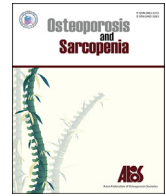




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Original article

The correlation between bone mineral density/trabecular bone score and body mass index, height, and weight

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ABSTRACT

Objectives: This study investigated the correlation between bone mineral density (BMD)/trabecular bone score (TBS) and body mass index (BMI), height and weight in Korean adults.**Methods:** We enrolled 2555 female participants in their 20s–80s and 1631 male participants in their 20s–70s. Participants with history of previous vertebral surgeries or current vertebral diseases were excluded. Female and male participants were divided into osteoporosis group (n = 136 and n = 31, respectively), osteopenia group (n = 822 and n = 460, respectively), and normal group (n = 1596 and n = 1140, respectively) based on their BMD T-score. Dual-energy X-ray absorptiometry image analysis and linear regression analysis were conducted on each participant in each group to determine the P-value and the correlation between BMD T-score/TBS T-score and BMI, weight, and height.**Results:** We found a significant correlation between BMI and TBS in both male and female participants. In the male participants, the correlation coefficient increased progressively from the normal group to the osteoporosis group. In the female group, we observed a significant positive correlation between height and TBS, and in the male group a significant negative correlation between weight and TBS was observed.**Conclusions:** BMI and weight are closely correlated to body fat content. BMD was positively correlated to BMI and weight, while TBS was negatively correlated to BMI and weight. Therefore, although BMI causes an increase in BMD, it appears to be negatively affecting bone quality.© 2017 The Korean Society of Osteoporosis. Publishing services by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

1. Introduction

Osteoporosis is a chronic skeletal disease characterized by a reduction in bone density that increases fracture risk. In fact, the most common complication of osteoporosis is bone fracture [1,2], and world widely, it is estimated that there are 9 million cases of osteoporosis-related fractures reported every year [3]. Currently, osteoporosis is diagnosed using dual-energy X-ray absorptiometry (DXA) which measures bone mineral density (BMD) [1]. However, many studies have claimed that BMD has limited value as an

independent predictor of fracture risk [4–7]. The most likely explanation for this is that fracture risk is not only influenced by the amount of bone mineral as measured by BMD, but also by the 3-dimensional (3D) microarchitecture of the bone tissue [8]. In order to overcome the limitations of BMD, the trabecular bone score (TBS) was developed to determine the bone's microarchitecture [9–11].

TBS is a texture parameter that quantifies the changes in pixel gray-level in DXA images [10,11]. A high TBS indicates that the trabecular bone microarchitecture has high connectivity, greater number of trabeculae and low trabecular spacing, and therefore high resistance to fracture. On the other hand, a low TBS indicates that the bone microarchitecture is prone to fracture [11,12]. Since the importance of TBS has been clinically recognized, many studies have been conducted and are ongoing with the aim of investigating this parameter. Several retrospective cross-sectional studies have

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reported that TBS could discern fracture in patients with similar effectiveness as BMD and some studies also reported that better results were observed when TBS and BMD were used together [12–16]. In addition, it was confirmed that TBS could predict fractures of the lumbar spine (LS) as effectively as areal BMD (aBMD) [17–19]. A cohort study, which conducted experiments on female subjects above 50 years of age for an average of 4.7 years in Manitoba, Canada, reported that individuals with low TBS were prone to fracture regardless of the aBMD score [18]. At present, ethnic differences in TBS are being evaluated with one study aimed at investigating differences in TBS between Caucasians and African Americans [19] and another study between European Caucasian males and females [20].

Most of the studies on TBS so far have solely been conducted on Caucasian subjects. The few studies conducted on Asian subjects [21–24] were limited by the fact that they enrolled only male participants or postmenstrual women. In addition, majority of the studies merely emphasize on age and fracture. As of now, there is no study that highlights the relationship between TBS/BMD and BMI, height and weight in Korean population, which is one of the most rapidly aging population in Asia.

TBS and BMD differ in units, but they are converted into T-scores, which allows reliable comparison. This study was conducted on 4186 male and female participants of all ages divided into three groups (osteoporosis, osteopenia, and normal groups) and the changes in TBS and BMD, which was later converted into T-score according to body mass index (BMI), height, and weight, were investigated. The goal of this study was to evaluate the correlation between TBS and physiological variables including BMI, height and weight, and to identify whether these correlations differ from those between BMD and the physiological variables stated previously.

2. Methods

2.1. Subjects

This study was conducted on 4186 subjects (2555 female and 1631 male subjects) who had DXA (Hologic Inc., Waltham, MA, USA) images taken at Dongguk University Hospital between August 2012 and July 2015. The coefficients of variation for these measurements were <1.5%. We enrolled the subjects from their health examinations results. Bone density was quantified based on T-score and used to categorize the subjects into three groups, e.g., osteoporosis group (T-score ≤ -2.5), osteopenia group ($2.5 < \text{T-score} \leq -1$) and normal group (T-score > -1). The lowest T-scores from L1–L4 were used to categorize females into an osteoporosis group (n = 136), osteopenia group (n = 822) and normal group (n = 1597). Males were also divided into an osteoporosis group (n = 31), osteopenia group (n = 460) and normal group (n = 1140). The study protocol was approved by the Institutional Review Board of Dongguk University Hospital (FWA-#00015287) and all subjects provided written informed consent prior to participation (Table 1).

2.2. TBS calculations

TBS is a DXA-derived parameter that is based on the gray-level analysis of DXA images and which measures the micro-architecture or bone tissue distribution of the trabecular bone. Although large spaces within the trabecular bone are considered to be bad in terms of bone density, TBS concludes that the bone's microarchitecture is good if the distribution of spaces is uniform.

In this study, it was observed that 2 participants of the same age (70 years) had TBS of -2.1 and 0.4 with an 84% difference (Fig. 1B, D) although their BMD T-scores were only different by 17% (-2.3 and -1.9) (Fig. 1A, C). This observation indicates that although bone

Table 1
Demographic data of the participants.

Variable	Mean \pm SD	Median (range)
Female (n = 2555)		
Age, yr	44.33 \pm 11.24	41 (20–84)
BMI, kg/m ²	22.25 \pm 3.41	21.63 (15.03–44.14)
Height, cm	159.49 \pm 5.62	159.6 (140.9–178)
Weight, kg	56.58 \pm 8.92	55 (39–113)
BMD T-score	-0.23 ± 1.1	$-0.3 (-4.22 \text{ to } 3.15)$
TBS T-score	0.26 ± 1.02	$0.4 (-3.8 \text{ to } 3)$
Male (n = 1631)		
Age, yr	40.08 \pm 6.16	38 (25–77)
BMI, kg/m ²	24.43 \pm 3.06	24.25 (15.38–38.53)
Height, cm	172.85 \pm 5.59	173 (151–190.5)
Weight, kg	73.07 \pm 10.31	72.9 (45–118)
BMD T-score	0.007 ± 1.028	$0 (-3.97 \text{ to } 2.97)$
TBS T-score	0.601 ± 0.65	$0.6 (-2.4 \text{ to } 3)$

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

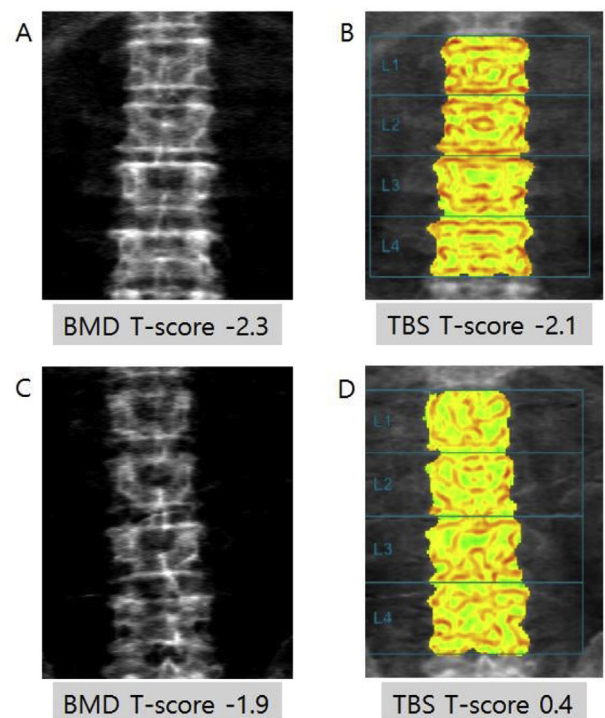


Fig. 1. (A–D) Images of a dual-energy X-ray absorptiometry analysis in two 70-year-old Korean women. It was observed that 2 participants had similar bone mineral density (BMD) but different trabecular bone score (TBS).

densities might be similar, TBS can vary depending on the micro-architecture and distribution of bone tissue.

TBS is correlated with bone volume (BV), total volume (TV), trabecular bone thickness, trabecular bone spacing, trabecular bone number and connectivity density, and these variables are used to calculate TBS [11,12].

In this study, LS TBS T-scores were calculated using the information retrieved from DXA images through TBS iNsite software ver. 2.1.1 (Med-Imaps, Bordeaux, France).

2.3. Statistical analysis

All statistical analyses were conducted using OriginPro 2015 (OriginLab Corp., Northampton, MA, USA). The participants were divided based on gender and further subdivided into osteoporosis,

osteopenia and normal groups. In each group, a regression analysis was conducted between each variable (age, BMI, height, and weight) and BMD/TBS T-scores. In each regression analysis, the correlation between variables was significant if the P-value was less than 0.05.

3. Results

Correlations between BMD/TBS T-scores and variables (BMI, height, and weight) were investigated in osteoporosis, osteopenia, and normal groups. BMD and BMI were observed to have a slightly positive correlation in female (Fig. 2A; $r = 0.24$, $P < 0.001$; $r = 0.09$, $P < 0.05$; $r = 0.18$, $P < 0.05$) and male groups (Fig. 2C; $r = 0.19$, $P < 0.001$; $r = 0.15$, $P < 0.05$; $r = -0.04$, $P = 0.84$). However, the negative correlation between TBS and BMI was higher than that between BMD and BMI in both female (Fig. 2B; $r = -0.14$, $P < 0.001$; $r = -0.45$, $P < 0.001$; $r = -0.40$, $P < 0.001$) and male groups (Fig. 2D; $r = -0.26$, $P < 0.001$; $r = -0.33$, $P < 0.001$; $r = -0.57$, $P < 0.001$). The degree of negative correlation increased in male subjects from the

normal group to the osteoporosis group. The correlation between BMD and height was slightly positive in all female groups (Fig. 3A, $r = 0.11$, $P < 0.001$; $r = 0.19$, $P < 0.001$; $r = 0.13$, $P = 0.123$) while the correlation between BMD and height was highly positive in the male osteoporosis group (Fig. 3C, $r = 0.08$, $P < 0.05$; $r = 0.11$, $P < 0.05$; $r = 0.36$, $P < 0.05$). The correlation between TBS and height was highly positive in female groups (Fig. 3B; $r = 0.26$, $P < 0.001$; $r = 0.38$, $P < 0.001$; $r = 0.46$, $P < 0.001$) and the correlation coefficient increased from the normal group to the osteoporosis group. In males (Fig. 3D; $r = 0.08$, $P < 0.05$; $r = 0.07$, $P = 0.122$; $r = 0.30$, $P = 0.101$), the correlation between TBS and height was only significant in the normal group, but the correlation coefficient was very small. The correlation coefficient between BMD and weight was slightly positive in both females (Fig. 4A; $r = 0.28$, $P < 0.001$; $r = 0.19$, $P < 0.001$; $r = 0.25$, $P < 0.05$) and males (Fig. 4C; $r = 0.20$, $P < 0.001$; $r = 0.18$, $P < 0.001$; $r = 0.10$, $P = 0.564$). The correlation between TBS and weight was slightly negative in females (Fig. 4B; $r = -0.02$, $P = 0.327$; $r = -0.26$, $P < 0.001$; $r = -0.18$, $P < 0.001$) and highly negative in males (Fig. 4D;

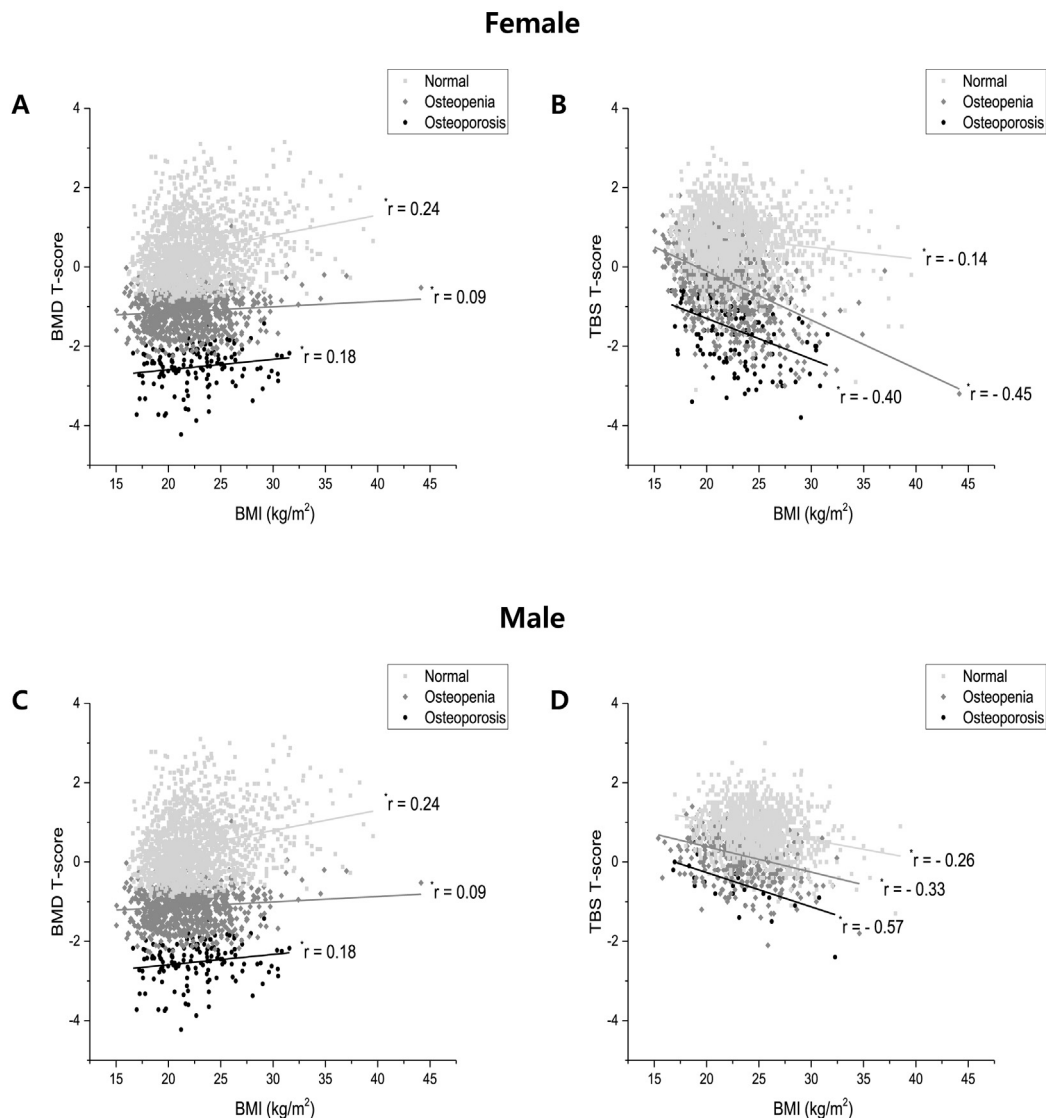


Fig. 2. The relationship between body mass index (BMI) and bone mineral density (BMD) T-score or trabecular bone score (TBS) T-score in female (A, B) and male sex (C, D). * $P < 0.05$.

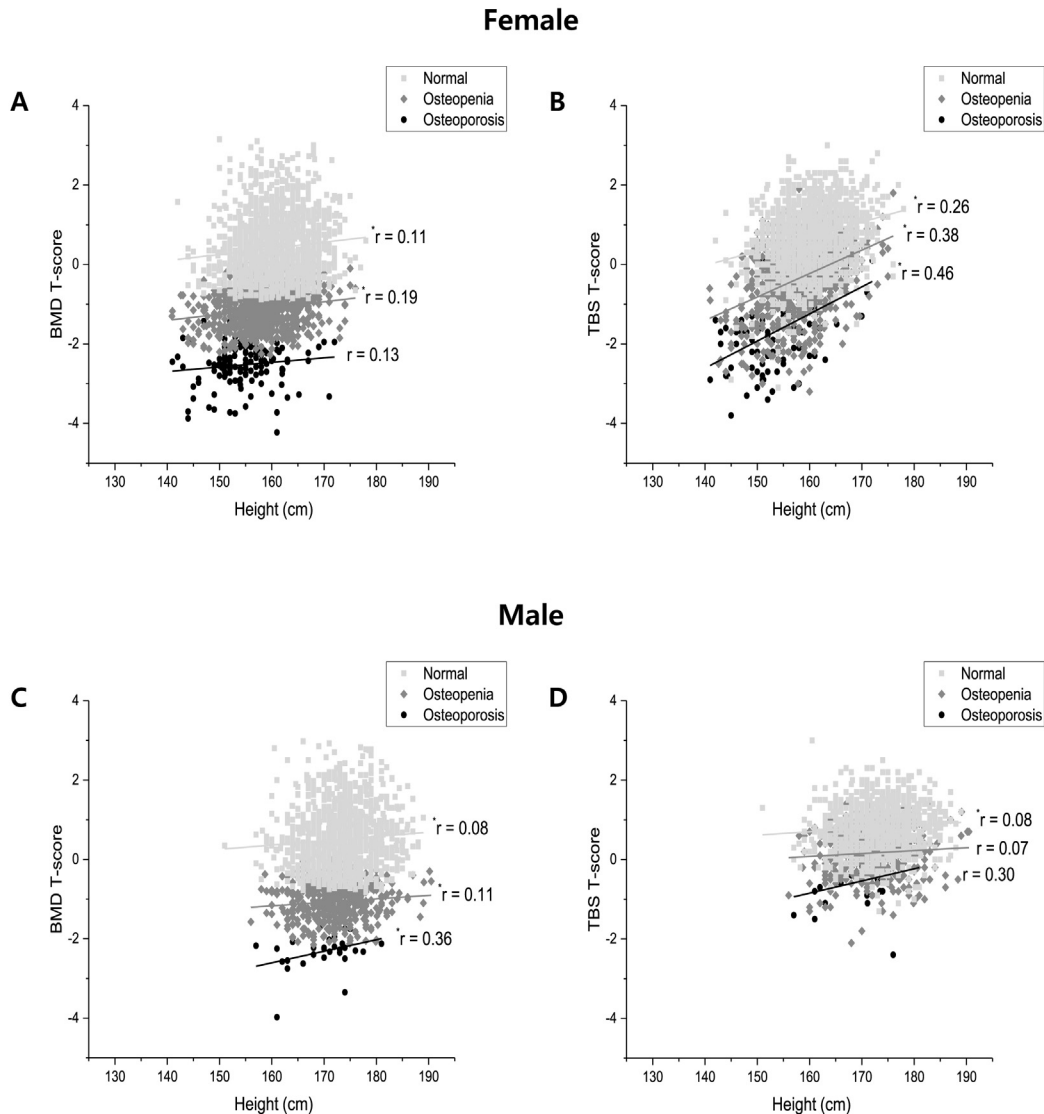


Fig. 3. The relationship between height and bone mineral density (BMD) T-score or trabecular bone score (TBS) T-score in female (A, B) and male sex (C, D). * $P < 0.05$.

$r = -0.19$, $P < 0.001$; $r = -0.26$, $P < 0.001$; $r = -0.44$, $P < 0.05$).

4. Discussion

TBS is a measure of bone texture which was previously mostly studied in Caucasians and female participants. In this study, we studied TBS in male and female participants of all ages categorized into osteoporosis, osteopenia, and normal groups based on BMD, and evaluated the correlations between TBS and clinical variables (BMI, height, and weight) in each group. Previous studies have reported a high correlation between BMI and body fat (correlation coefficient, 0.83–0.89) [25–28], which suggests that individuals with high BMI also have high body fat contents. In this study, we demonstrated a positive correlation between BMI and BMD, which is in agreement with the results of previous studies [29]. High BMI is associated with high bone density while low BMI is linked with low bone density. Since BMI and fat mass are closely related, it can be deduced that fat mass is also positively correlated to BMD in both males and females. The positive correlation between high BMI

and BMD indicates that the accumulation of fat results in an increase in bone density [30]. Alternatively, poor nutritional state causes a decrease in bone density, which in turn increases the risk of osteoporosis. The associations between fat and bone density described above may explain why BMD increased in proportion to increased BMI.

In our study, TBS was negatively correlated with weight, which could be due to the differences in BV/TV of the trabecular microarchitecture, as TBS is positively correlated to BV/TV. A previous study, which divided participants into three groups based on trunk fat, reported that BV/TV significantly decreased as BMI and trunk fat increased [31]. Increased body weight induces increasing insulin resistance and insulin resistance related to bone strength [32]. Previous studies also showed a negative correlation between BMI and TBS, but they were only women's results. We showed negative relationship between BMI and TBS in both women and men. Korean and Japanese women's negative correlation coefficient are more than French women's. Insulin resistance is not significantly related to BMD but negatively related to

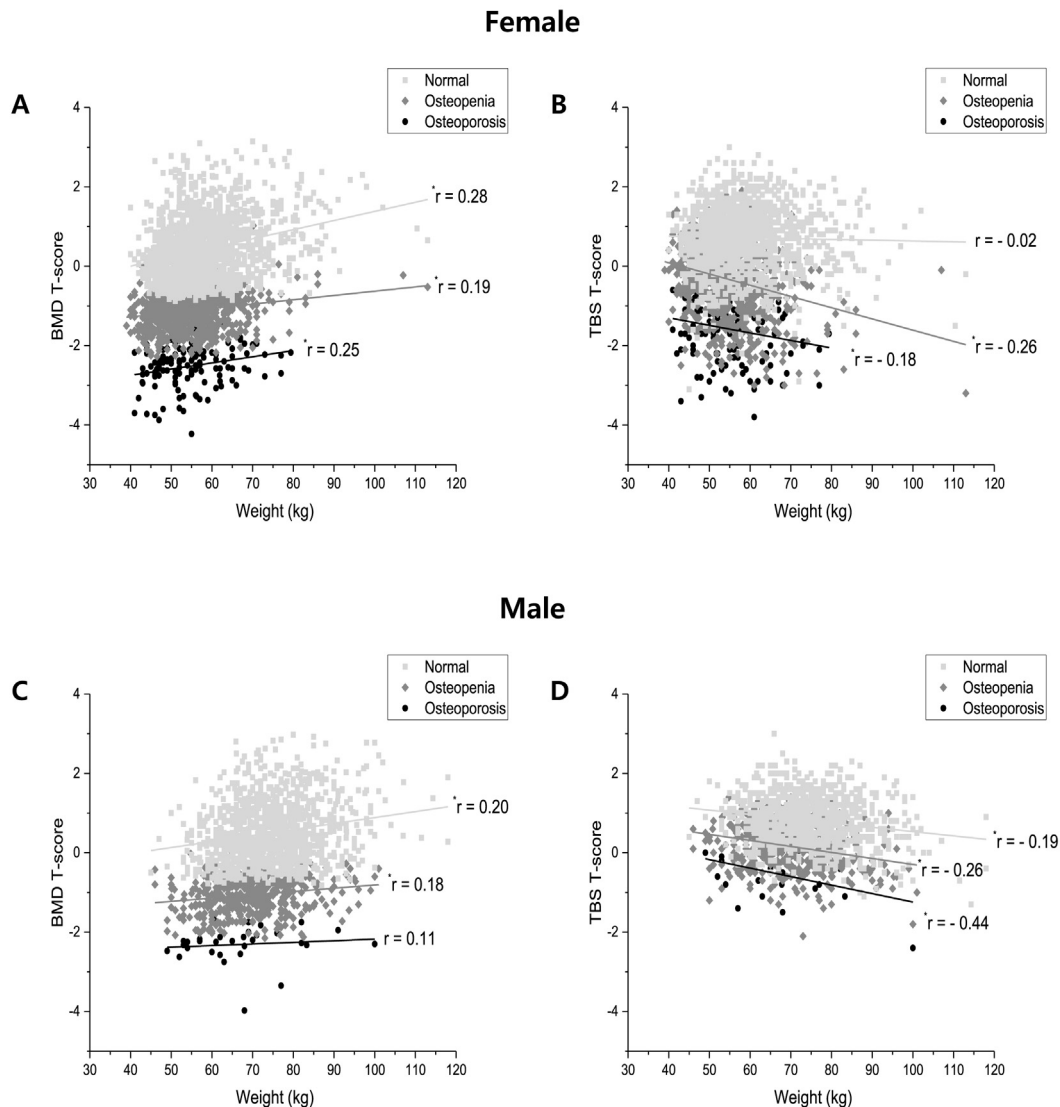


Fig. 4. The relationship between weight and bone mineral density (BMD) T-score or trabecular bone score (TBS) T-score in female (A, B) and male sex (C, D). * $P < 0.05$.

bone strength (compression strength, bending strength, impact strength) [33]. Therefore, this association can explain why TBS, which appears to give a more complete picture of bone strength, decreases as BMI increases.

In this study, we assessed the overall TBS of a pool of Korean subjects and evaluated the correlations between TBS and clinical variables including BMI, height and weight in a subject pool of males and females of all ages divided based on their BMD and osteoporosis status. This study could be used as a reference in future studies aimed at predicting fracture risk in Korean subjects based on TBS.

This study has a few limitations worth noting. First, although we reviewed considerably large samples of males and females and covered a wide age range, there were relatively few subjects in their 20s and 80s. Second, there was also a discrepancy in the number of participants in the osteoporosis, osteopenia and normal groups. Third, we cannot know exact number of patients with history of vertebral surgeries or active vertebral disease from DXA data. Finally, Asian references are not established in TBS software now, so we used European reference range for analyzing TBS T-score.

5. Conclusions

This study demonstrated that in a pool of male and female Korean subjects stratified by osteoporosis status, BMD was positively correlated to BMI and weight, while TBS was negatively correlated to BMI and weight. From these findings, it can be inferred that although an increase in BMI increases bone density, this change may have an adverse effect on bone structure, as indicated by the lower TBS.

Conflicts of interest

No potential conflict of interest relevant to this article was reported.

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