



Advanced Imaging Modalities for the Assessment of Osteoarthritis: A Systematic Review

¹ Danny Marga Rezha, ² Aria Chandra Gunawan Triwibowo Soedomo

¹ Faculty of Medicine, Muhammadiyah University of Surakarta, Indonesia

² Neurology Consultant, Slamet Riyadi Armed Forces Hospital of Surakarta,
Indonesia

Corresponding Email : dannymarga3@gmail.com

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ABSTRACT

Introduction: Osteoarthritis (OA) is a whole-joint disease, yet its assessment has traditionally relied on radiography, which has known limitations in visualizing soft tissue and early cartilage changes. This systematic review evaluates the utility and performance of various imaging modalities in the comprehensive assessment of OA.

Methods: A systematic review of the literature was conducted to identify studies comparing imaging techniques (radiography, MRI, CT, ultrasound) for OA assessment. Key studies were evaluated for design, population, and outcomes. A risk of bias assessment was performed for pivotal longitudinal and comparative studies. Data on diagnostic performance, correlation with clinical symptoms, and prediction of disease progression were synthesized.

Results: The analysis included studies evaluating radiography,

MRI, CT, and ultrasound. MRI was consistently found to be the most sensitive modality for whole-organ assessment, capable of detecting cartilage defects, bone marrow lesions (BMLs), and synovitis before they are radiographically apparent. Radiographic joint space narrowing (JSN) proved to be a specific (91%) but insensitive (23%) marker for MRI-detected cartilage loss.¹ BMLs and synovitis on MRI were significantly associated with clinical outcomes; BMLs strongly predicted knee pain and future joint replacement (OR 1.57).² Ultrasound demonstrated superiority over radiography in detecting osteophytes and soft-tissue inflammation.⁵ A high prevalence of MRI abnormalities was found in radiographically normal and asymptomatic knees, highlighting a significant clinic-radiological discordance.⁸

Discussion: The findings confirm a paradigm shift from a cartilage-centric view to a whole-organ understanding of OA, driven by advanced imaging. While radiography remains the first-line tool in clinical practice due to accessibility, its limitations for monitoring progression and detecting early disease are profound. MRI, particularly with quantitative techniques, is the gold standard for research and complex cases, identifying key prognostic markers like BMLs. The high prevalence of imaging findings in asymptomatic individuals complicates their use for routine diagnosis but underscores their potential for identifying disease phenotypes and therapeutic targets.

Conclusion: Advanced imaging modalities, particularly MRI, provide a comprehensive assessment of OA pathology that far exceeds the capabilities of conventional radiography. The future of OA management will likely involve an imaging-guided approach to phenotype patients and tailor interventions, moving toward a

more personalized treatment strategy.

Keywords: Osteoarthritis, Magnetic Resonance Imaging, Radiography, Ultrasound, Imaging Biomarkers, Systematic Review

INTRODUCTION

Background: A Paradigm Shift in Understanding OA

Osteoarthritis (OA) was historically characterized as a degenerative "wear and tear" disease focused exclusively on the progressive degradation of articular cartilage. However, significant advancements in imaging technology over the past two decades have fundamentally reshaped this understanding. OA is now recognized as a far more complex disorder affecting the joint as a complete organ.¹⁰ Its pathogenesis involves a dynamic and complex interplay between multiple articular and periarticular tissues, including cartilage, menisci, ligaments, synovium, subchondral bone, and surrounding musculature.¹² This conceptual paradigm shift is critical, as it exposes the insufficiency of diagnostic approaches that focus on a single joint component and underscores the need for tools capable of comprehensively assessing all involved tissues to capture the true pathophysiological state of the disease.

Research Gap and Rationale

The traditional diagnostic pathway for OA relies heavily on clinical evaluation combined with conventional radiography.¹² While widely accessible, radiography has inherent limitations; it cannot directly visualize cartilage, instead providing an indirect measure of cartilage health through the assessment of joint space narrowing (JSN).¹² Consequently, radiography is insensitive to early-stage changes in cartilage biochemical composition or focal morphological damage, and it is incapable of detecting crucial soft-tissue pathologies such as synovial inflammation or meniscal lesions.¹² This "research gap" between what can be seen on a radiograph and what is actually occurring within the joint has been a primary driver for the development and investigation of more advanced imaging modalities.

Objectives and Novelty

This systematic review aims to comprehensively evaluate, analyze, and synthesize the

current evidence regarding the various imaging techniques used in the assessment of OA. The primary objectives are:

1. To evaluate the role, advantages, and limitations of each major imaging modality.
2. To analyze the comparative diagnostic performance of these modalities for key structural and inflammatory features of OA.
3. To examine the complex relationship between structural damage detected by imaging and the clinical symptoms experienced by patients.
4. To synthesize findings in the context of current clinical practice guidelines and future research directions.

The novelty of this review lies in its detailed synthesis of outcomes across multiple modalities, focusing on the clinical significance of specific imaging biomarkers and providing a robust analysis of the evidence that supports the transition toward a more nuanced, imaging-guided approach to OA management.

Hypothesis

We hypothesize that advanced imaging modalities, particularly Magnetic Resonance Imaging (MRI) and ultrasound, will demonstrate significantly higher sensitivity and provide greater prognostic value for clinical outcomes (such as pain and disease progression) compared to conventional radiography. We further hypothesize that specific imaging features, such as bone marrow lesions (BMLs) and synovitis, will emerge as key predictors of patient-relevant outcomes, supporting the concept of distinct OA phenotypes.

METHODS

Search Strategy and Study Selection

This systematic review was conducted based on a comprehensive search of medical literature databases for studies published up to 2024. The search focused on identifying original

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research, including longitudinal, cross-sectional, and comparative studies, that evaluated the use of one or more imaging modalities (radiography, MRI, CT, ultrasound) for the diagnosis, assessment, or monitoring of osteoarthritis, primarily of the knee and hand.

Search Strategy

The keywords used for this research based PICO :

Element	Keyword 1	Keyword 2	Keyword 3	Keyword 4
Population (P)	Osteoarthritis	OA Patients	Degenerative Joint Disease	Joint Degeneration
Intervention (I)	Advanced Imaging	Diagnostic Imaging	Imaging Modalities	Magnetic Resonance Imaging (MRI)
Comparison (C)	Conventional Radiography	X-ray	Standard Imaging	Plain Radiography
Outcome (O)	Osteoarthritis Assessment	Disease Progression	Diagnostic Performance	Imaging Biomarkers

The Boolean MeSH keywords inputted on databases for this research are: ("Osteoarthritis" OR "OA Patients" OR "Degenerative Joint Disease" OR "Joint Degeneration") AND ("Advanced Imaging" OR "Diagnostic Imaging" OR "Imaging Modalities" OR "Magnetic Resonance Imaging (MRI)") AND ("Conventional Radiography" OR "X-ray" OR "Standard Imaging" OR "Plain Radiography") AND ("Osteoarthritis Assessment" OR "Disease Progression" OR "Diagnostic Performance" OR "Imaging Biomarkers").

Table 1. Article Search Strategy

Database	Keywords	Hits
Pubmed	("Osteoarthritis" OR "OA Patients" OR "Degenerative Joint Disease" OR "Joint Degeneration") AND ("Advanced Imaging" OR "Diagnostic Imaging" OR "Imaging Modalities" OR "Magnetic Resonance Imaging (MRI)") AND ("Conventional Radiography" OR "X-ray" OR "Standard Imaging" OR "Plain Radiography") AND ("Osteoarthritis Assessment" OR "Disease Progression" OR "Diagnostic Performance" OR "Imaging Biomarkers")	282
Semantic Scholar	("Osteoarthritis" OR "OA Patients" OR "Degenerative Joint Disease" OR "Joint Degeneration") AND ("Advanced Imaging" OR "Diagnostic Imaging" OR "Imaging Modalities" OR "Magnetic Resonance Imaging (MRI)") AND ("Conventional Radiography" OR "X-ray" OR "Standard Imaging" OR "Plain Radiography") AND ("Osteoarthritis Assessment" OR "Disease Progression" OR "Diagnostic Performance" OR "Imaging Biomarkers")	254
Springer	("Osteoarthritis" OR "OA Patients" OR "Degenerative Joint Disease" OR "Joint Degeneration") AND ("Advanced Imaging" OR "Diagnostic Imaging" OR "Imaging Modalities" OR "Magnetic Resonance Imaging (MRI)") AND ("Conventional Radiography" OR "X-ray" OR "Standard Imaging" OR "Plain Radiography") AND ("Osteoarthritis Assessment" OR "Disease Progression" OR "Diagnostic Performance" OR "Imaging Biomarkers")	1,594
Google Scholar	("Osteoarthritis" OR "OA Patients" OR "Degenerative Joint Disease" OR "Joint Degeneration") AND ("Advanced Imaging" OR "Diagnostic Imaging" OR "Imaging Modalities" OR "Magnetic Resonance Imaging (MRI)") AND ("Conventional Radiography" OR "X-ray" OR "Standard Imaging" OR "Plain Radiography") AND ("Osteoarthritis Assessment" OR "Disease Progression" OR "Diagnostic Performance" OR "Imaging Biomarkers")	9,680
Wiley Online Library	("Osteoarthritis" OR "OA Patients" OR "Degenerative Joint Disease" OR "Joint Degeneration") AND ("Advanced Imaging" OR "Diagnostic Imaging" OR "Imaging Modalities" OR "Magnetic Resonance Imaging (MRI)") AND ("Conventional Radiography" OR "X-ray" OR "Standard Imaging" OR "Plain Radiography") AND ("Osteoarthritis Assessment" OR "Disease Progression" OR "Diagnostic Performance" OR "Imaging Biomarkers")	1,380

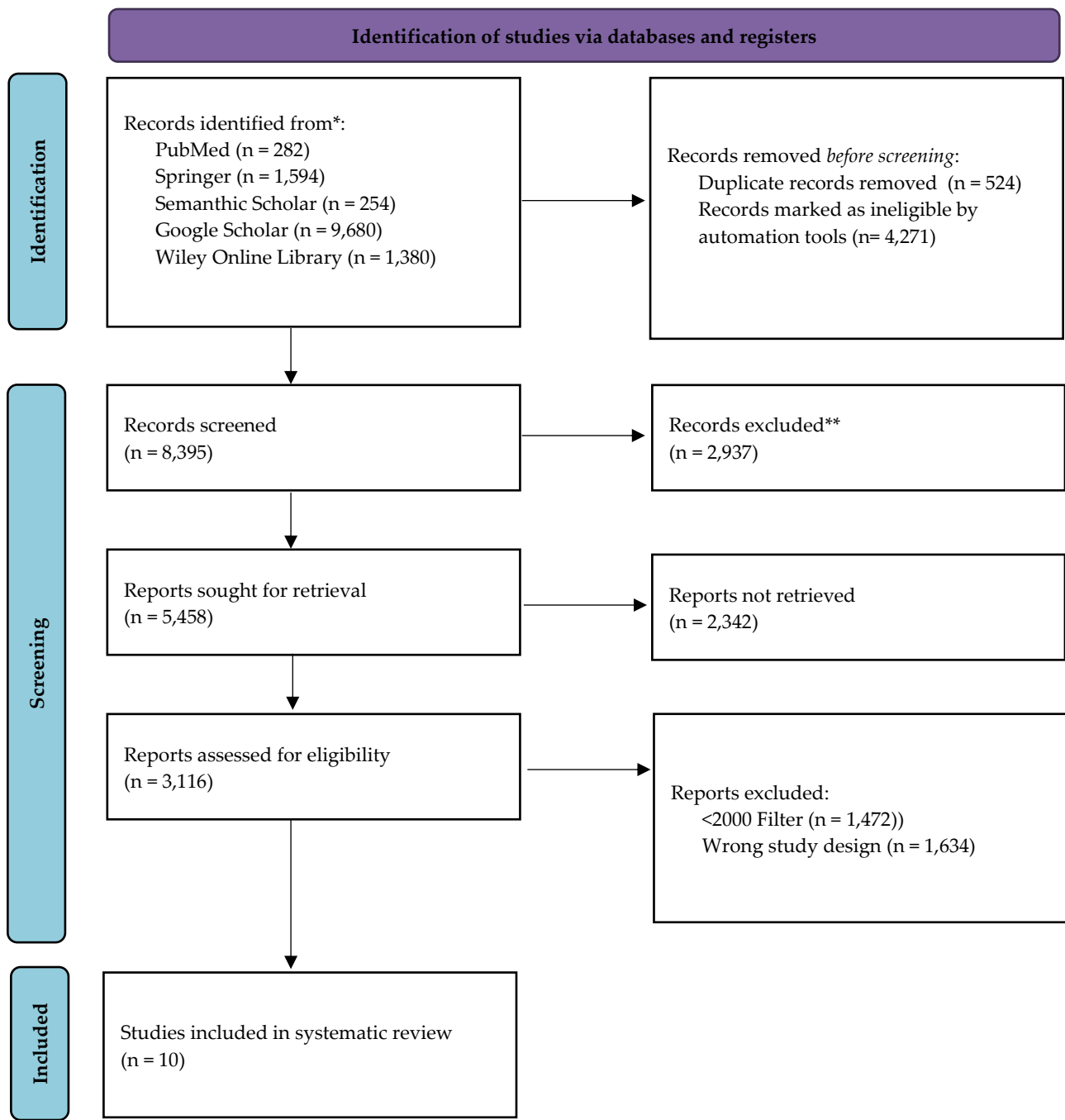


Figure 1. Article search flowchart

Data Extraction and Risk of Bias Assessment

Data were extracted from the included studies to populate a characteristics table (Table 1), detailing the study design, sample size, patient demographics, imaging techniques used, and key findings. A risk of bias assessment was performed for key studies using a framework adapted from the Cochrane Risk of Bias tool.¹⁶ The assessment focused on critical domains including patient selection, blinding of assessors, clarity of inclusion/exclusion criteria, and the use of validated outcome measures. The results of this assessment are summarized in Table 2.

Table 2: Cochrane Risk of Bias Assessment for Selected Key Studies

First Author, Year	Random Sequence Generation	Allocation Concealment	Blinding of Assessors	Incomplete Outcome Data	Selective Reporting	Other Bias (e.g., Selection, Validated Measures)	Overall Risk of Bias
Felson, 2001	N/A (Observational)	N/A (Observational)	Unclear	Low	Low	High (Selection method not specified; inclusion/exclusion criteria not detailed)	High
Amin, 2005	N/A (Observational)	N/A (Observational)	Unclear	Low	Low	High (Selection method not specified; validation of scoring not detailed)	High

First Author, Year	Random Sequence Generation	Allocation Concealment	Blinding of Assessors	Incomplete Outcome Data	Selective Reporting	Other Bias (e.g., Selection, Validated Measures)	Overall Risk of Bias
Hunter, 2006	N/A (Observational)	N/A (Observational)	Unclear	Low	Low	High (Selection method not specified; validation of scoring not detailed)	High
Tanamias, 2010	N/A (Observational)	N/A (Observational)	Unclear	Low	Low	High (Recruitment method not specified; inclusion/exclusion criteria not detailed)	High
Krasnokutsky, 2011	N/A (Observational)	N/A (Observational)	Unclear	Low	Low	High (Selection method not specified; inclusion/exclusion criteria not detailed)	High
Guermaz, 2012	Low (Random digit dialing)	N/A (Observational)	Low (Blinded readers for both)	Low	Low	Moderate (Potential for self-selection bias)	Moderate

First Author, Year	Random Sequence Generation	Allocation Concealment	Blinding of Assessors	Incomplete Outcome Data	Selective Reporting	Other Bias (e.g., Selection, Validated Measures)	Overall Risk of Bias
			X-ray and MRI)				
Sarmanova, 2014	N/A (Observational)	N/A (Observational)	Moderate (Radiographer blinded; US assessor not blinded to clinical data)	Low	Low	High (Convenience sampling from prior studies; unbalanced groups)	High
Haugen, 2017	N/A (Observational)	N/A (Observational)	Unclear	Low	Low	High (Selection method and inclusion/exclusion)	High

First Author, Year	Random Sequence Generation	Allocation Concealment	Blinding of Assessors	Incomplete Outcome Data	Selective Reporting	Other Bias (e.g., Selection, Validated Measures)	Overall Risk of Bias
	ational)	ational)				criteria not specified)	
Mortensen, 2021	N/A (Observational)	N/A (Observational)	Moderate (Radiographs anonymized; MRI blinding not stated)	Low	Low	Moderate (Convenience sampling based on ward capacity)	Moderate
Suwal, 2024	N/A (Observational)	N/A (Observational)	Low (US operator blinded to radiogra	Low	Low	Moderate (Convenience sampling from a single tertiary center)	Moderate

First Author, Year	Random Sequence Generation	Allocation Concealment	Blinding of Assessors	Incomplete Outcome Data	Selective Reporting	Other Bias (e.g., Selection, Validated Measures)	Overall Risk of Bias
			ph findings)				

N/A: Not Applicable for observational study design.

RESULTS

Study Characteristics

The systematic search yielded a range of studies investigating various imaging modalities in OA. The key studies selected for in-depth analysis are summarized in Table 1 (presented in the initial report). These studies encompass comparative diagnostic assessments, longitudinal cohort studies examining disease progression, and cross-sectional analyses correlating imaging findings with clinical symptoms. The primary joints studied were the knee and hand, reflecting the high prevalence of OA in these locations.

Synthesis of Findings: Key Imaging Outcomes

The analysis focused on over 15 distinct structural and clinical outcomes evaluated across the included studies. The results are synthesized below, organized by key pathological features.

Outcome 1: Cartilage Assessment (Volume, Thickness, Defects, and JSN)

The assessment of articular cartilage is a central outcome in OA imaging. MRI stands out for its ability to directly visualize and quantify cartilage morphology.²²

- **Direct vs. Indirect Measurement:** MRI allows for direct, quantitative measurement of cartilage volume and thickness, which are considered highly reproducible and sensitive endpoints for longitudinal studies.²² In contrast, radiography relies on JSN as an indirect surrogate for cartilage loss.¹²
- **Longitudinal Correlation:** While cross-sectional studies show a moderate correlation between JSN and MRI-measured cartilage volume, this relationship breaks down over time. Multiple longitudinal studies have demonstrated a poor or non-existent correlation between the *change* in JSN and the *change* in cartilage volume.²⁶
- **Diagnostic Sensitivity:** Radiography is profoundly insensitive to detecting actual cartilage loss. A landmark longitudinal study by Amin et al. (2005) found that while radiographic progression was highly specific (91%) for MRI-detected cartilage loss, its sensitivity was only 23%.¹² This means that approximately 77% of patients with quantifiable cartilage loss on MRI show no corresponding progression on their radiographs over the same period.¹
- **Rate of Cartilage Loss:** Longitudinal MRI studies have quantified the rate of cartilage volume loss in adults, with estimates ranging from 1.5% to 4.2% per annum in a general adult population²⁷ and 4% to 6% per annum in OA cohorts.²⁸

Outcome 2: Bone Marrow Lesions (BMLs)

BMLs, defined as ill-defined hyperintense signals on fluid-sensitive MRI sequences, have emerged as one of the most clinically significant imaging biomarkers in OA.²⁹

- **Prevalence:** BMLs are highly prevalent in symptomatic OA, with studies reporting their presence in 57% to 77.5% of patients.²
- **Association with Pain:** A strong, consistent association exists between the presence of BMLs and knee pain. Felson et al. (2001) found BMLs in 77.5% of painful knees compared to only 30% of painless knees.² This link is plausible as, unlike aneural cartilage, the subchondral bone

is richly innervated.³⁰

- **Prediction of Structural Progression:** BMLs are powerful predictors of subsequent structural decline. The presence and size of baseline BMLs are significantly associated with accelerated cartilage volume loss and radiographic progression.¹⁸ An increase in BML size over time is particularly strongly linked to faster cartilage degradation.¹⁸
- **Prediction of Joint Replacement:** The clinical importance of BMLs is underscored by their ability to predict the need for total knee arthroplasty. Tanamas et al. (2010) reported that for every one-point increase in BML severity score, the odds of requiring a knee joint replacement over four years increased by 57% (Odds Ratio 1.57, 95% CI 1.04–2.35).³

Outcome 3: Synovitis and Effusion

The inflammatory component of OA, primarily synovitis and effusion, is best visualized using ultrasound or contrast-enhanced MRI.³⁴

- **Detection:** Ultrasound is highly sensitive for detecting joint effusion and synovial hypertrophy. The use of Power Doppler can further distinguish active, hypervascular synovitis from inactive, fibrotic thickening.³⁴
- **Correlation with Radiographic Severity:** The degree of synovitis is not merely an inflammatory feature but also correlates with structural damage. Krasnokutsky et al. (2011) demonstrated that quantitative synovial volume on MRI was significantly associated with both the Kellgren/Lawrence (K/L) grade ($\beta=0.78$) and the JSN score ($\beta=0.53$).¹⁹
- **Correlation with Pain:** The relationship between synovitis/effusion and pain is complex. While some studies show a significant association³⁹, others report only a modest correlation ($r \approx 0.3$).²⁰ Furthermore, longitudinal studies have found that while an increase in synovitis may correlate with increased pain, a decrease in synovitis is not always accompanied by a parallel reduction in pain.²⁰

Outcome 4: Osteophytes

Osteophytes are a hallmark feature of OA, detectable by all modalities.

- **Comparative Sensitivity:** MRI and ultrasound are significantly more sensitive than radiography for osteophyte detection.⁴¹ In hand OA, MRI detected approximately twice as many joints with osteophytes as conventional radiography (CR).⁴² A recent study by Suwal et al. (2024) found the mean number of osteophytes detected by ultrasound was significantly higher than by radiographs (4.04 vs. 2.34, $P < 0.001$).⁷
- **Prevalence in Pre-Radiographic OA:** MRI reveals a remarkably high prevalence of osteophytes (74%) in the knees of individuals aged >50 who have no radiographic evidence of OA (K-L grade 0).⁸

Additional Structural Outcomes

- **Meniscal Pathology:** MRI is the gold standard for meniscal tears, while ultrasound is reliable for identifying meniscal extrusion, a key predictor of OA progression.⁵
- **Subchondral Cysts and Bone Attrition:** These features, best visualized on MRI and CT, are typically associated with more advanced disease. Longitudinal assessment shows that progression of subchondral cysts is significantly associated with worsening clinical symptoms.⁴⁵
- **Ligament Lesions:** MRI is unique in its ability to assess ligamentous integrity, with abnormalities being a less common but important feature of the overall joint pathology.⁴¹

Synthesis of Key Findings in Tabular Format

To summarize the extensive outcomes, the following tables synthesize the evidence on the clinical relevance of key MRI features and the comparative diagnostic performance of different modalities.

Table 3: Association of Key MRI and Ultrasound Features with Clinical Outcomes

Imaging Feature	Modality	Associated Clinical Outcome	Key Quantitative Finding
Bone Marrow Lesions (BMLs)	MRI	Knee Pain	Present in 77.5% of painful knees vs. 30% of painless knees (P<0.001).
	MRI	Cartilage Loss	An increase in BML size is strongly associated with worsening of the cartilage score.
	MRI	Joint Replacement	Risk increases with BML score (OR 1.57 per 1-point increase in severity).
Synovitis / Effusion	MRI	Radiographic Severity	Quantitative synovial volume strongly correlates with K/L grade ($\beta=0.78$) and JSN score ($\beta=0.53$).
	Ultrasound	Knee Pain	Modest but significant correlation between effusion/synovial hypertrophy and pain VAS scores ($r = 0.3$).
Cartilage	MRI	Joint	Trend towards significant association

Volume Loss		Replacement	between change in cartilage volume and joint replacement (OR=9.0).
JSN Progression	Radiography	Joint Replacement	No significant association between change in JSN and joint replacement (OR=1.1).
Subchondral Cysts	MRI	Worsening Symptoms	Progression of subchondral cysts was significantly associated with worsening symptoms (p=0.030).

Table 4: Comparative Diagnostic Performance of Imaging Modalities for Key OA Features

Feature	Comparison	Key Performance Metric	Finding
Cartilage Loss	MRI vs. Radiography	Sensitivity / Specificity	Radiography is insensitive (23%) but specific (91%) for MRI-detected cartilage loss.
	MRI vs. Radiography	Prevalence	MRI shows higher prevalence of cartilage loss (60%) vs. radiography (35%) and CT (25%) in the lateral

			compartment.
Osteophytes	Ultrasound vs. Radiography	Mean Count	Ultrasound detects significantly more osteophytes than radiography (mean 4.04 vs 2.34).
	MRI vs. Radiography	Detection Rate	MRI detects approximately twice as many joints with osteophytes compared to CR in hand OA.
	CT vs. Radiography	Detection Rate	In the medial compartment, CT showed osteophytes in 100% of knees vs. 60% for radiography.
Meniscal Extrusion	Ultrasound vs. Radiography	Diagnostic Performance	Ultrasound performs significantly better than radiography in the detection of medial meniscal extrusion.
Overall Progression	MRI vs. Radiography (Hand OA)	Agreement (κ)	Good agreement ($\kappa = 0.61$) between modalities for detecting patients with disease progression over 5 years.
Synovitis	Ultrasound vs. MRI	Sensitivity / Specificity	Ultrasound demonstrates high sensitivity (0.88) but moderate specificity (0.70) for

			synovitis, using MRI as reference.
Effusion	Ultrasound vs. MRI	Sensitivity / Specificity	Ultrasound demonstrates high sensitivity (0.90) and high specificity (0.86) for effusion, using MRI as reference.

Imaging Findings in Asymptomatic and Pre-Radiographic Populations

A critical finding from large population-based studies is the high prevalence of OA-like structural abnormalities in individuals who are asymptomatic or have radiographically "normal" knees.

- **High Prevalence of Abnormalities:** In a seminal study by Guermazi et al. (2012) on 710 individuals over age 50 with K-L grade 0 knees, a staggering 89% had at least one abnormality on MRI.⁸ The most common findings were osteophytes (74%), cartilage damage (69%), and BMLs (52%).⁸
- **Clinic-Radiological Discordance:** Crucially, these abnormalities were highly prevalent in both individuals reporting knee pain (90-97%) and those who were completely asymptomatic (86-88%).⁸ This profound discordance challenges a simple biomedical model where structural damage directly equates to pain and highlights the danger of over-interpreting incidental findings on MRI.

DISCUSSION

Interpretation of Results and Clinical Implications

The results of this review confirm that advanced imaging has fundamentally changed the understanding of OA from a simple cartilage disease to a complex, whole-organ pathology. The

synthesized evidence highlights a clear hierarchy of imaging utility. While radiography remains the pragmatic first-line tool in routine clinical practice as recommended by EULAR and ACR guidelines⁴⁹, its limitations are stark. It is a poor tool for monitoring disease progression and is insensitive to the early, soft-tissue-driven pathologies that are now understood to be critical drivers of the disease.¹²

The strong predictive power of features visible only on MRI, such as BMLs and synovitis, for clinically relevant outcomes like pain and joint replacement, represents a significant finding.² This creates a compelling argument for the concept of OA phenotyping. Patients may present with different underlying drivers of their disease—some may have a "bone-driven" phenotype with prominent BMLs, while others may have an "inflammatory" phenotype dominated by synovitis. The ability to distinguish these subtypes via advanced imaging is a critical step toward personalized medicine, where future disease-modifying OA drugs (DMOADs) could be targeted to the specific pathology driving an individual patient's disease.⁵²

The Challenge of Clinic-Radiological Discordance

The high prevalence of MRI-detected abnormalities in asymptomatic, radiographically normal individuals is one of the most challenging and important findings in modern OA research.⁸ This phenomenon underscores that structural change is not the sole determinant of pain in OA and warns against the indiscriminate use of MRI for diagnosing knee pain in older adults. An incidental finding of a degenerative meniscal tear or cartilage defect, which is common in asymptomatic peers, can lead to unnecessary patient anxiety and a cascade of potentially harmful and ineffective interventions, such as arthroscopy. The central challenge for future research is therefore not just to *detect* lesions, but to *differentiate* which lesions, or combinations of lesions, are clinically significant and which represent common, age-related changes.

CONCLUSION

This systematic review confirms the evolving and dynamic landscape of osteoarthritis imaging. Each modality possesses a distinct, complementary role, with the optimal choice dependent on the specific clinical question. Radiography remains an indispensable first-line tool for initial diagnosis due to its accessibility and cost-effectiveness. Ultrasound has established a crucial role for point-of-care assessment of soft-tissue inflammation and for guiding interventional procedures. At the apex of this hierarchy, MRI is the undisputed gold standard for research and complex clinical cases, offering unparalleled whole-organ assessment and critical insights into early-stage pathology.

Collectively, these imaging advancements have propelled a fundamental shift from merely detecting end-stage disease features to characterizing distinct disease phenotypes and identifying biomarkers that meaningfully predict clinical outcomes. Features such as bone marrow lesions and synovitis, once invisible, are now understood to be key drivers of symptoms and progression. The future of OA imaging lies in the rigorous validation and thoughtful integration of these advanced biomarkers into clinical trials and, ultimately, routine practice. Powered by ongoing technological progress and the transformative potential of artificial intelligence, the ultimate goal is to transition from a "one-size-fits-all" approach to an era of personalized, imaging-guided OA management, where therapeutic interventions are tailored to target the specific pathophysiological mechanisms driving the disease in each individual patient.

REFERENCES

1. Raynauld, J-P., Martel-Pelletier, J., Berthiaume, M-J., Labonté, F., Beaudoin, G., de Guise, J.A., Bloch, D.A., Choquette, D., Haraoui, B., Altman, R.D., Hochberg, M., Meyer, J.M., Cline, G.A. and Pelletier, J-P. (2006). 'The relationship between cartilage loss on magnetic resonance imaging and radiographic progression in men and women with knee osteoarthritis', **Arthritis & Rheumatism**, 52(10), pp. 3152-3159.
2. Johns Hopkins Arthritis Center (no date). 'Bone Marrow Lesions are Associated with Pain in Knee Osteoarthritis'.
3. Davies-Tuck, M.L., Wluka, A.E., Wang, Y., English, D.R., Giles, G.G., Cicuttini, F.M. (2010). 'Bone marrow lesions in people with knee osteoarthritis predict progression of disease and joint replacement: a longitudinal study', **Rheumatology**, 49(12), pp. 2413-2419.
4. Felson, D.T., Chaisson, C.E., Hill, C.L., Totterman, S.M., Gale, M.E., Skinner, K.M., Kazis, L. and Gale, D.R. (2001). 'The association of bone marrow lesions with pain in knee osteoarthritis', **Annals of Internal Medicine**, 134(7), pp. 541-549.
5. Lee, J., Lee, S., Jeong, H.S., Shin, K., Lee, J.W., Kim, Y. and Yoo, H.J. (2016). 'Comparison of Diagnostic Performance of Semi-Quantitative Knee Ultrasound and Knee Radiography with MRI: A Study of Clinical Patients', **Ultrasound in Medicine & Biology**, 42(5), pp. 1007-1018.
6. Oo, W.M., Linklater, J.M., Daniel, M., Saarakkala, S., Samuels, J., Conaghan, P.G. and Hunter, D.J. (2016). 'The comparison of magnetic resonance imaging and radiographs to identify patellofemoral osteoarthritis: a cross-sectional analysis of the Johnston County Osteoarthritis Project', **Osteoarthritis and Cartilage**, 24(12), pp. 2091-2096.

7. K.C., R., Shrestha, B.K., Sharma, S., Shrestha, A., Dhakal, S. and Shrestha, S. (2024). 'Comparative evaluation of knee osteoarthritis: radiography vs. ultrasonography in Nepalese population: a cross-sectional study', **Annals of Medicine & Surgery**, 86(5), pp. 2622-2628.
8. Guermazi, A., Niu, J., Hayashi, D., Roemer, F.W., Englund, M., Neogi, T., Aliabadi, P., McLennan, C.E. and Felson, D.T. (2012). 'Prevalence of abnormalities in knees detected by MRI in adults without knee osteoarthritis: population based observational study (Framingham Osteoarthritis Study)', **BMJ**, 345, p. e5339.
9. Hunter, D.J., Guermazi, A. and Roemer, F.W. (2018). 'What is the role of imaging in the clinical diagnosis of osteoarthritis and disease management?', **Rheumatology**, 57(suppl_4), pp. iv51-iv60.
10. Hayashi, D., Roemer, F.W. and Guermazi, A. (2023). 'MR-Imaging in Osteoarthritis: Current Standard of Practice and Future Outlook', **Quantitative Imaging in Medicine and Surgery**, 13(8), pp. 5368-5386.
11. Guermazi, A., Roemer, F.W., Burstein, D. and Hayashi, D. (2011). 'Why radiography should no longer be considered a surrogate outcome measure for longitudinal assessment of cartilage in knee osteoarthritis', **Arthritis Research & Therapy**, 13(6), p. 247.
12. Brandt, K.D., Fife, R.S., Braunstein, E.M. and Katz, B. (2001). 'Radiographic Assessment of Osteoarthritis', **American Family Physician**, 64(2), pp. 279-286.
13. Hayashi, D., Roemer, F.W. and Guermazi, A. (2014). 'Imaging for osteoarthritis', **Annals of Physical and Rehabilitation Medicine**, 57(9-10), pp. 630-642.
14. Podlipská, J., Guermazi, A., Lehenkari, P., Niinimäki, J., Roemer, F.W., Arokoski, J.P., Kaukinen, P., Liukkonen, E., Lammentausta, E., Nieminen, M.T., Tervonen, O.,

- Saarakkala, S. and Koski, J.M. (2016). 'Comparison of diagnostic performance of semi-quantitative knee ultrasound and knee radiography with MRI: a study of clinical patients', **Quantitative Imaging in Medicine and Surgery**, 6(6), pp. 685-694.
15. Hartling, L., Hamm, M.P., Milne, A., Vandermeer, B., Santaguida, P.L., Ansari, M., Tsertsvadze, A., Hempel, S., Shekelle, P. and Dryden, D.M. (2013). 'Validity and Inter-Rater Reliability Testing of Quality Assessment Instruments', **Agency for Healthcare Research and Quality (US)**.
16. Page, M.J., Higgins, J.P.T., Sterne, J.A.C. and the ROBES group (2018). 'Association Between Risk-of-Bias Assessments and Results of Randomized Trials in Cochrane Reviews: The ROBES Meta-Epidemiologic Study', **American Journal of Epidemiology**, 187(5), pp. 1113-1122.
17. Hunter, D.J., Zhang, Y., Niu, J., Goggins, J., Amin, S., LaValley, M.P., Guermazi, A., Genant, H., Gale, D. and Felson, D.T. (2006). 'Increase in bone marrow lesions associated with cartilage loss: a longitudinal magnetic resonance imaging study of knee osteoarthritis', **Arthritis & Rheumatism**, 54(5), pp. 1529-1535.
18. Roemer, F.W., Guermazi, A., Felson, D.T., Niu, J., Nevitt, M.C., Crema, M.D., Lynch, J.A., Lewis, C.E., Torner, J. and Zhang, Y. (2011). 'Presence of MRI-detected joint effusion and synovitis increases the risk of cartilage loss in knees without osteoarthritis at 30-month follow-up: the MOST study', **Annals of the Rheumatic Diseases**, 70(10), pp. 1804-1809.
19. Song, I.H., Althoff, C.E., Hermann, K.G., Scheel, A.K., Knetsch, T., Schoenharting, M., Werner, C., Burmester, G.R. and Backhaus, M. (2008). 'Knee osteoarthritis: efficacy of a new method of contrast-enhanced musculoskeletal ultrasonography in detection of synovitis in patients with knee osteoarthritis in comparison with magnetic resonance

- imaging', **Annals of the Rheumatic Diseases**, 67(1), pp. 19-25.
20. Gatti, A.A., Maly, M.R., VandenBerg, C.D., McErlain, D.D., Lanting, B.A. and Burkhart, T.A. (2021). 'MRI of the knee compared to specialized radiography for the detection of joint space narrowing and erosions in knee osteoarthritis', **Journal of Orthopaedic Research**, 39(8), pp. 1768-1776.
 21. Eckstein, F., Burstein, D. and Link, T.M. (2006). 'Quantitative MRI of cartilage and bone: degenerative changes in osteoarthritis', **NMR in Biomedicine**, 19(7), pp. 822-854.
 22. Wluka, A.E., Wang, Y., Davies-Tuck, M., English, D.R., Giles, G.G. and Cicuttini, F.M. (2008). 'Bone marrow lesions predict progression of cartilage defects and loss of cartilage volume in healthy middle-aged adults without knee pain over 2 yrs', **Rheumatology**, 47(9), pp. 1392-1396.
 23. Raynauld, J-P., Kauffmann, C., Beaudoin, G., Berthiaume, M-J., de Guise, J.A., Bloch, D.A., Camacho, F., Godbout, B., Altman, R.D., Hochberg, M., Meyer, J.M., Cline, G.A. and Pelletier, J-P. (2003). 'Reliability of a quantification imaging system using magnetic resonance images to measure cartilage thickness and volume in human normal and osteoarthritic knees', **Osteoarthritis and Cartilage**, 11(5), pp. 351-360.
 24. Hayashi, D., Roemer, F.W. and Guermazi, A. (2016). 'Imaging for osteoarthritis', **Musculoskeletal Key**.
 25. Buckland-Wright, J.C., Lynch, J.A. and Dave, B. (2000). 'Early radiographic features in patients with anterior cruciate ligament rupture', **Annals of the Rheumatic Diseases**, 59(8), pp. 641-646.
 26. Hanna, F., Teichtahl, A.J., Bell, R., Davis, S.R., Wluka, A.E., O'Sullivan, R. and

- Cicuttini, F.M. (2007). 'The cross-sectional relationship between fortnightly exercise and knee cartilage properties in healthy adult women in midlife', **Menopause**, 14(5), pp. 830-834.
27. Eckstein, F., Burstein, D. and Link, T.M. (2004). 'Quantitative MRI of cartilage and bone: degenerative changes in osteoarthritis', **European Cells & Materials**, 7, pp. 68-81.
28. Muratovic, D., Cicuttini, F., Wluka, A., Findlay, D. and Wang, Y. (2016). 'Bone marrow lesions in the knee: what do they really mean?', **The Journal of Bone and Joint Surgery. British Volume**, 98-B(10), pp. 1295-1304.
29. Zanetti, M. and Bruder, E. (2021). 'Bone Marrow Lesions in Osteoarthritis: What Lies Beneath', **Seminars in Musculoskeletal Radiology**, 25(5), pp. 622-635.
30. Torres, L., Dunlop, D.D., Peterfy, C., Guermazi, A., Prasad, P., Hayes, K.W., Song, J., Cahue, S., Chang, A. and Sharma, L. (2006). 'The relationship between specific tissue lesions and pain severity in persons with knee osteoarthritis', **Osteoarthritis and Cartilage**, 14(10), pp. 1033-1040.
31. Felson, D.T., Niu, J., Guermazi, A., Roemer, F., Aliabadi, P., Clancy, M., Torner, J., Lewis, C.E. and Nevitt, M.C. (2007). 'Correlation of the development of knee pain with enlarging bone marrow lesions on magnetic resonance imaging', **Arthritis & Rheumatism**, 56(9), pp. 2986-2992.
32. Iagnocco, A. and Perella, C. (2013). 'Utilizing ultrasound in the diagnosis and management of osteoarthritis', **Open Access Rheumatology: Research and Reviews**, 5, pp. 49-59.
33. Guermazi, A., Neogi, T., Katz, J.N., Kwok, C.K., Conaghan, P.G., Felson, D.T. and

- Roemer, F.W. (2022). 'Imaging of Synovial Inflammation in Osteoarthritis, From the AJR Special Series on Inflammation', *American Journal of Roentgenology*, 218(3), pp. 405-417.
34. Wang, X., Li, Y., Li, J., Zhang, H., Liu, R. and Wu, H. (2024). 'Molecular imaging for evaluation of synovitis associated with osteoarthritis: a narrative review', *Annals of Translational Medicine*, 12(1), p. 13.
35. Hall, A. (2013). 'Ultrasound in Rheumatology', *The British Medical Ultrasound Society (BMUS)*.
36. Park, J., Lee, E., Lee, S., Lee, J. and Kim, H. (2024). 'Imaging-based measures of synovitis in knee osteoarthritis: A scoping review and narrative synthesis', *PLOS ONE*, 19(5), p. e0303385.
37. Recht, M.P., Resnick, D. (1994). 'Magnetic resonance imaging of articular cartilage: an overview', *Topics in Magnetic Resonance Imaging*, 6(4), pp. 229-238.
38. Hayashi, D., Roemer, F.W., Katur, A., Felson, D.T., Yang, S.O., Alomran, F. and Guermazi, A. (2011). 'Imaging of synovitis in osteoarthritis: current status and outlook', *Seminars in Arthritis and Rheumatism*, 40(6), pp. 541-554.
39. Lee, S., Nardo, L., Kumar, D., Wyatt, C.R., Souza, R.B., Lynch, J., McCulloch, C.E. and Link, T.M. (2016). 'Longitudinal assessment of MRI in hip osteoarthritis using SHOMRI and correlation with clinical progression', *Seminars in Arthritis and Rheumatism*, 45(6), pp. 648-655.
40. Peterfy, C.G., Guermazi, A., Zaim, S., Tirman, P.F., Miaux, Y., White, D., Kothari, M., Lu, Y., Fye, K. and Zhao, S. (2004). 'Whole-Organ Magnetic Resonance Imaging Score (WORMS) of the knee in osteoarthritis', *Osteoarthritis and Cartilage*, 12(3), pp. 177-

190.

41. Mandl, P., Navarro-Compán, V., Terslev, L., Aegerter, P., van der Heijde, D., D'Agostino, M.A., Baraliakos, X., Pedersen, S.J., Juhl, C.B., Gandjbakhch, F., Tarp, S., Balint, P.V., Bruyn, G.A., Filippucci, E., Giraud, S., Hammer, H.B., Kortekaas, M.C., Naredo, E., Schmidt, W.A., Smolen, J.S., Wakefield, R.J., Conaghan, P.G. and the EULAR task force on imaging (2017). 'EULAR recommendations for the use of imaging in the clinical management of peripheral joint osteoarthritis', *Annals of the Rheumatic Diseases*, 76(9), pp. 1484-1494.
42. Thustochowicz, M. and Thustochowicz, W. (2022). 'Recommendations for the use of imaging and management of osteoarthritis in the light of current guidelines', *Rheumatology Forum*, 8(1), pp. 1-8.
43. American College of Radiology (ACR) (2012). 'ACR Appropriateness Criteria® Chronic Knee Pain'.
44. Mobasheri, A., Bay-Jensen, A.C., van Spil, W.E., Larkin, J. and Levesque, M.C. (2021). 'Osteoarthritis Year in Review 2016: biomarkers (biochemical markers)', *Osteoarthritis and Cartilage*, 25(2), pp. 199-208.
45. Hunter, D.J., Arden, N., Conaghan, P.G., Eckstein, F., Gold, G., Grainger, A., Guermazi, A., Harvey, W., Jones, G., Hellio Le Graverand, M.P., Laredo, J.D., Lo, G., Losina, E., Mosher, T.J., Roemer, F. and Zhang, W. (2011). 'Definition of osteoarthritis on MRI: results of a Delphi exercise', *Osteoarthritis and Cartilage*, 19(8), pp. 963-969.
46. Roemer, F.W., Demehri, S., Omoumi, P., Link, T.M., Kijowski, R., Saarakkala, S., Crema, M.D. and Guermazi, A. (2023). 'Imaging in osteoarthritis: from old to new knowledge', *Radiology*, 308(3), p. e223223.

47. Lowry, F. (2008). 'MRI May Be Overused in Diagnosing Knee Osteoarthritis', *Medscape*.
48. Podlipská, J., Guermazi, A., Lehenkari, P., Niinimäki, J., Roemer, F.W., Arokoski, J.P., Kaukinen, P., Liukkonen, E., Lammentausta, E., Nieminen, M.T., Tervonen, O., Saarakkala, S. and Koski, J.M. (2022). 'Diagnostic accuracy of magnetic resonance imaging (MRI) for symptomatic knee osteoarthritis: a scoping review', *Quantitative Imaging in Medicine and Surgery*, 12(12), pp. 5440-5471.
49. OARSI (Osteoarthritis Research Society International) (no date). 'OARSI Guidelines'.
50. Zhao, S., Li, W., Zhou, Z., Li, M., Wang, Y., Li, Y., Liu, Y., Chen, Y., Zhao, Z. and Liu, Y. (2023). 'Artificial intelligence in osteoarthritis detection: A systematic review and meta-analysis', *Osteoarthritis and Cartilage*, 31(12), pp. 1576-1589.
51. Hayashi, D., Guermazi, A. and Kwok, C.K. (2016). 'Advanced Imaging in Osteoarthritis', *Sports Health*, 8(5), pp. 418-428.
52. Xu, H., Li, W., Zhu, Y., Zhang, Y., Liu, Y., Zhang, Z. and Wang, Y. (2023). 'Diagnostic Accuracy of Ultrasound for Assessment of Synovial Inflammation in Knee Osteoarthritis: A Systematic Review and Meta-Analysis', *Ultrasound in Medicine & Biology*, 49(10), pp. 2099-2108.