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ORIGINAL RESEARCH

Diagnostic Value of Hounsfield Units for Osteoporotic Thoracolumbar Vertebral Non-Compression Fractures in Elderly Patients with Low-Energy Injuries

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Background: Thoracolumbar vertebral fractures are common pathological fractures caused by osteoporosis in the elderly. These fractures are challenging to detect. This study aimed to evaluate the diagnostic value of Hounsfield units for osteoporotic thoracolumbar vertebral non-compression fractures in elderly patients with low-energy fractures.

Methods: The retrospective case-control study included elderly patients diagnosed with osteoporotic thoracolumbar vertebral fractures and non-fractured patients who underwent computed tomography examinations for lumbar vertebra issues during July 2017 and June 2020.

Results: This study included 216 patients with fractures (38 males and 178 females; average age: 77.28±8.68 years) and 124 patients without fractures (21 males and 103 females; average age: 75.35±9.57 years). The difference in Hounsfield units of the target (intermediate) vertebral body significantly differed between the two groups (54.74 ± 21.84 vs 5.86 ± 5.14; $p<0.001$). The ratios of Hounsfield units were also significantly different between the two groups (1.38 ± 1.60 vs 0.13 ± 0.23; $p<0.001$). The cut-off value for the difference in Hounsfield units to detect osteoporotic spine fractures was 25.35, with high sensitivity (98.5%), specificity (99.9%), and the area under the curve (AUC) (0.999, 95% CI: 0.999–1). The cut-off value for the odds ratio of Hounsfield units was 0.260, with high sensitivity (99.1%), specificity (92.7%), and AUC (0.970, 95% CI: 0.949–0.992).

Conclusion: The difference between Hounsfield units and the odds ratio of Hounsfield units might help diagnose osteoporotic thoracolumbar vertebral non-compression fractures in elderly patients with low-energy fractures.

Keywords: multi-slice spiral computed tomography, thoracolumbar vertebrae, fractures, osteoporosis, morphological changes

Background

Osteoporotic thoracolumbar vertebral fractures are common pathological fractures caused by osteoporosis, especially in the elderly.[1] They can cause pain, immobility, hospitalization, and a decrease in quality of life. However, considering that most patients are asymptomatic or present with nonspecific symptoms, these fractures are challenging to detect, and their true incidence may be underestimated.[2,3] The fractures are generally detected through imaging analysis, such as magnetic resonance imaging (MRI),[3] radiography,[4] Dual energy X-ray absorptiometry (DXA),[5] etc. The false negative rate in the diagnosis of thoracolumbar fracture is as high as 67%.[6] The diagnostic rate of osteoporotic vertebral fractures was 87% (83/95) for plain X-ray imaging and 98% (93/95) for MRI.[7] DXA provides high-resolution scans and the diagnostic sensitivity and specificity of vertebral fractures assessment is comparable to spine radiography for moderate and severe vertebral fractures.[5] However, the diagnostic value of DXA for mild fractures is rarely reported. CT has been proven to represent a useful additional tool for the screening of osteoporotic vertebral fractures, even during CT examinations performed for different clinical reasons. Reliability of CT is affected by fracture grade and region, but also by the reader.

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The Limitations of CT include lack of ability to determine whether a fracture is recent or not.[8] MRI Is the gold standard in the diagnosis of osteoporotic thoracolumbar fracture, Winklhofer et al reported AO classification changed in 33% of patients using MRI compared to X-rays and CT analysis.[9] But for most healthcare facilities, MRI is not available immediately at the first visit, or for patients with heart valve replacement, pacemakers, or claustrophobia. Delayed diagnosis can worsen compression and instability, precluding certain treatments.[10] However, there are some limitations of these methods, such as high cost, access time, radiation dose, and sometimes misinterpretation of normal variations as mild vertebral deformities.[11] Thus, early and more accurate diagnosis is of crucial importance to reduce the risk of future fractures and improve the quality of life.[12]

Low-energy injuries cause osteoporotic non-compression fractures,[13] particularly in the elderly. However, these fractures can increase the reoccurrence[14] and complicate clinical presentations,[15] causing difficulties in diagnosing and differentiating between fresh and old fractures. Computed tomography (CT) scanners effectively detect and assess bone density. The Hounsfield or CT value is a standardized measurement of tissue density[16] that allows for observation of specific target areas, such as vertebral trabeculae.[17] CT sagittal reconstruction and quantitative CT (QCT) can improve diagnostic accuracy by detecting bone density in cancellous bone, distinguishing cortical bone, and providing realistic bone density values for clinical intervention. CT density of single or multi-segmental vertebral bodies can be used to assess osteoporosis,[18–20] and QCT is more accurate than Dual-energy X-ray absorptiometry (DXA) for bone density.[21] In addition, the advent of automated exposure control in modern CT scanners eliminates the need for calibrating phantoms traditionally used for QCT.[18] Fracture diagnosis depends on visual evaluation by an experienced diagnostician, with an 87% and 75% consistency for intra- and inter-diagnostic agreement, respectively,[4] However, the sensitivity and specificity of L1 density for detecting osteoporosis have been questioned,[22] and measuring L1 density from sagittal image reconstruction correlates well with an axial flat area and bone densitometry.[16] Previous studies have shown that in osteoporotic vertebral body fractures without morphological changes, there is an abnormal increase in Hounsfield units compared to the upper and lower vertebral bodies;[23] however, the exact amount of the elevation has not been extensively studied. In previous studies, the diagnosis was based on visual findings of vertebral body deformation or semi-quantitative studies. The application of specific number changes in Hounsfield units to determine the presence of fractures or not, which is less reported and may provide better intra-observer and inter-observer consistency and repeatability. This study aimed to evaluate the diagnostic value of Hounsfield units for osteoporotic thoracolumbar vertebral non-compression fractures in elderly patients with low-energy fractures.

Methods

Study Design and Subjects

The retrospective case-control study included elderly patients diagnosed with osteoporotic thoracolumbar vertebral fractures and non-fractured patients who underwent CT examinations for lumbar vertebra issues during July 2017 and June 2020 at a single institutions, academic medical center. Inclusion criteria for the fracture group were: (1) diagnosis of osteoporotic thoracolumbar vertebral fractures whose complaint was back pain or low back pain; (2) over 60 years of age; (3) underwent CT examination of the lumbar vertebra. Exclusion criteria were: (1) significant fracture fissure and compression, severe scoliosis (cobb angle>60°), and multiple fractures (≥2 vertebral fractures); (2) tumor or metastases in the thoracolumbar vertebral; (3) incomplete imaging data or imaging results.

Inclusion criteria for the non-fracture group of patients were: (1) diagnosis of protrusion of lumbar intervertebral disc, lumbar spinal stenosis, lumbar muscle degeneration, lumbar spinal cord fasciitis, lumbar facet osteoarthritis, lumbar spondylolisthesis, and lumbar vertebra CT examination, whose complaint was back pain or low back pain; (2) over 60 years of age. Exclusion criteria were: (1) concurrent fracture, lumbar vertebral pathology with Modic change, and severe scoliosis (cobb angle >60°); (2) primary tumors or metastases in the thoracolumbar vertebral; (3) incomplete imaging data or imaging results. The fracture diagnosis was based on the morphological diagnosis of a vertebral fracture on CT or MRI significant edema within the vertebral body. Similarly, osteoporosis was diagnosed based on bone density examinations for osteoporosis (T<-2.5 by DXA) or MRI results with significant edema within the vertebral body.

The study was approved by the ethics committee of the author's hospital.

Quantitative Image Measurement

The sagittal CT images of selected cases were retrieved and reconstructed using the picture archiving and communication system (PACS). To minimize the influence of cortical bone, the target vertebral body and adjacent vertebral body cancellous bone areas were selected in the cantered (spinous process) images. These selected areas were required to include as many vertebral bodies and cancellous bone areas as possible. Hounsfield units were obtained. To ensure measurement accuracy, each vertebral body was measured twice by a spine surgeon (HJ C) and twice by a radiologist (ZG X). The difference between the mean of the upper and lower vertebral body Hounsfield units and the target (intermediate) vertebral body Hounsfield units was defined as the difference in Hounsfield units. The ratio of the mean of the upper and lower vertebral body Hounsfield units and the difference of the target (intermediate) vertebral body Hounsfield units were defined as the ratio of Hounsfield units. (The typical cases Figure 1 and the control subject Figure 2)

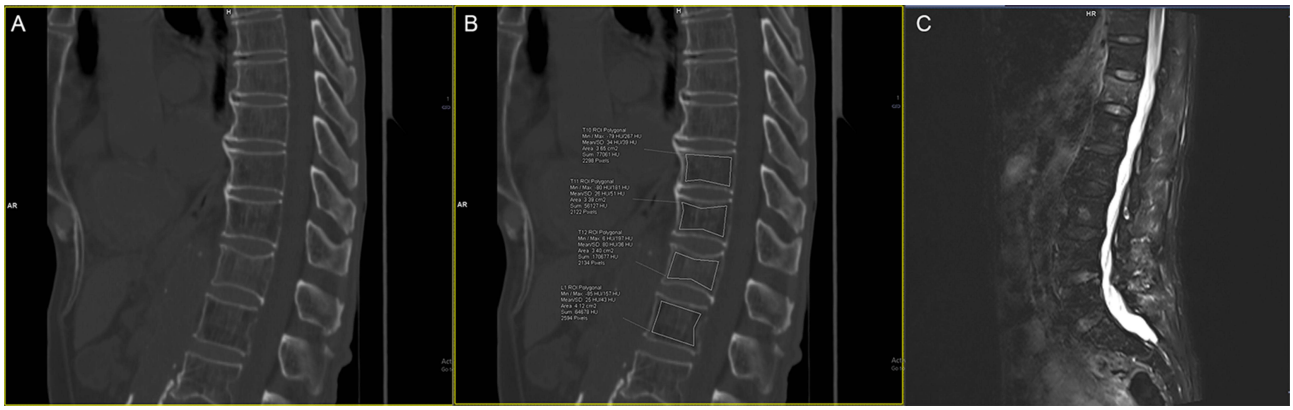

Figure 1 (**A**) (Typical cases, M, 92y, Low back pain for 1 week after coughing) CT sagittal reconstruction showed no obvious vertebral compression. (**B**) Measurements of HU showed that the Mean HU of T12 vertebrae (white arrow) was significantly higher than that of adjacent vertebrae. (**C**) The T2-image MRI showed a high signal in theT12 vertebrae, indicating a vertebral fracture.

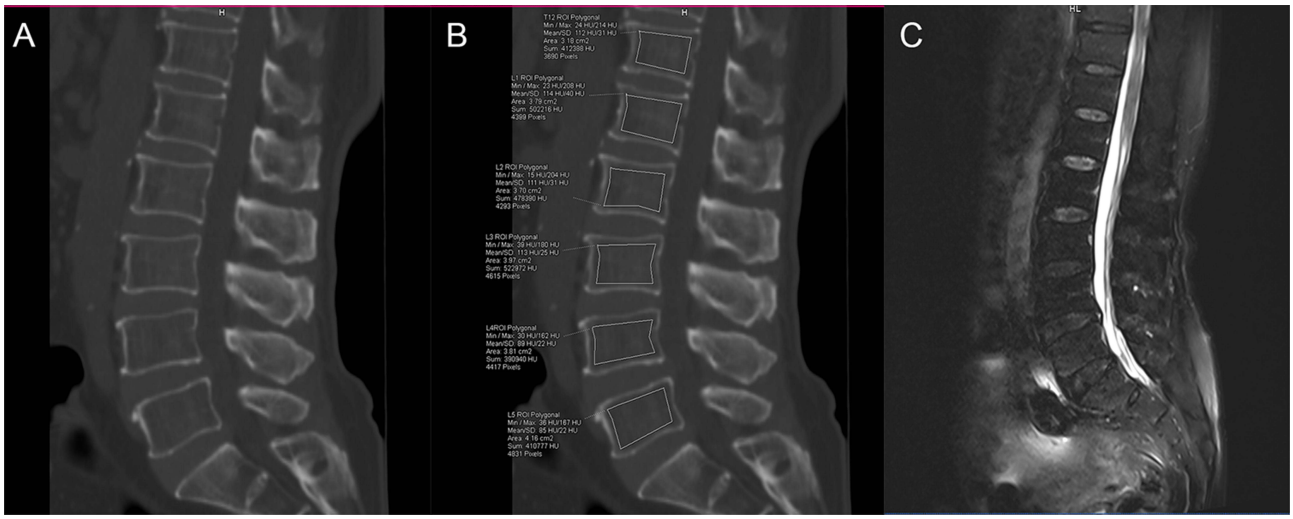

Figure 2 (**A**) (Control subject, M, 68y, Low back pain for 3 week because of the lumbar disc herniation) CT sagittal reconstruction. (**B**) Measurements of HU showed that the mean HU of vertebrae was no significantly higher than that of adjacent vertebrae with our means. (**C**) The T2-image MRI showed no abnormal signal in the vertebrae, indicating vertebral fracture was not exist.

Data Collection

Patient information, such as the gender, age, Hounsfield units of three consecutive vertebral bodies, and the ordinal number of the vertebral body, was recorded. For the fracture group, the Hounsfield units of three consecutive vertebral bodies and the ordinal number of the fractured vertebral body were collected.

Statistical Analysis

SPSS 20.0 statistical software (IBM, Armonk, NY, USA) was used for statistical analysis. Cohen's kappa coefficient was used to assess inter-rater agreement. Continuous data with a normal distribution (according to the Kolmogorov–Smirnov test) were described as means ± standard deviations and analysed using Student's *t*-test; otherwise, they were presented as medians (interquartile range (IQR)) and analysed using the Wilcoxon rank-sum test. Categorical data were described as n (%) and analysed using the chi-square test or Fisher's exact test. Discriminant analysis was performed using receiver operator characteristic (ROC) curves to obtain cut-off values. A p-value < 0.05 was considered statistically significant.

Results

The present study included 216 patients with fractures (38 males and 178 females; average age: 77.28±8.68 years) and 124 patients without fractures (21 males and 103 females; average age: 75.35±9.57 years). Table 1 shows the basic characteristics of both groups and the segmental distribution of the vertebral body examined. The inter-rater reliability showed good agreement in measuring Hounsfield units of the vertebral body with a correlation coefficient of 0.999.

The mean Hounsfield units were significantly higher in the fracture group compared to the non-fracture group ((81.69 ± 39.21 vs 70.09 ± 28.44; p<0.001). The difference of Hounsfield units of the target (intermediate) vertebral body in the two groups was significantly different between the two groups (54.74 ± 21.84 vs 5.86 ± 5.14; p<0.001). The ratios of Hounsfield units were also significantly different between the two groups (1.38 ± 1.60 vs 0.13 ± 0.23; p<0.001) (Table 2).

The cut-off value for the difference value in Hounsfield units to detect osteoporotic spine fractures was 25.35, with high sensitivity (98.5%), specificity (99.9%), and the area under the curve (AUC) (0.999) at 95% CI: 0.999–1. The cut-off value for the odds ratio of Hounsfield units was 0.260, with high sensitivity (99.1%), specificity (92.7%), and AUC (0.970) at 95% CI: 0.949–0.992 (Table 3 and Figure 3).

Table 1 Basic Characteristics of Patients in the Fracture and Non-Fracture Groups

Characteristics	Fracture Group (n=216)	Non-Fracture Group (n=124)	P
Male, n (%)	38 (17.59)	21 (16.94)	0.88
Age (years)	77.28±8.68	75.35±9.57	0.07
Number of thoracic vertebra, n (%)	209 (32.25)	123 (33.06)	0.79
T5	1 (0.15)	1 (0.27)	0.74
T6	3 (0.45)	2 (0.54)	
T7	3 (0.45)	2 (0.54)	
T8	4 (0.6)	3 (0.81)	
T9	3 (0.45)	6 (1.61)	
T10	15 (2.31)	10 (2.69)	
T11	56 (8.64)	34 (9.14)	
T12	124 (19.14)	65 (17.47)	
Number of lumbar vertebra, n (%)	439 (67.75)	249 (66.94)	0.79
L1	158 (24.38)	88 (23.66)	0.94
L2	139 (21.45)	75 (20.16)	
L3	85 (13.12)	48 (12.90)	
L4	40 (6.17)	26 (6.70)	
L5	17 (2.62)	12 (3.23)	

Table 2 Comparative Imaging Data Between the Fracture and Non-Fracture Groups

Characteristics	Fracture Group (n=216)	Non-Fracture Group (n=124)	*P*
Hounsfield's mean	81.69±39.21	70.09±28.44	<0.001
Difference value in Hounsfield units of the upper and lower vertebral body	9.72±13.97	9.37±14.50	0.828
Difference value of Hounsfield units	57.74±21.84	5.86±5.14	<0.001
The ratio of Hounsfield units	1.33±1.60	0.13±0.23	<0.001

Table 3 Results of the ROC Curve

	AUC	Cut-off	Sensitivity (%)	Specificity (%)	95% CI
Difference value of Hounsfield units	0.999	25.35	98.5	99.9	0.999–1.000
The ratio of Hounsfield units	0.970	0.260	99.1	92.7	0.949–0.992

Discussion

The ratio of the difference between the mean Hounsfield units of the upper and lower vertebral bodies and Hounsfield units of the target vertebral body could be an effective approach for identifying osteoporotic bone in the spine. This approach has high sensitivity and specificity in diagnosing osteoporotic thoracolumbar vertebral non-compression fractures in elderly patients. Our findings suggest that this method may be a straightforward and quick tool for diagnosing osteoporosis in clinical settings.

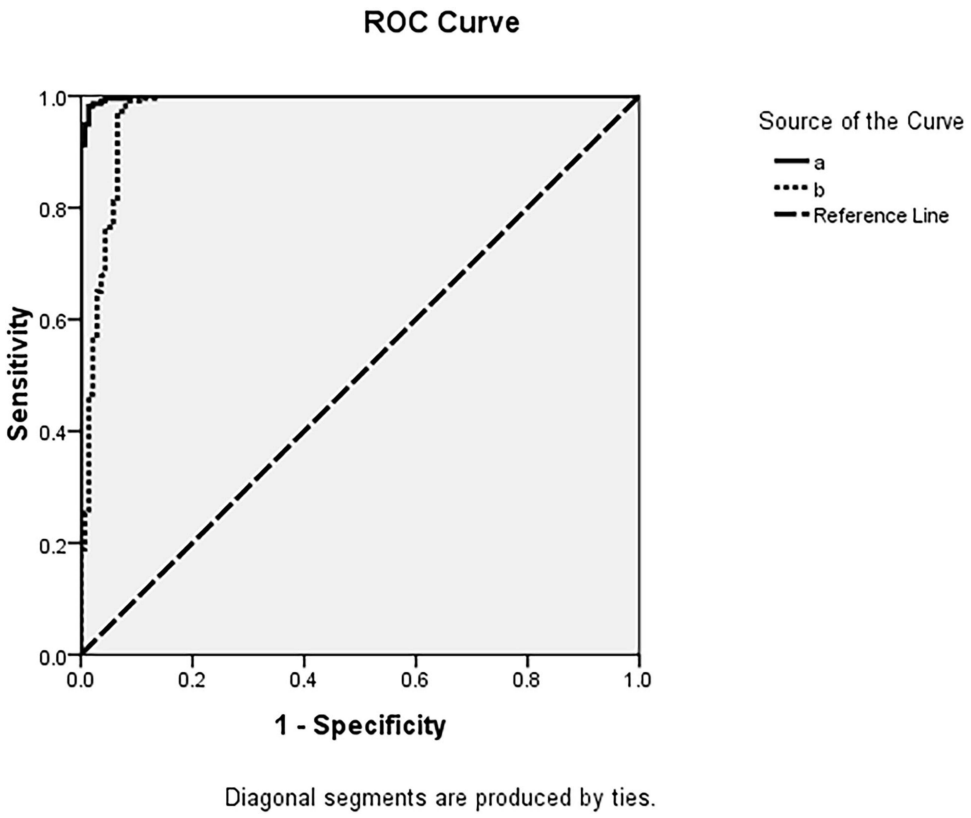

Figure 3 (**a**) Solid line, ROC curve for the difference value of Hounsfield units; (**b**) Dashed line, ROC curve for the ratio of Hounsfield units.

CT is fast and cost-effective, and has fewer contraindications than MRI which is not suitable for patients with permanent cardiac pacemakers, cardioverter defibrillators (ICDs), nerve stimulators, metallic implants like intravascular stents, heart valve prosthesis, artificial cochlea, and all ferromagnetic foreign matter.[24] CT is also an effective tool for evaluating almost all spinal bone tissue, especially for patients who cannot undergo an MRI.[25] The Hounsfield units in the vertebral body detected by CT indicate their bone density.

A previous study suggested that the Hounsfield units of the human vertebral body vary and are correlated with the bone density of each vertebral body, showing a regular pattern. However, there is a wide variation in Hounsfield units among individuals depending on their overall bone density.[18] To reduce bias, we selected the injured vertebral body and its adjacent vertebral bodies as subjects. Many factors, such as osteophyte, abdominal aorta calcification, intra-abdominal metal implants, or hyperplasia of posterior spinal structures, may influence DXA bone density measurements.[21] CT measurements are more responsive to cancellous bone density changes, with better agreement and reflection of a patient's bone density. The ROI is drawn exclusively around the cancellous bone, eliminating cortical margins, bone deformities, or voids such as vascular channels. This technique has demonstrated exceptional reliability among intra- and inter-raters.[26]

The present study found no significant difference between the Hounsfield units of the upper and lower vertebral body (excluding the middle vertebral body). This indicates that the Hounsfield units between the vertebral body of the two groups were balanced and comparable. In contrast, the responsible vertebral body in osteoporotic vertebral fractures had significantly higher Hounsfield units than the mean units of the upper and lower vertebral body, which was significantly different from the control group. Additionally, by using Fisher's discrimination, we found that when the difference between the target (intermediate) vertebral body and the mean of the upper and lower vertebral body was greater than 25.35 or the ratio was greater than 0.2595, the target vertebral body was the fractured vertebral body. These findings provide a valuable reference for clinicians in determining the responsible vertebral body, and our study demonstrated high reliability and reproducibility through these strategies.

Currently, there is no literature available regarding the use of Hounsfield units to determine osteoporotic vertebral fractures. However, utilizing CT may be useful to enhance osteoporosis detection with minimal additional cost or radiation exposure.[16,19,27] Recent evidence suggests that CT bone attenuation measurement can predict osteoporotic fractures with comparable sensitivity DXA.[28] Therefore, measuring vertebral body Hounsfield units through a CT scan can serve as a viable and practical screening method for osteoporotic vertebral fractures, particularly when the MRI examination is inaccessible or not immediately possible. This method can be clinically valuable when combined with the patient's general condition, age, gender, osteoporosis, history of minor trauma, constipation after lumbago, and localized pressure and percussion pain in the spine.

Computer aided diagnosis (CAD) software using machine learning to detect vertebral fractures has been developed[29] and has the potential to serve as a resource-efficient screening tool to detect at-risk populations for secondary prevention of fractures. It uses an axial image of a CT scan and creates a virtual sagittal plane of the spine, which is then split into multiple overlapping image blocks. The patches were then run through a combination of a convolutional neural network works (cnn) and a recurrent neural network (rnn) to output whether there was a break. The CAD software has a high specificity in CT scans for any indication to exclude vertebral fractures, and the moderate sensitivity suggests that manual validation of the detected vertebral compression fracture software is needed before the software can be further improved.

Artificial intelligence is used to diagnose thoracolumbar fractures on lateral X-ray film, which is based on fissures found on lateral X-ray film, fractures without fissures will be missed, resulting in a high false negative rate.[30] Artificial intelligence is emerging as a diagnostic method, using machine learning algorithms to study CT images of bones to predict osteoporosis. Current AI solutions can also perform analysis and pattern recognition on CT datasets, such as morphological recognition used in the detection of rib or vertebral fractures,[31] and the differential diagnosis of benign and malignant vertebral fractures on MR Images.[32] Limitations such as lack of load bearing site and vertebral body data, invasiveness, and time consumption make it impossible to use regularly. If we expand our research sample, obtain a certain amount of data, and introduce a computational algorithm to evaluate occult vertebral fractures without morphological changes, we believe that it can be applied to the artificial intelligence diagnosis of vertebral fractures in CT images. Future studies should also explore the diagnostic capabilities of AI based algorithms on more radiographic projections and eventually different imaging modalities.

The present study has some limitations. First, this is a single-center retrospective study. Second, the sample population primarily consisted of Asian post-menopausal women, who were more likely to have low bone density, and therefore, the diagnostic method may not generalize to all racial groups. Third, cases with morphological changes and malformation were excluded from this study, and thus additional research is required to determine whether these cases are equally applicable.

In conclusion, the difference between Hounsfield units and the odds ratio of Hounsfield units might help in the diagnosis of osteoporotic thoracolumbar vertebral non-compression fractures in elderly patients with low-energy fractures.

Abbreviations

DXA, Dual energy X-ray absorptiometry; CT, Computed tomography; QCT, Quantitative CT; PACS, Picture archiving and communication system; IQR, Interquartile range; ROC, Receiver operator characteristic.

Scope Statement

This retrospective study investigates the diagnostic value of Hounsfield units in identifying osteoporotic thoracolumbar vertebral fractures in elderly patients. Osteoporotic fractures, common among the elderly, pose a diagnostic challenge. The study compares Hounsfield units in fractured and non-fractured cases, revealing significant differences. The Hounsfield units difference and odds ratio emerge as potential indicators for diagnosing these fractures.

Analyzing data from 216 fractured and 124 non-fractured patients, the study establishes a substantial disparity in Hounsfield units between the two groups. With a high sensitivity of 98.5% and specificity of 99.9%, the Hounsfield value difference proves a reliable indicator, supported by a robust AUC of 0.999. The odds ratio of Hounsfield units also exhibits diagnostic promise, with a sensitivity of 99.1%, specificity of 92.7%, and an AUC of 0.970.

This research provides valuable insights into a challenging diagnostic landscape, offering clinicians a potential tool for identifying osteoporotic thoracolumbar vertebral fractures in elderly patients with low-energy fractures. The identified cut-off values enhance diagnostic accuracy, emphasizing the clinical relevance of Hounsfield units in this context. This contribution fills a crucial knowledge gap, aiding in the effective diagnosis of these fractures, thereby contributing to advancements in the field of osteoporosis management in the elderly population.

Data Sharing Statement

All data generated or analysed during this study are included in this published article.

Ethics Approval and Consent to Participate

All procedures were performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. The study was approved by the Ethics committee of the Tong Ren hospital, Shanghai Jiao Tong University School of Medicine (approval number: K2023-016-01). Due to the retrospective analysis, the Ethics committee of the Tong Ren hospital, Shanghai Jiao Tong University School of Medicine waived the need for individual consent. All methods were carried out in accordance with relevant guidelines and regulations. All authors declared confirmation of patient data confidentiality.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors report no conflicts of interest in this work.

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