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Associations between abdominal fat, psoas muscle fat, and lumbar spine bone density: insights from quantitative CT imaging

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Abstract

Purpose To investigate the correlation between abdominal adipose tissue (AAT), psoas muscle fat content, and lumbar vertebral bone mineral density (BMD) in different age and sex groups using quantitative CT(QCT) imaging.

Methods A total of 861 subjects were included in this study, comprising 404 males and 457 females, divided into 6 age groups. According to the BMI classification criteria, individuals are divided into four groups. QCT was used to measure BMD, visceral adipose tissue (VAT), subcutaneous adipose tissue (SAT), and psoas muscle fat content (Fp). Independent sample t-tests were used to compare intergroup differences in the above data between males and females in the same age group. One-way analysis of variance (ANOVA) was used to compare intergroup differences in the data between males and females in each age group. Kruskal-Wallis H test was used to compare QCT measurements among different BMI groups. Pearson correlation analysis was used to assess the correlations of BMD with BMI, VAT, SAT, and Fp, as well as the correlation between AAT and Fp.

Results There was no difference in Fp between males and females in each age group. In the 60–69 and 70–79 age groups, female BMD was significantly lower than that of males ($P<0.001$). Except for the 20–29 and 40–49 age groups, the SAT in females was higher than that of males ($P<0.001$), while except for the 20–29 age group, female VAT was lower than that of males ($P<0.001$) in each age group. There were differences in BMD ($F=72.07$, $P<0.001$), VAT ($F=22.12$, $P<0.001$), and Fp ($F=23.61$, $P<0.001$) among different age groups in males. Among different age groups in females, there were differences in BMD ($F=188.81$, $P<0.001$), VAT ($F=39.82$, $P<0.001$), SAT ($F=6.26$, $P<0.001$), and Fp ($F=26.22$, $P<0.001$). Among different BMI groups there were differences in BMD, VAT, SAT and Fp ($P<0.001$). BMD in males was negatively correlated with both VAT and Fp (R=-0.336, -0.422, $P<0.001$), and Fp was positively correlated with VAT and SAT ($R=0.405$, 0.125, $P<0.001$). BMD in females was negatively correlated with BMI, SAT, VAT, and Fp (R=-0.170, -0.112, -0.509, -0.469, $P<0.001$), and Fp was positively correlated with VAT and SAT ($R=0.521$, 0.325, $P<0.001$).

Conclusion VAT and psoas muscle fat content increase with age, while BMD decreases with age. Increased VAT, psoas muscle fat content, and SAT in females may be risk factors for osteoporosis.

Clinical trial number Not applicable.

Keywords Quantitative CT, Bone mineral density, Abdominal fat, Visceral adipose tissue, Psoas muscle, Fat content

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Introduction

Osteoporosis is a systemic bone disease characterized by reduced bone mass and disrupted bone microstructure. It leads to increased bone fragility and susceptibility to fractures. Bone mineral density (BMD) is the main screening and diagnostic indicator for osteoporosis. The prevalence of osteoporosis among males and females aged 50 and above in China is 6.46% and 29.13%, respectively, and it is estimated that by 2050, the number of osteoporosis patients will exceed 120 million [1]. Osteoporosis has become an important public health issue in China, garnering increasing attention.

Osteoporosis is influenced by factors such as age, sex, genetics, environment, and behavior like lifestyle, physical activity, alcohol consumption, and high-fat diets [2–3]. Obesity, characterized by the excessive or abnormal accumulation of fat tissue in the body, is associated with many chronic metabolic diseases. The impact of fat tissue on bone health is still debated. Previous studies have suggested that overweight or obesity may have a protective effect on bones, while low body mass index (BMI) is often associated with decreased BMD [4]. With in-depth research on visceral adipose tissue (VAT) and subcutaneous adipose tissue (SAT), differences between the two have been highlighted. VAT has higher metabolic activity compared to SAT, and can more significantly affect BMD by altering bone metabolism. A study by Jain [5] showed a significant negative correlation between increased VAT and BMD, regardless of sex or ethnicity, indicating that VAT is not a protective factor for BMD but rather a harmful one. Hind et al. [6] conducted a study on 300 elderly subjects and found that VAT is a risk factor for osteoporosis in women but not in men. The study also revealed that as age increases, the degree of fat infiltration in the psoas muscle, one of the important muscles involved in the maintenance of lumbar stability, also increases. Li et al. [7] studied 367 subjects by QCT and showed a negative correlation between BMD and fat infiltration of the paraspinal muscles.

Dual-energy X-ray absorptiometry (DXA), QCT, and magnetic resonance imaging (MRI) are the main techniques used for measuring body composition. DXA cannot differentiate between cortical and trabecular bone, and its results are influenced by factors such as osteophytes, adjacent structures, and patient body size, leading to an overestimation of BMD, nor can it accurately measure fat content of the tissue [8]. MRI, while capable of quantifying fat content in specific areas using special sequences, is time-consuming, expensive, and has many contraindications [9]. In contrast, QCT can measure volumetric BMD (vBMD), is not affected by cortical bone or surrounding structures, and can be synchronized with routine CT scans without additional radiation dose. QCT devices can quantitatively measure lumbar BMD, abdominal fat, and fat content of the paraspinal muscles in one scan, proving to be a reliable method for non-invasive assessment of body composition [10–11].

The study aimed to explore the correlations between abdominal adipose tissue and psoas muscle fat content and lumbar BMD, providing quantitative data reference for the prevention and treatment of osteoporosis.

Subject and methods

Study subjects

The study included 457 females and 404 males, aged 22 to 79 years (mean age, 51.4 ± 16.6 years), who underwent chest CT combined with QCT examination in our hospital from January 2020 to June 2022. They were divided into six age groups: 20–29 years, 30–39 years, 40–49 years, 50–59 years, 60–69 years, and 70–79 years. Age group 20–29 years consisted of 92 subjects (46 males, 46 females), age group 30–39 years consisted of 170 subjects (95 males, 75 females), age group 40–49 years consisted of 130 subjects (62 males, 68 females), age group 50–59 years consisted of 148 subjects (70 males, 78 females), age group 60–69 years consisted of 202 subjects (76 males, 126 females), age group 70–79 years consisted of 119 subjects (55 males, 64 females), respectively. According to the obesity criteria of the Working Group on Obesity in China (WGOC), the subjects were divided into the following groups: low weight group(LW, BMI: <18.5 kg/m^2), $n = 23$; normal weight group(NW, BMI: 18.5–23.9 kg/m^2), $n = 381$; overweight group(OW, BMI: 24.0–27.9 kg/m^2), $n = 320$; and obese group(OB, BMI: >28.0 kg/m^2), $n = 117$. Exclusion criteria include (1) patients with thoracolumbar fractures, tumor, infections or surgery, (2) patients with bone metabolic diseases, (3) patient with endocrine diseases or medication history affecting bone metabolism. Finally, a total of 861 participants were included in the study (Fig. 1).

Imaging examinations

Chest CT scans were performed on a CT750 scanner (GE Healthcare, Milwaukee, WI, USA). Prior to scanning, calibration was done using a QCT calibration phantom. The patient was placed in a supine position, and the scan range extended from 2 cm above the upper margin of the first rib to the lower margin of the third lumbar vertebral body. The scan parameters were as follows: field of view 50 cm, reconstructed field of view 38 cm, tube voltage 120 kV, tube current 200–300 mA, and slice thickness 1.25 mm. Images were transferred to the QCT workstation (Mindways QCT PRO V6.1, USA).

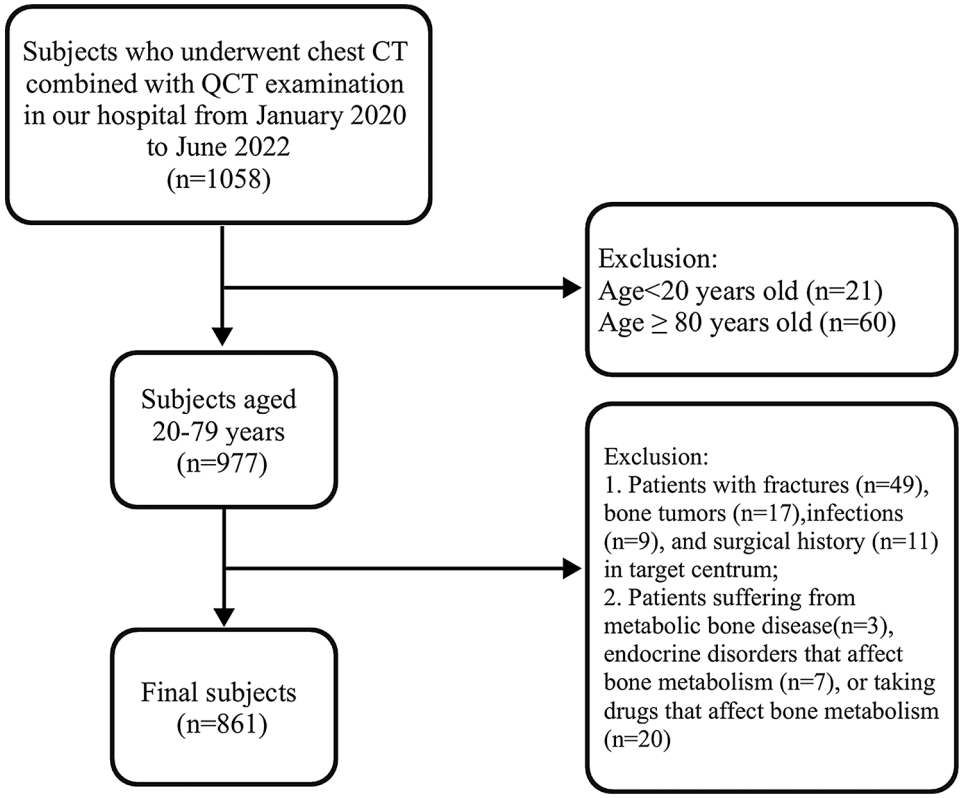

Fig. 1 Flow chart of subject enrollment and exclusion

Data measurement

Measurements were conducted by two experienced radiologists (MXH, with 12 years of experience in musculoskeletal imaging diagnosis; WZ, with 33 years of experience in musculoskeletal imaging diagnosis), and the results were averaged.

BMD measurement

Using the "New 3D Spine Examination Analysis" in QCT PRO software, the vBMD of the trabecular bone in the L1, L2, and L3 vertebrae was measured separately, and the average vBMD of L1–L3 was taken as the BMD of the vertebra. By adjusting the axial, coronal, and sagittal images simultaneously, the region of interest (ROI) was placed in the center of the vertebra being measured. The ROI had a height of 9 mm and a distance of more than 3 mm from the cortical bone boundary to avoid partial volume effects of the cortical bone, and the ROI was positioned away from areas of bone sclerosis and the posterior vertebral venous plexus (Fig. 2).

Abdominal adipose tissue measurement

Using the "New QCT slice range pick" on the QCT workstation, VAT and SAT area (cm^2) were semi-automatically measured (Fig. 3). SAT was defined as the area of fat between the skin and the outer edge of the abdominal and back muscles at the level of the L3 vertebra. VAT was defined as all intra-abdominal fat tissue regions at the level of the L3 vertebra, including the rectus abdominis, external oblique, quadratus lumborum, and enclosed area below the outer edge of the lumbar muscle.

Measurement of psoas muscle fat content

At the level of the L3 vertebra, the fat content of the psoas major was measured using the "New QCT slice range pick" method. An ROI was placed on each side of the psoas major muscle as centrally as possible without exceeding the muscle contour (Fig. 4). The area of the ROI is approximately 150 ~ 200 mm^2, which is placed in the center of the psoas muscle to avoid exceeding the psoas contour. The measured values were recorded as the left and right psoas major fat content (Fpsoas-L, Fpsoas-R), and their average was recorded as the psoas muscle fat content (Fp).

Statistical methods

Statistical analyses were conducted using SPSS 26.0 (IBM Corp., USA). The intra-class correlation coefficient (ICC) was used to calculate the inter-observer and intra-observer measurement reliability. Independent-sample t-tests were used to compare the differences in BMD, SAT, VAT, and Fp between males and females within the same age group. One-way analysis of variance (ANOVA) and least-square difference tests were employed to

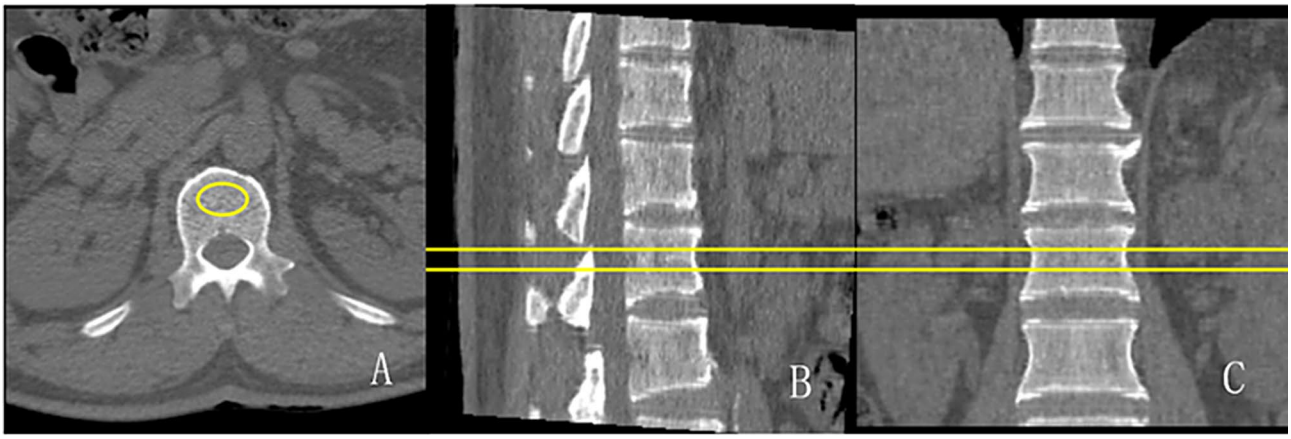

Fig. 2 Measurement of BMD of L1 by QCT PRO software. **A** shows that on the axial position, ROI (yellow ellipse) is located in the center of the L1 vertebra; **B** and **C** show the sagittal and coronal positions of ROI, respectively. ROI is located in the center of the vertebral body, avoiding the osteosclerosis area of the vertebral body and the posterior vertebral venous plexus

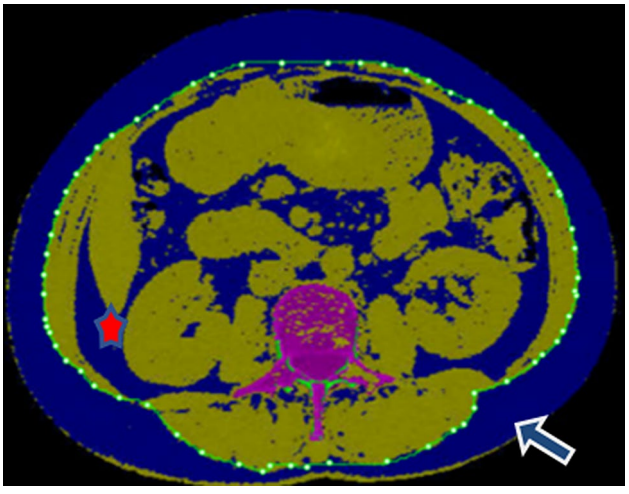

Fig. 3 Measurement of abdominal fat content at the L3 vertebra level by QCT PRO software. Total adipose tissue: all blue areas; SAT: blue area outside green circle (shown by →); VAT: Blue area in green circle (shown by ☆)

compare the intergroup differences in BMD, SAT, VAT, and Fp among different age groups for both males and females. Kruskal-Wallis H test was used to compare BMD, SAT, VAT, and Fp among different BMI groups. Pearson correlation analysis was utilized to examine the relationship between BMD and the fat content of abdominal fat as well as the psoas major muscle fat in males and females. $P < 0.05$ was considered statistically significant.

Results

General characteristics of the subjects

A total of 861 subjects were included in this study, with ages ranging from 20 to 79 years, and an average age of 51.04 ± 16.14 years. Detailed general characteristics is provided in Table 1. The interobserver agreement of the mean QCT measurements was good to excellent (Table 2).

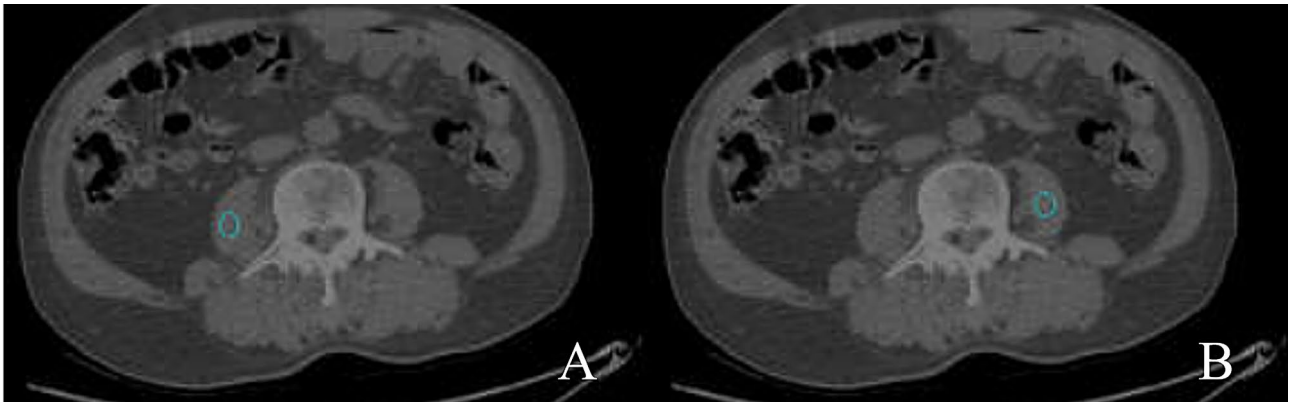

Fig. 4 Measurement of psoas fat content at the level of the L3 vertebra by QCT PRO software. **A** and **B** show that on the axial position, the ROI of the left and right psoas major muscles were selected at the L3 vertebra level respectively. The ROI is located in the center of the psoas and does not extend beyond the periphery of the psoas

Table 1 General characteristics of the subjects

Variables	Male($n=404$)	Female($n=457$)	*P*
Age	49.46 ± 16.76	52.42 ± 15.47	0.019
height(cm)	172.79 ± 6.61	161.42 ± 5.33	0.013
weight(kg)	73.88 ± 10.50	63.45 ± 10.21	0.348
BMI(kg/cm^2)	24.73 ± 3.52	24.28 ± 3.52	0.06
BMD(mg/cm^3)	123.06 ± 40.85	114.93 ± 51.07	<0.001
SAT(cm^2)	124.89 ± 52.08	153.62 ± 57.03	0.043
VAT(cm^2)	165.57 ± 69.81	130.51 ± 61.41	0.011
Fp(%)	4.13 ± 3.20	4.58 ± 3.39	0.237

Table 2 The interobserver agreement of the mean QCT measurements

Parameters	ICC	
	Inter-observer	Intra-observer
BMD(kg/m^2)	0.941	0.958
SAT(cm^2)	0.966	0.979

Comparison of BMD, SAT, VAT, and Fp between males and females within the same age group

In individuals below 60 years old, females exhibited higher BMD compared to males, with significant differences observed in the 30–39 age group ($P<0.001$). Females over 60 years old had significantly lower BMD compared to males, with significant differences observed in the 60–69 and 70–79 age groups ($P<0.001$ for both). Subcutaneous adipose tissue was higher in females across all age groups, and except for the 20–29 and 40–49 age groups, the differences were statistically significant ($P_{30-39} = 0.037$, $P_{50-59} < 0.001$, $P_{60-69} < 0.001$, $P_{70-79} < 0.001$). Conversely, visceral adipose tissue was lower in females across all age groups, and except for the 20–29 age groups, the differences were statistically significant ($P<0.001$ for all). No statistically significant differences were observed in the fat content of the psoas major muscle between males and females across all age groups. Table 3 shows the specific values.

Pattern of changes in lumbar BMD, abdominal adipose tissue, and psoas muscle fat content with age

In both males and females, the lumbar BMD peaked in the 20–29 age group, with females having a higher peak BMD than males. As age increased, both male and female lumbar BMD decreased. Apart from the BMD between 20–29 age and 30–39 age groups in female, statistically significant differences in BMD were observed between all other age groups for both males and females ($P<0.001$).

The VAT values increased with age for both sexes. There were no statistically significant differences in VAT between the 20–29 age group and the 30–39 age group, and between the 50–59 age group and the 60–69 age group, while there were statistically significant differences in VAT among the other female age groups ($P<0.001$). In males, a statistically significant difference in VAT was observed between the 20–29 and 30–39 age groups ($P<0.001$). VAT was higher in older age groups (60–69 and 70–79 age groups) where it differed significantly from the younger age groups (20–29 and 30–39 age groups) ($P<0.001$).

SAT was found to peak in the age groups of 50–59 in females and 30–39 in males. In males, the SAT did not differ significantly among age groups. For females, SAT was observed to be significantly lower in the 40–49 age group compared to the 20–29, 30–39, 50–59, 60–69, and 70–79 age groups ($P<0.001$).

Psoas major muscle fat content increased with age for both males and females. Table 3; Fig. 5 show the specific data.

Comparison of BMD, SAT, VAT, Fp among different BMI groups

Among the total study subjects, BMD showed a decreasing trend from the low weight group to the obese group, while SAT, VAT, and Fp showed an increasing trend from the low weight group to the obese group. There were

Table 3 Comparison of various measurement indicators between males and females within the same age group by independent-sample t-tests and comparison of indicators among different age groups for male and female subjects by ANOVA

Variable		20–29 years	30–39 years	40–49 years	50–59 years	60–69 years	70–79 years	F	*P*
		($n=46$)	($n=95$)	($n=62$)	($n=70$)	($n=76$)	($n=55$)		
BMD	Male	164.16 ± 30.61	149.72 ± 32.99	135.64 ± 28.52	109.27 ± 24.05	99.46 ± 31.14	78.56 ± 29.28	72.07	<0.001
(mg/cm^3)	Female	174.68 ± 29.42	169.39 ± 27.55	136.45 ± 27.61	114.62 ± 37.84	78.68 ± 25.01	56.69 ± 28.16	188.81	<0.001
	P	0.094	< 0.001	0.87	0.313	< 0.001	< 0.001		
SAT	Male	115.35 ± 66.74	133.73 ± 59.02	125.02 ± 44.41	121.78 ± 47.27	126.19 ± 39.53	119.57 ± 54.38	1.03	0.399
(cm^2)	Female	142.69 ± 74.37	154.01 ± 66.79	125.33 ± 43.83	170.13 ± 52.27	164.52 ± 53.89	151.93 ± 43.61	6.26	<0.001
	P	0.065	0.037(<0.05*)	0.968	< 0.001	< 0.001	< 0.001		
VAT	Male	89.23 ± 46.05	150.54 ± 59.77	167.66 ± 53.87	180.31 ± 70.27	185.59 ± 66.48	206.58 ± 68.83	22.12	<0.001
(cm^2)	Female	74.56 ± 38.97	85.22 ± 57.32	120.61 ± 54.97	139.04 ± 46.37	153.49 ± 46.78	178.39 ± 61.79	39.82	<0.001
	P	0.101	< 0.001	< 0.001	< 0.001	< 0.001	0.021(<0.05*)		
Fp (%)	Male	1.51 ± 1.65	2.90 ± 2.12	3.71 ± 2.81	4.37 ± 2.39	5.83 ± 3.88	6.26 ± 3.45	23.61	<0.001
	Female	2.14 ± 2.36	2.64 ± 2.05	3.67 ± 2.72	4.65 ± 3.11	5.83 ± 3.29	6.98 ± 3.78	26.22	<0.001
	P	0.14	0.436	0.936	0.527	0.989	0.286		

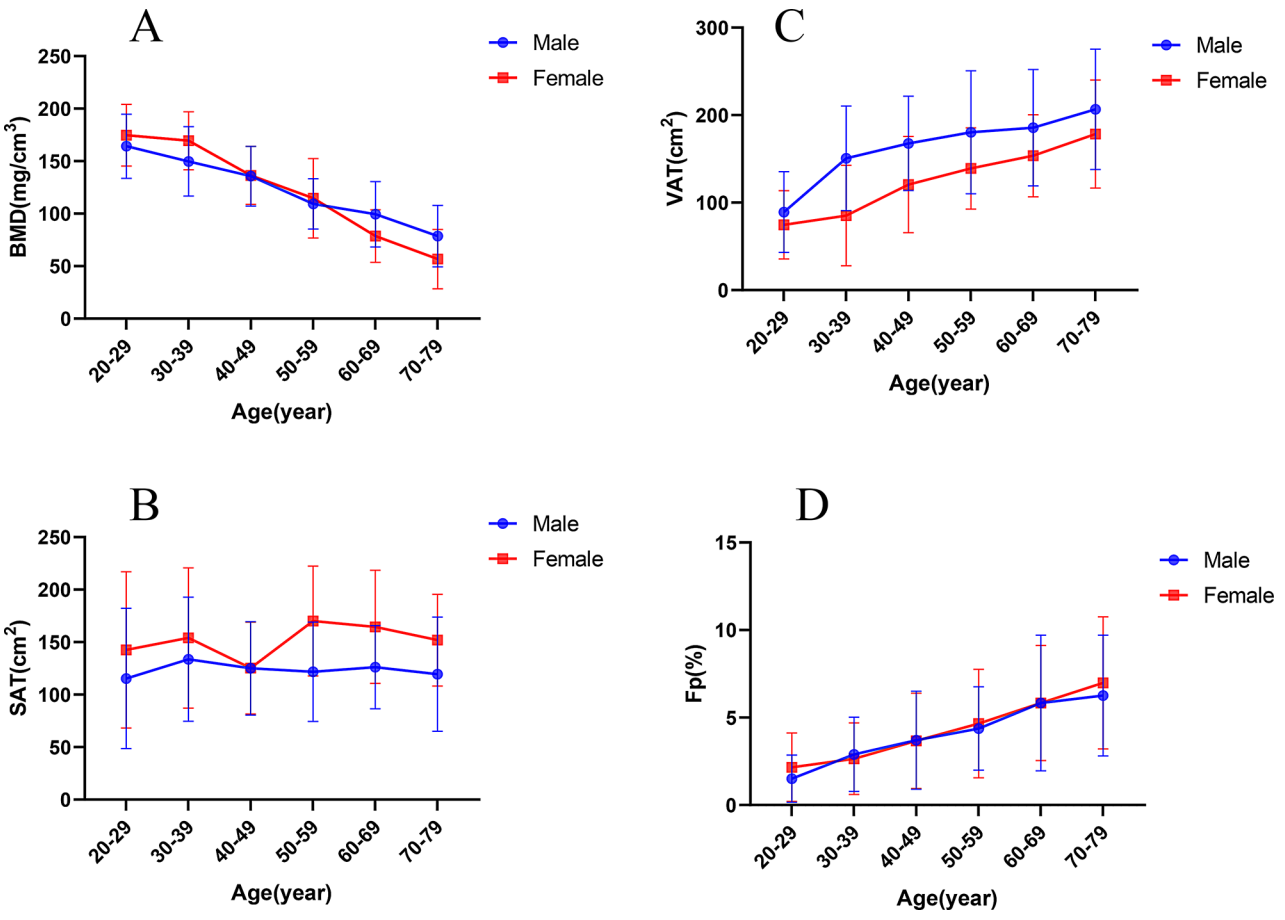

Fig. 5 Comparison of BMD, SAT, VAT and psoas muscle fat content among different age groups for both males and females by independent-sample t-tests. **A** shows the comparison of BMD among different age groups for both males and females; **B** shows the comparison of SAT among different age groups for both males and females; **C** shows the comparison of VAT among different age groups for both males and females; **D** shows the comparison of psoas muscle fat content between among different age groups for both males and females

Table 4 Comparison of BMD, SAT, VAT, fp among different BMI groups by Kruskal-Wallis H test

Variables	LW group	NW group	OW group	OB group	*P*
BMD(mg/cm^2)	146.72 ± 46.06	125.67 ± 50.68	115.69 ± 45.98	112.41 ± 42.64	<0.001
SAT(cm^2)	83.63 ± 52.72	123.00 ± 48.75	150.93 ± 51.79	197.43 ± 57.28	<0.001
VAT(cm^2)	70.64 ± 41.15	114.82 ± 53.21	171.84 ± 61.50	194.03 ± 61.94	<0.001
Fp(%)	2.08 ± 2.15	3.79 ± 3.24	4.77 ± 3.07	5.45 ± 3.50	<0.001

statistically significant differences among the groups ($P < 0.001$). See Table 4; Fig. 6.

Correlation of lumbar BMD with BMI, abdominal adipose tissue and Psoas fat content

Both VAT and Fp were negatively correlated with BMD in both men and women. BMI, SAT in females showed a negative correlation with BMD, although the correlation was weak ($R = -0.170$, $P < 0.001$; $R = -0.112$, $P < 0.001$), while BMI, SAT in males showed no significant correlation with BMD ($P = 0.113$, $P = 0.916$). Specific data can be found in and Figs. 7 and 8.

Correlation between abdominal adipose tissue and psoas major fat content

Both VAT and SAT were positively correlated with Fp in both males and females, with VAT showing a stronger correlation with Fp than SAT (male $R = 0.405$, $P < 0.001$; female $R = 0.521$, $P < 0.001$). Correlation between abdominal adipose tissue and psoas major fat content were summarized in and Figs. 9 and 10.

Discussion

This study found that both VAT and Fp were negatively correlated with BMD and Fp increased with the increase of SAT and VAT in both men and women. BMI, SAT showed a negative correlation with BMD in females.

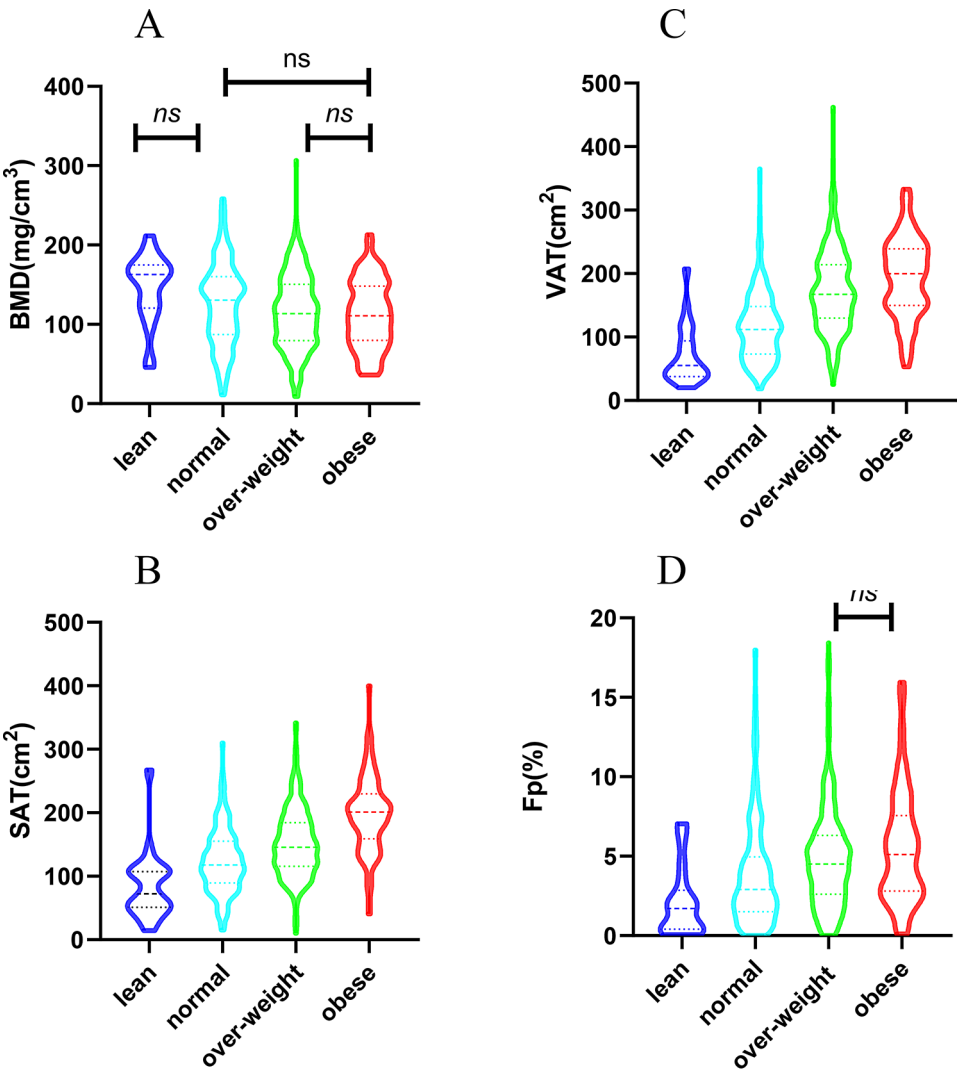

Fig. 6 Comparison of BMD, SAT, VAT, Fp among different BMI Groups by Kruskal-Wallis H test. Figure **A** shows there are statistically significant differences in BMD between NW group and OW group, LW group and OW group, LW group and OB group. **B** shows there are statistically significant differences in SAT among all BMI group. **C** shows there are statistically significant differences in VAT among all BMI group. **D** shows there are statistically significant differences in Fp among all BMI group expect between OW group and OB group. ($P<0.001$)

The impaction of the BMI on BMD is complex because BMI is only one of the indexes of obesity. Li Y [12] conducted a study on middle-aged adults showed that it may be beneficial to appropriately increase BMI to promote BMD. Postmenopausal osteoporosis in women is confirmed that there was a positive relationship between increased BMD values and increased BMI values by Głogowska-Szeląg [13].The present studied showed that BMI has no correlation in male which may be due to the fact that in men with higher BMI, the increased body weight may come more from muscle rather than fat, as muscle has a remodeling effect on bones. Alternatively, it could be because various factors act in concert to obscure the effect of body weight on bone density. The weak correlation between BMI and BMD in women may be related to the fact that fat distribution, estrogen levels are sensitive to changes in BMI, and bone metabolism is highly dependent on body weight.

The impact of abdominal adipose tissue on BMD has long been a subject of controversy. Previous studies have suggested that VAT, which has higher metabolic activity than SAT, can more effectively influence BMD by altering bone metabolism. Zhang et al. [14] conducted a study on 400 adult Chinese individuals, showing no significant correlation between VAT and BMD; however, the present study reveals a negative correlation between BMD and VAT, where BMD decreases with increasing VAT. Zhang et al. [15] studied VAT in relation to menopausal status in Chinese women, finding that postmenopausal groups had significantly higher VAT compared to

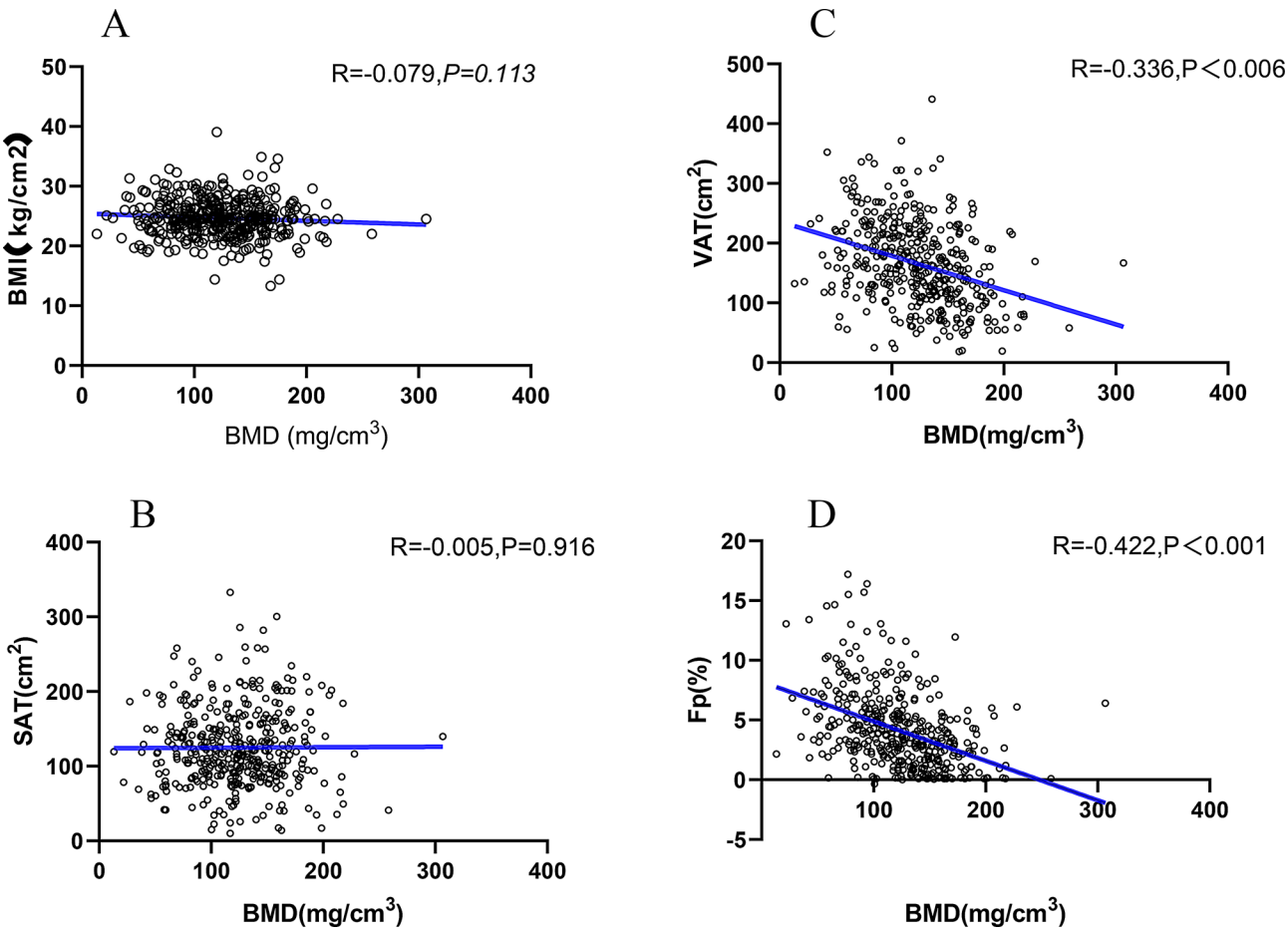

Fig. 7 Correlations between male BMD and BMI, SAT, VAT, and psoas major muscle fat content by Pearson correlation analysis. There was no correlation between BMD and BMI ($P=0.113$), SAT ($P=0.916$); the BMD value was negatively correlated with VAT and Fp ($P<0.001$)

peri-menopausal groups, and both groups' VAT adversely affected the lumbar spine BMD. Crivelli et al. [16] conducted research on 58 severely obese women, indicating that both visceral and subcutaneous adipose tissue may be detrimental to bone health, and severe obesity may increase the risk of vertebral fractures. Sharma et al. [17], through DXA, similarly confirmed a positive correlation between VAT and BMD; however, after controlling for BMI, VAT emerged as a negative predictor for BMD. The present study, involving 861 adults, demonstrated that visceral adipose tissue is detrimental to lumbar spine BMD, showing a negative correlation. Visceral adipose tissue secretes high levels of pro-inflammatory cytokines such as TNF and IL-6, which induce the generation of osteoclasts and bone resorption. Additionally, high concentrations of TNF and IL-6 can suppress adiponectin secretion, reducing its stimulatory effects on osteoblast proliferation, thereby reducing bone synthesis and increasing absorption, leading to decreased BMD [18]. SAT, known as "protective fat", produces leptin and adiponectin, which enhance bone quality by stimulating osteoblast activity. Furthermore, SAT is a primary source of aromatase, which is necessary for estrogen synthesis. Estrogen can reduce bone resorption and stimulate bone formation, thereby maintaining bone health. Ackerman et al.'s [19] study showed a positive correlation between subcutaneous adipose tissue and bone density in young women. Zhang et al. [13] found a negative correlation between BMD and SAT in postmenopausal women. The present study indicates that male SAT has no significant correlation with BMD, while female SAT shows a slight negative correlation with BMD, suggesting that the impact of SAT on bone density is a complex process and when metabolic dysregulation of adipose tissue outweighs the mechanical stimulation provided by SAT, its protective effect on bone density is diminished. When obesity exceeds a certain threshold, the harmful effects of SAT on bone quality may outweigh its protective effects.

Paravertebral muscles play an important role in maintaining spinal stability. Currently, the assessment of paravertebral muscle quality is primarily done by measuring the cross-sectional area, and further studies [20–21] have correlated the paravertebral muscles with lumbar vertebral BMD. Engelke et al. [22] found that the volume of

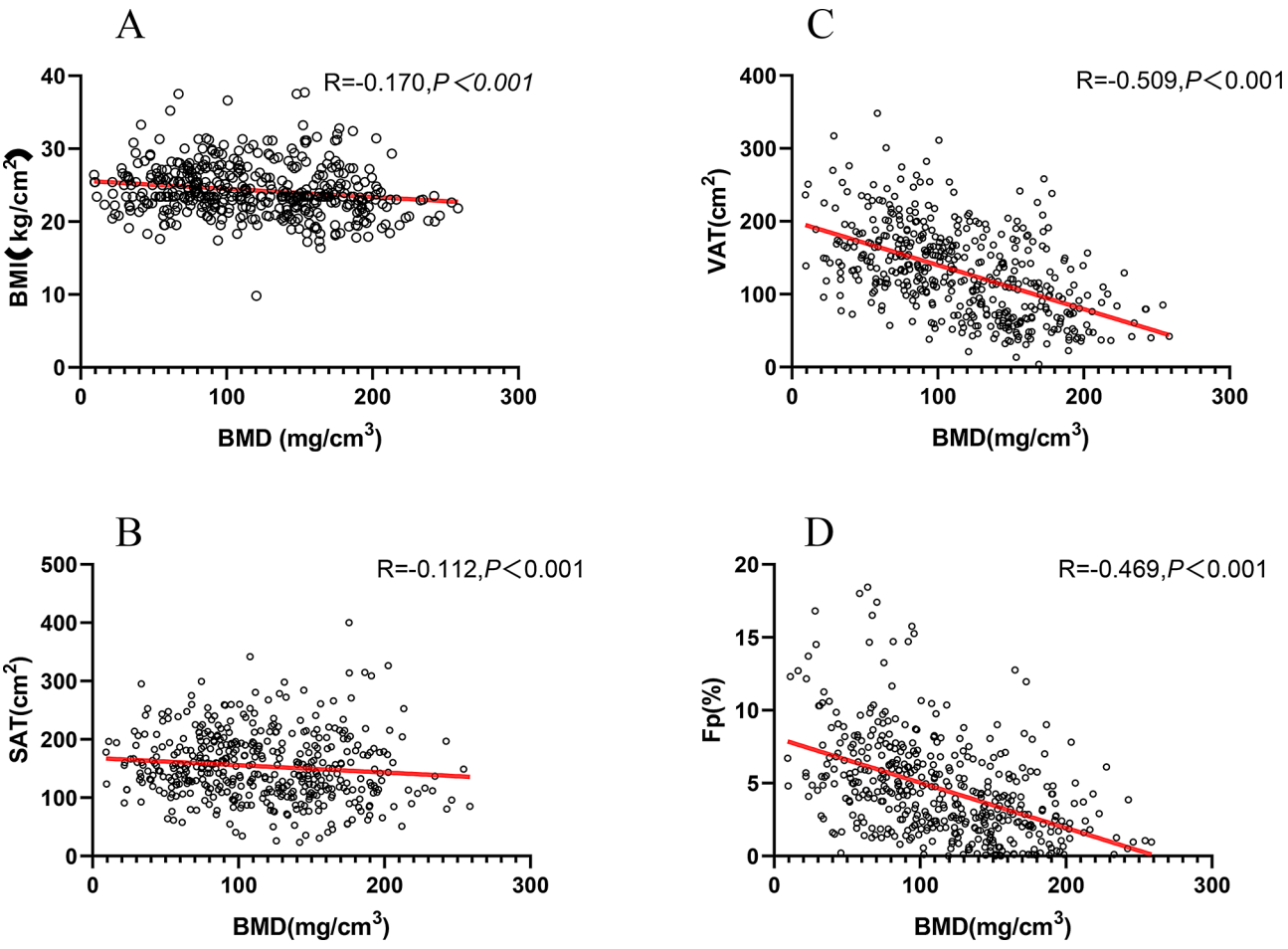

Fig. 8 Correlations between female BMD and BMI, SAT, VAT, and psoas major muscle fat content by Pearson correlation analysis. The BMD value was negatively correlated with BMI, SAT, VAT, and Fp ($P < 0.001$)

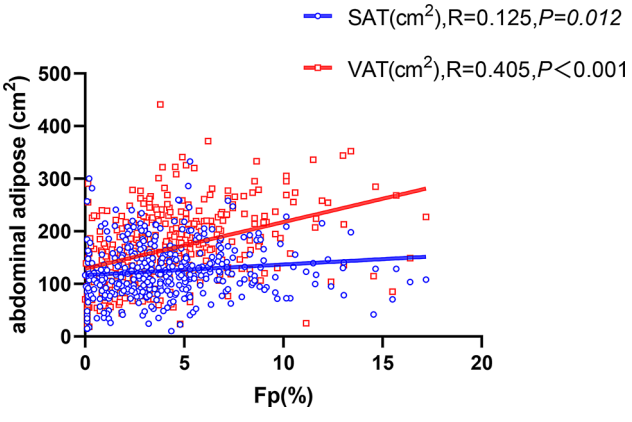

Fig. 9 Correlations of male psoas fat content with SAT and VAT by Pearson correlation analysis. The fat content of psoas major muscle was positively correlated with the SAT and VAT ($P < 0.001$)

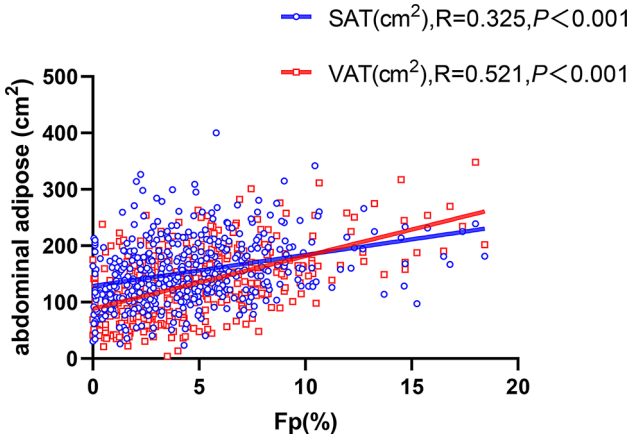

Fig. 10 Correlations of female psoas fat content with SAT and VAT by Pearson correlation analysis. The fat content of the psoas major muscle was positively correlated with the SAT and VAT ($P < 0.001$)

the psoas major muscle remains relatively stable with age, but the fat content within the muscle increases. Yang et al. [23] proposed that the fat content of the paravertebral muscles is an independent factor predicting lumbar vertebral BMD, suggesting that qualitative assessment of paravertebral muscle fat infiltration may more objectively evaluate clinical outcomes. The psoas major muscle is a single muscle bundle, and the invisible fat infiltration in

and between myocytes can more accurately reflect the intramuscular fat infiltration during the degeneration process. The present study utilized QCT to measure the fat content of the psoas major muscles to objectively reflect fat infiltration within the muscles. Li et al. [7] also demonstrated that with aging, the average fat content of the paravertebral muscles increases, emphasizing the impact of aging on sarcopenia. Yang et al. [23], by MRI examinations, revealed that regardless of sex, paravertebral muscle fat content increases with age, consistent with the present study's findings that the psoas major muscle fat content increased with age from adulthood onwards. Furthermore, the correlation analysis in the present study showed a negative relationship between the psoas major muscle fat content and lumbar vertebral BMD. This suggests that individuals with osteoporosis exhibit elevated fat infiltration within the psoas major muscle. Studies by Li et al. [24] using QCT similarly demonstrate a negative correlation between low bone mass and paravertebral muscle fat infiltration, consistent with the findings of the present study.

This study conducted a correlation analysis of the fat content of the psoas major muscle and the abdominal adipose tissue, finding a positive correlation between the fat content of the psoas major muscle and same-layer abdominal SAT and VAT, with a stronger correlation with VAT. This may suggest that the fat content of the psoas major muscle is more closely related to abdominal obesity than peripheral obesity. Previous studies have paid less attention to the correlation between the fat content of the psoas major muscle and abdominal adipose tissue. Ronnie et al. [25] conducted a retrospective study on subjects aged 18 years or older who underwent abdominal CT scans, showing that hepatic steatosis is positively correlated with fat content of trunk muscle, and that hepatic steatosis appears to be an independent predictor of fat content of psoas major muscle. The results of the present study may be related to the "energy overflow hypothesis". In obese individuals, fat cells in the abdominal fat increase in size, and excessive lipid deposition can lead to the accumulation of excess fat in other tissues such as skeletal muscle [26].

There are some limitations to this study. Firstly, due to insufficient sample size, this study did not conduct in-depth analysis on individuals aged 0–20 and over 80 years old. In the future, the sample size should be further expanded to explore the relationship between BMD and visceral adipose tissue and psoas major muscle fat content in males and females of all age groups. Secondly, this study was a single-center study and did not explore the impact of different regions and ethnicities on the results. A multicenter study including participants from more regions will be conducted in the future.

Conclusion

Visceral adipose tissue and psoas major muscle fat content increase with age, while BMD decreases with age. Visceral adipose tissue and psoas major muscle fat content are negatively correlated with lumbar spine BMD. Excessive deposition of visceral adipose tissue and psoas major muscle fat is a risk factor for osteoporosis.

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Author contributions
X: Experimental design, data statistical analysis, figure creation, manuscript writing; FL Z, YQ Z: Data collection, statistical analysis. W, M: Research guidance, manuscript review, funding support.

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Data availability
The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
In accordance with the Declaration of Helsinki, this study is approved by the Ethics Committee of Tianjin Hospital (Approved Text No.: 2021 医伦审 084). This study is a retrospective study, so it did not require patient informed consent.

Consent to publish
Not applicable.

Competing interests
The authors declare no competing interests.

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