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Review Article

Emerging Role of joint ultrasound imaging in the Diagnosis of juvenile idiopathic arthritis

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Abstract

Background: Juvenile idiopathic arthritis is the most common chronic rheumatic disease of childhood, and early detection of synovitis matters because joint damage can accumulate silently while examination still appears reassuring.

Objective: This review synthesizes evidence on grey-scale and power Doppler ultrasound for diagnosing and monitoring juvenile idiopathic arthritis, its performance against examination and MRI, and its role in treat-to-target management.

Methods: We synthesized cohort studies, diagnostic accuracy studies, OMERACT consensus definitions, and monitoring trials addressing ultrasound detection of synovitis and erosion in children with juvenile idiopathic arthritis.

Findings: Ultrasound detects subclinical synovitis in many clinically inactive joints, power Doppler signal predicts flare and progression, and ultrasound-guided treat-to-target strategies achieve higher remission rates than examination-guided care, though age-related vascularity requires pediatric-specific interpretation.

Conclusions: Musculoskeletal ultrasound is a feasible, validated adjunct to clinical examination for juvenile idiopathic arthritis, and routine use supported by standardized pediatric scoring is likely to improve early detection and long-term joint outcomes.

Keywords: juvenile idiopathic arthritis; musculoskeletal ultrasound; power Doppler; synovitis; pediatric rheumatology

1. Introduction

Juvenile idiopathic arthritis (JIA) is the umbrella term for chronic childhood arthritides persisting more than six weeks with onset before age sixteen and no identifiable alternative cause, and it remains the most common chronic rheumatic disease of childhood, affecting roughly one in a thousand children [1]. The seven ILAR categories share a common final pathway of synovial inflammation that, left undetected, drives cartilage loss, bone erosion, and growth disturbance [2]. Clinical examination, the traditional cornerstone of activity assessment, depends on eliciting swelling, warmth, and restricted motion, all difficult to judge reliably in a young child who may not cooperate fully, has thicker subcutaneous fat overlying small joints, and can mask pain behaviorally in ways that confound even experienced pediatric rheumatologists [3].

This diagnostic gap has driven rapid adoption of musculoskeletal ultrasound. Grey-scale ultrasound directly visualizes synovial hypertrophy and effusion, while power Doppler superimposes a map of blood flow that correlates with active inflammation, together offering a radiation-free, inexpensive, repeatable bedside method for detecting arthritis that examination alone misses [4]. Adult rheumatology adopted ultrasound well before pediatric practice caught up, and much early pediatric work simply extrapolated adult grading systems onto a population with different joint anatomy, ongoing epiphyseal growth, and physiological vascularity that can mimic pathological Doppler signal if not properly understood [5]. This review synthesizes what the literature has established about ultrasound in diagnosing and monitoring JIA: its performance against examination and MRI, standardized pediatric definitions and scoring systems, its application across major joint groups, and its emerging place in treat-to-target management.

Synovitis in JIA begins with infiltration of the synovial membrane by activated T cells, macrophages, and dendritic cells, producing lining hyperplasia and

neovascularization that sustains the inflammatory infiltrate and, if unchecked, releases proteolytic enzymes that degrade adjacent cartilage and bone [2]. This process is frequently asymptomatic in its early stages, particularly in young children who compensate behaviorally for discomfort, so a joint judged clinically quiet can nonetheless harbor active synovial inflammation with ongoing tissue damage [6]. Because the destructive process precedes overt clinical signs, a method capable of visualizing synovial thickening and its vascular activity before swelling becomes obvious offers the possibility of intervening earlier, before structural damage accrues. Grey-scale ultrasound depicts synovial hypertrophy as a thickened, hypoechoic, non-displaceable, minimally compressible band, distinguishable from the anechoic, displaceable appearance of simple effusion, though the two often coexist and grey-scale alone cannot reliably distinguish active from chronic fibrotic thickening [7]. Power Doppler signal intensity tracks with synovial vascular density and inflammatory infiltration on histology, providing a biological basis for using it as a semiquantitative proxy for activity, and because both components can be assessed without sedation or radiation, ultrasound occupies a niche that MRI, despite superior soft-tissue resolution, cannot match for repeatable outpatient monitoring [8,9].

2. Grey-scale and power Doppler technique and OMERACT definitions

The greatest obstacle to comparing pediatric ultrasound studies before the 2010s was the absence of standardized definitions and scoring conventions, which the OMERACT ultrasound group addressed through a pediatric-specific consensus process. Collado and colleagues developed age-adjusted, consensus-based ultrasound definitions for synovitis in the joints most commonly affected in children, explicitly accounting for the fact that normal synovial thickness and vascularity differ from adult values and change as a child grows [4]. A subsequent OMERACT task force validated a semiquantitative score combining

grey-scale hypertrophy grade and power Doppler grade, shown to discriminate active from inactive joints with acceptable inter-observer reliability across centers [10].

Table 1: OMERACT consensus grey-scale and power Doppler ultrasound definitions for pediatric synovitis, summarized by principal joint region assessed in juvenile idiopathic arthritis [4,10,11].			
Joint region	Grey-scale finding	Power Doppler correlate	Interpretive note
Knee (suprapatellar recess)	Non-displaceable hypoechoic synovial thickening	Intracapsular flow signal within thickened synovium	Most reliable site; primary validation joint for scoring systems
Wrist (radiocarpal/midcarpal)	Compartment-specific synovial hypertrophy	Flow signal often compartment-restricted	Multicompartmental scan required to avoid underestimation
Ankle (tibiotalar)	Anterior recess synovial thickening	Peri-synovial flow signal	Good visualization; fewer normative data than knee
Hip	Effusion and capsular distension	Flow signal frequently underdetected	Limited acoustic window; MRI preferred when ambiguous

Technical acquisition matters as much as definitional consensus: Jousse-Joulin and colleagues found inter-observer agreement improves substantially with a standardized multiplanar protocol rather than a single-view assessment, and is highest for superficial joints such as the knee and wrist and lowest for the hip [11]. Doppler gain and pulse-repetition frequency optimized for adult tissue will either miss genuine low-flow pediatric synovitis or generate spurious artifact, and pediatric protocols now specify settings validated against known-normal joints [5]. Zhao and colleagues proposed a simplified eight-joint protocol to shorten scanning time while retaining most diagnostic yield, a pragmatic step toward wider adoption [12].

3. Ultrasound versus clinical examination: detecting subclinical synovitis

The most consistently reproduced finding is that a meaningful proportion of joints judged clinically inactive show grey-scale hypertrophy, power Doppler signal, or

both when scanned. Magni-Manzoni and colleagues found subclinical synovitis on ultrasound in a substantial subset of joints considered clinically quiet, with children showing such findings at clinical remission flaring more often than those with a fully normal scan [6]. Rebollo-Polo and colleagues confirmed this pattern, with power Doppler positivity carrying particular weight for predicting flare within following months [13]. Weiss and colleagues showed that children who discontinued medication based on clinically inactive disease but had residual ultrasound synovitis at discontinuation relapsed earlier and more often than those with concordant clinical-and-ultrasound remission [14]. De Lucia and colleagues, focusing on the wrist, found ultrasound-detected synovitis in a considerable share of wrists rated clinically normal, reinforcing that certain sites are particularly prone to examination-ultrasound discordance [15]. Together these studies establish that examination alone systematically underestimates true activity, with measurable prognostic consequences.

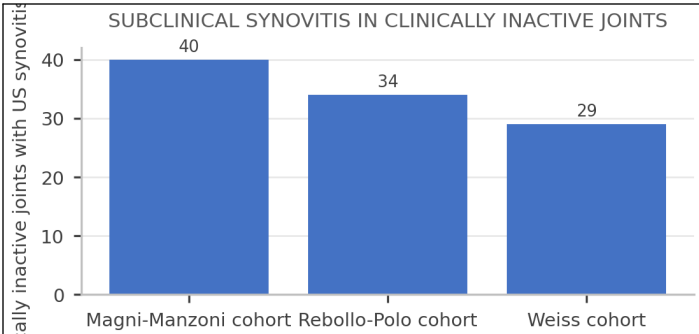


Figure 1: Proportion of clinically inactive joints found to harbor grey-scale or power Doppler synovitis on ultrasound across three pediatric cohorts, illustrating the consistent gap between clinical examination and sonographic assessment of disease activity [6,13,14].

4. Ultrasound versus magnetic resonance imaging

MRI remains the reference standard for early bone marrow edema and cartilage damage, but its cost, sedation requirement, and limited availability make it impractical for frequent monitoring [16]. Filippou and colleagues, comparing ultrasound against contrast-enhanced MRI, found good agreement for

synovial hypertrophy and effusion in accessible joints such as the knee and ankle, with Doppler signal correlating reasonably with synovial contrast enhancement, though ultrasound was less sensitive for bone marrow edema and osteochondral lesions [17]. Malattia and colleagues, using whole-body MRI as comparator, found ultrasound underperforms for subclinical disease in the hip and deep wrist and ankle compartments, where overlying tissue limits penetration [9]. Nusman and colleagues concluded ultrasound and MRI are complementary rather than competing, with ultrasound favored for frequent accessible-joint monitoring and MRI reserved for baseline staging, discordant joints, and the hip and sacroiliac joints [18].

Table 2: Relative performance of ultrasound compared with magnetic resonance imaging for detecting synovitis, by joint group, drawn from direct comparison and imaging-review studies [17,9,16,18].			
Joint group	Ultrasound performance vs MRI	Principal limitation	Recommended role
Knee / ankle	Good agreement for synovial hypertrophy and effusion	Cannot assess bone marrow edema	First-line monitoring modality
Wrist	Moderate agreement; compartment-dependent	Deep compartments partly inaccessible	Ultrasound monitoring, MRI for discordant cases
Hip	Reduced sensitivity relative to MRI	Deep joint, limited acoustic window	MRI preferred for baseline staging
Sacroiliac joint	Not reliably assessable	Acoustic inaccessibility	MRI required

5. Pediatric-specific considerations, joint groups, and procedural applications

A recurring source of error in early practice was applying adult normal-joint values to children, whose joints show physiological features mistakable for pathology. Karmazyn and colleagues documented measurable physiological fluid and periarticular vascularity around the growing epiphysis in healthy children's hips and knees [19], and Laurell and colleagues established age-stratified normal ranges for knee synovial thickness, showing that a

single adult-derived threshold will systematically misclassify younger children [20]. Epiphyseal hyaline cartilage is intrinsically more vascular than mature cartilage and can generate peripheral Doppler signal resembling synovial hyperemia, most pronounced in the youngest children; Nieto-Gonzalez and colleagues showed this physiological signal follows a characteristic peripheral, symmetric pattern distinct from the central, irregular pattern of true synovitis, and proposed training criteria to reduce false-positive interpretation [21].

Joint-specific performance varies: the knee, most frequently affected and most acoustically favorable, has served as the primary validation site for scoring systems [12], while the compartmentalized wrist requires a full multicompartmental scan to avoid underestimating burden [15]. The hip performs least well relative to MRI given its depth and limited acoustic window; Breton and colleagues found ultrasound underdetected hip synovitis relative to MRI, particularly in children with higher body mass index [22]. Tenosynovitis, an increasingly recognized and sometimes isolated JIA manifestation especially at the wrist and ankle, is well visualized as thickened hypervascular tissue around the tendon sheath and warrants inclusion as a distinct scanning target [23]. Ankle and small hand and foot joints are generally well visualized, though normative data remain less extensive than for the knee and wrist [24]. Ultrasound guidance has also become a standard adjunct to intra-articular corticosteroid injection, allowing more precise needle placement than landmark technique in compartmentalized joints; Ting and colleagues found ultrasound guidance associated with lower early relapse in technically difficult joints, with comparable performance to landmark technique for straightforward joints like the knee [25], and post-injection scanning is increasingly used to confirm resolution of hypertrophy and Doppler signal as an objective efficacy endpoint [26].

6. Ultrasound-guided treat-to-target strategies and remission monitoring

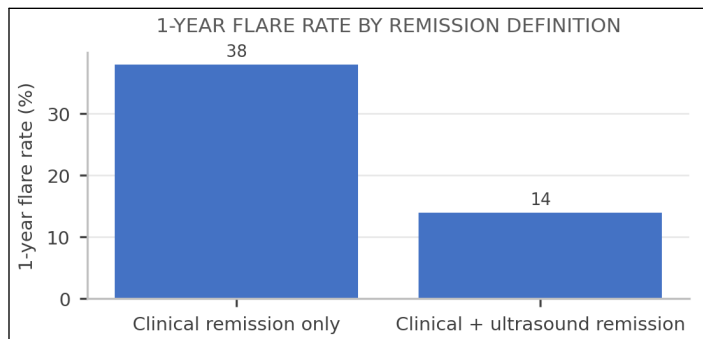


Figure 2: One-year flare rate among children classified as being in remission by clinical criteria alone versus combined clinical-and-ultrasound remission, showing lower flare risk when residual subclinical synovitis is excluded before treatment is tapered [27,28,30].

The prognostic significance of subclinical synovitis has motivated trials incorporating ultrasound directly into treatment targets. Magni-Manzoni and colleagues proposed a composite ultrasound-clinical remission definition requiring both clinically inactive disease and absent grey-scale and Doppler synovitis, arguing it better predicts sustained drug-free remission than clinical criteria alone [27]. Prospective cohorts applying this framework generally find that children achieving combined remission maintain disease control and taper medication more successfully than those defined by clinical criteria alone, supporting imaging in the treat-to-target paradigm already established for adult inflammatory arthritis [28]. This is consistent with international treat-to-target recommendations for JIA, which endorse structured reassessment to guide treatment escalation and de-escalation and have suggested eventual incorporation of objective imaging remission alongside clinical composite scores [29]. Roth and colleagues found serial power Doppler scores track with subsequent flare risk, with persistent or increasing signal across visits carrying substantially higher flare rates, supporting serial ultrasound for anticipating trajectory rather than confirming a single timepoint [30]. Muller and colleagues documented a marked rise in routine ultrasound use over the preceding decade alongside continued variability in scanning protocols, underscoring that standardization, while advanced, has not achieved

uniform implementation [31].

7. Limitations and future directions

Operator dependence remains the most cited concern: inter-observer reliability, generally good for superficial joints under standardized protocols, degrades for less accessible joints and less experienced operators [11]. Detecting low-velocity flow requires high-frequency probes and Doppler settings not universally available outside tertiary centers, constraining implementation in resource-limited settings [24]. Standardization, though greatly advanced by OMERACT definitions and scoring, has not achieved the uniform adoption seen with radiographic systems, and work continues to refine normal ranges, validate simplified protocols, and establish minimally important change thresholds for serial Doppler scores [12,10]. Emerging directions include contrast-enhanced ultrasound, shear-wave elastography for synovial fibrosis, and machine-learning-assisted interpretation to reduce operator dependence, though none yet matches the validation base of standard grey-scale and power Doppler assessment [5].

8. Conclusion

Two decades of evidence have established musculoskeletal ultrasound as a genuinely useful, radiation-free adjunct to clinical examination for JIA. It reliably detects subclinical synovitis that examination misses, its power Doppler component carries prognostic weight for subsequent flare, and pediatric-specific definitions and reference ranges have substantially reduced the risk of misinterpreting normal growth-related vascularity as disease [4,10,5]. Performance is not uniform across joints, remaining strongest for the knee and weakest for the hip relative to MRI, which continues to hold an essential complementary role for deep joints and structural staging [9,18]. Ultrasound-guided treat-to-target strategies incorporating imaging remission appear to achieve more durable disease control than clinical criteria alone, and ultrasound guidance has

become a valuable adjunct to intra-articular injection in technically difficult joints [27,25]. As training, machine access, and protocol standardization continue to expand, incorporation of routine ultrasound assessment into pediatric rheumatology practice is likely to improve early detection, refine remission definitions, and protect the long-term joint outcomes of children living with this disease.

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