Original Article

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Radiology Section

Correlation of Lumbar Spine MRI Signal Alterations with DEXA-derived Bone Mineral Density and T-scores: A Cross-sectional Analytical Study

AMIT SARMA[1], MRINAL KANTI SINGHA[2]

ABSTRACT

Introduction: Osteoporosis is a systemic skeletal disorder that increases the risk of fragility fracture and constitutes a major global health burden. Dual-Energy X-Ray Absorptiometry (DEXA) is the clinical reference standard for Bone Mineral Density (BMD) assessment but, as a two-dimensional projection technique, does not directly evaluate trabecular microarchitecture or marrow composition. Magnetic Resonance Imaging (MRI) signal characteristics of vertebral marrow have been proposed as opportunistic markers of Vertebral Bone Quality (VBQ).

Aim: To evaluate the correlation between lumbar spine MRI signal alterations (T1- and T2-weighted) and DEXA-derived BMD parameters, including BMD, T-score and Z-score, in patients undergoing lumbar spine imaging.

Materials and Methods: A cross-sectional analytical study was conducted at Assam Down Town University, Guwahati, Assam, India, from October 2023 to April 2024. A total of 100 adults of either sex who underwent both lumbar spine MRI (1.5 Tesla) and DEXA were evaluated. A circular Region Of Interest (ROI) of 1 cm^2 was placed in the central trabecular portion of the L3 vertebral body on T1- and T2- weighted sagittal images, avoiding cortical bone, end-plate changes and focal lesions. DEXA-derived BMD was classified according to World Health Organisation (WHO) T-score criteria. Pearson's correlation coefficient with 95% Confidence Intervals (CI) was used to assess associations; a two-tailed p-value <0.05 was considered significant.

Results: The cohort comprised 52 females (52%) and 48 males (48%). Based on lumbar (L1-L4) T-scores, 42 (42%) participants had normal BMD, 31 (31%) osteopenia and 27 (27%) osteoporosis. Reduced BMD was more frequent among females and older participants. The T-score showed weak but statistically significant negative correlations with T1-weighted (r=-0.214; 95% CI -0.394 to -0.018; p-value=0.033) and T2-weighted (r=-0.208; 95% CI -0.389 to -0.012; p-value=0.038) signal values. The Z-score correlated strongly with mean BMD (r=0.685; 95% CI 0.565 to 0.777; p-value <0.001); as the Z-score is derived from BMD, this served as an internal consistency check.

Conclusion: Lumbar vertebral MRI signal alterations showed weak but statistically significant associations with DEXA-derived BMD, suggesting that routinely acquired lumbar MRI may provide supplementary, opportunistic information on VBQ. The modest strength of these correlations indicates that MRI signal cannot currently replace DEXA for the diagnosis of osteoporosis.

Keywords: Absorptiometry, Bone density, Bone marrow, Lumbar vertebrae, Magnetic resonance imaging, Osteoporosis

INTRODUCTION

Osteoporosis is a systemic skeletal disorder characterised by reduced bone strength and deterioration of bone quality, predisposing affected individuals to an increased risk of fragility fractures [1]. Osteoporotic fractures represent a major global health burden; in the year 2000 an estimated nine million osteoporotic fractures occurred worldwide, with substantial associated morbidity, disability, and healthcare cost [2]. Clinically, the diagnosis is most commonly established using DEXA, which provides areal BMD measurements along with T-score classification based on the WHO criteria [3]. Owing to its wide availability, low radiation exposure, and established prognostic utility, DEXA remains the clinical reference standard for the assessment of BMD; however, as a two-dimensional projection technique, it cannot directly evaluate trabecular microarchitecture or marrow composition and is additionally subject to well-recognised positioning and degenerative-artefact pitfalls that may confound areal BMD values, particularly in the degenerative spine [4].

In view of these limitations, volumetric and structural imaging techniques, including Quantitative Computed Tomography (QCT), peripheral QCT, and MRI, have been increasingly investigated for their ability to provide three-dimensional and tissue-sensitive assessment of bone quality [5]; high-resolution peripheral QCT, for example, can directly characterise trabecular and cortical microarchitecture in metabolic bone disease [6]. Among these modalities, MRI offers a unique non-ionising capability for the assessment of marrow composition, trabecular structure (indirectly), and cortical porosity using advanced imaging sequences such as T1-weighted imaging, Ultrashort Echo Time (UTE), and quantitative T2 mapping [7]. Furthermore, the VBQ index, derived from normalised T1 signal intensities relative to Cerebrospinal Fluid (CSF), has been proposed as a reproducible MRI biomarker demonstrating correlation with BMD and fracture risk [8]. The principal differences between DEXA and MRI for the evaluation of bone density are illustrated and summarised in [Table/Fig-1,2].

MRI		DEXA
Magnetic Field + Radiofrequency	*Bone Mineral Density Quantification*	Dual-Energy X-Rays
Non-ionising		Ionising

[Table/Fig-1]: Schematic comparison of MRI and DEXA imaging principles.

Recent investigations involving MRI-derived VBQ assessment have shown promising correlations with DEXA-derived T-scores and fracture-risk prediction. The Lumbar Vertebral Bone Quality (LVBQ) score, derived from T1-weighted MRI signal intensities,

Feature	DEXA	MRI
Measurement type	Areal BMD (g/cm²)	Volumetric and structural assessment
Radiation exposure	Low (ionising)	None
Scan duration	5–10 minutes	20–40 minutes
Bone quality assessment	Limited	Excellent (microarchitecture, marrow)
Clinical use	Reference standard for diagnosis	Research and advanced evaluation
Cost and accessibility	Low and widespread	High and limited

[Table/Fig-2]: Difference between DEXA and MRI for bone density evaluation.

has emerged as a reliable and reproducible imaging biomarker for assessing vertebral bone status. MRI-based VBQ scores have been reported to correlate with DEXA- and CT-derived bone density and to predict fragility fractures [9-11]. This technique uses routine MRI sequences and provides a radiation-free, cost-effective, and clinically practical method for opportunistic evaluation of bone quality in patients undergoing lumbar spine imaging. Furthermore, MRI-based vertebral assessment may offer additional value in patients with lumbar degenerative abnormalities, in whom conventional DEXA measurements may be affected by structural alterations.

Despite growing interest in MRI-based assessment of bone quality, the relationship between lumbar spine MRI signal alterations and DEXA-derived BMD parameters remains incompletely understood [9,10]. Few studies have comprehensively evaluated the correlation of lumbar vertebral MRI signal characteristics with BMD values, T-scores, and Z-scores in patients with lumbar spine abnormalities. Evaluating and establishing such correlations could improve the utility of routinely acquired lumbar MRI scans in identifying patients with reduced bone density and may contribute to the care of high-risk individuals through the early detection of osteoporosis.

Therefore, the present study aims to evaluate the correlation between lumbar spine MRI signal alterations and DEXA-derived BMD parameters, including BMD, T-scores, and Z-scores, in patients with lumbar spine abnormalities.

MATERIALS AND METHODS

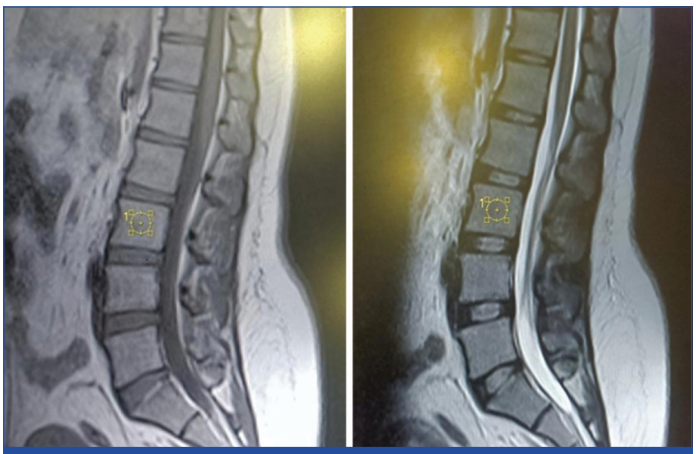
The present cross-sectional analytical study was conducted at Assam Down Town University, Guwahati, Assam, India, from October 2023 to April 2024. The study included 100 adult patients of either sex who underwent both lumbar spine MRI and DEXA. The study was approved by the Institutional Ethics Committee ([approval number: Adtu/Ethics/PhD Scholar/2023/34 Date: 11/10/2023]). It was conducted in accordance with the ethical standards of the responsible institutional committee on human experimentation and with the Declaration of Helsinki (1964, as revised in 2013). Written informed consent for participation and for the use of imaging data was obtained from all participants.

Inclusion criteria: Patients 20 years of age or older and had undergone both lumbar spine MRI and DEXA as part of their clinical evaluation were included in the study.

Exclusion criteria: Patients with the history of traumatic spinal injury, a known primary or secondary metabolic bone disorder, drug therapy known to affect bone metabolism (for example corticosteroids or bisphosphonates), or previous spinal surgery or radiotherapy were excluded from the study.

Study Procedure

Basic demographic information, including age and sex, was collected from all participants. To assess spinal alignment abnormalities, intervertebral disc pathology and degenerative changes, lumbar spine MRI scans were reviewed. Quantitative MRI assessment was performed using vertebral bone-marrow signal-intensity measurements obtained from T1-weighted and T2-weighted sagittal MRI images. A circular ROI measuring 1 cm² was placed in the central trabecular region of the L3 vertebral body for each patient [Table/Fig-3,4]. Due care, with appropriate precautions and safety measures, was taken to avoid the cortical bone, focal lesions, end-plate changes and other structural abnormalities, to ensure accurate sampling of the cancellous bone marrow. The mean signal intensity and Standard Deviation (SD) were recorded for each ROI.



[Table/Fig-3,4]: A 1 cm² Region Of Interest (ROI) manually delineated at the central trabecular portion of the L3 vertebral body on T1-weighted (left) and T2-weighted (right) sagittal images. (Images from left to right)

The DEXA was used to measure BMD, and the WHO T-score criteria were used to classify the results. Patients were categorised as having normal BMD (T-score ≥ -1.0), osteopenia (T-score between -1.0 and -2.5), or osteoporosis (T-score ≤ -2.5). Descriptive statistics were used to determine the frequency of MRI findings and the distribution of BMD categories based on DEXA. Quantitative MRI values were expressed as mean±SD. The relationships between age, BMD and MRI signal intensity of the lumbar vertebrae were analysed to evaluate the correlation between bone-marrow changes and bone-density status.

STATISTICAL ANALYSIS

Continuous variables were expressed as mean±SD. Pearson's correlation coefficient (r) was used to quantify the linear association between DEXA-derived parameters (BMD, T-score, Z-score) and MRI signal-intensity values. Two-sided 95% CI for each correlation coefficient were derived using Fisher's z-transformation. Analyses were performed using statistical software SPSS 2025 version 31.0.0. A two-tailed p-value <0.05 was considered statistically significant.

RESULTS

A total of 100 participants with lumbar spine abnormalities were evaluated. The cohort demonstrated an approximately equal sex distribution, with 52 females (52%) and 48 males (48%). The prevalence of lumbar spine abnormalities increased with advancing age, with more than half of the affected participants belonging to the age group > 40 years.

Based on DEXA-derived lumbar spine (L1-L4) T-scores, 42 participants (42%) were classified as having normal BMD, 31 (31%) as osteopenic and 27 (27%) as osteoporotic.

Sex-wise analysis demonstrated that osteopenia and osteoporosis were more frequently observed among females, whereas normal BMD was more prevalent among males [Table/Fig-5].

Age-wise analysis demonstrated a progressive decline in BMD with increasing age. In younger age groups, normal BMD predominated, whereas osteopenia and osteoporosis became increasingly common

S. No.	Sex	Normal BMD n (%)	Osteopenia n (%)	Osteoporosis n (%)
1	Female (n=52)	20 (38.5%)	18 (34.6%)	14 (26.9%)
2	Male (n=48)	22 (45.8%)	13 (27.11%)	13 (27.1%)

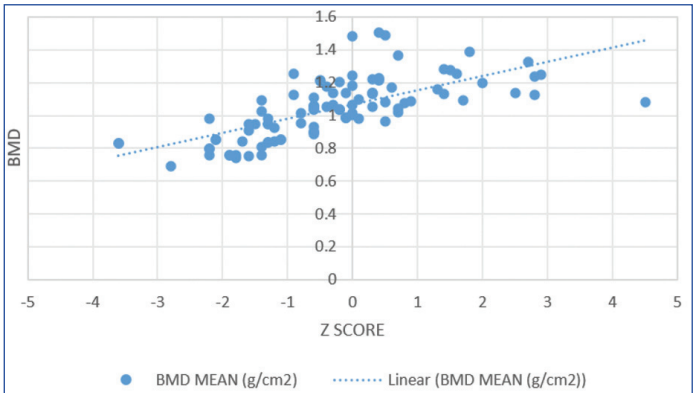
[Table/Fig-5]: Sex-wise distribution of lumbar spine BMD categories.

among older participants. The highest prevalence of osteoporosis was observed in participants aged > 61 years [Table/Fig-6].

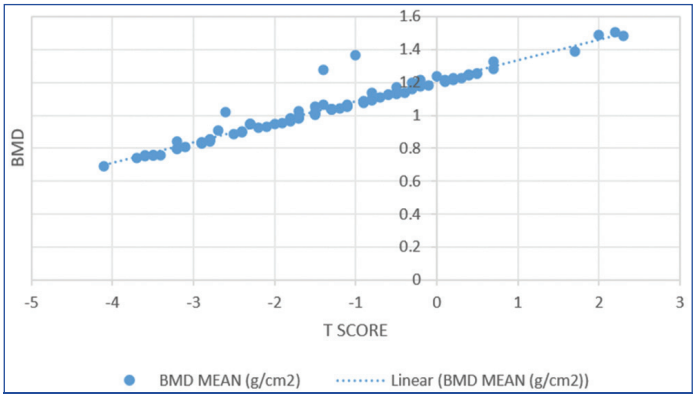
S. No.	Age group (years)	Normal	Osteopenia	Osteoporosis	Total
1	21–30	12	1	0	13
2	31–40	11	3	0	14
3	41–50	8	8	4	20
4	51–60	6	9	8	23
5	>61	5	10	15	30
	Total	42	31	27	100

[Table/Fig-6]: Age-wise distribution of lumbar spine BMD categories (assessed by DEXA). Highlighted cells were completed/corrected so that all rows and columns reconcile to a total of 100 participants.

As an internal consistency check of the DEXA measurements, scatter-plot analysis demonstrated a positive linear relationship between the lumbar spine Z-score (L1-L4) and mean BMD. Pearson's correlation revealed a strong, statistically significant positive correlation between Z-score and mean BMD (r=0.685; 95% CI 0.565 to 0.777; p-value <0.001; n=100) [Table/Fig-7]. Because the Z-score is mathematically derived from BMD, this association reflects the internal consistency of the DEXA data and validates the measurement process, rather than representing an independent biomarker finding. The relationship between T-score and mean BMD is presented in [Table/Fig-8].



[Table/Fig-7]: Relationship between lumbar spine Z-score (L1-L4) and mean Bone Mineral Density (BMD).



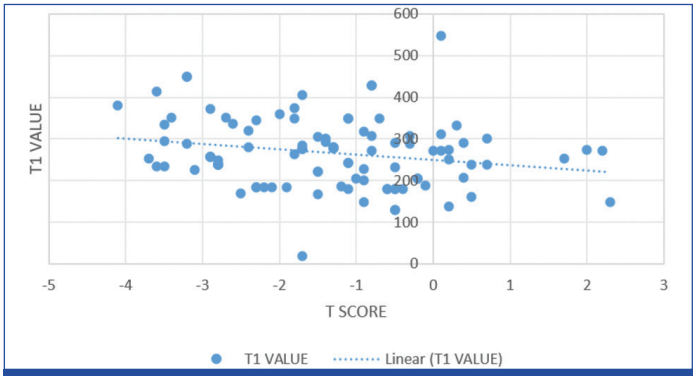
[Table/Fig-8]: Relationship between lumbar spine (L1-L4) T-score and mean Bone Mineral Density (BMD).

Correlation analysis was then performed to evaluate the relationship between the lumbar spine T-score and MRI-derived vertebral signal values [Table/Fig-9]. A weak but statistically significant negative correlation was observed between T-score and T1-weighted MRI signal values (r=-0.214; 95% CI -0.394 to -0.018; p-value=0.033) [Table/Fig-10], indicating that lower T-scores were associated with higher T1-weighted signal intensities.

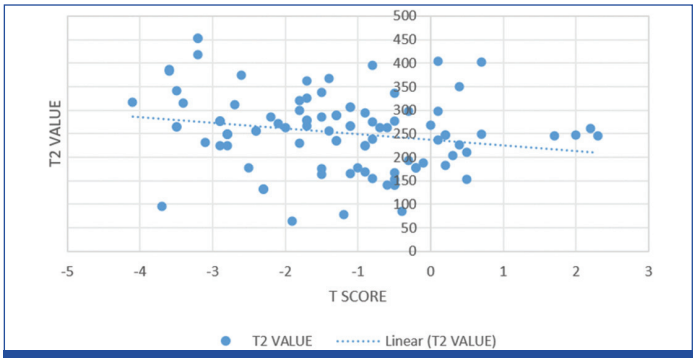
Similarly, a weak but statistically significant negative correlation was observed between the lumbar spine T-score and T2-weighted MRI signal values (r=-0.208; 95% CI -0.389 to -0.012; p-value=0.038) [Table/Fig-11], suggesting that participants with lower BMD tended to demonstrate higher T2-weighted signal intensities.

S. No.	Variables Correlated	r	95% CI	p-value	Interpretation
1	T-score vs T1-weighted MRI signal	-0.214	-0.394 to -0.018	0.033	Weak negative
2	T-score vs T2-weighted MRI signal	-0.208	-0.389 to -0.012	0.038	Weak negative

[Table/Fig-9]: Correlation between lumbar spine T-score and MRI-derived signal values.



[Table/Fig-10]: Relationship between T-score and vertebral T1 values.



[Table/Fig-11]: Scatter plot showing the correlation between the lumbar spine T-score and T2 relaxation values.

Overall, reduced BMD was more frequently observed among females and older adults. MRI-derived vertebral signal alterations demonstrated weak but statistically significant associations with reduced BMD, suggesting that MRI may provide supplementary information regarding vertebral bone-quality changes in addition to conventional DEXA assessment.

DISCUSSION

In this cross-sectional analytical study of 100 patients undergoing lumbar spine imaging, reduced BMD was more common among women and older participants, and lumbar vertebral MRI signal intensities showed weak but statistically significant inverse correlations with the DEXA-derived T-score. Specifically, lower T-scores (indicating lower bone density) were associated with higher T1- and T2-weighted signal intensities at the L3 vertebral body. These findings support the concept that routinely acquired lumbar MRI may carry opportunistic information about VBQ.

The observed inverse relationship between bone density and T1-weighted signal is biologically plausible. Loss of trabecular bone is accompanied by a relative increase in marrow adipose tissue, and fat produces high signal on T1-weighted images; an increase in vertebral T1 signal with declining BMD is therefore consistent with marrow adipose replacement of trabecular bone. An inverse relationship between vertebral marrow adiposity and bone density has been demonstrated directly using MRI and MR spectroscopy, in which higher marrow fat content accompanies lower BMD [12,13]. This is the same physiological basis that underlies the VBQ and LVBQ scores derived from T1-weighted MRI, which several groups

have reported to correlate with DEXA- and CT-based measures of bone density [7-10]. The weak negative correlation between T-score and T2-weighted signal observed here is directionally consistent with altered marrow fat and water composition in low-density bone, although T2-weighted signal is influenced by multiple tissue factors and should be interpreted with caution.

The strong correlation between the Z-score and mean BMD (r=0.685) should not be over-interpreted. Because the Z-score is computed from BMD, this association is expected and is best regarded as an internal consistency check confirming the reliability of the DEXA measurements, rather than as an independent result.

From a clinical perspective, the principal value of these observations is the possibility of opportunistic screening: patients who undergo lumbar MRI for degenerative or mechanical complaints could be flagged for formal DEXA assessment on the basis of qualitative or quantitative marrow signal changes, without additional cost or radiation. Comparable opportunistic strategies applied to routine imaging are already supported by the literature, including quantitative MRI-based osteoporosis scores derived from lumbar-spine signal intensity and computed-tomography Hounsfield-unit measurements [14,15]. Importantly, the VBQ score has been reported to predict fragility fractures independently of DEXA-derived BMD [11], underscoring the potential complementary value of MRI-based assessment. Nevertheless, the modest strength of the correlations in the present study ($|r| \approx 0.21$ for the MRI-T-score relationships, corresponding to roughly 4–5% of shared variance) means that MRI signal, as measured here, cannot replace DEXA for diagnosis and is, at most, a supplementary indicator that warrants further evaluation.

Limitation(s)

This study had several limitations that temper its conclusions. First, it was a single-centre, cross-sectional study with a modest sample of 100 patients, which limits statistical power to detect weak associations and precludes inferences about causation or temporal change. Second, MRI signal was sampled from a single vertebral level (L3), whereas DEXA-derived T- and Z-scores are mean values across L1-L4; L3 was selected because it is a mid-lumbar level that is consistently visualised and relatively less affected by aortic calcification and end-plate degeneration, but this single-level sampling remains a methodological mismatch, and measurement of L1, L2 and L4 would allow a level-matched comparison. Third, the analysis was confined to bivariate Pearson correlations; group-comparison tests across BMD categories, multivariable adjustment for known confounders such as age and sex, and diagnostic threshold (ROC) analysis were not performed and represent important directions for future work. Fourth, the correlations between MRI signal and BMD were weak, so the clinical discriminative value of the signal thresholds remains uncertain.

Future studies should ideally be prospective and multicentre, incorporate multi-level ROI measurements matched to the DEXA region, adjust for age and sex, and evaluate the diagnostic performance (sensitivity, specificity and area under the ROC curve) of standardised MRI-based signal or VBQ thresholds against DEXA and, where available, quantitative CT.

CONCLUSION(S)

Lumbar vertebral MRI signal alterations showed weak but statistically significant inverse correlations with DEXA-derived T-scores, with lower bone density associated with higher T1- and T2-weighted signal intensities. These findings suggest that routinely acquired lumbar MRI may provide supplementary, opportunistic information on VBQ and could help identify patients who would benefit from formal DEXA assessment. Given the modest correlation strength and the single-level, single-centre design, MRI signal cannot at present replace DEXA for the diagnosis of osteoporosis, and larger, prospective, level-matched studies with multivariable and diagnostic-accuracy analyses are required to define its clinical role.

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PARTICULARS OF CONTRIBUTORS:
1. PhD Research Scholar, Faculty of Paramedical Sciences, Assam Down Town University, Sankar Madhab Path, Gandhi Nagar, Panikhaiti, Guwahati, Assam, India; Swami Vivekananda University, Telinipara, Barasat - Barrackpore Road, Bara Kanthalia, West Bengal, India.
2. Professor, Faculty of Paramedical Sciences, Assam Down Town University, Sankar Madhab Path, Gandhi Nagar, Panikhaiti, Guwahati, Assam, India.

NAME, ADDRESS, E-MAIL ID OF THE CORRESPONDING AUTHOR:
Dr. Mrinal Kanti Singha,
Professor, Faculty of Paramedical Sciences, Assam Down Town University, Sankar Madhab Path, Gandhi Nagar, Panikhaiti, Guwahati-781026, Assam, India.
E-mail: drmrinalkantisingha@gmail.com

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