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Combined application of vertebral CT values and MRI vertebral bone scores in the evaluation of osteoporosis

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Pei Wang, Qun Zhang, Tianran Li, Jing Lu, Yi Zhang, Liutong Shang declare that they have no conflict of interest.

Abstract

Purpose: To retrospectively analyze the correlation between vertebral CT values and vertebral bone scores from MRI, and evaluate their diagnostic efficacy for osteoporosis.

Materials and methods: This retrospective analysis 212 patients at the one center from April 2024 to January 2025. Patients were divided into the non-osteoporosis and osteoporosis group according to vertebral QCT values. CT values and VBQ scores were measured and calculated manually. T-tests and chi-square tests were used for inter-group comparisons of risk factors. Pearson correlation coefficients were used to assess the linear relationships between T1&T2 VBQ scores, and CT values. ROC curves were constructed to determine the diagnostic performance of them.

Results: 212 patients were divided into non-osteoporotic group (n=90) and osteoporotic group (n=122) based on QCT. The mean age of the osteoporotic group (62.73 ± 10.80 years) was significantly higher than non-osteoporotic group (44.28 ± 15.05 years), $t = -10.37, p < 0.01$. The age and status were significant risk factors for osteoporosis ($p < 0.01$). CT values in osteoporosis group were lower than those in non-osteoporosis group, while T1 VBQ scores and T2 VBQ scores were both higher, significant correlations among T1 VBQ scores, T2 VBQ scores, and CT values ($p < 0.01$) support VBQ scores and CT values as complementary indicators. The diagnostic efficiency of T1 VBQ and T2 VBQ scores was excellent (AUC=0.810, AUC=0.811).

Conclusions: Age and gender are key osteoporosis risk factors. The inverse relationship between CT values and MRI VBQ scores supports their complementary use. VBQ scores demonstrate high diagnostic utility for osteoporosis, suggesting combined indicator application improves accuracy.

Key point

QCT requires specialized equipment and software, a new user-friendly and widely applicable auxiliary method for osteoporosis is especially needed.

Decreased CT values and increased VBQ scores support VBQ score and CT value as complementary indicators.

The VBQ technology of CT combined with MRI enables comprehensive evaluation from bone density to bone quality, accurately predicting surgical risks, optimizing spinal surgery decision-making, and serves as an efficient radiation-free supplementary diagnostic tool.

Key words: Quantitative computed tomography; Vertebral bone quality; MRI

Abbreviations: CT, Computed tomography; MRI, Magnetic resonance imaging; QCT, Quantitative computed tomography; VBQ, Vertebral bone quality; ROC, Receiver Operating Characteristic.

1.0 Introduction

Osteoporosis (OP) is a systemic bone metabolic disease characterized by decreased bone mass and bone mineral density, resulting in reduced bone strength and increased risk of fractures(1). Chinese people over the age of 50, the probability of them suffering from OP is approximately 7% and 32%. Currently, there are more than 50 million osteoporosis patients in China(2,3). Currently, the gold standard for bone mineral density (BMD) assessment is still dual-energy X-ray absorptiometry (DXA). DXA results are easily influenced by factors including lumbar degenerative changes, spinal scoliosis, osteophytes, vertebral fractures, and vascular calcification. QCT, in particular, can quantify trabecular volumetric bone density and is non-invasive. However, QCT requires specialized equipment and software, its clinical adoption is relatively low. Thus, a new user-friendly and widely applicable auxiliary method for BMD detection is especially needed.

VBQ based on MRI is an auxiliary examination method that evaluates the condition of the bone by using the signal intensity within the vertebral marrow. Due to advantages such as high reliability, simple operation, no radiation, and minimal interference from lumbar degeneration, it has gradually attracted the attention of scholars in recent years. CT has also been studied by some scholars, such as Schreiber and others proposed a method of using standardized linear attenuation coefficients (Hounsfield Units, HU) of spinal CT tissues to assess regional BMD(4). Pickhardt P J examined the correlation between HU values and DXA results among 1,867 patients, and evaluated the diagnostic value for OP. The results showed that HU values defined in the osteoporosis group by DXA were significantly lower than those of the non-osteoporosis group ($p < 0.001$)(5).

This study intends to use routine lumbar CT and MRI scan images from our center to measure CT values and calculate VBQ scores, compare them with QCT-measured lumbar BMD results, and explore the relationship between them, and further clarify the role of VBQ scores and CT values in BMD assessment for patients.

2. Materials and Methods

2.1 Patients

The study followed the Declaration of Helsinki and was approved by the Ethics Committee of the Fourth Medical Center of the Chinese PLA General Hospital. Patient data for this study were collected according to the

inclusion and exclusion criteria. From April 2024 to January 2025, patients visiting the outpatient clinic and those hospitalized at our hospital were enrolled. Inclusion criteria: (a) outpatients or inpatients with complete medical histories; (b) patients who underwent lumbar CT examination, lumbar MR examination, and lumbar QCT examination, with an interval between CT and MR scans ≤ 3 months. Exclusion criteria: (a) patients with congenital spinal deformities, spinal tumors, spinal tuberculosis, spinal infections, ankylosing spondylitis, and other diseases; (b) patients with acute traumatic lumbar fractures or severe spinal scoliosis; (c) patients with lumbar internal fixation devices or lumbar surgery history; (d) patients with incomplete medical history or clinical case data.

2.2 Study Methods

2.2.1 General Data Collection

Through inquiry, phone consultation, and retrospective review of medical records, the following were documented: patient age, gender, body mass index (BMI), history of diabetes, hypertension, hyperlipidemia, and medication history (over 3 months). In female patients, time information must also be collected.

2.2.2 QCT Data Collection

The American Philips 64-slice spiral CT scanner was used to scan the lumbar spine (tube voltage 120 kV, tube current 400–500 mA, reconstructed slice thickness 1 mm, bone window width 1500 HU, window level 500 HU). The thin-slice images reconstructed by CT were automatically transmitted to the QCT Pro workstation to measure the BMD of the L1–L3 vertebral bodies. The largest central section of the vertebral body was selected, and the region of interest (ROI) was placed on it (Figure 1). According to the diagnostic criteria of OP by QCT, the patients were divided into the OP group and non-OP group. The above criteria refer to the “Practice Guideline for the Performance of QCT Bone Densitometry” by the American College of Radiology, which recommends that a QCT BMD value (mean BMD from T12 to L2 segments) less than 80 mg/cm³ is diagnosed as OP.

2.2.3 CT Value Measurement

The lumbar spine was scanned using an American Philips 64-slice spiral CT (tube voltage 120 kV, tube current 400–500 mA, reconstruction slice thickness 1 mm, bone window width 1500 HU, window level 500 HU) and a German Siemens 64-slice spiral CT (tube voltage 120 kV, tube current 400–500 mA, reconstruction slice thickness 1 mm, bone window width 1500 HU, window level 500 HU). The CT value of the L3 was measured in the conventional bone window; three cross-sectional slices were selected. The largest possible region of interest was outlined within the cancellous bone, and the average value of the regions of interest from the three cross-sections was calculated and recorded (Figure 2). Figure A shows the sagittal view of the lumbar CT with the marked line indicating the level of the third lumbar vertebra; Figure B–D shows the transverse section of the third lumbar vertebra, with HU values of 189.5 HU/185.1HU/179.4HU.

2.2.4 VBQ Value Measurement and Calculation

VBQ scores is performed using non-contrast MRI scans (United Imaging 1.5T, sagittal T2: TR=2447ms, TE=101.8ms; sagittal T1: TR=604ms, TE=11ms; slice thickness 4.0mm), (United Imaging 3T, sagittal T2: TR=2390ms, TE=97.7ms; sagittal T1: TR=669ms, TE=9.7ms; slice thickness 4.0mm), and (Siemens 3T, sagittal T2: TR=2790ms, TE=101ms; sagittal T1: TR=600ms, TE=8.3ms; slice thickness 4.0mm). The scanned segment must include the complete L1–L4 vertebral bodies. On the mid-sagittal T1- and T2-weighted images, regions of interest (ROIs) are set on the medullary portions of L1–L4 vertebral bodies and the cerebrospinal fluid (CSF) area at the L3 level to measure the average signal intensity within each ROI. The median or mean signal intensity of the L1–L4 vertebral bodies is taken and corrected by the mean ROI signal intensity of CSF at the L3 level (see Figure 4). In this study, for the purpose of optimizing the simplicity and generalizability of the VBQ score, no restrictions were placed on MRI parameters or manufacturer.

$$VBQ = \frac{SI(L1-L4)}{SI_{CSF}}$$

Formula 1. VBQ score calculation formula

Figure 3. Median sagittal views of lumbar MRI T2WI and T1WI

Two trained independent researchers measured and calculated all CT values and VBQ scores without knowledge of the QCT results.

2.3 Statistical Analysis

This study adopted a retrospective analytical design. Statistical methods strictly followed the principles of biostatistics, and statistical analyses were performed using SPSS 26.0 software (IBM Corporation, Armonk). Inter-group comparisons: Continuous variables were analyzed using independent sample t-tests, assuming data were normally distributed; categorical variables were analyzed using the χ^2 test. Correlation analysis: Pearson correlation coefficients were used to evaluate the linear relationships among T1VBQ score, T2VBQ score, and CT value. Assessment of diagnostic value: ROC curve analysis was performed to calculate the area under the curve (AUC), sensitivity, specificity, and 95% confidence interval (95% CI). An AUC >0.7 indicated high diagnostic value, and the cutoff value was determined based on the Youden index. All analyses were conducted with $\alpha=0.05$ as the significance threshold, and results were presented as mean $\pm$ standard deviation ($\bar{x} \pm s$) or percentage (%). $p < 0.05$ was considered statistically significant.

3. Results

3.1 Comparison of Baseline Data among Groups

Analysis results showed that the osteoporosis group was older than the non-osteoporosis group ($p<0.01$), and the proportion of vertebral fractures in the osteoporosis group was higher than in the non-osteoporosis group ($p=0.01$). Among the 94 women in the study, the proportion in the osteoporosis group was higher than in the non-osteoporosis group ($p<0.01$). For details, see Table 1.

3.2 Comparison of T1 VBQ scores, T2 VBQ scores, and CT values between groups

Analysis showed that CT values in the osteoporosis group were lower than in the non-osteoporosis group, while T1 VBQ scores and T2 VBQ scores were higher, with statistically significant differences (all $P<0.01$). See Table 2 for details.

3.3 Correlation analysis among T1 VBQ score, T2 VBQ score, and CT values

Analysis results showed that T1 VBQ scores were positively correlated with T2 VBQ scores ($r=0.60$, $p<0.01$), T1 VBQ scores were negatively correlated with CT (HU) values ($r=-0.31$, $p<0.01$), and T2 VBQ scores were also negatively correlated with CT values ($r=-0.34$, $p<0.01$). see figure 5.

3.4 Diagnostic value of T1 VBQ score, T2 VBQ score, and CT value for osteoporosis

Analysis showed that CT value (HU) (AUC=0.741, 95%CI=0.675~0.807), T1 VBQ score (AUC=0.810, 95%CI=0.752~0.868), and T2 VBQ score (AUC=0.811, 95%CI=0.752~0.869) all demonstrated high degrees when compared with QCT results. See Table 3 and Figure 6 for details.

4. Discussion

A total of 212 patients were included in this study, divided into non-osteoporotic group ($n=90$) and osteoporotic group ($n=122$) according to vertebral QCT values. General characteristics comparison showed that the mean age of the osteoporotic group (62.73 ± 10.80 years) was significantly higher than that of the non-osteoporotic group (44.28 ± 15.05 years), $t=-10.37$, $p<0.01$, indicating that age is an independent risk factor for osteoporosis. Peri-menopausal women experience rapid declines in bone mineral density(6). Our study showed that among 94 women, the proportion in the osteoporosis group (81.8%) was significantly higher than in the non-osteoporotic group (18.2%), $\chi^2=29.73$, $p<0.01$, confirming it as a key factor for female bone mass. The reason is partly direct, affecting the activity of bone cells (osteoblasts, osteoclasts, bone lining cells). On the other hand, mediation of bone immunity is also essential in postmenopausal osteoporotic bone mass loss(7). In addition, in cases of deficiency, changes in pro-inflammatory cytokines (including IL-6 and Midkine) can alter bone fracture healing, potentially causing delayed healing(8). Our results show that there are no statistically significant differences between groups in gender, weight, BMI, smoking history, alcohol consumption history, or history of diabetes ($p>0.05$), indicating that these factors have minimal impact on bone mass.

This study found that for vertebral fractures, the proportion in the osteoporosis group (88.2%) was significantly higher than in the normal bone mass group (11.8%), $\chi^2=7.21$, $p=0.01$, suggesting a close association between fractures and osteoporosis. Globally, nearly 200 million people are diagnosed with osteoporosis annually, with almost 9 million osteoporotic fractures each year(9). The incidence of osteoporotic fractures makes it one of the leading causes of death among the elderly(10). Therefore, accurate early diagnosis and assessment of osteoporosis have always been among the main concerns of orthopedic physicians and researchers. Our study shows that T1 VBQ score in the osteoporosis group (3.67 ± 0.64) was significantly higher than in the normal bone mass group (2.97 ± 0.52), $t=-8.52$, $p<0.01$. T2 VBQ score in the osteoporosis group (0.57 ± 0.12) was significantly higher than in the normal group (0.45 ± 0.10), $t=-8.02$, $p<0.01$, indicating that rising T1VBQ and T2VBQ scores indicate bone mass. Ehrean et al. found that T1 VBQ scores could significantly distinguish healthy from osteoporotic bone and moderately correlate with minimal femoral neck T values. The VBQ score is negatively correlated with T score; higher T1 VBQ scores indicate lower bonemass (11), which is consistent with our research findings. The occurrence of osteoporosis is often accompanied by an increase in bone marrow adipocytes and an elevated content of various fat tissues in the bone marrow(12). Thus, changes in fat cells in the bone marrow may indirectly reflect bone, and MRI technology can be used to assess bone marrow fat content and changes early, comprehensively, and non-invasively. In patients with osteoporosis, the trabecular bone shows signal enhancement on MRI T1 and T2 weighted images, which is due to the infiltration of fat into bone. Early studies have confirmed that osteoporosis is characterized by trabecular bone atrophy and localized replacement by fat cells(13). The VBQ value is standardized using cerebrospinal fluid, and since individual cerebrospinal fluid composition is similar, it can be used for different types of MRI scanners(14). And this study conducted statistical analysis based on both 1.5T and 3.0T MRI scanners. However, Lin et al. suggested that VBQ scores measured on 1.5T MRI were higher than those on 3.0T and reflected bone mineral density better(15); while another study found no statistical difference in VBQ measured at different field strengths (1.5T vs. 3.0T)(16). Therefore, whether appropriate magnetic field strength is required to ensure the accuracy of VBQ score measurements still needs further investigation. However, our research data indicate that different MRI machine manufacturers have a significant impact on the measurement of VBQ scores. T1VBQ and T2VBQ scores measured by Siemens 3.0T differ excessively from those measured by United Imaging 1.5T and United Imaging 3.0T; thus, the 12 patients assessed by Siemens machines were excluded due to osteoporosis, although the specific reasons have not been clarified.

Pearson correlation analysis showed a positive correlation between T1VBQ and T2VBQ scores ($r=0.60$, $P<0.01$), indicating that both reflect bone pathological changes synergistically. There was a negative correlation between T1VBQ scores and CT values ($r=-0.31$, $P<0.01$), suggesting that an increase in T1VBQ score accompanies a decrease in bone mineral density. T2VBQ scores were also negatively correlated with CT values

($r=-0.34$, $P<0.01$), further strengthening the negative association between VBQ scores and bone mineral density. All correlations were significant ($P<0.01$), indicating that combining multiple indicators may improve diagnostic accuracy.

Many previous studies have confirmed that VBQ scores based on T1-weighted MRI can effectively evaluate osteoporosis and predict the risk of fragility fracture(11,17,18). Yan S et al.(19) found that T2VBQ score has greater prospects for evaluating osteoporosis status in patients with vertebral degenerative changes. In addition, Roch's studies have found that combining different sequences yields better diagnostic efficacy, suggesting that joint diagnosis may be an effective approach to improve the accuracy of osteoporosis diagnosis(20). Research shows that elevated VBQ scores are an independent risk factor for vertebral fractures and can predict vertebral fractures; studies also confirm that higher VBQ scores are an independent risk factor for vertebral fractures (OR ranges from 2.4 to 2.51). When VBQ scores exceed 3.36, the risk of vertebral fracture is higher(11,18). However, some researchers believe the predictive ability of VBQ scores for osteoporosis is moderate, and it may be more valuable as a supplement to QCT(21). Through ROC analysis, we evaluated diagnostic efficiency. CT value AUC=0.741 (95%CI=0.675~0.807), cut-off value 103.000, sensitivity 0.867, specificity 0.579, indicating moderate diagnostic value. T1VBQ score AUC=0.810 (95%CI=0.752~0.868), cut-off value 3.175, sensitivity 0.810, specificity 0.689, showing higher diagnostic value. T2VBQ score AUC=0.811 (95%CI=0.752~0.869), cut-off value 0.475, sensitivity 0.802, specificity 0.700, achieving the best diagnostic performance (AUC>0.8). The excellent diagnostic performance of T1VBQ and T2VBQ scores, superior to CT values (AUC=0.741), may be related to the higher sensitivity of VBQ scores to marrow fat changes. Previous studies have drawn similar conclusions, and Salzmänn Kadri(22) and others believed that the cut-off value of VBQ score for distinguishing osteoporotic patients with low BMD from those with normal BMD is 2.388, with a sensitivity of 74.3%, specificity of 57.0%, and an AUC of 0.7079, indicating moderate diagnostic ability. Kadri et al. (23) determined a VBQ score cutoff of 2.95 for osteoporosis detection based on DXA T score, showing good sensitivity and specificity, and suggested that patients with VBQ >3.0 require additional diagnostic evaluation.

This study was the first to analyze the accuracy of MRI in assessing bone mass. Due to its low invasiveness, MRI has attracted widespread attention. However, this study also has limitations that need careful consideration, including a relatively small sample size and failure to control for all confounding factors (such as calcium intake, medication, etc. Future research should expand the sample size and explore the application of the VBQ score in predicting fracture risk. Multi-index models may further improve screening accuracy.

Declarations

Ethics approval

The study followed the Declaration of Helsinki and was approved by the Ethics Committee of the Fourth Medical Center of the Chinese PLA General Hospital. Patient data for this study were collected according to the inclusion and exclusion criteria.

Consent to participate

The requirement for written informed consent was waived by the Ethics Committee due to the retrospective and anonymized nature of the study.

Consent for publication: Not applicable.

Data availability

The datasets generated and analyzed during the current study are not publicly available due to institutional data privacy regulations but are available from the corresponding author on reasonable request.

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Competing interests

The authors declare that they have no competing interests.

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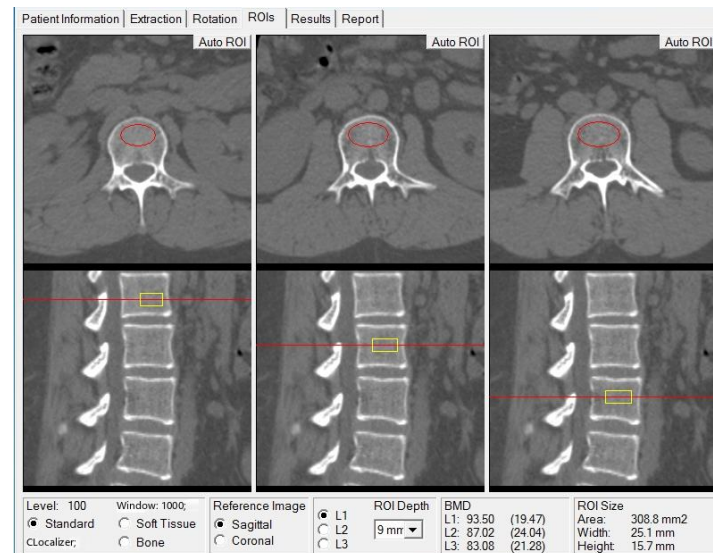


Figure 1. Delineation of lumbar ROI on the QCT workstation

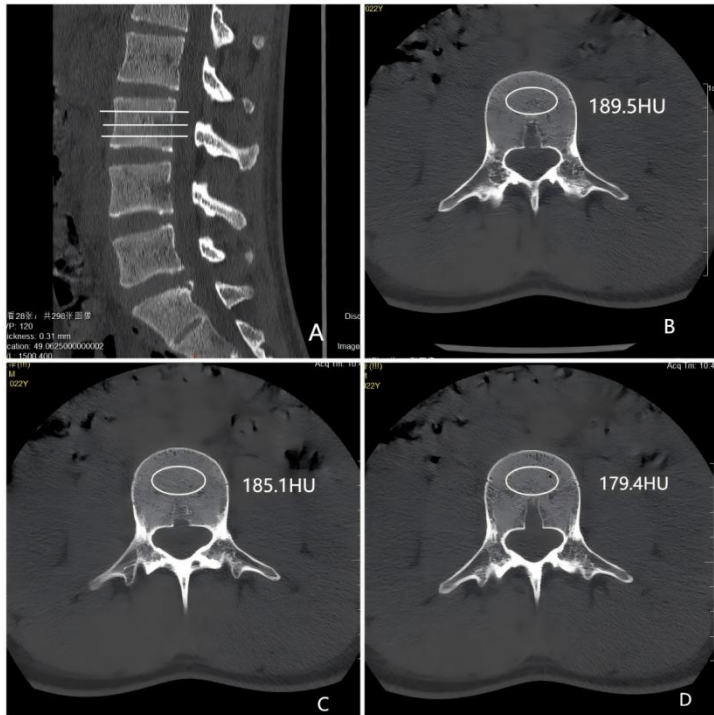
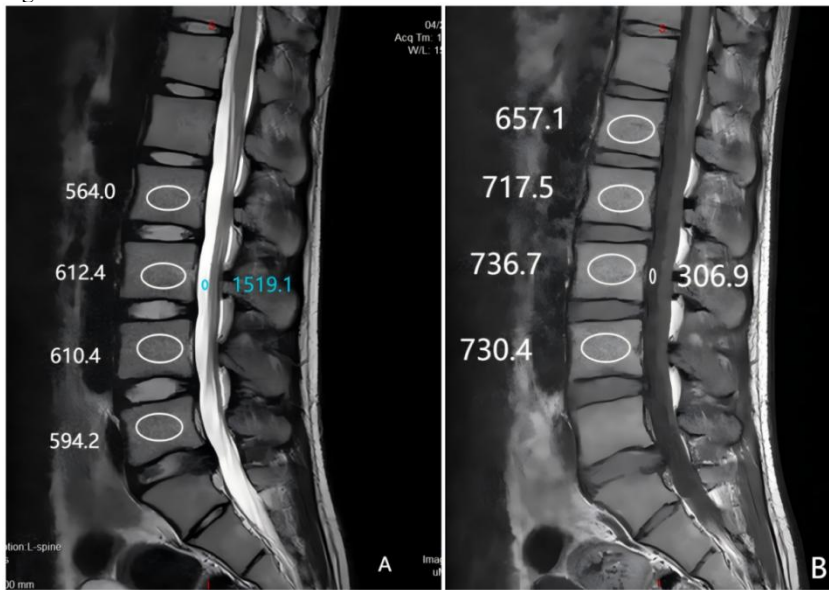


Figure 2. HU measurement value of L3



Note: SI represents the average signal intensity within the measured ROI; L1-L4 refer to lumbar vertebrae 1 to 4; CSF denotes cerebrospinal fluid; VBQ is the ratio of the mean signal intensity of the medullary portions of the L1-4 vertebrae to that of CSF at the L3 level.

Figure 3. Median sagittal views of lumbar MRI T2WI and T1WI

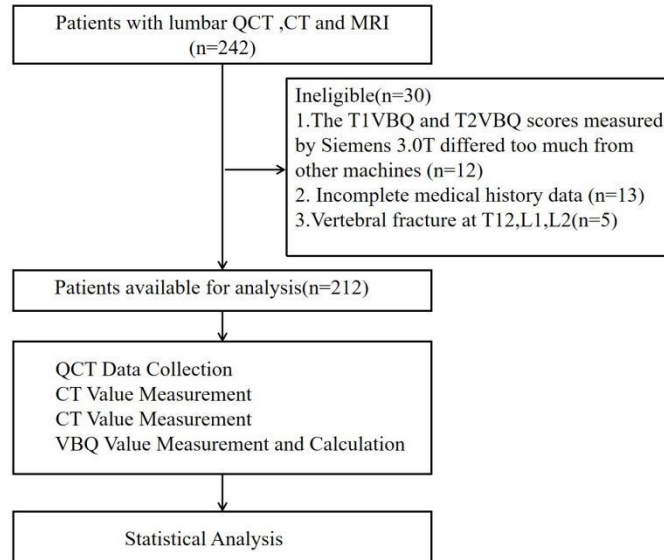


Figure 4. flowchart

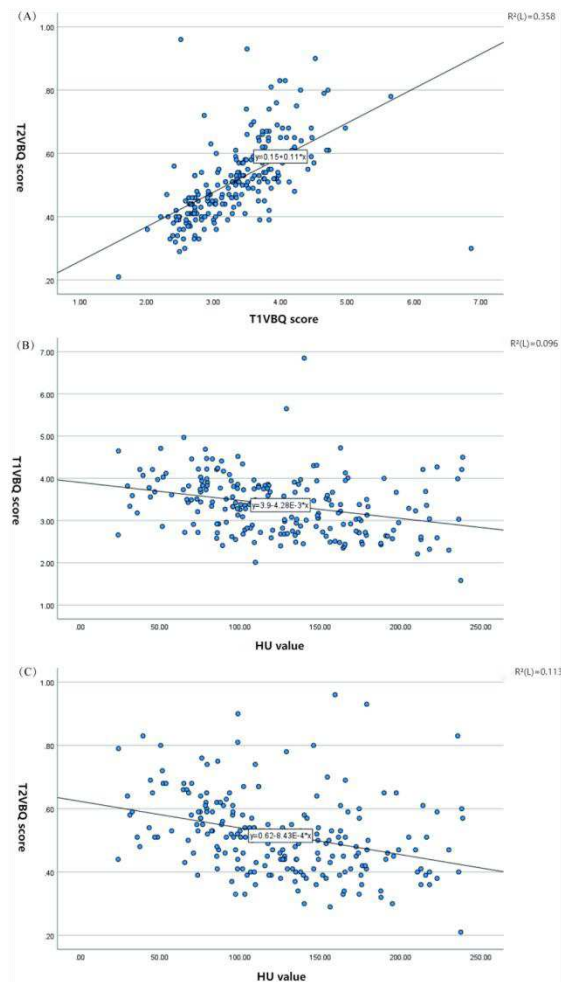


Figure 5. Correlation analysis among T1 VBQ score, T2 VBQ score, and CT value (A) T1 VBQ vs T2 VBQ; (B) CT value vs T1 VBQ score; (C) CT value vs T2 VBQ score

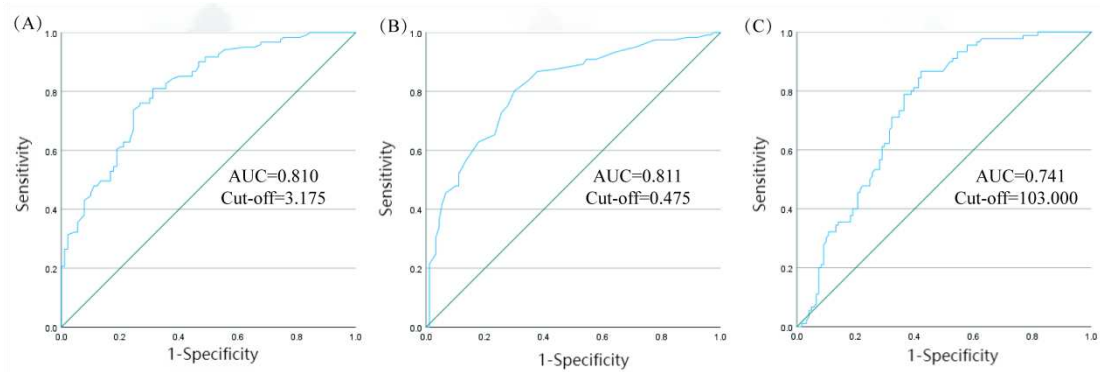


Figure 6. ROC curves of T1 VBQ score, T2 VBQ score, and CT value for the diagnostic value in osteoporosis (A) T1 VBQ score; (B) T2 VBQ score; (C) CT value

Table 1 Comparison of general characteristics between groups [($\bar{x} \pm s$, n(%), N=212)]

Characteristics		Non-osteoporosis group (n=90)	Osteoporosis group (n=122)	$^2/t$ value	P value
Gender	Male	57 (48.3)	61 (51.7)	3.50	0.06
	Female	33 (35.5)	60 (64.5)		
Age (years)		44.28 $\pm$ 15.05	62.73 $\pm$ 10.80	-10.37	<0.01
Weight (kg)		73.11 $\pm$ 10.52	71.28 $\pm$ 10.92	1.23	0.22
BMI		25.51 $\pm$ 3.17	25.89 $\pm$ 3.47	-0.82	0.42
Smoking history	Yes	27 (37.5)	45 (62.5)	1.19	0.28
	No	63 (45.3)	76 (54.7)		
Drinking history	Yes	24 (43.6)	31 (56.4)	0.03	0.86
	No	66 (42.3)	90 (57.7)		
History of diabetes	Yes	14 (33.3)	28 (66.7)	1.86	0.17
	No	76 (45.0)	93 (55.0)		
Vertebral fracture	Yes	2 (11.8)	15 (88.2)	7.21	0.01
	No	88 (45.4)	106 (54.6)		
Menopause	Yes	12 (18.2)	54 (81.8)	29.73	<0.01
	No	21 (77.8)	6 (22.8)		

Note: *Comparisons are made only among 107 female subjects.

Table 2 Comparison of T1 VBQ scores, T2 VBQ scores, and CT (HU) values between groups (($\bar{x} \pm s$, N=212)

Index	Non-osteoporosis group (n=90)	Osteoporosis group (n=122)	t/Z value	P value
CT (HU) Value	146.83 $\pm$ 39.94	108.14 $\pm$ 50.54	6.00	<0.01
T1 VBQ score	2.97 $\pm$ 0.52	3.67 $\pm$ 0.64	-8.52	<0.01
T2 VBQ score	0.45 $\pm$ 0.10	0.57 $\pm$ 0.12	-8.02	<0.01

Table 3 Diagnostic value of T1 VBQ score, T2 VBQ score, and CT (HU) value in osteoporosis

Index	Cut-off	AUC	Degree	Specificity	Youden Index
CT Value (HU)	103.000	0.741 (0.675~0.807)	0.867	0.579	0.446
T1 VBQ score	3.175	0.810 (0.752~0.868)	0.810	0.689	0.499
T2 VBQ score	0.475	0.811 (0.752~0.869)	0.802	0.700	0.502