Original Article

Relationship between abdominal fat volume and bone base material pairs from dual-energy spectral computed tomography in young and middle-aged patients with metabolic syndrome

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Background: Metabolic syndrome (MetS) has complex effects on bone health, and dual-energy spectral computed tomography (CT) has become increasingly valuable for bone quantification. However, the relationship between bone base material pairs (BMPs) and abdominal fat volume in patients with MetS remains underexplored. This study thus aimed to analyze the relationship between abdominal fat volume and various bone BMPs using dual-energy spectral CT in young and middle-aged patients with MetS.

Methods: Patients with MetS who underwent sleeve gastrectomy at the Center of Obesity and Metabolic Diseases, Beijing Shijitan Hospital, Capital Medical University, from June to November 2021 were retrospectively collected. The abdominal fat measurements and BMPs were acquired using dual-energy spectral CT imaging. These included the volumes of total abdominal fat (TAF), abdominal visceral fat (AVF), and abdominal subcutaneous fat (ASF), as well as bone densities based on hydroxyapatite (water), i.e., HAP (water), and calcium (water), i.e., Ca (water), BMPs. After grouping the patients by sex, we analyzed the differences in clinical and imaging features. The correlation between the clinical and imaging parameters of patients with MetS was evaluated with Pearson correlation coefficients. Age- and sex-adjusted partial correlation analysis between fat volume and bone BMPs was conducted for patients of different sexes. Additionally, multiple linear regression analyses were performed with age, sex, and TAF volume as the independent variables and with Ca (water) and HAP (water) as dependent variables.

Results: A total of 112 young and middle-aged patients with MetS were included in this study, including 85 females and 27 males. Compared to male patients with MetS, the females with MetS exhibited higher lumbar Ca (water) and HAP (water) BMPs, with lower volumes of TAF and AVF and a smaller abdominal circumference ($P<0.01$). The volumes of TAF, AVF, and ASF were negatively correlated with the average Ca (water) and HAP (water) BMPs in the first to third lumbar vertebrae (L1–L3) ($P<0.05$). Ca (water) and HAP (water) BMPs decreased with age and increasing TAF volume ($P<0.001$). The fitted equations for the relationship between bone BMPs with age, sex, and TAF volume were as follows: (I) bone Ca (water) BMP = 76.469 – 0.500 age + 6.762 sex – 0.002 TAF volume; (II) bone HAP (water) BMP =171.704 – 1.138 age + 11.825 sex – 0.004 TAF volume.

Conclusions: In young and middle-aged patients with MetS, the abdominal fat volume was negatively

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correlated with lumbar bone Ca (water) and HAP (water) BMPs, implying that increased abdominal fat volume may play a crucial role in the pathogenesis of osteopenia among those with MetS. The reduction of bone Ca (water) and HAP (water) with high abdominal fat volume may hold clinical significance for fracture risk in individuals with MetS.

Keywords: Metabolic syndrome (MetS); abdominal fat; bone base material pair (BMP); dual-energy spectral computed tomography (dual-energy spectral CT)

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Introduction

Metabolic syndrome (MetS), also known as syndrome X and the insulin resistance syndrome, is a pathological condition characterized by abdominal obesity, insulin resistance, hypertension, and hyperlipidemia and which poses a threat to human health worldwide (1,2). By modifying body burden and hormonal and metabolic metabolism, among other processes, MetS exerts a complicated influence on bone (3). Previous studies have shown that obesity is a protective factor for bone mineral density (BMD) (4,5), but research in recent years has indicated that obesity is a critical risk factor for bone loss and osteoporosis in patients. It has further been suggested that MetS is associated with reduced BMD and increased risk of osteopenia or osteoporosis. Several studies using dual-energy X-ray absorptiometry (DXA) and quantitative ultrasound have reported that patients with MetS tend to have lower BMD, suggesting a higher susceptibility to bone fragility and fractures (4,6,7). DXA and quantitative computed tomography (QCT) are important methods for obtaining BMD measurements, but the former is highly susceptible to the overlapping of the adjacent tissues, and the latter is affected by body-mode correction factors and is not available in some centers (8,9). Therefore, developing a convenient and practical examination method to evaluate BMD is crucial for improved clinical practice.

The application of dual-energy spectral CT has been expanded to include the quantification of bone (10,11). Studies have shown that material decomposition technology based on dual-energy spectral CT can be used for bone quantification (12,13). Yue *et al.* (14) reported that calcium (water), i.e., Ca (water), can reflect age-related changes in the lumbar spine of adult women and is correlated with BMD, suggesting its suitability for BMD evaluation. Wang *et al.* (13) obtained various bone base material pair (BMP) indices, including bone Ca (water) and hydroxyapatite (water), i.e., HAP (water), BMPs, in the spinal vertebrae using the material decomposition technology of dual-energy spectral CT. They discovered a strong relationship between HAP (water) and BMD on QCT, which provided a high degree of diagnostic accuracy, and found that HAP (water) showed the best predictive capability in patients with osteopenia and osteoporosis. Hence, it is likely that Ca (water) and HAP (water) BMPs can be used for BMD evaluation. Therefore, in this study, we used the Ca (water) and HAP (water) measurement from dual-energy spectral CT to assess the bone status of patients with MetS.

In the past, the diagnosis and assessment of the degree of obesity focused mainly on body weight, body mass index (BMI), and abdominal circumference; however, in recent years, the quantification of abdominal fat in this context, especially visceral fat, has attracted extensive attention (15). Visceral fat is a key contributor to insulin resistance and a chronic inflammatory state and is closely linked to MetS and cardiovascular disease (16). Therefore, understanding the distribution of fat in patients can inform clinical judgment. Since abdominal obesity is characteristic of MetS, measuring and segmenting the abdominal fat volume may be critical for diagnosis, treatment, and follow-up. However, there has been limited research analyzing the relationship between BMPs and abdominal fat volume in patients with MetS.

This study had two main objectives: first, we aimed to use a set of dual-energy spectral CT indices, including Ca (water), HAP (water), and measurements of abdominal fat volumes to characterize the bone status and body composition in young and middle-aged patients with MetS. Second, we sought to clarify the associations between these parameters in order to provide a basis for clinical prevention and management of MetS. We present this article in accordance with the STROBE reporting checklist (available

at https://qims.amegroups.com/article/view/10.21037/qims-24-573/rc).

Methods

Study population

This study retrospectively collected data from patients with MetS scheduled for gastric sleeve resection at the Center for Obesity and Metabolic Diseases, Beijing Shijitan Hospital, Capital Medical University, from June to November 2021. Patients with MetS were included based on the 2006 International Diabetes Federation Diagnostic Criteria (2) which specifies a waist circumference >94 cm in men or >80 cm in women and the presence of two or more of the following: (I) blood glucose levels >5.6 mmol/L or a diagnosis of diabetes mellitus; (II) high-density lipoprotein cholesterol levels <1.0 mmol/L in men and <1.3 mmol/L in women or medication for low high-density lipoprotein cholesterol; (III) blood triglyceride levels >1.7 mmol/L or medication for elevated triglycerides; and (IV) blood pressure >130/85 mmHg or medication for hypertension.

The inclusion criteria for this study were as follows: MetS diagnosed in the Obesity and Metabolic Disease Center of our hospital in young and middle-aged patients aged 23–59 years (17,18) (to minimize the confounding effects of age-related bone loss, especially those associated with the menopausal transition in women) who underwent an abdominal dual-energy spectral CT scan at the time of consultation. The exclusion criteria were as follows: (I) other diseases affecting bone metabolism (such as thyroid, pituitary, and adrenal diseases); (II) long-term use of drugs affecting bone metabolism (such as calcitonin, thyroid hormones, glucocorticoids, and hypoglycemic drugs), (III) presence of severe hepatic and/or renal insufficiency (severe hepatic insufficiency was defined as significant elevation in serum aminotransferases levels, approximately 15 times or more above the upper limit of normal; renal insufficiency was defined as an estimated glomerular filtration rate (eGFR) less than 60 mL/(min·1.73 m^2), (IV) diabetic ketoacidosis, (V) experiencing stress state (19), (VI) incomplete clinical or imaging information, and (VII) the presence of the vertebral collapse or previous intervention/operation in the L1–L3 vertebrae (*Figure 1*). This study was conducted in accordance with the Declaration of Helsinki (as revised in 2013) and was approved by the Institutional Ethics Committee of Beijing Shijitan Hospital of Capital Medical University (No. IIT2023-029-001). The requirement for individual consent was waived due to the retrospective nature of the analysis.

Sample size

In our study, the sample size was determined based on an established rule in statistics, which recommends having at least 10 events for each predictor parameter that is being considered for inclusion in the prediction model equation (20). In our multiple linear regression analysis, we included a total of three variables. Therefore, adhering to the aforementioned rule, our sample size was at least 30 cases. This could ensure that our estimates of the model parameters were sufficiently stable and reliable.

Clinical information

Patient characteristics were collected from the electronic medical records and included age, sex, height, and weight. BMI was calculated as follows: weight (kg)/height^2 (m^2). A venous blood sample was drawn under standard conditions after an overnight fasting period. Laboratory parameters included fasting plasma glucose level, fasting insulin C-peptide level, fasting insulin level, glycated hemoglobin 2-hour post-prandial glucose level, total cholesterol level, total triglyceride high-density lipoprotein cholesterol level, low-density lipoprotein cholesterol level, and total calcium concentrations.

Imaging information

The patient's abdominal CT plain image was acquired with a GE Revolution CT device (GE HealthCare, Chicago, IL, USA) under the following scanning parameters: switching, 80/140 kVp (0.5 ms); automatic tube current, 200–485 mA; pitch, 0.992:1; anterior adaptive statistical iterative reconstruction, 40%; reconstructed layer thickness, 1.25 mm; and layer spacing, 1.25 mm. Images were transferred to an Advantage Workstation 4.7 (GE HealthCare) for postprocessing with the gemstone spectral imaging mode.

Quantitative analysis of the first to third lumbar vertebrae (L1–L3) was performed using Ca (water) and HAP (water) as the base substance. With the vertebral venous plexus and bone island being avoided, a 100- to 120-mm^2 region of interest (ROI) was placed at the central level of the vertebral body. The values of Ca (water) and HAP (water) in the L1–L3 vertebrae were measured twice, and the average values of the bone Ca (water) and HAP

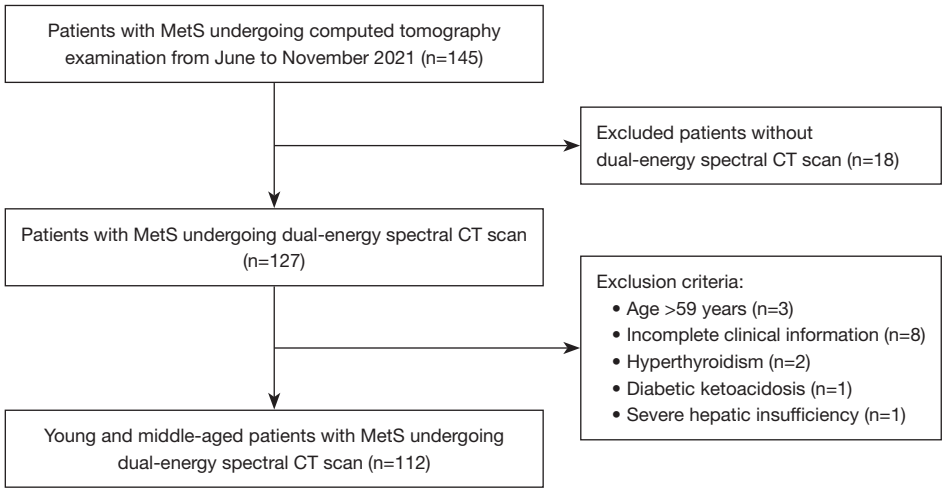

Figure 1 Flowchart of participant selection. MetS, metabolic syndrome; CT, computed tomography.

(water) BMPs in the L1–L3 vertebrae were obtained. In addition, the L1–L3 vertebrae level was selected to measure the patient's fat volume, which mainly included total abdominal fat (TAF) volume, abdominal visceral fat (AVF) volume, and abdominal subcutaneous fat (ASF) volume. The ratio of visceral fat to subcutaneous fat volume (VF/SF) was calculated. This choice was informed by prior research demonstrating that a multislice approach provides a more representative measurement of abdominal fat distribution as compared to single-slice methods (21). Furthermore, the abdominal circumference at the level of the third lumbar vertebrae (L3) and the thickness of the subcutaneous fat adjacent to the posterior vertebral muscles were measured (recorded as the fat thickness), as shown in *Figure 2*.

Statistical analysis

Statistical analysis was performed using SPSS 26.0 software (IBM Corp., Armonk, NY, USA). Patients were categorized by sex, with the mean and standard deviation being calculated. The *t*-test was used to analyze the differences in clinical and imaging parameters between two groups. Pearson correlation coefficient was used to assess the relationship between the clinical and imaging indices of patients with MetS, and partial correlation analysis was performed in patients for fat volume corrected for age, sex, and bone BMPs. A correlation coefficient less than 0.30 was considered to be poor, 0.31–0.50 fair, 0.51–0.80 moderate, and greater than 0.80 substantial. Furthermore, age, sex, and TAF volume were analyzed using multiple linear regression, with the dependent variables being the Ca (water) and HAP (water) BMPs. Statistical significance was defined at a P value <0.05.

Results

Baseline characteristics

A total of 112 young and middle-aged patients with MetS were included in this study (*Figure 1*), including 85 females and 27 males, with a mean age of 37.99±8.60 (range, 23–59) years and a mean BMI of 35.22±4.92 (range, 26.57–51.19) kg/m^2. The average values of Ca (water) and HAP (water) BMPs in the L1–L3 vertebrae of patients with MetS were 58.27±10.81 and 124.23±22.74 mg/cm^3, respectively. The average TAF volume was 5,418.83±1,688.07 mL, the AVF volume was 2,223.31±851.10 mL, and the ASF volume was 3,195.5±1,254.75 mL. Furthermore, the average abdominal circumference and fat thickness were 110.91±11.45 and 4.78±1.65 cm, respectively.

The patients were divided into two groups according to sex. In terms of imaging indicators, women had higher lumbar vertebral Ca (water) and HAP (water) BMPs (P<0.01). Additionally, the TAF volume, AVF volume, VF/SF ratio, and abdominal circumference were lower in women (P<0.01), as shown in *Table 1* and *Figure 3*. In terms of clinical indicators, women had a lower fasting insulin C-peptide level (P=0.006), total calcium concentration (P=0.048), and a high-density lipoprotein cholesterol level (P=0.002), as shown in Table S1.

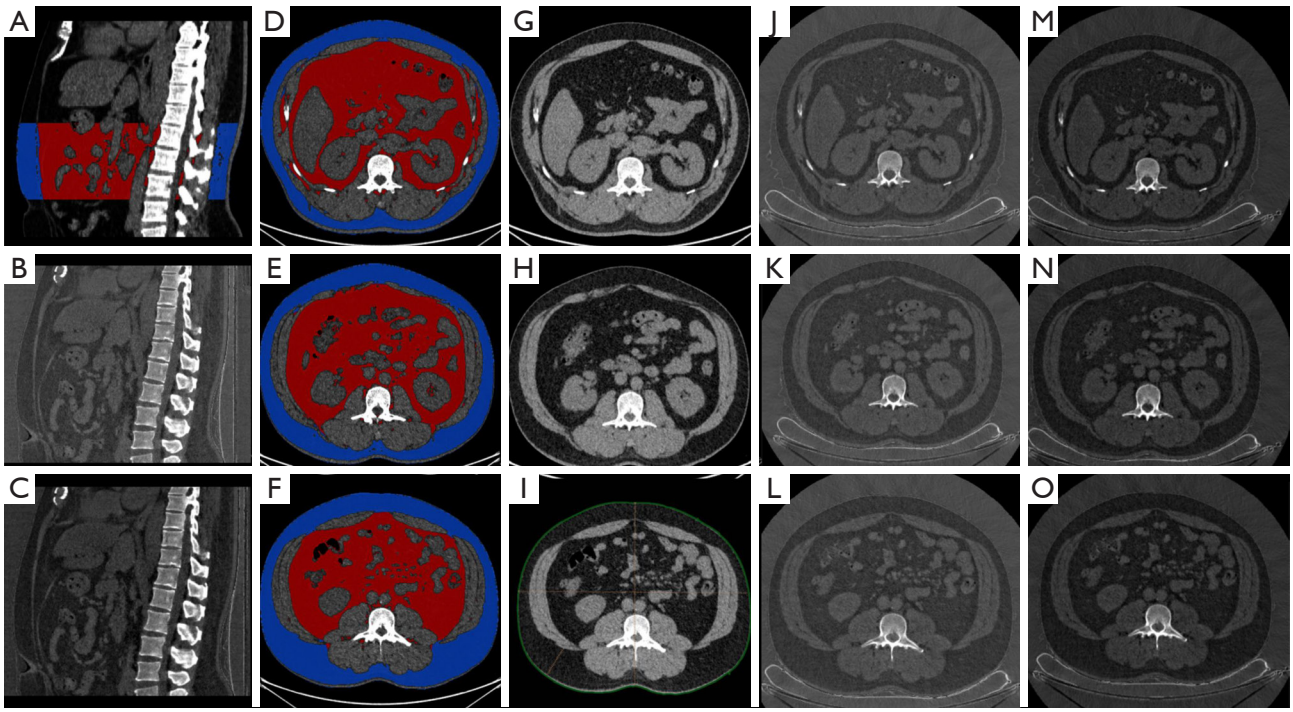

Figure 2 A 43-year-old man with metabolic syndrome. The method of acquisition of the patient's bone base material pairs and abdominal fat volume. (A-C) The fat volume, Ca (water), and HAP (water) figures of the patient's spine in the sagittal position are shown, with the horizontal line corresponding to the level of the L1–L3 vertebrae, respectively. (D-F) Segmentation of the visceral (red areas) and subcutaneous fat (blue areas). (G-I) Spectral CT images at 70 keV for (J-L) Ca (water) figures and (M-O) HAP (water) figures of the L1–L3 vertebrae. Ca, calcium; HAP, hydroxyapatite; CT, computed tomography.

Correlation and partial correlation analysis of fat volume and bone BMPs

We performed correlation analyses to identify variables associated with bone BMPs. The average Ca (water) and HAP (water) BMPs of the L1–L3 vertebrae of the patients were found to be negatively correlated with age (R=–0.408, fair correlation; R=–0.446, fair correlation; both P values <0.001) and BMI (R=–0.216, poor correlation; R=–0.230, poor correlation; both P values <0.05). Our results indicated that the volumes of TAF, AVF, and VF/SF ratio showed negative correlations with the average Ca (water) BMPs of the L1–L3 vertebrae in patients with MetS (TAF: R=–0.371, fair correlation; AVF: R=–0.499, fair correlation; VF/SF ratio: R=–0.295, poor correlation; all P values <0.01). Similarly, these fat parameters also showed negative correlations with HAP (water) BMPs (TAF: R=–0.374, fair correlation; AVF: R=–0.511, moderate correlation; VF/SF ratio: R=–0.305, poor correlation; all P values <0.01). *Table 2* provides a detailed overview of these correlations. Furthermore, none of the clinical parameters assessed showed a statistically significant correlation with bone BMPs (P>0.05), as shown in Table S2. In addition, the correlations between bone BMPs and fat for patients with MetS of different sexes are shown in Table S3.

After adjustments were made for age and sex, a partial correlation analysis of fat volume and BMPs was performed, as shown in *Table 3*. The results demonstrated that the volumes of TAF, AVF, and ASF were negatively correlated with the average Ca (water) and HAP (water) BMPs of the L1–L3 vertebrae, respectively (P<0.01). Specifically, TAF volume showed a fair negative correlation with average Ca (water) (r=–0.362; P<0.001) and HAP (water) BMPs (r=–0.383; P<0.001). AVF volume had a poor negative correlation with average Ca (water) (r=–0.270; P=0.004) and a fair negative correlation with HAP (water) BMPs (r=–0.301; P=0.001). ASF volume showed a fair negative correlation with average Ca (water) (r=–0.339; P<0.001) and HAP (water) BMPs (r=–0.349; P<0.001). The VF/SF ratio showed no significant correlation with either average Ca (water) or HAP (water) BMPs (P>0.05). The univariate

Table 1 Baseline bone BMPs and abdominal fat volume of young and middle-aged patients with metabolic syndrome

Characteristic	All (n=112)	Female (n=85)	Male (n=27)	P value
Age (years)	38.0±8.6	37.4±8.5	39.9±8.8	0.198
BMI (kg/m^2)	35.2±4.9	35.0±4.8	36.0±5.4	0.369
Ca (water) BMPs (mg/cm^3)				
L1 vertebra	60.36±10.98	62.66±10.27	53.11±10.11	<0.001*
L2 vertebra	59.15±11.45	61.48±10.62	51.81±11.00	<0.001*
L3 vertebra	55.29±11.90	58.19±10.20	46.15±12.41	<0.001*
Average L1–L3 vertebrae	58.27±10.81	60.78±9.71	50.36±10.40	<0.001*
HAP (water) BMPs (mg/cm^3)				
L1 vertebra	128.95±23.44	133.87±21.94	113.45±21.49	<0.001*
L2 vertebra	125.11±26.33	129.69±25.67	110.70±23.39	0.001*
L3 vertebra	118.63±24.27	124.25±21.63	100.93±23.97	<0.001*
Average L1–L3 vertebrae	124.23±22.74	129.27±20.69	108.36±21.90	<0.001*
Fat volume at the L1–L3 vertebral level				
TAF (mL)	5,418.83±1,688.07	5,135.8±1,366.20	6,309.86±2,247.00	0.015*
AVF (mL)	2,223.31±851.10	1,916±541.77	3,190.78±929.24	<0.001*
ASF (mL)	3,195.52±1,254.75	3,219.8±1,120.14	3,119.08±1,630.91	0.767
VF/SF ratio	0.79±0.42	0.65±0.25	1.21±0.57	<0.001*
Abdominal circumference (cm)	110.9±11.5	109.0±9.8	116.8±14.3	0.013*
Fat thickness (cm)	4.8±1.7	4.8±1.6	4.6±1.9	0.516

Data are presented as mean ± standard error of the mean. *, P<0.05. BMP, base material pair; BMI, body mass index; Ca, calcium; HAP, hydroxyapatite; TAF, total abdominal fat; AVF, abdominal visceral fat; ASF, abdominal subcutaneous fat; VF/SF ratio, the ratio of visceral fat to subcutaneous fat volume.

analysis of fat factors associated with bone BMPs in young and middle-aged patients with MetS is shown in Table S4.

Multiple linear regression models

Multiple linear regression equations were fitted for age, sex, TAF volume, ASF volume, and AVF volume, with the average L1–L3 vertebral Ca (water) and HAP (water) BMPs serving as dependent variables. Age, sex, TAF volume, and AVF volume were found to be significantly associated with Ca (water) and HAP (water) BMPs of patients with MetS, while ASF volume was excluded from the model. As shown in *Table 4*, the Ca (water) and HAP (water) BMPs decreased with increasing age and TAF volume (P<0.001). ASF volume was excluded from the final multiple linear regression model. The equation fitted to the average L1–L3 vertebral Ca (water) and HAP (water) BMPs versus age, sex, and TAF volume was as follows:

Bone Ca (water) BMPs = 76.469 – 0.500 age + 6.762 sex – 0.002 TAF volume;

Bone HAP (water) BMP =171.704 – 1.138 age + 11.825 sex – 0.004 TAF volume.

Discussion

MetS is a series of clinical syndromes characterized by abdominal obesity, insulin resistance, hypertension, and hyperlipidemia. Among them, abdominal obesity is a key manifestation. Consequently, it holds immense importance in segmenting and quantifying abdominal fat. Previous research has indicated that obesity has a positive impact on BMD (22). More recent research, however, has brought attention to the possible link between obesity and osteopenia and osteoporosis (4,6,7). Therefore, clarifying

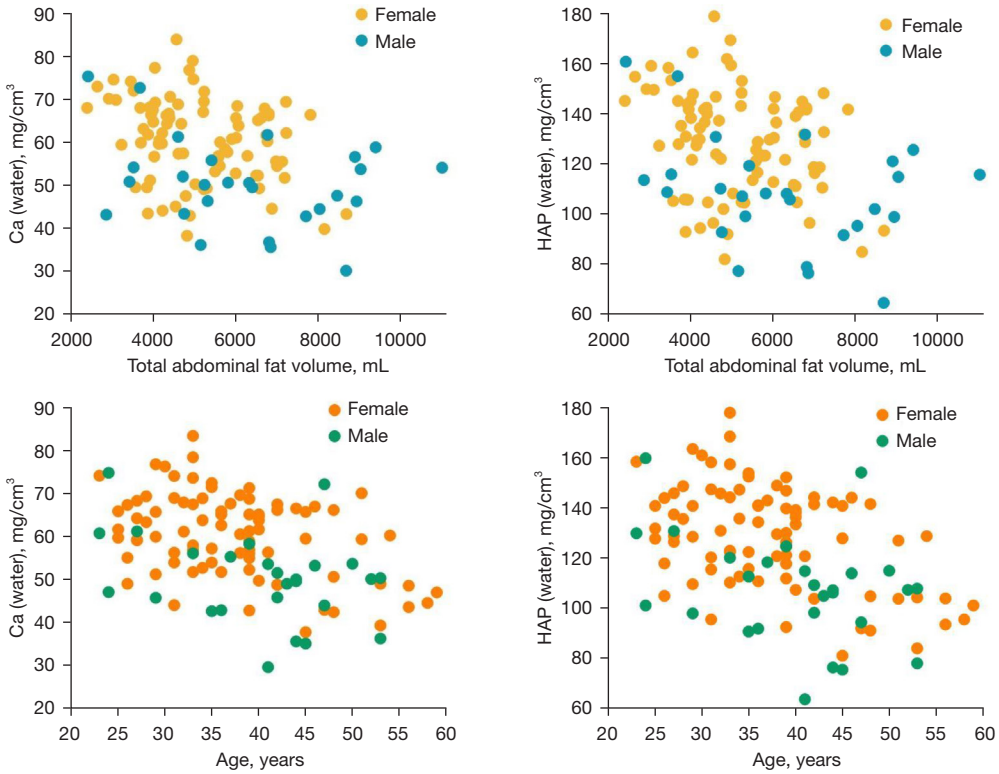

Figure 3 Correlation between BMPs, total abdominal fat volume, and age in patients with metabolic syndrome by sex. Ca, calcium; HAP, hydroxyapatite; BMP, base material pair.

Table 2 Correlation analysis of bone BMPs and fat volume in young and middle-aged patients with metabolic syndrome

Pearson coefficient	Average Ca (water) BMPs		Average HAP (water) BMPs	
	Correlation	P value	Correlation	P value
Age	−0.408	<0.001	−0.446	<0.001
BMI	−0.216	0.022	−0.230	0.014
TAF	−0.371	<0.001	−0.374	<0.001
AVF	−0.499	<0.001	−0.511	<0.001
ASF	−0.161	0.090	−0.156	0.100
VF/SF ratio	−0.295	0.002	−0.305	0.001

BMP, base material pair; Ca, calcium; HAP, hydroxyapatite; BMI, body mass index; TAF, total abdominal fat; AVF, abdominal visceral fat; ASF, abdominal subcutaneous fat; VF/SF ratio, the ratio of visceral fat to subcutaneous fat volume.

Table 3 Partial correlation of fat volume and BMPs in young and middle-aged patients with metabolic syndrome after correction for age and sex

Characteristics	TAF		AVF		ASF		VF/SF ratio	
	Correlation	P value	Correlation	P value	Correlation	P value	Correlation	P value
Average Ca (water) BMPs	−0.362	<0.001	−0.270	0.004	−0.339	<0.001	0.105	0.274
Average HAP (water) BMPs	−0.383	<0.001	−0.301	0.001	−0.349	<0.001	0.095	0.322

BMP, base material pair; TAF, total abdominal fat; AVF, abdominal visceral fat; ASF, abdominal subcutaneous fat; VF/SF ratio, the ratio of visceral fat to subcutaneous fat volume; Ca, calcium; HAP, hydroxyapatite.

Table 4 Multiple linear regression analysis of factors affecting bone BMPs in young and middle-aged patients with metabolic syndrome

Characteristic	B (95% CI)	Standardized coefficient	P
Ca (water) BMPs			
Age	−0.500 (−0.711, −0.288)	−0.398	<0.001
Sex	6.762 (1.587, 11.937)	0.269	0.010
TAF volume	−0.002 (−0.004, −0.001)	−0.318	0.008
AVF volume	−0.00003 (−0.004, 0.004)	−0.003	0.985
HAP (water) BMPs			
Age	−1.138 (−1.574, −0.701)	−0.430	<0.001
Sex	11.825 (1.149, 22.500)	0.223	0.030
TAF volume	−0.004 (−0.007, −0.001)	−0.310	0.009
AVF volume	−0.001 (−0.009, 0.007)	−0.041	0.782

Abdominal subcutaneous fat was excluded from the final multiple linear regression model. BMP, base material pair; CI, confidence interval; Ca, calcium; TAF, total abdominal fat; AVF, abdominal visceral fat; HAP, hydroxyapatite.

the relationship between abdominal fat content and fat distribution and BMD among individuals diagnosed with MetS holds considerable clinical significance. In this study, the abdominal fat volume and bone Ca (water) and HAP (water) BMPs at the L1–L3 vertebral levels in patients with MetS were obtained using dual-energy spectral CT, the differences between patients with MetS of different sexes were compared, and the relationship between the above parameters and laboratory indices was analyzed. Furthermore, a comprehensive analysis of the association between abdominal fat volume, distribution, and bone Ca (water) and HAP (water) BMPs demonstrated that increased levels of abdominal fat in patients with MetS were a significant contributing factors to osteoporosis.

Previous studies using linear regression analysis on cancellous bone CT values while accounting for factors related to body composition, such as HAP, demonstrated that the use of quantitative CT can obtain accurate measurements of BMD (23,24). Precise evaluations of bone geometric parameters can also be obtained using QCT; however, QCT is dependent on the scanning process and calibration model (9). As an opportunistic mode of CT (using the imaging modality beyond the primary diagnostic purpose), dual-energy CT allows for the screening of bone Ca (water), HAP (water), and abdominal fat volume without additional radiation and cost. Recent research findings have demonstrated that dual-energy spectral CT can provide precise quantitative data on bone composition and structure. Wang *et al.* (13) examined the application of dual-energy spectral CT for quantifying the bone HAP (water) BMPs in accurately reflecting changes in bone microstructure among patients. They compared the BMD indexes obtained from dual-energy spectral CT and quantitative CT, providing valuable insights for evaluating vertebral BMD and diagnosing osteoporosis. Therefore, we aimed to evaluate the Ca (water) and HAP (water) BMPs in the L1–L3 vertebral body as indicators of mineral density. Moreover, previous research mostly assessed the distribution of fat in the abdominal region at the level of the L3 vertebral body to ascertain the total distribution of fat in patients (15). Assessing the fat distribution of patients with MetS solely based on a single layer's fat area is challenging despite the presence of primary manifestations of abdominal obesity. Therefore, in our study, abdominal fat volume was measured at the L1–L3 vertebral level to accurately depict abdominal obesity features among patients. Additionally, subcutaneous and visceral fat were categorized to provide a comprehensive understanding of fat distribution characteristics.

We used dual-energy CT to analyze fat and bone composition in individuals with MetS of different sexes. We found that females had higher lumbar vertebral Ca (water) and HAP (water) BMPs, while their TAF volume, visceral fat volume, VF/SF ratio, and abdominal circumference were relatively lower. The distribution of fat and BMD is significantly influenced by sex. Notably, there are significant differences in fat distribution between males and females. In our study, males exhibited significantly higher levels of visceral fat compared to females, consistent with previous research (25,26). Males typically have 10–20% of their total body fat as visceral fat, whereas females tend to have 5–10% (27,28). Females may exhibit a more advantageous thermogenic capacity and increased neuroregulation of adipose tissues, which could play a crucial role in promoting a healthier metabolic profile in adipose tissues compared to their male counterparts (25). This sexual dimorphism in fat biology is attributed to genetic differences, including the impact of sex hormones, receptor functionality, and gene expression patterns. Sex hormones play a crucial role in adipocyte development, fat cell proliferation, and modulation of gene expression related to insulin resistance and lipid metabolism (29).

Sex hormones have a significant impact on skeletal development and metabolism, similar to adipose tissue

distribution. Male individuals demonstrate enhanced bone strength, elongated long bones with increased width, and elevated peak bone mineral content, which is primarily attributable to the modulation of sex hormones (30). The androgen hormone and its derivative dihydrotestosterone directly interact with androgen receptors, thereby augmenting bone trabecular density. Conversely, estrogen facilitates periosteum development and bone trabeculae, while also regulating the activities of osteoblasts and osteoclasts (31,32). The results of this study, however, demonstrate that female patients exhibited increased levels of bone Ca (water) and HAP (water) BMPs in the lumbar spine. The potential explanation for this could be that women tend to exhibit lower overall abdominal fat volume and visceral fat volume, thereby reinforcing the association between adiposity and bone health.

In this study, bone Ca (water) and HAP (water) demonstrated a significant inverse association with the TAF volumes, visceral fat, and subcutaneous fat in patients with MetS. An increase in abdominal fat volume was associated with a relative decrease in both bone Ca (water) and HAP (water). Previous research suggests that visceral fat presents a substantial threat to BMD as a result of its increased metabolic activity (33,34). Multiple mechanisms are implicated in facilitating this impact. (I) Visceral fat releases proinflammatory cytokines such as interleukin-6 (IL-6) and tumor necrosis factor-α (TNF-α) to affect bone metabolism. The nuclear factor-κB (NF-κB) signaling pathway is activated in obese individuals as a result of TNF-α stimulation, leading to an upregulation of colony-stimulating factor receptor, RANK, and its ligand RANKL. This enhances osteoclast activity and ultimately culminates in bone loss (35). Moreover, IL-6 predominantly facilitates osteoclastogenesis and bone resorption, while also promoting osteoblast proliferation and early differentiation, thus influencing skeletal architecture (35,36). (II) The release of free fatty acids and other substances by visceral fat impedes the expression of insulin receptors, leading to the development of insulin resistance. However, it is important to note that insulin is crucial for promoting bone formation and preventing bone loss. In cases where insulin resistance occurs, the ability of insulin to stimulate osteoblasts is diminished while bone resorption is enhanced, thereby impacting an individual's BMD (37,38).

The focus of this study was patients with MetS. Previous research has indicated that the level of visceral fat can serve as a predictive factor for the occurrence and progression of MetS, with insulin resistance being a key component. Consequently, a previous study found that compared to individuals without MetS in the general population, those affected by MetS have more pronounced skeletal alterations (39). The current understanding of the association between subcutaneous fat and bone remains inconclusive, but our study identified an inverse relationship between them. These findings are in line with the investigations conducted by Lin *et al.* and Katzmarzyk *et al.* (36,40). Similarly, the study conducted by Zhang *et al.* (41) yielded similar findings to our own, as they also observed no significant association between BMD and the levels of subcutaneous fat and visceral fat in males. The aforementioned results may be attributed to factors such as the size of the sample, the age distribution, and the sex composition of the enrolled population. Consequently, it is imperative to further augment the sample size to advance our research.

Certain limitations to our study should be discussed. First, this study involved a retrospective design with a limited sample size. To gain deeper insights, large-sample, prospective studies should be conducted. Additionally, the research population of this study consisted exclusively of young and middle-aged patients with MetS. In future studies, it is advisable to broaden the sample by including patients with MetS from all age groups and implementing stratification. Moreover, this study did not include a direct measurement of BMD using QCT, and future studies incorporating QCT would be beneficial to provide a more comprehensive assessment of bone status in patients with MetS. Finally, we did not evaluate the modifications in patients with MetS after sleeve gastrectomy.

Conclusions

In summary, the dual-energy spectral CT analysis revealed a significant inverse correlation of bone Ca (water) and HAP (water) with abdominal fat volume in young and middle-aged female patients with MetS, suggesting that elevated levels of abdominal fat volume may be crucial in the pathogenesis of osteopenia among individuals with MetS. Therefore, it is imperative for individuals with MetS to actively engage in weight management and reduce fat volume to mitigate bone loss. Simultaneously, spectral CT is highly valuable to the acquisition of bone density indexes. Parameters such as bone Ca (water) and HAP (water) BMPs can be used as crucial measures to assess bone changes, thereby providing relevant assistance for clinical applications.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://qims.amegroups.com/article/view/10.21037/qims-24-573/rc

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://qims.amegroups.com/article/view/10.21037/qims-24-573/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. This study was conducted in accordance with the Declaration of Helsinki (as revised in 2013) and was approved by the Institutional Ethics Committee of Beijing Shijitan Hospital, Capital Medical University (no. IIT2023-029-001). The requirement for individual consent was waived due to the retrospective nature of the analysis.

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