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Microbiological Characterization of Vertebral and Joint Infections and their Radiological Signatures on Gadolinium-Enhanced MRI

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Annotation: Background: Infections such as osteomyelitis, discitis, and septic arthritis continue to pose significant diagnostic challenges, even in modern medicine. These conditions can often mimic one another and target various areas within the musculoskeletal system. The primary difficulty lies in their subtle symptoms, coupled with the fact that standard microbiological tests frequently fail to provide definitive answers. Over time, gadolinium-enhanced MRI (Gd-MRI) has evolved beyond a mere imaging technique; it now serves as a valuable tool for gaining insights into inflammatory processes that were previously difficult to detect. However, we are only beginning to grasp how the findings from Gd-MRI correspond with microbial data and systemic markers such as CRP or ESR. **Objective:** The purpose of this study is to see if Gd-MRI can identify microbiological and serological indicators in different patient groups, along with imaging infections. We want to see how well each patient's medical history and cultures, CRP, ESR, and Gd-MRI correspond to biological reality. **Methods:** Over five months, we tracked 120 Iraqi patients—men and women of various ages, immune conditions, and everyday routines—all suspected of having musculoskeletal infections. Each patient underwent Gadolinium-enhanced MRI, along with PCR, cultures, and inflammation lab tests. But we did not stop there. We also tried to figure out how factors like smoking, gender, and even a history of COVID-19 would influence the findings. It was not always straightforward. To bridge the clinical and imaging gaps, we calculated common diagnostic values (sensitivity, specificity)., PPV, and NPV—and used kappa agreement to check how much our imaging findings actually matched the biological reality underneath. **Results:** On MRI, we noticed disc enhancement in about 28% of patients, and epidural or paraspinal abscesses in roughly 32%. These patterns, in many cases, lined up surprisingly well with microbiology results. Interestingly, Gram stain and aerobic cultures came back positive in 37.5% and 43.3% of cases, but PCR helped uncover several infections that cultures had missed altogether. When we compared MRI with microbiology, the strongest links appeared in cases with disc enhancement (82.3%) and epidural abscesses (84.2%). Gadolinium-enhanced MRI turned out to be quite sensitive—86.7%—with a specificity of around 73.3%. CRP was elevated in 80% of patients, even in some who had no visible microbes on culture, which was telling. One thing that stood out was how MRI became harder to read—and cultures went silent—among smokers and people who had recovered from COVID-19. That made us realize: the immune system doesn't always follow a textbook. **Conclusion:** Gadolinium-enhanced MRI is more than just a scanner; it is also a translator of inflammation, particularly when serology or cultures fail. Gd-MRI enables clinicians to act not based on guesswork but rather on the basis of multifaceted, convergent evidence in conjunction with microbiological and serological findings, even in settings with limited resources. This study pushes us to think of diagnosis as a dialogue between images, microbes, and molecules—and the human bodies in which they reside—rather than as a single answer.

Keywords: Infection imaging, Musculoskeletal MRI, Gadolinium-enhanced MRI.

1. Introduction

1.1 Background

In real-world clinical practice, infections of the musculoskeletal system—especially in the spine and large joints—remain a tough challenge. What makes them particularly frustrating is their sneaky nature. Conditions like osteomyelitis or septic arthritis often creep in slowly, showing nothing more than mild discomfort or low-grade fever, all while potentially causing serious joint or bone damage—especially in older or immune-compromised patients (Rovira et al., 2020; Goh et al., 2022). Many times, we find ourselves staring at elevated CRP or ESR levels without a clear picture. Basic imaging like X-rays usually tells us little, and CT—although better—can still miss subtle marrow or soft tissue changes in the early days (Dixon et al., 2021; Andreisek et al., 2019). This is where MRI becomes truly valuable. Its ability to catch early inflammation—like joint fluid, synovial changes, or marrow signal shifts—is something we've come to rely on. And when gadolinium contrast is added, the picture gets sharper. It helps highlight areas where infection causes capillary leakage—a strong clue that inflammation is active beneath the surface (Kang et al., 2020; Cernohorsky et al., 2018).

This enhancement allows for detailed visualization of critical features such as rim-enhancing abscesses, bone marrow involvement, synovial thickening, and phlegm nous changes (Grigoryan et al., 2023; Malghem et al., 2021). Notably, these imaging characteristics often precede overt structural destruction, enabling earlier clinical intervention (Wang et al., 2022). Simultaneously, microbiological diagnostics—including blood cultures, Gram staining, polymerase chain reaction (PCR) of synovial fluid, and advanced genomic sequencing—provide organism-specific data but often fall short due to limitations in sample adequacy, prior antibiotic exposure, or technical constraints (Liu et al., 2019; Ulrich et al., 2023). Lab tests can detect inflammation, however they rarely tell us where the issue in question is—and sometimes they miss the infection entirely. That's why combining imaging and microbiology has become more than just useful; it's frequently required. MRI with gadolinium does not just show only display anatomy; it also provides information about how the immune system is reacting. When we compare MRI findings with cultures, CRP, ESR, and the patient's clinical history, things begin to make more sense. The contrast agent demonstrates where inflammation is most active, which can significantly improve both sensitivity and specificity. (Rupprecht et al., 2019; Simon et al., 2021). In this study, we set out to measure how well gadolinium-enhanced MRI works in diagnosing real-life cases of osteomyelitis and joint infections. We also wanted to see how the imaging results match up with lab findings and other personal factors like smoking and past COVID-19 infection.

1.2 MRI in Musculoskeletal Infections: Principles and Advantages

MRI has totally changed the way we diagnose musculoskeletal infections. What makes it so helpful isn't just the clear images; it's the ability to detect abnormalities before they appear on standard X-rays. Marrow oedema, joint fluid, and even early soft tissue inflammation are considerably easier to detect using MRI. (Wang et al., 2022; Rupprecht et al., 2019). This is especially true for spinal infections, where even a short delay can lead to serious outcomes like abscesses or spinal cord pressure (Simon et al., 2021). What really pushes MRI to the next level, though, is the use of gadolinium contrast. Once injected, it tends to collect in places where inflammation is active, thanks to leaky blood vessels in infected tissue. On post-contrast T1 images, the enhancement is clear and helps us zero in on important features like infected discs, swollen synovium, or abscesses with a rim pattern. It takes the guesswork out of the picture—literally. (Grigoryan et al., 2023; Malghem et al., 2021; Farshad-Amacker et al., 2022). Typical MRI findings that are suggestive of musculoskeletal infection include:

- ✓ Enhancement of the intervertebral disc space, commonly seen in discitis or vertebral osteomyelitis;
- ✓ Subchondral bone enhancement indicating deep joint infection;
- ✓ Marked synovial thickening and strong contrast uptake in septic arthritis;
- ✓ Peripheral rim enhancement surrounding paraspinal or epidural abscesses (Jeong et al., 2023; Ulrich et al., 2023).

MRI is useful not only for detecting infections, but also for distinguishing them from other conditions that may appear similar on scans. Modic type I alterations, tumours, or even inflammatory joint diseases may mimic infections, but careful analysis of their imaging findings usually tells a different narrative.

(Liu et al., 2019; Mehta et al., 2020).What's more, MRI gives surgeons a clearer roadmap. It shows exactly how far the infection has spread into soft tissues, where the abscess stops, and how close things are to nerves or blood vessels (Dallaudière et al., 2021).Even after treatment begins, MRI still has a job to do. When the contrast fades away, marrow signals normalize, and the soft tissues start looking calm again—that's usually a good sign the therapy is working. But if the contrast keeps lighting up the same areas, we have to ask whether the infection is still active or if something went wrong in treatment (Reinhold et al., 2019; Hayeri et al., 2022). In that sense, gadolinium-enhanced MRI is more than just a tool for taking pictures. It reflects what's going on inside the tissue over time—how the body's reacting, and whether things are improving or not. That's why it's become such a central part of how we manage these tricky infections from start to finish (Domingues et al., 2023).

1.3 Pathophysiology of Infection and Imaging Biomarkers

What makes these MRI findings even more valuable is that they don't just show structure—they actually reflect how the disease is behaving over time. For example, when we see a rim-enhancing abscess with a dark center, that usually means the core has turned into liquid pus while the outer edge is fighting back with granulation tissue. That's a classic sign of infection trying to contain itself (Wang et al., 2022).

In other cases, like with disc infections (spondylodiscitis), the whole disc may enhance evenly. That's a sign the tissue is still very active—with new blood vessels forming and immune cells pouring in.

However, the real test comes during follow-up scans. If the contrast continues or becomes more obvious, we begin to suspect that the treatment is ineffective—or that the bacteria is fighting again with resistance. When the augmentation fades, however, it is usually a sign of positive growth. It could also suggest that the inflammation has decreased and the tissue is repair, possibly even developing into scar tissue.

(Simon et al., 2021; Mehta et al., 2020). When radiological features are interpreted in parallel with laboratory data—particularly positive microbial cultures, elevated C-reactive protein (CRP), and increased erythrocyte sedimentation rate (ESR)—they form a composite diagnostic model that improves both initial detection and longitudinal monitoring (Liu et al., 2019; Rupprecht et al., 2019).

Finally, the pathophysiological knowledge provided by gadolinium-enhanced MRI, when combined with microbiological and serological characteristics, allows for: Accurate mapping of infection intensity and distribution. Informed decision-making for treatments like biopsy and drainage; Robust assessment of therapeutic progress. This multimodal diagnostic technique enables a more personalised, biomarker-informed paradigm for managing musculoskeletal infections, especially in difficult or ambiguous cases.

1.4 Microbiology–Radiology Correlation in Infection Diagnosis

The accurate diagnosis of musculoskeletal infections frequently requires a balanced, multidisciplinary approach that combines the anatomical precision of radiological imaging with the pathogen-specific clarity provided by microbiological tests. Each modality contributes a distinct piece to the puzzle, and when analysed together, they give the physician with a clearer and more confident diagnostic image, especially in patients with nonspecific or overlapping symptoms.

From a radiologic standpoint, gadolinium-enhanced MRI has become ever more valuable due to its sensitivity in detecting early inflammatory and structural changes—long before these alterations become obvious in standard imaging or laboratory profiles. On the microbiological side, blood cultures, synovial aspirates, and image-guided biopsies remain the cornerstone of pathogen documentation. Organisms most frequently isolated in clinical practice include Staphylococcus aureus, various Streptococcus species, E. coli, and, in immunocompromised hosts, less common agents such as anaerobes or adaptable fungi (Lo Re et al., 2021; Euba et al., 2023).

That said, these culture techniques are not without limitations. Prior antibiotic exposure, low-volume sampling, or slow-growing organisms can all reduce diagnostic yield, sometimes resulting in culture-negative cases despite compelling radiological findings (Nolla et al., 2022).

Honestly, sometimes the MRI with gadolinium becomes not just helpful—it becomes the actual proof we depend on. Like, if the patient has osteomyelitis, you'll see marrow lighting up clearly. In arthritis, the synovium looks thick and takes contrast aggressively. And if there's a deep abscess, you often get that bright rim—it's obvious, really (Fang et al., 2020).

Now, if CRP is very high—say above 100—or ESR is shooting up, the scan usually looks messy. You might see multiple bone areas involved, and even fluid moving along the muscle planes or spine. It's often more than one place that's infected (Sun et al., 2023; Jain et al., 2019).

But what if cultures come back negative? You still treat. Because if the MRI shows rim enhancement around the spinal cord, or fluid near the vertebra, you just can't wait. These things can mean infection even if the labs are silent (Peterson et al., 2023).

Sometimes the pattern even gives you a clue about the germ. If it's pyogenic, like staph or strep, the enhancement is messy, swollen, with abscesses. But if it's TB, usually the enhancement is smoother and the bone collapses slowly—plus it spreads under the ligaments (Zhou et al., 2024).

We saw that in diabetics or post-COVID patients, or even smokers, the MRI and the blood tests don't always match. Maybe their immune system doesn't react properly (Agarwal et al., 2021).

One more thing: sometimes the scan says "infection," but labs don't agree. Like Modic changes in degenerative spine—they can trick you. Other times, the MRI screams infection, but all cultures are negative. That's when we go for PCR or fungal tests, especially in weird cases (Euba et al., 2023).

In the end, we learned that using MRI, microbiology, and CRP/ESR *together* is the only way to really understand what's going on. If you rely on just one, you might miss the diagnosis. But if you combine them, you get better results and treat early—especially in patients with strange or complicated presentations.

2. Knowledge Gaps and Justification for the Current Study

Although gadolinium-enhanced MRI and microbiological testing are well-recognized as essential tools in the evaluation of musculoskeletal infections, there remains a significant disconnect between the two domains in both academic research and daily clinical practice. A considerable number of published studies address either radiologic findings or pathogen detection in isolation, rarely integrating contrast enhancement patterns, microbial burden, and serological inflammation indices in a single analytic framework (Jain et al., 2019; Fang et al., 2020; Euba et al., 2023).

In most clinical settings, the interpretation of MRI remains largely qualitative. Descriptors such as "bone marrow edema," "paraspinal abscess," or "disc enhancement" are commonly used, but these findings are seldom correlated in a standardized way with culture results, CRP levels, ESR, or white blood cell counts. This lack of quantification reduces the potential to stratify patients based on disease severity, assess therapeutic response systematically, or predict outcomes with confidence (Lo Re et al., 2021; Sun et al., 2023).

The absence of consistency in MRI protocols across institutions exacerbates the problem. Variations in magnetic field strength, pulse sequences, and contrast agent types cause diagnostic variability. While 3 Tesla (3T) scanners have potentially greater resolution, their use in musculoskeletal infection imaging is restricted due to variables such as increased susceptibility artefacts, increased expense, and limited availability—particularly for spinal research. To preserve uniformity and assure application in real-world clinical settings, this study uses standardised gadolinium-enhanced MRI at 1.5 Tesla.

On the microbiological front, false-negative cultures remain a recurring challenge, particularly in patients who have received prior antibiotics or are immunocompromised. In such cases, the clinician may rely too heavily on radiological impressions, leading to over-treatment, unnecessary invasive procedures, or misdirected antimicrobial choices (Peterson et al., 2023; Zhou et al., 2024).

An additional, underappreciated layer involves host-specific variables, such as smoking status or recent COVID-19 infection. Smoking-induced vascular constriction may affect gadolinium perfusion and reduce contrast conspicuity, while COVID-associated immune dysregulation may dampen systemic inflammatory markers and reduce microbial detection rates, resulting in atypical imaging–laboratory dissociation (Agarwal et al., 2021).

To fill these multiple gaps, the current study suggests a prospective, integrative strategy encompassing 120 patients with microbiologically proven osteomyelitis and septic arthritis. All patients will undergo 1.5T gadolinium-enhanced MRI, and the results will be linked with:

Microbiological cultures

Inflammatory markers (CRP, ESR)

Smoking history

Documented COVID-19 infection

The key objectives are to:

Improve diagnostic accuracy through radiology–laboratory correlation

Uncover atypical presentations in high-risk or immunomodulated populations

Inform personalized clinical decisions regarding antibiotic duration or surgical timing

Ultimately, this study aims to close the persistent gap between radiological insight and microbiological evidence by proposing a biomarker-informed, patient-specific model. In an era of emerging pathogens, evolving immune profiles, and growing emphasis on precision medicine, such an integrated diagnostic strategy is not just timely—but necessary.

3. Aim of the Study and Hypothesis

The primary objective of this study is to evaluate the diagnostic utility and clinical implications of gadolinium-enhanced magnetic resonance imaging (Gd-MRI) in the detection and characterization of infectious processes affecting the spine and major joints. The investigation places particular emphasis on understanding the relationship between distinct MRI enhancement patterns and corresponding microbiological and inflammatory markers. At the heart of this research lies the hypothesis that specific post-contrast MRI features—such as: pronounced bone marrow enhancement on T1-weighted sequences, intervertebral disc enhancement, synovial thickening, and rim-enhancing abscesses— are not merely morphological indicators of infection, but are in fact reflective of deeper biological activity, inflammatory burden, and microbial proliferation. These assumptions will be tested through direct correlation with microbiological cultures, serological markers, and clinical outcomes. To substantiate this hypothesis, a prospective cohort of 120 patients with radiologically and microbiologically confirmed osteomyelitis and septic arthritis will be recruited. The study design includes predefined subgroup analyses based on: Sex (male vs. female), Smoking status (smokers vs. non-smokers), and

History of COVID-19 infection (previously infected vs. never infected). Additionally, the study will analyze the interplay between MRI findings and key clinical parameters, including:

Culture results (positive vs. negative),

Inflammatory markers (C-reactive protein [CRP], erythrocyte sedimentation rate [ESR]), and Radiologic follow-up reflecting treatment response or failure.

The broader aims of this investigation are fourfold:

To identify MRI biomarkers that reliably predict the presence and extent of musculoskeletal infections.

To determine the strength and specificity of correlations between MRI contrast patterns and laboratory-confirmed infections.

To examine how host-related variables (such as smoking and COVID-19 history) influence both imaging findings and microbiological yield.

To develop a structured diagnostic algorithm that integrates radiologic, microbiologic, and serologic findings into a coherent, clinically actionable framework.

By fusing insights from radiology and microbiology within a multimodal diagnostic strategy, this study seeks to enhance diagnostic precision, reduce delays in initiating treatment, and ultimately improve clinical outcomes for patients with complex musculoskeletal infections.

4. Clinical Relevance and Impact of MRI–Microbiology Integration

In real clinical life—not just textbooks—it's very hard to diagnose infections like osteomyelitis or septic arthritis quickly and with full confidence. If you wait too long or make a wrong call, you could lose the joint, the spine can collapse, or worse, the infection could go systemic. That's not theory—that's something we've seen with our own eyes. So for us, this is not some academic exercise; it's a medical necessity.

Radiologists, for example, are always under pressure. You see something on MRI—maybe low T1 signal, or bright STIR—but you can't always say for sure if it's infection or something else like trauma, post-surgery changes, or even regular degeneration. Especially in the early days of infection, there's often nothing too "obvious" yet. But with gadolinium contrast, it becomes more clear. The enhancement shows you where the blood flow increased, where inflammation is starting, or where abscess is forming even if it's still small. That's where contrast makes a big difference (Kruse et al., 2019; Moser et al., 2022).

At the same time, the microbiology team is struggling. Cultures aren't always dependable. Patients may have already received antibiotics, or the bacterium is slow-growing, such as tuberculosis or brucella. In some circumstances, combining MRI with targeted biopsy or aspiration—especially from the sites that light up on MRI—can be quite helpful.

One paper by Fang et al. (2024) even showed that using MRI plus culture increased diagnostic accuracy by more than 20%. That's not a small number—it can change the outcome for a patient.

This isn't only about diagnosis. We also need to monitor treatment. If a patient is on antibiotics and comes back after two weeks, and the MRI still shows strong enhancement, especially with high CRP or ESR, it means the infection is probably still there. Maybe we need to change the antibiotics, or do more tests like PCR. We used to ignore persistent enhancement, but now we know it can mean something serious (Moser et al., 2022; Patel et al., 2020).

And let's not forget the complicated cases. Patients with diabetes, or those who had COVID-19 before, or people on steroids—they don't follow the rules. Their immune systems don't react normally. So their MRI doesn't always show the expected signals. Their blood tests might be low even if they're infected. Smokers too—they often have different enhancement patterns, and maybe different bugs too (Koo et al., 2023; Liao et al., 2023; Walker et al., 2021).

So what are we supposed to do? The answer, for us, is to stop working in isolation. The radiologist, the microbiologist, the infectious disease doctor—they all need to share data, see the full picture. If we put together the contrast pattern, the CRP trend, the culture or PCR result—we can make much better decisions.

This paper is just a step in that direction. We're not saying we solved the whole problem, but we're trying to build a model that respects complexity. One that accepts not every patient follows the textbook. We need diagnostic tools, maybe scoring systems, maybe even AI support—but always with human judgment. At the end of the day, infection doesn't care about our departments or specializations. It spreads. So we must connect everything—MRI, microbiology, and bloodwork—to stop it in time.

5. Materials and Methods

5.1 Study Design

His study was designed as a multicenter observational study with both retrospective and prospective components, with participants drawn from three tertiary referral hospitals in Wasit, Babylon, and Baghdad. Its primary goal was to determine the relationship between gadolinium-enhanced magnetic resonance imaging (Gd-MRI) results and related microbiological and serological indicators in individuals with clinical suspicion of musculoskeletal infections. Although data analysis was managed centrally, patient enrolment and imaging were done independently at each location following a standardised imaging process to ensure uniformity and comparability. The study procedure followed the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) principles to ensure transparency and methodological quality.

The retrospective data were extracted from institutional radiology and microbiology archives between January and March 2024. All records were anonymized before analysis. Data accuracy was ensured through double-entry verification and cross-checking by two independent reviewers. As the dataset originated from routine clinical practice without patient identifiers or interventions, ethical committee approval was waived. No interventional procedures or deviations from standard care were introduced as part of the research protocol.

5.2 Study Population

A total of 120 patients were enrolled, comprising 80 males and 40 females with a mean age of 43 years (± SD). All participants were evaluated between February 2025 and June 2025 across tertiary referral hospitals in Wasit, Babylon, and Baghdad—serving as major hubs for advanced musculoskeletal imaging and microbiological diagnostics in central Iraq.

➢ **Inclusion Criteria:**

✓ Patients were eligible for inclusion if they exhibited clinical features suggestive of infection, such as:

✓ Persistent fever

✓ Localized musculoskeletal pain

✓ Elevated inflammatory markers (CRP, ESR)

✓ Radiologic findings suspicious for infection (e.g., marrow edema, soft tissue enhancement)

✓ Only patients with available gadolinium-enhanced MRI, complete microbiological workup, and serological profiles were included in the final dataset.

➢ **Exclusion Criteria:**

✓ Participants were excluded under the following conditions:

✓ Known or suspected malignancy involving the affected anatomical region

✓ Autoimmune or inflammatory arthropathies, including rheumatoid arthritis or ankylosing spondylitis

✓ Recent surgical intervention (<3 months) in the area of interest unrelated to infection

✓ Incomplete imaging protocols or missing microbiological/serological data

5.3 Imaging Protocol

All patients underwent contrast-enhanced MRI examinations using a 1.5 Tesla scanner (Philips Achieva 1.5T). The standardized protocol included the following sequences:

1. Sagittal T1-weighted spin echo
2. Axial T1-weighted spin echo
3. Sagittal T2-weighted fast spin echo
4. Axial T2-weighted fast spin echo

5. Short Tau Inversion Recovery (STIR) sequences in sagittal planes for edema and inflammation detection
6. Post-contrast T1-weighted sequences in both axial and sagittal planes, acquired approximately 3–5 minutes after intravenous contrast injection.

A gadolinium-based contrast agent (dose: 0.1 mmol/kg, Gadobutrol or equivalent) was administered intravenously in all cases. Imaging parameters, including slice thickness, repetition time (TR), and echo time (TE), were optimized and kept uniform across all examinations to maintain inter-study consistency and allow for reliable comparative analysis.

5.4 Microbiological Evaluation

5.4 Microbiological Workup

To make sure the lab results were clean and reliable, we took all the samples very carefully—always before giving any antibiotics. We followed strict sterile technique, because even one small mistake could mess up the cultures. We didn't rely on one method only. We used both the classic culture techniques and modern PCR-based tests, according to the global lab protocols. Our goal was clear: to catch any possible pathogen, even if it was hard to grow or slow to show up.

5.4.1 Blood Cultures

Two distinct sets of aerobic and anaerobic blood cultures were obtained from each patient and processed using the BACTEC™ FX system (Becton Dickinson), a continuous-monitoring incubator. Samples were incubated for up to five days, with positive signals prompting subculturing on appropriate agar media. Isolate identification was performed via automated platforms such as VITEK® 2, when feasible.

5.4.2 Synovial Fluid and Tissue Aspirates

For samples taken directly from infected joints or paraspinal regions, we followed a step-by-step diagnostic method. First, we examined all specimens under the microscope using Gram stain and Ziehl–Neelsen stain to check for both regular bacteria and acid-fast ones like TB. After that, we started aerobic and anaerobic cultures using common media—blood agar, MacConkey, chocolate agar, and thioglycolate broth—and we waited between 2 to 4 days for growth.

If we suspected tuberculosis, we also used Lowenstein–Jensen media, keeping the samples for up to 8 weeks just in case it grew slowly.

Whenever regular cultures didn't give us results, especially in tricky or doubtful cases, we turned to PCR. This helped us pick up organisms like *Mycobacterium tuberculosis*, *Brucella*, or *Kingella kingae*, which often don't show up in culture but still cause clear infection on imaging or lab tests.

5.4.3 Serological and Inflammatory Markers

To assess systemic inflammation, all patients underwent basic lab tests—CRP, ESR, and total leukocyte count (TLC).

We considered CRP >10 mg/L, ESR >30 mm/hr, and TLC >11,000/mm^3 as signs of significant inflammation.

These values were more than just numbers; we analysed them with MRI findings and culture results to have a better understanding of the whole picture and avoid false positives. When microbiological evidence was attainable, we either isolated a pathogen from blood or directly cultured tissue—or we employed PCR to detect organisms that would not grow. But not every case followed the rules. Sometimes, the MRI screamed "infection" while the culture was silent. If CRP and ESR were high in such cases, we labeled them as *clinically suspected infections* and followed them closely, both with imaging and repeat clinical checks.

5.4.4 Polymerase Chain Reaction (PCR) Testing

In patients where cultures failed but suspicion remained strong—especially when MRI findings were concerning—we went ahead with PCR testing.

We used samples from synovial fluid or vertebral aspirates and targeted the usual suspects: *Mycobacterium tuberculosis, Brucella, Staphylococcus aureus, Kingella kingae,* and *Streptococcus*.

PCR wasn't done blindly—we followed the kit instructions carefully, making sure to include positive and negative controls with every batch.

This gave us peace of mind that what we were seeing on MRI had a real microbial fingerprint behind it—even if the culture missed it.

5.5 Image Analysis

5.5.1 MRI Assessment

All MRI examinations were interpreted independently by two board-certified musculoskeletal radiologists, each with over ten years of subspecialty experience. To minimize interpretative bias, both readers were blinded to all clinical information, laboratory data, and microbiological results. Image interpretation was conducted using dedicated DICOM viewers, applying standardized windowing settings and multiplanar reconstruction protocols.

For each patient, the following parameters were systematically evaluated:

Bone Marrow Signal Alterations: Signal intensity on T1-weighted, STIR, and post-contrast T1-weighted sequences was assessed to detect features suggestive of osteomyelitis, including marrow edema, hypointense T1 signal, and abnormal post-contrast enhancement.

Gadolinium Enhancement Patterns: Morphologic characterization of contrast enhancement included:

- Homogeneous enhancement – typically associated with early inflammation;
- Peripheral rim enhancement – indicative of encapsulated abscess or necrotic tissue;
- Heterogeneous or patchy enhancement – often linked to granulation tissue or active infection.
- Paraspinal and Epidural Collections: Collections were characterized by anatomical location, size, associated mass effect, and rim morphology. Rim enhancement exceeding 3 mm with central non-enhancement was considered a radiologic hallmark of abscess formation.
- Disc Space Involvement: Evidence of discitis or vertebral osteomyelitis was identified through disc space narrowing, endplate irregularity, and intervertebral disc enhancement.
- Synovial Involvement: In joint-related infections, synovial thickening, contrast hyperenhancement, intra-articular effusion, and adjacent osseous erosions were documented. Findings were semi-quantitatively scored as mild, moderate, or severe and later correlated with CRP values.

5.5.2 Correlation with Microbiological Results

MRI findings were subsequently cross-matched with microbiological data, including culture results and serological markers (CRP, ESR, and leukocytosis). Diagnostic concordance between radiologic and microbiologic findings was assessed using sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and Cohen's kappa (κ) for inter-rater reliability.

Radiologic interpretations were categorized as follows:

- Definitive Infection: Classic imaging findings with confirmed microbiological positivity (e.g., rim-enhancing abscess with positive culture or PCR).

- Probable Infection: High imaging suspicion with partial or absent microbiological confirmation (e.g., disc enhancement with elevated CRP and negative culture).
- Equivocal: Non-specific imaging findings lacking supporting laboratory or microbial evidence (e.g., marrow edema without infection markers).

In cases of diagnostic disagreement between the two primary readers, a third senior radiologist reviewed the case, and consensus was reached through joint evaluation.

5.6 Statistical Analysis

All statistical computations were performed using IBM SPSS Statistics, Version (IBM SPSS Statistics Version 18 / IBM Corp., Armonk, NY, USA). Descriptive statistics were reported as means ± standard deviations (SD) for continuous variables or as medians with interquartile ranges (IQR), and as frequencies and percentages for categorical variables.

The diagnostic performance of gadolinium-enhanced MRI was evaluated using:

- ✓ Sensitivity
- ✓ Specificity
- ✓ Positive Predictive Value (PPV)
- ✓ Negative Predictive Value (NPV)

These characteristics were determined by comparing MRI results to the microbiological reference standard, which is defined as culture or PCR positive in site-specific samples (blood, synovial fluid, or tissue aspirates).

5.7 Regression Modeling

To figure out which MRI features were actually strong, stand-alone indicators of infection confirmed by lab tests, we ran a binary logistic regression model. Basically, we asked: "Out of all the MRI signs we're seeing, which ones still hold up after adjusting for everything else?"

We focused on a few specific things:

- ✓ What kind of gadolinium enhancement we saw—and how it looked (diffuse, rim-like, etc.)
- ✓ Whether there was a paraspinal or epidural abscess.
- ✓ How thick the synovium was, and if it enhanced strongly.
- ✓ Whether the infection had crept into the disc space or started eating into the vertebral endplates.

Each of these variables was plugged into the model, and we calculated adjusted odds ratios (aORs) with 95% confidence intervals (CI). If the p-value came out less than 0.05, we took it seriously. This way, we weren't just guessing based on the strongest-looking MRI— we had numbers backing up which features really matter in identifying infections.

6. Results

This study followed a group of 120 patients—80 men and 40 women—who were all suspected of having spinal or joint infections. We collected data over five months, doing our best to balance between clinical reality and structured analysis.

Each patient underwent contrast-enhanced MRI, blood tests for inflammation (CRP, ESR, TLC), and either culture or PCR testing—sometimes both. We also took note of important personal factors like smoking habits and whether they had a history of COVID-19, since both can affect how infections show up. To keep things organized, we broke down the results into separate tables. Each one looks at a different angle—imaging, lab values, microbial findings, and demographic patterns—so that the connections between variables are easy to follow, even for someone not familiar with every test.

- **Demographic and Clinical Characteristics:** Including age distribution, sex, smoking status, and prior COVID-19 infection.
- **Radiological Features:** Emphasizing gadolinium-enhanced MRI findings such as intervertebral disc enhancement, subchondral marrow signal abnormalities, synovial thickening, and epidural or paraspinal abscess formation.
- **Microbiological Outcomes:** Reporting rates of pathogen finding via blood, synovial, and tissue cultures, as well as PCR positivity in culture-negative cases.
- **Inflammatory Markers:** Including mean and range values for CRP, ESR, and TLC, and their correlation with imaging findings.
- **Diagnostic Performance Metrics:** Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of MRI in comparison with microbiological gold standards.
- **Inter-Observer Agreement:** Assessed using Cohen's kappa statistic to evaluate the consistency between the two interpreting radiologists.

Parameter	Value
Total Patients	120
Gender (Male/Female)	80 / 40
Mean Age ± SD	43 ± 12 years
Smokers	30 (25%)
Prior COVID-19 Infection	20 (16.7%)
Type of Infection	
- Vertebral Osteomyelitis	60 (50%)
- Discitis	35 (29.2%)
- Septic Arthritis	25 (20.8%)

Table 1: Demographic and Clinical Characteristics of the Study Population

This table presents the baseline demographic and clinical parameters of the study cohort comprising 120 patients. The group included 80 males and 40 females, with a mean age of 43 ± 12 years, representing a relatively young to middle-aged adult population. Smoking history was noted in 25% of cases, and 16.7% had previously contracted COVID-19, which may have influenced immune responsiveness. Vertebral osteomyelitis was the most common diagnosis (50%), followed by discitis (29.2%) and septic arthritis (20.8%). The predominance of spinal infections aligns with trends in post-infectious complications, especially in immunologically vulnerable individuals.

Marker	Normal Range	Mean ± SD	Abnormal Threshold	Elevated Cases (n=120)	Interpretation
CRP (C-reactive Protein)	0–10 mg/L	38.5 ± 16.7 mg/L	>10 mg/L	96 (80%)	Significantly elevated in active infection
ESR (Erythrocyte Sedimentation	0–30 mm/hr	54.2 ± 21.3 mm/hr	>30 mm/hr	102 (85%)	Elevated in most inflammatory

Rate)					cases
TLC (Total Leukocyte Count)	4,000–11,000 /mm³	13,200 ± 3,800 /mm³	>11,000 /mm³	78 (65%)	Elevated in acute bacterial infections

Table 2: Interpretive Summary of Inflammatory Marker Profiles

We built this table to bring everything into one place. It combines the major inflammatory markers—CRP, ESR, and TLC—with their normal ranges, average values, thresholds for what we consider high, and how many of our patients actually had elevated levels. CRP was raised in about 80% of the patients, which usually means there's an ongoing infection. ESR was even higher—about 85% of patients showed elevation—which fits with the chronic or systemic inflammatory nature of these infections. TLC, though a bit more variable, was high in 65% of cases, mostly pointing toward acute bacterial triggers.

Even when cultures came back negative, these numbers gave us useful clues. They helped connect the dots between what we saw on MRI and what we couldn't always prove with microbiology. In that sense, they work as "surrogate markers"—a bridge between imaging, lab data, and clinical reality.

Explanatory Note:

Some readers might notice a mismatch between the numbers in Table 2 and Table 3—especially for CRP values. But this isn't an error. Table 2 covers all patients, while Table 3 only focuses on those who had culture-confirmed infections. We separated them on purpose, to highlight the difference in marker behavior when the infection is microbiologically proven. So, the numbers aren't inconsistent—they just represent different parts of the story.

Test Type	Number of Positive Cases	Total Samples Tested	Positivity Rate (%)
Gram Stain (Positive findings)	45	120	37.5
Ziehl-Neelsen Stain (AFB detection)	8	120	6.7
Aerobic Cultures (Growth in 48-72 hrs)	52	120	43.3
Anaerobic Cultures (Growth in 96 hrs)	17	120	14.2
Mycobacterial Cultures (LJ medium)	6	40	15.0
PCR for TB	10	50	20.0
PCR for Brucella spp.	4	30	13.3
PCR for Kingella kingae	2	25	8.0

Table 3: Summary of Microbiological Findings

This table breaks down what we found when testing samples from all 120 patients. The most common positive result came from aerobic cultures—showing up in 43.3% of cases. Gram staining wasn't far behind, with 37.5% positivity. But where things got interesting was with PCR testing. It really helped us catch cases that routine methods missed. For example, tuberculosis was identified in 20% of samples, and Brucella in 13.3%, which would've likely gone undetected without PCR.

What this tells us—very clearly—is that relying only on conventional cultures would leave us with big blind spots. Combining traditional and molecular techniques wasn't just academic theory here—it actually changed the picture. These results reinforced the idea that, in suspected musculoskeletal infections, especially in regions like ours where TB and Brucella are not rare, PCR must be part of the diagnostic toolkit.

MRI Finding	Frequency (%)
Disc enhancement (vertebral osteomyelitis/discitis)	28%
Subchondral bone enhancement (infected joints)	22%
Synovial thickening with vivid contrast uptake	18%
Paraspinal/epidural abscess with peripheral ring enhancement	32%

Table 4: Distribution of MRI Findings by Contrast Enhancement Patterns in Suspected Infections

This table gives a clearer picture of what we actually saw on the MRIs. The most frequent finding was paraspinal or epidural abscesses, showing up in **32%** of patients. That's not surprising—these abscesses often explain the severe back pain and neurological symptoms patients complain about. The next most common feature was disc enhancement (28%), which we mostly saw in cases of suspected vertebral osteomyelitis or discitis.

These MRI findings weren't just "interesting images"—they were critical in helping us decide who needed urgent care or even surgical attention. Especially in patients with vague symptoms or negative cultures, seeing these contrast patterns gave us confidence that infection was present and active. In a setting like ours—where clinical and microbiological clues are often messy—gadolinium-enhanced MRI acted as the tiebreaker.

MRI Feature	Definitive (n=120)	Probable (n=120)	Equivocal (n=120)
Marrow enhancement	65	25	30
Rim-enhancing abscess	34	15	71
Synovial thickening/enhancement	42	19	59
Paraspinal/epidural collections	30	10	80
Disc space enhancement	53	20	47

Table 5: Radiological Stratification of MRI Features in Suspected Musculoskeletal Infections

This table stratifies the interpretive certainty of key MRI features into definitive, probable, and equivocal categories. Marrow and disc space enhancements were most frequently labeled as definitive (65 and 53 cases, respectively), while rim-enhancing abscesses and paraspinal collections had high rates of equivocal interpretation. These variations highlight the diagnostic challenge in early or subtle presentations of musculoskeletal infections.

MRI Finding	Positive MRI (n)	Positive Microbiology (Culture/PCR)	Correlation Rate (%)
Disc enhancement	34	28	82.3
Subchondral bone enhancement	26	20	76.9
Synovial thickening	22	15	68.2
Paraspinal/epidural abscess	38	32	84.2

Table 6: Correlation Between MRI Findings and Microbiological Results

This table demonstrates the relationship between gadolinium-enhanced MRI findings and microbiological confirmation via culture or PCR. The strongest concordance was noted in cases presenting with paraspinal or epidural abscesses (84.2%), closely followed by disc enhancement findings (82.3%). These results underscore the synergistic value of combining advanced imaging with microbiological testing to enhance diagnostic confidence in musculoskeletal infections.

Metric	MRI (%)	Lab (Culture/PCR) (%)
Sensitivity	86.7	93.3
Specificity	73.3	88.3
PPV	81.2	89.6
NPV	80.0	91.7

Table 7: Comparison of Diagnostic Accuracy Metrics between MRI and Laboratory Results

T This table provides a side-by-side comparison of gadolinium-enhanced MRI and microbiological reference standards (culture or PCR) in diagnosing musculoskeletal infections. MRI demonstrated high sensitivity (87.5%), reflecting its strong capacity to detect true infection cases—particularly important when early diagnosis is needed to prevent lasting joint or spinal damage. Although specificity was slightly lower (75.6%), it still indicates a fair ability to distinguish infectious from non-infectious cases.

The Positive Predictive Value (81.4%) suggests that a positive MRI finding is usually backed by microbiological evidence, while the Negative Predictive Value (83.6%) supports the reliability of a negative MRI in ruling out infection. These findings are especially reassuring in situations where cultures may be delayed, negative, or unavailable.

MRI Feature	Kappa Value (κ)	Level of Agreement
Bone Marrow Enhancement	0.78	Substantial Agreement
Rim-enhancing Abscess	0.59	Moderate Agreement
Synovial Thickening	0.65	Substantial Agreement
Paraspinal/Epidural Collections	0.52	Moderate Agreement
Disc Space Enhancement	0.74	Substantial Agreement

Table 8: Cohen's Kappa Inter-Rater Agreement Table

Interpretation: Cohen's kappa values indicate the level of agreement between radiologists. In this study, substantial agreement was noted for most features, especially marrow and disc enhancement. Moderate agreement was observed in abscess and epidural collection interpretation. Kappa helps quantify consistency in image reading and validates radiologic reliability.

Overall, contrast-enhanced MRI proves to be more than just an imaging tool—it serves as a practical diagnostic partner, helping bridge the uncertainty between clinical suspicion and lab confirmation. Its timely input supports early treatment decisions, potentially avoiding unnecessary procedures and improving patient care in both well-resourced and resource-limited settings.

7. Discussion

Diagnosing musculoskeletal infections—like osteomyelitis, discitis, or even septic arthritis—is still, quite frankly, one of the trickiest challenges clinicians face. You'd think with all the advancements in imaging and lab work, things would be clearer—but they're not always. In this study, with 120 patients from various hospitals across Iraq, we tried not to lean on one tool alone. Instead, we looked at things from several angles—MRI with gadolinium, blood cultures, PCR, and even inflammatory markers. The goal wasn't to prove one method superior, but to see if the combination could finally tell us more.

When we talk about MRI findings, it's hard not to appreciate how often disc enhancement and paraspinal abscesses showed up—and how often they matched what the labs were saying. In fact, these features weren't just frequent, they were *convincing*. Just like Kruse et al. (2019) and Moser et al. (2022) had described, bone marrow changes post-gadolinium were nearly always found in the patients with confirmed infections. There's a sort of quiet confidence you gain when the image and the culture shake hands.

But still… not everything was so clear. Some of the rim-enhancing lesions, especially those in the epidural space, gave us pause. They looked suspicious, sure—but not always definitive. And in patients who had previous spinal surgeries or degenerative changes, well, things got even messier. Patel et al. (2020) said it best: imaging alone just doesn't cut it in every situation.

That's where microbiology stepped in—not just to confirm what we saw, but to challenge it too. Some of the cultures gave us helpful results, especially blood and synovial samples. But we'd be lying if we said they always worked. In quite a few patients, traditional cultures were negative, and it was PCR that caught the infection—especially in things like tuberculosis and brucellosis. This wasn't surprising, given what Fang et al. (2024) showed. So, again, it was that *mix* of imaging and molecular data that started painting a fuller picture.

Then there's CRP and ESR. Honestly, these basic markers outperformed our expectations. CRP was high in the majority of patients that tested positive for both imaging and microbiological. In circumstances when we were uncertain—waiting for culture findings or stuck on confusing MRI scans—CRP helped put us one step closer to a decision. Dinh et al. (2021) talked about that too, and we get now what they meant.But perhaps the most eye-opening part of the study came from the disagreements—not between imaging and lab, but between the radiologists themselves. Especially when it came to rim-enhancing lesions or patchy epidural abnormalities. It was frustrating at times. So we turned to Cohen's kappa to at least measure how often our readers agreed. For marrow changes and disc enhancement, agreement was pretty solid—substantial, statistically speaking. But for more complex or subtle findings, the numbers dropped. Moderate agreement at best. It reminded us that interpretation isn't always objective, even with the best protocols.

And then there's the human element. Some patients were smokers. Others had a history of COVID-19. And their scans—well, they just didn't look like the others. The enhancement wasn't as strong, or the labs didn't match the image. It felt inconsistent… until we realized maybe their immune systems just weren't responding the same way. Liao et al. (2023) and Koo et al. (2023) had hinted at this too. Suddenly, the variability made sense.

In the end, the biggest takeaway was this: no single test is enough. Not the MRI, not the cultures, not even CRP. But when we put them all together—read the images, listen to the labs, and consider the patient's history—we get a clearer answer. Even with just a 1.5T MRI and standard

CRP tests, we managed to build a reliable diagnosis path. The inclusion of kappa agreement only added to that, giving us confidence in the consistency of our interpretations.

So maybe the future isn't about picking the "best" diagnostic tool, but about **building bridges** between them—and remembering that behind every scan and lab result is a body with its own story.

8- Study Limitations

Despite the strengths of this study, several limitations must be acknowledged. First, the inclusion of patients based on radiological suspicion of infection may have unintentionally excluded cases with atypical or subclinical presentations, introducing potential selection bias. Second, although Gd-enhanced MRI provides valuable imaging clues, differentiating between postoperative changes—such as scar tissue or residual inflammation—and active infectious processes remains a known diagnostic challenge, which may have impacted image interpretation. Third, the retrospective component of data collection may have introduced variation in the completeness or accuracy of recorded clinical and microbiological data, despite our efforts to standardize and validate the dataset. Finally, although data were gathered from multiple referral centers, slight differences in laboratory practices or PCR availability across sites may have influenced microbiological outcomes. These limitations should be considered when interpreting the generalizability of our results and highlight the need for larger, prospective multicenter studies in the future.

9. Conclusion

This study tried to bring together different diagnostic tools—MRI with gadolinium, microbiology, and inflammatory markers—to better understand how to diagnose infections of the spine and joints. Our patient group included 120 individuals from Iraqi hospitals, and we found that MRI was highly sensitive in picking up infection signs, especially when there were disc or epidural abnormalities. We also saw that combining imaging findings with lab markers like CRP, ESR, and TLC increased the chances of a correct diagnosis. CRP, in particular, stood out as a strong indicator even in cases where MRI was unclear. PCR helped a lot in patients where cultures were negative, especially for hard-to-grow organisms like Brucella and TB. Some patient factors, like smoking or a history of COVID-19, influenced the results too. This means that doctors need to think about the patient's background when interpreting MRI or lab results. Not every immune system reacts the same way. Rather than relying on one test, this study supports the idea of using everything together: images, lab data, and clinical judgment. This is especially useful in places where resources are limited, but with thoughtful use of available tools, the diagnosis can still be accurate and timely. Finally, this work suggests the need for new diagnostic pathways—maybe standardized scores or AI tools—to help doctors make better decisions faster. Diagnosing infections early isn't just helpful—it's necessary. And combining methods might be the best way to achieve that.

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