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ORIGINAL ARTICLE

Fatty infiltration of paraspinal muscles is associated with bone mineral density of the lumbar spine

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Abstract

Summary A total of 88 subjects were enrolled to investigate the relationship between paraspinal muscle fatty infiltration and lumbar bone mineral density (BMD) using chemical shift encoding-based water-fat MRI and quantitative computed tomography (QCT), respectively. A moderate inverse correlation between paraspinal muscle proton density fat fraction and lumbar QCT-BMD was found with age, sex, and BMI controlled.

Purpose To investigate the relationship between paraspinal muscle fatty infiltration and lumbar bone mineral density (BMD).

Methods A total of 88 subjects were enrolled in this study (52 females, 36 males; age, 46.6 ± 14.2 years old; BMI, 23.2 ± 3.49 kg/m^2). Proton density fat fractions (PDFF) of paraspinal muscles (erector spinae, multifidus, and psoas) were measured at L2/3, L3/4, and L4/5 levels using chemical shift encoding-based water-fat MRI. Quantitative computed tomography (QCT) was used to assess BMD of L1, L2, and L3. The differences in paraspinal muscle PDFF among subjects with normal bone density, osteopenia, and osteoporosis were tested using one-way ANOVA. The relationship between paraspinal muscle PDFF and QCT-BMD was analyzed using linear regression with age, sex, and BMI variables.

Results PDFF of the erector spinae, multifidus, and psoas of subjects with normal bone density were all significantly less than those with osteopenia and those with osteoporosis (all $p < 0.001$). There was an inverse correlation between paraspinal muscle PDFF and BMD after controlling for age, sex, and BMI (standardized beta coefficient, − 0.21∼− 0.29; all $p < 0.05$).

Conclusions Paraspinal muscle fatty infiltration increased while lumbar BMD decreased after adjusting for age, sex, and BMI. Paraspinal muscles and vertebrae are interacting tissues. Paraspinal muscle fatty infiltration may be a marker of low lumbar BMD. Chemical shift imaging is an efficient and fast quantitative method and can be easily added to the clinical protocol to measure paraspinal muscle PDFF when the patient underwent the routine lumbar MRI with low-back pain.

Keywords Paraspinal muscles · Osteoporosis · Bone density · Chemical shift imaging

Introduction

Osteoporosis, which can be diagnosed based on low bone mineral density (BMD), is an increasingly large problem in aging societies. Reduced BMD is the most important risk factor for fragility fractures, which increases societal financial burden and decreases patient quality of life [1, 2]. At the same time, muscle weakness plays an important role in fractures as it can lead to falls. Muscle and bone are interconnected musculoskeletal units both in biomechanical and biochemical

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aspects [3, 4]. With aging, the musculoskeletal system degenerates, leading to reduced strength and function. Muscle fatty infiltration was reported to be the main factor in decreasing muscle strength [5]. Fatty infiltration processes decrease insulin sensitivity, which impairs the capacity for normal protein synthesis in skeletal muscle. Protein synthesis enhances muscle hypertrophy and the maintenance of muscle strength, whereas impaired protein synthesis contributes to muscle atrophy [6, 7]. Sarcopenia, defined as age-associated loss of skeletal muscle mass and function, has been shown to be correlated with low BMD and osteoporosis [8–10]. In addition, body fat mass has been seen to relate with BMD, but the correlation between them is controversial [8, 11]. All of these previous studies evaluated muscle and fat mass independently, with the direct relationship between fat tissue in the muscle and BMD remaining unclear. However, the relation is apparent by the improvement of muscle strength and reduction in risk of bone fracture with the use of techniques for the prevention of fatty infiltration into the muscle (i.e., resistance exercise and whole-body vibration) [6]. Fatty infiltration, as observed in age-related muscle and bone loss, is a major player that affects the musculoskeletal unit [12].

Fatty infiltration of paraspinal muscles has been evaluated through conventional T2-weighted imaging by counting the fat and muscle pixels [13, 14]. However, the accuracy of this approach is limited. Chemical shift encoding-based water-fat MRI was originally developed to quantify the fat content of the liver and has been shown to be extremely accurate, especially when used with multiple echoes and iterative fitting algorithms [15–17]. Recently, this technique was also used to evaluate fat content for many other tissues such as breast, bone, and muscles [18–21]. It is capable of visualizing both anatomical structures as well as quantifying proton density fat fractions (PDFF). Modern MRI Dixon technique uses robust water-fat separation algorithm and was found to have excellent accuracy in quantifying muscle fat content compared with T1-weighted imaging, MR spectroscopy, and histology [22–24]. It also has good spatial coverage, short acquisition time, and simple technical requirements, and provides accurate fat quantification [25, 26]. As for calculating BMD of the lumbar vertebrae, dual-energy X-ray absorptiometry (DXA) is the most frequently utilized quantitative technique to investigate bone mass and body composition in clinical settings due to its wide availability, low cost, and low ionizing radiation dose. Quantitative computed tomography (QCT), which can selectively measure the cancellous trabecular bone through three-dimensional imaging, was shown to be more accurate than DXA [27]. It can provide a true bone density expressed in grams per cubic centimeter instead of an areal density as measured by DXA, avoiding the overestimation of BMD by DXA resulting from spinal degenerative changes, vascular calcification, and other sclerotic lesions in the surrounding soft tissues [27].

Improved understanding of the relationship between fatty infiltration and BMD can potentially help in the development of interventions benefiting musculoskeletal function; improving musculoskeletal function can lead to reduced adverse clinical outcomes such as falls and fractures. To investigate this relationship, we used a six-echo chemical shift encoding-based water-fat MRI (mDixon Quant, Philips Healthcare) to assess paraspinal muscle fatty infiltration and QCT to calculate the BMD of the lumbar spine. In this prospective cross-sectional study, we hypothesize that paraspinal muscle fatty infiltration and lumbar QCT-BMD are correlated even after controlling for age, BMI, and sex in a general population.

Material and methods

Subjects

Participants were recruited via poster and internal emails approved by the local institutional review board (IRB). Written consent was obtained before the examination of all participants. Inclusion criteria include (1) age between 20 and 80 years, (2) capacity to consent, and (3) no contraindication to MRI such as cardiac pacemaker or claustrophobia. Exclusion criteria include (1) known spinal tumor, (2) history of trauma and dysplasia, (3) previous spinal surgery, and (4) previous or current hormone therapy. Additional subjects were excluded from the analysis due to end-plate Modic changes [28], infectious lesions of the spine, paraspinal tumor, and fresh fracture seen on T1WI and T2WI sequences, identified by a musculoskeletal radiologist (WF) with 2 years of experience.

Between October 2016 and March 2017 there were, in total, 88 subjects enrolled in this study (52 females and 36 males). The age ranged from 22 to 69 years old (mean 46.6 ± 14.2) with body mass index (BMI) ranging from 16.6 to 32.9 kg/m^2 (mean 23.2 ± 3.49). This patient cohort has been previously reported in part in prediction of abnormal bone density which investigated bone marrow [29].

Quantitative computed tomography (QCT) examination

Bone mineral density of lumbar vertebrae (L1 to L3) was obtained by quantitative computed tomography using a multidetector CT scanner (Aquilion64, Toshiba, Tokyo, Japan) with a solid phantom (Mindways, Austin, USA) placed under each participant's lumbar spine [27]. The helical scanning region covered mid-T12 to mid-L4 in the supine position. The following protocol was used for all QCT scans: 120 kV peak, 75 mAs, 2.0-mm reconstruction slice thickness, 65-cm table height, and large field of view that covered the five density columns. The lumbar spine volumetric data were sent to a computer workstation (Mindways QCT Pro, Austin, USA) for analysis. Elliptical regions of interest (ROIs) were drawn on the midplane of the L1, L2, and L3 vertebral bodies to calculate the trabecular BMD, avoiding the cortical bone, by a radiologist (ML) with 5 years of experience. Average BMD of spinal trabecular bone is expressed in milligrams per cubic centimeter of calcium hydroxyapatite. The following thresholds were used for vertebral BMD as recommended by the International Society for Clinical Densitometry (ISCD) in 2007 [30] and the American College of Radiology in 2013 [31]: osteoporosis, < 80 mg/cm^3; osteopenia, 80 to 120 mg/cm^3; normal, > 120 mg/cm^3. The final reference diagnosis was determined using the mean BMD of L1, L2, and L3 for each subject.

Magnetic resonance imaging (MRI) examination

All MR examinations of the lumbar spine were performed on the same 3.0T MR scanner (Ingenia, Phillips, Amsterdam, Netherlands) with a posterior coil. Conventional T1-weighted imaging (sagittal, turbo spin echo (TSE), repetition time/echo time (TR/TE) = 2000/90 ms, FOV = 160 × 303 mm^2, matrix size = 268 × 397, slice thickness = 4 mm, gap = 0.4 mm, acquisition time = 152 s) and T2WI (sagittal, TSE, TR/TE = 540/8 ms, FOV = 160 × 303 mm^2, matrix size = 268 × 397, slice thickness = 4 mm, gap = 0.4 mm, acquisition time = 107 s) were first obtained for anatomical and morphological assessments of the lumbar spine. Chemical shift encoding-based water-fat MRI (mDixon Quant, Philips Healthcare) sequence (axial, 3D fast field echo (FFE), TR/TE$_1$/ΔTE = 5.7/1.0/0.7 ms, FOV = 400 × 350 mm^2, matrix size = 160 × 140, slice thickness = 3 mm, gap = 0, flip angle = 3°, acquisition time = 10 s) with six echoes was obtained for quantification of PDFF.

MR image analysis

All MR images were reviewed by a radiologist (WF) with 2 years of experience who was blinded to the BMD results. Chemical shift encoding-based water-fat MR images were transferred to a post-processing workstation (InterlliSpaceTM Portal, Philips), and the PDFF maps were automatically generated with seven fat peaks modeling and T2* correction. Free-hand drawn ROIs were separately placed in the axial view of both sides of the erector spinae, multifidus, and psoas at levels L2/3, L3/4, and L4/5 on the fat fraction maps (Fig. 1). Each ROI was drawn along the margin of the muscle, and the facet joint was used as a landmark between the multifidus and erector spinae. The PDFF of the erector spinae, multifidus, and psoas were obtained directly, and the mean FF of each muscle of both sides and three levels was calculated. It takes about 2 min to draw all the ROIs of paraspinal muscles for each subject. PDFF is a quantitative indicator of fatty infiltration.

In addition, 20 studies were randomly selected using a randomization table generated by SPSS from the entire data set to evaluate the intra- and inter-reader reliability (A second radiologist (LC) with 2 years of experience).

Statistical analysis

Statistical difference analysis of age, BMI, paraspinal muscle PDFF, and spinal BMD between the three groups (normal bone density, osteopenia, and osteoporosis) was performed using one-way ANOVA. The post hoc tests of paraspinal muscle PDFF between different BMD groups were performed as well. Linear regression was used to analyze the relationship between BMD (dependent variable) and the paraspinal muscle PDFF with age, sex, and BMI variables of the lumbar spine. Post hoc analysis was performed to investigate the relationship between BMD, paraspinal muscle PDFF, age, and BMI for males and females. Partial correlation analyses between paraspinal muscle PDFF and either age, sex, or BMI—with control of the other two variables—were also performed. Intraclass correlation coefficient (ICC) of the intra- and inter-reader reliability for muscle PDFF was calculated using modelling of two-way random, absolute agreement, and single measures. All of these tests were performed using SPSS statistics (IBM, version 24) and the significant levels were set at 0.05.

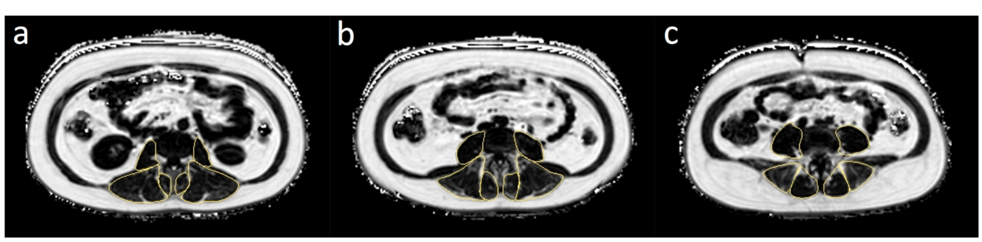

Fig. 1 PDFF of erector spinae, multifidus, and psoas were measured respectively by drawing ROI at L2/3 (**a**), L3/4, (**b**) and L4/5 (**c**) levels on axial fat fraction map

Results

Clinical characteristics and the values of paraspinal muscle PDFF and lumbar BMD

According to the diagnostic criteria from ISCD, there were 56 (26 females, 30 males) subjects with normal bone density, 21 (17 females, 4 males) subjects with osteopenia, and 11 (9 females, 2 males) subjects with osteoporosis. The clinical characteristics of the participants and quantitative measurements of paraspinal muscle PDFF and lumbar BMD are summarized in Table 1. The post hoc tests of paraspinal muscle PDFF between different BMD groups were summarized in Table 2. There were significant differences in paraspinal muscle PDFF between the subjects with normal bone density, osteopenia, and osteoporosis. There was significant difference in paraspinal muscle PDFF between the subjects with normal bone density and osteopenia, and the subjects with normal bone density and osteoporosis. The subjects with lower BMD had higher paraspinal muscle PDFF (Fig. 2).

Relationship between lumbar BMD and paraspinal muscle PDFF controlled for age, sex, and BMI

Figure 3 shows the scatter plots of PDFF of erector spinae (a), multifidus (b), and psoas(c) versus lumbar BMD. The relationship between lumbar BMD and paraspinal muscle PDFF was further tested using linear regression with age, sex, and BMI variables. The statistical results are summarized in Table 3. The PDFF of erector spinae, multifidus, and psoas had a statistically significant inverse correlation with lumbar BMD after controlling for these confounding effects.

Even though sex was found to be not significant in the analysis, post hoc analysis was also performed on females and males separately to identify which group is driving the analysis. The results are summarized in Tables 4 and 5. The PDFF of erector spinae and psoas had an inverse correlation with lumbar BMD after controlling for age and BMI in females but not observed in males. The PDFF of multifidus had no statistically significant correlation with lumbar BMD both in females and males.

Partial correlation between paraspinal muscle PDFF and either age, sex, or BMI

It was found that there is a moderate correlation between PDFF of erector spinae, multifidus, psoas, and age (correlation coefficient $r = 0.670$, $p < 0.001$; $r = 0.634$, $p < 0.001$; $r = 0.554$, $p < 0.001$, respectively) when controlling for sex and BMI. The PDFF of erector spinae and multifidus were also found to relate with sex (correlation coefficient $r = 0.352$, $p = 0.001$; $r = 0.419$, $p < 0.001$, respectively) controlling for age and BMI. But no statistically significant correlation was found between the PDFF of erector spinae, multifidus, psoas, and BMI ($p = 0.800$, $p = 0.628$, and $p = 0.380$, respectively) controlling for age and sex.

Intra- and inter-reader ICC for PDFF of erector spinae, multifidus, and psoas are summarized in Table 6; all are excellent.

Discussion

Our study demonstrated that PDFF of erector spinae, multifidus, and psoas of subjects with normal bone density are all significantly less than those of subjects with osteopenia and those with osteoporosis. There is an inverse correlation between paraspinal muscle PDFF and vertebral BMD after controlling for age, sex, and BMI.

Fatty infiltration of paraspinal muscle represents the fat content in the muscle. It has two components on the cellular level: intramyocellular lipid (IMCL) and extramyocellular lipid (EMCL). PDFF that obtained by chemical encoding-based water-fat MRI in our study is a quantitative variable including both IMCL and EMCL. There have been numerous studies regarding the relationship between muscle, body fat mass, and BMD. Previous studies found that BMD loss is correlated with decreased muscle mass, strength, and function [8, 32]. Sarcopenia is an age-related condition which is characterized

Table 1 Clinical characteristics of the subjects and the values of paraspinal muscle PDFF and lumbar BMD[a]

	Normal bone density (54% male)	Osteopenia (19% male)	Osteoporosis (18% male)	p value[b]
PDFF of erector spinae (%)	11.4 ± 5.5 (9.9–12.9)	18.6 ± 3.5 (17.0–20.2)	22.6 ± 8.6 (16.8–28.4)	< 0.001
PDFF of multifidus (%)	12.0 ± 5.7 (10.4–13.5)	20.4 ± 4.3 (18.5–22.3)	24.0 ± 10.5 (16.9–31.0)	< 0.001
PDFF of psoas (%)	7.0 ± 3.3 (6.1–7.8)	10.9 ± 2.7 (9.7–12.1)	13.5 ± 6.0 (9.5–17.6)	< 0.001
Age (years old)	39.2 ± 12.3 (35.9–42.5)	59.3 ± 5.2 (57.0–61.7)	60.4 ± 4.9 (57.1–63.6)	< 0.001
BMI (kg/m^2)	22.8 ± 3.4 (21.8–23.7)	24.5 ± 2.9 (23.2–25.8)	22.9 ± 4.4 (20.0–25.9)	0.142

[a] Values are expressed as mean ± SD (95% CI)

[b] The significant tests of the PDFF, age, and BMI between normal bone density, osteopenia, and osteoporosis were performed using one-way ANOVA

CI, confidence interval; *SD*, standard deviation; *PDFF*, proton density fat fraction; *BMD*, bone mineral density; *BMI*, bone mass index

Table 2 Post hoc tests[a] of paraspinal muscles PDFF between different BMD groups[b]

	Normal bone density and osteopenia	Normal bone density and osteoporosis	Osteopenia and osteoporosis
Erector spinae	< 0.001	< 0.001	0.168
Multifidus	< 0.001	< 0.001	0.378
Psoas	< 0.001	< 0.001	0.157

[a] Post hoc tests were using Bonferroni

[b] Significance between different groups was express as *p* values

PDFF, proton density fat fraction; *BMD*, bone mineral density

by loss of skeletal muscle mass and function. It has been found to be associated with low BMD and osteoporosis [8, 33, 34]. Some studies showed that not only lean body mass but also the fat body mass has an influence on bone mass [35, 36]. Kim et al. [37] found fat mass negatively correlated with bone mineral content in both men and women after controlling for age and weight. A similar relationship was also demonstrated by Hsu et al. [38] and He et al. [8] in different populations, whereas Pluijm et al. [39] found that both fat mass and muscle mass are positively associated with BMD. These seemingly contradictory findings could be due to (a) the positive impact on bone metabolism via increased mechanical loading, which increases the BMD and (b) the negative impact on bone metabolism by the excess body fat mass [40]. Therefore, when evaluating the correlation between body fat mass and BMD, the lean mass should also be considered. In contrast to these studies, we investigate the fat fraction of the muscle, which may better reflect the function of the muscle. Similarly, Sollmann et al. [21] evaluated the relationship between paraspinal muscle and lumbar vertebral bone marrow fat compositions using chemical shift encoding-based water-fat MRI and found there was a significant correlation in postmenopausal women. Our study focused on the relationship between paraspinal muscle PDFF and lumbar BMD which was used to diagnosis osteoporosis. The difference was that they focused on the fat content in both paraspinal muscles and vertebral while we evaluated the BMD of the lumbar. Additionally, the study cohort was different. We evaluated the correlation between paraspinal muscles and lumbar BMD in the general cohort. The work by Sollmann et al. suggests that there is statistical significance between the PDFF of the erector spinae muscles and the PDFF of the bone marrow of lumbar vertebral bodies in postmenopausal women. Our results suggest that higher paraspinal muscle PDFF might be a marker of low bone mass risk. This could be explained by the competition between the vertebral bone marrow fat and the vertebral bone mass, which are both associated with PDFF of paraspinal muscles. The result demonstrated that the paraspinal muscle fatty infiltration is negatively correlated with lumbar BMD. Similar inverse correlation has been found between the body fat mass and BMD in some studies [8, 37, 38]. Muscle fatty infiltration is a key factor that affects muscle function and

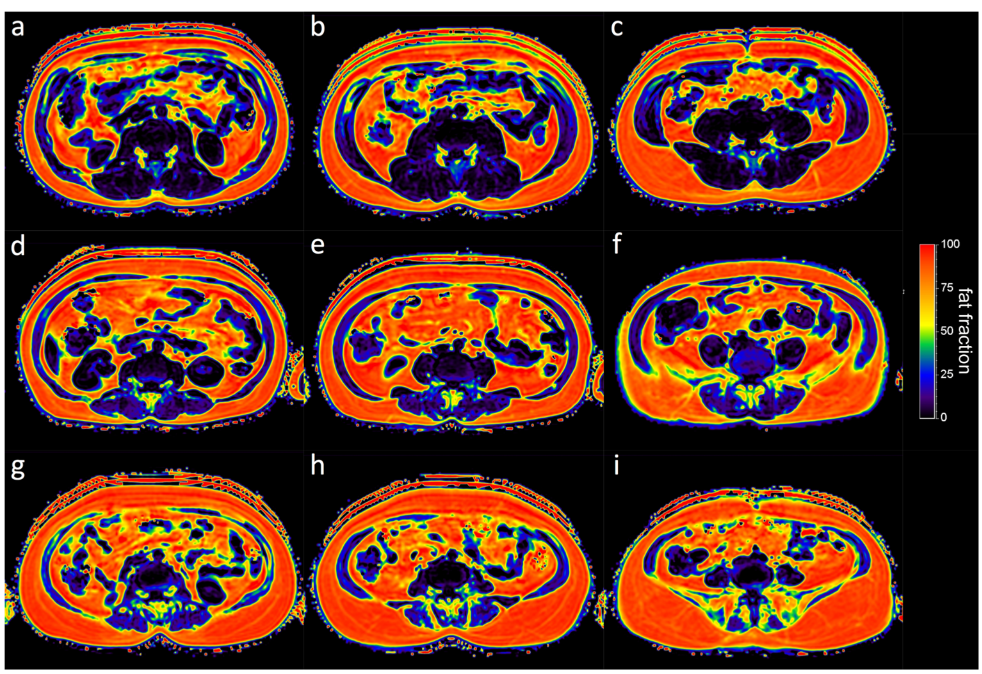

Fig. 2 Fat fraction color maps of paraspinal muscles at L2/3 (**a**, **d**, **g**), L3/4 (**b**, **e**, **h**), and L4/5 (**c**, **f**, **i**) among subjects with normal bone density (**a**, **b**, **c**), osteopenia (**d**, **e**, **f**), and osteoporosis (**g**, **h**, **i**). **a**–**c**: male; 27 years old; mean lumbar BMD, 172.1 mg/cm^3; mean PDFF of erector spinae, 6.7%; mean PDFF of multifidus, 6.3%; mean PDFF of psoas, 4.7%. **d**–**f**: female; 65 years old; mean lumbar BMD, 110.9 mg/cm^3; mean PDFF of erector spinae, 16.5%; mean PDFF of multifidus, 20.6%; mean PDFF of psoas, 7.1%. **g**–**i**: female; 65 years old; mean lumbar BMD, 62.3 mg/cm^3; mean PDFF of erector spinae, 33.1%; mean PDFF of multifidus, 31.2%; mean PDFF of psoas, 13.1%

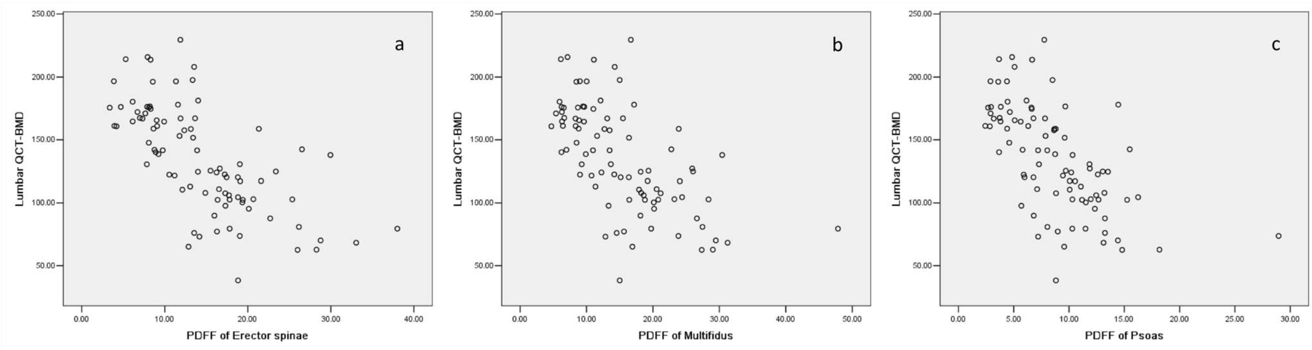

Fig. 3 Scatter plots of PDFF of erector spinae (**a**), multifidus (**b**), and psoas(**c**) versus lumbar BMD

plays an important role in the relationship between muscle and bone. Consequently, skeletal muscle fatty infiltration could be an important factor for sarcopenia. Kim et al. [41] found the fatty infiltration of paraspinal muscles in patients with osteoporotic spinal compression fracture was higher than those without fractures in postmenopausal women with osteoporosis. This agrees with our finding that PDFF of paraspinal muscles and BMD have a negative correlation, as low BMD is the main risk factor of osteoporotic fracture.

Furthermore, although sex was not found to be a statistically significant variable in the linear regression model, post hoc analysis of each sex was performed to identify which group is driving the analysis. It is interesting that PDFF of erector spinae and psoas have an inverse correlation with BMD after controlling for age and BMI in females, but no statistical significance is found in males from the post hoc analysis. Similar sex difference has been previously reported in regard to the correlation between body fat mass and BMD [40]. It was found that higher body fat with the same BMI is associated with lower BMD in women but not in men; this suggests that increased fat mass without an accompanying increase in lean mass may be deleterious to the bone. This agrees with our finding. However, as the sample of the males in our study is small ($n = 36$), the age distribution is uneven and the volunteers with low BMD are limited (only 4 osteopenia and 2 osteoporosis among the male participants), there is not enough evidence to tell that there was no significance between paraspinal muscle PDFF and lumbar BMD in males so far in our study. Further study is needed to investigate this.

More interestingly, in our study, no statistically significant correlation is found between BMI and lumbar BMD or paraspinal muscle fatty infiltration after controlling for sex and age. As BMI is an indicator of whole-body fat, the results here demonstrate that paraspinal muscle fatty infiltration as the intramuscular and intermuscular fat incorporated in local muscle might not be affected by total body fat; fat fraction of the muscle—but not the whole body mass—correlated with BMD. Additionally, age is an important factor that affects both paraspinal muscle PDFF and BMD. Fatty infiltration increased while BMD decreased with aging. These findings agree with previous studies. Chen et al. [42] found lumbar paravertebral muscle fat content increases with aging in healthy volunteers 20–62 years of age. Here in our study, we have a larger age range (20–80 years old).

In this work, we evaluated the fatty infiltration of erector spinae, multifidus, and psoas independently, and found that all of these paraspinal muscles were negatively correlated with

Table 3 The relationship between PDFF of paraspinal muscles and lumbar BMD controlling for age, sex, and BMI[a]

		PDFF	Age	Sex	BMI
Erector spinae	Model adjusted R^2	0.606			
	Standardized beta coefficient	− 0.285	− 0.557	0.008	− 0.048
	p value	0.006	< 0.001	0.922	0.513
Multifidus	Model adjusted R^2	0.590			
	Standardized beta coefficient	− 0.210	− 0.616	0.001	− 0.050
	p value [b]	0.045	< 0.001	0.990	0.501
Psoas	Model adjusted R^2	0.601			
	Standardized beta coefficient	− 0.224	− 0.615	− 0.038	− 0.024
	p value[b]	0.012	< 0.001	0.613	0.745

[a] Relationships were tested by linear regression; dependent variable: lumbar BMD

PDFF, proton density fat fraction; *BMD*, bone mineral density; *BMI*, bone mass index

Table 4 The relationship between PDFF of paraspinal muscles and lumbar BMD controlling for age and BMI in females[a]

		PDFF	Age	BMI
Erector spinae	Model adjusted R^2	0.671		
	Standardized beta coefficient	− 0.222	− 0.634	− 0.084
	p value	0.047	< 0.001	0.325
Multifidus	Model adjusted R^2	0.661		
	Standardized beta coefficient	− 0.172	− 0.672	− 0.093
	p value	0.113	< 0.001	0.284
Psoas	Model adjusted R^2	0.696		
	Standardized beta coefficient	− 0.270	− 0.660	− 0.027
	p value	0.006	< 0.001	0.747

[a] Relationships were tested by linear regression; dependent variable: lumbar BMD

PDFF, proton density fat fraction; *BMD*, bone mineral density; *BMI*, bone mass index

lumbar BMD in our subjects. As erector spinae and multifidus have a similar relationship with BMD from our results and they are anatomically adjacent to each other, their ROIs can be combined in future analysis. Even though the time to segment these three paraspinal muscles is short (2 min), the time needed can be further reduced in clinical practice by combining the erector spinae and multifidus. Moreover, we chose paraspinal muscles which were closest to the spine anatomically in this preliminary study. Previous studies have shown that paraspinal muscle fatty infiltration is related to vertebral bone marrow, inter-vertebral disc degeneration, and low-back pain [13, 21, 43]. And in our work, we found that muscle fatty infiltration was also related to lumbar BMD; this is expected since paraspinal muscles and spine are one interconnected musculoskeletal unit. Furthermore, there is a study showing that abdominal muscles affect the spine stability [44]; further study is needed to understand the impact of fatty infiltration in the abdominal muscle on the spine.

Table 5 The relationship between PDFF of paraspinal muscles and lumbar BMD controlling for age and BMI in males[a]

		PDFF	Age	BMI
Erector spinae	Model adjusted R^2	0.446		
	Standardized beta coefficient	− 0.183	− 0.564	0.046
	p value	0.337	0.006	0.724
Multifidus	Model adjusted R^2	0.429		
	Standardized beta coefficient	− 0.002	− 0.700	0.060
	p value	0.989	0.001	0.651
Psoas	Model adjusted R^2	0.429		
	Standardized beta coefficient	0.021	− 0.717	0.062
	p value	0.910	< 0.001	0.641

[a] Relationships were tested by linear regression; dependent variable: lumbar BMD

PDFF, proton density fat fraction; *BMD*, bone mineral density; *BMI*, bone mass index

In our study, the paraspinal muscle PDFF was measured by an image-based Dixon fat/water separation technique which has gained more popularity due to its fast acquisition speed (the maps were acquired in 10 s in this study), quantitative accuracy, easy implementation, simple workflow, and ability to correct for field inhomogeneity [25, 26, 45]. Moreover, in order to access the true lumbar 3D-BMD, we used QCT which has been shown more accurate than DXA. Our work is the first study that used the combination of chemical shift encoding-based water-fat MRI to investigate the paraspinal muscle PDFF and QCT to measure BMD.

As demonstrated in this work, paraspinal muscle fatty infiltration has an inverse correlation with spinal BMD in females. Although this is a cross-sectional study, it suggests a possibility of improving BMD through reducing paraspinal muscle fatty infiltration, such as by exercise. Further prospective studies are warranted to investigate this. Also, for current clinical practice, the finding of this work suggests that increased paraspinal muscle fatty infiltration can be used as an imaging marker for identifying the risk of low BMD, and an indication of necessary BMD monitoring to prevent osteoporotic fracture. We expect monitoring using chemical shift encoding-based water-fat separation MRI would be easily adoptable into clinical practice because it is an efficient and fast quantitative method. When the patient undergoes the

Table 6 ICC of intra- and inter-reader reliability for the PDFF of paraspinal muscles[a]

	Erector spinae	Multifidus	Psoas
Intra-reader ICC	0.893***	0.899***	0.852***
Inter-reader ICC	0.874***	0.883***	0.671***

[a] Left sides of the paraspinal muscles were used as samples to calculate the ICC

****p* value < 0.001

ICC, intraclass correlation coefficient routine lumbar MRI with low-back pain, this sequence can be easily added into the routine clinical protocol, allowing easy measurement of PDFF in paraspinal muscles to indicate potentially abnormal BMD without ionizing radiation. Frequent monitoring is particularly important in elderly women with high paraspinal muscle PDFF. Investigation of the relationship between paraspinal muscles and spine would provide better understanding of the complex pathophysiology of muscle and bone (loss). Additionally, this knowledge could be useful in the monitoring of treatment response and prevention of osteoporosis in the future. A natural next step is to investigate whether exercise, which is expected to decrease the fat content in the paraspinal muscles, has the potential to prevent osteoporosis and maintain high bone mass.

There are some limitations to our study. First, the number of subjects is relatively small, and the number of female and male participants were not well balanced, especially in the osteopenia and osteoporosis groups. Specifically, the number of males is indeed small; this is expected since women are more likely to have osteoporosis [46]. Consequently, sex was controlled when studying the relationship between paraspinal muscle fatty infiltration and BMD and further study to extend the sample is needed to gain more evidence. Secondly, this is a single-site study, and this is a secondary analysis. Further prospective multi-center study is needed to verify our findings. Abdominal muscles also were found to have effects on spinal stability in some studies [44]. Extending the enrolling muscles will be more rigorous in the future research. Thirdly, the everyday activity level of the participants was not considered in this study. In the future, we plan to further evaluate the effect of everyday activity on both paraspinal muscle PDFF and BMD.

In conclusion, our study demonstrated an inverse correlation between paraspinal muscle fatty infiltration and BMD after controlling for age, sex, and BMI. Better understanding of the complex relationship between fatty changes of paraspinal muscles and BMD would help us gain more insight into preventing osteoporosis and related complications. Patients with high fatty infiltration in paraspinal muscles need to strengthen the paraspinal muscle function and reduce fat. This may decrease bone loss and the risk of osteoporosis fractures. Further prospective multi-center studies should be performed to investigate this hypothesis.

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Compliance with ethical standards

Participants were recruited via poster and internal emails approved by the local institutional review board (IRB). Written consent was obtained before the examination of all participants

Conflict of interest None.

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