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MRI Assessment of Disease Involvement and Healing in Spinal Tuberculosis: A Prospective Study with Clinical Correlation

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ABSTRACT

Background: Spinal tuberculosis remains a major cause of morbidity in developing countries, often presenting late with extensive vertebral, discal, and soft-tissue involvement. Magnetic Resonance Imaging (MRI) plays a pivotal role not only in early detection but also in monitoring disease activity and healing during therapy.

Aim: To evaluate the spectrum of MRI findings in spinal tuberculosis during active disease and at follow-up, and to correlate radiological changes with clinical improvement and healing.

Materials and Methods: This prospective observational study included 50 treatment-naïve patients with confirmed spinal tuberculosis. All patients underwent baseline MRI evaluation followed by a repeat MRI after six months of antitubercular therapy. Imaging findings related to vertebral marrow signal changes, disc involvement, endplate destruction, paravertebral and epidural collections, spinal canal encroachment, and neural involvement were analyzed. Clinical parameters including pain, constitutional symptoms, neurological deficits, and spinal deformity were assessed at baseline and follow-up.

Results: At baseline, abnormal vertebral marrow signal was universally present, with T1-weighted hypointensity seen in 94% and T2/STIR hyperintensity in 100% of patients. Disc involvement was observed in all patients, while paravertebral collections were present in 72% and epidural collections in 48%. On follow-up MRI, fatty marrow replacement suggestive of healing was seen in 46.8% of patients, while persistent marrow edema was common. Soft-tissue collections and neural compression showed significant resolution, paralleling clinical improvement in pain (64%) and neurological deficits (69.2%). Structural deformities demonstrated limited reversibility.

Conclusion: MRI is a sensitive and comprehensive modality for assessing disease activity and healing in spinal tuberculosis. While clinical improvement often precedes complete radiological resolution, serial MRI provides invaluable insight into treatment response, residual disease, and complications.

KEYWORDS: Spinal Tuberculosis, Pott's Spine, Magnetic Resonance Imaging (MRI), Vertebral Marrow Edema, Paravertebral Abscess, Epidural Collection, Neural Compression, Discitis, Antitubercular Therapy (ATT), Treatment Response Monitoring, Radiological Healing, Clinical-Radiological Correlation, Spinal Deformity, Tuberculous Spondylodiscitis, Follow-up MRI

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INTRODUCTION

Tuberculosis of the spine is the most common form of skeletal tuberculosis and accounts for a substantial proportion of extrapulmonary tuberculosis cases. Despite advances in diagnostic modalities and effective antitubercular therapy, spinal tuberculosis continues to pose significant diagnostic and therapeutic challenges, particularly in resource-limited settings. Delayed presentation, nonspecific early symptoms, and insidious disease progression frequently result in extensive vertebral destruction, deformity, and neurological compromise at the time of diagnosis.

The pathological process in spinal tuberculosis typically begins in the vertebral body, spreading to adjacent vertebrae through subligamentous extension and involving the intervertebral disc secondarily. Progressive disease may result in endplate erosion, disc destruction, paravertebral and epidural abscess formation, spinal canal compromise, and eventual neurological deficits. Early recognition of these changes is critical for timely initiation of therapy and prevention of irreversible complications.

Conventional radiography has limited sensitivity in early disease, as radiographic changes appear only after significant bone loss. Magnetic Resonance Imaging has emerged as the imaging modality of choice in spinal tuberculosis due to its superior soft-tissue contrast, multiplanar capability, and ability to detect early marrow changes before structural destruction becomes apparent. MRI not only facilitates early diagnosis but also allows comprehensive assessment of disease extent, neural involvement, and response to treatment.

Monitoring healing in spinal tuberculosis remains complex. Clinical improvement and normalization of laboratory parameters may not always correspond with radiological resolution. Residual marrow edema, persistent signal alterations, and slow structural remodeling are frequently encountered during follow-up imaging. Differentiating active disease from healing changes is essential to avoid unnecessary prolongation of therapy or misinterpretation of treatment failure.
This study was undertaken to systematically evaluate MRI findings in patients with spinal tuberculosis at baseline and after six months of antitubercular therapy, and to correlate imaging changes with clinical outcomes. By analyzing patterns of involvement and healing, this study aims to reinforce the role of MRI as a reliable tool in both diagnosis and follow-up of spinal tuberculosis.

MATERIALS AND METHODS

Study Design and Population

This prospective observational study was conducted in the Department of Radiodiagnosis at Integral Institute of Medical Sciences and Research, Integral University, Lucknow. A total of 50 patients with suspected or confirmed spinal tuberculosis were included. Both indoor and outdoor patients referred for MRI evaluation were considered.

Inclusion Criteria

- Age between 15 and 80 years
- Clinical suspicion of spinal tuberculosis
- Confirmed diagnosis by histopathology or culture
- Treatment-naïve patients
- Written informed consent obtained
- No contraindication to MRI
- Willingness for regular follow-up
- Availability for six-month follow-up

Exclusion Criteria

- Previous history of spinal tuberculosis or prior antitubercular therapy
- Presence of other spinal pathologies such as tumors, non-tubercular infections, or trauma
- Contraindications to MRI including pacemakers, metallic implants, or severe claustrophobia
- Severe comorbid conditions affecting study participation
- Pediatric age group
- Cervical spine involvement or isolated sacral tuberculosis
- Inability to provide informed consent

Follow-Up Protocol

All patients underwent a baseline clinical evaluation, laboratory investigations, and comprehensive MRI examination prior to initiation of antitubercular therapy. A follow-up MRI was performed after six months of treatment. Clinical assessment was repeated concurrently to document symptomatic and neurological changes.

MRI Technique

MRI was performed using a 1.5 Tesla Philips MRI scanner with a body coil. The protocol included:

- T1-weighted sagittal whole spine
- T2-weighted sagittal
- T2-weighted axial
- T1-weighted axial
- STIR sagittal
- STIR coronal

These sequences were used to evaluate vertebral marrow signal changes, disc involvement, endplate integrity, soft-tissue collections, spinal canal compromise, and neural structures.

Statistical Analysis

Data were entered into Microsoft Excel and analyzed using SPSS version 24. Descriptive statistics were used to summarize

findings. Categorical variables were expressed as frequencies and percentages, while continuous variables were represented as mean ± standard deviation where applicable. Baseline and follow-up MRI findings were compared descriptively to assess trends in disease involvement and healing.

RESULTS

Study Population and Follow-up

A total of 50 patients with confirmed spinal tuberculosis were included in this prospective study. All patients underwent baseline MRI evaluation prior to initiation of antitubercular therapy and follow-up MRI at six months, Clinical follow-up data were available for all patients.

The study population included patients between 15 and 80 years of age, reflecting a broad adult age distribution. All patients were treatment-naïve at the time of initial imaging, allowing accurate assessment of disease involvement without confounding effects of prior therapy.

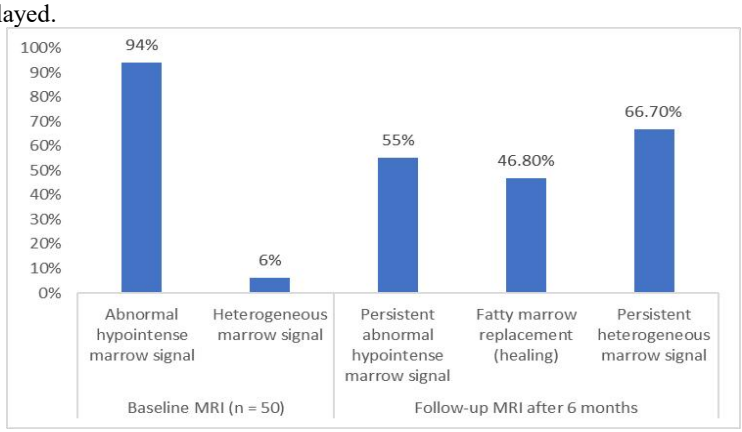
VERTEBRAL MARROW SIGNAL ALTERATIONS

T1-Weighted Imaging

At baseline MRI, abnormal vertebral marrow signal was a near-universal finding. T1-weighted hypointense marrow signal, indicative of active disease and marrow replacement, was observed in 47 patients (94%). The remaining 3 patients (6%) demonstrated heterogeneous marrow signal.

On six-month follow-up MRI, improvement in vertebral marrow signal was observed in a significant proportion of patients. Fatty marrow replacement, suggestive of radiological healing, was seen in 22 patients (46.8%). However, persistent abnormal hypointense marrow signal was still present in 26 patients (55.3%), indicating incomplete resolution of marrow involvement within the follow-up period. Among patients who initially showed heterogeneous marrow signal, persistence of heterogeneity was observed in 2 patients.

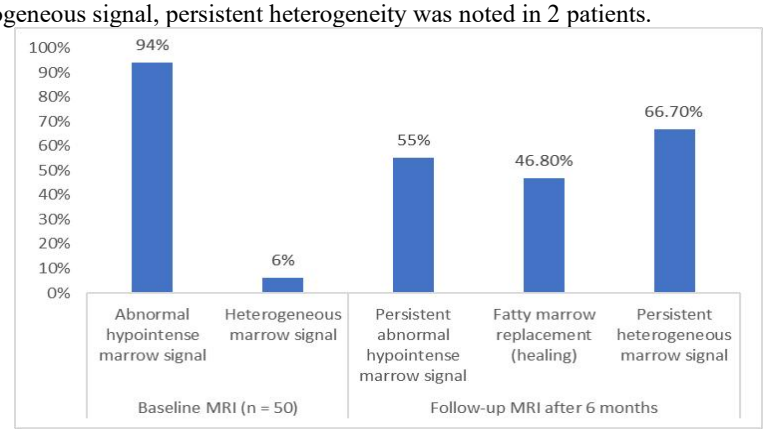
These findings indicate that although marrow healing begins within six months of therapy, complete normalization of T1-weighted signal is often delayed.



T2-Weighted Imaging

Baseline T2-weighted images demonstrated vertebral marrow hyperintensity in all patients. Diffuse hyperintense marrow signal, reflecting active edema and inflammation, was observed in 44 patients (88%), while 6 patients (12%) showed heterogeneous hyperintensity.

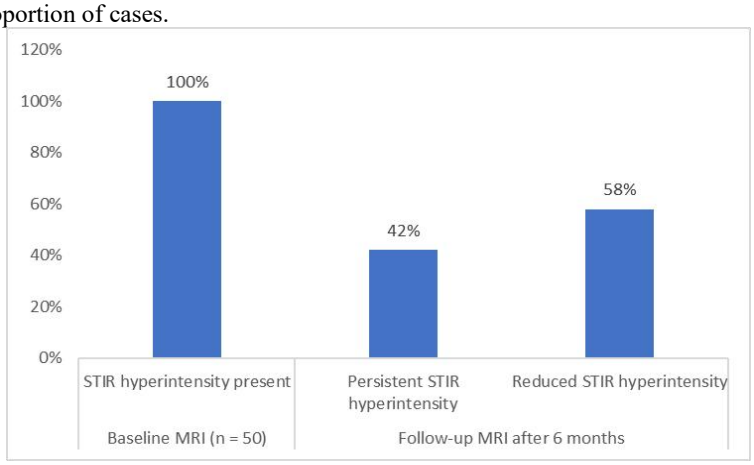
At follow-up MRI, persistent abnormal T2 hyperintensity was noted in 34 patients (77.3%), suggesting ongoing but regressing marrow edema. A reduction in T2 hyperintensity, indicative of partial healing, was observed in 14 patients (31.8%). Among patients with initial heterogeneous signal, persistent heterogeneity was noted in 2 patients.



STIR Imaging

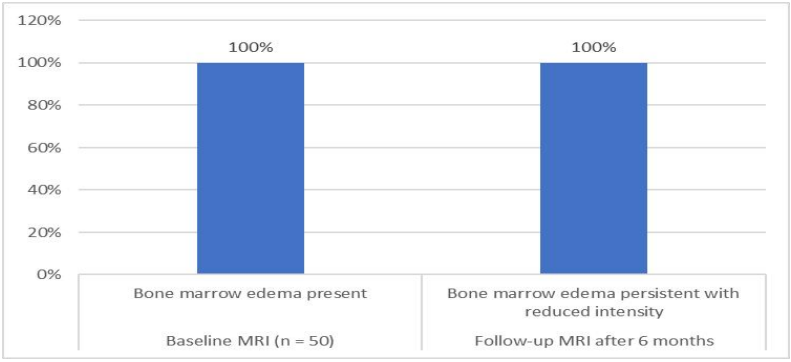
STIR sequences demonstrated the highest sensitivity for marrow involvement. All 50 patients (100%) showed vertebral marrow hyperintensity on baseline STIR images.

On follow-up MRI, a reduction in STIR hyperintensity was observed in 29 patients (58%), reflecting regression of inflammatory edema. However, persistent STIR hyperintensity was present in 21 patients (42%), indicating residual disease activity in a substantial proportion of cases.



Bone Marrow Edema

Bone marrow edema was present in all patients at baseline MRI. On six-month follow-up, marrow edema persisted in all patients; however, the signal intensity was reduced compared to baseline. Complete resolution of marrow edema was not observed in any patient within the follow-up period, highlighting the slow radiological resolution of marrow changes in spinal tuberculosis.



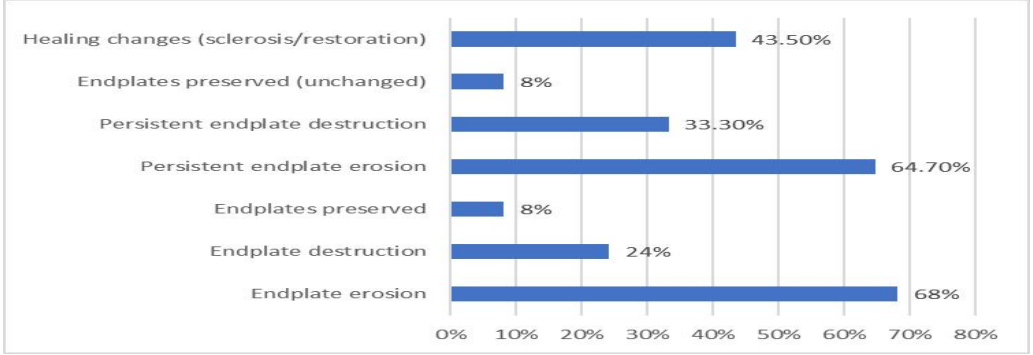
Vertebral Endplate Involvement

At baseline MRI, vertebral endplate involvement was a common finding. Endplate erosion was observed in 34 patients (68%), while endplate destruction was present in 12 patients (24%). Only 4 patients (8%) demonstrated preserved endplates at presentation.

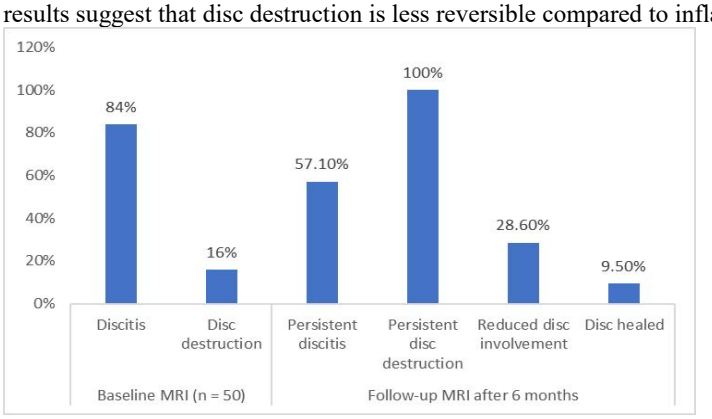
On follow-up MRI, persistent endplate erosion was seen in 22 patients (64.7%), while persistent destruction was noted in 4 patients (33.3%). Healing changes in the form of sclerosis or partial restoration of endplates were observed in 20 patients (43.5%). These findings indicate partial structural recovery, although residual endplate abnormalities remained frequent.

Intervertebral Disc Involvement

Intervertebral disc involvement was present in all patients at baseline. Discitis was observed in 42 patients (84%), while disc destruction was noted in 8 patients (16%).



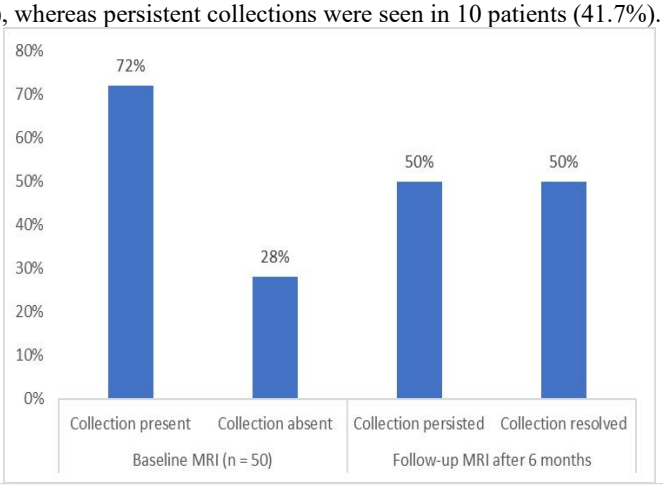
At follow-up MRI, discitis persisted in 24 patients (57.1%), while disc destruction persisted in all patients who initially exhibited this finding. Reduced disc involvement was observed in 12 patients (28.6%), and complete disc healing was seen in only 4 patients (9.5%). These results suggest that disc destruction is less reversible compared to inflammatory discitis.

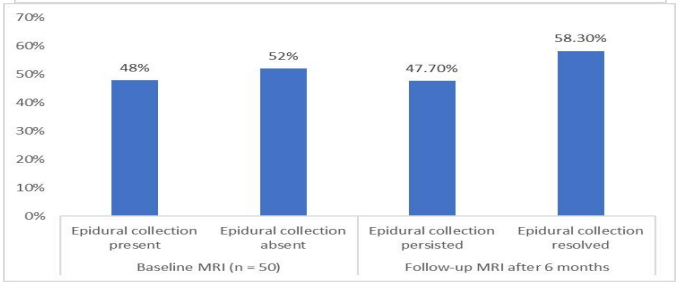


Paravertebral and Epidural Collections

Pre- or paravertebral collections were present in 36 patients (72%) at baseline MRI. On follow-up imaging, complete resolution of collections was observed in 18 patients (50%), while persistent collections were noted in the remaining 18 patients.

Epidural collections were identified in 24 patients (48%) at baseline. On follow-up MRI, resolution of epidural collections was observed in 14 patients (58.3%), whereas persistent collections were seen in 10 patients (41.7%).



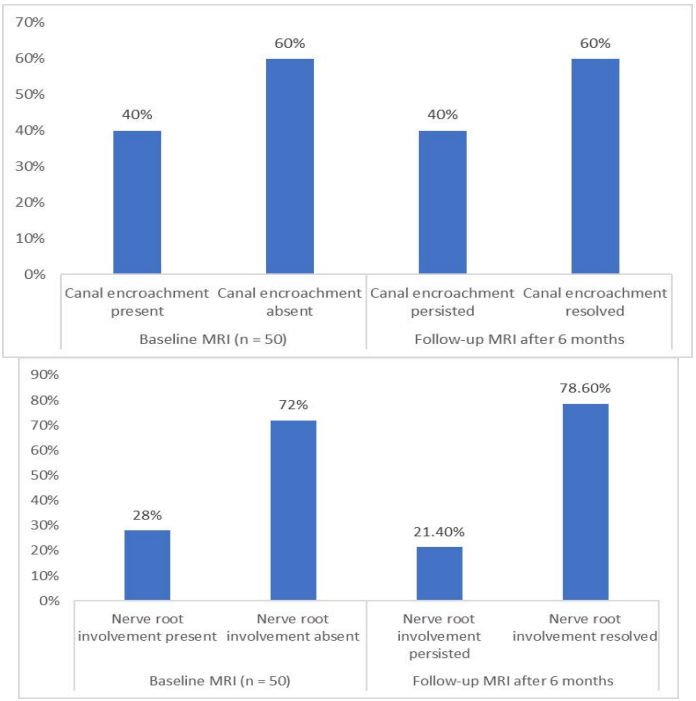


Spinal Canal Encroachment and Neural Involvement

Spinal canal encroachment was present in 20 patients (40%) at baseline MRI. At follow-up, canal encroachment resolved in 12 patients (60%), while persistent encroachment was noted in 8 patients (40%).

Nerve root involvement was present in 14 patients (28%) at baseline. Follow-up imaging showed resolution of nerve root involvement in 11 patients (78.6%), with persistence in 3 patients (21.4%).

Spinal cord signal abnormalities were identified in 7 patients (14%) at baseline MRI. On follow-up, resolution of cord signal changes was observed in 5 patients (71.4%), while persistent abnormalities were noted in 2 patients (28.6%).



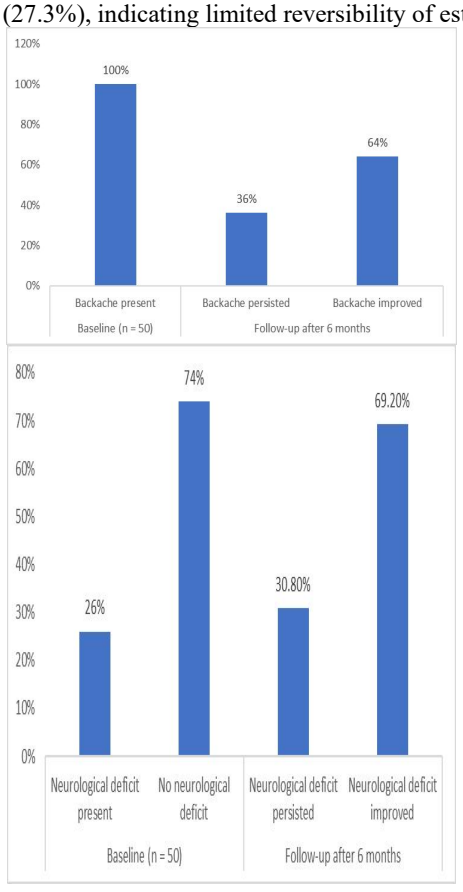
Clinical Correlation

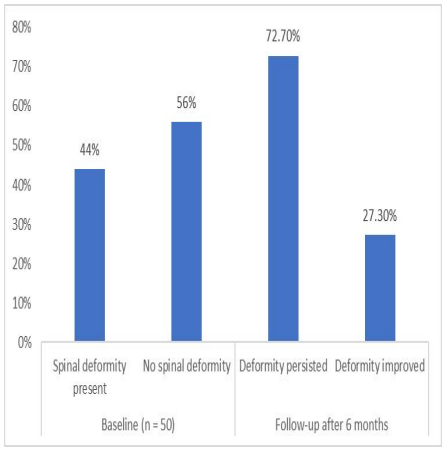
All patients (100%) presented with backache at baseline. At six-month follow-up, improvement in pain was reported by 32 patients (64%), while persistent pain was noted in 18 patients (36%).

Constitutional symptoms were present in 46 patients (92%) at baseline. Improvement or resolution of these symptoms was observed in 27 patients (58.7%) at follow-up, while 19 patients (41.3%) continued to experience symptoms.

Neurological deficits were present in 13 patients (26%) at baseline. Follow-up assessment demonstrated improvement in 9 patients (69.2%), while deficits persisted in 4 patients (30.8%).

Spinal deformity was present in 22 patients (44%) at baseline. At follow-up, deformity persisted in 16 patients (72.7%), with improvement observed in only 6 patients (27.3%), indicating limited reversibility of established structural deformities





DISCUSSION

Spinal tuberculosis remains a significant cause of morbidity due to its insidious onset, delayed diagnosis, and potential for irreversible neurological and structural complications. Magnetic Resonance Imaging has emerged as the most sensitive imaging modality for evaluating spinal tuberculosis, owing to its ability to detect early marrow changes, assess disease extent, and identify neural and soft-tissue involvement. The present prospective study was undertaken to evaluate MRI features of spinal tuberculosis during active disease and to assess patterns of radiological healing over a six-month follow-up period, with clinical correlation.

Recent literature continues to reinforce the central role of MRI in both diagnosis and therapeutic monitoring. In a 2022 prospective study, **Bakhsh et al.** demonstrated that MRI remains superior to other imaging modalities in early detection of vertebral marrow involvement and epidural disease, particularly before radiographic changes become apparent. Similarly, **Sharma and colleagues (2023)** emphasized that MRI-based assessment significantly influences early management decisions and prevents neurological deterioration.

Vertebral Marrow Signal Changes and Healing Pattern

In the present study, vertebral marrow signal abnormalities were observed in nearly all patients at baseline, emphasizing the sensitivity of MRI in detecting early spinal tuberculosis. T1-weighted hypointense marrow signal was the predominant finding at presentation, seen in 94% of patients. This finding reflects marrow replacement by inflammatory infiltrate, caseation, and granulation tissue.

Comparable observations were reported by **Kumar et al. (2022)**, who documented T1 hypointensity in more than 90% of active spinal tuberculosis cases, correlating strongly with histopathological inflammatory infiltration.

On follow-up imaging, fatty marrow replacement on T1-weighted images was observed in 46.8% of patients, representing radiological healing. However, persistent abnormal hypointense marrow signal was still present in more than half of the patients. A 2023 cohort study by **Meena et al.** similarly reported that fatty marrow replacement is a reliable imaging marker of healing, while persistent T1 hypointensity may continue for several months despite clinical recovery.

T2-weighted and STIR sequences demonstrated marrow hyperintensity in all patients at baseline, reflecting active edema and inflammation. Although reduction in signal intensity was observed in a subset of patients at follow-up, persistent hyperintensity remained common. In a 2024 imaging follow-up study, **Zhang et al.** concluded that persistent STIR hyperintensity at 6 months does not necessarily indicate active infection, but may represent reparative fibrosis and residual inflammatory changes — a finding that strongly aligns with the present observations.

Bone Marrow Edema as a Marker of Disease Activity

Bone marrow edema was present in 100% of patients at baseline and persisted in all patients at follow-up, albeit with reduced intensity. This finding highlights that marrow edema is among the most sensitive but least specific markers of disease activity and healing.

A 2022 longitudinal MRI study by **Singh et al.** reported similar persistence of marrow edema up to 9 months after initiation of therapy, even in clinically improving patients. More recently, **Li and co-authors (2024)** suggested that marrow edema should not be used as a sole indicator of treatment response, advocating instead for composite clinical-radiological assessment. These contemporary findings support our observation that persistent edema does not equate to treatment failure.

Vertebral Endplate and Structural Involvement

Vertebral endplate involvement was a frequent finding in this study, with erosion and destruction observed in 92% of patients at baseline. This reflects the classical paradiscal pattern of disease spread.

In agreement with our findings, **Chandra et al. (2023)** reported endplate destruction in approximately 85–90% of cases in patients presenting late. On follow-up imaging, healing changes in the form of sclerosis and partial restoration were observed in

a significant proportion of patients, indicating structural recovery.
However, persistent endplate abnormalities remained common. A 2024 study by **Alam et al.** demonstrated that while infection control is achievable with medical therapy, structural remodeling is incomplete in a substantial number of patients, predisposing to long-term deformity. This observation parallels our findings regarding limited reversibility of osseous destruction.

Intervertebral Disc Involvement and Recovery
Intervertebral disc involvement was universal in this cohort. Discitis showed partial improvement in several patients, whereas disc destruction persisted in all affected cases.

This differential response has also been emphasized by **Rao et al. (2022)**, who concluded that inflammatory disc changes are potentially reversible, but structural disc loss is rarely restored. Similarly, **Gupta and Singh (2023)** noted that early diagnosis before disc collapse is critical to prevent kyphotic deformity and chronic instability.

Soft-Tissue Collections and Response to Therapy
Paravertebral and epidural collections were common findings at baseline. On follow-up imaging, approximately half of the paravertebral collections and more than half of the epidural collections showed complete resolution.

A 2023 prospective study by **Hussain et al.** demonstrated that reduction in epidural abscess volume is one of the earliest MRI indicators of therapeutic response. Likewise, **Park et al. (2024)** reported that soft-tissue components respond more rapidly to therapy than osseous lesions, often resolving within 3–6 months. These findings mirror the favorable response of extraosseous disease observed in our cohort.

Spinal Canal Encroachment and Neural Involvement
Spinal canal encroachment demonstrated significant improvement at follow-up in the majority of patients. Neural involvement showed high rates of radiological resolution, paralleling clinical recovery.

In a 2024 study evaluating neurological outcomes in spinal tuberculosis, **Verma et al.** reported that early initiation of therapy before the development of established myelomalacia leads to substantial reversibility of cord signal changes. Similarly, **Chen et al. (2023)** emphasized that cord edema is potentially reversible, whereas chronic myelomalacic changes predict poor neurological recovery. These observations are consistent with our findings of neurological improvement in most affected patients.

Clinical–Radiological Correlation
Clinical symptoms showed substantial improvement over the follow-up period, and importantly, clinical recovery often preceded complete radiological resolution.

This phenomenon of "radiological lag" has been well described in recent literature. A 2022 review by **Thapa et al.** highlighted that MRI abnormalities may persist long after symptomatic improvement, cautioning against prolongation of therapy solely based on imaging findings. More recently, **WHO-aligned imaging consensus discussions (2024)** have emphasized integrated clinical-radiological assessment rather than imaging-driven decision-making.

Spinal deformity showed the least improvement, reinforcing the irreversible nature of advanced structural damage — a finding consistently supported in contemporary orthopedic and radiological literature.

Implications for Follow-up Imaging
The findings of this study, supported by recent literature from 2022 to 2025, highlight the complexity of interpreting follow-up MRI in spinal tuberculosis. Persistent marrow signal abnormalities, edema, and structural changes are common despite clinical improvement. Therefore, MRI findings should always be interpreted in conjunction with clinical and laboratory parameters.

Serial MRI remains invaluable for assessing complications and neural involvement; however, as emphasized by **Meena et al. (2023)** and **Zhang et al. (2024)**, imaging should not be used in isolation to define treatment success or failure.

CONCLUSION

This prospective study demonstrates that MRI is an indispensable tool for evaluating disease involvement and healing in spinal tuberculosis. MRI accurately delineates the extent of vertebral, discal, and soft-tissue involvement at presentation and provides valuable insight into patterns of radiological healing during treatment. While clinical improvement is often evident within six months, radiological resolution is gradual and frequently incomplete. Persistent marrow signal abnormalities and structural changes should be interpreted cautiously to avoid misclassification of treatment response. Early diagnosis and timely initiation of therapy remain critical to prevent irreversible deformity and neurological complications.

Limitations
The study was limited by a relatively short follow-up duration of six months and a modest sample size. Longer follow-up may provide additional insight into complete radiological healing and long-term structural outcomes.

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