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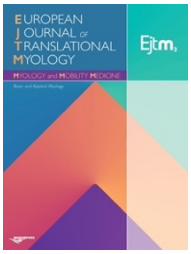

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Vertebral bone quality score as a new tool for osteoporosis diagnosis in patients undergoing lumbosacral fusion surgery: a single center cohort study

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Abstract

Osteoporosis, a common bone disorder, increases fracture and spinal surgery complications risk. This study evaluates the potential of the Magnetic Resonance Imaging (MRI)-based Vertebral Bone Quality (VBQ) score as an alternative for assessing bone density in lumbosacral fusion surgery patients. In a prospective cohort study from April 2021 to November 2022, 134 patients with lumbar degenerative diseases underwent lumbar Dual-Energy X-ray Absorptiometry (DXA) and lumbosacral non-contrast T1-weighted MRI. VBQ scores were calculated and analyzed using IBM SPSS Statistics and MedCalc software. Osteopenia/Osteoporosis patients exhibited significantly higher VBQ scores than normal bone mineral density patients (3.37 ± 0.51 vs. 2.99 ± 0.44, P<0.001). VBQ correlated significantly with lumbar DXA T scores (r value= -0.415, p<0.001). Receiver Operating Characteristic (ROC) analysis showed VBQ AUC values of 0.730

(CI 95% 0.647-0.803, P<0.001) and 0.839 (CI 95% 0.765-0.897, P<0.001) for Osteopenia/Osteoporosis and osteoporosis diagnosis, respectively. The study suggests MRI-derived VBQ scores may benefit pre-lumbosacral fusion surgery bone density assessment, potentially improving patient care and aiding osteoporosis detection in spinal surgery candidates.

Key words: vertebral bone quality; magnetic resonance imaging; osteoporosis; osteopenia; spinal fusion surgery.

Introduction

Osteoporosis is the most common bone disease and a significant global public health problem called "the silent epidemic of the 21st century".[1] This skeletal disorder is characterized by decreased bone density, resulting in an increased fracture risk, leading to disability, independence, economic burden, and mortality.[2,3] About 50% of white women and 20% of men may experience an osteoporotic fracture in their lifetime.[2] As life expectancy increases in developing countries, osteoporosis is expected to become more prevalent.[4] Vertebrae, distal radius, and proximal femur are at higher risk of osteoporotic fractures.[3] Osteoporosis brought poor surgical outcomes.[5] Fragility fractures during orthopedic surgery are more incident in osteoporotic bone.[5] Postoperatively, osteoporosis is associated with an increased risk of implementation failures, extended hospitalization, rate of revision surgery, and higher patient

mortality.[6] This skeletal disorder is a chronic asymptomatic disease; thus, many patients with undiagnosed osteoporosis have been deprived of treatment. In contrast, early diagnosis and timely treatment can prevent fragility fractures.

Bone Mineral Density (BMD) is the amount of minerals in the bone tissue.[7] According to the World Health Organization (WHO), BMD T score ≤ -2.5 describes osteoporosis in Dual-energy X-ray Absorptiometry (DXA).[8] Various scanning methods are available to measure BMD and diagnosis of osteoporosis. DXA is a commonly used method for BMD analysis.[7] DXA uses absorption of high and low-energy X-ray photons to evaluate bone density. The DXA test can measure the whole body, usually the hips and the lower spine. In this method, we need to know the patient's age, T-score, and Z-score to determine whether the patient has osteoporosis. The main disadvantage of DXA is that currently, there is no standardization in the measurement of bone and soft tissue.[7] Additionally, pregnancy, recent consumption of oral contrast, degenerative changes, severe deformities, and the presence of a foreign body in the study area are the other disadvantages of DXA.

Moreover, the precision of BMD measurement may be disrupted by vascular calcification and obesity. An alternative method of bone density measurement is the vertebral bone quality (VBQ) score, measured based on Magnetic Resonance Imaging (MRI). One of the advantages of MRI is that since osteoporosis is an asymptomatic disease, many patients are not examined with DXA, and their condition is not detected. However, the same patients may be scanned with MRI because of low back pain and complications caused by osteoporosis.[9] Due to few studies in these fields and various findings in different studies,[10,11] we aimed to determine MRI-based vertebral bone quality score accuracy for osteoporosis in patients undergoing lumbosacral fusion surgery for lumbar degenerative diseases.

Materials and Methods

Study design and participants

This prospective cohort study was conducted at Shahid Madani Educational and Medical Center, Karaj, Iran, from April 2021 to November 2022. Based on inclusion and exclusion criteria, we enrolled 139 patients referred to our center due to lumbar degenerative diseases. Aged more than 50 years men and women (only postmenopausal), candidates for lumbar fusion surgery for degenerative diseases of the lumbar spine, underwent lumbar DXA and lumbosacral noncontract T1 weighted MRI (1.5 T) within eight weeks before surgery, and consent to participate in the study, were inclusion criteria. Exclusion criteria included a history of spine tuberculosis, spinal infection, malignancies, Modic changes, bone islands, metastasis, bone masses, radiotherapy treatment, diagnosis of metabolic bone disease, previous spinal fracture, and lumbar spine surgery. For each patient who met the inclusion criteria, demographic information was collected, including age, gender, Body Mass Index (BMI), comorbidities (Diabetes mellitus, cardiovascular diseases, rheumatic diseases), smoking history (current smoker), long-term corticosteroid use (therapeutic daily doses more than 30 days during last day) and prior diagnosis of osteoporosis and osteopenia during the previous year.

Bone mass densitometry and diagnostic category

All patients underwent a DXA of the lumbar spine (L1-4) under the supervision of a rheumatologist within eight weeks before surgery in a single center. Patients were examined by DXA (Lunar DPX-Bravo, GE Healthcare) of the lumbar spine (L1-4) according to the

manufacturer's standard protocol, and T-scores were recorded. The osteoporosis diagnostic categories from the World Health Organization were used to categorize the areal BMD measured with DXA: osteoporosis, T score≤-2.5; osteopenia; -2.5 <T score<-1; and normal T score≥-1.

MRI-based VBQ score

Noncontract T1 weighted MRI of the lumbar spine (L1-4) was conducted by 1.5 T MRI (Philips Ingenia, Eindhoven, the Netherlands) with a standard protocol including sagittal cuts for L1–L4 vertebra using T_1 weighted spine-echo sequence (TSE, repetition time = 400 ms, echo time = 16 ms, squared field of view = 160 * 304 * 48 mm, slice thickness = 4 mm).

Two authors (Orthopedic and radiology specialists) who were blinded to patients' DXA results calculated the VBQ score for each patient independently. To measure the Vertebral Bone Quality (VBQ) score, the Regions Of Interest (ROIs) are first placed in the middle of the L1 to L4 vertebrae and the cerebrospinal fluid at the L3 level. Then, signal intensities (SI) are calculated in each ROI.

The VBQ score is calculated according to the SI corresponding to each ROI with the help of the following formula (The location of ROIs and how to calculate VBQ is according to the study of Ehresman *et al.*):[11]

$$\mathrm{VBQ} = \frac{\text{median of SI (L1} - \text{L4)}}{\text{SI (CSF)}}$$

Statistical analysis

For descriptive analysis, data normality was assessed using Kolmogorov-Smirnov and Shapiro-Wilk Tests. In the case of data normality, an independent t-test was used, and Mann-Whitney for

non-normally distributed data. Categorical data are expressed as percentages and were analyzed using Fisher's exact test (using IBM SPSS Statistics software, version 28.0, SPSS, Chicago, Illinois). The Pearson correlation coefficient was used to analyze the correlation between the T-score and the VBQ score and inter-rater reliability was calculated for the VBQ core (using MedCalc for Windows Software, version 19.4, Ostend, Belgium). A receiver operating characteristic curve (ROC) was used (using MedCalc for Windows Software, version 19.4, Ostend, Belgium) to analyze the differential value of the VBQ score in osteoporosis and calculate its specificity, sensitivity, and area under the curve (AUC). The Youden index was used to determine the cutoff value for the VBQ score to differentiate patients with osteoporosis/osteopenia and osteoporosis. A p-value <0.05 was considered statistically significant.

Results

Of 139 patients who met the inclusion criteria, 134 were examined in this study, and five were excluded because of incomplete data. The mean age of patients was 67.6 (Sd= 8.5) and 59% (n= 79) were female. The most common primary diagnosis was lumbar disc herniation (75.4%, n=101). Osteopenia/osteoporosis had been diagnosed prior in 19.4% (n=26). Regarding BMD, Based on DXA T-score results, osteoporosis (23.1%, n=31), osteopenia (38.1%, n=51), and normal BMD (38.8%, n=52) were diagnosed. The characteristics of patients are shown in Table 1.

The mean VBQ score in Osteopenia/Osteoporosis patients was significantly higher than normal BMD patients ($P<0.001$). The mean DXA T score of the lumbar spine was -1.03 (Sd= 1.49).

VBQ score and lumbar DXA T score were found to have a significant linear correlation (r value= -0.415, p<0.001), Figure 1. Between the two independent authors, the VBQ score inter-rater reliability was good (ICC= 0.84).

Using ROC to analyze VBQ score AUC, as diagnostic tools for Osteopenia/Osteoporosis and osteoporosis were 0.730 (Cl 95% 0.647-0.803, P<0.001) and 0.839 (Cl 95% 0.765-0.897, P<0.001), respectively (Figures 2 and 3). The sensitivity, specificity, and cut-off value of the VBQ score based on the highest Youden index for diagnosing osteopenia/osteoporosis and osteoporosis are calculated and are shown in Table 2.

Discussion

This study aimed to determine MRI-based VBQ score accuracy for osteoporosis diagnosis in patients undergoing lumbosacral fusion surgery. Osteoporosis is a prevalent condition defined by reduced bone mass and deterioration of bone microarchitecture. It has become a worldwide epidemic, mainly attributed to the increasing proportion of elderly individuals.[12,13] Many patients fail to receive timely diagnoses, resulting in inadequate identification and management and, underdiagnosis and under-treatment.[14] It is imperative to know the patient's BMD status before spinal fusion surgery in terms of the occurrence of complications and fractures; on the other hand, in many patients (for various reasons such as the lack of request by the surgeon and the impossibility of doing DXA), the DXA BMD results before surgery is not available.[10,15,16] DXA screening rates in eligible individuals are low despite effective therapies for poor bone quality.[17] Therefore, many surgical patients arrive without baseline DXA data. When patients need spine

fusion surgery, DXA might delay surgery. Consequently, it is essential to use available alternative diagnostic/screening methods.

We enrolled 134 patients and 82 were diagnosed with osteoporosis/osteopenia (Lumbar DXA T score <-1). In osteoporosis/osteopenia patients, the VBQ score was significantly higher than in normal BMD patients, and a significant negative linear correlation was found between the VBQ score and the lumbar DXA T score. In the study of Ehresman *et al.*,[10] by examining spinal surgery patients, a significant difference was seen in the VBQ score of patients with osteoporosis/osteopenia compared to patients with normal BMD, and a negative and significant correlation was observed between VBQ score and lumbar DXA T score, which is in line with our findings. The Pu *et al.*[18] study reported similar results regarding the correlation between VBQ score and lumbar DXA T score in spinal surgery patients. A systematic review and meta-analysis also found moderate and negative significant correlations between VBQ score and lumbar DXA T score in spinal surgery patients.[19] These findings show the significant correlations between these two scores in patients who are candidates for spinal surgery, which is very important in identifying alternative diagnostic/screening methods for BMD in these patients.

Regarding the accuracy of the VBQ score for diagnosing osteoporosis and osteopenia/osteoporosis in these patients based on the DXA lumbar T score WHO category, we found the AUC of 0.83 and 0.73, with VBQ score cut-off value of 3.38 and 3.37, respectively. The sensitivity and specificity were 83% and 70% for osteoporosis and 58% and 82% for osteopenia/osteoporosis, respectively. Ehresman *et al.*[10] found a similarly high sensitivity (81%) for the VBQ score in diagnosing osteoporosis/osteopenia. Although their study had a smaller sample size, the AUC of 0.81 indicates a robust discriminatory ability, which aligns with our findings. Pu *et al.*[18] reported slightly higher specificities (87%) for osteoporosis diagnosis with a

VBQ score greater than 3.05. They have also demonstrated good AUC values for osteoporosis (0.81) and osteopenia (0.79), which aligns with the diagnostic accuracy we observed. Salzmann *et al.*[20] found a VBQ score cutoff value of more than 2.38 for osteoporosis/osteopenia diagnosis, sensitivity (74%) and specificity (57%) were slightly lower, the AUC of 0.70 still suggests a reasonable discriminatory capacity for the VBQ score in diagnosing bone density abnormalities. Chang *et al*.[21] reported an excellent AUC of 0.80 for the VBQ score in diagnosing osteoporosis/osteopenia in patients with spinal degenerative disease. Kim *et al.*[22] study revealed that a greater VBQ score was associated with the presence of osteoporosis (area under the curve=0.754, P=0.006). The cut-off VBQ for osteoporosis was 2.6 (Youden index 0.484; sensitivity: 58%; specificity: 90%), which further supports the VBQ score's diagnostic potential. Also, a recent study found that the VBQ score was independently associated with low BMD (OR: 4.134, 95% CI 2.136–8.000, P< 0.001), and the area under the ROC curve indicated that the diagnostic accuracy of the VBQ score for predicting low BMD was 81% in patients with adolescent idiopathic scoliosis.[23]

In light of the findings, as mentioned earlier, our research highlights the importance of the VBQ score in assessing bone density in patients enduring lumbosacral fusion surgery. Osteoporosis is a global health concern, especially among the geriatric population, necessitating accurate and prompt diagnoses. Before surgery, patients frequently lack baseline DXA data, which can potentially delay vital procedures. The VBQ score is a valuable alternative diagnostic and screening tool in this context.

This prospective cohort study's strengths include well-defined inclusion and exclusion criteria, multiple diagnostic tools (DXA and MRI-based VBQ score) to assess bone density, robust statistical analysis methods, and clinical relevance in addressing alternative diagnostic

approaches in osteoporosis patients undergoing spinal surgery. The study's single-center nature, small sample size, and lack of external validation limit its generalizability and scope. These strengths and limitations should guide this field's research interpretation and direction.

Conclusions

In conclusion, our study highlights the potential of the MRI-based Vertebral Bone Quality (VBQ) score as a promising tool for assessing bone density in patients undergoing lumbosacral fusion surgery. Osteoporosis, a widespread health concern, necessitates effective diagnostic methods, and traditional approaches like Dual-energy X-ray absorptiometry (DXA) have limitations. Our findings demonstrate a significant correlation between VBQ scores and lumbar DXA T scores, indicating the potential of VBQ as an alternative diagnostic tool. The study also shows higher VBQ scores in patients with osteoporosis or osteopenia, suggesting its diagnostic accuracy. However, the study acknowledges limitations such as its single-center nature and the need for larger-scale validation studies. Despite these limitations, our results suggest that the VBQ score could be a valuable alternative for timely osteoporosis diagnosis in the context of spinal surgery, improving patient care.

List of abbreviations

VBQ, Vertebral bone quality

MRI, Magnetic resonance imaging

DXA, Dual-energy X-ray absorptiometry

BMD, Bone mineral density

WHO, World Health Organization

AUC, Area under the curve

Yo, Youden index

SE, Sensitivity

SP, Specificity

ROC, Receiver operating characteristic curve

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Contributions

Conceptualization: AN; Methodology: ABB, AM; Formal analysis and investigation: AM, SA, DH, DC; Writing - original draft preparation: DH, PC; Writing - review and editing: SA, AN, PC, Supervision: ABB. All authors read and approved the final manuscript.

Conflict of interest

No funding was received for conducting this study. The authors have no relevant financial or non-financial interests to disclose.

Ethics approval

All procedures performed in studies involving human participants were under the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The Alborz University of Medical Sciences Ethics Committee approved the study protocol (Project number: IR.ABZUMS.REC.1400202).

Consent to participate

Informed consent was obtained from all individual participants included in the study.

Availability of data and materials

The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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Table 1. The characteristics of patients.

Variables*	Total n=134 (%)	Normal BMD n=52 (%)	Osteopenia/Osteoporosis n=82, (%)	P value
Age (years)	67.68 (8.55)	66.34 (8.81)	68.53 (8.33)	0.163
Gender (male)	55 (41.0)	25 (48.1)	30 (36.5)	0.210
BMI (Kg/m^2)	26.68 (3.69)	26.22 (3.74)	26.96 (3.64)	0.261
Smoking (yes)	9 (6.7)	1 (1.9)	8 (9.8)	0.153
Long-term steroid use	4 (3.0)	1 (1.9)	3 (3.7)	0.999
Comorbidities				
Diabetes mellitus	20 (14.9)	6 (11.5)	14 (17.1)	0.461
Cardiovascular diseases	42 (31.3)	19 (36.5)	23 (28.0)	0.342
Rheumatoid diseases	7 (5.2)	2 (3.8)	5 (6.1)	0.706
Primary diagnosis				
Lumbar disc herniation	101 (75.4)	42 (80.8)	59 (72.0)	0.306
Lumbar spinal stenosis	33 (24.6)	10 (19.2)	23 (28.0)	

VBQ score	3.22 (0.52)	2.99 (0.44)	3.37 (0.51)	<0.001

*: Continuous variables were expressed as means and standard deviation; Categorical variables represent counts and frequencies. BMI: Body mass index, and VBQ: Vertebral bone quality.

Table 2. The accuracy of the VBQ score for diagnosing Osteopenia/Osteoporosis and osteoporosis based on the DXA T score category.

Diagnosis	AUC	CI 95%	Yo	Cut-off	SE	SP	P value
Osteoporosis	0.839	0.765-0.897	0.54	3.38	83.87	70.87	<0.001
Osteopenia/Osteoporosis	0.730	0.647-0.803	0.41	3.37	58.54	82.69	<0.001

AUC, Area under the curve, Yo, Youden index, SE, Sensitivity, SP, Specificity.

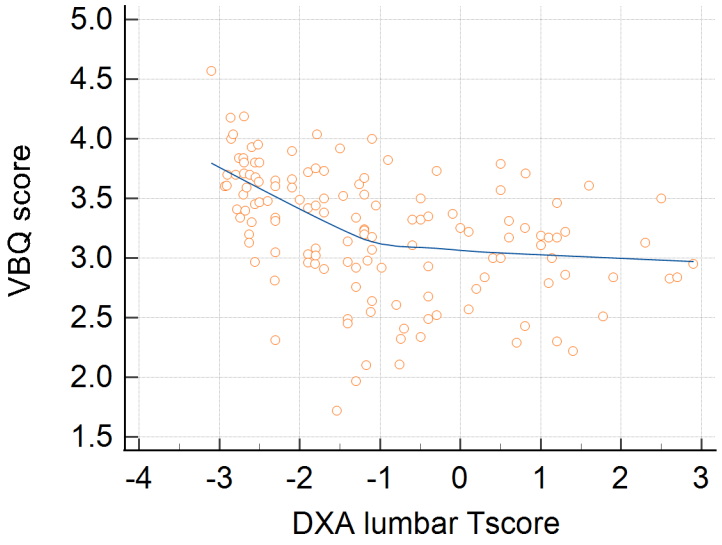

Figure 1. VBQ score correlated with the Lumbar DXA T score.

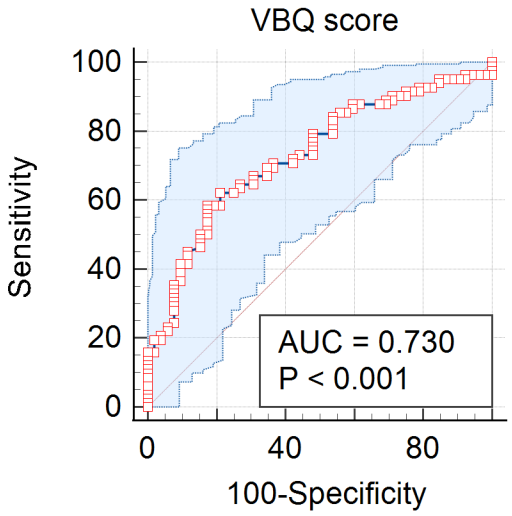

Figure 2. Area under the curve (AUC) using ROC analysis illustrating the accuracy of VBQ score for osteopenia/osteoporosis diagnosis based on lumbar DXA T score category.

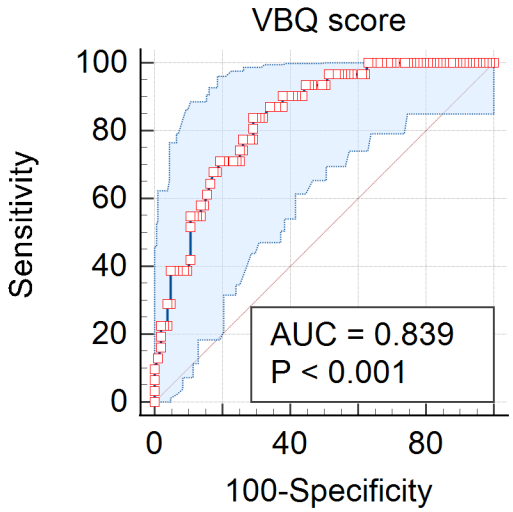

Figure 3. Area under the curve (AUC) using ROC analysis illustrating the accuracy of VBQ score for osteoporosis diagnosis based on lumbar DXA T score category.

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