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Assessment of Novel MRI Tools in Tuberculosis of the Spine

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ABSTRACT

Background: Spinal tuberculosis remains an important cause of non-traumatic vertebral pathology in tuberculosis-endemic regions. Conventional MRI is sensitive for marrow, disc, epidural and paraspinal disease, but overlap with non-tuberculous vertebral lesions can reduce diagnostic confidence. Quantitative MRI markers such as the T1 ratio of marrow (TROM), apparent diffusion coefficient (ADC) and chemical shift imaging-derived in-phase/opposed-phase signal behavior may improve characterization.

Objective: To evaluate the role of TROM, diffusion-weighted imaging with ADC measurement and chemical shift imaging in multiparametric MRI assessment of spinal tuberculosis.

Materials and methods: This comparative cross-sectional study was conducted at Teerthanker Mahaveer Medical College and Research Centre over 18 months using a 1.5 Tesla Siemens Magnetom Avanto MRI scanner. The analysis compared 86 patients with spinal tuberculosis with 86 controls with non-tuberculous vertebral lesions. Routine spine MRI was supplemented with sagittal DWI/ADC maps and sagittal T1 GRE Dixon in-phase and opposed-phase imaging. TROM, ADC and IP/OP ratio were measured using region-of-interest analysis. Diagnostic performance was assessed using sensitivity, specificity, accuracy and receiver-operating characteristic analysis.

Results: Mean age and sex distribution were comparable between groups. TROM was significantly lower in spinal tuberculosis than controls. ADC was significantly higher in spinal tuberculosis and IP/OP ratio was also significantly higher (280.51 +/- 38.13 vs 197.08 +/- 53.56, $p < 0.001$). ADC showed the highest diagnostic performance at a cutoff >=1000 x10^{-6} mm^2/s, with sensitivity 98%, specificity 100% and accuracy 99%. TROM at a cutoff <=0.75 showed sensitivity 95%, specificity
90% and accuracy 92%, while IP/OP ratio at a cutoff >=250 showed sensitivity 93%, specificity 85% and accuracy 89%. AUC values were 0.999 for ADC, 0.998 for TROM and 0.891 for IP/OP ratio. TROM correlated negatively with ADC and IP/OP ratio, while ADC correlated positively with IP/OP ratio.

Conclusion: Quantitative MRI parameters are useful adjuncts for differentiating spinal tuberculosis from non-tuberculous vertebral lesions. ADC was the strongest individual marker, while TROM and IP/OP ratio provided complementary diagnostic value. Incorporating these parameters into routine multiparametric spine MRI may improve diagnostic confidence without contrast administration.

Keywords: Spinal tuberculosis; T1 ratio of marrow; diffusion-weighted imaging; apparent diffusion coefficient; chemical shift imaging; Dixon MRI; vertebral marrow lesions

INTRODUCTION

Tuberculosis remains a major infectious disease worldwide, including in India. Although pulmonary tuberculosis is the commonest manifestation, extrapulmonary tuberculosis is increasingly identified because of broader use of advanced imaging and greater recognition in immunocompromised patients. The vertebral column is the most frequent site of skeletal tuberculosis and represents a substantial proportion of musculoskeletal tuberculosis.[1,2]

Spinal tuberculosis, classically described as Pott disease, can involve vertebral bodies, intervertebral discs, epidural tissues and paraspinal soft tissues. The thoracic spine is commonly involved, followed by the lumbar spine, although any spinal level can be affected.[2] Hematogenous spread through arterial channels or Batson venous plexus results in vertebral marrow infection, endplate involvement and disc spread. Paraspinal and epidural abscess formation, vertebral collapse, kyphotic deformity and neural compression may occur in advanced disease.[3]

Clinical presentation is often indolent and non-specific. Persistent back pain may precede diagnosis by weeks or months, while fever, malaise, night sweats, weight loss and neurological deficits may be variable. Delay in diagnosis can lead to irreversible deformity and neurological morbidity. Imaging is therefore central to early recognition and differentiation from mimics such as pyogenic spondylodiscitis, fungal infection, lymphoma, metastases, myeloma and osteoporotic collapse.

MRI is the modality of choice for detecting early marrow edema, disc involvement, endplate breach, epidural extension, paraspinal collections and cord compression. However, conventional T1- weighted, T2-weighted and STIR images may show overlapping features among infective, inflammatory and neoplastic vertebral lesions. Functional and quantitative

MRI techniques can provide additional information on tissue cellularity, diffusion, fat content and water composition.[3-6]

Diffusion-weighted imaging (DWI) and ADC mapping evaluate microscopic water motion. Lesions with edema, necrosis and increased extracellular fluid tend to show higher ADC, while densely cellular lesions often show lower ADC.[7-10] Chemical shift imaging (CSI), including Dixon-based in- phase and opposed-phase imaging, assesses microscopic fat content by measuring signal loss on opposed-phase images. TROM is a simple ratio calculated from routine T1-weighted images by comparing signal intensity of abnormal marrow with adjacent normal vertebral marrow. These techniques may be performed without contrast and can be incorporated into routine spine MRI protocols.[1,4,5,7,11,12,13-16]

The present study was undertaken to assess the diagnostic contribution of TROM, DWI-derived ADC and CSI-derived IP/OP ratio in multiparametric MRI evaluation of spinal tuberculosis.[6]

MATERIALS AND METHODS

This was a comparative cross-sectional study conducted in the Department of Radiodiagnosis at Teerthanker Mahaveer Medical College and Research Centre, Moradabad. The study period was 18 months. Institutional ethics approval was obtained before commencement of the study. The analysis included patients undergoing MRI of the spine for non-traumatic indications. The results section of the thesis reports 86 patients with spinal tuberculosis and 86 controls with non-tuberculous vertebral lesions. Patients aged more than 30 years and diagnosed with tubercular vertebral pathology were included in the spinal tuberculosis group. Inclusion criteria were patients diagnosed with tubercular vertebral pathology and age more than 30 years. Exclusion criteria were history of spinal surgery, history of spinal trauma, contraindication to MRI and known hematological disease associated with diffuse bone marrow infiltration. All patients underwent MRI using a Siemens Magnetom Avanto 1.5 Tesla scanner. Routine protocol included sagittal and axial T1-weighted images, sagittal and axial T2-weighted images, and sagittal and coronal STIR images as per departmental standards. Sagittal DWI was acquired and ADC maps were generated using b values of 800 and 1000 s/mm2. In-phase and opposed-phase image sets were obtained using sagittal non-contrast T1-weighted GRE Dixon sequences with TR 366 ms and TE values of 7 ms and 11.98 ms.

TROM was measured by placing a circular region of interest of approximately 0.8-1 cm2 over abnormal vertebral marrow. Similar regions of interest were placed in adjacent uninvolved vertebral bodies above and below the lesion that showed normal T1-weighted marrow signal. TROM was calculated as the ratio of T1 signal intensity of abnormal vertebral marrow to reference normal marrow signal intensity. ADC values were obtained by placing a circular region of interest of approximately 0.8-1 cm2 within the vertebral lesion on ADC maps. For CSI analysis, circular regions of interest of similar size were positioned over abnormal vertebral marrow on in-phase and opposed- phase images. The IP/OP ratio was calculated from the signal difference between in-phase and opposed-phase images, expressed as a percentage relative to in-phase signal. Quantitative variables were summarized as mean +/- standard deviation. Group comparisons were performed for demographic variables and MRI parameters. Diagnostic cutoffs were evaluated using sensitivity, specificity and accuracy. ROC analysis was used to determine discriminatory ability, and correlation analysis was performed to assess relationships among quantitative MRI parameters. A p value less than 0.05 was considered statistically significant.

Results Demographic profile

The mean age was comparable between spinal tuberculosis and control groups (46.00 +/- 14.80 vs 44.93 +/- 13.85 years, p = 0.625). Sex distribution also did not differ significantly between groups (p = 0.170).

Table 1. Demographic profile of study population.

Variable	Spinal TB (n=86)	Control group (n=86)	p value
Age, years (mean +/- SD)	46.00 +/- 14.80	44.93 +/- 13.85	0.625
Male, n (%)	38 (44.2%)	47 (54.7%)	0.170
Female, n (%)	48 (55.8%)	39 (45.3%)	

Table 2. Quantitative MRI parameters, diagnostic performance and ROC analysis

Parameter	Spinal TB (n=86)	Control group (n=86)	Group comparison p value	Diagnostic cutoff	Sensitivity	Specificity	Accuracy	AUC	95% CI	ROC p-value
TROM	0.661 ± 0.065	0.929 ± 0.035	<0.001	≤0.75	95%	90%	92%	0.998	0.994–1.000	<0.001
ADC ($\times10^{-6}$ mm²/s)	1140.45 ± 87.43	680.40 ± 120.45	<0.001	≥1000 $\times10^{-6}$ mm²/s	98%	100%	99%	0.999	0.996–1.000	<0.001
IP/OP ratio	280.51 ± 38.13	197.08 ± 53.56	<0.001	≥250	93%	85%	89%	0.891	0.839–0.943	<0.001

All three quantitative MRI parameters showed statistically significant differences between spinal tuberculosis and control groups. TROM was markedly reduced in spinal tuberculosis, reflecting loss of normal fatty marrow signal on T1-weighted imaging, whereas ADC values were substantially elevated, consistent with inflammatory edema, necrosis and increased extracellular water content. The IP/OP ratio was also higher in spinal tuberculosis, indicating altered marrow fat-water composition with reduced opposed-phase signal drop. Among the evaluated parameters, ADC demonstrated the best diagnostic performance, with an AUC of 0.999 and 99% overall accuracy at a cutoff of ≥1000 $\times10^{-6}$ mm²/s. TROM also showed excellent discrimination, with an AUC of 0.998 and accuracy of 92% at a cutoff of ≤0.75. The IP/OP ratio showed good but comparatively lower diagnostic value, with an AUC of 0.891. These findings support the combined use of TROM, ADC and CSI-derived IP/OP ratio for multiparametric MRI evaluation of spinal tuberculosis in routine practice.

Correlation among MRI parameters

TROM showed a strong negative correlation with ADC and a moderate negative correlation with IP/OP ratio. ADC showed a moderate positive correlation with IP/OP ratio.

Table 3. Correlation between MRI parameters.

Variables compared	Correlation coefficient (r)	p value
TROM vs ADC	-0.862	<0.001
TROM vs IP/OP ratio	-0.634	<0.001
ADC vs IP/OP ratio	+0.605	<0.001

Vertebral level involvement

Spinal tuberculosis was more frequent at lower lumbar levels, particularly L4 and L5.

Table 4. Distribution of vertebral level involvement.

Level	Spinal TB	Control group
L1	15 (42.9%)	20 (57.1%)
L2	28 (41.8%)	39 (58.2%)
L3	19 (45.2%)	23 (54.8%)
L4	16 (80.0%)	4 (20.0%)
L5	8 (100%)	0 (0%)

Subgroup analysis

No significant difference was observed in TROM, ADC or IP/OP ratio between males and females. Similarly, age-wise subgroup analysis across <40 years, 40-60 years and >60 years showed no significant differences in the evaluated quantitative MRI parameters.

Representative image examples

Representative examples from the image gallery demonstrate the region-of-interest based measurement technique for TROM, ADC and chemical shift imaging. Acquisition headers were masked for anonymization (Figures 1-3).

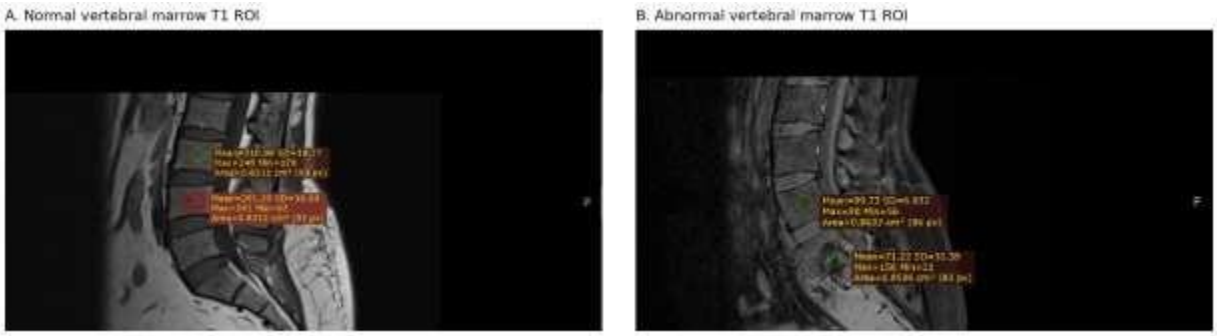

Figure 1. Representative TROM measurement. (A) Normal vertebral marrow T1 ROI showing preserved marrow signal. (B) Abnormal vertebral marrow T1 ROI in spinal tuberculosis showing reduced TROM.

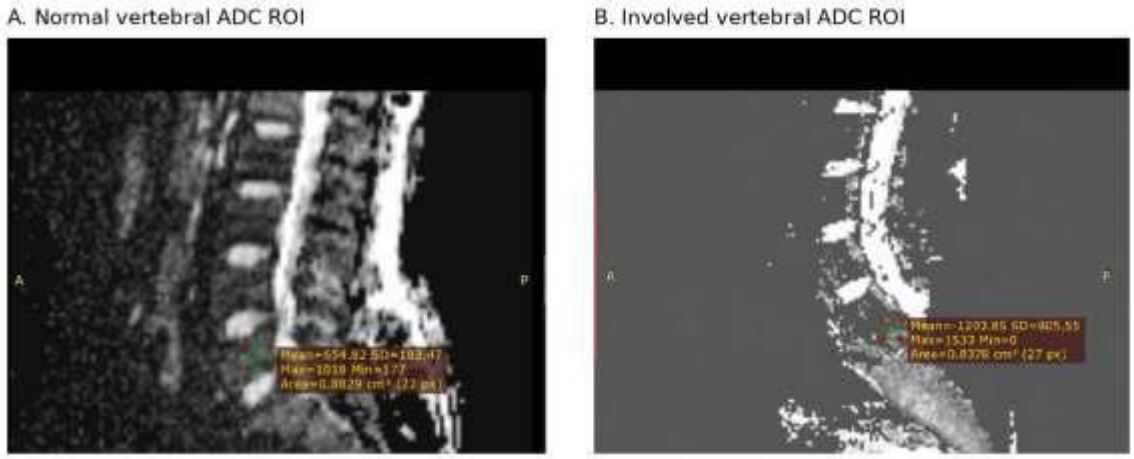

Figure 2. Representative ADC measurement. (A) Normal vertebral ADC ROI. (B) Involved vertebral body ADC ROI demonstrating higher diffusivity in spinal tuberculosis.

Figure 3. Representative chemical shift imaging measurement. (A) Normal in-phase/opposed-phase ROI assessment. (B) Involved vertebral marrow IP/OP ROI assessment.

DISCUSSION

The present study demonstrated that quantitative MRI parameters significantly differentiate spinal tuberculosis from non-tuberculous vertebral lesions. TROM was significantly lower in spinal tuberculosis, whereas ADC and IP/OP ratio were significantly higher. Among the three evaluated parameters, ADC showed the best overall performance, with an AUC of 0.998 and 98% sensitivity, 100% specificity and 99% accuracy at a cutoff of >=1000 x 10^-6 mm2/s. These findings support the
use of multiparametric MRI as an adjunct to routine morphological assessment in patients with suspected spinal tuberculosis.[5,6,8,20]

The strong performance of ADC in the present study is comparable with previous DWI-based studies on vertebral marrow lesions. Allam et al. reported that ADC mapping was useful for differentiating vertebral lesions, while Kaur et al. also supported DWI as an adjunct sequence in vertebral lesion evaluation. Tadros and Louka reported 94% sensitivity, 79% specificity and 87% accuracy for DWI using an ADC cutoff of 0.67 x 10^-3 mm2/s. In comparison, the present study showed higher specificity and accuracy, probably because spinal tuberculosis in this cohort showed marked inflammatory edema, necrosis and increased extracellular water content, producing higher ADC values than the control lesions.[5,16,18]

The present ADC findings are also in agreement with recent multiparametric work by Mijaljevic et al., who reported an ADC AUC of 0.894 with 88.2% sensitivity and 92.3% specificity, and further improvement when ADC was combined with chemical shift parameters. The higher AUC observed in the present study suggests that ADC is particularly powerful when the diagnostic question is focused on spinal tuberculosis versus non-tuberculous vertebral pathology, rather than a broader benign-versus-malignant comparison.[20]

TROM was the second strongest parameter in this study, with a cutoff of <=0.74 showing 95% sensitivity, 99% specificity and 97% accuracy. This finding is consistent with the concept that tuberculous involvement replaces normal fatty marrow with inflammatory tissue, granulation tissue and edema, thereby reducing T1-weighted signal intensity. Idrees et al. similarly evaluated T1 marrow ratio in spinal tuberculosis and reported reduction in T1 marrow ratio in affected vertebrae, supporting its value as a simple, non-contrast, PACS-based quantitative marker. The advantage of TROM in routine practice is that it can be obtained from standard T1-weighted images without additional scan time or post-processing software.[6]

Chemical shift imaging also showed significant discriminatory ability in the present study. The IP/OP ratio cutoff of >=1.59 yielded 88% sensitivity, 90% specificity and 89% accuracy. This is broadly comparable with El-Samie and El-Ghany, who reported high sensitivity and specificity using opposed-phase/in-phase signal analysis, and with Tadros and Louka, who found that chemical shift imaging achieved 94% sensitivity, 71% specificity and 83% diagnostic accuracy. The present results therefore support CSI as a useful adjunct, although its diagnostic performance was lower than ADC in this cohort.[15,16] The CSI results are further supported by Fatima et al., who found that quantitative chemical shift-derived fat fraction improved discrimination between benign and malignant vertebral lesions, and by Suh et al., whose meta-analysis showed pooled sensitivity of 0.92, pooled specificity of 0.89 and AUC of 0.95 for CSI in vertebral marrow lesion characterization. In the present study, CSI specificity was similar to these reports, but AUC was lower than ADC. This difference may reflect the biological heterogeneity of spinal tuberculosis, where edema, caseation and inflammatory granulation tissue may alter the fat-water relationship differently from malignant marrow replacement.[1,17]

Compared with studies focusing on malignant or metastatic vertebral disease, the present study emphasizes a tuberculosis-endemic clinical problem. Prior multiparametric MRI studies have shown that combining DWI, chemical shift imaging and fat-water techniques improves diagnostic confidence in vertebral marrow lesions. The present findings extend this principle to spinal tuberculosis by showing that ADC, TROM and IP/OP ratio assess different tissue characteristics and provide complementary information rather than duplicating one another.[4,7,8,14,19,20]

The correlation analysis also supports a multiparametric approach. TROM showed a strong negative correlation with ADC and a moderate negative correlation with IP/OP ratio, while ADC showed a moderate positive correlation with IP/OP ratio. These relationships are biologically plausible: as normal fatty marrow is replaced by inflammatory tissue, T1 signal decreases, while water diffusivity and fat-water signal alteration increase. Therefore, combined interpretation of TROM, ADC and CSI can improve confidence when conventional MRI features overlap with pyogenic infection, degenerative endplate change, metastasis or other marrow infiltrative disorders.[6,8,20]

Overall, the present results are concordant with previous evidence supporting DWI and CSI in vertebral marrow lesion characterization, but they also highlight the added practical value of TROM in spinal tuberculosis. ADC emerged as the most reliable individual parameter, while TROM and IP/OP ratio provided supportive diagnostic information. In clinical practice, using these parameters together may help avoid over-reliance on morphology alone and may guide early diagnosis, targeted biopsy decisions and treatment planning in suspected spinal tuberculosis.[1,5,6,15-20]

CONCLUSION

Quantitative MRI parameters are helpful in discriminating spinal tuberculosis from non-tuberculous vertebral lesions. TROM was significantly lower in spinal tuberculosis, whereas ADC and IP/OP ratio were significantly higher. ADC

was the most reliable individual marker, showing the highest sensitivity, specificity and accuracy, followed by TROM and IP/OP ratio. These parameters provide complementary information and may improve diagnostic confidence in routine multiparametric spine MRI without the need for contrast administration.

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