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CT measurement and analysis of the target vertebral body in elderly patients with uncompressed osteoporotic thoracolumbar fractures

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Abstract. – OBJECTIVE: To evaluate the feasibility of determining the target vertebral body (TV) of uncompressed elderly osteoporotic thoracolumbar fractures through measuring Hounsfield unit (HU) value.

PATIENTS AND METHODS: Elderly patients with osteoporotic thoracolumbar fractures aged above 65 years old hospitalized from 2015 to 2016 were retrospectively analyzed. The cases whose TV could not be determined by computed tomography (CT) imaging but confirmed by magnetic resonance imaging (MRI) were selected. The mean HU values of the trabecular bone regions of TV and adjacent vertebral body in the multi-detector CT (MDCT) sagittal three-dimensional reconstructed image were measured and compared. At the same time, 60 thoracolumbar adjacent vertebral bodies without fractures were selected from 20 people, and the mean HU value of the trabecular bone region of each vertebra in the MDCT sagittal three-dimensional reconstructed image was measured and compared.

RESULTS: There were correlations among the mean HU values of 60 thoracolumbar adjacent vertebral bodies in the 20 people without fractures, and there were no differences in the correlations between middle vertebral body (MV) and upper vertebral body (UV) and between MV and lower vertebral body (LV) compared with the correlation between UV and LV. In the 31 fracture cases, the mean HU values had correlations among TV, UV and LV, there was no difference in the comparison of correlations between TV and UV and between TV and LV, but the correlations between TV and UV and between TV and LV had differences compared with the correlation between UV and LV.

CONCLUSIONS: The mean HU value of TV of uncompressed elderly osteoporotic thoracolumbar fractures is increased abnormally compared with that of the adjacent vertebral body, and it is feasible to determine the TV of uncompressed osteoporotic thoracolumbar fractures according to the mean HU value.

Key Words

Spine, Osteoporotic vertebral fractures, CT, Hounsfield unit value, Elderly, Target vertebral body.

Introduction

Osteoporosis is a major public health issue related to health care, the society and financial burdens. Low bone mass and microstructural degeneration increase the bone vulnerability, producing the risk of fractures, mainly osteoporotic vertebral compression fractures and the resulting pain, malformation, paralysis and even death[1]. The incidence rate of osteoporotic fractures is increased with age. Osteoporotic vertebral fractures (OVFs) occur at least once in about 25% women aged above 70 years old and more than half of women aged above 80 years old[2]. This type of fracture is characterized by slow healing, high difficulty in surgical treatment, high risk of re-fracture, and high disability and mortality rates[3,4]. Vertebral fractures will lead to severe symptoms, such as pain, loss of body mobility and kyphosis deformity. The relative risk of death of vertebral fractures is about 9 times higher than that of patients without vertebral fractures[5]. Elderly osteoporotic thoracolumbar fractures are often non-high-energy injuries and can even be induced by bending and coughing, and the changes in vertebral compression are not obvious sometimes. Due to the lack of standardized methods, the diagnosis of vertebral fractures is often ignored in clinical practice, and patients are not evaluated accurately.

Ordinary X-ray or computed tomography (CT) can display most compression fractures, but their sensitivities to little deformed or uncompressed

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fractures is relatively low. Some vertebral fractures occur under the condition of no specific trauma, leading to inadequate diagnosis and delayed treatment[6,7]. Atypical fractures displayed in X-ray are known as "occult" OVFs[8], in the diagnosis of which magnetic resonance imaging (MRI) can locate the fracture through the abnormal bone marrow signal inside the vertebrae, and can distinguish old fractures from new fractures[9]. The treatment plan is changed in 57% patients after MR examination[10]. However, for many elderly patients may not be appropriate to receive MRI examination because of the implantation of paramagnetic metal materials in early years. Additionally, there are patients with claustrophobia, causing confusion and difficulty in the diagnosis and treatment by clinicians.

The values of hematoma or water and air on the CT image are not the same. The slight compression changes in the morphology of fractured vertebrae probably cannot be clearly determined, but can the resulting increase in the bone trabecula per unit area and hematoma be found via CT? It has been reported that the trabecular bone image based on the trabecular bone score (TBS) is applied to measure the bone strength, which is also considered feasible[11,12]. Muller et al[13], shown that compared with axial multi-detector CT (MDCT) images, OVFs can be better detected in the abdominal MDCT sagittal reconstructed image but errors are inevitable in the diagnosis based on morphological measurement and physicians' experience.

In our institution, the sagittal reconstruction is routinely performed for the CT of each thoracolumbar vertebra, so that the Hounsfield unit (HU) value can be measured with low technical level and little time. In particular, the partial volume effect can be avoided and special software is not required. Therefore, the correlation between target vertebral body (TV) and adjacent vertebral body was compared through measuring the HU value in three-dimensional reconstructed images, so as to provide a certain reference for clinical decision-making and effective treatment.

Patients and Methods

Patients

Elderly patients with osteoporotic thoracolumbar fractures hospitalized from 2015 to 2016 were selected. This study was approved by the Ethics Committee of The Affiliated Tongren Hospital of Shanghai Jiao Tong University, School of Medicine. Signed written informed consents were obtained from all participants before the study.

Inclusion criteria: (1) patients with symptomatic fractures and receiving diagnosis and treatment due to acute back pain recently, (2) patients aged ≥ 65 years old, (3) patients whose TV could not be determined *via* visual semi-quantitative evaluation of CT images using the Genant method[14], and who had no or very mild vertebral deformation, (4) patients with fresh fractures confirmed by MRI, and (5) patients with secondary fractures to osteoporosis. The diagnosis of osteoporosis was determined through the existing osteoporosis: osteoporosis was diagnosed definitely in the past, or based on previous or accompanied low-energy fractures in addition to common clinical risk factors, or through measuring the -2.5 DS or larger T value of the spine or femoral neck *via* the dual-energy X-ray absorptiometry. The underlying diseases were ruled out through laboratory examinations, bone scintigraphy, MRI and additional examinations as needed.

Exclusion criteria: (1) patients with primary or metastatic spinal tumors, multiple myeloma, metabolic bone diseases (such as osteomalacia and renal osteodystrophy), hyperparathyroidism, Scheuermann's disease, Paget's disease, hemangioma, infection or dysplasia (Cobb angle > 60° and congenital spinal deformity in patients with severe scoliosis), (2) patients in Genant's grade 1 or above, (3) patients with multiple fractures of adjacent vertebral bodies, or (4) patients without CT sagittal three-dimensional reconstructed images or with poor image quality.

Imaging Examination

Patients were examined *via* CT (LightSpeed pro VCT 32, GE, Buckinghamshire, UK) and MRI (Skyra 3.0T, Siemens, Berlin, Germany). Vertebral fractures were confirmed *via* morphological diagnosis when the vertebral body met the following two criteria: 1) Signs of vertebral fractures in the axial image were analyzed, including the fracture line, and more region could be seen in the posterior part of vertebrae than that in the anterior part, indicating the wedge-shaped deformity and pathologically increased diameter, and 2) the deformity whose height declined by more than 20% in the subsequent images was defined as the fracture according to the semi-quantitative (SQ) classification based on the Genant method[14].

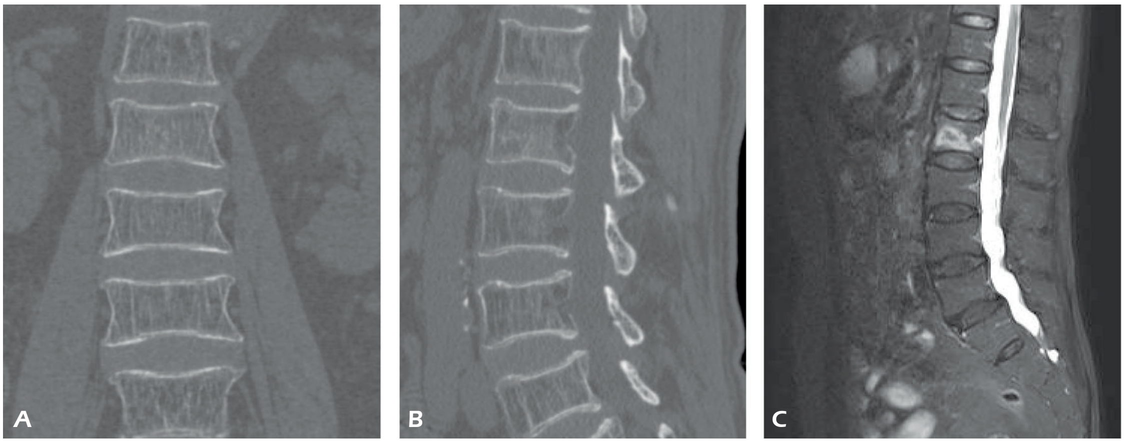

Figure 1. Radiological images of a case (83 years old) with L2 osteoporotic fracture. **A**, Coronal CT image. **B**, Sagittal CT image. **C**, MR image (increased signal intensity).

Measurement of the Mean HU Value

In PACS, the sagittal CT three-dimensional reconstructed images of the selected cases were taken, the trabecular bone regions of TV and adjacent vertebral body were selected in the middle image (where the spinous process was located) to avoid the effect of cortical bone to the largest extent, and the area, mean, maximum and minimum HU values and standard deviation of the region of interest (ROI) were obtained (Figures 1 and 2). The region selected should contain as many vertebral trabecular bone regions as possible.

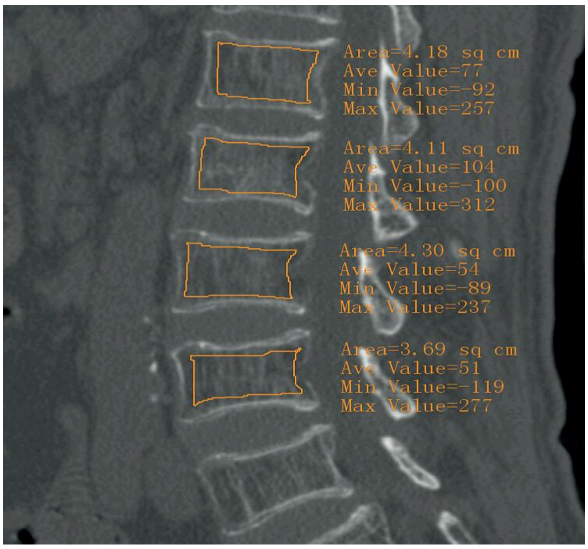

Figure 2. ROI area and mean HU value of trabecular bone regions of TV and adjacent vertebral body calculated based on the sagittal CT image.

Statistical Analysis

To evaluate the observer's measurement error, TV and adjacent vertebral body of the fracture cases were measured twice, and the repeatability was compared *via* simple linear regression. Pearson's analysis was performed for each group of data using statistical analysis system (SAS) software (Raleigh, NC, USA), and the correlation was compared. $p<0.05$ suggested that the difference was statistically significant.

Results

Baseline Data of the Two Groups

In this study, a total of 20 non-fracture cases were enrolled, including 2 males and 18 females with an average age of (77.65±8.65) years old, and a total of 60 thoracolumbar adjacent vertebral bodies were included. At the same time, 31 fracture cases were enrolled, including 4 males and 27 females aged (78.71±8.53) years old. The distributions of vertebral bodies in both groups are shown in Table I. The repeatability of data measurement was also analyzed (correlation coefficient = 0.99971) (Figure 3).

Correlation Analyses of Thoracolumbar Vertebral Bodies in Non-Fracture Group

There were correlations among the mean HU values of adjacent vertebral bodies ($p<0.0001$), and there were no statistically significant differences in the correlations between middle vertebral body (MV) and upper vertebral body (UV) and between MV and lower vertebral body (LV) compared with the correlation between UV and LV ($p=0.3179$, $p=0.45520$).

Table I. Baseline data for the included patients of the two groups.

Items		Without fracture	Without fracture
N (male/female)		**20 (2/18)**	**31 (4/27)**
Age		**77.65±8.65**	**78.71±8.53**
Vertebral body distribution	T7	1	1
	T9	1	1
	T11	2	5
	T12	7	10
	L1	3	4
	L2	4	6
	L3	1	2
	L4	1	2

Correlation Analyses of Thoracolumbar Vertebral Bodies in Fracture Group

According to correlation analyses, the correlation coefficient of the mean HU value was 0.81234 between UV and TV ($p<0.0001$) (Figure 4A), 0.70940 between LV and TV ($p<0.0001$) (Figure 4B), and 0.79898 between UV and LV ($p<0.0001$) (Figure 4C).

Regression Analyses of Thoracolumbar Vertebral Bodies in Fracture Group

According to correlation analyses, the regression coefficient of correlation was 1.2869 between UV and TV ($t=7.5$, $p<0.0001$) (Figure 5A), 1.093 between LV and TV ($t=5.42$, $p<0.0001$) (Figure 5B) and 0.7557 between UV and LV ($t=7.15$, $p<0.0001$) (Figure 5C). The regression coefficients between UV and TV and between LV and TV had statistically significant differences compared with the regression coefficient between UV and LV ($p=0.038$, $p=0.0093$).

Discussion

It is reported in the literature that the T-value in bone density has no significant correlations with the grading and number of vertebral fractures[15]. Therefore, the dual-energy X-ray bone density was not used as an observation index in this paper. Several simple radiology-based methods for evaluating osteoporotic vertebral fractures are used to describe vertebral fractures[16-20], including visual evaluation of standard radiographs, SQ evaluation of Genant, qualitative method of Jiang, morphometric radiology and dual-energy X-ray absorptiometry (DXA), which are widely used in clinic[20]. However, a large-scale prospective study found that only about a quarter of OVFs were diagnosed[21]. According to a retrospective study on standard radiographs obtained in the emergency treatment center, the diagnostic rate of OVFs is 55-65%[22,23]. In a transnational study on 2,000 postmenopausal women with osteoporosis, the

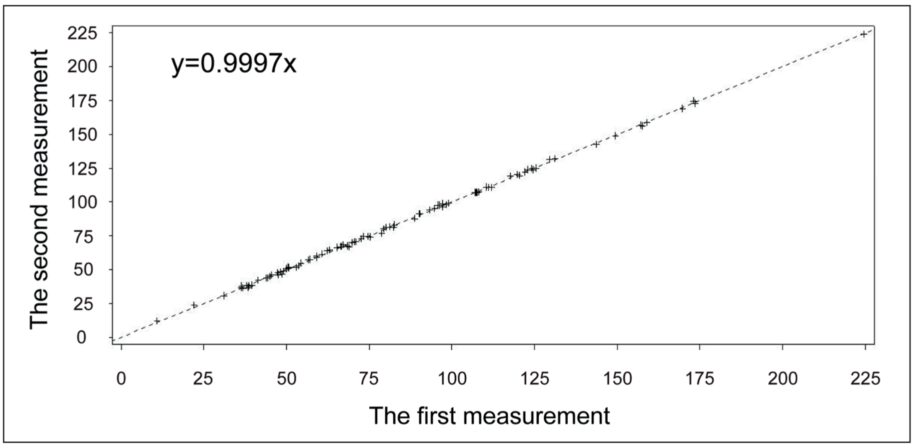

Figure 3. Repeatability of data measurement (x: first measurement, y: second measurement).

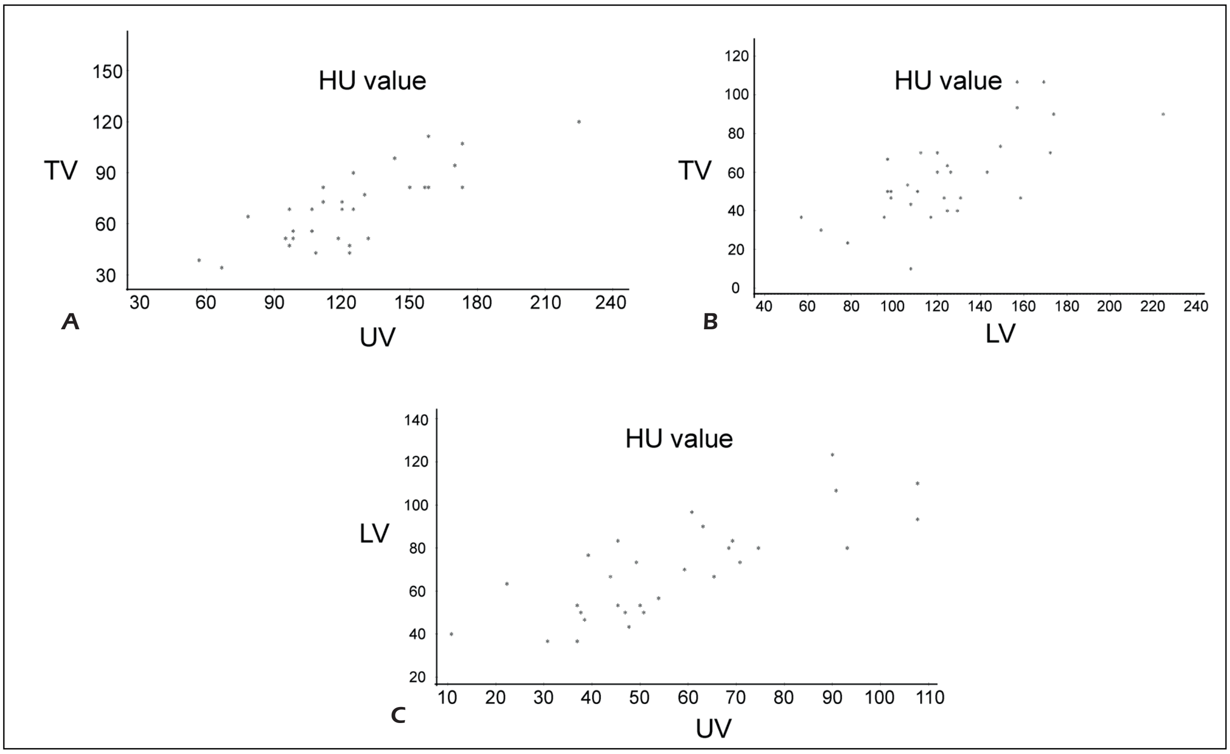

Figure 4. Correlation analyses of HU values of vertebral bodies in fracture group. **A**, x (UV), y (TV). **B**, x (LV), y (TV). **C**, x (UV), y (LV).

accuracy of radiologic diagnosis of OVFs was partially assessed, and the false negative rate of 27-45% was reported[24].

In terms of the positioning of OVFs' TV, Gaitanis et al[25] reported that the fresh vertebral fractures can be accurately diagnosed *via* the local tenderness of spinous process. However, some patients suffer from chest and back pain and radiating pain in lateral thorax with diffuse tenderness points due to severe osteoporosis, so it is difficult to accurately locate TV using the simple physical examination[26]. At present, it is generally believed that MRI examination is the best mean of diagnosing fresh vertebral fractures[27]. However, some patients cannot receive MRI examination, such as those implanted with cardiac pacemaker, artificial metal valves and corneas, intraocular metal foreign bodies, metal foreign bodies or metal implants in the body (such as internal fixation plates, stents, prosthesis and artificial joints), and those receiving incarceration of aneurysm or with claustrophobia[28]. These patients can do nothing but rest in bed, orally take analgesics and receive other conservative treatments before TV is identified using a better examination method.

The difficulty in accurately diagnosing OVFs is the parallax effect (compression of normal vertebrae). In addition, there is a lack of consistency with adjacent vertebrae in the diagnosis of OVFs, and the strict morphometric measurement on radiographs may lead to missed diagnosis or misdiagnosis[29,30]. One paper mentioned that MRI showed abnormal signals in 10 out of 34 patients with OVFs, but it was not seen on X-ray films due to no or very slight deformity[31]. Multiplanar reconstruction (MPR) is particularly attractive for spine surgery, because it has the potential of proving OVFs, and defines the osteoporotic fractures via the degree and shape of vertebral deformity, which, however, is also limited by the scan slice thickness and the experience of radiologists, displaying differences in sensitivity and specificity[32]. Besides, it is not easy to see microfractures on the CT image[10], so "operator bias" is inevitable.

The CT value varies from substance to substance. With the development of digital orthopedics, digital statistics can be used for judgment when naked eye fail, making the results more convincing. Based on the finite element analysis model applied in DXA grayscale image, X-ray image finite element analysis (FLEXI)[33]. TBS does not represent the direct physical measurement of the bone microarchitecture, which is not related to bone mineral density (BMD) in human cadavers

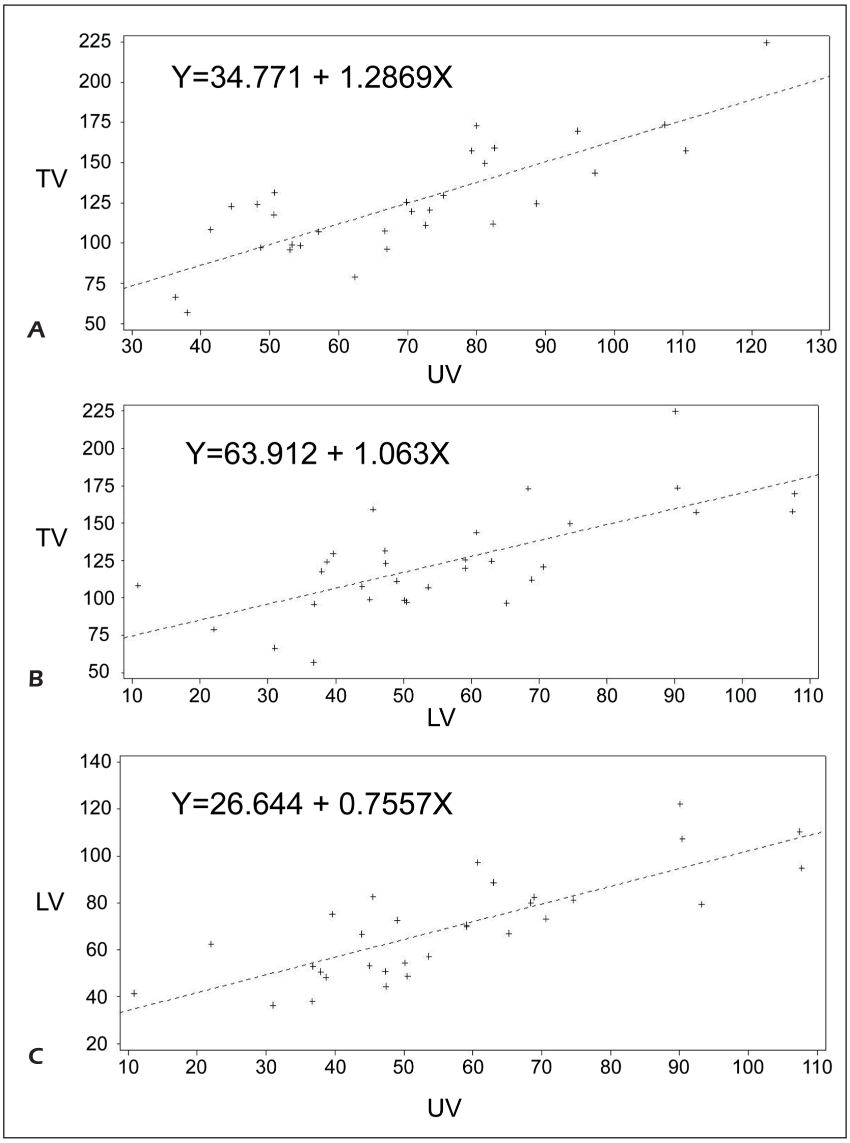

Figure 5. Regression analyses of HU values of vertebral bodies in fracture group. **A**, x (UV), y (TV). **B**, x (LV), y (TV). **C**, x (UV), y (LV).

but significantly correlated with the three-dimensional parameters of microstructure[34]. BMD converted according to the CT value, namely quantitative CT (QCT), can accurately reflect the degree of osteoporosis. Some scholars[35] evaluated the BMD of L1-3 using standard QCT first, then obtained L1-3 images through abdominal enhanced CT scan using sagittal reconstruction, and calculated the BMD in spiral CT scan according to the conversion equation of standard QCT and BMD. This measurement method can reflect the BMD of trabecular bone or cortical bone, respectively, avoid the influences of spinal degeneration, aortic calcification, etc., on BMD, and reflect the changes in bone mass more accurately and reliably, which is superior to DXA in the measurement of BMD[36]. The above steps of obtaining the BMD value are extremely cumbersome. The single photon emission computed tomography (SPECT)-CT developed in recent years can integrate the functional imaging of radioisotope scanning and structural imaging of CT. CT scan is performed simultaneously with SPECT, and the images acquired are integrated using software to obtain both functional metabolic information and anatomical morphological information, increasing the accuracy of OVF positioning and qualitative analysis. However, SPET-CT is relatively expensive and cannot be equipped in primary hospitals, thus limiting its application.

In this study, the conventional lumbar CT scan data were imported into three-dimensional reconstruction software to create the three-dimensional model and obtain the HU value of the model, and quantitative value of BMD was calculated using the HU value of trabecular bone in ROI, thus obtaining the BMD parameter quickly and accurately. BMD varies greatly among individuals, and it is needed to eliminate the confounding effects of bone morphology and shape before comparing BMD. Measurements of overall BMD and BMD of trabecular bone differ due to the effect of degenerative disease, and the relative values of overall and partial measurements may be different due to the age, gender and degree of degenerative disease. ROI of bone trabecula does not include sources of deformity, such as osteophytes and hypertrophic posterior structures. TBS is a recently-developed analysis tool, which is used to perform the novel grayscale texture measurement for lumbar DXA images, thereby obtaining information about the trabecular microstructure. TBS is independently associated with fracture risk, which is easily available and appropriate for risk assessment in the treatment of osteoporosis under ideal conditions[37]. Similarly, the thoracolumbar trabecular bone was selected as the site for BMD measurement. The HU value of CT three-dimensional reconstructed sagittal image is similar to TBS, the latter of which, however, is a parameter based on DXA image. Pothuaud et al[38] studied and found that TBS supplements the BMD in the diagnosis of osteoporosis, but vertebral bodies with any fractures and/or arthrosis were excluded in their study, so changes in BMD of fractured vertebral body were not clarified. Romagnoli et al[39] agreed that the higher score reflects the stronger and more fracture-resistant microarchitecture, and trabecular bone is more sensitive to changes in bone mass and BMD than cortical bone. Some studies have shown that trabecular bone plays a more important role than cortical bone in spinal load bearing and occurrence of compression fractures[40].

Lee et al[41] measured BMD of 128 patients with low back pain using dual-energy X-ray and QCT, analyzed the correlation between HU and T values and found a significant positive correlation between them. Moreover, they also made a conclusion that the HU value has a highly positive correlation with the BMD value. A large-scale study of trabecular bone density measurement of Matthew et al[42] manifested that the BMD value gradually declines from T1 to L3, which shows a good correlation with the standard BMD (BMD of L1-3). In this study, the measurements of non-fractured vertebral bodies displayed that the HU values of vertebral bodies were correlated and there were no differences in correlations. The measurements of HU values of fractured and adjacent vertebral bodies revealed that although the HU values had correlations in the comparisons between UV and TV and between LV and TV, their correlations had significant differences compared with the correlation between UV and LV, indicating that the HU value of TV is increased, displaying statistical significance.

The prediction of fractures via measurement of HU is affected by vertebral lesions. For example, the sensitivity is affected by osteoblastic diseases, such as metastatic or primary osteoblastic tumor, and the specificity is affected by diseases characterized by the loss of bone mass, such as osteoclast tumor, ischemic osteonecrosis or fat liquefaction, metabolic bone diseases (such as osteomalacia and renal osteodystrophy) and hyperparathyroidism. The above diseases all restrict the application of this measurement method. In this paper, the objects of study were the elderly osteoporotic patients with low trabecular bone density, and the increase in BMD caused by vertebral edema after fractures was relatively obvious or could be easily observed. However, the application of the measurement method in this study may be limited in young people with bone contusion or non-osteoporosis patients, because the increase in BMD caused by vertebral edema may not be significant. We did not conduct in-depth research on it and could not make conclusions, but it is seemingly meaningless, because young people seldom have MR contraindications, and conservative treatment is sufficient even in case of uncompressed fractures.

There were some limitations in this study, which might affect the applicability of conclusions. First, physicians already knew the responsible vertebral bodies due to the retrospective analysis, so there might be selection bias. Second, the sample size was relatively small, so more cases are needed for validation. Third, the errors among observers might cause deviations, which, however, will be reduced with the increase of sample size. Finally, an obvious shortcoming is the lack of prospective, double-blind, randomized and controlled tests. If more randomized controlled tests can be included and the sample size can be increased in the future research, the deficiencies in this paper can probably be made up for.

Conclusions

The measurement of HU value can help diagnose OVFs without collapse in imaging. In this study, it was proposed that changes in the HU value should be carefully observed during examination of OVFs under sagittal three-dimensional reconstructed images. When general conditions, including risk factors, clinical signs and symptoms and laboratory examinations, are highly consistent with the diagnosis of OVFs, this method should be considered. Although specific parameters remain to be further studied, it is of certain significance in the improvement of the accuracy of CT in detecting vertebral fractures, and the definitive diagnosis and appropriate treatment of osteoporotic patients who cannot undergo MR examination.

Conflict of Interests:

The authors declared no conflict of interest.

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