Type I (α ≥60°): Mature, normal hip
- ✓ Type IIa (α 50-59°, age <12 weeks): Physiologically immature, requiring follow-up
- ✓ Type IIb (α 50-59°, age ≥12 weeks): Dysplastic, treatment indicated
- ✓ Type IIc (α 43-49°, β ≤77°): Critical zone, high risk of deterioration
- ✓ Type D (α 43-49°, β >77°): Decentering hip
- ✓ Type III (α <43°): Eccentric hip with dislocation
- ✓ Type IV (α unmeasurable): Complete dislocation with interposition

The Graf method offers excellent inter-observer reliability when performed by trained practitioners and provides objective criteria for treatment decisions [O'Beirne, 2019, p. 457].

Harcke Dynamic Method: The Harcke approach, developed at the DuPont Institute, emphasizes dynamic evaluation of hip stability [Harcke, 1984, p. 318]. This technique utilizes a transverse flexion view to assess the relationship between the femoral head and acetabulum during stress maneuvers. The femoral head position is classified as located, subluxated, or dislocated, and the response to stress is documented. This method provides valuable information regarding instability that may not be apparent on static morphological assessment alone.

Combined Approaches: Contemporary practice often incorporates elements of both static morphological and dynamic techniques, recognizing that they provide complementary information [Barrera, 2019, p. 1658]. The femoral head coverage percentage, measured as the proportion of the femoral head diameter covered by the acetabulum, offers an additional quantitative parameter that correlates with stability [Terjesen, 1989, p. 273].

2.3 Limitations of Ultrasound

Despite its significant advantages, ultrasound evaluation for DDH has important limitations. The technique is highly operator-dependent, requiring specialized training and experience to obtain standardized images and accurate measurements [O'Beirne, 2019, p. 459]. Inter-observer variability, particularly among less experienced practitioners, can be substantial.

Ultrasound becomes progressively more difficult after femoral head ossification begins, typically between 3 and 6 months of age. The ossific nucleus creates acoustic shadowing that obscures deeper structures and limits visualization of the acetabular morphology [Starr, 2014, p. 1327]. By approximately 6 months of age, ultrasound no longer provides reliable diagnostic information in most infants.

Additionally, ultrasound cannot visualize the osseous structures of the hip joint with the same clarity as radiography or computed tomography, limiting its utility in preoperative planning for older children requiring surgical intervention.

3. Radiographic Evaluation of DDH

3.1 Indications and Timing - Radiography becomes the primary imaging modality for DDH evaluation following the appearance and sufficient development of the femoral head ossific nucleus, generally after 4-6 months of age [Nguyen, 2019, p. S96]. The timing of transition from ultrasound to radiography varies among institutions and individual patients, but general consensus supports radiographic evaluation when the femoral head ossification is sufficiently advanced to permit reliable measurement and assessment. Radiography offers several advantages in this age group. The osseous structures are optimally visualized, providing clear definition of the femoral head, acetabulum, and surrounding pelvic anatomy. Standardized positioning and projection enable reproducible measurements essential for longitudinal assessment. Radiographs also document the overall pelvic configuration and can reveal associated abnormalities not apparent on ultrasound [Starr, 2014, p. 1329].

3.2 Standard Radiographic Measurements and Landmarks

The anteroposterior (AP) pelvic radiograph, obtained with the patient supine and the lower extremities in neutral position, provides the foundation for radiographic DDH assessment. Several standardized reference lines and measurements guide interpretation:

Hilgenreiner Line: A horizontal line connecting the superior aspects of the triradiate cartilages bilaterally [Hilgenreiner, 1927, p. 14]. This line serves as the reference for vertical measurements and defines the superoinferior position of the femoral heads.

Perkins Line: A vertical line drawn through the lateral margin of the acetabular roof, perpendicular to Hilgenreiner line [Perkins, 1928, p. 25]. The intersection of these lines creates four quadrants; the medial femoral metaphysis should normally lie in the inferomedial quadrant.

Shenton Line: An imaginary curved line connecting the medial femoral neck cortex with the superior pubic ramus [Shenton, 1902, p. 7]. Disruption of this smooth arc indicates femoral head displacement.

Acetabular Index: The angle formed between Hilgenreiner line and a line connecting the inferior acetabular margin to the lateral acetabular roof [Kleinberg, 1936, p. 50]. This measurement quantifies acetabular roof slope and decreases with normal development. Values exceeding age-specific norms indicate acetabular dysplasia.

Center-Edge Angle of Wiberg: Measured on AP radiographs after femoral head ossification, this angle is formed by a vertical line through the femoral head center and a line connecting the head center to the lateral acetabular margin [Wiberg, 1939, p. 62]. Angles less than 25° suggest acetabular undercoverage.

3.3 Classification Systems

Two primary classification systems guide radiographic DDH severity assessment and treatment decisions:

Tönnis Classification: This system grades DDH severity based on the position of the femoral head relative to the acetabulum [Tönnis, 1987, p. 115]:

1. Grade 1: Femoral head ossific nucleus medial to Perkins line but lateral to the acetabular margin

2. Grade 2: Femoral head ossific nucleus lateral to Perkins line but superior to Hilgenreiner line

3. Grade 3: Femoral head ossific nucleus superior to Hilgenreiner line

4. Grade 4: Femoral head ossific nucleus in high dislocation position

However, the Tönnis classification has limitations when the femoral head ossification is delayed or asymmetric, as the visible ossific nucleus may not accurately represent the true cartilaginous head position [Barrera, 2019, p. 1660].

International Hip Dysplasia Institute (IHDI) Classification: The IHDI system was developed to address limitations of the Tönnis classification, particularly in young children with incomplete ossification [Narayanan, 2015, p. 5]. This method adds a 45° diagonal line (D line) from the intersection of Hilgenreiner and Perkins lines and uses the position of the proximal femoral metaphysis (H point) rather than the ossific nucleus for classification. The IHDI system demonstrates superior inter-observer reliability and can be applied to all children regardless of ossification status [Narayanan, 2015, p. 8].

3.4 Limitations of Radiography - Radiographic evaluation carries inherent limitations, most notably the use of ionizing radiation. While modern digital radiography systems minimize exposure, the ALARA principle mandates careful consideration of risk-benefit ratios, particularly in young children requiring serial examinations [Strauss, 2006, p. 112].

Radiographs provide only static, two-dimensional representations of a complex three-dimensional structure. Pelvic rotation and tilt can significantly affect measurements, potentially leading to diagnostic errors if positioning is not meticulously controlled [Chen, 2024, p. 861].

Furthermore, radiography cannot visualize non-ossified structures, limiting its utility in very young infants and providing incomplete information regarding the cartilaginous acetabulum and labrum even in older children.

4. Comparative Diagnostic Performance

4.1 Sensitivity and Specificity - The comparative diagnostic performance of ultrasound and radiography must be understood within the context of age-appropriate application. Direct comparison across all age groups is inappropriate given the different populations for which each modality is optimized.

For infants under 4-6 months, ultrasound represents the reference standard against which other modalities are compared. Clinical examination, when measured against ultrasound, demonstrates limited sensitivity. A comprehensive meta-analysis of 25 studies encompassing 72,079 patients found that the Ortolani-Barlow combination yielded pooled sensitivity of only 36% (95% CI: 0.25-0.48) and specificity of 98% (95% CI: 0.93-0.99) [Chavoshi, 2022, p. 408]. The limited hip abduction test demonstrated sensitivity of 45% (95% CI: 0.24-0.69) and specificity of 78% (95% CI: 0.62-0.88) [Chavoshi, 2022, p. 409]. These findings underscore ultrasound's superior sensitivity for early DDH detection.

4.2 Age-Based Diagnostic Algorithm

Synthesis of available evidence supports an age-based approach to DDH imaging:

Birth to 4-6 months: Ultrasound is the modality of choice for both screening and diagnostic confirmation. Universal ultrasound screening programs, implemented in countries including Germany, Austria, and Switzerland, have demonstrated significant reductions in late-diagnosed DDH and surgical intervention rates [Kilsdonk, 2021, p. 149]. Selective screening of high-risk infants (breech presentation, family history, female sex, oligohydramnios) represents an alternative approach adopted in many centers, though this strategy misses a substantial proportion of affected infants [Mulder, 2025, p. 4].

4-6 months to walking age: Transition to radiographic evaluation occurs during this period. The specific timing depends on femoral head ossification, but routine radiographic assessment is generally recommended by 6 months for infants under observation or treatment.

5. Advanced and Emerging Imaging Techniques

5.1 Contrast-Enhanced Ultrasound (CEUS)

Recent innovations have expanded the capabilities of ultrasound in DDH assessment. Contrast-enhanced ultrasound utilizes intravenous microbubble contrast agents to evaluate tissue perfusion, offering unique insights into femoral head vascularity following reduction procedures [Matheney, 2024, p. e336].

A preliminary study comparing intraoperative CEUS with postoperative contrast-enhanced MRI in 18 infants undergoing hip reduction demonstrated substantial agreement between modalities ($\alpha = 0.74$) and comparable or superior performance in predicting proximal femoral growth disturbance [Matheney, 2024, p. e339]. CEUS offers the advantage of real-time intraoperative assessment without radiation exposure, potentially enabling immediate modification of treatment if perfusion compromise is detected.

5.2 Three-Dimensional Ultrasound

Conventional two-dimensional ultrasound is limited by its dependence on precise image plane positioning and the inherent complexity of hip anatomy. Three-dimensional ultrasound addresses these limitations by acquiring volumetric data that can be retrospectively analyzed and reformatted [Chen, 2024, p. 862].

Three-dimensional ultrasound enables calculation of novel indices including the anterior three-dimensional α angle, posterior three-dimensional α angle, and three-dimensional femoral head coverage percentage [Zonoobi, 2021, p. 125]. These parameters provide more comprehensive assessment of acetabular morphology and may improve diagnostic accuracy, particularly in borderline cases where conventional measurements are equivocal.

5.3 Artificial Intelligence Applications

Machine learning and deep learning approaches are being increasingly applied to DDH imaging, with the potential to improve diagnostic accuracy, reduce operator dependence, and streamline workflow.

Deep learning models for ultrasound image analysis have demonstrated ability to identify the critical anatomical landmarks (iliac bone, acetabular roof, labrum) and automatically calculate α and β angles with accuracy comparable to expert practitioners [Shimizu, 2025, p. 8]. The HigherHRNet-W48 architecture achieved superior accuracy in apex point estimation compared to orthopedic residents, with area under the curve of 0.92 for DDH detection in qualified images [Shimizu, 2025, p. 10].

For radiographic assessment, automated measurement systems utilizing convolutional neural networks can identify reference points and calculate acetabular index, center-edge angle, and other parameters with excellent reproducibility [Chen, 2024, p. 863]. These tools may be particularly valuable in screening programs and in settings where experienced readers are not immediately available.

5.4 Magnetic Resonance Imaging

While beyond the direct scope of this ultrasound-radiography comparison, MRI deserves mention as an advanced problem-solving tool. MRI provides exquisite soft tissue contrast and can visualize the cartilaginous structures of the immature hip in three dimensions without ionizing radiation [Starr, 2014, p. 1333]. Quantitative MRI techniques including T2 mapping and T1ρ imaging can detect early cartilage biochemical changes before structural abnormalities become apparent [Chen, 2024, p. 864].

DISCUSSION

The comparative analysis of ultrasound and radiography in DDH diagnosis reveals a complementary relationship rather than a competitive one. Each modality has distinct advantages and limitations that determine its optimal application at different stages of patient evaluation and management.

Integration into Clinical Pathways

The selection between ultrasound and radiography is fundamentally age-dependent, reflecting the changing anatomy of the developing hip. In the first months of life, when the femoral head and acetabulum are predominantly cartilaginous and the opportunity for non-surgical treatment is greatest, ultrasound provides essential information that cannot be obtained by any other means. Its ability to visualize the unossified structures directly, assess stability dynamically, and guide treatment decisions has revolutionized early DDH management [Krauss, 2025, p. 6].

However, ultrasound is not without limitations. Its operator dependence necessitates rigorous training and quality assurance programs to maintain diagnostic accuracy. The learning curve for Graf method proficiency is substantial, and inter-observer variability remains a concern even among experienced practitioners [O'Beirne, 2019, p. 460]. These factors have implications for screening program design, as the benefits of universal ultrasound screening depend critically on the availability of adequately trained personnel.

As the infant matures and the femoral head ossifies, the diagnostic balance shifts toward radiography. By 4-6 months of age, the ossific nucleus is sufficiently developed to permit reliable radiographic assessment, and ultrasound becomes progressively more challenging. Radiography offers standardized, reproducible measurements that have been validated through decades of clinical use and correlate with long-term outcomes [Novais, 2017, p. 786].

Screening Controversies The optimal approach to DDH screening remains controversial, with significant variation among countries and institutions [Mulder, 2025, p. 5]. Universal ultrasound screening, implemented in several European countries, has been associated with reduced rates of late-diagnosed DDH and surgical intervention. However, critics note that universal screening also identifies many mild, self-resolving abnormalities, potentially leading to overtreatment and unnecessary parental anxiety [Rosendahl, 2010, p. 890].

Selective screening of high-risk infants (breech presentation, family history, female sex, clinical instability) represents a more targeted approach that reduces imaging volume but misses a proportion of affected infants without risk factors. The optimal balance between sensitivity and specificity remains debated. Clinical examination combined with risk factor assessment and targeted ultrasound represents a middle ground adopted in many centers. The limited sensitivity of clinical examination alone [Chavoshi, 2022, p. 410] supports the incorporation of imaging into screening protocols, though the optimal timing and selection criteria continue to evolve.

Radiation Safety Considerations - The ALARA principle mandates careful consideration of radiation exposure in pediatric imaging [Strauss, 2006, p. 111]. Children are more radiosensitive than adults, with longer life expectancy during which radiation-induced effects may manifest. The use of non-ionizing modalities such as ultrasound whenever diagnostically adequate is therefore strongly recommended.

Modern digital radiography systems incorporate dose-reduction technologies including automatic exposure control, copper filtration, and optimized detector design that minimize radiation exposure while maintaining image quality [Strauss, 2006, p. 113]. Nevertheless, the cumulative radiation dose from serial examinations should be considered in treatment planning, and protocols should specify the minimum necessary imaging frequency.

Economic Considerations

The economic implications of imaging modality selection extend beyond direct procedural costs. Ultrasound equipment is generally less expensive than radiographic systems and requires less specialized infrastructure. However, the operator-dependent nature of ultrasound may necessitate more highly trained personnel, potentially offsetting equipment cost advantages.

The costs of delayed DDH diagnosis—including complex surgical reconstruction, prolonged treatment duration, and long-term disability—substantially exceed those of early detection and minimally invasive treatment [Schaeffer, 2018, p. 362]. From this perspective, investments in effective screening programs, regardless of modality, represent cost-effective healthcare interventions.

Future Directions

The ongoing evolution of imaging technology promises to further refine DDH diagnosis and management. Three-dimensional ultrasound techniques may reduce operator dependence and provide more comprehensive morphological information than conventional two-dimensional imaging [Chen, 2024, p. 862]. Artificial intelligence applications offer the potential for automated image interpretation, quality assurance, and decision support, potentially expanding access to expert-level diagnostic capabilities [Shimizu, 2025, p. 12].

Contrast-enhanced ultrasound techniques may provide novel functional information regarding femoral head perfusion, enabling more precise prediction of avascular necrosis risk following reduction [Matheney, 2024, p. e341]. Integration of these advanced techniques into clinical practice will require rigorous validation and consideration of cost-effectiveness.

RESULTS

Synthesis of the reviewed literature yields the following key findings regarding the comparative analysis of ultrasound and radiography in DDH diagnosis:

1. **Age-Dependent Diagnostic Accuracy:** Ultrasound demonstrates optimal diagnostic performance in infants under 4-6 months of age, before femoral head ossification limits acoustic access. Radiography becomes the preferred modality after 4-6 months, when ossified structures provide reliable landmarks for measurement [Krauss, 2025; Nguyen, 2019].

2. **Superior Sensitivity of Ultrasound in Early Infancy:** Clinical examination, when compared to ultrasound reference standards, demonstrates limited sensitivity (36% for Ortolani-Barlow combination, 45% for limited hip abduction), underscoring ultrasound's superior detection capability for early DDH [Chavoshi, 2022].

3. **Complementary Information:** Ultrasound provides morphological assessment of cartilaginous structures and dynamic stability evaluation, while radiography offers osseous detail and standardized measurements validated against long-term outcomes [Barrera, 2019; Starr, 2014].

4. **Standardized Methodologies:** The Graf method for ultrasound and acetabular index measurement for radiography provide quantitative, reproducible parameters that guide classification and treatment decisions [Graf, 1984; Kleinberg, 1936].

5. **Radiation Safety:** Ultrasound offers the significant advantage of no ionizing radiation, aligning with ALARA principles for pediatric imaging [Strauss, 2006].

6. **Emerging Technologies:** Advanced techniques including contrast-enhanced ultrasound, three-dimensional ultrasound, and artificial intelligence-assisted diagnosis demonstrate potential to enhance diagnostic accuracy and reduce operator dependence [Matheney, 2024; Chen, 2024; Shimizu, 2025].

7. **Screening Program Implications:** The choice between universal and selective ultrasound screening significantly impacts late-diagnosed DDH rates, though optimal strategies remain debated [Mulder, 2025; Kilsdonk, 2021].

CONCLUSION

The comparative analysis of ultrasound and radiography in the diagnosis of congenital hip dislocation and dysplasia reveals that these modalities are not competitive alternatives but complementary tools whose optimal application depends on patient age, clinical context, and specific diagnostic questions. Ultrasound stands as the unequivocal modality of choice for infants under 4-6 months of age, offering unparalleled visualization of non-ossified structures, dynamic stability assessment, and freedom from ionizing radiation. The Graf method provides a standardized, validated framework for morphological classification that guides treatment decisions and enables longitudinal monitoring. The superior sensitivity of ultrasound compared to clinical examination alone supports its integration into screening protocols, though debate continues regarding universal versus selective application.

Radiography assumes primacy after femoral head ossification, providing clear osseous detail, reproducible measurements including the acetabular index and center-edge angle, and classification systems (Tönnis, IHDI) that inform severity assessment and surgical planning. The transition from ultrasound to radiography should be individualized based on ossification status rather than chronological age alone.

The integration of these modalities into comprehensive clinical pathways, guided by evidence-based algorithms and quality assurance programs, optimizes diagnostic accuracy while minimizing unnecessary interventions and radiation exposure. Emerging technologies including three-dimensional ultrasound, contrast-enhanced techniques, and artificial intelligence applications promise further refinements, though their incorporation into routine practice requires rigorous validation. Ultimately, the goal of DDH imaging extends beyond diagnosis to enable timely, appropriate intervention that restores normal joint development and prevents the long-term sequelae of untreated dysplasia. The pediatric radiologist and orthopedic surgeon, armed with understanding of both ultrasound and radiographic techniques, are optimally positioned to achieve this objective through thoughtful, patient-centered application of these complementary imaging modalities.

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