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Associations between paraspinal muscles fatty infiltration and lumbar vertebral bone mineral density – An investigation by fast kVp switching dual-energy CT and QCT☆

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ABSTRACT

Purpose: To investigate the relationship between paraspinal muscles fat content and lumbar bone mineral density (BMD).
Methods: A total of 119 participants were enrolled in our study (60 males, age: 50.88 ± 17.79 years, BMI: 22.80 ± 3.80 $kg{\cdot}m^{-2}$; 59 females, age: 49.41 ± 17.69 years, BMI: 22.22 ± 3.12 $kg{\cdot}m^{-2}$). Fat content of paraspinal muscles (erector spinae (ES), multifidus (MS), and psoas (PS)) were measured at (ES L1/2-L4/5; MS L2/3-L5/S1; PS L2/3-L5/S1) levels using dual-energy computed tomography (DECT). Quantitative computed tomography (QCT) was used to assess BMD of L1 and L2. Linear regression analysis was used to assess the relationship between BMD of the lumbar spine and paraspinal muscles fat content with age, sex, and BMI. The variance inflation factor (VIF) was used to detect the degree of multicollinearity among the variables. $P < .05$ was considered to indicate a statistically significant difference.
Results: The paraspinal muscles fat content had a fairly significant inverse association with lumbar BMD after controlling for age, sex, and BMI (adjusted $R^2 = 0.584$–0.630, all $P < .05$).
Conclusion: Paraspinal muscles fat content was negatively associated with BMD.
Paraspinal muscles fatty infiltration may be considered as a potential marker to identify BMD loss.

1. Introduction

As lifespan increase, age-related degeneration in musculoskeletal (MSK) system is becoming one of the great social and medical challenges facing humanity. Osteoporosis is a widespread MSK disorder resulting from low bone mineral density (BMD) and the changes in bone geometry, and microstructure. Bone and muscle are two highly interconnected tissues not only anatomically, but also metabolically, chemically and functionally, and so called "bone-muscle unit" [1]. Fatty infiltration, as common risk factors in age-dependent muscle and bone loss and frailty, is a major role that affects the MSK unit. To date, there have been studies mostly evaluated muscle and body composition (fat

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Abbreviations: ES, Erector spinae; MS, Multifidus; PS, Psoas; DECT, Dual-energy computed tomography; QCT, Quantitative computed tomography; VIF, Variance inflation factor; MSK, Musculoskeletal; BMD, Bone mineral density; FM, Fat mass; LM, Lean mass; DXA, Dual-energy x-ray absorptiometry; BIA, Bioimpedance analysis; MRI, Magnetic resonance imaging; EMCL, extramyocellular lipids; IMCL, intramyocellular lipids; FF, fat fraction; GSI, Gemstone spectral imaging; MD, Material decomposition; ASiR-V, Adaptive statistical iterative reconstruction-Veo; CNR, Contrast-to-noise ratio; PDFF, Proton density fat fractions; FI %, Fatty infiltration ratio.

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mass (FM) and lean mass (LM)) independently, but scarcely assessed the adipose tissue in the adjacent muscle.

Several imaging techniques can assess such morphologic changes by various cross section imaging methods, including Dual x-ray absorptiometry (DXA), bioimpedance analysis (BIA), magnetic resonance imaging (MRI), and computed tomography (CT). Among them only CT and MRI can provide three-dimensional (3D) measurements and show very good contrast between muscle and adipose tissue. The conventional CT can only reflect fat content in muscle by measuring the muscle density or indirectly using some models and statistical procedures to determine the percentage of adipose tissue volume within the muscle [2,3]. The combined % fat of muscle (extramyocellular lipids [EMCL] and intramyocellular lipids [IMCL]) described as fat fraction (FF) can be directly quantified by MRI [4]. However, clinically, MRI is usually limited by long scanning time, high standards for patients, and expensive costs.

More recently, rapid advances in the field of high-resolution quantitative imaging techniques have shown promising results and improved dramatically our knowledge of musculoskeletal disorders. Recently introduced dual-energy (DE) CT offers not only monochromatic images, but also accurate material decomposition (MD) images by gemstone spectral imaging (GSI) [5,6]. MD images provide qualitative and quantitative information about tissue composition. Some studies have demonstrated that the X-ray attenuation of any kind of tissue could be determined by the proportions of its base materials, and the density of base material could reflect the content of the actual material with appropriate selection of base materials [7–9]. Fat content of muscles can be estimated by the quantification of base materials using MD algorithms. Several applications of MD images have been developed in different body systems, including musculoskeletal system etc [10,11]., and active research is ongoing to improve existing applications and to explore more underlying applications of this technique. Of note, DECT could provide wider detector coverage, better image quality and the radiation exposure dose of DECT with ASiR-V technique is equal to or lower than the conventional CT [9,12,13].

Improving the understanding of the relationship between fatty infiltration of skeletal muscle and BMD is of paramount importance to develop interventions benefiting musculoskeletal function whilst reduce adverse clinical outcomes such as fractures and falls. In our present study, different from previous researches, fat and muscle material basis pair was used to assess fat content within lumber paraspinal muscles by using MD techniques of DECT to further investigate the relationship between paraspinal muscles fat content and lumbar BMD.

2. Materials and methods

2.1. Study population

For our retrospective study, ethics approval was obtained from the institutional ethics committee in the First Hospital of Hunan University of Chinese Medicine (NO.: HN-LL-KY-2021–019–01), and the informed consents were waived. The data were collected from participants who underwent DECT lumbar examinations from June 2021 to February 2022. The demographic characteristics (age, gender, and BMI) were recorded before scanning. The exclusion criteria included lack of a simultaneous QCT calibration phantom, spinal tumor, spinal tumor-like lesion or infection, lumbar fracture, spinal surgery, severe degenerative changes, contrast enhanced scan, spinal deformity, and hematologic disorder [14,15]. Finally, a total of 119 participants were enrolled. Fig. 1 shows a flowchart of the study following the guidelines of Standards for Reporting of Diagnostic Accuracy. The sample size consideration is shown in Supplementary A1.

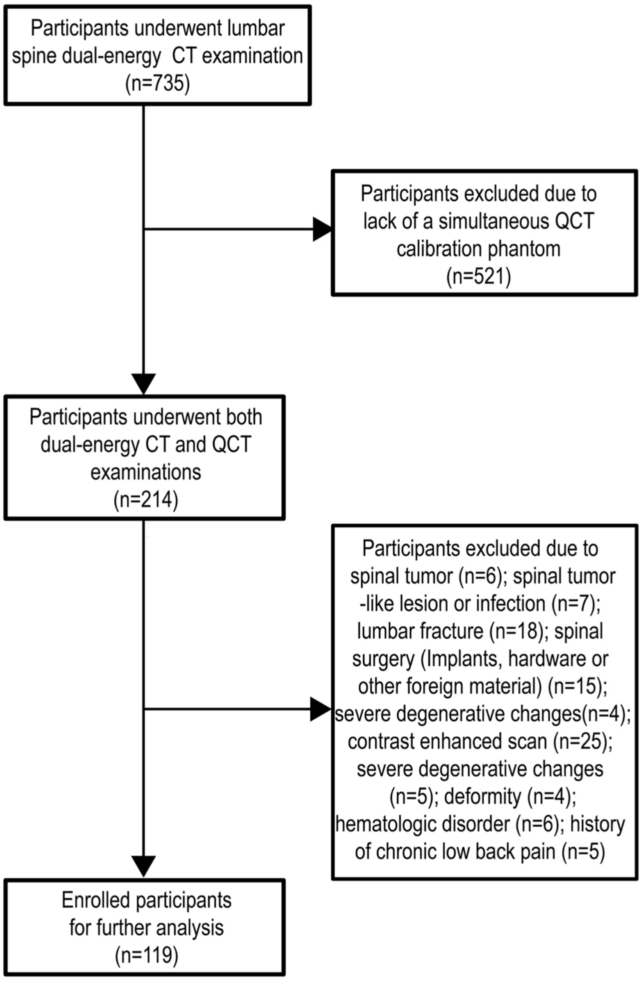

Fig. 1. : Flow chart shows Standards for Reporting of Diagnostic Accuracy Studies.

2.2. Dual-energy CT and phantom-calibrated QCT scan protocols

In our study, Non enhanced CT imaging of the spine was performed on a Revolution Gemstone Spectral Imaging (GSI) CT scanner (GE Medical Systems, Milwaukee, WI, USA) from L1 to S1. The scanning parameters of DECT are exactly shown in Table 1. Of note, the radiation exposure dose during the lumbar examination of DECT with ASiR-V technique is equal to or lower than the conventional CT. The radiation exposure dose consideration is shown in supplementary A2. A QCT calibration phantom (QRM, Moehrendorf, Germany) was placed beneath the spine and scanned simultaneously according to the protocol of our previous study [16], which could avoid additional radiation exposure of QCT examinations. Our DECT scanner performed 'Fast calibration' protocol each week to ensure correct CT numbers of water

Table 1
Scanning parameters of dual-energy CT.

CT parameters	Details
Mode	GSI helical
Rotation speed (s/rot)	0.8
Pitch	0.984:1
Tube voltage (kVp)	80/140
Tube current (mA)	230
Beam collimation (mm)	256 × 0.625
ASiR-V	50%
Recon type	Stnd
CTDIvol (mGy)	9.09

Note:
GSI = Gemstone Spectral Imaging
ASiR-V = Adaptive Statistical Iterative Reconstruction-Veo
CTDIvol = Volume Computed Tomography Dose Index

and no artifacts, the accuracy and precision of our QCT devices based on DECT was tested each week by using the same scan protocol.

2.3. *Image post-processing of dual-energy CT and phantom-calibrated QCT Data*

Dicom data with datafile were transferred to the advantage workstation (AW4.6; GE Medical Systems, Milwaukee, WI, USA) to generate 70 keV monochromatic images and Fat (Muscle) images. Material decomposition data and QCT data were evaluated by H.G. and Y.L. (with 5 and 8 years of experience in musculoskeletal radiology respectively) respectively. 70 keV monochromatic images were used to measure CT values of lumbar paraspinal muscles, vertebrae and phantom in this study because approximately 70 keV monochromatic images had the lower image noise and the higher contrast-to-noise ratio (CNR) than 120-kVp CT images. The following lumbar paraspinal muscles were evaluated: erector spinae (ES), multifidus (MS) and psoas (PS). 5-mm axial images were viewed for further analysis. For paraspinal muscles fat content measurement, all the muscles were measured on the bilateral sides of each lumbar intervertebral level paralleling to the vertebral endplates (ES L1/2-L4/5; MS L2/3-L5/S1; PS L2/3-L5/S1) to calculate the muscles mean fat content. The ROI was manually constructed on individual muscles within a 2–3 mm inner margin to avoid blurred margins and to exclude the fat regions in the periphery, while avoiding gross visible blood vessels (Fig. 2a-b). In addition, the density of fat (muscle), was measured in material decomposition (MD) images. BMD measurement and calculation are as described in the previous study [16] (Fig. 2c).

2.4. *Statistical analysis*

SPSS statistical analysis software (v.20.0; IBM) was used for statistical analysis. The homogeneity and normality of the data were performed using the Levene's and Shapiro-Wilk tests, respectively. Linear regression analysis was used to assess the relationship between BMD of the lumbar spine and paraspinal muscles fat content controlled for age, sex, and BMI. The variance inflation factor (VIF) was used to detect the degree of multicollinearity among the variables. VIF > 10 was considered indicative of multicollinearity and should be excluded from the regression model. $P < .05$ was considered to indicate a statistically significant difference.

3. Results

3.1. *Characteristics of Subjects*

A total of 119 consecutive participants were enrolled (60 males, age: 50.88 ± 17.79 years, BMI: 22.80 ± 3.80 $\text{kg}\cdot\text{m}^{-2}$; 59 females, age: 49.41 ± 17.69 years, BMI: 22.22 ± 3.12 $\text{kg}\cdot\text{m}^{-2}$). They were divided into 2 subgroups according to the WHO age standard:[17] ≤ 44 years (the youngers, n = 47) and > 44 years (the middle-aged and elderly, n = 72); 2 subgroups according to the BMI: $< 25\ \text{kg}\cdot\text{m}^{-2}$ (n = 97), $\geq 25\ \text{kg}\cdot\text{m}^{-2}$ (n = 22).

3.2. *Relationship between BMD and fat content of paraspinal muscles controlled for age, sex, and BMI*

The results showed that all VIF values were close to 1, indicating the absence of multicollinearity (Table S1).

Fig. 3 shows the scatter plots of fat content of erector spinae, multifidus, and psoas versus lumbar BMD.

Table 2 displays the regression coefficients, adjusted for age, sex, and BMI covariates, for lumbar BMD and paraspinal muscles fat content. The paraspinal muscles fat content had a fairly significant inverse association with lumbar BMD after controlling for these confounding effects (adjusted $R^2 = 0.584$–0.630, all $P < .05$).

Post hoc analysis was performed on age, sex and BMI groups separately for profound understanding. The results are shown in Tables 3–5. For different age subgroups, no statistically significant correlation was found between the fat content of all the three paraspinal muscles and BMD (All $P > .218$) in the subgroup of age ≤ 44 years after controlling for sex and BMI. In contrast to the above, a significant inverse correlation between the fat content of all the three paraspinal muscles and BMD was observed in the subgroup of age > 44 years (All $P < .05$) (Table 3). For different sex subgroups, the fat content of erector spinae and multifidus had an inverse correlation with lumbar BMD after controlling for age and BMI in both males and females, and the correlation in females (all $P < .001$) were stronger than males. No statistically significant correlation was observed between the fat content of psoas in both males and females (Table 4). For different BMI subgroups, the fat content of erector spinae, multifidus and psoas had an inverse correlation with lumbar BMD after controlling for age and sex in participants with BMI $< 25\ \text{kg}\cdot\text{m}^{-2}$ ($P < .001$, $P < .001$, $P = .008$, respectively). Only the fat content of multifidus had an inverse association with lumbar BMD in participants with BMI $\geq 25\ \text{kg}\cdot\text{m}^{-2}$ ($P = .007$) (Table 5).

4. Discussion

Our current study evaluated the relationship between fatty infiltration of paraspinal muscles and BMD using DECT. There were fairly significant inverse associations between the paraspinal muscles fat content and lumbar BMD after consideration of age, sex, and BMI as control variables.

Fatty infiltration of paraspinal muscles can be quantitatively represented by the measurement of the fat content in the muscles. Over the last few years, MRI and CT have been used widely to quantify the fat content of muscles [2,3,18–22]. The innovative aspect of our study was the use of the recently introduced DECT which offers not only monochromatic images, but also accurate MD images by gemstone spectral imaging (GSI). MD images can provide qualitative and quantitative information about paraspinal muscles fat compositions.

More recently, there has been growing interest in the relationship

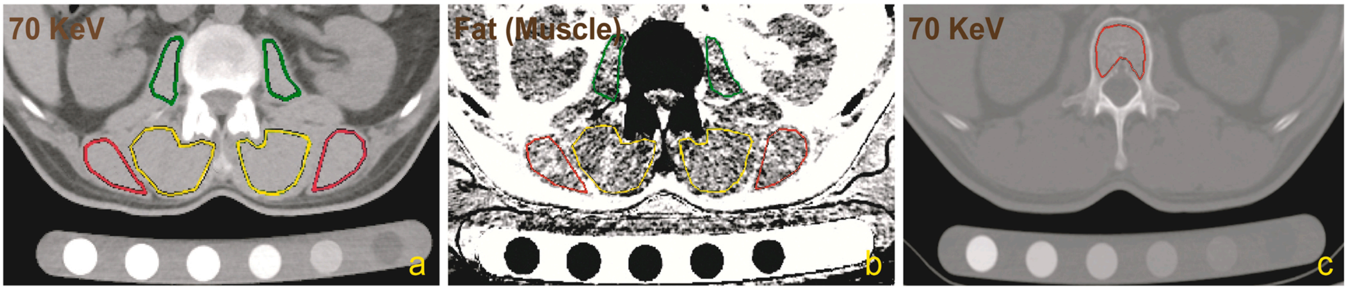

Fig. 2. : Measurement of paraspinal muscles fat content (erector spinae (red), multifidus (yellow) and psoas (green)) in 70-KeV monochromatic images (a) and Fat (muscle) material decomposition images (b) at L2/3 lumbar intervertebral level. BMD were measured as shown at L2 level (c).

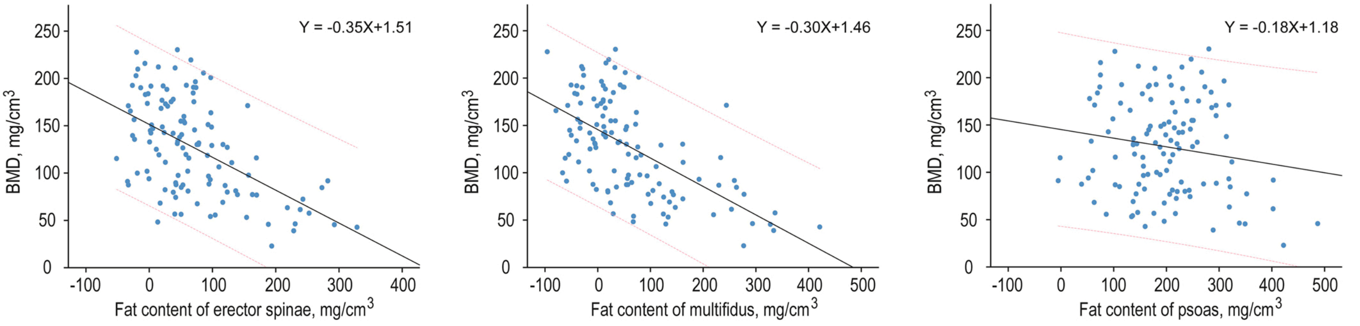

Fig. 3. **:** Associations between fat content of erector spinae, multifidus, and psoas and lumbar BMD. The solid black lines indicate linear relationship. Red dashed lines indicate 95% confidence Interval for individual prediction intervals. BMD = Bone mineral density.

Table 2
The relationship between paraspinal muscles fat content and lumbar BMD controlling for age, sex, and BMI* .

		Fat Content (mg/cm^3)	Age	Sex	BMI
Erector spinae	Adjusted R^2	0.618			
	Standardized beta coefficient	-0.268	-0.645	0.019	-0.031
	P value	< .001	< 0.001	0.741	0.587
Multifidus	Adjusted R^2	0.630			
	Standardized beta coefficient	-0.301	-0.610	-0.001	-0.027
	P value	< .001	< 0.001	0.994	0.637
Psoas	Adjusted R^2	0.584			
	Standardized beta coefficient	-0.151	-0.758	-0.017	-0.019
	P value	.013	< 0.001	0.773	0.749

Note:
* Relationships were assessed by linear regression; Dependent variable: lumbar BMD
BMD, bone mineral density; BMI, bone mass index

between body composition ((fat mass (FM) and lean mass (LM)) and BMD. Several studies showed that both FM and LM have an influence on BMD. Xueli Zhang et al [15]. found that, LM showed positive correlation on BMD and FM showed negative correlation on BMD in both males and females. Likewise, Seong Hee Ahn et al [23]. and Lan T Ho-Pham et al [24]. also demonstrated the similar conclusion in different populations. Whereas some studies have shown that FM is positively associated with BMD [25–27]. These contradictory findings could be due to the uncomplete exclusion of the interference of the mechanical loading effect of fat tissue on bone in these studies. Muscle, the main component of LM, loads the skeleton directly and associates positively with BMD in both males and females [28]. Comparatively, different from the previously discussed studies, we quantified the fat content of muscles to better reflect the muscle function.

To our knowledge, several previous studies have found that paraspinal muscles fatty infiltration is related to age, disc level, intervertebral disc degeneration, vertebral bone marrow and low-back pain [21,29–31], and many researches have investigated the relationship between the changes of paraspinal muscles(muscle and fat volume, cross sectional area etc.) and osteoporotic spinal compression fractures [32–34], but relatively few researches have been carried out to directly investigate the interaction between fatty infiltration of paraspinal muscles and BMD so far. Recently Yinxia Zhao et al. reported that the technique of six-echo chemical shift encoding-based water-fat MRI was capable of assessing paraspinal muscles fat infiltration using quantifying proton density fat fractions (PDFF) [19]. Their study focused on the relationship between paraspinal muscles PDFF and lumbar BMD, demonstrating that paraspinal muscle PDFF has an inverse correlation with vertebral BMD after controlling for age, sex, and BMI. Different from that , the technique we used for assessing paraspinal muscles fat infiltration was gemstone spectral imaging DECT, which can provide quantitative measurement of paraspinal muscles in fat content MD images. DECT can provide high image quality and low radiation exposure

Table 3
The relationship between paraspinal muscles fat content and lumbar BMD controlling for sex and BMI in age groups* .

			Fat Content (mg/cm^3)	Sex	BMI
Age ≤ 44	**Erector spinae**	Adjusted R^2	-0.017		
		Standardized beta coefficient	-0.188	0.123	-0.091
		P value	.284	0.514	0.591
	Multifidus	Adjusted R^2	-0.042		
		Standardized beta coefficient	-0.062	0.041	-0.127
		P value	.701	0.811	0.454
	Psoas	Adjusted R^2	-0.009		
		Standardized beta coefficient	-0.188	0.056	-0.118
		P value	.218	0.733	0.468
Age > 44	**Erector spinae**	Adjusted R^2	0.629		
		Standardized beta coefficient	-0.414	-0.036	-0.012
		P value	< .001	0.749	0.918
	Multifidus	Adjusted R^2	0.194		
		Standardized beta coefficient	-4.360	-0.525	-0.010
		P value	< .001	0.601	0.992
	Psoas	Adjusted R^2	0.141		
		Standardized beta coefficient	-0.244	-0.090	0.027
		P value	.041	< 0.445	0.816

Note:
* Relationships were assessed by linear regression; Dependent variable: lumbar BMD
BMD, bone mineral density; BMI, bone mass index

Table 4
The relationship between paraspinal muscles fat content and lumbar BMD controlling for age and BMI in sex groups* .

			Fat Content (mg/cm^3)	Age	BMI
Males	**Erector spinae**	Adjusted R^2	0.550		
		Standardized beta coefficient	-0.200	-0.653	-0.046
		P value	.049	< 0.001	0.616
	Multifidus	Adjusted R^2	0.553		
		Standardized beta coefficient	-0.217	-0.629	-0.039
		P value	.040	< 0.001	0.671
	Psoas	Adjusted R^2	0.540		
		Standardized beta coefficient	-0.147	-0.746	-0.060
		P value	.102	< 0.001	0.517
Females	**Erector spinae**	Adjusted R^2	0.673		
		Standardized beta coefficient	-0.310	-0.654	-0.003
		P value	< .001	< 0.001	0.971
	Multifidus	Adjusted R^2	0.692		
		Standardized beta coefficient	-0.355	-0.612	-0.005
		P value	< .001	< 0.001	0.951
	Psoas	Adjusted R^2	0.618		
		Standardized beta coefficient	-0.159	-0.790	0.051
		P value	.056	< 0.001	0.539

Note:
* Relationships were assessed by linear regression; Dependent variable: lumbar BMD
BMD, bone mineral density; BMI, bone mass index

dose, and save time and money for patients. Moreover, our study enrolled 119 participants, with wider range of age (22–90 years) and balanced male to female ratio, which can reflect better on bone and muscle developmental stages throughout life.

In our present study, we evaluated the fat content of erector spinae, multifidus and psoas independently, and found that the correlations between BMD and the fat content of erector spinae and multifidus (All $P < .001$) were stronger than that between BMD and psoas fat content ($P = .013$). Interestingly, Chi Wen C Huang et al [33]. have somewhat consistently found that the paraspinal muscles fat volumes of the group with osteoporotic compression fractures are significantly higher than the control groups, especially in erector spinae and multifidus, only the psoas fat volumes show insignificant increases. Additionally, Takahide Sasaki et al [35]. have found that the psoas showed the mildest tendency to increased FI % (fatty infiltration ratio) among all three paraspinal muscles. Moreover, Shin Heon Lee et al [20]. have shown that there was a significant change in the mean density of erector spinae and multifidus according to age, and erector spinae showed wider and earlier fatty degeneration than the multifidus, whereas the psoas showed the least fatty infiltration according to age in their recent study [21]. This phenomenon can also be a possible explanation for the least correlation between BMD and psoas. Another possible explanation is that not only age, but also stress load is generally seen as a factor strongly related to fatty infiltration of muscles [21,36]. It might be estimated that the psoas muscle receives less tension than the multifidus and erector spinae due to the characteristics of muscle (position, direction and length etc.) [37]. Paraspinal muscles (especially erector spinae and multifidus) fatty infiltration may be a marker of low lumbar BMD.

For different age subgroups, we found that there was no statistical correlation for the fat content of all three paraspinal muscles and BMD (All $P > .218$) in the youngers after controlling for sex and BMI. In contrast, a fairly good inverse correlation between the fat content of erector spinae, multifidus and BMD was observed in the middle-aged and the elderly (All $P < .001$), and a relatively mild correlation between fat content of psoas and BMD did so ($P = .041$) (Table 3). Most of related studies conducted on the middle-aged or the elderly, found that sarcopenia or body FM is significantly associated with BMD. Few studies demonstrate the relationship between them in youngers. Nico Sollmann et al [18]. reported that significant correlations between the PDFF of paraspinal muscle and vertebral bone marrow compartments in postmenopausal females (54–78 years) but no statistical correlations in premenopausal females (21–42 years). In addition, some studies found that total FM was not significantly associated with BMD in children at 7 years old. These results are somewhat in line with what we have found. It could be that on one hand, the fat content of paraspinal muscle range is relatively wider in postmenopausal women, so DECT can more sensitively reflect the changes of fat content in postmenopausal women than in premenopausal women. On the other hand, LM more affect BMD than FM in those of age of bone growing or remodeling stage but FM more affect BMD than LM in those of the bone loss stage.

For different sex subgroups, we surprisingly found a relatively good inverse correlation between fat content of erector spinae and multifidus and BMD in females (Adjusted $R^2 = 0.673$, 0.692; All $P < .001$) but modest correlation in males (Adjusted $R^2 = 0.550$, 0.553;

Table 5
The relationship between paraspinal muscles fat content and lumbar BMD controlling for age and sex in BMI groups* .

			Fat Content (mg/cm^3)	Age	Sex
BMI < 25	**Erector spinae**	Adjusted R^2	0.608		
		Standardized beta coefficient	-0.271	-0.631	0.024
		P value	< .001	< 0.001	0.719
	Multifidus	Adjusted R^2	0.612		
		Standardized beta coefficient	-0.284	-0.607	-0.002
		P value	< .001	< 0.001	0.977
	Psoas	Adjusted R^2	0.584		
		Standardized beta coefficient	-0.179	-0.740	-0.026
		P value	.008	< 0.001	0.692
BMI ≥ 25	**Erector spinae**	Adjusted R^2	0.629		
		Standardized beta coefficient	-0.262	-0.694	0.027
		P value	.091	< 0.001	0.849
	Multifidus	Adjusted R^2	0.710		
		Standardized beta coefficient	-0.404	-0.607	-0.0002
		P value	.007	< 0.001	0.999
	Psoas	Adjusted R^2	0.564		
		Standardized beta coefficient	0.017	-0.798	0.069
		P value	.916	< 0.001	0.650

Note:
* Relationships were assessed by linear regression; Dependent variable: lumbar BMD
BMD, bone mineral density; BMI, bone mass index

$P = .049, 0.040$, respectively) after controlling for age and BMI. K. Zhu et al. made a similar point in his previous study of the relationship between body FM and BMD. It was observed that higher body FM was significantly association with lower BMD in females with the same BMI but not in males [38]. Additionally, some studies found that females had a significantly higher FI% of paraspinal muscles than males and the increasing tendency of the FI % of males was milder compared with that of females in all paraspinal muscles [35,39]. Several factors could explain this observation. Firstly, the interaction between paraspinal muscles fat content and lumbar BMD is sensitively affected by some factors such as estrogen deficiency which are driving bone loss and fat infiltration [40]. Secondly, fatty conversion is present particularly in women [41]. Thirdly, BMD in females was lower than that in males [15]. Thus, a greater proportion of the variance in BMD and FM in females than in males. In our study, the P values in males were near the critical point ($P = .05$), may be due to the small sample sizes, which needs further work to establish whether there is a statistic relationship between paraspinal muscles FM and BMD.

For different BMI subgroups, we found a relatively good inverse correlation between fat content of erector spinae and multifidus and BMD in lower BMI (BMI $< 25\ \text{kg}\cdot\text{m}^{-2}$) group (Adjusted $R^2 = 0.608$, 0.612; All $P < .001$) but in higher BMI (BMI $\geq 25\ \text{kg}\cdot\text{m}^{-2}$) group this condition only found in multifidus (Adjusted $R^2 = 0.710$, $P = .007$). That may due to that lower BMI group include most participants and was concordant in 47.4% of males and 52.6% of females but higher BMI group include only 22 participants and was composed of 63.6% males and 36.4% females. There has not been enough evidence to tell that there was no significance between paraspinal muscle fat content and BMD in higher BMI group so far in our study. Further studies need to be carried out.

When interpreting the results of the present study, several limitations should also be noted. First, this was a single-center study, and all data were limited in Chinese populations. Second, the medical history was collected from a questionnaire, which introduced a potential source of bias. And the last, the everyday activity level was not considered in our study. We plan to further assess the effect of everyday activity on paraspinal muscles fat content and BMD.

In conclusion, our study demonstrated that the fat content of paraspinal muscles (erector spinae, multifidus, and psoas) measured by DECT had a negative correlation with lumbar BMD after controlling for age, sex, and BMI, and erector spinae and multifidus revealed similar and significant relationship with BMD. Paraspinal muscles fatty infiltration may be considered as a potential marker to identify BMD loss. This also agree with the “bone-muscle unit” theory, it suggests a possibility to improve lumbar BMD by reducing paraspinal muscle fatty infiltration, such as by exercising. Nowadays, there have been some novel image analysis methods to quantify bone marrow changes related to osteoporosis , such as texture analysis combined with machine learning used in clinical CT scans for vertebrae fractures prediction [42]. Further investigations along with continued follow-up surveys will continue to confirm the association between fatty infiltration of skeletal muscles and local BMD and clinical symptoms.

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CRediT authorship contribution statement

Shuwei Zhou: Conceptualization, Writing – review & editing, Writing – original draft. **Suping Chen:** Methodology, Software. **Xu Zhu:** Formal analysis, Investigation. **Tian You:** Validation, Investigation. **Ping Li:** Resources, Data curation. **Hongrong Shen:** Data curation. **Hui Gao:** Supervision. **Yewen He:** Visualization, Project administration. **Kun Zhang:** Funding acquisition.

Conflict of Interest

Shuwei Zhou, Suping Chen, Xu Zhu, Tian You, Ping Li, Hongrong Shen, Hui Gao, Yewen He, and Kun Zhang declare no relationships with any companies, whose products or services may be related to the subject matter of the article.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ejro.2022.100447.

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