

REVIEW ARTICLE

Indications and Techniques for Ultrasonography of the Paediatric Orthopaedic Hip

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ABSTRACT

Ultrasound of the paediatric hip has vast utility. The purpose of this paper is to outline the clinical indications for infantile hip ultrasound, describe the method by which it can be implemented, and describe the benefits of implementing such technology into orthopaedic paediatric practice. Indications for the use of paediatric ultrasound in the acute setting include infectious and inflammatory processes such as transient synovitis and septic arthritis, whereas indications in the chronic setting include developmental dysplasia, juvenile arthropathies, and Perthes disease. The following technique guide outlines the static (Classic Graf Method) assessment of the infantile hip while adding further development and instruction on the implementation of additional dynamic techniques promoted by Harcke et al. Ultrasound accurately identifies early stages of pathology; however, it also clearly outlines the anatomy of the paediatric hip without the disadvantage of radiologic exposure. As ultrasound techniques evolve, their utility also continues to expand. This paper is a useful tool for the paediatric orthopaedic surgeon to understand their diagnostic application.

1 | Introduction

The use of ultrasound in the diagnosis, classification, and monitoring of hip pathology in those under school age is vast and versatile. Throughout medical advancement it has provided accuracy, ease of use, and promoted safety in radiation-free diagnostics [1, 2]. With such breadth of use, the implementation of ultrasound into the investigation of the paediatric hip provides great utility, clinical value, and clarity in the right hands [1, 2]. The purpose of this paper is to outline the clinical indications for infantile hip ultrasound, describe the method by which it can be implemented, and describe the benefits of implementing such technology into orthopaedic paediatric practice.

2 | Materials and Methods

In this review the indications and methods of paediatric ultrasound were investigated using a systematic literature review. Key words and phrases included; “indications of pediatric ultrasound of the hip”, “static pediatric hip ultrasound”, and “dynamic pediatric hip ultrasound”. Over 90 relevant papers were critically reviewed and 44 were included to develop the following technique guide. The following review details the appropriate indications for the use of paediatric ultrasound of the hip in both the acute and chronic setting and further details the static and dynamic methods of ultrasound in our identified population.

Given the nature of this article as a comprehensive literature review, an educational review on standard practice without human intervention, and a purely technical guide, this paper was deemed to be exempt from IRB review per multiple research bodies [3, 4]. This allows for the development of critical knowledge and advancement of medical skill. Consent, however, was collected from the parents of the models for the technique guide.

3 | Results

3.1 | Indications

The paediatric patient presenting with an irritable or painful hip has long posed great query and challenge to orthopaedic surgeons due to the vast array of differential diagnoses that must be investigated [5]. The implementation of ultrasound, however, can often provide diagnostic guidance in both acute and chronic conditions.

3.2 | Chronic Indications

Ultrasound may be used in patients presenting with chronic conditions, including conditions that may be developmental, rheumatological, or vascular in nature. Most notably, ultrasound has been proven to provide great benefit in the diagnosis, classification, monitoring, and screening of developmental dysplasia of the hip (DDH) [1, 6–8]. Studies have shown negative predictive values reaching 98% in the diagnosis of DDH with ultrasound [9]. Not only has ultrasound proven to be diagnostic, it has also been used in the development of classification systems that aid in clinical decision making regarding treatment, most notably the Graf classification of hip instability [7]. Furthermore, these techniques can be expanded to the monitoring and tracking of clinical progression in infants diagnosed with this disease, thus reducing repeat exposure to harmful radiation [8]. Finally, when used for screening in appropriate populations, ultrasound has been shown to be cost effective, promote early detection, efficient, and preventative of long-term complications associated with DDH [1, 10, 11]. Identified risk factors include female sex, family history of DDH, breech birth, oligohydramnios, high birth weight, and post maturity [12]. Cost analyses suggest US screening of all infants with risk factors of DDH to be a cost-effective manner of early detection of hip abnormalities and routine follow up in the management of hip dysplasia [10]. This early detection also boasts the benefit of prevention of long-term complications including surgical salvage procedures such as open reduction for developmental dysplasia [11].

Although developmental dysplasia of the hip certainly dominates the historic discourse of ultrasonography, its benefits can be applied to rheumatological and vascular conditions of the paediatric hip. Ultrasound examination may be indicated in suspected cases of juvenile arthropathies having been shown to detect even subclinical synovitis, thus allowing early detection and initiation of disease modifying treatments [13]. Furthermore, ultrasound can be implemented in the detection and characterisation of avascular necrosis of the proximal femoral epiphysis in pre-school aged children, also known as Legg-Calve-Perthes

Disease [14]. US criteria (prolonged effusion, cartilage thickening and quadriceps atrophy) for the diagnosis of Perthes disease have shown a positive predictive value of 95%, a negative predictive value of 95%, a sensitivity of 71%, and a specificity of 99% [14]. In the assessment of chronic hip pathology, US has been shown to be helpful in developmental, rheumatological, and vascular pathologies thus making it a crucial feature in the paediatric orthopaedic surgeon's toolbelt.

3.3 | Acute Indications

The clinical potential for the use of ultrasound expands beyond the outpatient clinic and has proven itself to be a compelling and critical feature in emergency paediatric care. Infectious and inflammatory processes again pose a diagnostic challenge, one that through the appropriate implementation, ultrasound may ameliorate. The total lifetime risk of transient synovitis in pre-school aged children reaches about 3%, often presenting with vague symptoms of atraumatic knee or hip pain [15]. The use of ultrasound can help bring clarity to this condition via the detection of hyperechoic effusion or increased capsule to bone distance; this method has shown improved detection rates compared to radiography alone [16]. This method can further confirm the transient nature of this condition compared to more serious conditions such as septic arthritis by accurately detecting effusion regression [16]. Ultrasound has additionally been implicated in the diagnosis of septic arthritis. In septic arthritis, ultrasound is able to identify infectious processes by detailing hip joint effusion, synovial thickening, and cartilage damage and importantly exclude this condition when the anterior recess is free of effusion; thus, determining the need for aspiration and reducing unnecessary aspirations [17, 18]. The use of US in the emergency setting can help diagnose serious paediatric pathologies of the hip while also reducing unnecessary hip aspirations via clinical findings in the hope of reducing patient discomfort and costs.

3.4 | Overview of Ultrasound Methods

Over time, many methods of US have been developed using variable patient positioning, probe type, the implementation of dynamic manoeuvres, and data to be collected from these protocols (Tables 1 and 2). Some of these techniques include static methods designed by Graf, Morin, Suzuki, Terjesen, and Treguier. Others include dynamic manoeuvres such as those detailed by Harcke, Finnbogson, the Stress test, and Tosendahl. The Graf method has proven to be the gold standard of hip ultrasonography but not without its setbacks, including a need for thorough training and education in its methodology [6]. Though it has maintained a long-standing reputation for efficacy and accuracy, many other techniques have proven to be viable options; for example, the Morin technique boasts a sensitivity of 81.12%–89.47%, and the Suzuki and Stress tests reach 100% specificity [21]. Furthermore, the Harcke dynamic technique has shown a sensitivity of 18.21% but a specificity of 99.32% [21].

The Graf method has been the long-standing gold standard for US examination of the infantile hip. The Graf method has

TABLE 1 | Brief comparison of different techniques for ultrasonography of the paediatric hips for orthopaedic evaluation including uses and value (Sn = sensitivity, Sp = specificity).

Technique	Type	Measurements	Pros	Cons	Accuracy/Reliability
Graf	Static	α -angle, β -angle, femoral head cover (FHC)	Standardised examination technique, well-defined numeric hip typing system, does not require measurements from other techniques	Complex, need for thorough training and education [19, 20], recommend use of probe-guiding system to avoid tilting effects, intraobserver and interobserver variability	Sn = 93%, Sp = 97% [21]
Morin	Static	Estimates percentage of femoral head medial to lateral iliac margin (the iliac line) and consequently covered by bony acetabulum.	—	Requires additional measurements acquired by the Graf method	Sn = 81.12%–89.47% [18]
Suzuki	Static	One line drawn along anterior surface of pubic bones (P) and another line perpendicular to line P drawn from lateral margins of both pubic bones (E). Normal hip femoral head lies behind P and intersects medially with E.	Simultaneous examination of both hips, even in abduction brace or plaster cast, comparable diagnostic results to Graf method, well-standardised	Requires additional measurements acquired by the Graf method	Sp ~ 100% [18]
Terjesen	Static	FHC, lateral head distance (LHD)	Good level of reproducibility	Use of ossific nucleus as landmark in sonogram questionable in younger infants as it is not always located in the center of the cartilaginous femoral head (unreliable landmarks in young infants).	Sn = 14.41%, Sp = 99.74% [22, 23]
Treguier	Static	Pubofemoral distance (PFD)	Measures PFD in coronal plane including largest circumference of femoral head and most lateral aspect of pubis [18].	—	Sn = 63.55%, Sp = 62.22%, overall accuracy of 62.42% [24]
Harcke	Dynamic	Femoral head at rest and during stress examination [21]	Can identify extensive anatomy of the hip [25], easy to locate femoral head in acetabulum [26]	—	Sn = 18.21%, Sp = 99.32% [18]
Finnbogason	Dynamic	Oblique sagittal image of the hip including the anterior acetabular rim and femoral head and neck	Better assesses acetabular morphology of hip instability, less indeterminate results needing f/u than Graf's method [27], probe in holder allows hands-free evaluation [21]	—	Sn = 39.48%, Sp = 96.83%, overall accuracy = 83.73% [27, 28]

(Continues)

TABLE 1 | (Continued)

Technique	Type	Measurements	Pros	Cons	Accuracy/Reliability
The stress test	Dynamic	Used to identify an abnormal lax hip.	Assesses stability of the hip by observing abduction and adduction, looking for a change in the relationship between the femoral head and acetabulum [29]	—	Sp ~100% [18]
Rosendahl	Dynamic	Used to identify an abnormal elastic hip.	Highly accurate identification of dynamic paediatric hip dysplasia [30]	—	Sn = 50.78%, Sp = 97.51%, overall accuracy 89.49% [30]
Barlow manoeuvre	Dynamic	The relationship of the femoral head to the posterior acetabulum is assessed, posterior dislocation can be quantified numerically [25, 31].	Assesses relationship of femoral head to posterior acetabulum to determine instability or posterior dislocation [25, 31]	—	Sn = 26%, Sp = 84% [32]

TABLE 2 | Positioning and views for various tested methods of paediatric hip ultrasonography.

Technique	Patient positioning	Hip positioning	Transducer location	View achieved
Graf	Lateral decubitus maintained by cradle	Natural (15°–20° flexion) or 90° flexion then adducted and medially rotated	Parallel to lateral aspect of hips, moved anteroposterior	Coronal
Terjesen	Supine	Hip lightly flexed, examines iliac bone as a straight line parallel to edge of coronal mid-acetabular image	Probe linear or sector	Coronal
Suzuki	Supine	Abduction (flexion or extension)	Anterior groin approach, Probe transverse over lower pelvis in region of pubic bones	Coronal lateral view
Morin	Supine or lateral	Flexed	Place the transducer on the lateral side, rotating the superior edge posteriorly by 10°–15° so the hip is in a coronal view.	Coronal
Harcke	Supine	Flexed 90° with Barlow manoeuvre	Posterolateral, perpendicular to lateral aspect of hip, moved cephalo-caudad	Axial and coronal.
Stress test	Lateral	Dynamic stress test with hip in flexion.	The transducer is then placed on the lateral side of the hip, rotated posteriorly by 10°–15°, and kept parallel to the femoral shaft.	Coronal
Barlow manoeuvre	Supine	Adduction with applied posterior force	Transinguinal (anterior).	Axial

been shown to be not only accurate but effective in the detection of pathologic hips [9, 19]. While its efficiency and efficacy have been proven time and time again, it is also clear that education, training, and a skillful hand are necessary for appropriate implementation of this often complex technique [20, 26]. The following technique guide outlines the static (Classic Graf Method) assessment of the infantile hip while adding further development and instruction on the implementation of additional dynamic techniques promoted by Harcke et al.

3.5 | The Static Method (Graf)

The patient should be placed in the lateral position. Once placed in the lateral position, the patient's hip should be placed in a natural position (about 15°–20° flexion) or in 90° flexion, then adducted and medially rotated. In this position, a coronal view may be achieved. The appropriate probe is necessary, with a high resolution, 5–10 MHz linear transducer providing the best results [6].

To achieve the coronal view, the transducer is placed parallel to the lateral aspect of the infant's hip and then can be moved in the anteroposterior direction to locate the femoral head and acetabulum [33] (Figure 1). The landmarks demonstrated by the coronal view include the acetabular cartilage, the capsule, the greater trochanter, the cartilaginous femoral head, the ilium, the labrum, the ligamentum teres, the femoral metaphysis, and the triradiate cartilage [34]. Identification of the bony acetabular rim, the ischial bone in a horizontal arrangement, the triradiate cartilage, and the center of the labrum is crucial to orientation [35]. A transverse view may also be achieved by rotating the transducer 90° (Figure 2). The transverse plane demonstrates the axial view (Figure 3), with the femoral shaft anteriorly becoming the femoral head, which rests on the ischium. This position has also been described in dynamic methods allowing for the implementation of the Ortolani and Barlow manoeuvres to assess hip stability [34].

With the use of this static positioning, bony development and cartilaginous formation of the acetabular roof can be assessed via the alpha and beta angles; femoral head coverage may also be determined to differentiate between subluxation, dislocation,

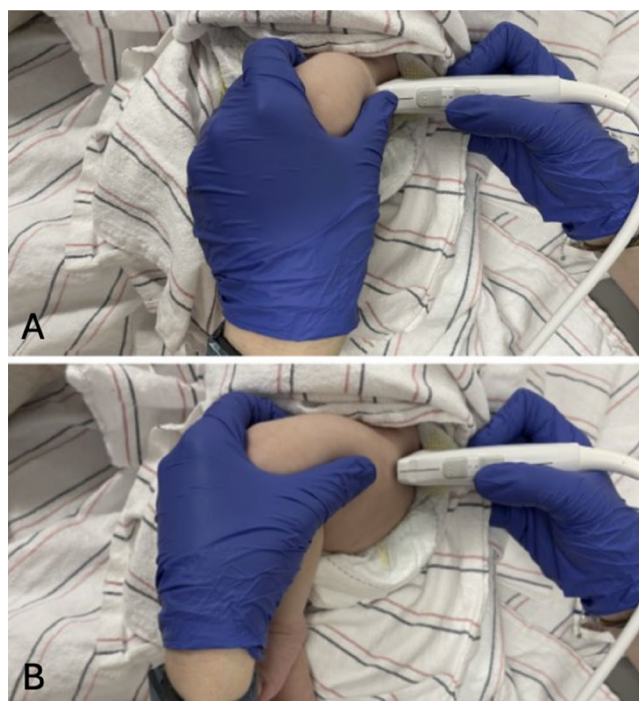


FIGURE 2 | Positioning for obtaining a transverse view of the Graf ultrasound with (A) 90° hip flexion and (B) 90° hip flexion and 30° adduction.

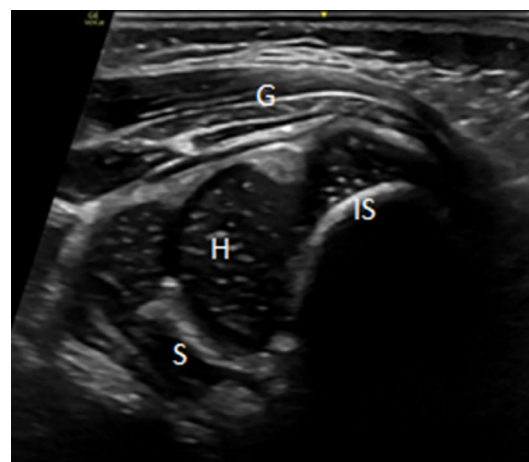


FIGURE 3 | Transverse view of the infant hip. (H; femoral head, IS; ischium, G; gluteal muscle, S; femoral shaft).

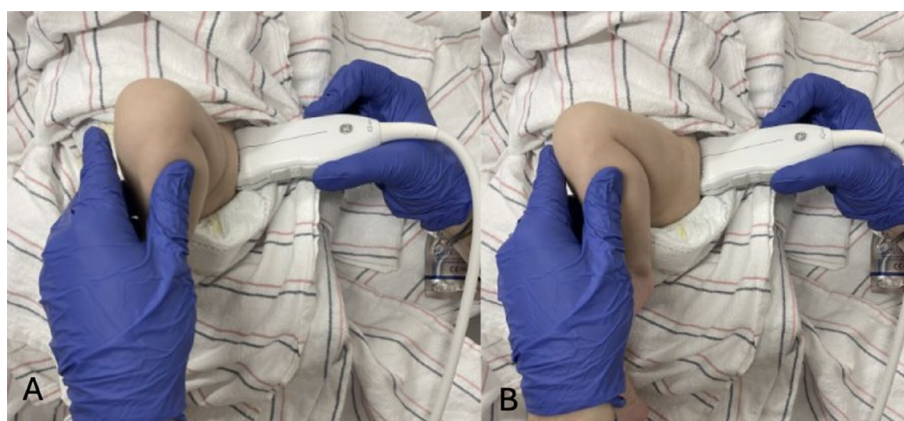


FIGURE 1 | Positioning for obtaining a standard Graf ultrasound with (A) 90° hip flexion and (B) 90° hip flexion and 30° adduction.

or unstable hips [36]. In order to determine the alpha and beta levels and femoral head coverage, first a line, Line A, is to be drawn down the axis of the ilium in the coronal view. Next, a line, Line B, is drawn along the bony acetabular roof medially to intersect with line A, thus forming the alpha angle (Figure 4). A final line, Line C, is drawn along the lateral edge of the acetabular labrum, thus forming the beta angle (Figure 4). In order to assess femoral head coverage, the diameter of the femoral head is measured at its two widest points; this is D. To determine FHC, the tangential distance (d) from Line A to the medial edge of the acetabular roof is measured, then used to calculate $d/D \times 100$ [37–39] (Figure 5).

It is suggested that up until the 6th month of life the alpha and beta angles and FHC will continuously change and then stabilise; thus, patient age is crucial when assessing these values. Riad et al. found that FHC progressed from 58% to 69%, alpha angle from 70° to 80° and beta angle from 52° to 42° in clinically stable hips from the age of 0 weeks to 12 weeks [29]. Furthermore, it has been proposed that Graf α -angle $< 60^\circ$ is abnormal, thus meaning that the osseous acetabulum is too shallow and

predisposes to femoral dislocation, while a Graf β -angle $> 55^\circ$ is also considered abnormal, and means the labrum is elevated due to femoral dislocation [35]. These values can be used to classify the dysplastic hip and further guide clinical management. Graf et al. classified the infantile hip into the following categories: Type I the mature hip, Type IIa the physiologically immature hip, Type IIb—delay of ossification, Type IIc—the critical hip, Type D the decentring hip, and finally both Type III and IV describe the fully dislocated hip [31].

3.6 | Dynamic Methods

Although Graf et al. described a static examination of the hip, dynamic procedures have been introduced in the coronal view to assess the position of the femoral head at rest and with passive abduction and adduction [25]. The implementation of the stress test can assess the stability of the hip by observing the hip while being abducted and adducted, looking for a change in the relationship between the femoral head and the acetabulum [40]. Dynamic methods can also be used to assess femoral head

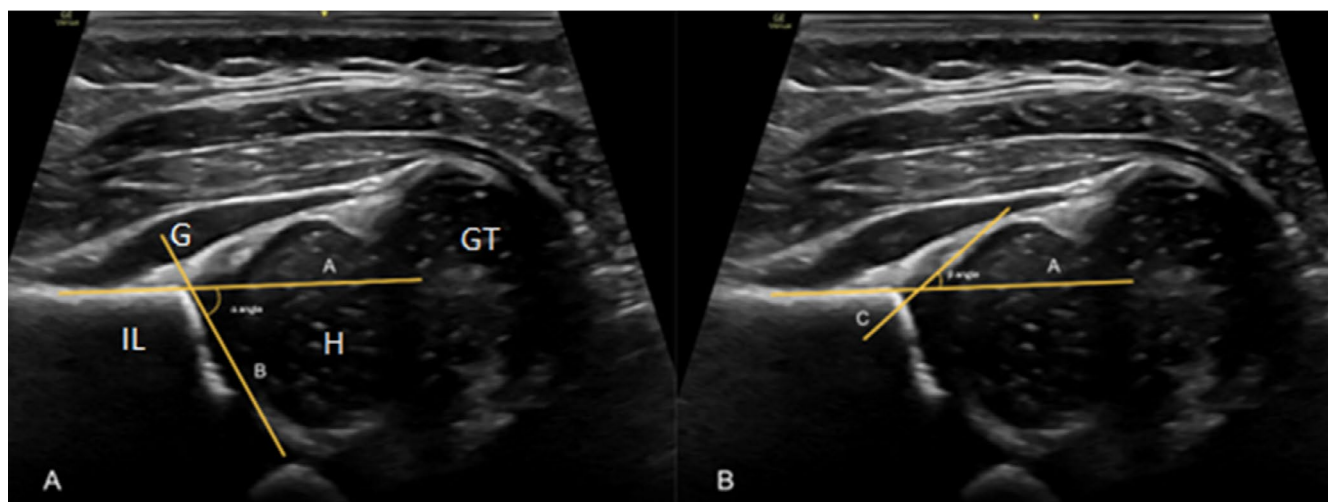


FIGURE 4 | Coronal view of the infant hip, showing measurements for the (A) alpha and (B) beta angles. (H; femoral head, GT; greater trochanter, IL; ilium, G; gluteal muscles).

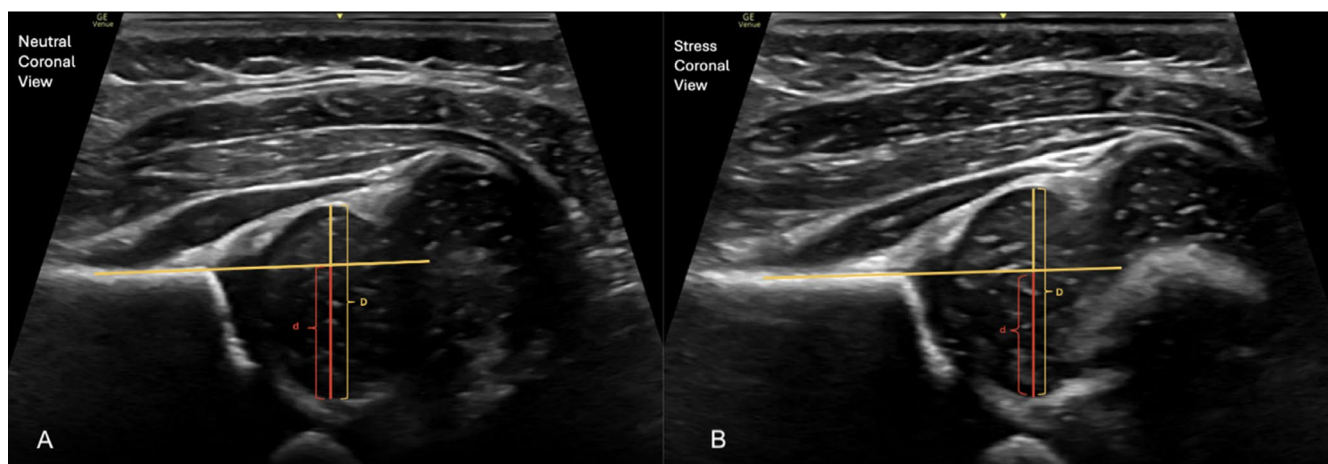


FIGURE 5 | Coronal view of the infant hip, showing measurements for femoral head coverage both (A) in a neutral alignment and (B) with stress.

coverage using the calculation, $FHC = (d/D) \times 100$, as previously described (Figure 4). With the use of ultrasound, the FHC can be dynamically assessed; values of $< 50\%$ are suggestive of instability [37, 38].

Additionally, the Barlow manoeuvre may be implemented to quantify movement of the hip within the acetabulum using a transinguinal positioning. With the probe in a transinguinal position (also described as anterior placement) an axial view is obtained at the level of the pubis, the hip is observed while being adducted, and a posterior force is applied. The relationship of the femoral head to the posterior acetabulum is assessed to determine instability; posterior dislocation can be quantified numerically [25, 41].

An additional view that may be obtained is the transverse flexion view, proposed by Harcke et al.; this is analogous to the axial view on CT imaging [26]. The implementation of multi-view sonography adds nuance to the concept of dynamic imaging. In this view, the anatomic features that can be identified include the acetabular cartilage, the gluteus muscles, the greater trochanter, the cartilaginous femoral head, the ischium, labrum, the ligamentum teres, femoral metaphysis, pubis, and triradiate cartilage [25] (Figure 5). The examination is performed with the hip flexed to 90° with the transducer in the posterolateral position perpendicular to the lateral aspect of the infant's hip (90° turn from the coronal position); movement of the transducer in a cephalo-caudal direction allows for easy location of the femoral head in the acetabulum [26] (Figure 2).

3.7 | Additional Radiographic Findings

It is clear ultrasound provides a compelling opportunity to describe and characterise infantile anatomy; however, its capacity to detect effusions further promotes its clinical value. Ultrasound has been shown to have the capacity to detect even minor fluid collections of 1–2 mL [40]. To distinguish between benign and malignant pathologies, one may look for echofree effusions about the hip joint indicating transient synovitis or acute haemorrhage, whereas non-echofree effusions suggest clotted hemorrhagic collections or septic arthritis [42].

4 | Discussion/Conclusion

This review is not without limitations. As with all review papers, an inherent bias by the author is impossible to eradicate, as well as the inability to ensure completeness of the review, as knowledge is constantly evolving. In order to address this, we defined our scope and aim clearly and completed a thorough and extensive literature search to our maximal capacity.

Although thoroughly investigated in the realm of developmental dysplasia of the hip, paediatric ultrasonography of the hip provides a safe, non-invasive, and accurate method for viewing the anatomy of the paediatric hip and thus providing diagnostic value in a wide variety of clinical pathologies [1, 22, 23, 43, 44].

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Conflicts of Interest

The authors declare no conflicts of interest.

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