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*Original Article*

# Could the Trabecular Bone Score Be a Complementary Tool for Evaluating Degenerative Lumbar Vertebrae?

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**Evaluating vertebral bone mass and quality in the elderly poses challenges due to degenerative changes. This study aims to elucidate the usefulness of the trabecular bone score (TBS) by examining the relationship between bone mineral density (BMD), TBS, and Hounsfield unit (HU) values. A retrospective analysis of 599 vertebrae from 152 patients (mean age 69.0 years; range 44-89; 74 males and 78 females) undergoing dual-energy X-ray absorptiometry (DXA) and CT scans was conducted. Vertebrae were categorized into three grades based on the degree of degeneration. The TBS was calculated from DXA images, and the HU value was measured by placing a region of interest on an axial image of the vertebral mid-body. One-way analysis of variance and Pearson's correlation tests were employed to investigate the relationship between BMD and TBS or HU values. While lumbar BMD significantly increased ($p < 0.01$) with degenerative changes, TBS and HU values showed no significant differences. The correlations between lumbar BMD and TBS values, and between BMD and HU values, were stronger without degenerative changes than with degenerative changes. Significantly different HU values were observed between the right and left sides of severely degenerated vertebrae. Severe degenerative changes, particularly those associated with sclerosis, may impact HU values. TBS exhibits greater potential than HU values as a complementary tool.**

**Key words:** trabecular bone score, computed tomography Hounsfield unit, lumbar degenerative change, radiodensity

Bone mineral density (BMD) of the lumbar spine and hip, measured using dual-energy X-ray absorptiometry (DXA), is widely used as the gold standard for the screening and diagnosis of osteoporosis and prediction of fragility fractures [1]. DXA is advantageous because of its low effective radiation dose and low cost. However, lumbar BMD in patients with lumbar degenerative changes tends to increase in response to factors such as osteophytes, bone sclerosis, disk space narrowing, and vertebral fractures [2,3]. Such elevation in lumbar BMD has the potential to lead to undiagnosed osteoporosis and underestimation of fracture risk [2].

Several methods have been proposed to address the overestimation of lumbar BMD [4-7]. One method involves utilizing the trabecular bone score (TBS), a texture parameter calculated using the gray-level variation of adjacent pixels derived from lumbar DXA scans [8]. An important advantage of TBS is its retrospective calculation from the same DXA scan image as BMD, eliminating the need for additional cost, time, or radi-

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ation exposure. A lower TBS is associated with a higher risk of vertebral fracture, independent of lumbar BMD [9]. Recent studies have investigated the relationship between lumbar BMD and TBS in patients with degenerative changes and demonstrated that TBS is less affected by degenerative spinal changes than lumbar BMD [4-6].

Another method involves utilizing Hounsfield unit (HU) values obtained from computed tomography (CT) images. Schreiber *et al.* initially described the method of assessing vertebral HU values by considering only trabecular bone while avoiding cortical bone and osteophytes [10]. The HU value directly reflects trabecular bone mass, which tends to decrease with age. Several studies have demonstrated that a low lumbar vertebral HU value is indicative of an increased risk of fracture [10-13]. A previous study proposed that HU measurement has the potential to serve as a complementary method for identifying osteoporosis in patients with degenerative lumbar changes [7]. Importantly, assessment of HU values is a clinically valuable approach for directly evaluating lumbar vertebral bone mass [7]. However, this method incurs additional costs and radiation exposure.

These previous studies revealed that TBS and HU values were either not significantly increased or were less affected, whereas the BMD was significantly increased in the presence of degenerative changes, suggesting the potential of TBS or HU measurement as alternative methods for assessing degenerated vertebrae [4-7]. Considering the lower cost and radiation exposure, TBS may be a more effective method than HU measurement. Moreover, in some clinical cases, sclerosis extends over the entire vertebral body or parts of it, and such severe degenerative changes may affect HU values because of the difficulty in avoiding sclerotic regions. However, to the best of our knowledge, no previous study has investigated the relationship between TBS and HU values. This study aims to evaluate the usefulness of TBS as a complementary method to limit reliance on BMD by evaluating the relationship among BMD, TBS, and HU values in patients with lumbar degenerative changes.

## Materials and Methods

We conducted a retrospective review of 152 patients hospitalized for spinal surgery at our hospital between May 1, 2019 and December 31, 2020 due to various spinal conditions. Patient characteristics, including age, sex, and body mass index (BMI) were documented. As inclusion criteria, patients were required to be > 40 years of age and to have undergone both DXA and lumbar CT within a month before spinal surgery as part of the routine preoperative planning. Patients were not enrolled if they met any of the following exclusion criteria: (1) a BMI outside the recommended range for accurate TBS calculation (BMI < 15 or > 37 kg/m$^2$); (2) a history of lumbar instrumentation surgery; (3) a vertebral bone tumor or metastatic lesion; or (4) ankylosing spondylitis, diffuse idiopathic skeletal hyperostosis, or lumbar ossification of the posterior longitudinal ligament.

All L1-L4 vertebrae were reviewed, excluding vertebrae with severe fractures (Grade 3, compression > 40%), as proposed by Genant *et al.* [14]. This exclusion was based on the difficulty in measuring the radiodensity of severely compressed vertebrae due to the substantial loss of vertebral body height. The study protocol was approved by the Institutional Review Board of the authors' affiliated institutions, and patients were given to the option to opt out of the study.

***BMD and TBS measurement.*** In this study, we quantified areal BMD (g/cm$^2$) (of L1-L4) using DXA scans in the posterior–anterior projection with the Horizon system (Hologic, Bedford, MA, USA). All DXA scans were performed and analyzed according to the manufacturer's recommendations by certified radiological technologists who were blinded to the clinical outcomes. Anthropomorphic data (height and weight) were measured at the time of the DXA scan. TBS was retrospectively calculated from the same DXA scan using the TBS iNsight software version 2.2 (Medimaps, Merignac, France). The TBS was derived from the experimental variograms of the 2D projection images. A variogram of the projected images, calculated as the sum of the squared gray-level differences between pixels at a specific distance, can be used to estimate a 3D structure from existing variations in 2D projected images [15]. TBS values were determined for all L1-L4 vertebrae, inclusive of those exhibiting degenerative changes.

***HU measurement.*** CT scans were acquired using a multidetector computed tomography system (Aquilion; Canon Medical Systems Corporation, Otawara, Japan) with a standard protocol (tube voltage: 120 kV), and a calibration phantom was employed to ensure accuracy.

Raw data were reconstructed from axial images with a slice thickness of 1.0 mm. We reviewed the CT scans to obtain the CT HU values by using the multiplanar reformat tools of a picture archiving and communications system (SYNAPSE VINCENT; Fujifilm Corporation, Tokyo). Following the method outlined by Schreiber *et al.* [10], the HU values were measured by placing the largest possible circular region of interest (ROI) markers on one axial image of the vertebral midbody through L1-L4, while avoiding cortical bone and heterogeneous areas (such as the posterior venous plexus and bone island), and then placing two circle-shaped ROIs on the right and left sides of the same axial image, as illustrated in Fig. 1. This process was performed in all patients by a single observer who was blinded to the BMD and TBS data. All L1-L4 vertebrae were reviewed as mentioned earlier, and HU values were measured by placing these three ROIs, followed by calculation of the difference in HU values between the right and left sides.

***Degenerative changes.*** Lumbar degenerative changes were evaluated retrospectively in the lateral view of the lumbar spine radiographs to obtain blinded BMD, TBS, and CT HU data using the summary grading system of the lumbar spine reported by Lane *et al.* [16]. This grading scale ranges from 0 to 2 according to the severity of osteophytes and joint narrowing (Table 1), and has been recommended as a clear and easy system to use [16]. We reviewed and graded all L1-L4 vertebrae according to this grading system.

***Statistical analyses.*** We performed one-way analysis of variance (ANOVA) to compare the BMD, TBS, and HU values of the lumbar spine (L1-L4) among the three groups with degenerative changes. Correlations among three parameters were determined using Pearson's correlation coefficients. The Kolmogorov–Smirnov test was used to test for normality. All the statistical analyses were performed using SPSS version 26 (IBM, Armonk, NY, USA). Values of $p < 0.05$ were considered to indicate statistical significance.

## Results

The characteristics of the study participants are summarized in Table 2. The mean age of the patients was

**Table 1** Radiographic summary grading of lumbar degeneration on lateral views described by Lane *et al.* [16]

| Score | Joint space narrowing | Osteophytes anterior and posterior | Sclerosis |
|---|---|---|---|
| 0 | None | None | None |
| 1 | Mild | Small | Present |
| 2 | Moderate | Moderate | – |
| 3 | Severe (or complete loss of joint space) | Large | – |

Based on these features, an overall grading was given from 0 to 2:
Grade 0 = Normal (score 0 for narrowing and osteophytes)
Grade 1 = Mild (1) narrowing or small (1) osteophytes
Grade 2 = Moderate-severe (2-3) narrowing and/or moderate-large (2-3) osteophytes

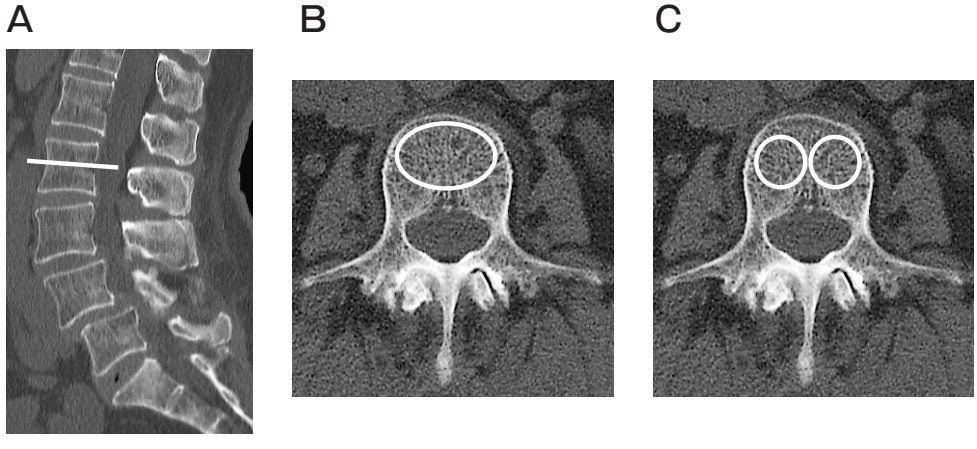


**Fig. 1** (**A**) The HU values were measured using a single axial image of the vertebral midbody. The measurements were conducted by placing (**B**) one oval-shaped region of interest (ROI) and (**C**) two circular ROIs on the right and left sides using an axial image of the vertebral mid-body while avoiding cortical bone and heterogeneous areas.

69.0 ± 10.6 years (range: 44-89) and there were 74 men and 78 women.

***Prevalence of summary grades of lumbar degenerative change.*** In total, we reviewed 608 vertebrae, and 9 vertebrae were excluded because of the presence of severe fractures (grade 3, as proposed by Genant's classification). The remaining 599 vertebrae were classified as grade 0, 1, or 2 based on the degree of degenerative change. A total of 200 vertebrae were classified as grade 0, 190 as grade 1, and 208 as grade 2.

***Lumbar BMD, TBS, and HU values by lumbar spine grade.*** The BMD, TBS, and HU values for L1-L4 for each of the three lumbar spine grades described above are presented in Table 3. Among L1-L4, lumbar BMD significantly increased with increasing grade ($p < 0.01$), but there were no significant differences in HU values or TBS among the three grades. Lumbar BMD at each level of L1-L4 exhibited a significant increase with the grade.

The HU values, acquired through a modified version of Schreiber's method, are presented in Table 4. The difference in HU values between the right and left sides exhibited a significant increase with the grade, despite there being no significant difference in the HU values obtained by placing the largest oval-shaped ROI.

***Correlation between the TBS or HU values and lumbar BMD.*** Positive correlations were observed between BMD and the corresponding HU values or TBS for each grade. Scatter plots illustrating the relationship between BMD and TBS or HU values are shown in Fig. 2. The correlation between BMD and TBS was moderate in grades 1 and 2 but strong in grade 0 (correlation coefficients at grades 0-2: 0.735, 0.659, and 0.520, respectively). Similarly, the correlation between BMD and HU values was moderate in grade 1 or 2 (correlation coefficients for grade 1 or 2: 0.694 or 0.626, respectively) but strong in grade 0 (correlation coefficient: 0.715). Notably, the correlation coefficients for the relationships between BMD and TBS or HU values were higher for grade 0 than for all grades combined. The correlation between the TBS and HU values was strong for grades 0-2 (correlation coefficients for grades 0-2 were 0.765, 0.773, and 0.702, respectively).

**Table 2** Characteristics of patients ($N = 152$)

| | Mean ± SD |
|---|---|
| Age (years) | 69.0 ± 10.6 |
| Weight (Kg) | 62.0 ± 14.3 |
| Height (cm) | 159.1 ± 10.7 |
| BMI (kg/m$^2$) | 24.5 ± 4.6 |
| Lumbar BMD L1-4 (g/cm$^2$) | 1.05 ± 0.30 |
| TBS L1-4 | 1.29 ± 0.09 |
| CT HU (HU) | 123.82 ± 49.44 |

BMI, body mass index; BMD, bone mineral density; TBS, trabecular bone score.

**Table 3** Results of values of lumbar BMD measured by DXA, TBS and CT radiodensity according to the degree of degenerative changes, evaluated by summary grading reported by Lane *et al*. [16]

| | Grade 0 | Grade 1 | Grade 2 | *P*-value (between groups) |
|---|---|---|---|---|
| Lumbar BMD (g/cm$^2$) L1-4 | 0.880 ± 0.175 | 1.048 ± 0.383 | 1.189 ± 0.264 | < 0.01 |
| TBS (unitless) L1-4 | 1.267 ± 0.115 | 1.268 ± 0.111 | 1.281 ± 0.113 | *NS* |
| CT radiodensity (HU) L1-4 | 117.3 ± 46.3 | 115.5 ± 56.1 | 119.8 ± 48.1 | *NS* |

BMD, bone mineral density; TBS, trabecular bone score; HU, Hounsfield unit.

**Table 4** Value of CT radiodensity (whole vertebral body and the gap between right and left side) according to the degree of degenerative changes

| | Grade 0 | Grade 1 | Grade 2 | |
|---|---|---|---|---|
| CT HU (oval-shaped) | 110.0 ± 48.2 | 115.5 ± 56.1 | 118.39 ± 56.1 | *NS* |
| CT HU (gap RL*) | 4.0 ± 3.4 | 8.2 ± 6.1 | 18.2 ± 14.5 | $P < 0.05$ |

*gap, RL the gap between right and left side.

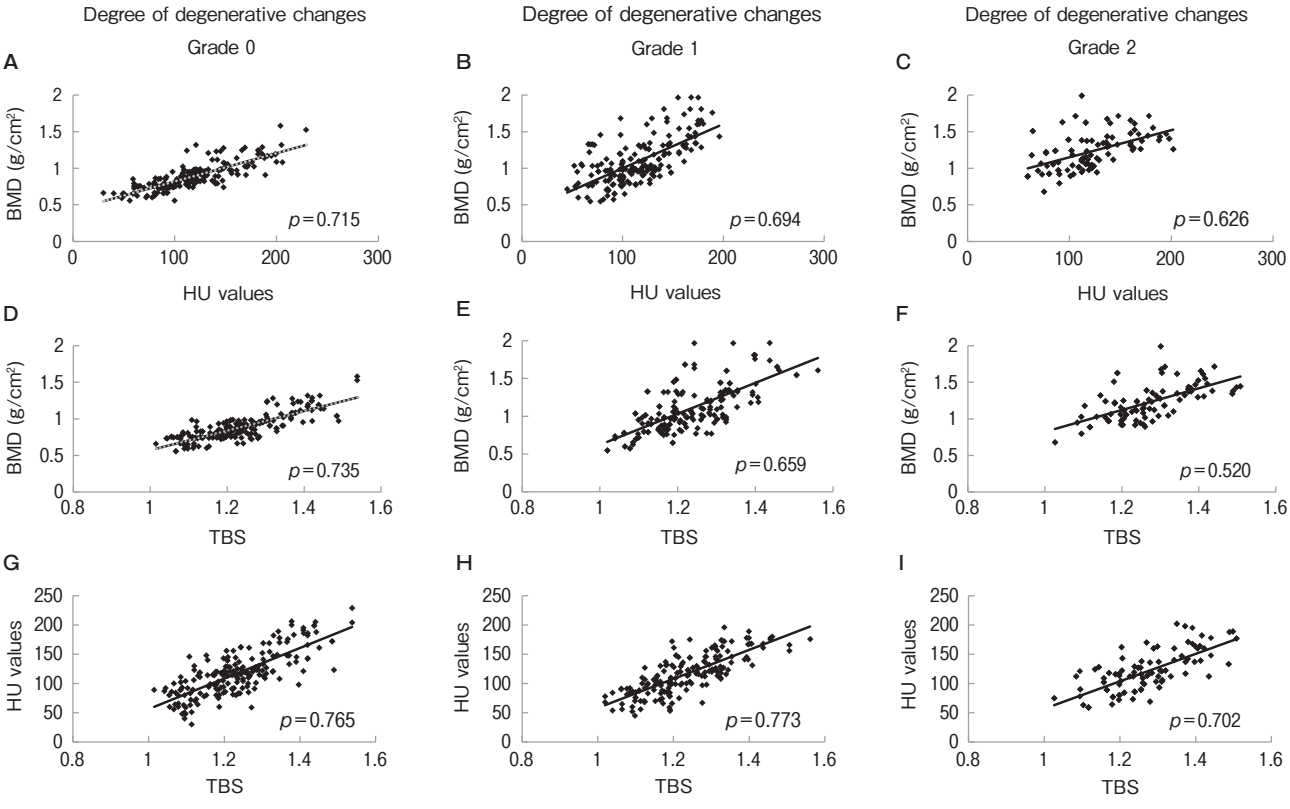


Fig. 2 Scatter plots demonstrating the correlations between BMD and TBS, as well as HU values across different grades of lumbar degenerative changes. Linear regression lines are included to highlight trends. (**A-C**): Correlations between BMD and HU values for lumbar degenerative grades 0, 1, and 2, respectively. The correlation coefficients ($\rho$) were 0.715, 0.694, and 0.626, indicating a moderate to strong correlation. (**D-F**): Correlations between BMD and TBS for lumbar degenerative grades 0, 1, and 2, respectively. The correlation coefficients ($\rho$) were 0.735, 0.659, and 0.520, indicating a strong correlation in grade 0 and moderate correlations in grades 1 and 2. (**G-I**): Correlations between HU values and TBS for lumbar degenerative grades 0, 1, and 2, respectively. The correlation coefficients ($\rho$) were 0.765, 0.773, and 0.702, indicating strong correlations across all grades.

## Discussion

This study is the first to concurrently evaluate the relationships among BMD, TBS, and HU value within the same samples, with consideration for the extent of lumbar degenerative changes. Our findings revealed that, while lumbar BMD of L1-L4, assessed through DXA, increased with the severity of lumbar degenerative changes, the corresponding TBS and HU values, measured using the modified Schreiber's method, exhibited no differences among the three groups. These results align with previous studies [4-7]. Our investigation revealed that both TBS and HU values were less affected by the presence of lumbar degenerative changes compared to lumbar BMD measured using DXA scans. This result confirms those of previous studies that used TBS or HU measurement to resolve the limitations of BMD. Moreover, our findings suggest that TBS may be less susceptible to degenerative changes than HU values, positioning it as a preferred choice for assessing vertebral bone strength in patients with degenerative changes.

Although DXA scans are standard tools for diagnosing osteoporosis or osteopenia and predicting the risk of osteoporotic fractures, it has been reported in previous studies that lumbar spine BMD measured using DXA scans increases in the presence of lumbar degenerative changes [2]. Consistent with these findings, in our present study we observed an increase in lumbar BMD with the severity of degenerative changes. To address this limitation of lumbar BMD, we focused on two complementary methods, TBS and HU measurement, for assessing lumbar vertebrae with degenerative

changes. Several studies have reported that TBS is either not affected or less affected by lumbar degenerative changes, in contrast to lumbar BMD, which tends to increase with such changes [3-6]. These results can be explained by the TBS calculation method, which uses local variations in gray levels rather than the absolute values used in BMD determination [8]. In our study, the TBS was not significantly increased in any of the four vertebrae studied, *i.e.*, L1-L4. This result suggests that the TBS is not affected or is less affected by lumbar degenerative changes than BMD. The advantage of using HU values obtained from lumbar CT images lies in the direct representation of vertebral bone mass achieved by manually placing the ROI on trabecular bone of plane CT images. This approach avoids any impact from sclerosis and osteophytes caused by degenerative changes. Significant correlations have been observed between HU values and BMD, age, and T-score [11], with lower HU values in patients with osteoporosis and vertebral fractures [10, 12]. Notably, these studies excluded patients with lumbar degenerative changes. Zou *et al.* reported that, while lumbar BMD was higher in patients with degenerative changes, there was no significant difference in HU values between patients with and without degenerative changes [7]. In our study, HU values obtained through the modified Schreiber's method were not significantly increased in any of the four vertebrae studied, *i.e.*, L1-L4. This result further implies that HU values are not influenced or are less influenced by lumbar degenerative changes than BMD.

The correlation between the TBS and HU values remained strong across all grades, with a slight weakening in grade 2 compared to other grades. This phenomenon may be attributed to the effects of degenerative changes (particularly vertebral body sclerosis). The increasing difference in HU values between the right and left sides with increasing grade demonstrated that the uneven distribution of HU values resulted from the localization of sclerosis in the vertebral body. Sclerotic vertebral changes are often observed on the right or left side. Therefore, our modified Schreiber's method has limited use in the assessment of vertebrae in the presence of severe degenerative changes. HU values can be measured while avoiding the cortical bone and osteophytes of the vertebral body, making the modified method an effective one for directly assessing vertebral bone mass. Given its strong correlation with HU values, TBS is also considered a valuable tool for estimating vertebral bone mass. Furthermore, TBS offers advantages over HU values, including lower cost and reduced radiation exposure. Moreover, in cases of severe vertebral degeneration, the occurrence of differences in CT values between the left and right sides suggests that HU values may be somewhat affected by degeneration. This further supports the potential utility of TBS in the presence of degenerative changes.

Our study has some limitations. First, because the sample size was not large, we analyzed all vertebrae without considering age or sex; the vertebrae of men and women of all ages were assessed, which may have affected the BMD, TBS, and HU values. Second, although vascular calcification and obesity may also affect the aforementioned factors, they were not analyzed in this study. Third, the data used in this study were obtained preoperatively from patients who had undergone spinal surgery and not from the general population. Our results should be further verified in the general population by using a larger sample size. Fourth, our study included patients with ossification of the posterior longitudinal ligament in the cervical spine. Some studies have indicated an increase in BMD in patients with ossification of the posterior longitudinal ligament [18-20]. Although we did not assess TBS and HU values in patients with ossification of the posterior longitudinal ligament, the presence of this condition could have influenced our data. Finally, we focused solely on radiological parameters such as BMD, TBS, and HU values, and were unable to establish a direct relationship between fracture risk and these parameters. To confirm the greater effectiveness of TBS compared to BMD for the prediction of fragility fractures in patients with lumbar degenerative changes, a long-term, longitudinal cohort study is needed. By incorporating not only BMD but also TBS and HU values measured by the modified Schreiber's method, such an extended investigation could elucidate the risk factors contributing to the incidence of vertebral deformities, including degenerative changes or fractures.

In conclusion, to the best of our knowledge, this is the first study to assess the relationships between TBS or HU values and lumbar BMD simultaneously in the same patient cohort. While lumbar BMD significantly increases with lumbar degenerative changes, it has the potential to lead to an underestimation of bone fragility and fracture risk; TBS and HU values measured by the

modified Schreiber's method are less affected. TBS shows a strong correlation with HU values, which directly measure vertebral bone mass, and it also has the advantages of lower cost and reduced radiation exposure. Furthermore, given the possibility that HU values may be influenced by degeneration, TBS is a potential complementary tool for assessing vertebral bone mass and its quality in the presence of severe degenerative changes.

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## References

1. Morgan SL and Prater GL: Quality in dual-energy X-ray absorptiometry scans. Bone (2017) 104: 13–28.
2. Muraki S, Yamamoto S, Ishibashi H, Horiuchi T, Hosoi T, Orimo H and Nakamura K: Impact of degenerative spinal diseases on bone mineral density of the lumbar spine in elderly women. Osteoporos Int (2004) 15: 724–728.
3. Pappou IP, Girardi FP, Sandhu HS, Parvataneni HK, Cammisa FP, Schneider R, Frelinghuysen P and Lane JM: Discordantly high spinal bone mineral density values in patients with adult lumbar scoliosis. Spine (2006) 31: 1614–1620.
4. Kolta S, Briot K, Fechtenbaum J, Paternotte S, Armbrecht G, Felsenberg D, Gluer CC, Eastell R and Roux C: TBS result is not affected by lumbar spine osteoarthritis. Osteoporos Int (2014) 25: 1759–1764.
5. Padlina I, Gonzalez-Rodriguez E, Hans D, Metzger M, Stoll D, Aubry-Rozier B and Lamy O: The lumbar spine age-related degenerative disease influences the BMD not the TBS: the Osteolaus cohort. Osteoporos Int (2017) 28: 909–915.
6. Anderson KB, Holloway-Kew KL, Mohebbi M, Kotowicz MA, Hans D and Pasco JA: Is trabecular bone score less affected by degenerative-changes at the spine than lumbar spine BMD? Arch Osteoporos (2018) 13: 127–136.
7. Zou D, Li W, Deng C, Du G and Xu N: The use of CT Hounsfield unit values to identify the undiagnosed spinal osteoporosis in patients with lumbar degenerative diseases. Eur Spine J (2019) 28: 1758–1766.
8. Pothuaud L, Barthe N, Krieg MA, Mehsen N, Carceller P and Hans D: Evaluation of the potential use of trabecular bone score to complement bone mineral density in the diagnosis of osteoporosis: a preliminary spine BMD-matched, case-control study. J Clin Densitom (2009) 12: 170–176.
9. Iki M, Tamaki J, Kadowaki E, Sato Y, Dongmei N, Winzenrieth R, Kagamimori S, Kagawa Y and Yoneshima H: Trabecular bone score (TBS) predicts vertebral fractures in Japanese women over 10 years independently of bone density and prevalent vertebral deformity: the Japanese population-based osteoporosis (JPOS) cohort study. J Bone Miner Res (2014) 29: 399–407.
10. Schreiber JJ, Anderson PA, Rosas HG, Buchholz AL and Au AG: Hounsfield units for assessing bone mineral density and strength: a tool for osteoporosis management. J Bone Joint Surg Am (2011) 93: 1057–1063.
11. Pickhardt PJ, Pooler BD, Lauder T, del Rio AM, Bruce RJ and Binkley N: Opportunistic screening for osteoporosis using abdominal computed tomography scans obtained for other indications. Ann Intern Med (2013) 158: 588–595.
12. Li YL, Wong KH, Law MW, Fang BX, Lau VW, Vardhanabuti VV, Lee VKH, Cheng AKC, Ho WY and Lam WWM: Opportunistic screening for osteoporosis in abdominal computed tomography for Chinese population. Arch Osteoporos (2018) 13: 76–83.
13. Lee SJ, Graffy PM, Zea RD, Ziemlewicz TJ and Pickhardt PJ: Future osteoporotic fracture risk related to lumbar vertebral trabecular attenuation measured at routine body CT. J Bone Miner Res (2018) 43: 1010–1015.
14. Genant HK, Wu CY, van Kuijk C and Nevitt MC: Vertebral fracture assessment using a semiquantitative technique: J Bone Miner Res (1993) 8: 1137–1148.
15. Silva BC, Leslie WD, Resch H, Lamy O, Lesnyak O, Binkley N, McCloskey EV, Kanis JA and Bilezikian JP: Trabecular Bone Score: A Noninvasive Analytical Method Based Upon the DXA Image. J Bone Miner Res (2014) 29: 518–530.
16. Lane NE, Nevitt MC, Genant HK and Hochberg MC: Reliability of new indices of radiographic osteoarthritis of the hand and hip and lumbar disc degeneration. J Rheumatol (1993) 20: 1911–1918.
17. Kettler A and Wilke HJ: Review of existing grading systems for cervical or lumbar disc and facet joint degeneration. Eur Spine J (2006) 15: 705–718.
18. Yamauchi T, Taketomi E, Matsunaga S and Sakou T: Bone mineral density in patients with ossification of the posterior longitudinal ligament in the cervical spine. J Bone Miner Metab (1999) 17: 296–300.
19. Hirai N, Ikata T, Murase M, Morita T and Katoh S: Bone mineral density of the lumbar spine in patients with ossification of the posterior longitudinal ligament of the cervical spine. J Spinal Disord (1999) 8: 337–371.
20. Sohn S and Chung CK: Increased bone mineral density and decreased prevalence of osteoporosis in cervical ossification of the posterior longitudinal ligament: case-control study. Calcif Tissue Int (2013): 28–34.