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QUANTITATIVE DIAGNOSIS OF OSTEOPOROSIS USING LUMBAR SPINE SIGNAL INTENSITY IN MAGNETIC RESONANCE IMAGING AMONG JORDANIAN POPULATION

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ABSTRACT:
Background: Osteoporosis is a global health problem characterized by low bone mineral density (BMD), which may lead to greater bone fragility and fracture risk, especially in postmenopausal females. Magnetic resonance imaging (MRI) can be utilized, in addition to dual-energy X-ray absorptiometry (DXA). The purpose of our study was to determine the MRI-based score (M-score) corresponding to the T-score used in DXA and to assess the correlation between lumbar spine signal-to-noise ratio (SNR) measured by MRI and T-score among Jordanian postmenopausal women.
Methods: Following approval by the Ethics Committee, we randomly selected 173 postmenopausal female patients who had DXA and lumbar-spine MRI, as well as a reference group of 34 premenopausal healthy adult patients (23-36 years) who had lumbar-spine MRI. In L1-L4, we calculated the SNR. Based on the T-score model, we proposed the M-score and the SNR. Receiver operator characteristic (ROC) analysis was utilized to identify the diagnostic performance of the M-score and SNR for osteoporosis detection with DXA.
Results: Postmenopausal patients in the control group had significantly lower DXA scores overall and higher SNRL1-L4 and M-score than controls ($p<0.0001$). For differentiating between osteoporotic and non-osteoporotic females, the SNRL1-L4 diagnostic threshold was 184.2 with a sensitivity of 80% and specificity of 92%. The M-score diagnostic threshold was 3.5 with a sensitivity of 93.3% and specificity of 83.5%. A negative correlation between M-score and T-score was detected. An optimal cut-off threshold of 5.95 was found for the M-score with a sensitivity of 80%, a specificity of 92%, and an accuracy of 95% for detecting osteoporotic patients from non-osteoporotic individuals.
Conclusion: The lumbar spine MRI-based score (M-score) quantitative technique for differentiating osteoporotic from non-osteoporotic females. There was a strong correlation between osteoporotic indices (T-score and BMD) and M-score and SNRL1-L4.

KEYWORDS: Dual-energy X-ray absorptiometry, Lumbar spine, Magnetic resonance imaging, M score, Osteoporosis, Signal-to-noise ratio.

INTRODUCTION

Osteoporosis is characterized by low bone mineral density (BMD) and micro-architectural deterioration that increases the risk of fractures (1,2). In healthcare settings, BMD is used as a proxy for osteoporosis (3). Dual-energy X-ray Absorptiometry (DXA) is considered the most efficient densitometry method for determining BMD by the World Health Organization (WHO) (3). Other techniques, such as quantitative computed tomography (CT) and quantitative ultrasonography, can be used to predict osteoporosis (4). This represents an opportunistic screening that would enable quick detection of high-risk patient populations that require additional testing, DXA, or therapy. Regular abdominal CT scans acquired for other clinical causes are explored as a quantitative approach to assess osteoporosis (5). Since osteoporosis is an asymptomatic disorder, numerous individuals may not get a DXA even if BMD testing is required and go undetected, but they might get an MRI due to low back pain and osteoporosis-related consequences (6). There was a significant unfavorable relationship found between BMD as determined by DXA and MRI measurements of pelvic and total bone marrow adipose tissue(7). It appears that as bone density declines in osteoporotic patients, the amount of fat in the vertebral marrow rises (8). Additionally, patients with osteoporosis may have significantly more bone marrow fat tissue (7–10). Importantly, individuals who had greater quantities of fat also had a greater incidence of fragility fractures (11). Because MRI lacks a quantitative score, it is ineffective as an indicator for osteoporosis, even if there is a relationship between the amount of adipose tissue shown in T1-weighted images and the BMD determined by DXA. Furthermore, MRI has been shown before to be able to reliably identify fractures that are fragile, linked to osteoporosis (12). Bandirali et al. introduced a novel quantitative lumbar spine MRI technique based on T1-weighted images, proposing the use of M-score and SNR in L1-L4 for osteoporosis identification (13). The M-score is an MRI score

derived from the T-score model that uses SNR rather than BMD. They found that BMD is adversely correlated with SNR in the L1-L4 vertebrae, and a T-score ≤-2.5 in DXA is correlated with M-score ≥5.5 (14). Such thresholds enable physicians to utilize MRI as an opportunistic tool to identify the etiology of low back pain and identify osteoporosis patients who might benefit from medical treatment.
This study aimed to determine the sensitivity, specificity, and diagnostic effectiveness of the M-score in Jordanian society based on the lumbar spine.

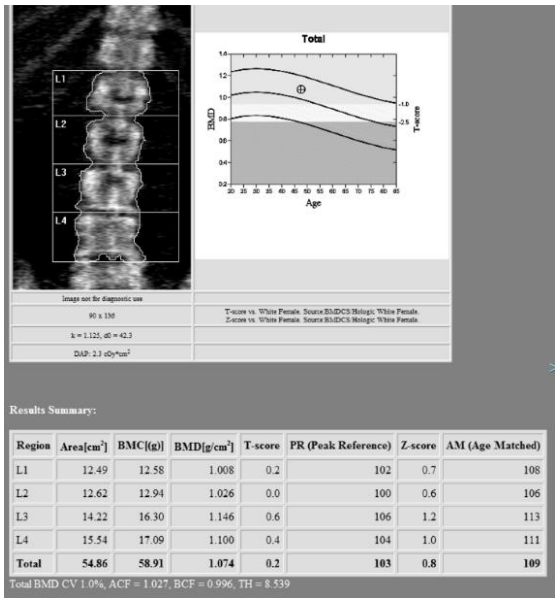
MATERIALS AND METHODS

Study population

The Institutional Review Board (IRB) has approved this study. Because of the retrospective nature of the study, a waiver of the patients' consent was obtained. All patients' information collected was anonymized. This study was conducted at King Abdullah University Hospital (KAUH), a tertiary care hospital in Irbid, north of Jordan. 173 postmenopausal females over 50 years old were selected randomly as a control group from all postmenopausal females who underwent both a lumbar spine MRI for low back pain and a lumbar and hip DXA within one year. A reference group of 34 healthy premenopausal patients aged (20-29 years) with normal body mass index (BMI =19- 25 kg/m2) who underwent lumbar-spine MRI was included.
The criteria for exclusion comprised both groups were a lumbar spine MRI with intravenous contrast, a history of benign or malignant tumor, metal prosthesis, demyelinating neurological conditions, history of lumbar vertebral fractures, patients who had less than two vertebrae measurement values in their DXA report, osseous lesions (e.g. bony islands or hemangioma), errors in DXA technique, a time interval between an MRI and a DXA longer than one year, existence of pertinent study artifacts and participants whose two adjacent vertebral T-scores value differed by more than one score.

DXA scan

BMD and T-scores of the lumbar spine were measured using standard techniques on a DXA machine (Hologic Horizon®) with 140 Kvp and 2.5 mAs. Before the examination, daily quality calibration was conducted as part of the pre-examination process. Patients were classified as having normal BMD (T-score ≥ -1.0), osteopenia (T-score between -1.0 and -2.5), and osteoporosis (T-score ≤-2.5), based on the WHO standards (15). T-scores for each L1-L4 were extracted from the DXA report.



Region	Area[cm²]	BMC[(g)]	BMD[g/cm²]	T-score	PR (Peak Reference)	Z-score	AM (Age Matched)
L1	12.49	12.58	1.008	0.2	102	0.7	108
L2	12.62	12.94	1.026	0.0	100	0.6	106
L3	14.22	16.30	1.146	0.6	106	1.2	113
L4	15.54	17.09	1.100	0.4	104	1.0	111
Total	**54.86**	**58.91**	**1.074**	**0.2**	**103**	**0.8**	**109**

Total BMD CV 1.0%, ACF = 1.027, BCF = 0.996, TH = 8.539

Figure 1. Measurement of bone density at the L1-4 levels of the lumbar spine. BMD, bone mineral density, GE, General Electric

Magnetic resonance imaging methods and image analysis

All patients underwent lumbar MRI scans by using MRI machine (Intera Achieva 1.5 T, Philips Medical Systems, Eindhoven, The Netherlands). All MRI scans were done for medical diagnosis due to low back pain. Standard lumbar spine assessment from L1-L4 was usually done by obtaining sagittal T1W spin-echo sequence, the best sequence for evaluating bone marrow (TR=600 ms; TE=11 ms; slice thickness=4mm; square field of view=280 mm; matrix 320 × 320). All MRI exams were acquired without injection of intravenous contrast media.
MRI images were extracted from the PACS system Synapse (Fujifilm Medical Systems, Tokyo, Japan), MR images were analyzed utilizing the RadiAnt DICOM Viewer (Medixant, Poznan, Poland) by using a region of interest (ROI) tool. Two radiologists, with six and eight years of experience in spinal MRI, performed the evaluation. ROIs were placed by using the largest possible circle diameter within the trabecular bone in sagittal plane of the vertebral body avoiding the areas that might alter the BMD values such as the vertebral cortex and basivertebral venous plexus posterior. For every vertebra, three ROIs were obtained on each of L1-L4, and then the mean of these ROIs was utilized for analysis. To assess the noise, a ROI was also placed exterior to the patient in an area free of artifacts 1 cm away from

the patient's body at the L2-L3 vertebral level (Figure 3). Signal-to-noise ratio (SNR) was obtained by dividing the mean of intra-vertebral intensity by the standard deviation of the noise measurements. The M-score (MRI-based score) for the diagnosis of osteoporosis was obtained by estimating the diagnostic performance of SNRL1-L4 for each individual. The mean (SNR ref) and standard deviation (SD ref) of the control group's SNRL1-L4 were also utilized in the calculation. The following equation was used to determine the M-score:
M-score = (SNRL1-L4 -SNR ref) / SD ref

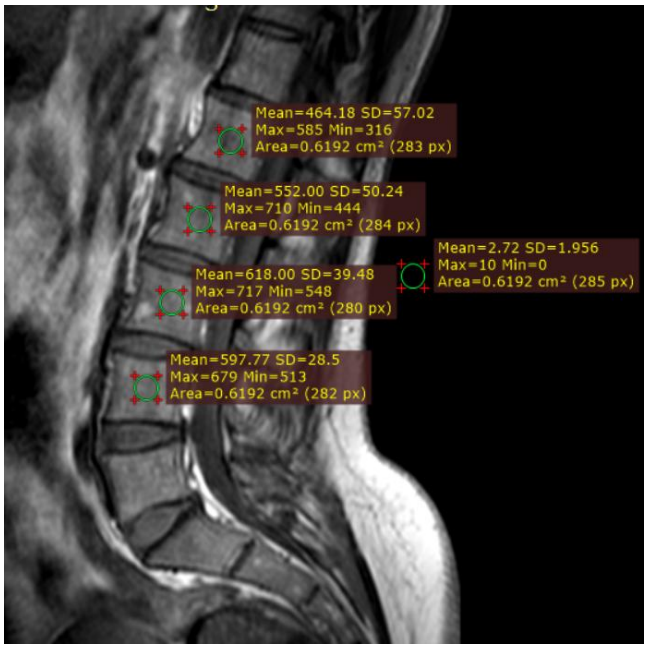


Figure 2. Measurement of signal and noise in the T1-weighted image at L1-4 of the lumbar spine. Min, minimum; Max, maximum; SD, standard deviation.

Across vertebrae, SNRL1-L4 of the intra-reader and inter-reader reproducibility results were 92% and 84%, respectively.

Statistical analysis

Data were presented as median interquartile range (IQR). Spearman correlation test was used to compare different continuous variables. The relationship between different categorical variables was assessed using the Chi-squared test ($\chi 2$). The diagnostic performance of SNRL1-L4 and M-score was estimated by receiver operator characteristic (ROC) analysis using the pROC package. Area under the curve (AUC) was estimated to assess the quality of the test. The best threshold cutoff was determined based on the closest top-left decision rule. Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were obtained accordingly. A two-sided p-value of less than 0.05 indicates statistical significance for all analyses. The statistical analysis was conducted using R software (version 4.3.3; R Core Team, 2026).

RESULTS

Patient characteristics

This retrospective study included 173 postmenopausal female patients and 34 female patients in the reference group. The median age of the study cases was 60 years (IQR: 54-70.2 years), with a median body mass index (BMI) of 28 kg/m² (IQR: 26-32kg/m²). While the median age of the reference group was 34 years (IQR: 29-35) with normal BMI (19- 25 kg/m2). The mean T-score was -1.40 (range: -4.5 to 3.5). Median BMI was significantly higher for osteoporosis patients (33.27 kg/m2, IQR: 31.89, 34.81) than in the non-osteoporosis group (normal and osteopenia) (27.27 kg/m2, IQR: 25.71, 29.99; p<0.001). Median age was 60 years (IQR: 54-70.25) in the non-osteoporosis group and 61.00 years (IQR: 55.00-66.00) in the osteoporosis group (p = 0.844). The median time interval between MRI and DXA scan was 60.0 days (IQR: 112.0) in the non-osteoporosis patients and 20.0 days (IQR: 58:00) in the osteoporosis patients. DXA was done within 6 months of MRI in 72.7% (96/132) of the non-osteoporosis group and 65.5 (27/41) of the osteoporosis group. There was no statistically significant difference between groups.

Table 1. Demographic and clinical characteristics of the study groups

Parameter	Normal	Osteopenia	Osteoporosis	p-value
Number of cases	71	61	41	
Age (Years)	60.00 [53.00,71.00]	60.00 [55.00,70.00]	61.00 [55.00, 66.00]	0.975
BMI (Kg/m2)	26.62 [25.56,28.29]	28.40 [26.57,32.60]	33.27 [31.89, 34.81]	<0.001

MRI within 6 months (%)	No	19 (26.8)	17 (27.9)	14 (34.1)	
	Yes	52 (73.2)	44 (72.1)	27 (65.9)	

Data for age and BMI are presented as median [interquartile range]; MRI data are presented as number (%). BMI: body mass index

The distribution of WHO classification is presented in Table 2. Among the non -osteoporosis group, 71 patients (53.8%) had normal values, and 61 patients (46.2%) had osteopenia, All 41 patients (100%) in the osteoporosis group met the criteria for osteoporosis. The chi-square showed a statistically significant correlation between the non-osteoporosis and osteoporosis groups ($\chi^2 = 172.95$, df = 2, $p<0.001$).

Table 2. The distribution of WHO classification

WHO classification	Non -osteoporosis (n=132)	Osteoporosis (n=41)
Normal	71 (53)	0(0.0)
Osteopenia	61(46.2)	0(0.0)
Osteoporosis	0(0.0)	41(100.0)

Data are presented as number (%), WHO: World Health Organization

The MRI-based M-score was computed using a different reference group of 34 healthy premenopausal patients aged 23-36 years with a normal BMI (19-25 kg/m²) without any abnormalities found on MRI. For this reference group, the mean and standard deviation (SD_ref) of SNRL1-L4 (SNR_ref) were 77 ± 18, respectively. Each postmenopausal patient's M-score was determined using the following formula: M-score = (SNRL1-L4 (patient) - 77) / 18.0.

T scores were significantly lower in the osteoporosis group compared to non-osteoporotic patients ($p<0.0001$) ,conversely, SNRL1-L4 and M-score were significantly higher ($p<0.0001$) in osteoporosis compared to the non-osteoporotic groups. The Median SNR L1-L4 (IQR) was 89.55 (78.03-161.99) in the non-osteoporotic group and 285.18 (207.19,360.90) in the osteoporosis group (Table 3). The median M-score (IQR) was 0.70 (0.06, 4.72) for the non-osteoporosis group and 11.57 (7.23-15.77) in the osteoporosis group ($p<0.0001$)

Table 3. Raw MRI Mean Signal Intensity by Vertebral Level

Parameter	Non-osteoporosis (n=132)	Osteoporosis (n=41)	P-value
SNR L1	89.21 [75.16, 160.60]	248.75 [198.47, 328.35]	<0.001
SNR L2	90.19 [78.41, 161.85]	269.96 [214.27, 348.95]	<0.001
SNR L3	92.22 [78.08, 162.67]	284.73 [203.44, 382.48]	<0.001
SNR L4	92.75 [77.90, 163.39]	272.74 [213.06, 355.90]	<0.001
Median SNR(L1-L4)	89.55 [78.03, 161.99]	285.18 [207.19, 360.90]	<0.001

Data are presented as median [interquartile range]

In the overall study population, M-score negatively correlated with T-score ($r = -0.95$, $p<0.0001$). When stratified by WHO classification, the correlation remained very strong in the normal group ($r = -0.93$, $p <0.0001$) and the osteoporosis group ($r = -0.93$, $p<0.0001$), while a moderate negative correlation was observed in the osteopenia group ($r=-0.57$, $p=0.0001$)

Table 4. M score and T score by group

Parameter	Normal	Osteopenia	Osteoporosis	p
M-score (median [IQR])	0.13 [-0.35, 0.43]	4.78 [3.81, 5.26]	11.57 [7.23, 15.77]	<0.001
T score: L1 (median [IQR])	-0.20 [-0.80, 0.35]	-1.60 [-2.00, -1.20]	-2.90 [-3.00, -2.30]	<0.001
T score: L2 (median [IQR])	0.00 [-0.50, 0.50]	-1.60 [-2.10, -1.20]	-2.80 [-3.40, -2.60]	<0.001
T score: L3 (median [IQR])	-0.10 [-0.65, 0.60]	-2.00 [-2.40, -1.60]	-3.40 [-3.80, -3.00]	<0.001
T score: L4 (median [IQR])	0.00 [-0.70, 0.65]	-1.90 [-2.30, -1.50]	-3.00 [-3.90, -2.50]	<0.001
T score: L1-L4 (median [IQR])	-0.20 [-0.50, 0.20]	-1.80 [-2.10, -1.50]	-3.20 [-3.40, -2.80]	<0.001

Data are presented as median [IQR]

The ROC curve assessment of SNR L1-L4 and M-score for the discernment of osteoporotic from non-osteoporotic groups had the same performance (AUC = 0.95 (95% CI: 0.91-0.98) when optimized for their respective threshold. Based on threshold of 184.2 for SNR L1-L4 and 5.96 for M-score, the diagnostic performance had a sensitivity of 80.5%, specificity 91.7%, PPV 75%, and NPV 93.7.%; p<0.0001 and with overall accuracy of 89.0%. (P value = 0.0043)

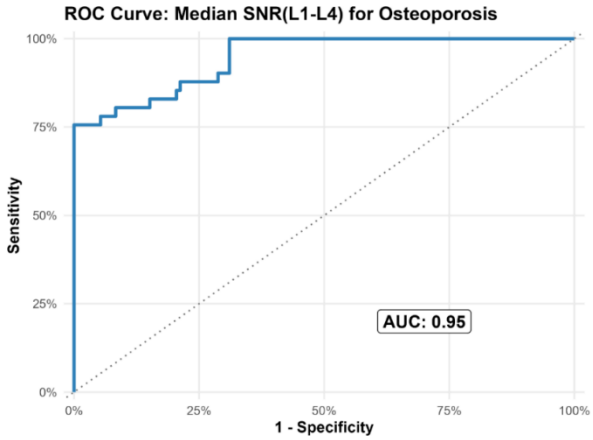


Figure 3. Receiver operator characteristic (ROC) curve of SNRL1-L4 for the discrimination of osteoporosis from non-osteoporosis patients: Area under the curve (AUC) was 0.94 (95% CI: 0.90-0.97). CI, confidence interval.

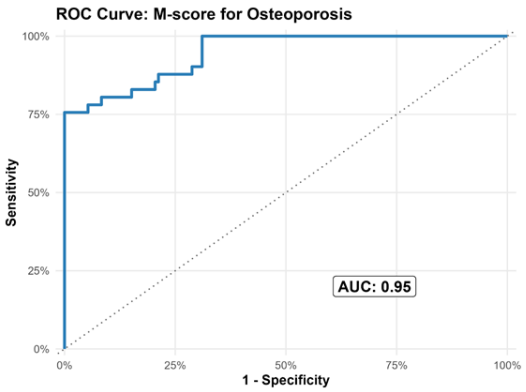


Figure 4. Receiver operator characteristic (ROC) curve of M-score for the discrimination of osteoporosis from non-osteoporosis patients: Area under the curve (AUC) were 0.95 (95% CI: 0.91-0.98). CI, confidence interval.

In the overall study population, Spearman correlation analysis revealed that M-score had a strong negative correlation with T-score (r = -0.95, p<0.0001) (Figure 5A). When stratified by WHO classification, the correlation showed negative strong correlation in both normal and osteoporosis groups (r = -0.93, p<0.0001), while a moderate negative correlation was noticed in osteopenia group (r = -0.57, p<0.0001) (Figure 5B).

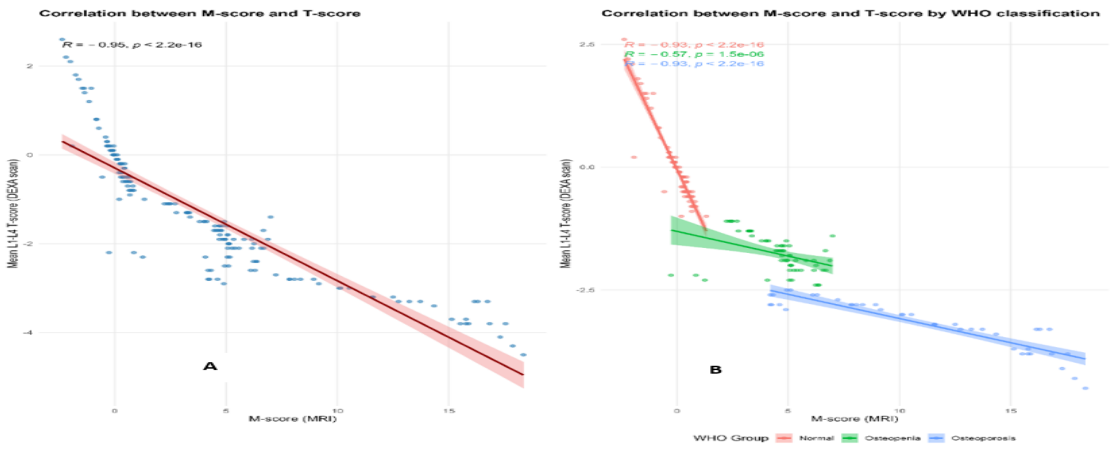


Figure 5. (A, B) Scatter plots showing correlation between M-score and T-score. A: according to and B: according to WHO classification

All DXA scores including T-score and BMD were significantly lower in post-menopausal females compared to the control group (P value < 0.0001). Meanwhile, SNRL1-L4 and M-score were significantly higher among cases than controls (P value < 0.0001).

DISCUSSION

Only individuals at a significant risk of fractures due to fragility undergo DXA screenings, and a minority of these patients presenting with fractures receive appropriate evaluation and treatment for osteoporosis (16) despite the fact that DXA is a broadly as gold standard quantitative diagnostic method for osteoporosis assessment and treatment (3). The absence of a screening policy is most likely the cause of the high-risk patients remaining underdiagnosed (13). In addition, T-score measurement can be increased in lumbar BMD measured by DXA examination in patients with obesity and degenerative disease, leading to an inaccurate perception of low likelihood of fractures in these patients (17). Moreover, the frequency of routine lumbar MRIs is rising as a result of the high incidence of low back pain. Clinicians can identify people at risk for osteoporosis and employ a novel quantitative MRI method based on M-score and SNR in patients who have had standard MRI as an opportunity-based screening technique (18). Due to the substantial fat content associated with hematological components, the T1-weighted spin-echo sequence is the most effective way to distinguish the cell composition in bone marrow, and osteoporosis may be linked to this characteristic (13). Compared to age-matched counterparts, osteoporotic patients (whether they are of primary or secondary origin) have higher levels of fat in their bone marrow (19). Many studies showed that all DXA scores, including T-score and BMD, were significantly lower in post-menopausal females compared to the control group (P value < 0.0001) (7,13,14,17,20). Consistent with this, in our study, SNRL1-L4 and M-score were significantly higher among cases than controls (P value < 0.0001).

The optimal M Score cut-off threshold for identifying osteoporosis differs among studies. Shayganfar et al reported a cut-off of 2.05 with a sensitivity of 90% and specificity of 87% in Iranian patients(17). In another study performed by Saad et al. among the Egyptian population, they reported a cut-off of 3.5 with a sensitivity of 93.3% and specificity of 83.5% (14). Kuzan and Kuzan conveyed a significantly lower cut-off of 0.5 with a sensitivity of 87% and specificity of 76.0% in Turkish female patients(20). Our study reported a cut-off of 5.96 with a sensitivity of 80.0% and specificity of 92.0%, which is closest to the original Bandirali threshold of 5.5.

In this study, we utilized a quantitative lumbar spine MRI-based technique to recognize Jordanian patients with longer menopausal time, normal or overweight BMI, lack of physical activity, family history of osteoporosis, insufficient sunlight exposure, excessive daily caffeine drinking, inadequate daily calcium consumption, and delayed menstrual age, all positively associated with osteoporosis (2). These elevated risk factors highlight the potential for osteoporosis screening utilizing standard T1-weighted images and lumbar DXA as a reference standard. We showed that lumbar spine MRI, which is frequently done for pain in the lower back, may be utilized as an opportunistic screening technique for osteoporosis with a sensitivity of 80%, specificity of 92%, and an accuracy of 95%. The goal of this new measure is intended to offer a dependable, user-friendly, and highly repeatable instrument that, among individuals having lumbar spine MRI for various purposes, may enable an opportunistic screening to detect individuals who require DXA. It has to be acknowledged that the M-score is a device-specific value and varies across various devices and protocols. The correlation between T-score and M-score was examined in accordance with the lack of an M-score cut-off point for identifying osteoporosis using the MRI machine in Jordan. Thresholds of M-score and SNR have been proposed in identifying osteoporotic patients using MRI machines, which is an advance toward minimizing the potential hazards of osteoporosis. We observed that the lumbar spine vertebrae are not equal in terms of SNR, which supports the use of their mean, as in lumbar DXA. It should be noted that each center should develop independent thresholds according to the various SNR/M score values supplied by each MR equipment for use in clinical settings.

Our study has limitations. The retrospective nature of the study may limit the power of some of our conclusions. The data from MRI and DXA scans were typically obtained under different conditions. Additionally, every individual center will have a distinct M-score cutoff value based on the various SNRs that each MRI scanner provides. Additionally, versus a spectroscopic measurement, the SNR determined by placing the ROI outside of the patient and within the vertebral body, excluding the cortical bone, subchondral abnormalities, osseous lesions (e.g., bony islands or hemangioma), and posterior venous plexus, is a straightforward method of assessing(21). Finally, because the control group of young women receiving MRI did not undergo DXA, bone density results were missing for our reference.

CONCLUSION

In conclusion, our study demonstrated that the standard lumbar spine MRI T1-weighted sequence can be utilized for predicting osteoporosis. This presents an intriguing chance for expanding assessment for osteoporosis to an extensive population of patients who undergo lumbar spine MRI daily for low back pain, avoiding any further imaging, radiation exposure, expense, or patient time. Its analytical utility needs to be proven on a sizable prospective patient population.

Author Contributions:

All authors meet the four ICMJE criteria: considerable contributions to conception, design, data acquisition, analysis, and interpretation; drafting and critical revision; final approval; and accountability for all aspects of the study.

Conflicts of Interest:

The authors have no potential conflicts of interest to disclose.

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