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ORIGINAL ARTICLE

# The use of CT Hounsfield unit values to identify the undiagnosed spinal osteoporosis in patients with lumbar degenerative diseases

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## Abstract

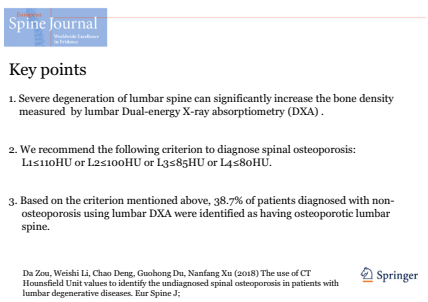
**Purposes** Our purpose was to use computed tomography (CT) Hounsfield unit (HU) values to identify the undiagnosed spinal osteoporosis in patients with lumbar degenerative diseases.

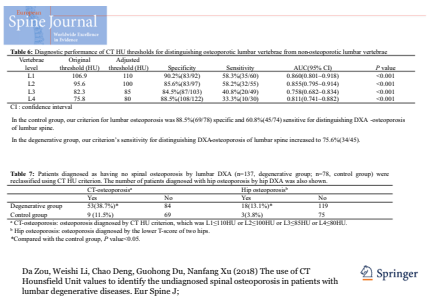
**Methods** A total of 334 patients with lumbar degenerative diseases were retrospectively reviewed and divided into two groups according to the degree of lumbar degenerative changes in preoperative lumbar CT images. Patients who had at least three vertebrae with severe degeneration at L1–L4 were placed in the degenerative group, and others were placed in the control group. HU value of trabecular bone in middle axial CT image of vertebral body, *T*-score and bone mineral density (BMD) at L1–L4 and hips were measured. CT HU thresholds for osteoporosis were obtained from control group and then applied to identify undiagnosed spinal osteoporosis.

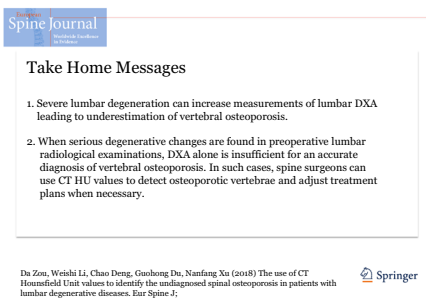
**Results** There were 182 patients in the degenerative group and 152 patients in the control group. CT HU value had a positive correlation with *T*-score and BMD of lumbar spine in both groups ($P < 0.001$), while the correlation coefficients at L1–L4 were higher in the control group (> 0.7) than in the degenerative group (< 0.7). *T*-score and BMD of lumbar spine were higher in the degenerative group ($P < 0.05$), while CT HU value, *T*-score and BMD of hips had no significant difference between two groups. According to the linear regression equations of vertebral *T*-score and CT HU value in the control group, the thresholds matching *T*-score of − 2.5 were 110, 100, 85 and 80HU for L1, L2, L3 and L4, respectively. Defining CT osteoporosis as L1 ≤ 110HU or L2 ≤ 100HU or L3 ≤ 85HU or L4 ≤ 80HU was 88.5% (69/78) specific and 60.8% (45/74) sensitive for distinguishing DXA osteoporosis of lumbar spine in the control group. The rate of undiagnosed spinal osteoporosis was higher in the degenerative group than in the control group according to CT HU thresholds (38.7% vs. 11.5%, $P < 0.05$).

**Conclusions** Degenerative changes in the lumbar spine can increase BMD and *T*-score provided by lumbar DXA, leading to an underestimation of vertebral osteoporosis. Thresholds for osteoporosis based on CT HU values can be used as a complementary method to identify undiagnosed spinal osteoporosis in patients with lumbar degenerative diseases.

**Graphical abstract** These slides can be retrieved under Electronic Supplementary Material.

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Extended author information available on the last page of the article

**Keywords** Lumbar degenerative disease · Osteoporosis · CT Hounsfield unit value · Dual-energy X-ray absorptiometry

## Introduction

Osteoporosis is a disease characterized by loss of bone mass and worsening of bone quality. Osteoporotic patients, especially elderly population, are at high risk of fragility fractures, secondary functional impairment and higher mortality [1]. Osteoporosis has become a global health problem as the population ages. In China, the prevalence of osteoporosis among those aged over 50 has increased from 14.94 to 27.96% over the past dozen years [2]. Meanwhile, osteoporosis is one of the major causes of certain complications after spine surgery, such as fixation failure, non-union, adjacent level fractures [3]. The rate of osteoporosis in patients over 50 years old who underwent spine operations is 51.3% among females and 14.5% among males, which is higher than that of the general population [4]. Thus, the preoperative screening of osteoporosis is of vital importance for surgical planning. Dual-energy X-ray absorptiometry (DXA) is recommended by World Health Organization (WHO) and widely used for screening and diagnosis of osteoporosis. However, the bone mineral density (BMD) measurements from lumbar DXA in patients with lumbar degenerative diseases are increased because of scoliosis, degenerative arthritis, osteophyte formation, bone sclerosis, etc. [5–7]. Particularly, intervertebral disc degeneration can result in decreased BMD in the vertebral body anteriorly through a stress-shielding effect. However, this decrease is frequently under-assessed by DXA as it can be masked by the relatively higher BMD in the posterolateral structures [8]. Thus, a complementary method of assessing BMD with Hounsfield unit (HU) measurements from computed tomography (CT) images was recommended by many studies [9–14], in which a positive correlation between CT HU value and DXA BMD was confirmed. CT HU measurement has the advantage of avoiding regions with obvious degeneration and choosing the trabecular bone which is more affected by osteoporosis [15]. Since the lumbar three-dimensional reconstructive CT is a routine preoperative examination for patients requiring lumbar surgery in many health centres, the application of CT HU value needs no additional cost. Therefore, we reviewed the lumbar CT images and DXA measurements of patients diagnosed with lumbar degenerative diseases in our hospital to determine the diagnostic CT HU thresholds for osteoporosis and identify the undiagnosed osteoporosis with such thresholds.

## Materials and methods

### Patient cohort

We reviewed 511 patients who were hospitalized to undergo lumbar surgery in our department of orthopaedics because of lumbar degenerative diseases from 1 July 2015 to 31 December 2015. Inclusion criteria were (1) men over 50 years old or postmenopausal women and (2) those who had both lumbar CT scan and DXA scan in our hospital within a month before the operation. Exclusion criteria were (1) history of spinal surgery and (2) presence of bone tumour, ankylosing spondylitis, diffuse idiopathic skeletal hyperostosis. A total of 334 patients were selected in the end. This study was approved by the Ethical Committee of our hospital and conducted according to the principles of Declaration of Helsinki. The informed consent was waived because this was a retrospective study.

We reviewed the preoperative three-dimensional reconstructive CT (Siemens, Dual Source Computed Tomography, DEFINITION, tube voltage 120 kV) images of L1–L4 through a picture archiving and communication system (PACS). Although all of the patients' lumbar spines were degenerative, a lumbar vertebra was considered as

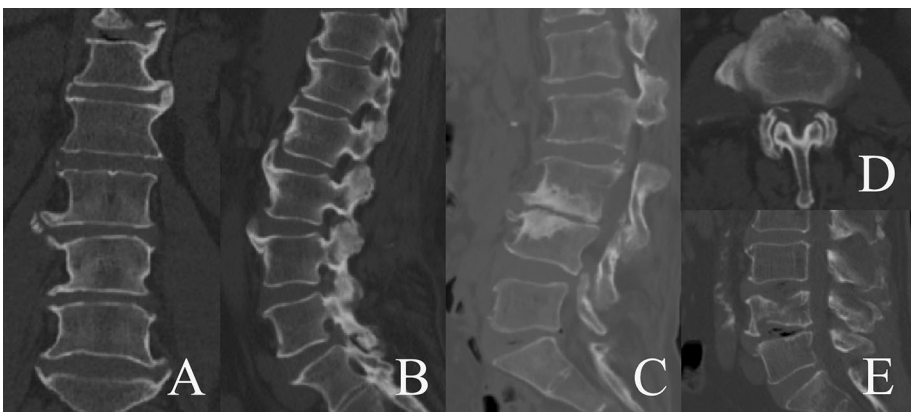


**Fig. 1** Examples of degenerative vertebrae. **A**, **B** Osteophytes in the shape of bird's beak and bone bridge. **C** Disc degeneration of fourth degree (UCLA). **D** Degeneration of facet joints. **E** Vertebral compression

degenerative only if any one of the following radiological appearances existed (Fig. 1):

(1) Third-degree osteophytes featured the shape of bird's beak or fourth-degree osteophytes featured a bone bridge according to the four-degree classification system of osteophytes [16] (Table 1);
(2) Adjacent disc degeneration of fourth degree according to University of California at Los Angeles Grading Scale [17] (Table 2);
(3) Narrowing of the adjacent facet joint space (< 1 mm) with large osteophytes [18];
(4) Obvious vertebral compression (≥ 25% loss of height) [10].

Patients were assigned to the degenerative group when they had at least three degenerative vertebrae between L1 and L4 because at least two readable vertebrae were needed for DXA analysis. Patients with no more than two degenerative vertebrae according to the above-mentioned criteria were included in the control group.

### Bone density evaluation

Dual-energy X-ray absorptiometry (DXA, Discover A densitometers, Hologic Inc, Bedford, MA, USA) was performed on the lumbar spine (L1–L4) and two hips of every patient. *T*-scores were derived using the NHANES III database provided by the manufacturer. Osteoporosis in any given lumbar vertebra was diagnosed by its *T*-score. Osteoporosis of lumbar spine was diagnosed by the lowest *T*-score of vertebrae among L1–L4. Osteoporosis of hips was diagnosed by the lower *T*-score of two hips. WHO's criteria were used [1]: osteoporosis ($T \leq -2.5$), osteopenia ($-2.5 < T < -1$) and normal BMD ($T \geq -1$).

PACS was used to calculate CT HU value. All lumbar CT scans were performed by using a dual-source computed tomography as mentioned above. The type of CT window did not change the HU value. CT HU value was measured by placing an oval region of interest (ROI) over an axial image of vertebral mid-body through L1–L4 (Fig. 2). The rule of placing the ROI was including as much trabecular bone as possible and avoiding cortical bone and heterogeneous areas, such as posterior venous plexus, bone island, compressed bone. Average HU value calculated by PACS was used to represent the bone density of vertebral trabecular bone.

**Table 2** University of California at Los Angeles Grading Scale for disc degeneration

| Grade | Disc space narrowing | Osteophytes | End plate sclerosis |
|---|---|---|---|
| I | − | − | − |
| II | + | − | − |
| III | ± | + | − |
| IV | ± | ± | + |

+: positive; −: negative; ± positive or negative

## Statistical analysis

Statistical analysis was conducted using SPSS version 22 (SPSS, USA). The independent samples Student's t-test was used for continuous variables. Chi-squared test was used for categorical data. Analysis of variance (ANOVA) was used to compare the CT HU value of L1–L4. The correlation of CT HU value with vertebral *T*-score and BMD was analysed by Pearson correlation coefficient and binary linear regression. Receiver-operating characteristic curve analysis (ROC) was used to evaluate the value of CT HU values in distinguishing osteoporosis.

## Results

The degenerative group consisted of 182 patients, and the remaining 152 patients were in the control group. The rate of spinal osteoporosis diagnosed with lumbar DXA was lower in the degenerative group (24.7%, 45/182 vs. 48.7%, 74/152, $P < 0.001$). Their demographic characteristics and bone density measured by DXA or CT HU value are summarized in Table 3.

**Table 1** Classification system for osteophytes of the vertebral column

| Grade | Description |
|---|---|
| I | Isolated points of initial hyperostosis |
| II | Bone protrusions projecting more or less horizontally from the vertebral body |
| III | Shape of bird's beak, free ends of osteophytes curving in the direction of intervertebral disc, often coming into more or less close contact with the free ends of the osteophytes on the adjacent vertebra |
| IV | Osteophytes of two adjacent vertebrae are fused together, thereby forming a bone bridge across the intervening intervertebral disc and immobilizing the corresponding intervertebral joint |

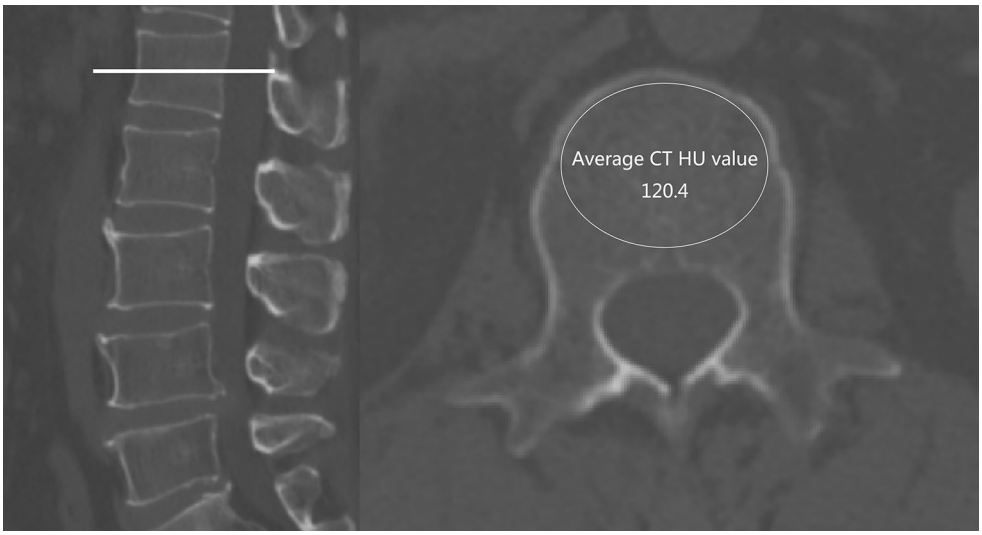


**Fig. 2** Example of CT HU measurement: when an oval click-and-drag region of interest (ROI) is placed over an axial image of L1 mid-body, PACS software automatically calculates the average CT HU for the region of interest

**Table 3** Demographic characteristics and bone density

| | Degenerative group | Control group |
|---|---|---|
| Age (y) | 63.9 ± 6.3* | 58.5 ± 6.4 |
| Gender ratio (male: female) | 81:101 | 65:87 |
| Height (cm) | 164.0 ± 8.4 | 164.3 ± 7.9 |
| Weight (kg) | 71.7 ± 11.6* | 68.7 ± 10.9 |
| BMI (kg/m$^2$) | 26.6 ± 3.6* | 25.4 ± 3.3 |
| L1 BMD (g/cm$^2$) | 0.883 ± 0.171* | 0.814 ± 0.146 |
| L2 BMD (g/cm$^2$) | 0.952 ± 0.185* | 0.854 ± 0.156 |
| L3 BMD (g/cm$^2$) | 1.041 ± 0.191* | 0.910 ± 0.168 |
| L4 BMD (g/cm$^2$) | 1.099 ± 0.222* | 0.970 ± 0.215 |
| L1 *T*-score | − 1.3 ± 1.4* | − 1.9 ± 1.3 |
| L2 *T*-score | − 1.0 ± 1.6* | − 1.8 ± 1.4 |
| L3 *T*-score | − 0.5 ± 1.7* | − 1.6 ± 1.5 |
| L4 *T*-score | 0.2 ± 2.0* | − 0.9 ± 2.0 |
| L1 CT HU value | 120.2 ± 39.4 | 128.1 ± 35.8 |
| L2 CT HU value | 112.1 ± 38.0 | 118.1 ± 35.9 |
| L3 CT HU value | 106.1 ± 37.1 | 111.5 ± 35.1 |
| L4 CT HU value | 107.0 ± 41.6 | 114.7 ± 37.6 |
| Femoral neck BMD (g/cm$^2$) | 0.681 ± 0.126 | 0.689 ± 0.121 |
| Total hip BMD (g/cm$^2$) | 0.840 ± 0.141 | 0.829 ± 0.126 |
| Femoral neck *T*-score | − 1.70 ± 0.97 | − 1.61 ± 0.97 |
| Total hip *T*-score | − 1.09 ± 0.96 | − 1.13 ± 0.91 |

*BMI* body mass index

*$P$ value < 0.05, compared with control group

On average, patients in the degenerative group were 5 years older and 3 kg heavier than in the control group ($P < 0.05$). Their lumbar BMDs and *T*-scores at L1–L4 were higher than those of the control group ($P < 0.001$), while the CT HU values and hip DXA measurements showed no significant difference between two groups. According to ANOVA analysis, CT HU values of L1–L4 were not the same ($P < 0.001$).

**Table 4** Pearson correlation coefficients between CT HU value and vertebral *T*-score or BMD

| | Correlation coefficients | |
|---|---|---|
| | *T*-score | BMD |
| Degenerative group | | |
| L1 CT HU value | 0.667* | 0.665* |
| L2 CT HU value | 0.640* | 0.647* |
| L3 CT HU value | 0.658* | 0.662* |
| L4 CT HU value | 0.667* | 0.672* |
| Control group | | |
| L1 CT HU value | 0.767* | 0.771* |
| L2 CT HU value | 0.767* | 0.764* |
| L3 CT HU value | 0.717* | 0.732* |
| L4 CT HU value | 0.764* | 0.770* |

*$P$ value < 0.001

The correlations between CT HU values and their corresponding *T*-scores or BMDs of lumbar vertebrae were positive in both groups ($P < 0.001$), and all Pearson correlation coefficients at L1–L4 in the control group were > 0.7, which were higher than those in the degenerative group (Table 4).

Scatter plots showing the relationship between CT HU values and *T*-scores at each vertebra (L1–L4) are shown in Fig. 3. For the control group, linear regression equations indicating the line of best fit were used to calculate the CT HU values at *T*-scores of − 1 and − 2.5 (Table 5).

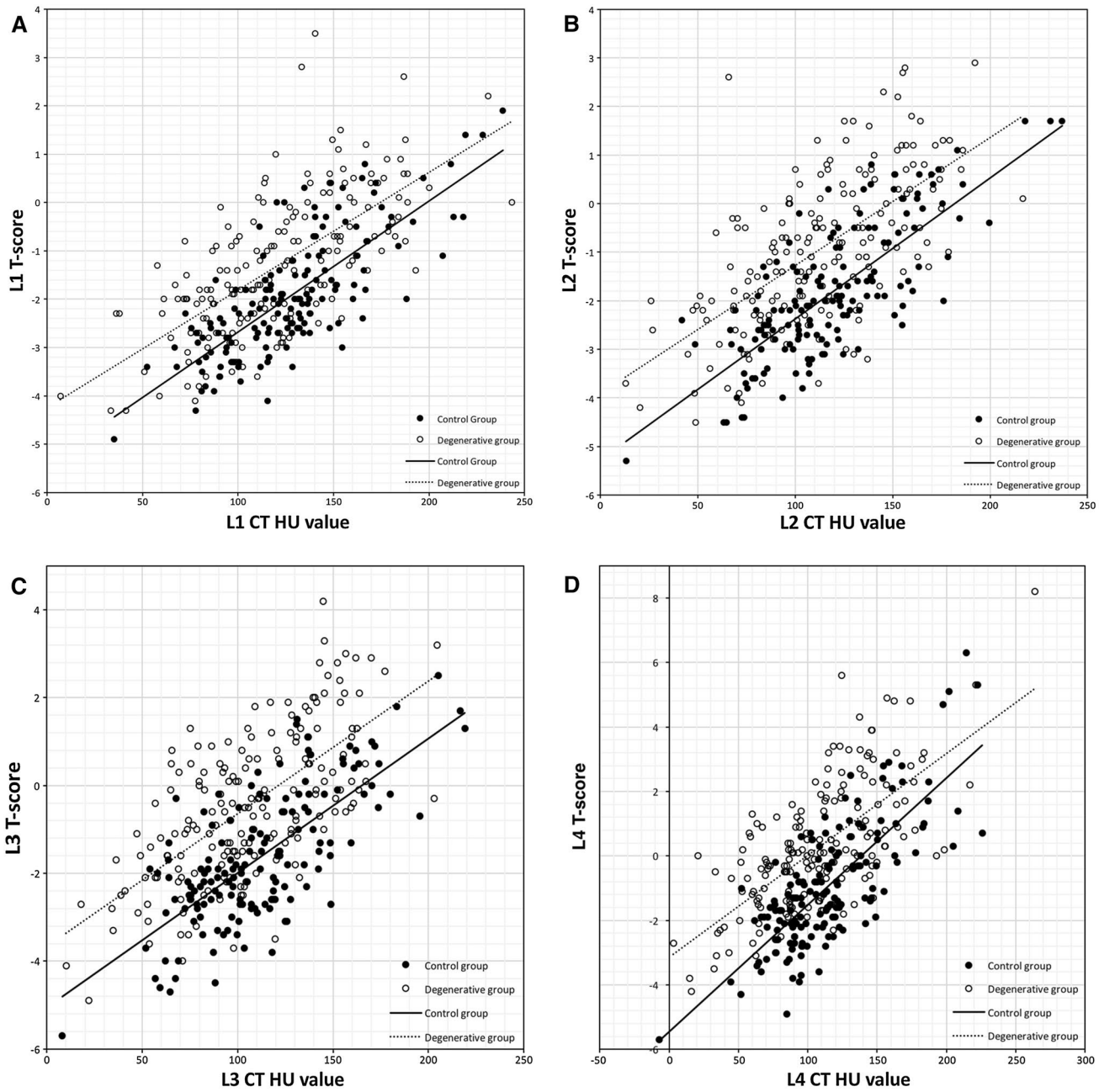


**Fig. 3** Scatter plots showing the correlation between vertebral *T*-score and CT HU value are shown for L1, L2, L3 and L4 in figures **A** to **D**, respectively. In each figure, regression lines are also shown for degenerative group and control group

**Table 5** Linear regression equation between CT HU value and vertebral *T*-score in control group ($n=152$)

| | Linear regression equation | $T=-1.0$[a] | $T=-2.5$[a] |
|---|---|---|---|
| L1 CT value | $T1=-5.385+0.027\times$L1 CT HU value | 162.4 | 106.9 |
| L2 CT value | $T2=-5.272+0.029\times$L2 CT HU value | 147.3 | 95.6 |
| L3 CT value | $T3=-5.052+0.031\times$L3 CT HU value | 130.7 | 82.3 |
| L4 CT value | $T4=-5.455+0.039\times$L4 CT HU value | 114.2 | 75.8 |

[a]The CT HU values at *T*-score of −1 and −2.5 were calculated with the linear regression equations

The CT HU values matching *T*-score of − 2.5 was 106.9HU, 95.6HU, 82.3HU and 75.8HU for L1, L2, L3 and L4, respectively. In the interest of clinical use, each of the CT HU thresholds was adjusted to its next "multiple of five", respectively, i.e. 106.9 was adjusted to 110, 95.6 to 100, 82.3 to 85 and 75.8 to 80. Their specificity and sensitivity for distinguishing osteoporotic vertebrae from non-osteoporotic vertebrae are summarized in Table 6. With ROC analysis, the area under curves (AUCs) across thresholds at L1, L2, L3 and L4 to distinguish vertebral osteoporosis were also established.

The criterion for diagnosing spinal osteoporosis is a CT HU value lower than or equal to the adjusted threshold value (shown in Table 6) at any spinal level between L1 and L4. This criterion was L1 ≤ 110HU or L2 ≤ 100HU or L3 ≤ 85HU or L4 ≤ 80HU. It was 88.5% (69/78) specific and 60.8% (45/74) sensitive for distinguishing osteoporotic lumbar spine from non-osteoporotic lumbar spine in the control group. Among the 45 patients in the degenerative group who were diagnosed as having osteoporotic lumbar spine by DXA, 75.6% (34/45) patients met our CT HU criterion for spinal osteoporosis. Furthermore, we used this criterion to compare the rate of undiagnosed spinal osteoporosis in 215 patients from both groups who were originally classified as having no spinal osteoporosis based on the lumbar DXA results (Table 7). According to the CT HU criterion, we found that the rate of undiagnosed spinal osteoporosis was higher in the degenerative group (38.7% vs. 11.5%). Among these 215 patients, the rate of hip osteoporosis identified by hip DXA is also shown in Table 7, and we found it was higher in the degenerative group (13.1% vs. 3.8%). In comparison with hip DXA, CT HU criterion could identify more osteoporotic patients in both groups (degenerative group: 38.7% vs. 13.1%; control group: 11.5% vs. 3.8%).

## Discussion

To identify osteoporotic lumbar spine preoperatively and prevent osteoporosis-related complications, surgeons usually choose DXA which was recommended by WHO and based on epidemiological evidence related to osteoporotic fractures [1, 19]. However, the disadvantages of measuring bone mass of central skeleton with DXA have been addressed over the years, especially for the degenerative spine [5–8]. Muraki et al. found that lumbar degenerative changes like osteophyte formation, bone sclerosis and disc space narrowing could significantly increase lumbar spine BMD by 15% [7]. Adams et al. reported that severe disc degeneration was associated with the increase in BMD in the neural arch and the decrease in BMD in the vertebral body. However, reduced BMD in the vertebral body is not adequately detected by routine posteroanterior DXA of the spine because it is masked by the increase in neural arch BMD [8]. To deal with this problem, hip DXA was used as a complement to lumbar DXA. Arabi et al. reported that DXA was a better tool for detection of osteoporosis in the hips than in the lumbar spine [20]. The International Society for Clinical Densitometry (ISCD) recommended that both the spine and hips should be measured and the diagnosis of osteoporosis should be based on the lowest *T*-score of L1–L4 and hips [15]. Meanwhile, quantitative computed tomography (QCT) evaluation of the trabecular bone mass in vertebrae has been widely studied. This method can be used to identify specific regions of interest, enabling trabecular bone density to be assessed independently of the cortical bone [21]. However, QCT has not been popularized because it needs extra investment in

**Table 7** Patients diagnosed as having no spinal osteoporosis by lumbar DXA ($n = 137$, degenerative group; $n = 78$, control group) were reclassified using CT HU criterion

| | CT osteoporosis[a] | | Hip osteoporosis[b] | |
|---|---|---|---|---|
| | Yes | No | Yes | No |
| Degenerative group | 53 (38.7%)* | 84 | 18 (13.1%)* | 119 |
| Control group | 9 (11.5%) | 69 | 3 (3.8%) | 75 |

The number of patients diagnosed with hip osteoporosis by hip DXA was also shown

[a]CT osteoporosis: osteoporosis diagnosed by CT HU criterion, which was L1 ≤ 110HU or L2 ≤ 100HU or L3 ≤ 85HU or L4 ≤ 80HU

[b]Hip osteoporosis: osteoporosis diagnosed by the lower *T*-score of two hips

*Compared with the control group, *P* value < 0.05

**Table 6** Diagnostic performance of CT HU thresholds for distinguishing osteoporotic lumbar vertebrae from non-osteoporotic lumbar vertebrae

| Vertebrae level | Original threshold (HU) | Adjusted threshold (HU) | Specificity | Sensitivity | AUC (95% CI) | *P* value |
|---|---|---|---|---|---|---|
| L1 | 106.9 | 110 | 90.2% (83/92) | 58.3% (35/60) | 0.860 (0.801–0.918) | < 0.001 |
| L2 | 95.6 | 100 | 85.6% (83/97) | 58.2% (32/55) | 0.855 (0.795–0.914) | < 0.001 |
| L3 | 82.3 | 85 | 84.5% (87/103) | 40.8% (20/49) | 0.758 (0.682–0.834) | < 0.001 |
| L4 | 75.8 | 80 | 88.5% (108/122) | 33.3% (10/30) | 0.811 (0.741–0.882) | < 0.001 |

CI: confidence interval

equipment, software and personnel training. Obviously, retrospective studies related to trabecular BMD cannot be conducted as many medical institutions have no QCT.

The measurement of CT HU value is a simple method using tissue density of vertebrae trabecular bone mass to represent BMD. Its general principle is similar to QCT. Since lumbar CT is a routine preoperative examination for patients who need surgery for lumbar degenerative diseases, CT HU value can make the best use of CT images at no extra cost and may avoid DXA evaluation for some patients.

Despite the doubt regarding the ability of CT to detect osteoporosis and concerns about the reliability of manual measurements, many studies have demonstrated a strong positive correlation between CT HU values and DXA values as well as good to excellent interexamination and interobserver reliability [9–14, 22]. As for the CT HU thresholds for osteoporosis, Pickhardt et al. who studied the largest patient population (1867) reported L1-CT HU threshold of 110HU was 90% specific and a threshold of 160HU was 90% sensitive for distinguishing osteoporosis from non-osteoporosis [10]. However, this study's sample consisted of patients with a variety of indications for DXA and CT. About half of its CT scans were obtained after intravenous contrast administration, which could increase CT HU value [11]. Wagner et al. studied 143 patients who underwent transforaminal lumbar interbody fusion over 50 years, but only 29 patients had both preoperative lumbar CT scans and DXA scans [14]. The upper limit of the 95% confidence interval (CI) of CT HU average in osteoporotic group, which was 112.4HU, was used as the threshold for osteoporosis. Although lumbar DXA could give overestimated *T*-scores, all of these thresholds mentioned above or in other studies [9, 11, 22] were directly based on these DXA measurements. As a result, these thresholds may not be appropriate for clinical use. To reduce the influence of this drawback, Choi et al. [23] divided 110 patients into degenerative group and non-degenerative group according to the degree of lumbar degeneration. Then they only used the patients' data of non-degenerative group to analyse the diagnostic efficacy of CT HU values. However, no specific thresholds for lumbar osteoporosis were given by their study. Moreover, they used the mean value of four vertebrae (L1–L4) rather than individual values of L1–L4, which was quite different from the diagnostic principle recommended by WHO and ISCD.

In order to reduce the impact of degenerative changes mentioned above, we also assigned patients with severe degenerative changes to the degenerative group, similar to Choi et al.'s study. The remaining patients, who were in the control group, were used to establish regression equations of DXA measurements and CT HU values. The results of our study showed that lumbar degenerative changes could increase BMD and *T*-score provided by lumbar DXA, but had no significant influence on CT HU values and measurements of hip DXA.

We identified CT HU thresholds for identifying osteoporosis by calculating the CT HU values that corresponded to a *T*-score of −2.5 using linear regression equations obtained in the control group. These thresholds were 110HU, 100HU, 85HU and 80HU for L1–L4, respectively. The significant difference between CT HU values of L1–L4, which was also reported by Pickhardt et al. [10], can explain the difference between their thresholds. According to WHO's standard, a patient's lumbar spine will be diagnosed with osteoporosis by DXA if any one of L1–L4 is osteoporotic. Thus, we established the criterion for lumbar osteoporosis as L1 ≤ 110HU or L2 ≤ 100HU or L3 ≤ 85HU or L4 ≤ 80HU, instead of using L1 as representative vertebra or using mean value of L1–L4 like other research [10, 23].

The specificity of our criterion was around 90% (88.5%), which was high enough to prevent over-diagnosis of lumbar osteoporosis. Since spine surgeons may recommend anti-osteoporosis drugs or even surgical intervention for patients diagnosed with osteoporosis, such a high specificity can make their recommendation more valid and convincing. Although the sensitivity of our criterion was relatively low (60.8%) in the control group, it increased to 75.6% in the degenerative group. Moreover, we found that over one-third of (38.7%) the non-osteoporotic patients diagnosed by lumbar DXA were actually osteoporotic according to our criterion. Hip DXA was also recommended by previous studies as a complement to lumbar DXA [5, 7, 15]; thus, we compared the ability of CT HU and hip DXA to identify osteoporosis in patients who were originally classified as having no spinal osteoporosis based on the lumbar DXA results. We found that CT HU thresholds could identify more osteoporotic patients than hip DXA in both groups (degenerative group: 38.7% vs. 13.1%; control group: 11.5% vs. 3.8%). Compared to degenerative group, the rate of undiagnosed spinal osteoporosis was significantly lower in the control group. Thus, we still suggest the use of DXA as the first choice to evaluate the bone mineral density of patients without severe lumbar degeneration, just like the patients in the control group. When serious degenerative changes are found in preoperative lumbar radiological examinations, DXA alone is insufficient for an accurate diagnosis of vertebral osteoporosis. In such cases, spine surgeons can use CT HU values to detect osteoporotic vertebrae and adjust treatment plans when necessary.

There were several limitations of this study. First, the main drawback of using our thresholds in CT HU to detect osteoporosis is its relatively low sensitivity which was discussed above. Second, certain changes, such as vascular calcification and ligament ossification, may also affect BMD, but they were not analysed in our study. Third, our CT HU criterion for lumbar osteoporosis was obtained from patients

with lumbar degenerative diseases, and its applicability in other patient population should be further verified.

## Conclusion

Degenerative changes in the lumbar spine can increase BMD and *T*-score provided by DXA, leading to an underestimation of vertebral osteoporosis. Thresholds for osteoporosis based on CT HU values can be used as a complementary method to identify undiagnosed spinal osteoporosis in patients with lumbar degenerative diseases.

### Compliance with ethical standards

**Conflict of interest** The authors declared that they have no conflict of interest.

**Ethical approval** All data collection and analysis conducted in this study were in accordance with 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. For this type of study, formal consent is not required.

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