International Journal of General Medicine

Dovepress
Taylor & Francis Group

Open Access Full Text Article

REVIEW

Advances in the Application of Musculoskeletal Ultrasound in the Diagnosis of Rheumatoid Arthritis: A Review

Hongping Zhang

Department of Ultrasound, The People's Hospital of Jianyang City, Jianyang, Sichuan, People's Republic of China

Correspondence: Hongping Zhang, Email zhp000zhp123@163.com

Abstract: Rheumatoid arthritis (RA) is a chronic autoimmune disorder that primarily targets the joints, causing persistent inflammation, progressive joint destruction, and functional disability. Early and accurate diagnosis is essential for initiating timely treatment and improving patient outcomes. Musculoskeletal ultrasound (MSUS), a non-invasive and real-time imaging technique, has attracted considerable interest for its high-resolution visualization and ability to assess joints dynamically. This narrative review synthesizes current literature on the role of MSUS in the diagnosis of RA, with particular emphasis on its unique value in the early detection of subclinical synovitis and in supporting the diagnosis of seronegative RA, where conventional serological markers are absent. MSUS enables sensitive detection of synovial hypertrophy, tenosynovitis, joint effusion, increased vascularity on power Doppler imaging, and early bone erosions, facilitating timely recognition of inflammatory activity and structural damage. Despite these advantages, limitations such as operator dependence and variability in standardization remain. Recent advances—including consensus-based EULAR-OMERACT definitions and scoring systems, standardised scanning protocols, and emerging artificial intelligence applications—have broadened the clinical value of MSUS, indicating promising opportunities for its incorporation into routine RA management. This article aims to synthesize existing evidence, address ongoing challenges, and explore future directions to further enhance the diagnostic and monitoring capabilities of MSUS in patients with RA.

Keywords: rheumatoid arthritis, musculoskeletal ultrasound, diagnosis, inflammation assessment, structural damage

Introduction

RA is a systemic autoimmune disorder characterized primarily by chronic synovial inflammation, which leads to progressive joint destruction, functional impairment, and diminished quality of life. Synovitis, most commonly involving small joints of the hands and feet, is the hallmark pathological feature of RA, presenting clinically with joint swelling, pain, and stiffness. Early diagnosis and prompt initiation of targeted therapy are critical to preventing irreversible structural damage and improving long-term patient outcomes.[1,2] Because a substantial proportion of early structural changes occurs before radiographic abnormalities become apparent, imaging modalities capable of detecting subclinical inflammation and incipient erosive changes are of pivotal clinical importance.

Traditional diagnostic evaluation relies on a combination of clinical examination, laboratory testing such as rheumatoid factor (RF) and anti-citrullinated protein antibodies (ACPA), and conventional radiography. However, clinical assessment alone may fail to detect subclinical synovitis or early inflammatory changes, particularly in seronegative individuals or those with atypical presentations. Laboratory markers, while informative, lack sufficient sensitivity and specificity when used in isolation. Conventional radiography is limited by its inability to visualize soft-tissue inflammation or early erosive changes, typically revealing structural damage only in more advanced disease.[1–3] This gap between clinical or serological suspicion and radiographically detectable damage defines the imaging window that MSUS is uniquely positioned to fill.

https://doi.org/10.2147/IJGM.S588398
Received: 12 December 2025
Accepted: 28 May 2026
Published: 5 June 2026

MSUS has become an important imaging modality in the evaluation of inflammatory arthritis, including RA. It is non-invasive, radiation-free, widely available, and capable of providing real-time, dynamic visualization of joints and periarticular soft tissues. MSUS can sensitively detect synovial hypertrophy, joint effusions, tenosynovitis, bone erosions, and increased vascularity on power Doppler imaging, which reflects active inflammation.[4–6] In early RA, MSUS is particularly valuable because it can identify subclinical synovitis and tenosynovitis that may be missed on physical examination, thereby improving diagnostic accuracy and facilitating earlier therapeutic intervention.[7,8] The ability of MSUS to demonstrate microvascular blood flow within the synovium—whether through power Doppler or advanced methods such as superb microvascular imaging—further strengthens its role in assessing disease activity and monitoring treatment response.[9]

Advances in ultrasound technology, including the development of high-frequency probes and the adoption of standardized scoring systems, have enhanced the reliability and reproducibility of MSUS assessments. MSUS features such as synovial thickness and power Doppler signal correlate with laboratory measures of inflammation (eg, ESR, CRP, RF, ACPA) as well as clinical disease activity indices, supporting its utility as an objective marker of joint inflammation.[10,11] Moreover, MSUS has demonstrated sensitivity and specificity comparable to contrast-enhanced magnetic resonance imaging (MRI) for detecting subclinical synovitis and tenosynovitis, while offering advantages in cost, accessibility, and feasibility in routine outpatient care.[4]

The applications of MSUS extend beyond diagnosis to include prognostication and treatment monitoring. Ultrasound-detected synovitis and tenosynovitis are associated with an increased risk of radiographic progression and disease relapse, even in patients who meet conventional criteria for clinical remission. Incorporating MSUS into a treat-to-target strategy may allow for more precise identification of residual inflammation.[12,13] MSUS also supports differential diagnosis by distinguishing RA from other inflammatory arthritides and mimicking conditions such as gout, psoriatic arthritis, and osteoarthritis through characterization of distinct patterns of joint and soft-tissue involvement.[14,15] Notably, MSUS is especially helpful in evaluating seronegative RA, in which traditional serological markers are absent but ultrasound evidence of synovitis and bone erosion can substantiate the diagnosis.[3]

Despite these advantages, MSUS has limitations, including operator dependence and variability in scanning protocols. Ongoing efforts to develop standardized acquisition methods and scoring systems have improved its clinical utility and interobserver reliability.[6] Emerging research is also exploring the integration of machine learning with MSUS data to enhance diagnostic precision and predict disease progression.[8] The increasing availability of portable ultrasound devices is further expanding MSUS accessibility, supporting early detection of RA across diverse healthcare settings.[16]

In summary, MSUS addresses many of the sensitivity and specificity limitations of traditional diagnostic methods by directly visualising synovial and periarticular inflammation as well as early structural changes. The objective of this narrative review is to synthesise recent advances (2019–2025) in the application of MSUS to the diagnosis of RA, with three specific aims: (i) to summarise MSUS technical standards and consensus-based scoring systems (EULAR-OMERACT); (ii) to critically appraise the diagnostic performance of MSUS for synovitis, tenosynovitis, and bone erosion in comparison with radiography and MRI, including its limitations; and (iii) to evaluate emerging technological innovations—particularly artificial intelligence—that may shape the future role of MSUS in RA management.

Methods

This is a narrative review of the literature on musculoskeletal ultrasound in the diagnosis of rheumatoid arthritis. A literature search was conducted in the PubMed database using combinations of the following keywords: “rheumatoid arthritis”, “musculoskeletal ultrasound”, “ultrasonography”, “synovitis”, “tenosynovitis”, “power Doppler”, “bone erosion”, “seronegative rheumatoid arthritis”, “EULAR”, “OMERACT”, and “artificial intelligence”. The search was restricted to English-language articles published between January 2019 and September 2025. Selected seminal references published outside this window were retained when considered foundational to the field (for example, the 2017 EULAR standardised procedures, OMERACT definitions of ultrasound pathology, and the ARCTIC randomised controlled trial). Inclusion criteria comprised original research studies, systematic reviews, meta-analyses, and authoritative clinical guidelines focusing on the application of MSUS to RA diagnosis, disease activity assessment, treatment monitoring, or differential diagnosis. Case reports were generally excluded unless they illustrated specific diagnostic utility. References cited within included articles were also

screened for additional relevant publications. This review does not follow a formal systematic methodology such as PRISMA and is not intended as a quantitative meta-analysis.

Pathophysiology and Diagnostic Needs of Rheumatoid Arthritis

Pathological Mechanisms and Clinical Manifestations of RA

RA is a chronic systemic autoimmune disease characterized primarily by persistent synovial inflammation, which leads to synovial hyperplasia, neovascularization, and infiltration of inflammatory cells into the joint lining. This synovitis represents the hallmark pathological feature of RA and is the principal driver of progressive joint destruction.[17,18] From an imaging standpoint, three pathological hallmarks are particularly relevant to MSUS detection: synovial hypertrophy with increased vascularity (detectable by grey-scale and power Doppler ultrasound), tenosynovitis (expansion of the tendon sheath with hypoechoic tissue and Doppler signal), and early marginal bone erosions (cortical discontinuities visualisable at the metacarpophalangeal, metatarsophalangeal, and other small joints).[17,19,20] Clinically, early RA typically presents as symmetrical polyarthritis involving small joints, particularly the metacarpophalangeal and proximal interphalangeal joints, with joint swelling, pain, and prolonged morning stiffness. Timely recognition and early therapeutic intervention are essential to prevent irreversible joint damage and optimize long-term outcomes.[17,18,21]

Limitations of Traditional Diagnostic Methods

Traditional diagnostic approaches for RA rely heavily on laboratory testing and imaging, yet each has notable limitations. Serological markers such as RF and ACPA provide reasonable sensitivity and specificity, but their presence does not consistently correlate with disease activity or accurately reflect underlying joint inflammation.[22,23] Moreover, a proportion of patients with seronegative RA lack these autoantibodies entirely, further complicating diagnosis.[3] Conventional radiography detects structural changes such as bone erosions and joint space narrowing, but these are typically late findings, making X-rays insensitive to early soft-tissue abnormalities including synovitis and tenosynovitis.[17,24] Magnetic resonance imaging (MRI) offers superior visualization of soft tissues, enabling detection of early synovial inflammation and bone marrow oedema before radiographic damage becomes apparent.[17] However, the diagnostic performance of MRI depends heavily on the imaging protocol. Non-contrast MRI using T2-weighted or STIR sequences provides only moderate reliability for assessing synovitis and tenosynovitis because joint effusion and proliferative synovium cannot always be reliably distinguished. Contrast-enhanced T1-weighted imaging with gadolinium is the reference standard, as it enables differentiation of enhancing inflammatory synovium from non-enhancing joint fluid and conforms to the OMERACT definition of MRI synovitis. Nonetheless, contrast-enhanced MRI is limited by its substantially higher cost, prolonged acquisition time, restricted accessibility, and the potential risks associated with gadolinium administration in patients with impaired renal function.[25] Collectively, these constraints highlight the need for diagnostic tools that are more sensitive, more accessible, and free of contrast-related risks for the identification of early inflammatory changes and longitudinal disease monitoring.

Diagnostic Needs Driving the Development of Musculoskeletal Ultrasound

The limitations of traditional diagnostic techniques have accelerated the development and clinical adoption of MSUS in RA. MSUS provides dynamic, real-time visualization of synovial inflammation, joint effusions, tenosynovitis, and early bone erosions with high sensitivity, often outperforming clinical examination and conventional radiography in detecting subclinical disease activity.[3,26] In particular, the combination of non-invasiveness, absence of ionising radiation or contrast agents, bedside availability, and capacity for repeated assessment makes MSUS uniquely suited to longitudinal monitoring and point-of-care evaluation in the diagnostic and follow-up pathway of RA.[26,27]

MSUS Technology and Diagnostic Capabilities

Musculoskeletal Ultrasound Technology and Operational Standards

MSUS has become an indispensable tool in the diagnostic evaluation of RA due to its high-resolution imaging capabilities and non-invasive nature. Optimal visualization of superficial musculoskeletal structures such as synovium, tendons, and the small joints commonly affected in RA requires the use of a high-frequency linear probe, typically ranging from 10 to 18 MHz. The imaging workflow begins with grey-scale (GS) ultrasound to assess structural abnormalities, including synovial hypertrophy,

joint effusion, and bone surface irregularities. Power Doppler (PD) ultrasound is then applied to detect and quantify synovial vascularity, providing functional insight into active inflammation. The integration of grey-scale and Doppler imaging enables a comprehensive assessment of both morphological and haemodynamic aspects of RA-related joint pathology.

Standardised scanning procedures are essential to ensure reproducibility. The 2017 EULAR guidelines on standardised ultrasound imaging in rheumatology provide a consensus-based, practical framework for probe positioning, scanning planes, and acquisition of key joint regions, and remain the most widely adopted reference in clinical practice and multicentre research.[28]

Regarding joint selection for early RA, the most frequently recommended targets include bilateral wrists (radiocarpal and midcarpal joints), the second to fifth metacarpophalangeal (MCP) joints, the proximal interphalangeal (PIP) joints, and the second and fifth metatarsophalangeal (MTP) joints, as these sites are most commonly affected at disease onset. The German 7-joint ultrasound score (US7) developed by Backhaus et al—which examines the clinically dominant wrist, MCP 2–3, PIP 2–3, and MTP 2 and 5 for synovitis, tenosynovitis/paratenonitis, and erosions—has been widely validated as a feasible composite scoring system combining inflammatory and destructive lesions in one framework.[29] Larger scanning protocols (eg, 12-joint or 22-joint bilateral hand and wrist assessments) may be used when comprehensive evaluation is warranted, for example in clinical trials or detailed baseline assessments.

The OMERACT Ultrasound Working Group has provided consensus definitions of the elementary ultrasound lesions in RA, including synovitis (encompassing both synovial hypertrophy and power Doppler signal), tenosynovitis, tendon damage, enthesitis, and bone erosion; these definitions have been iteratively validated and remain the internationally accepted terminology for RA ultrasound.[30] Building on these definitions, the EULAR-OMERACT ultrasound taskforce developed and validated a standardised, consensus-based scoring system for RA synovitis in which synovial hypertrophy (SH) and power Doppler (PD) are each graded 0–3 and combined into a composite grade.[31,32] The grading criteria are summarised in Table 1.

Interobserver and intraobserver reliability are critical performance metrics for MSUS. Reliability studies of experienced rheumatologists have shown moderate-to-substantial agreement overall, with reliability improving when standardised scan acquisition is used. In the EULAR "Train the Trainers" exercise, Scheel et al reported an overall κ of 0.76 across all examined joints, with higher agreement for knee (κ = 1.0) and shoulder (κ = 0.76), intermediate agreement for hand/finger (κ = 0.59), and lower agreement for ankle/toe joints (κ = 0.28).[33] The EULAR "Teach the Teachers" exercise reported overall agreement of 91% for joint effusion/synovitis and 83% for PD signal, with κ values of 0.61 for wrist/hand and 0.60 for knee.[34] For the EULAR-OMERACT combined score in MCP joints using standardised scanning, Terslev et al reported interobserver κ values of 0.87 for SH, 0.79 for PD, and 0.86 for the combined score.[32] Comparable reliability has been demonstrated for the US7 score, supporting its use in multicentre settings.[35] These data underscore that, with adequate training and standardised acquisition, MSUS can be a reliable outcome measurement instrument in both clinical practice and research.

Detection Capability of Musculoskeletal Ultrasound for Synovitis

MSUS demonstrates high diagnostic performance for detecting synovitis, establishing it as a pivotal imaging modality in the early diagnosis of RA. MSUS enables direct visualization of synovial membrane thickening, joint effusion, and increased synovial vascularity—key features of active synovitis. A systematic review and meta-analysis by Takase-Minegishi et al

Table 1 EULAR-OMERACT Combined Scoring System for Ultrasound Synovitis in RA[31,32]

Grade	Grey-Scale (Synovial Hypertrophy, SH)	Combined Score (GS + PD)
0 (Normal)	No synovial hypertrophy	GS = 0 and PD = 0
1 (Minimal)	Minimal SH, not extending beyond the joint line	GS = 1 with PD ≤ 1
2 (Moderate)	Moderate SH extending beyond the joint line, without bony surface distension	GS = 2 with PD ≤ 2, or GS = 1 with PD = 2
3 (Severe)	Severe SH with bony surface distension	GS = 3 with PD ≤ 3, or GS = 1 or 2 with PD = 3

Note: Adapted from D'Agostino et al 2017 and Terslev et al 2017.[31,32]
Abbreviations: GS, grey-scale; PD, power Doppler.

evaluating the diagnostic test accuracy of ultrasound for synovitis against MRI as the reference standard reported a pooled area under the curve (AUC) of 0.91 and a diagnostic odds ratio (DOR) of 28 for MCP joints, and an AUC of 0.81 with a DOR of 11.6 for wrist joints, with power Doppler showing higher accuracy than grey-scale alone.[36] In a direct comparison of ultrasound against contrast-enhanced MRI in 450 small joints from 75 patients, the two modalities were statistically equivalent for detecting subclinical synovitis and tenosynovitis (ultrasound sensitivity 0.795 vs contrast-enhanced MRI 0.855; $p = 0.055$).[4] PD signal intensity has been shown to predict disease activity and structural progression, with higher grades of synovial vascularity associated with an increased risk of radiographic damage and clinical relapse.[12,37] MSUS also effectively identifies subclinical synovitis in patients with seropositive arthralgia and undifferentiated arthritis, enabling early recognition of individuals at heightened risk of progression to RA.[38,39]

Several important caveats should be acknowledged when interpreting power Doppler findings. First, physiological synovial blood flow can be detected in healthy joints with modern high-sensitivity ultrasound machines, so Doppler positivity is not inherently pathological and pathological flow must be differentiated from normal perfusion.[40] Second, the detectability of low-velocity synovial flow varies substantially between ultrasound systems; using a microvessel flow phantom, Torp-Pedersen et al demonstrated that only a minority of commercial machines could reliably detect the very low flows characteristic of inflamed synovium, such that the same patient may appear PD-positive on one machine and PD-negative on another.[41] Third, Doppler signal is highly sensitive to technical parameters—pulse repetition frequency, wall filter, Doppler frequency, and gain settings—as well as to the transducer pressure applied during scanning. A negative PD signal therefore does not exclude active synovitis, and PD intensity does not strictly correlate with the histological extent of inflammation. Fourth, most correlations between PD findings and outcomes reported in the literature are associations rather than validated predictive biomarkers; although PD positivity is associated with flare and radiographic progression, its independent predictive value in the context of contemporary treat-to-target strategies remains an area of active investigation.[12,37] Taken together, these considerations argue for cautious, context-specific interpretation of Doppler findings rather than application as stand-alone diagnostic criteria.

Assessment of Bone Erosion and Soft Tissue Damage by Musculoskeletal Ultrasound

MSUS offers detailed visualization of bone surface integrity and periarticular soft tissue structures, facilitating the early detection and monitoring of bone erosions and soft tissue damage in RA. Ultrasound demonstrably outperforms conventional radiography for the detection of early erosions in small joints, particularly at the MCP and MTP joints, with studies consistently demonstrating that ultrasound detects a substantially higher number of erosions than plain radiography in early RA cohorts.[3,15] Compared with MRI, MSUS shows good agreement for cortical erosions accessible from the joint surface but may miss deeper intraosseous lesions; MRI therefore remains more sensitive for global erosion burden, whereas ultrasound offers superior real-time, radiation-free, and cost-effective longitudinal assessment.[25] Semi-quantitative scoring of bone erosions via ultrasound correlates with disease severity and serological markers, including ACPA positivity, a strong predictor of erosive progression.[42] Gray-scale and power Doppler imaging of tendon sheaths and surrounding soft tissues provides valuable information on tenosynovitis and prognosis.[3,43] Ultrasound also differentiates inflammatory from degenerative soft tissue changes, supporting more accurate differential diagnosis.

Clinical Value and Challenges of Musculoskeletal Ultrasound in the Diagnosis of Rheumatoid Arthritis

Clinical Value in Early Diagnosis and Disease Activity Assessment

MSUS has emerged as a pivotal imaging modality for the early detection and management of RA, offering substantial clinical value in both diagnosis and assessment of disease activity. MSUS contributes to early identification by providing high-resolution visualization of key joint structures affected in RA, including synovium, tendons, bone, cartilage, and synovial fluid.[5] MSUS findings such as synovial blood flow detected on power Doppler imaging correlate with established serum markers of inflammation and autoimmunity, including RF, ACPA, ESR, and CRP, highlighting its utility as an indicator of underlying disease activity.[10]

Dynamic assessment of inflammatory changes via MSUS, particularly using power Doppler, allows clinicians to monitor therapeutic responses and tailor individualized treatment regimens. The presence and intensity of PD signals have been shown to influence treatment decisions, with PD positivity serving as a predictor for therapy escalation.[37] Moreover, MSUS can

detect subclinical synovitis even in patients in clinical remission, functioning as a sensitive tool to predict disease relapse and radiographic progression.[12] This is especially valuable in seronegative RA, where conventional serological markers may be absent; combining MSUS with ACPA testing enhances early diagnostic accuracy and facilitates detection of bone erosions.[3]

A balanced appraisal, however, requires acknowledging evidence from randomised controlled trials that have challenged the incremental clinical benefit of MSUS-guided strategies. In the ARCTIC trial (Haavardsholm et al, 2016), 230 DMARD-naïve patients with early RA were randomised to an ultrasound-informed treat-to-target strategy versus a conventional clinical strategy; the addition of structured ultrasound assessment did not translate into significantly better clinical remission rates or reduced structural damage over two years.[44] The similarly designed TaSER trial produced comparable results. A subsequent MRI-outcome analysis of the ARCTIC cohort likewise found no significant reduction in MRI inflammation or joint damage. Although both trials showed a non-significant trend toward less radiographic progression in the ultrasound arm, the authors concluded that systematic use of MSUS for routine follow-up of early RA is not justified on the basis of these results. These findings should be interpreted alongside observational and cohort data supporting the prognostic value of MSUS, and underscore that the optimal role of MSUS in treat-to-target strategies remains an area of active refinement rather than a settled question.

Integration of MSUS with clinical and laboratory parameters nonetheless enhances diagnostic accuracy and informs disease management. Semi-quantitative MSUS scoring correlates with established measures of disease activity, such as the Disease Activity Score in 28 joints (DAS28) and inflammatory biomarkers, providing objective evidence that complements subjective clinical assessment.[45] Moreover, MSUS facilitates differentiation of RA from other arthritides, such as gouty arthritis, by revealing characteristic imaging features, thereby guiding accurate diagnosis and appropriate management.[15,46]

Dependence on Operator Skill and Standardization Issues

Despite its clinical advantages, MSUS in the diagnosis and monitoring of RA faces notable challenges related to operator dependency and the need for harmonised protocols. The accuracy and reliability of MSUS are influenced by the sonographer's experience and expertise, introducing variability in both image acquisition and interpretation.[6]

International initiatives have substantially narrowed this variability. The 2017 EULAR standardised procedures for ultrasound imaging in rheumatology provide a comprehensive, expert-consensus framework covering probe selection, scanning planes, and systematic examination of the most relevant joints in inflammatory arthritis.[28] Complemented by the OMERACT definitions and the EULAR-OMERACT semi-quantitative scoring system outlined in Musculoskeletal Ultrasound Technology and Operational Standards, these guidelines form an internationally recognised basis for training, reporting, and research. The more recent EULAR recommendations for the reporting of ultrasound studies in rheumatic and musculoskeletal diseases further promote transparency and reproducibility by defining a checklist of 23 items that should be reported in every ultrasound study.[47] While multiple semi-quantitative scoring systems exist for evaluating synovitis, tenosynovitis, and bone erosions, heterogeneity in their application still complicates cross-study comparisons.[12]

Beyond definitions and scoring, structured training is essential to translate guideline standards into reproducible practice. Formal EULAR ultrasound courses and certification pathways—together with institutional quality assurance measures such as regular competency assessments—have been shown to improve interobserver reliability in multicentre settings.[33,34] Technical factors also matter: variations in ultrasound equipment, probe frequency, machine settings, and software capabilities can materially affect image quality and diagnostic accuracy, and B-mode artefacts, if not correctly recognised, may lead to misinterpretation.[48] A coordinated combination of standardised protocols, structured training, and quality control therefore remains the most effective strategy to mitigate operator dependence.

Future Directions and Technological Innovations

The future of MSUS in RA diagnosis and management is poised for transformative advancements driven by technological innovation and integration with artificial intelligence (AI). The application of deep learning and machine learning algorithms to automate image analysis and provide quantitative assessments of synovitis, tenosynovitis, and bone erosions is a particularly active area.[49]

Recent studies have reported concrete performance metrics for AI-assisted MSUS. Andersen et al developed convolutional neural networks to score RA disease activity on Doppler ultrasound images according to the OMERACT-

EULAR Synovitis Scoring system, achieving an accuracy of 86.4–86.9% (sensitivity 0.864–0.875, specificity 0.864) for binary healthy/diseased classification and a quadratically weighted κ of 0.84 for four-class PD grading.[50] Wu et al trained ResNet-type deep learning models on 1244 multimodal ultrasound images and evaluated them on two independent test cohorts, with the best-performing models achieving AUCs of 0.87–0.95 across different OMERACT-EULAR grades; dynamic models tended to outperform static ones and were comparable to experienced radiologists.[51] Fiorentino et al reported AUCs of 0.848–0.916 for DenseNet-based classification of synovial proliferation in MCP joints.[52] In the prognostic domain, Daskareh et al followed 326 patients with hand arthralgia over 24 months and showed that machine-learning models integrating hand ultrasound features (radiocarpal synovial thickness, wrist effusion, MCP/PIP synovitis) with serology outperformed individual variables for predicting progression to RA.[8]

Despite these encouraging results, several validation limitations must be emphasised. The majority of AI-MSUS studies have been conducted in single centres with modest sample sizes; external validation on independent, multi-vendor, multi-ethnic datasets is still scarce. Heterogeneity in image acquisition (machine model, transducer frequency, Doppler settings) introduces domain shift that can degrade performance when models are deployed outside the training environment. Most studies focus on the MCP joint and rely on still images, rather than the full multi-joint, dynamic acquisition used in clinical practice. Finally, transparent performance reporting, code availability, and prospective clinical utility studies remain uncommon. The forthcoming phase of the field will therefore depend less on further raw performance gains and more on standardised external validation, regulatory-grade evaluation, and demonstration of downstream impact on patient care.

Multi-modal imaging fusion—combining MSUS with MRI, photoacoustic imaging, or contrast-enhanced ultrasound—represents another frontier. Photoacoustic imaging provides information on synovial oxygenation and vascularization that correlates with disease activity, potentially augmenting diagnostic accuracy beyond conventional MSUS.[53] The proliferation of portable and handheld MSUS devices is further expanding access to ultrasound imaging beyond specialized centers, enabling point-of-care assessments in primary care and resource-limited settings.[54] When combined with AI-driven analysis and telemedicine workflows incorporating remote expert interpretation, these devices could enhance continuity of care and reduce healthcare disparities.[55]

Emerging ultrasound technologies, such as superb microvascular imaging (SMI), provide enhanced visualization of synovial vascularity with greater sensitivity than conventional power Doppler, enabling more precise assessment of inflammation and treatment response.[9] Continuous improvements in ultrasound transducers, software algorithms, and contrast agents are further advancing image resolution and diagnostic capabilities.

A concise comparison of MSUS, conventional radiography, and contrast-enhanced MRI for RA diagnosis is provided in Table 2.

Table 2 Comparative Features of Musculoskeletal Ultrasound (MSUS), Conventional Radiography, and MRI in the Diagnosis of Rheumatoid Arthritis

Feature	MSUS	Radiography (X-ray)	MRI (Contrast-Enhanced)
Early synovitis detection	High sensitivity (AUC 0.81–0.91 vs MRI reference)[36]	Not visible	Reference standard
Early bone erosion	Superior to X-ray in small joints[3,15]	Late finding only	Most sensitive overall
Active inflammation (vascularity)	Power Doppler/SMI; real-time	Not assessed	Dynamic contrast enhancement
Ionising radiation	None	Yes	None
Contrast agent required	No	No	Gadolinium (renal risk)
Cost and availability	Low cost, widely available, point-of-care	Low cost, widely available	High cost, limited access, long scan time
Operator dependence	Significant; mitigated by training/standardisation	Low	Moderate (protocol-dependent)
Suitability for repeated follow-up	Excellent	Limited (radiation)	Limited (cost/access)

Abbreviations: AUC, area under the curve; SMI, superb microvascular imaging.

Conclusion

Musculoskeletal ultrasound has evolved into a powerful, non-invasive imaging modality that meaningfully enhances the diagnosis and activity assessment of rheumatoid arthritis. Its particular strengths lie in the sensitive detection of subclinical synovitis and tenosynovitis, in the early identification of marginal bone erosions, and in supporting the diagnosis of seronegative RA—domains in which clinical examination, serology, and conventional radiography each have material limitations. The maturation of consensus-based definitions and scoring systems (notably the OMERACT and EULAR-OMERACT frameworks) and of standardised acquisition protocols (EULAR 2017) has substantially improved the reproducibility of MSUS, positioning it as a reliable outcome measurement instrument in both clinical practice and research.

At the same time, a balanced appraisal must recognise that MSUS has well-characterised limitations. Operator dependence, machine-to-machine variability in low-flow Doppler sensitivity, physiological synovial flow in healthy joints, and the dependence of power Doppler signal on technical parameters all constrain interpretation. Randomised controlled trials such as ARCTIC have shown that adding structured ultrasound to a treat-to-target strategy does not automatically improve clinical outcomes, highlighting that the value of MSUS is realised when it is embedded in carefully defined clinical questions rather than applied as routine universal monitoring.

Looking forward, the integration of artificial intelligence into MSUS analysis, the diffusion of portable and point-of-care devices, and continued international harmonisation of training and reporting standards are the most promising avenues for further advancement. Priority areas for future research include large, multi-centre, multi-vendor external validation of AI models; prospective studies designed to identify the specific clinical scenarios in which MSUS changes patient outcomes; and the continued refinement of consensus-based scoring to capture change sensitively without introducing new variability. With these developments, MSUS is well placed to remain a cornerstone of modern rheumatology practice for patients with RA.

Disclosure

The author reports no conflict of interest in this work.

References

1. Bollow M. [Rheumatoid arthritis of the hand: part 1: clinical aspects]. *Radiologe*. 2021;61(4):351–361. German. doi:10.1007/s00117-021-00831-5
2. Bollow M. [Rheumatoid arthritis of the hand: part 2: imaging]. *Radiologe*. 2021;61(4):362–374. German. doi:10.1007/s00117-021-00833-3
3. Cen Y, He D, Wang P, Qin Y, Huang M. Contribution of musculoskeletal ultrasound in the diagnosis of seronegative rheumatoid arthritis. *J Ultrasound Med*. 2024;43(10):1929–1936. doi:10.1002/jum.16527
4. Bao Z, Zhao Y, Chen S, et al. Ultrasound versus contrast-enhanced magnetic resonance imaging for subclinical synovitis and tenosynovitis: a diagnostic performance study. *Clinics*. 2020;75:e1500. doi:10.6061/clinics/2020/e1500
5. Ishizaki J. Assessment of musculoskeletal ultrasound of rheumatoid arthritis. *Methods Mol Biol*. 2024;2766:335–342. doi:10.1007/978-1-0716-3682-4_34
6. Elangovan S, Tan YK. The role of musculoskeletal ultrasound imaging in rheumatoid arthritis. *Ultrasound Med Biol*. 2020;46(8):1841–1853. doi:10.1016/j.ultrasmedbio.2020.04.015
7. Suzuki T, Shirai H. Subcalcaneal bursitis as the initial manifestation of rheumatoid arthritis: ultrasonographic observation of two cases. *Reumatismo*. 2020;71(4):230–234. doi:10.4081/reumatismo.2019.1249
8. Daskareh M, Vakilpour A, Barzegar-Golmoghani E, et al. Predicting rheumatoid arthritis development using hand ultrasound and machine learning — a two-year follow-up cohort study. *Diagnostics*. 2024;14(11):1181. doi:10.3390/diagnostics14111181
9. Santos JA, Tee CA, Galsim RJG, Tee ML. Musculoskeletal ultrasound using superb microvascular imaging documents treatment response to biosimilar infliximab in rheumatoid arthritis. *BMJ Case Rep*. 2021;14(2):e239112. doi:10.1136/bcr-2020-239112
10. Wang X, Qian G, Duan H. Diagnostic value of musculoskeletal ultrasound in rheumatoid finger arthritis. *J Coll Physicians Surg Pak*. 2020;30(6):617–621. doi:10.29271/jcpsp.2020.06.617
11. Song PZ, Wu N, Huo C, Wang XM. Correlation analysis and clinical significance of Musculoskeletal Ultrasound semi-quantitative grading with bone salt metabolism, Rheumatoid factor and Erythrocyte Sedimentation rate in patients with Rheumatoid Arthritis. *Pak J Med Sci*. 2023;39(6):1652–1656. doi:10.12669/pjms.39.6.7144
12. Silvagni E, Zandonella Callegher S, Mauric E, et al. Musculoskeletal ultrasound for treating rheumatoid arthritis to target — a systematic literature review. *Rheumatology*. 2022;61(12):4590–4602. doi:10.1093/rheumatology/keac261
13. Floris A, Rozza D, Zanetti A, et al. Musculoskeletal ultrasound may narrow the gap between patients and physicians in the assessment of rheumatoid arthritis disease activity. *Rheumatology*. 2023;62(1):116–123. doi:10.1093/rheumatology/keac255
14. Sakellariou G, Scirè CA, Adinolfi A, et al. Differential diagnosis of inflammatory arthropathies by musculoskeletal ultrasonography: a systematic literature review. *Front Med*. 2020;7:141. doi:10.3389/fmed.2020.00141
15. Xue SW, Luo YK, Zhao YR, Jiao ZY. Musculoskeletal ultrasound in the differential diagnosis of gouty arthritis and rheumatoid arthritis. *Pak J Med Sci*. 2020;36(5):977–981. doi:10.12669/pjms.36.5.2716
16. Lautwein A, Ostendorf B, Vordenbäumen S, et al. Musculoskeletal ultrasound as a screening-tool for rheumatoid arthritis: results of the "Rheuma-Truck" screening and awareness initiative. *Adv Rheumatol*. 2022;62(1):1. doi:10.1186/s42358-021-00233-0

17. Jayatilleke A. Arthritis: rheumatoid Arthritis. *FP Essent*. 2024;548:25–30.
18. Díaz-González F, Hernández-Hernández MV. Rheumatoid arthritis. *Med Clin*. 2023;161(12):533–542. doi:10.1016/j.medcli.2023.07.014
19. Ma H, Liang X, Li SS, Li W, Li TF. The role of anti-citrullinated protein antibody in pathogenesis of RA. *Clin Exp Med*. 2024;24(1):153. doi:10.1007/s10238-024-01359-3
20. Lehmann J, Kyburz D. [Rheumatoid Arthritis]. *Ther Umsch*. 2023;80(1):27–33. German. doi:10.1024/0040-5930/a001403
21. Tanaka Y. Rheumatoid arthritis. *Inflamm Regen*. 2020;40:20. doi:10.1186/s41232-020-00133-8
22. Handa R. Rheumatoid factor and rheumatoid arthritis. *J Clin Orthop Trauma*. 2019;10(3):629–630. doi:10.1016/j.jcot.2019.03.007
23. Van Hoovels L, Vander Cruyssen B, Sieghart D, et al. IgA rheumatoid factor in rheumatoid arthritis. *Clin Chem Lab Med*. 2022;60(10):1617–1626. doi:10.1515/cclm-2022-0244
24. Hoffmann T, Mawrin C, Oelzner P, Wolf G, Pfeil A. Musculoskeletal ultrasound can aid in diagnosis and follow-up of a patient with eosinophilic fasciitis. *J Clin Rheumatol*. 2021;27(8S):S784–S785. doi:10.1097/RHU.0000000000001477
25. Sudoł-Szopińska I, Jans L, Teh J. Rheumatoid arthritis: what do MRI and ultrasound show. *J Ultrason*. 2017;17(68):5–16. doi:10.15557/JoU.2017.0001
26. Kondo Y, Kaneko Y, Takeuchi T. Differential diagnosis of inflammatory arthritis from musculoskeletal ultrasound view. *Rheumatol Immunol Res*. 2022;3(2):54–60. doi:10.2478/rir-2022-0010
27. Zhang M, Xie K. Advances in musculoskeletal ultrasound for assistive diagnosis in pain clinics. *Pain Ther*. 2025;14(3):791–801. doi:10.1007/s40122-025-00721-x
28. Möller I, Janta I, Backhaus M, et al. The 2017 EULAR standardised procedures for ultrasound imaging in rheumatology. *Ann Rheum Dis*. 2017;76(12):1974–1979. doi:10.1136/annrheumdis-2017-211585
29. Backhaus M, Ohrndorf S, Kellner H, et al. Evaluation of a novel 7-joint ultrasound score in daily rheumatologic practice: a pilot project. *Arthritis Rheum*. 2009;61(9):1194–1201. doi:10.1002/art.24646
30. Bruyn GA, Iagnocco A, Naredo E, et al. OMERACT definitions for ultrasonographic pathologies and elementary lesions of rheumatic disorders 15 years on. *J Rheumatol*. 2019;46(10):1388–1393. doi:10.3899/jrheum.181095
31. D'Agostino MA, Terslev L, Aegerter P, et al. Scoring ultrasound synovitis in rheumatoid arthritis: a EULAR-OMERACT ultrasound taskforce — part 1: definition and development of a standardised, consensus-based scoring system. *RMD Open*. 2017;3(1):e000428. doi:10.1136/rmdopen-2016-000428
32. Terslev L, Naredo E, Aegerter P, et al. Scoring ultrasound synovitis in rheumatoid arthritis: a EULAR-OMERACT ultrasound taskforce — part 2: reliability and application to multiple joints of a standardised consensus-based scoring system. *RMD Open*. 2017;3(1):e000427. doi:10.1136/rmdopen-2016-000427
33. Scheel AK, Schmidt WA, Hermann KG, et al. Interobserver reliability of rheumatologists performing musculoskeletal ultrasonography: results from a EULAR "Train the trainers" course. *Ann Rheum Dis*. 2005;64(7):1043–1049. doi:10.1136/ard.2004.030387
34. Naredo E, Möller I, Moragues C, et al. Interobserver reliability in musculoskeletal ultrasonography: results from a "Teach the Teachers" rheumatologist course. *Ann Rheum Dis*. 2006;65(1):14–19. doi:10.1136/ard.2005.037382
35. Ohrndorf S, Fischer IU, Kellner H, et al. Reliability of the novel 7-joint ultrasound score: results from an inter- and intraobserver study performed by rheumatologists. *Arthritis Care Res*. 2012;64(8):1238–1243. doi:10.1002/acr.21679
36. Takase-Minegishi K, Horita N, Kobayashi K, et al. Diagnostic test accuracy of ultrasound for synovitis in rheumatoid arthritis: systematic review and meta-analysis. *Rheumatology*. 2018;57(1):49–58. doi:10.1093/rheumatology/kex036
37. Molina Collada J, Castrejón I, Pérez M, et al. Clinical impact of musculoskeletal ultrasound on rheumatoid arthritis in routine care. *Int J Rheum Dis*. 2021;24(3):341–346. doi:10.1111/1756-185X.14040
38. Di Matteo A, Mankia K, Azukizawa M, Wakefield RJ. The role of musculoskeletal ultrasound in the rheumatoid arthritis continuum. *Curr Rheumatol Rep*. 2020;22(8):41. doi:10.1007/s11926-020-00911-w
39. Garcia-Montoya L, Kang J, Duquenne L, et al. Factors associated with resolution of ultrasound subclinical synovitis in anti-CCP-positive individuals with musculoskeletal symptoms: a UK prospective cohort study. *Lancet Rheumatol*. 2024;6(2):e72–e80. doi:10.1016/S2665-9913(23)00305-3
40. Terslev L, Torp-Pedersen S, Qvistgaard E, et al. Doppler ultrasound findings in healthy wrists and finger joints. *Ann Rheum Dis*. 2004;63(6):644–648. doi:10.1136/ard.2003.009548
41. Torp-Pedersen S, Christensen R, Szkudlarek M, et al. Very different performance of the power Doppler modalities of several ultrasound machines ascertained by a microvessel flow phantom. *Arthritis Res Ther*. 2013;15(5):R114. doi:10.1186/ar4345
42. Yan L, Lin M, Ye X, et al. Prediction model for bone erosion in rheumatoid arthritis based on musculoskeletal ultrasound and clinical risk factors. *Clin Rheumatol*. 2025;44(1):143–152. doi:10.1007/s10067-024-07219-5
43. Enache L, Popescu CC, Micu M, et al. Ankle involvement in rheumatoid arthritis — a comparison of inflammatory signs on musculoskeletal ultrasound and magnetic resonance imaging. *Med Ultrason*. 2019;21(3):265–272. doi:10.11152/mu-2038
44. Haavardsholm EA, Aga AB, Olsen IC, et al. Ultrasound in management of rheumatoid arthritis: arctic randomised controlled strategy trial. *BMJ*. 2016;354:i4205. doi:10.1136/bmj.i4205
45. Shi YM, Wu LJ, Wang WJ, Luo CN, Chen YJ. [Value of musculoskeletal ultrasound in assessing the disease activity in rheumatoid arthritis]. *Zhonghua Yi Xue Za Zhi*. 2019;99(13):1008–1011. Chinese. doi:10.3760/cma.j.issn.0376-2491.2019.13.010
46. Wu J, Yan J, Chang J, et al. Diagnostic values of different musculoskeletal ultrasound signs, serum uric acid, and their combined detection for gouty arthritis. *Arch Rheumatol*. 2024;39(2):265–273. doi:10.46497/ArchRheumatol.2024.10366
47. Costantino F, Carmona L, Boers M, et al. EULAR recommendations for the reporting of ultrasound studies in rheumatic and musculoskeletal diseases (RMDs). *Ann Rheum Dis*. 2021;80(7):840–847. doi:10.1136/annrheumdis-2020-219816
48. Terslev L, Filippucci E, Torp-Pedersen S. B-mode artefacts relevant in rheumatological musculoskeletal ultrasound — impact on image interpretation and their diagnostic value. *Skeletal Radiol*. 2025;54(11):2373–2383. doi:10.1007/s00256-025-04928-z
49. Nooh N, Turkawi R, Maybury M, Cardy C, Sahbudin I. Applications of musculoskeletal ultrasound in inflammatory arthritis. *Clin Med*. 2025;25(5):100508. doi:10.1016/j.clinme.2025.100508
50. Andersen JKH, Pedersen JS, Laursen MS, et al. Neural networks for automatic scoring of arthritis disease activity on ultrasound images. *RMD Open*. 2019;5(1):e000891. doi:10.1136/rmdopen-2018-000891

51. Wu H, Ye X, Jiang Y, et al. Deep learning-based automatic scoring models for the disease activity of rheumatoid arthritis based on multimodal ultrasound images. *Rheumatology*. 2024;63(7):1953–1962. doi:10.1093/rheumatology/kead552
52. Fiorentino MC, Cipolletta E, Filippucci E, et al. A deep learning classification of metacarpophalangeal joints synovial proliferation in rheumatoid arthritis by ultrasound images. *J Ultrasound Med*. 2022;41(8):2007–2016. doi:10.1002/jum.15891
53. Yang M, Zhao C, Wang M, et al. Synovial oxygenation at photoacoustic imaging to assess rheumatoid arthritis disease activity. *Radiology*. 2023;306(1):220–228. doi:10.1148/radiol.212257
54. Ziegler CI, Recker F, Behning C, et al. Deciphering the influence of pregnancy on rheumatoid arthritis and psoriatic arthritis: insights from musculoskeletal ultrasound dynamics. *Arch Gynecol Obstet*. 2025;312(4):1133–1143. doi:10.1007/s00404-025-08107-2
55. Avouac J, Molto A, Allanore Y. Evaluation of the Rheumatoid Arthritis Impact of Disease (RAID) score in assessing rheumatoid arthritis activity in teleconsultation. *J Rheumatol*. 2024;51(10):973–977. doi:10.3899/jrheum.2024-0143