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ORIGINAL ARTICLE

Effect of compression fracture on trabecular bone score at lumbar spine

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Abstract

Summary Bone mineral density (BMD) may be increased due to vertebral compression fractures (VCF). Our study showed trabecular bone scores (TBS) was less affected than BMD by fractured vertebrae. The TBS of most compression fractures, including old and recent VCF with mild or moderate deformity and old VCF with severe deformity, could still be used in predicting fracture risk.

Introduction Trabecular bone score (TBS), a noninvasive tool estimating bone microarchitecture, provides complementary information to lumbar spine bone mineral density (BMD). Lumbar spine BMD might be increased due to both degenerative disease and vertebral compression fractures (VCF). Lumbar spine TBS has been confirmed not influenced by osteoarthrosis, but the effects of VCF are still not been well evaluated. This study aimed to investigate whether lumbar spine TBS was affected by fractured vertebrae.

Methods We studied postmenopausal women and men above 50 years old who underwent DXA between January 1, 2017, and May 31, 2019. By calculating the difference of BMD and TBS between L1 and the mean of L2-3, the study compared the difference of values between the control group and fracture group to determine the effects of fractured vertebrae on BMD and TBS.

Results A total of 377 participants were enrolled with 202 in the control group (157 females; age: 68.06 ± 6.47 years) and 175 in the fracture group (147 females; age: 71.71 ± 9.44 years). The mean BMD of the L1 vertebrae in the fracture group was significantly higher than that in the control group ($p < 0.0001$). There was no significant difference between the mean differences of TBS between L1 and the means of L2-3 vertebrae in the control group and the most compression fractures, including old and recent VCF with mild or moderate deformity and old VCF with severe deformity.

Conclusion Lumbar spine TBS, unlike BMD, is less affected by fractured vertebrae. The TBS of most compression fractures, including old and recent VCF with mild or moderate deformity and old VCF with severe deformity, could still be used in predicting fracture risk.

Keywords Bone mineral density · Compression fracture · Dual-energy X-ray absorptiometry · Osteoporosis · Trabecular bone scores

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Introduction

Osteoporosis is a systemic skeletal disease of poor bone quality, resulting in increased bone fragility and subsequently increased risk of fracture [1]. Both bone mass and microarchitecture contribute to bone strength [2]. Bone mineral density (BMD) of the lumbar spine, hip, and/or forearm, measured by dual-energy X-ray absorptiometry (DXA), is a widely accepted tool to evaluate the bone mass. According to WHO classification, a T-score equal to or less than 2.5 is defined as osteoporosis, necessitating treatment [3–5]. Furthermore, BMD is used in the fracture risk assessment tool (FRAX) to improve prediction of who would be at a higher risk of osteoporotic fracture [6].

Nowadays, trabecular bone score (TBS), a gray-level textural index derived from lumbar spine DXA images to the evaluation of bone microarchitecture, has added complementary value beyond bone mass [7, 8]. Quantitative computed tomography and magnetic resonance imaging, while allowing for measurement of bone microarchitecture, also remain impractical in daily practice owing to high costs and lack of availability [9]. A low TBS reflects poor bone quality despite normal bone density and increases the risk of osteoporotic fractures [10]. Because TBS is partly independent of CRF and BMD in fracture risk prediction, adding TBS values to compute FRAX can more accurately help calculate the probabilities of a fracture [11–14]. Moreover, the TBS-adjusted fracture risk performs better in subjects with secondary osteoporosis or a prior osteoporotic fracture [15–17].

However, lumbar area BMD might increase with increasing age due to degenerative changes, such as osteoarthrosis, aortic calcification, scoliosis, and vertebral compression fractures (VCF) [18, 19]. To minimize these artifacts, the official positions of the International Society of Clinical Densitometry (ISCD) suggest excluding fractured vertebrae and vertebra from the analysis that have more than one SD difference in BMD from the adjacent vertebra [20]. If only one or zero evaluable vertebra remains after excluding other vertebrae, the diagnosis should be based on different valid skeletal sites, such as hip and forearm. However, only AP lumbar spine TBS is available now. Several studies discussed the influences of the issues that result in useless BMD measurement, on spine TBS, and revealed that lumbar TBS, in contrast to BMD, is influenced minimally by lumbar spine degenerative disease [21–24]. In these studies, the possible effects of compression fracture on TBS were mentioned in only two studies to date [23, 24]. However, the different compositions of fracture lines and callus formation at the fractured bones may lead to different and inhomogeneous densities and the change of densities will subside after bone union [25, 26]. The influences of compression fractures in different healing status, before or after union, on TBS are not discussed clearly.

The purpose of this study was to evaluate the usability of TBS data in vertebral body compression fractures and discuss the influence in different healing status, before or after union. Therefore, we hypothesized that a VCF had less effect on lumbar TBS than BMD and might have different influences according to different healing status.

Materials and methods

This retrospective study was approved by the local institutional review board of our hospital. Because the images were de-identified and patients remained anonymous, the requirement to obtain informed consent was waived.

Study population

This is a retrospective study conducted in a single medical center. The study enrolled patients with L1 vertebral fracture and acceptable L2-3 vertebrae in the fracture group and patients with an acceptable L1-L3 vertebra in the control group. Eligible patients were postmenopausal women and men greater than 50 years of age, who underwent the DXA bone densitometry exam between January 1, 2017, and May 31, 2019 (n = 16,213). Lumbar spine BMD (L1 to L4) was measured by a DXA (Discovery Wi, Hologic, Bedford, MA, USA). TBS was retrospectively calculated using TBS iNsight software, Version 2.2 (Med-Imaps SASU, Merignac, France) based on the same DXA scan.

In all participants, exclusion criteria were based on clinical and image data: (1) BMI < 16 kg/m^2 or > 37 kg/m^2; (2) any VCF at L2, L3; (3) severe spine deformations, including ankylosis, scoliosis, or lordosis; (4) any vertebrae with hardware implantation, cementoplasty, osteosynthesis, or laminectomy in the lumbar spine. Participants were then divided into the control or fracture groups based on whether a compression fracture of L1 was identified. In the control group, patients also were excluded based on image data: (1) significant osteophytes or high-density lesions such as a bone island at L2, L3; (2) L2 or L3 vertebra with more than one SD difference in BMD from the adjacent vertebra. In the fracture group, patients also were excluded when: (1) significant osteophytes or high-density lesions such as a bone island at L1, L2, L3; (2) L1, L2 or L3 vertebra with more than one SD difference in BMD from the adjacent vertebra; (3) an intravertebral vacuum cleft (osteonecrosis) in fractured L1 vertebrae, because the air density and instability of the fracture may lead to unreliable data; (4) severe collapse (> 70%) at fractured L1 vertebrae, because severe vertebral deformity and significantly decreased height most likely make DXA measurement unsuitable or prone to error.

In the fracture group, these patients were divided into recent and old fracture groups. The recent fracture is subgrouped because these individuals may present with different densities in their various healing status. A recent fracture is

recognized by the presence of cortical breaking, impaction of trabeculae, or obvious callus formation on a lumbar DXA image or radiographs [27]. Subjects with a newly noted VCF within 1 year without clinical or radiographic evidence of bone union are also determined as having a recent fracture [28–30]. Otherwise, the VCF is designated as an old fracture. Unlike recent fractures, the old fracture is healed and not troubled by different healing processes. For evaluating the influence of decrease of vertebral height at the fractured vertebrae, the semi-quantitative grading is used at the recent and old fracture groups as mildly deformed (< 25% reduction of height), moderately deformed (25–40% reduction of height), and severely deformed (> 40% reduction of height) [31].

Data extraction

The BMD and T-scores of the lumbar spine were obtained from the DXA workstation and the TBS values from the iNsight workstation. The respective levels of the lumbar spine are determined according to the ISCD official position. The least significant changes (LSC) of lumbar spine BMD and TBS were also calculated according to the ISCD official position. The diagnosis of osteoporosis is based on the lowest BMD categories of the lumbar spine, total hip, and femoral neck: osteoporosis: T-score ≤ -2.5; low bone mass: $-1.0 >$ T-score > -2.5; normal bone density: T-score ≥ -1.0. The risk thresholds defined by the tertile of TBS were 1.230 and 1.310: degraded: TBS $\leq$ 1.230; partially degraded: 1.230 < TBS < 1.310; normal: TBS $\geq$ 1.310 [32]. The high fracture risk category by combination of BMD and TBS is assessed using osteoporosis, or low bone mass with degraded TBS. The 10-year probability of major osteoporotic fracture with BMD is assessed by the FRAX calculation tool and the probability adjusted for TBS is also assessed.

The means of L2-3 values were used to represent the baseline of lumbar spine BMD and TBS because there were either more or less degenerative changes of L4 vertebrae in patients with or without L1 VCF. To simplify the influence of fractured vertebrae, L4 vertebrae were not accounted into the calculation to avoid an abnormal increase in lumbar spine BMD due to degenerative changes. To evaluate the influence of L1 VCF, we compared the differences between BMD and TBS of L1 and the mean of L2-3 instead of the BMD and TBS values of L1 to minimalize the effects of possible confounding factors. The difference between BMD of L1 and the mean of L2-L3 (dif_BMD) and the difference between TBS of L1 and the mean of L2-L3 (dif_TBS) were calculated as

$$\text{dif\_BMD} = (\text{BMD of L1}) - (\text{mean BMD of L2}-3).$$

$$\text{dif\_TBS} = (\text{TBS of L1}) - (\text{mean TBS of L2}-3).$$

Statistical analysis

The categorical variables were presented as the frequency with percentage and were analyzed using Pearson's chi-square test or Fisher's exact test for the distribution difference between control and fracture groups. Continuous variables are displayed as the mean with standard deviation or the median with interquartile ranges. The difference of those continuous variables between controls and the fracture groups, after testing for normality, was compared using Student's t test or Wilcoxon rank-sum test for two-group analysis and analysis of variance or Kruskal-Wallis test for multiple-group analysis. Pearson's correlation approach was used to assess the possible linear association between L2-3 BMD and L2-3 TBS. A box plot was used to show the distribution difference between controls and different fracture groups among L1 and mean L2-3 BMD and TBS. Both SAS 9.4 for Windows (SAS Institute, Cary, NC, USA) and Stata 12 (Stata Corp., College Station, TX, USA) were used to perform all analyses and figures. Statistical significance was considered as $p < 0.05$. Considering the hypothesis for multiple comparisons, Bonferroni-corrected p values were estimated as 0.0125 (0.05/4). To avoid prevision problems, significant differences were considered when the differences between L1 and the mean of L2-3 of the fracture group from the control group were large than the LSC. Considering age as a confounding factor, the stratified analysis of different age groups (age < 70 and age $\geq$ 70 years old) was performed.

Results

Descriptive statistics for the study participants

A total of 377 participants were included in this study. The control group enrolled 202 participants (157 females, age: 68.06 ± 6.47 years old) with normal L1-L3 vertebrae and the other 175 patients (147 females, age: 71.71 ± 9.44 years old) with an L1 fracture were enrolled in the fracture group. Demographic, anthropometric characteristics and assessments of BMD and TBS of the study participants are depicted in Table 1. In the fracture group, there were 97 patients (74 females; age: 72.24 ± 9.58 years old) with old fractures and 78 patients (73 females; age: 71.06 ± 9.29 years old) with recent fractures. The mean height of the fracture group was significantly less than that of the control group (153.17 ± 7.78 cm vs. 156.32 ± 8.15 cm, $p = 0.0001$). The mean weight of the fracture group was higher than that of the control group (59.14 ± 10.96 kg vs. 56.87 ± 10.01 kg, $p = 0.0376$). The mean BMI of the fracture group was significantly higher than that of the control group (25.16 ± 3.98 kg/m^2 vs. 23.20 ± 3.29 kg/m^2, $p < 0.0001$). The respective LSCs were 0.022 g/cm^2

Table 1 Demographic, anthropometric characteristics of the study participants

	Control group (n = 202)	Fracture groups		
		Total VCF (n = 175)	Old VCF (n = 97)	Recent VCF (n = 78)
Female (n (%))	157 (77.72%)	147 (84.00%)	74 (76.29%)	73 (93.59%)
		p = 0.1505	p = 0.7705	p = 0.0015**
Age (year)				
Mean ± SD	68.06 ± 6.47	71.71 ± 9.44	72.24 ± 9.58	71.06 ± 9.29
Median	67.00	72.00	73.00	72.00
(Q1, Q3)	(63.00, 71.00)	(64.00, 79.00)	(64.00, 79.50)	(64.00, 78.00)
		p < 0.0001**	p < 0.0001**	p = 0.0051**
Height (cm)				
Mean ± SD	156.32 ± 8.15	153.17 ± 7.78	153.45 ± 7.98	152.82 ± 7.56
Median	155.0	152.00	153.10	151.00
(Q1,Q3)	(150.58, 160.48)	(148.00, 158.00)	(148.00, 158.00)	(148.00, 156.50)
		p = 0.0001**	p = 0.0039**	p = 0.0011**
Weight (kg)				
Mean ± SD	56.87 ± 10.01	59.14 ± 10.96	59.68 ± 11.89	58.48 ± 9.71
Median	55.80	58.00	58.00	58.00
(Q1,Q3)	(50.00, 64.00)	(52.00, 65.50)	(52.00, 68.00)	(51.65, 63.45)
		p = 0.0376*	p = 0.0307*	p = 0.2510
BMI (kg/m^2)				
Mean ± SD	23.20 ± 3.29	25.16 ± 3.98	25.27 ± 4.19	25.03 ± 3.72
Median	23.12	24.87	24.78	25.23
(Q1,Q3)	(21.21, 24.81)	(22.44, 27.56)	(22.44, 28.02)	(22.50, 27.09)
		p < 0.0001**	p < 0.0001**	p = 0.0002**
Genant grade				
Mild		17 (9.7%)	14 (14.4%)	3 (3.9%)
Moderate		66 (37.7%)	39 (40.2%)	27 (34.6%)
Severe		92 (52.6%)	44 (45.4%)	48 (61.5%)
				p = 0.0125*

VCF vertebral compression fracture

*p < 0.05 in comparison with the control group; **p < 0.0125 in comparison with the control group

for BMD and 0.019 for TBS. In the fracture group, 52.6% had severely deformed vertebrae and the recent fracture group had a significantly higher rate of severely deformed vertebrae than the old fracture group (61.5% vs. 45.4%, p = 0.0125).

Predicted events

The distribution of predicted events, including osteoporosis by BMD, degraded tertile by TBS, combination of BMD and TBS, and 10-year probability of major osteoporotic fracture by FRAX, of the control and fracture groups is presented in Table 2. The fracture group had significantly higher percentages of osteoporosis category by BMD (68.6% vs. 50.5%, p = 0.0004), degraded tertile by TBS (38.9% vs. 26.2%, p = 0.0093) and the combination of BMD and TBS (74.3% vs. 55.5%, p = 0.0001) than the control group. The fracture group had also significantly higher 10-year probabilities of major osteoporotic fracture with BMD (20.31 ± 9.32% vs. 11.16 ± 6.51%, p < 0.0001) and that adjusted for TBS (19.83 ± 9.65% vs. 11.19 ± 6.91%, p < 0.0001) than the control group.

L2-3 BMD and TBS reference data comparison

In this study, the baseline bone health condition of the patients was represented by the means of L2-3 BMD and TBS. The BMD of L1 and mean L2-3 and dif_BMD of the control and the fracture groups were presented in Table 3 and the TBS data in Table 4. The means of L2-3 BMD were moderately correlated to the means of L2-3 TBS in both the control (r = 0.625) and fracture (r = 0.614) groups. There was no significant difference at the means of L2-3 BMD between the control group and the fracture group (0.811 ± 0.145 g/cm^2 vs. 0.796 ±

Table 2 Distribution of the predicted events based on BMD, TBS, and combination of BMD and TBS and the 10-year probabilities of a major osteoporotic fracture of the study participants

Predicted events	Control group (n = 202)	Fracture groups		
		Total VCF (n = 175)	Old VCF (n = 97)	Recent VCF (n = 78)
Osteoporosis by BMD (n (%))a	102 (50.5%)	120 (68.6%)	66 (68.0%)	54 (69.2%)
		p = 0.0004**	p = 0.0042**	p = 0.0047**
Degraded tertile by TBS (n (%))b	53 (26.2%)	68 (38.9%)	37 (38.1%)	31 (39.7%)
		p = 0.0093**	p = 0.0386*	p = 0.0298*
Combination of BMD and TBS (n (%))c	112 (55.5%)	130 (74.3%)	73 (75.3%)	57 (73.1%)
		p = 0.0001**	p = 0.0010**	p = 0.0069**
FRAX with BMD (%)d				
Mean ± SD	11.16 ± 6.51	20.31 ± 9.32	19.98 ± 9.09	20.72 ± 9.64
Median	9.45	19.00	18.00	19.00
(Q1, Q3)	(6.50, 14.00)	(13.00, 27.00)	(14.00, 26.00)	(12.00, 29.00)
		p < 0.0001**	p < 0.0001**	p < 0.0001**
FRAX with BMD and TBS (%)e				
Mean ± SD	11.19 ± 6.91	19.83 ± 9.65	19.36 ± 9.40	20.41 ± 9.99
Median	10.00	18.00	18.00	18.50
(Q1, Q3)	(6.30, 15.00)	(13.00, 27.00)	(13.00, 25.00)	(12.00, 28.00)
		p < 0.0001**	p < 0.0001**	p < 0.0001**

VCF vertebral compression fracture, *BMD* bone mineral density, *TBS* trabecular bone score, *FRAX* Fracture Risk Assessment Tool

*p < 0.05 in comparison with the control group; **p < 0.0125 in comparison with the control group

[a] Predicted event: lowest BMD T-score of the lumbar spine, total hip, and femoral neck ≤ − 2.5

[b] Predicted event: TBS ≤ 1.230

[c] Predicted event: lowest BMD T-score of the lumbar spine, total hip, and femoral neck ≤ − 2.5, or − 2.5 < lowest BMD T-score < − 1 and TBS ≤ 1.230

[d] Predicted event: 10-year probability of major osteoporotic fracture with BMD

[e] Predicted event: 10-year probability of major osteoporotic fracture with BMD and adjusted for TBS

0.162 g/cm^2, p = 0.3277). In the fracture subgroups, the means of L2-3 BMD also presented no significant differences between the control group and the subgroups of old fracture and recent fracture (0.803 ± 0.145 g/cm^2, p = 0.6126; 0.788 ± 0.182 g/cm^2, p = 0.3099). Unlike the BMD result, the L2-3 vertebrae mean TBS of the fracture group (1.266 ± 0.099), including the old and recent fracture subgroups (1.267 ± 0.096, 1.266 ± 0.104), were significantly lower than that of the control group (1.300 ± 0.093; p = 0.0009, p = 0.0051, p = 0.0084, respectively).

Fracture-related BMD changes at L1

The mean BMD of the L1 vertebrae in the fracture group (0.878 ± 0.170 g/cm^2), including in the old and recent fracture subgroups (0.855 ± 0.158 g/cm^2, 0.906 ± 0.180 g/cm^2), were significantly higher than that in the control group (0.782 ± 0.132 g/cm^2; p < 0.0001, p = 0.0002, p < 0.0001, respectively) (Table 3). Figure 1 shows the mean BMD of L1-L4 in the control and fracture groups. The control group meets the natural trend of lumbar BMD and the L1 BMD is slightly lower than the mean L2-L3 BMD (dif_BMD = − 0.029 ± 0.045 g/cm^2). However, the L1 BMD in the fracture group is higher than the mean L2-L3 BMD (dif_BMD = 0.082 ± 0.102 g/cm^2) and the subgroup analysis shows similar findings (old fracture: dif_BMD = 0.052 ± 0.098 g/cm^2; recent fracture: dif_BMD = 0.118 ± 0.094 g/cm^2). The mean dif_BMD in the fracture group is significantly higher than the control group, including subgroups of old fracture and recent fracture, (all p < 0.0001) and the difference between the dif_BMD in the control and fracture groups is greater than the LSC of BMD (0.022 g/cm^2) (Table 3).

Fracture-related TBS changes at L1

There was no significant difference between the mean TBS of the L1 vertebrae in the control group (1.250 ± 0.116) and the fracture group (1.241 ± 0.125, p = 0.4207), whether the subgroup was an old fracture (1.229 ± 0.126, p = 0.1203) or recent fracture (1.256 ± 0.123, p = 0.7054) (Table 4). Figure 2 shows the natural upward trend of L1-L3 TBS in the control group and the fracture subgroups have a similar

Table 3 BMD of L1, mean of L2-3, and the difference between L1 and mean L2-3 in the control and fracture groups

BMD (g/cm^2)	Control group (n = 202)	Fracture group								
		Total VCF			Old VCF			Recent VCF		
		Total (n = 175)	Genant grade		Total (n = 97)	Genant grade		Total (n = 78)	Genant grade	
			Mild/moderate (n = 83)	Severe (n = 92)		Mild/moderate (n = 53)	Severe (n = 44)		Mild/moderate (n = 30)	Severe (n = 48)
L1	0.782 ± 0.132	0.878 ± 0.170	0.867 ± 0.168	0.888 ± 0.171	0.855 ± 0.158	0.857 ± 0.173	0.853 ± 0.140	0.906 ± 0.180	0.885 ± 0.161	0.919 ± 0.192
		p < 0.0001**	p < 0.0001**	p < 0.0001**	p = 0.0002**	p = 0.0046**	p = 0.0034**	p < 0.0001**	p = 0.0001**	p < 0.0001**
Mean L2-3	0.811 ± 0.145	0.796 ± 0.162	0.816 ± 0.171	0.778 ± 0.152	0.803 ± 0.145	0.830 ± 0.145	0.771 ± 0.110	0.788 ± 0.182	0.792 ± 0.183	0.785 ± 0.814
		p = 0.3277	p = 0.8150	p = 0.0690	p = 0.6126	p = 0.4290	p = 0.0321*	p = 0.3099	p = 0.5120	p = 0.3627
L1-(Mean L2-3)	− 0.029 ± 0.045	0.082 ± 0.102$^{\#}$	0.051 ± 0.085$^{\#}$	0.109 ± 0.108$^{\#}$	0.052 ± 0.098$^{\#}$	0.028 ± 0.083$^{\#}$	0.082 ± 0.108$^{\#}$	0.118 ± 0.094$^{\#}$	0.093 ± 0.073$^{\#}$	0.134 ± 0.103$^{\#}$
		p < 0.0001**	p < 0.0001**	p < 0.0001**	p < 0.0001**	p < 0.0001**	p < 0.0001**	p < 0.0001**	p < 0.0001**	p < 0.0001**

VCF vertebral compression fracture, *BMD* bone mineral density

*p < 0.05 in comparison with the control group; **p < 0.0125 in comparison with the control group

$^{\#}$ Difference between the [L1 – (Mean L2-L3)] BMD in the facture group and in the control group < least significant change (0.022 g/cm^2)

Table 4 TBS of L1-3, mean of L2-3, and the difference between L1 and mean L2-3 in the control and fracture groups

TBS	Control group (n = 202)	Fracture group									
		Total VCF			Old VCF			Recent VCF			
		Total (n = 175)	Genant grade		Total (n = 97)	Genant grade		Total (n = 78)	Genant grade		
			Mild/moderate (n = 83)	Severe (n = 92)		Mild/moderate (n = 53)	Severe (n = 44)		Mild/moderate (n = 30)	Severe (n = 48)	
L1	1.250 ± 0.116	1.241 ± 0.125	1.233 ± 0.119	1.248 ± 0.130	1.229 ± 0.126	1.228 ± 0.127	1.230 ± 0.125	1.256 ± 0.123	1.241 ± 0.104	1.265 ± 0.133	
		p = 0.4207	p = 0.2775	p = 0.7945	p = 0.1203	p = 0.2479	p = 0.2034	p = 0.7054	p = 0.7061	p = 0.4363	
Mean L2-3	1.300 ± 0.093	1.266 ± 0.099	1.278 ± 0.100	1.256 ± 0.098	1.267 ± 0.096	1.279 ± 0.105	1.253 ± 0.083	1.266 ± 0.104	1.278 ± 0.092	1.259 ± 0.112	
		p = 0.0009**	p = 0.0809	p = 0.0003**	p = 0.0051**	p = 0.1449	p = 0.0025*	p = 0.0084**	p = 0.2279	p = 0.0079**	
L1-(Mean L2-3)	− 0.050 ± 0.094	− 0.026 ± 0.115#	− 0.045 ± 0.091	− 0.008 ± 0.130#	− 0.038 ± 0.109	− 0.050 ± 0.089	− 0.023 ± 0.128#	− 0.011 ± 0.121#	− 0.037 ± 0.096	0.006 ± 0.133#	
		p = 0.0312*	p = 0.6736	p = 0.0083**	p = 0.4104	p = 0.9792	p = 0.1760	p = 0.0097**	p = 0.4640	p = 0.0070**	

VCF vertebral compression fracture, *TBS* trabecular bone score

*p < 0.05 in comparison with the control group; **p < 0.0125 in comparison with the control group

Difference between the [L1 − (Mean L2-L3)] TBS in the facture group and the control group < least significant change (0.019)

trend except for the recent fracture with severe deformity. In the subgroup of the recent fracture with severe deformity, the L1 TBS is higher than the mean L2-L3 TBS (dif_TBS = 0.006 ± 0.133). There is a significant difference between the dif_TBS in the recent fracture with severe deformity and the control group (0.006 ± 0.133 vs. − 0.026 ± 0.115, p = 0.0070) and the difference between these two groups is greater than the LSC of TBS (0.019). In the stratified analysis of different age groups (age < 70 and age ≥ 70 years) for the recent fracture with severe deformity, only the subgroup of age ≥ 70 years presented significant higher dif_TBS than the control group (0.032 ± 0.131 vs. − 0.035 ± 0.099, p = 0.0058) (Supplementary Tables). There was no significant difference between the dif_TBS in the control group (− 0.050 ± 0.094) and the other fracture subgroups, including recent fracture with mild/moderate deformity (− 0.037 ± 0.089, p = 0.4640), old fracture with mild/moderate deformity (− 0.050 ± 0.089, p = 0.9792), and old fracture with severe deformity (− 0.023 ± 0.128, p = 0.1760) (Table 4).

Discussion

This study showed that fractured vertebrae, except for the collapsed vertebrae subtype, have fewer effects on TBS than on BMD. Compression fractures and degenerative spondylopathy are common reasons resulting in abnormally increased BMD excluded in the calculation of lumbar area BMD and T-score. TBS is considered to be the index of bone microarchitecture and lower TBS indicates a higher risk of fracture. Previous studies suggest that TBS is not significantly affected by degenerative spondylopathy. However, the impact of compression fracture on TBS is not well-defined. In our study, the influences on TBS are negligible even in old compression fractures. Our findings suggest that the TBS of most compression fractures, including old and recent VCF with mild or moderate deformity and old VCF with severe deformity, could still be used in predicting fracture risk.

The study from Padlina I et al. of 1500 postmenopausal women also showed that TBS was not affected by lumbar spine degenerative disease (including VCF); however, it still did not give a definite suggestion about VCF due to its low case number (5%, 40 fractured vertebrae in 800 lumbar degenerative disease subjects) [23]. The TBS, with calculated local variations in gray levels, is theoretically less affected by bone area size and more suitable to represent internal heterogeneity, just like when previously used in lumbar osteoarthrosis [21–24]. Our data also confirmed that the lumbar spine TBS, unlike BMD, is less affected by VCF.

In our study, the BMD and TBS in the control group meet the natural trends that the BMD and TBS values of L1 vertebral bodies with acceptable morphology is supposed to be slightly lower than that of L2 and L3 vertebral bodies [22]. Due to

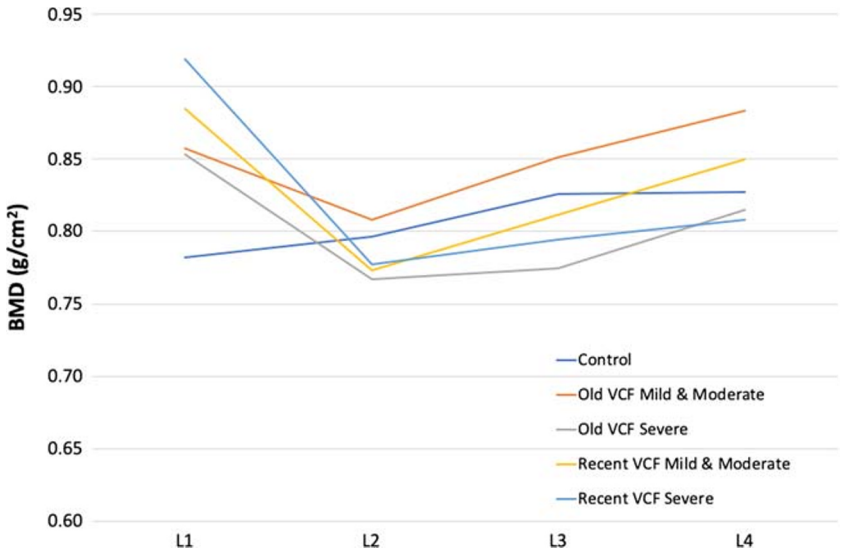

Fig. 1 Graph showing the mean bone mineral density (BMD) of L1 vertebrae was significantly higher in the recent vertebral compression fracture (VCF) and old VCF subgroups than in the control group

underlying differences of lumbar spine BMD and TBS, we used the differences between L1 and the means of L2-3 vertebrae to minimize the errors caused by inter-individual differences. All subgroups of the fracture group present significantly higher differences of BMD between L1 and the means of L2-3 vertebrae than the control group and the finding suggested exclusion of fractured vertebrae in BMD assessment. Not like the findings in BMD data, the differences of TBS between L1 and the means of L2-3 vertebrae in the VCF, including old and recent VCF, with mild or moderate deformity show no significant differences as compared with the control group. The findings suggest that mild and moderate deformities of fractured vertebrae do not result in a significant change of TBS and the TBS could still be used in the assessment of the fracture risk. However, in the VCF with severe deformity, a similar finding with unaffected TBS is noted only in the old VCF but not in the recent VCF, especially in the patients with age ≥ 70 years old. The findings may be due to different severity and healing stages of fractured vertebrae, such as a bone fracture, and these reparative and remodeling processes may have variable deterioration of trabeculae, bone-forming or resorbing timeframes, and changes in bone size [26]. Eventually, when old fractured vertebrae underwent restoration, the normal cortical structure would become relatively homogeneous without the fracture line [25, 33, 34]. These changes of fractured vertebrae may show that bone microarchitecture is a contributor to bone strength.

In our study, though the fracture group demonstrates a higher mean age, the mean BMD of L2-3 showed no significant difference between the control group and the fracture group. However, the fracture group still demonstrated a significantly lower lumbar spine TBS than the control group despite equivalent fracture risk based on BMD results. This finding also supports that TBS could be an effective measurement added on to BMD in better evaluating bone quality.

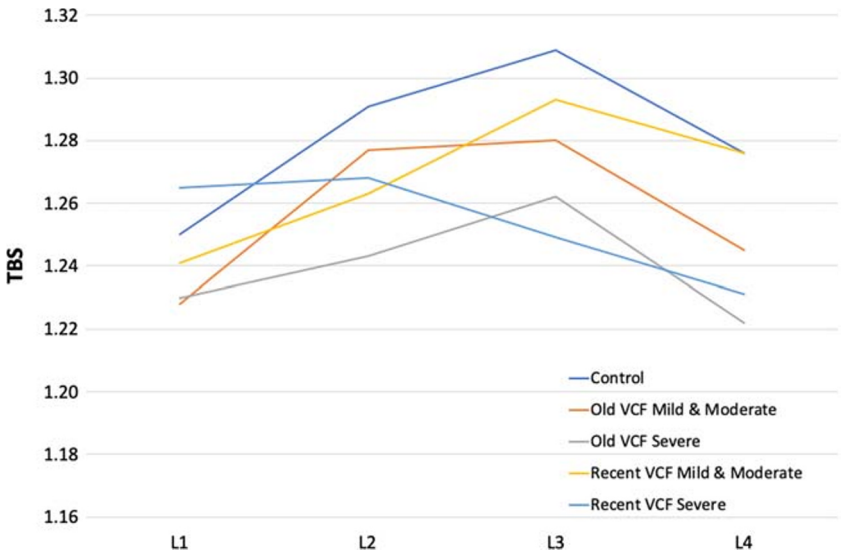

Fig. 2 Graph showing the mean trabecular bone score (TBS) of L1 vertebrae was lower in the control group and most fracture subgroups, including vertebral compression fracture (VCF) with mild or moderate deformity and old VCF with severe deformity

According to the lowest T-score, 68.6% of patients with VCF presented osteoporosis and the percentage is significantly higher than that in the control group (50.5%). Similar to the resulting osteoporosis diagnosis, the percentage of high fracture risk determined by the degraded range of TBS in the fracture group was significantly higher than the control group. If combining the diagnosis of osteoporosis by BMD and the degraded range by TBS, the prediction of high fracture risk will increase by 5.0%. Our finding suggests that TBS can provide more information in the bone strength that may affect the risk of fracture, similar to findings in previous studies.

Our study has several limitations. First, this is a single-center study using only one DXA machine (Hologic, Marlborough, MA). Second, the major population of our cases was Asian postmenopausal women. Hence, further research in premenopausal women, men, or even other ethnicities will be needed to support the hypothesis that the effects of VCF have a similar effect on TBS. Third, other potentially confounding conditions, such as body mass index (BMI), underlying illnesses effects on bone matrix, and previous or ongoing osteoporotic treatment, were not excluded or discussed in our study. Fourth, the types of VCF could not be classified because not all participants had lateral radiographs, vertebral fracture assessment (VFA) results, computed tomography, or magnetic resonance imaging. Fifth, only fractures at L1 vertebral bodies were evaluated in our study. The influences of different sites of vertebral fractures with or without degeneration changes need a larger study. The case population of collapsed fractures is small and further studies with larger population sizes are necessary.

In conclusion, lumbar spine TBS, unlike BMD, is less affected by fractured vertebrae. Most compression fractures, including VCF with mild or moderate deformity and old VCF with severe deformity, could be deemed available in lumbar spine TBS, at least in Asian. Nowadays, lumbar spine TBS, as corresponding to bone microarchitecture, in conjunction with BMD, or added in FRAX, provides better risk prediction in osteoporotic fracture [11–14]. After recognizing the valid data of lumbar VCF, lumbar spine TBS could be more accepted and flexibly applied in our routine daily clinical practice.

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Compliance with ethical standards

Conflicts of interest None.

Ethical approval The studies have been approved by the appropriate institutional and/or national research ethics committee and have been performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. This study was approved by the Institutional Review Board of Chi Mei medical center (IRB No: 10812002).

Informed consent For this type of study formal consent is not required.

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