Correlation between wrist bone mineral density measured by dual-energy X-ray absorptiometry and Hounsfield Units value measured by CT in lumbar spine

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Research Article

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Abstract

Background With the aging of society, the incidence of osteoporosis increases significantly. Wrist dual-energy X-ray absorptiometry enables assessment of whole-body bone mineral density as a diagnostic method for osteoporosis. Our purpose was to use DXA-measured wrist bone mineral density to evaluate bone contion of lumbar spine in patients with degenerative diseases.

Methods A retrospective analysis of 164 patients with degenerative diseases of the lumbar spine was performed. DXA was used to measure the bone mineral density(BMD) and T- scores of each patient's wrist; lumbar CT was used to measure the CT HU values in three axial images of the L1-L4 vertebral bodies, and the average was calculated. According to the preoperative DXA T-score, they were divided into normal group, osteopenia group and osteoporosis group. Pearson correlation coefficient was used to analyze the correlations of CT HU values in L1-L4 with BMD and T-scores in corresponding vertebral body.Receiver operating characteristic curve (ROC) was used to determine the CT HU thresholds between osteoporosis and non-osteoporosis groups.

Results CT values in L1-L4 were moderately correlated with BMD (0.4≤R^2≤0.6), and the correlation coefficients (R^2) were 0.552, 0.578, 0.582 and 0.577, respectively (all $p<0.001$). The thresholds of L1-L4 between the osteoporosis group ($t\leq-2.5$) and the non-osteoporosis group ($t>-2.5$) respectively were 110.0HU (sensitivity 74% and specificity 76%) , 112.5HU (sensitivity 67% and 83% specificity), 92.4HU (81% sensitivity and 70% specificity), and 98.7HU (74% sensitivity and 78% specificity).

Conclusions Wrist BMD is an effective tool for evaluating lumbar BMD. Preoperative wrist DXA can accurately reflect the lumbar vertebral bone condition.

Introduction

As the population ages, the incidence of osteoporosis is also increasing. The study found that in the next 30 years, the prevalence of osteoporosis in women and men over the age of 50 will increase from 29.13% to 39.19%, and 6.46% to 7.46%, respectively[1][2]. Chin et al. [3] found that the incidence of osteoporosis was 37.6% in the population requiring surgical treatment for lumbar degenerative diseases. Studies have shown that osteoporosis is a risk factor for poor outcomes after spinal surgery, which can increase the risk of nonunion, internal fixation failure, and adjacent segmental vertebral fractures and other related complications [4, 5]. Therefore, accurate preoperative judgment of lumbar vertebral bone condition is very important for the formulation of surgical plan and the prevention of postoperative complications.

At present, dual-energy X-ray absorptiometry (DXA) is still the main method for clinical diagnosis of osteoporosis, and the measurement of bone mineral density（BMD） in hip and lumbar vertebrae is the first choice [6]. However, due to lumbar spondylolisthesis, intervertebral space stenosis, osteophyte formation, osteosclerosis, abdominal wall calcification, etc., DXA will overestimate BMD in patients with lumbar degenerative diseases, leading to misdiagnosis of osteoporosis [7]. In recent years, studies have found [8, 9] that the method of measuring lumbar CT HU values from CT scans is superior to lumbar DXA in judging the accuracy of lumbar BMD in patients with lumbar degenerative diseases.

However, due to the cumbersome steps, large radiation, and high price of CT to measure BMD, its clinical promotion is still low. Some studies have found [10] that peripheral DXA can be used as an alternative method to evaluate the BMD of the whole body, and the wrist is the most commonly used clinical site. Studies have shown that wrist DXA can predict not only the risk of forearm fractures, but also the risk of lumbar spine and hip fractures [11]. In addition, due to the convenience of its detection,wrist DXA is still used clinically to judge the bone condition of lumbar in patients diagnosed with lumbar degenerative diseases. However, there are few related studies directly comparing densitometry of wrist and spine bones . Therefore, the aim of this study was to use wrist BMD measured by DXA to evaluate BMD of lumbar spine in patients with degenerative lumbar spine diseases.

Materials And Methods

Patient cohort

Following approval by the Ethics Review Board, we retrospectively investigated 524 patients hospitalized in the Department of Orthopedics for lumbar degenerative diseases between June 1, 2021, and December 31, 2021. Inclusion criteria: (1)men over 50 years old or postmenopausal women; (2) lumbar spine CT and wrist DXA scans in our hospital within 1 month before surgery. Patients who met one or more of the following criteria were excluded from the study based on clinical and radiological data: 1. Presence of any history of spinal surgery. 2. The existence of spinal tuberculosis, spinal tumors, ankylosing spondylitis and other spinal diseases. 3. Non-dominant wrist DXA. 4. There is a history of non-dominant hand forearm and wrist fractures and surgery. Finally, 164 patients who met the criteria (78 males and 86 females) were screened. All patients were of yellow race.

Radiological assessment

Dual-energy X-ray absorptiometry

Dual-energy x-ray absorptiometry was used to measure the wrist bone mineral density (BMD, measured in g/cm2) of each patient, with preference given to the left wrist—using the technical standards of the International Society for Clinical Bone Densitometry [12]. According to the World Health Organization (WHO) standard classification, osteoporosis was defined as a DXA T-score less than −2.5, osteopenia as a T-score between −1.0 and −2.4, and normal bone density as a T-score greater than −1.0.

Computed tomography

All CT scans were performed with dual-source computed tomography. The CT window type does not change the HU value. The HU value was measured by placing an oval region of interest (ROI) on three images in the axial direction of the L1-4 vertebral body, slightly below the superior endplate, in the middle of the vertebral body, and slightly above the inferior endplate. For each measurement, draw the largest possible elliptical area of interest and exclude the cortical edge. The PACS system automatically calculates the average HU value for the region of interest. The average HU value of the three regions of interest was taken to represent the bone mineral density of the corresponding vertebral body trabecular bone（Figure 1）. The rule for placing the ROI is to include as much trabecular bone as possible and avoid cortical bone and areas of heterogeneity such as posterior venous plexus, bony islands, compressed bone. The measurers were blinded to the patients' DXA measurements.

Statistical analysis

Statistical analysis was performed using SPSS version 26 (SPSS, USA). Continuous variables were tested by independent samples T test, and categorical variables were tested by chi-square test. Analysis of variance (ANOV A) was used to examine the differences in the mean HU values of the L1-L4 vertebral bodies among the three groups (normal group, osteopenia group and osteoporosis group). Pearson correlation coefficient was used to analyze the correlation between L1-L4 HU values and T score and BMD in corresponding vertebral body. Receiver operating characteristic curve analysis (ROC) was used to estimate HU thresholds for osteoporosis and non-osteoporosis groups.

Results

This study included 164 patients (78 males and 86 females), who were divided into normal group (n=29), osteopenia group (n=57) and osteoporosis group (n=78) according to the wrist DXA T-score), and Table 1 summarizes the demographic characteristics and DXA-measured and CT HU values of the patients in this study.

Table 1 Demographic characteristics and bone mineral density

	Normal group	osteopenia group	Osteoporosi group
Age:	55.76 ± 7.02	60.54 ± 8.35	64 ± 8.81
Gender ratio (male:female):	13:16	26:31	20:58
BMD (g/cm^2):	0.521 ± 0.078	0.419 ± 0.060	0.286 ± 0.808
BMI（kg/m^2）：	31.1 ± 2.3	29.4 ± 1.9	25.3 ± 2.7
T-score:	-0.03 ± 1.15	-1.78 ± 0.36	-3.59 ± 0.77
L1 CT HU:	155.52 ± 37.18	121.32 ± 33.55	93.53 ± 34.69
L2 CT HU:	151.03 ± 39.28	114.60 ± 32.16	86.58 ± 33.98
L3 CT HU:	145.62 ± 35.70	109.66 ± 31.33	80.56 ± 34.39
L4 CT HU:	145.23 ± 35.80	111.35 ± 34.87	80.23 ± 34.75

Age was significantly different between normal, reduced bone mass and osteoporosis groups ($P < 0.05$). Age significantly affected CT HU values. In L1-L4, CT HU values decreased by 2.688, 2.633, 2.547, and 2.614 HU for each additional year (all $P < 0.05$)

There were significant differences in gender ratio and BMI among normal group, osteopenia group and osteoporosis group ($P<0.05$). The female ratio in the normal group, osteopenia group, and osteoporosis group were 55.1%, 54.3%, and 73.0%, respectively.

There were significant differences in T-scores among the normal group, osteopenia group and osteoporosis group ($P<0.05$). T-scores was higher than -1 in 29 cases (18%), between -1 and -2.5 in 57 cases (35%), and less than -2.5 in 78 cases (47%).

There were significant differences in CT HU values of L1-L4 among the normal group, osteopenia group and osteoporosis group (all P＜0.05). CT HU values of L1-L4 were not exactly the same ($P=0.03$).There were significant differences between L1 and L3 ,L4 (all $P<0.05$). There were no significant differences between L1 and L2($P=0.158$), L2 and L3($P=0.230$), and L3 and L4($P=0.265$) (post hoc multiple comparisons).

CT HU values of L1-L4 were moderately correlated with BMD and T-scores. As shown in Figure 2, CT HU values of L1-L4 and T-scores were linearly correlated, with correlation coefficients (R^2) of 0.595, 0.609, 0.605, and 0.605, respectively (Table 2), while the correlation coefficients between CT HU values of L1-L4 and BMD (R^2) were 0.552, 0.578, 0.582 and 0.577, respectively (Table 2). All obtained correlation coefficients were significant ($p<0.001$).

Table 2 Pearson correlation coefficient of CT value with wrist BMD and T-score.

	Correlation coefficient	
	BMD value	T score
L1 mean CT value	0.552**	0.595**
L2 mean CT value	0.578**	0.609**
L3 mean CT value	0.582**	0.605**
L4 mean CT value	0.577**	0.605**

**P value < 0.001

Figure 3 shows the ROC curves for T-score ≤-2.5 (osteoporosis group) and >-2.5 (non-osteoporosis group). At L1-L4, the AUCs were 0.787 (0.716–0.857), 0.795 (0.726–0.864), 0.803 (0.734–0.871), and 0.799 (0.731–0.867). Through ROC curve analysis, the thresholds of L1-L4 between the osteoporosis group (T≤-2.5) and the non-osteoporosis group (T>-2.5) were respectively 110.0HU (sensitivity 74% and specificity 76%) , 112.5HU (sensitivity 67% and specificity 83%), 92.4HU (sensitivity 81% and specificity 70%), 98.7HU (sensitivity 74% and specificity 78%).

Discussion

Osteoporosis is a major challenge faced by spine surgeons today, and many studies have found that vertebral osteoporosis is associated with various postoperative complications, such as pedicle screw loosening, nonunion, adjacent segments Vertebral fractures [13, 14]. In order to reduce the occurrence of osteoporosis-related complications, preoperative and postoperative anti-osteoporosis therapy has been widely recommended [15]. Therefore, accurate preoperative judgment of vertebral bone condition is an important factor in preventing complications after spinal surgery.

Although hip and spine DXA testing is the main method for clinical diagnosis of osteoporosis in patients with degenerative lumbar spine diseases, this method may overestimate BMD in lumbar spine, thus limiting its application in this field. Therefore, many studies have been devoted to finding alternative methods to accurately assess lumbar BMD in this population, Such as the measurement of vertebral CT HU value, trabecular bone score (TBS) and the definition of extended spinal osteoporosis [16]. Among them, the measurement of vertebral CT HU value is widely considered to be a more accurate assessment of lumbar BMD [17-19].

CT HU value is a simple method to express BMD by measuring the density of cancellous bone in the vertebral body. CT HU value represent tissue density values. The CT image divides the human body into several volume units. The attenuation coefficient of the material in each volume unit to X-ray represents the material density of the volume unit, which is recorded as the CT HU value, and the unit is Hounsfield Units (HU). Bone density is higher, generally 300~3000HU. In L1-L4, 110HU, 100HU, 85HU, 80HU have been proposed as CT HU thresholds for the diagnosis of osteoporosis [20].

Due to the shortcomings of CT HU value, such as cumbersome steps, large radiation, and high price, wrist DXA is a fast, inexpensive and less radiation-based method for assessing bone status [21]. Therefore, Rey and Bina et al. [22][23] compared the measured values of wrist DXA and lumbar DXA, and reported that wrist BMD and lumbar BMD had a significant linear correlation and wrist DXA has better accuracy than lumbar DXA in diagnosing osteoporosis in postmenopausal women. However, the study population they included did not take into account that spinal degeneration would improve DXA measurements in lumbar spine.

In order to establish the correlation between the CT HU value of lumbar spine and the value measured by DXA of lumbar spine and identify the CT HU value threshold for the diagnosis of osteoporosis. Li[8] compared the CT HU values with the DXA values in 109 patients, and the results showed that there was a good correlation between the mean CT HU value and T-score and BMD , with correlation coefficients of 0.61 and 0.62, respectively, and reported the CT HU value threshold . It is 136HU (sensitivity 90.3% and specificity 72.3%), but its threshold is based on the measured value of DXA, and does not consider the increase in T-score caused by DXA. In order to reduce the influence of lumbar degenerative changes on the results, Zou[20] divided 330 patients into a degenerative group and a control group according to the degree of lumbar degenerative changes. CT HU values in L1-L4 and DXA measured values were significantly correlated (R^2>0.6), and the linear regression equation of T-score of the L1-L4 vertebral body and CT HU value was established from the data of the control group with a lower degree of degeneration, and the thresholds in L1-L4 was respectively calculated as 110, 100, 85 and 80HU according to T=-2.5. Therefore, CT HU values is superior to DXA in assessing BMD in patients with lumbar degenerative diseases, which provides a rationale for using CT HU values to judge lumbar BMD in our study.

To investigate the accuracy of wrist BMD in assessing lumbar BMD in patients with lumbar spine degenerative diseases, our study included patients with lumbar spine degenerative diseases, and our results showed a moderate linear correlation between wrist DXA values and CT HU values (0.4 <R^2<0.6), and the highest correlation with L2 (R^2=0.605), Choi and Lee et al.[18,24] also reported that the measured values of DXA had the highest correlation with L2. Using the ROC curve, we calculated that the CT HU thresholds for L1-L4 to diagnose osteoporosis were 110.0, 112.5, 92.4, and 98.7HU, respectively. Pickhardt and Zou et al. [3, 4]also reported a difference between the CT HU thresholds of L1-L4, which may well explain our results. As shown in Table 3, Our CT HU thresholds and areas under the curve AUC were similar to those of Zou, but our specificity was 76.9%, lower than Zou's 87.2%, and the sensitivity was 74.4%, higher than Zou's 47.6%. our study is consistent with the population, ethnicity, and diagnostic vertebral body studied by Zou et al. The different thresholds may be related to age, BMI, sex ratio, measurement equipment (CT machine type and parameters) and method. The reasons are as follows:First, among people >65 years old, BMD of the lumbar spine increased with age, with the highest increase in African Americans in the United States, and only higher in Hong Kong Chinese than in Koreans.[5]. Second, higher BMI is crucial in improving lumbar BMD, because higher BMI increases the mechanical load on the lumbar spine, activates bone formation, and thus improves BMD [6]. At the same time, low BMI indicates poor nutritional status, leading to lower BMD [7]. However, a higher BMI will

increase the mechanical load of the lumbar spine, aggravate the degenerative changes of the lumbar spine, and thus erroneously increase the BMD . Third, postmenopausal women have a progressive decrease in bone density due to hormonal influence. We obtained thresholds similar to those of Zou's results, indicating that despite these differences, wrist DXA can still accurately assess lumbar BMD levels to a certain extent, providing information for spine surgeons to judge lumbar spine osteoporosis preoperatively, and encouraging spine surgeons further research, including the relationship between wrist DXA and spinal surgery complications.

This study has several limitations. First, due to the retrospective single-center study design, the accuracy of wrist DXA for assessing lumbar spine BMD needs to be validated in further prospective experimental studies. Second, our CT HU thresholds were obtained from patients hospitalized for degenerative lumbar spine disease, and their applicability in other populations needs further validation. Finally, patients included in our study were not analyzed for the possible combination of other alterations affecting BMD, such as abdominal vascular calcification and ligamentous ossification.

Table 3 CT HU thresholds and efficacy assessment for the diagnosis of osteoporosis in this study and the study by Zou et al.

	sample size	crowd	age)	Female ratio (%)	BMI(kg/m²)	DXA measurement site	CT Type	Diagnostic vertebrae	Threshold (HU)	Sensitivity (%)	Specificity (%)	AUC
This study	164	China	61.8	63	26.1	Left wrist	Lumbar spine CT	L1	110.0	74.4	75.6	0.787
								L2	112.5	67.4	83.3	0.795
								L3	92.4	81.4	70.5	0.803
								L4	98.7	74.4	78.2	0.799
Zou's research	152	China	58.5	57	25.4	Lumbar spine and hip	Lumbar spine CT	L1	110	58.3	90.2	0.860
								L2	100	58.2	85.6	0.855
								L3	85	40.8	84.6	0.758
								L4	80	33.3	88.5	0.811

Conclusion

We established a correlation between wrist DXA measurements and CT HU values and obtained CT HU thresholds similar to those in the Zou study suggesting that wrist BMD is a valid tool for assessing lumbar BMD. Preoperative wrist DXA may be useful for surgical planning and prevention of postoperative complications in patients with degenerative lumbar spine diseases.

Abbreviations

DXA:Dual-energy X-ray absorptiometry ;BMD:bone mineral density ;CT：Computed tomography； HU：Hounsfield Units；ROI：region of interest；TBS:Trabecular bone score

Declarations

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contribution to this study.

Authors' contributions

HYP,QC and PW designed this study. HYP,QC,PW,KH,PJ and CZ were responsible for collecting, analyzing and interpreting the data, and writing the manuscript. HYP and QC identified the case, performed the operation,and made contributions to revising the manuscript for crucial intellectual content. The final version of the text has been reviewed and approved by all authors.

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Availability of data and materials

All data analyzed during this study are included within the manuscript. The

datasets used and/or analyzed during this study are available from the first

author on reasonable request.

Ethics approval and consent to participate

This study was approved by the Institutional Review Board at the Affiliated

Hospital of North Sichuan Medical College. All the investigations were conducted in accordance with ethical principles. The

participant involved in the study gave their informed consent and signed

and an informed consent form.

Consent for publication

Written consent to publish this information was obtained from the patient.

Proof of consent to publish from the patient can be requested at any time.

Competing interests

The authors declare that they do not have any competing interests.

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Figures

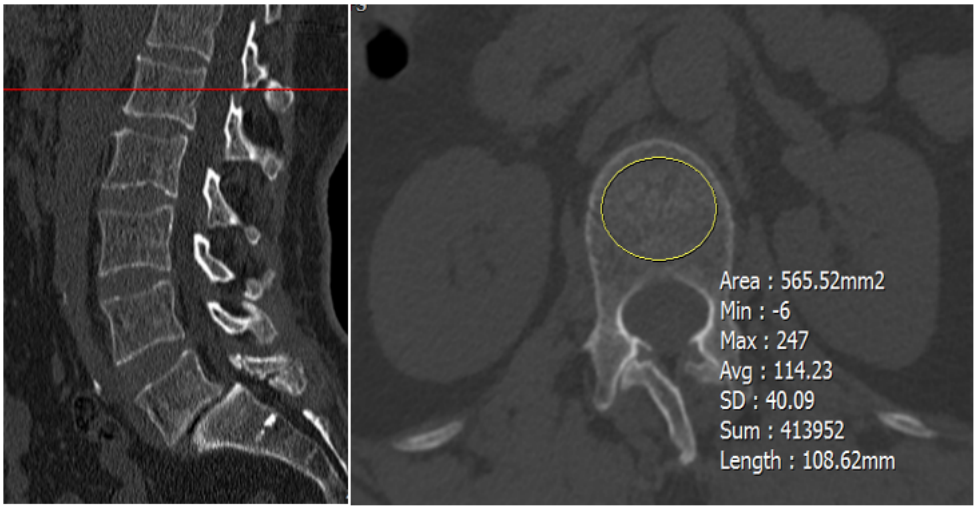

Figure 1

The left panel indicates the selection of the middle L1 vertebral body in the sagittal position of the CT image, and the right panel indicates the placement of the ROI in the mid-level axial position of the L1 vertebral body and the automatic calculation of the mean HU value within the ROI by the PACS system.

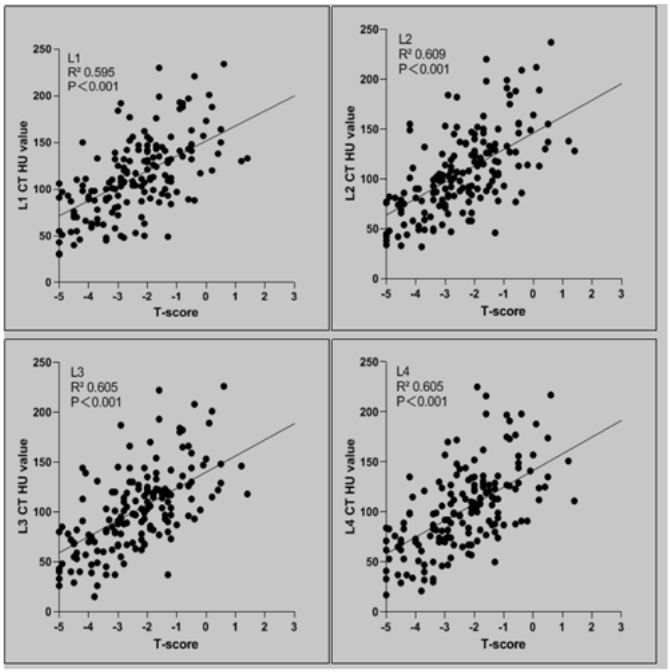

Figure 2

Scatter plots showing the correlation between CT HU values obtained from CT and T-scores obtained from L1-L4 DXA. The correlation coefficients were all significant ($p < 0.001$)

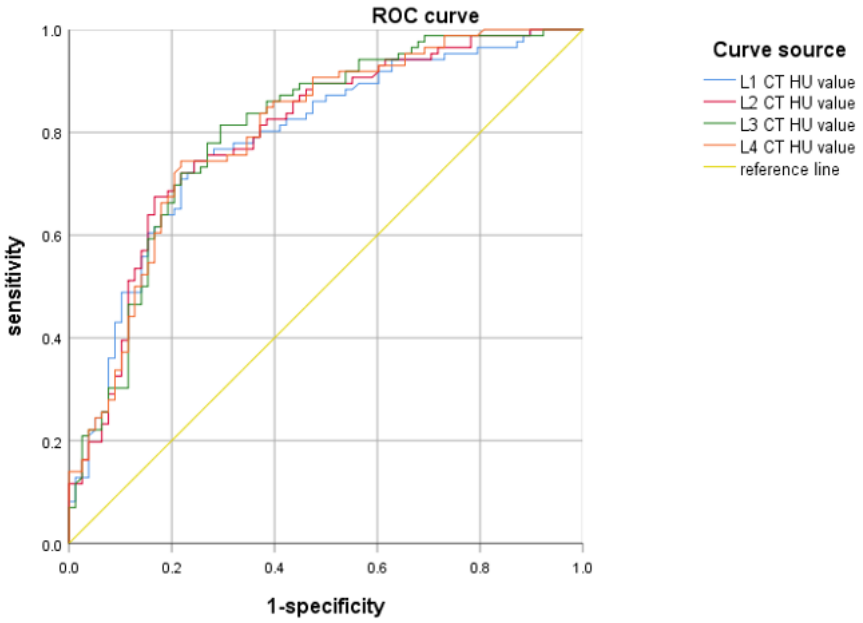

Figure 3

ROC curve distinguishes osteoporosis group from non-osteoporosis group