Correlation analysis of the vertebral compression degree and CT Hounsfield units in elderly patients with osteoporotic thoracolumbar fractures

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Research Article

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Abstract

Background

To explore the correlation analysis of the vertebral compression degree and cancellous bone CT Hounsfield units (HUs) in elderly patients with osteoporotic thoracolumbar fractures.

Methods

Forty-five elderly patients (32 females and 13 males) with single acute vertebral fragility fractures were retrospectively reviewed, and thoracolumbar MRI was used to assess whether each patient's vertebral compression fracture was fresh and whether the fractured vertebral body was single. All patients were diagnosed with osteoporosis or osteopenia by DXA. The consistency of measurement between two spine surgeons was evaluated. If the cancellous bone CT HU values of the vertebral bodies could not be measured due to moderate or severe compression, the average cancellous bone CT HU values of the upper and lower vertebral bodies were used instead.

Results

There were 18 L1 vertebral fractures, 16 T12, 6 L2, 3 T11, and 2 T10 fractures. The patients' average age was 70.89 ± 9.59 years (53 to 94 years), and the average CT HU value was 92.01 ± 34.11 HU (36 to 167 HU). The average vertebral compression ratio was 0.54 ± 0.16 (0.26 to 0.83). Measurements showed both good intrarater repeatability and good interrater reproducibility of the vertebral compression ratio (the intraclass correlation coefficient (ICC) was 0.982). The degree of vertebral compression in thoracolumbar osteoporotic fractures was highly positively correlated with the CT HU values of cancellous bone ($P < 0.01$).

Conclusions

This study provides the quantitative evidence that the degree of thoracolumbar osteoporotic compression fracture is associated with the CT HU units of cancellous bone in elderly patients. Further longitudinal studies with larger cohorts are needed to verify this relationship.

Background

With an aging population, osteoporosis is becoming a global problem and affects 200 million people worldwide [1]. Spinal vertebral fractures are the most common form of osteoporotic fracture, followed by fractures of the femoral proximal and distal radius. Due to specific spine biomechanical conduction [2], the thoracolumbar vertebral body (T10-L2) is the easiest vertebral body to fracture in spine trauma.

Dual-energy X-ray absorptiometry (DXA) is currently considered to be the gold standard for bone mineral density (BMD) quantification and has been shown to correlate with fracture risk and the efficacy of treatment [3]. However, BMD is one of the risk factors for fracture, some fragility fractures occur in individuals with BMD T values above the -2.5 threshold, which suggests that BMD has limited value for the prediction of osteoporosis in the clinic [4, 5]. BMD is also the most commonly used method for evaluating bone density in spine surgery. Elderly patients with osteoporotic fractures tend to merge degenerative diseases, however, lumbar degenerative diseases easily leads to increased pseudo DXA measurement values, cause osteoporosis diagnosis. It has been proven [6] that the prevalence of osteoporosis in patients with lumbar degenerative disease is high, and the rate of missed diagnosis by DXA is also high. It is insufficient to use DXA alone to assess BMD in patients with lumbar degenerative disease.

Studies [7, 8] have found that the CT HU value of the vertebral trabecular (noncortical) region can reflect the BMD, and routine CT examination can be used to identify patients with osteoporosis. It is recommended that the CT HU value of the vertebral body be combined to improve the accuracy of BMD assessment. CT HU values can also be used to assess the risk of thoracolumbar vertebral fragility fractures. The lower the CT HU values of the vertebral body, the higher is the risk of frangible fracture of the vertebral body, and the greater is the number of vertebral fractures that may exist [9]. In addition, there is no research using vertebral CT HU values to qualitatively analyze the severity of vertebral body osteoporotic fractures. For this reason, this study aimed to further explore the relationship between osteoporotic vertebral cancellous bone fracture CT HU values and the severity of vertebral compression fractures.

Methods

Patient cohort

This study was reviewed and approved by the Fifth Clinical Medical College of Guilin Medical University. The informed consent requirement was waived because this study was retrospective. All methods were performed following relevant guidelines and regulations.

All patient data were retrieved retrospectively from our institute's radiology information system. We reviewed elderly patients undergoing surgery for acute vertebral fragility fractures in our department from January 2019 to December 2020. Inclusion criteria were (1) a single segment of the acute vertebral compression fractures (positioned in T10 - L2); (2) no obvious history of high-energy trauma; (3) clear magnetic resonance imaging (MRI) and CT scan images for DXA diagnosis of osteoporosis or osteopenia; and (4) no history of spinal surgery associated with disease. Exclusion criteria were (1) a single segment of acute vertebral compression fractures outside the thoracolumbar location and more segmental frangible compression fractures; (2) a clear history of high-energy injury; (3) no concurrence with MRI, CT, or DXA imaging scans; (4) old vertebral compression fractures; (5) a secondary osteoporosis fracture (oral hormone usage, etc.), pathological (metastases) and ankylosing spondylitis

fractures; (6) postoperative status, or known history of disability; and (7) history of spinal surgery associated with disease.

All patients underwent a routine MRI study of the thoracolumbar spine in the supine position. Sagittal or coronal T2-weighted fat-saturated MRI images were used to assess acute vertebral compression fractures. The degree of vertebral compression and the CT HU values of cancellous bone were measured by three-dimensional CT scans.

CT and measurements

All MRI scans were performed using either of two 1.5-T scanners (Signa, GE Healthcare). The thoracolumbar vertebral body was chosen as the site for CT HU value measurements with preoperative three-dimensional reconstructive spinal CT scans (American GE Company, Light Speed VCT, scanning conditions: tube voltage: 120 kV, tube current: 355 mA, slice thickness: 5 mm, slice spacing: 5 mm, bone window width: 2000 HU, window level: 350 HU). The picture archiving and communication system (PACS) was used to measure the vertebral compression degree and cancellous bone CT HU values. The oval region of interest (ROI) was placed on the middle-axial image within the trabecular bone of the thoracolumbar vertebral body; however, the vertebral venous plexus, cortical bone, hyperosteo-geny and artifacts should be avoided [10–12]. Through the analysis of two spine surgeons independently assessing the axial CT measurement of vertebral cancellous bone fracture CT HU values on a single axial CT image at the appropriate level by manually placing, it was proven that CT HU measurements have excellent interobserver and intraobserver reliability [13, 14]. If the compressed vertebral body had moderate to severe fractures, the average CT HU values of the superior and inferior vertebral bodies of the compressed vertebral body were used instead (Fig. 1). Commonly, osteoporotic vertebral compression fractures compression ratio is the low of sagittal scan compressed vertebral bodies and the same height of vertebral rear on the three-dimensional CT. And if whole-body compression occurred, the degree of compression was calculated as the ratio of the height of the lowest compressed vertebral body to that of the posterior edge of the superior vertebral body (Fig. 2) [9, 15].

Statistical analyses

The statistical analysis in this study was conducted using SPSS version 26 (SPSS, USA). Input and analysis of measured data and measurement data were recorded as means $\pm$ standard deviations. Two spinal surgeons measured the data consistency inspection. Intrarater repeatability was assessed using the intraclass correlation coefficient (ICC) to determine the reliability. Using the Spearman correlation test to correlation analysis both vertebral compression degree and cancellous bone CT HU values in thoracolumbar osteoporotic fracture. $P < 0.01$ was considered to indicate a statistically significant difference.

Results

A total of 45 elderly patients with 32 females and 13 males were included in the final analysis. These included 18 L1 osteoporotic vertebral fractures, 16 T12 fractures, 6 L2 fractures, 3 T11 fractures, and 2 T10 fractures. The patients' average age was 70.89 ± 9.59 years (53 to 94 years), and the average CT HU value was 92.01 ± 34.11 HU (36 to 167 HU). The average vertebral compression ratio was 0.54 ± 0.16 (0.26 to 0.83)..

Consistency test

The consistency of the measurement results of the two spine surgeons was tested, and the consistency of the compression ratio data of thoracolumbar fractures was evaluated ($ICC = 0.982 > 0.75$). The consistency of the data measured by the two spine surgeons was high (Table 1).

Table1 Consistency test of fracture vertebral compression ratio measured by two spinal surgeons

	Intra-class correlation	95% confidence interval		F-test with Ture value 0			
		Lower Limit	Upper limit	Value	df1	df2	Significance
Single Measurement	.964	.935	.980	56.298	44	44	.000
Average measurement	.982	.966	.990	56.298	44	44	.000

Correlation between vertebral compression degree and cancellous bone CT HU values in thoracolumbar osteoporotic fracture

The degree of vertebral compression in thoracolumbar osteoporotic fracture was correlated with the CT HU value of cancellous bone ($P \leq 0.01$), and the correlation coefficient was $r = 0.645$ (Table 2). The degree of vertebral compression in thoracolumbar osteoporotic fracture was highly positively correlated with the CT value of cancellous bone (Fig. 3).

Table2: Spearman correlation test of vertebral compression ratio and CT HU value

		Vertebral compression ratio	CT HU value
Vertebral compression ratio	Spearman correlation	1.000	.645**
	P		0.000
	N	45	45
CT HU value	Spearman correlation	.645**	1.000
	P	0.000	
	N	45	45
**. At the 0.01 level (two-tailed), the correlation is significant.			

Figure 3 The degree of vertebral compression in thoracolumbar osteoporotic fracture was highly positively correlated with the CT value of cancellous bone($R^2_{\text{liner}}=0.448$)

Discussion

Our study initially demonstrated that for osteoporotic vertebral fractures, with the decrease in cancellous bone CT HU values in the thoracolumbar segment (T10-L2), the degree of compression became increasingly obvious for low-energy vertebral bodies. There was a typical linear relationship between the degree of vertebral compression and the CT HU values of cancellous bone. In our study, patients had experienced a low-energy injury, and all patients were diagnosed with osteoporosis or osteopenia based on DXA bone mineral density after admission. MRI is currently the preferred imaging method for the diagnosis and treatment of fragile vertebral fractures [16], we used thoracolumbar MRI to assess that the patient's vertebral compression fracture was fresh and the fractured vertebral body was single.

The commonly used classification method for osteoporotic vertebral compression fractures was proposed by Genant et al [15], which is named the semipolicy (SQ) criteria, this approach involves the use of thoracolumbar lateral X-ray to determine the degree of vertebral compression. However, the angle of the subject to exposure, the patient position, the operation of the vertebral body levels morphology, and X-ray technician experience, which in some cases may cause small errors in judgment of the degree of vertebral body compression. While computed tomography (CT) scans can make use of sagittal alignment evaluation, they are good enough to determine the degree of compression. Because of the limitations of the SQ criteria in assessing vertebral compression, we chose three-dimensional CT scans to assess vertebral compression in the sagittal plane of a frangible fracture.

The CT value represents the attenuation value of X-rays after they pass through the tissue and are absorbed. It is a unit for measuring the density of a local tissue or organ in the human body and is usually called the Hounsfield unit (HU). The CT HU value is based on water and is equal to the difference between the attenuation coefficient of the substance and the absorption coefficient of water multiplied by

1000 after determining the ratio to the attenuation coefficient of water [12]. The CT HU value reflects the density of the material; the higher the density of the material is, the higher the CT HU value, so the human skeleton is no exception. The HU value for bone typically ranges from 300 to 3000 [17]. Compared with DXA examination, CT HU value measurement in evaluating BMD confers an obvious advantage: (1) DXA measurement of BMD cannot distinguish between cortical bone or cancellous bone [8]. Moreover, a study [18] has suggested that cancellous bone in the spine plays a more important role in the process of loadbearing and compression fractures than does the bone cortex. (2) Conventional DXA can only detect the lumbar spine and hip BMD values of these easy-to-fracture positions. However, CT examination is not limited by the examination site, and a large number of high-risk groups of vertebral fragility fractures have not received standardized bone mineral density assessment. On the other hand, many elderly people have received clinical CT examinations for various diseases (chest CT, abdominal and pelvic CT, spinal CT, urinary CT, etc.). We can use these existing CT images to measure the CT HU value of the vertebral body to assess the BMD to easily and quickly identify patients at high risk of osteoporosis and brittle vertebral fracture. (3) The prevalence of row helical CT machines in medical institutions is significantly higher than that of DXA; at the same time, the measurement of HU is convenient and has good to excellent interactive tests between observers for reliability, which makes this method simple and easy to popularize [13].

At present, many conventional CT studies of osteoporosis fractures at the L1 vertebral level have been performed. Studies [19] have proven that conventional CT-measured CT HU values can be used to identify normal vertebral bone mass and osteoporosis. Emohare et al. [20] reported thoracolumbar compression fractures in elderly patients to have a value of approximately 110 HU, but approximately a quarter of the fractures in the elderly patients in the study were not caused by low-energy trauma. Lee et al. [10] reported the average L1-HU value of vertebral fractures in elderly patients to be approximately 85 HU, which was lower than the average L1-HU value of normal people (approximately 125 HU). However, the use of an enhanced CT contrast agent can increase the L1-HU value by an average of 11 HU compared with that of plain CT [21]. Zou et al. [9] reported that the average L1-HU value of acute vertebral fragility fractures was 66.0 HU by age and sex matching, and the AUC value for predicting vertebral fragility fractures by the vertebral CT value was 0.77 (95% CI, 0.70–0.85; $P < 0.001$). The cutoff values of vertebral CT values corresponding to 90% specificity and 90% sensitivity were 60 HU and 100 HU, respectively, in the elderly population; conventional CT measured the CT value of L1 vertebral body trabecular bone, which is closely related to the occurrence of vertebral fracture, and L1 attenuation ≤ 90 HU may represent the best threshold for determining the risk of osteoporotic vertebral fracture [10, 22]. Schreiber et al. [12], using the polyurethane module through mechanical dynamics experiments, proved that the CT HU value has a significant correlation with the compressive strength of bone. At the same time, our study preliminarily demonstrated that for low-energy frangible fractures in elderly individuals, the lower the CT HU value of cancellous bone, the more serious was the loss of vertebral height; conversely, the higher the CT HU value of cancellous bone, the less obvious was the loss of vertebral height.

This study has two limitations. First, the sample size of patients was small because we used strict inclusion criteria for this retrospective investigation. Further longitudinal studies with larger cohorts are

needed to verify this relationship. Second, we only studied the effect of the cancellous bone CT HU value on the vertebral body of frangible fractures; However, other studies [23] have shown that compression fractures are associated with paraspinal fractures. Muscles such as the psoas are related to volume reduction. Therefore, the factors related to the height loss of vertebral compression fractures are worthy of further study.

Conclusions

In conclusion, the CT HU values are one of the important factors affecting the compression degree in osteoporotic vertebral fracture. This study provides the first quantitative evidence that the degree of thoracolumbar osteoporotic compression fracture is associated with the CT HU value of cancellous bone in elderly patients. Further longitudinal studies with larger cohorts are needed to verify this relationship.

Abbreviations

DXA: Dual-energy X-ray absorptiometry; BMD: bone mineral density; ICC: intraclass correlation coefficient; HU: Hounsfield unit

Declarations

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Authors' contributions

Cheng Li: Drafting the article or revising it critically for important intellectual content.

Wei Hu: Drafting the article or revising it critically for important intellectual content.

Yang Lin: Substantial contributions to conception and design, or acquisition of data, or analysis and interpretation of data.

Xinyu Huang: Substantial contributions to conception and design, or acquisition of data, or analysis and interpretation of data.

Xingming Lai: Substantial contributions to conception and design, or acquisition of data, or analysis and interpretation of data.

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Availability of data and materials

The datasets generated during and/or analysed during the current study are available in the Guilin Medical University Library's repository, [<https://mgmt.glmc.edu.cn/tsg/dzzy/zjsjk.htm>].

Ethics approval and consent to participate

The study was approved by the **licensing ethical committee of** Fifth Clinical Medical College, Guilin Medical University, and the informed consent requirement was waived because this study was retrospective. All procedures performed in studies involving human participants 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.

Consent for publication

Not applicable

Conflicts of interest/Competing interests

Cheng Li, Wei Hu, Yang Lin, Xinyu Huang and Xingming Lai declare that they have no conflict of interest.

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Figures

Figure 1

The patient was an 81-year-old male with a compression fracture of the L1 vertebral body, and the average cancellous bone CT values were used instead by the T12 and L2 vertebral bodies ,because of severe compression.

Figure 2

If the compressed vertebral body had moderate to severe fractures,the degree of vertebral compression ratio for a/c, rather than a/b.

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Figure 3

The degree of vertebral compression in thoracolumbar osteoporotic fracture was highly positively correlated with the CT value of cancellous bone($R^2 \text{ liner} = 0.448$)