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MUSCULOSKELETAL

Lumbar muscle volume in postmenopausal women with osteoporotic compression fractures: quantitative measurement using MRI

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Abstract

Objective To investigate the relationship between paraspinal and psoas muscle volumes and acute osteoporotic or low-bone-mass compression fractures of the lumbar spine in postmenopausal women.

Methods Patient data were retrieved retrospectively for postmenopausal women with L-spine magnetic resonance imaging (MRI) and dual-energy X-ray absorptiometry showing osteoporosis/low bone mass. Group 1 comprised eight women aged 60–80 years with MRI showing a single acute compression fracture. The age-matched group 2a ($N = 12$) and younger group 2b ($N = 12$) comprised of women whose MRIs showed no fractures. Cross-sectional MRIs of the paraspinal and psoas muscles and intramuscular fat volume for each muscle group were measured. Operator repeatability and reproducibility were obtained.

Results Group 1 showed significantly smaller lean muscle volume for all muscle groups at L5/S1. Intramuscular fat volume was also smaller in most muscle groups in group 1, though only reaching statistical significance at variable muscle groups and levels. Measurements show both good intrarater repeatability and interrater reproducibility of lean muscle volume estimations (intraclass correlation coefficient (ICC), 0.999 for rater A and 0.997 for rater B; Cronbach's alpha 0.995) and intramuscular fat volume estimations (ICC, 0.995 for rater A and 0.982 for rater B; Cronbach's alpha was 0.981).

Conclusions This study provides the first quantitative evidence that compression fractures in postmenopausal women with underlying osteoporosis/low bone mass are associated with less paraspinal and psoas muscle volumes. Further longitudinal studies with larger cohorts are needed to verify this relationship.

Key Points

- *The risk of osteoporotic compression fractures is higher in older women with smaller paraspinal muscle volume.*
- *Older women show smaller paraspinal muscle volume and more intramuscular fat compared to younger controls.*

Keywords Compression fracture · Magnetic resonance imaging · Paraspinal muscles

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Abbreviations

BMD	Bone mineral density
BMI	Body mass index
CSA	Cross-sectional area
DXA	Dual-energy X-ray absorptiometry
ES	Erector spinae
ICC	Intraclass correlation coefficient
IVD	Intervertebral disc
L-spine	Lumbar spine
MF	Multifidus
MRI	Magnetic resonance imaging
ROI	Region of interest

Introduction

Vertebral compression fractures can be associated with chronic disabling pain affecting daily activity and quality of life. Osteoporotic compression fractures can result from traumatic events ranging from high-impact falls to normal lifting and bending in the presence of compromised bone strength [1]. Bone mineral density (BMD) measured by dual-energy X-ray absorptiometry (DXA) can predict fracture risk, but it lacks specificity and sensitivity [2, 3]. Non-skeletal factors can also affect fracture risk.

Rosenberg et al introduced “sarcopenia” as an age-related change in body composition, defining it as a progressive decline in muscle mass and strength [4–6]. It has been linked to morbidities such as increased risk of falls, fall-related fractures, and loss of independence in daily activities [4, 7, 8]. Studies have also found a relationship between paraspinal muscle quality and sagittal balance, important in maintaining a stable standing position [9]. In sarcopenia, reduced muscle mass and strength affect body support and balance. This increases the risk of a fall and an ensuing response, and this affects fracture risk [8, 10].

Sarcopenia has also been associated with decreased bone strength. Reduced loading, mechanical stimulation, and relative immobility can cause decreased bone formation [11–15]. However, few studies have addressed muscle composition such as lean muscle fibers and intramuscular fat infiltration deep to the epimysium of the muscles, nor have these studies evaluated its relationship with vertebral compression fractures. Kim et al [16] reported an association between vertebral compression fractures and paraspinal muscle atrophy and fat infiltration; however, intramuscular fat infiltration was assessed only qualitatively.

Studies have been conducted to assess methods for quantitatively and qualitatively evaluating muscle and determine how those results are related to age and various clinical symptoms such as low back pain, leg pain, and muscle function/force. Ultrasound, computed tomography, and magnetic resonance imaging (MRI) have also been used to assess the cross-sectional area (CSA) of paraspinal muscle and intramuscular fat content [17–28]. Of these, MRI is most commonly used to assess muscular disorders because it uses no ionizing radiation and offers superior resolution and soft tissue delineation. Thus far, many MRI assessment methods have been proposed, including a semi-quantitative grading method [29, 30], quantitative measurement of signal intensity changes [28], quantitative histogram analysis [22, 31], MR spectroscopy [32], Dixon-based fat suppression [33], two-dimensional ultra-short echo time [33], opposed-phase MRI [34], and other methods of texture analysis [35]. These can offer accurate measurements of muscle quantity and quality with proper controls [36]; however, a standard protocol has not yet been determined, and most use cross-sectional areas for assessment.

An animal model showed that fat infiltrates the multifidus (MF) muscle beginning at 3 weeks after spinal operation [26]. Another study reported a 5% decrease of the psoas muscle after a 17-day flight [37]. Advanced visualization and analysis software offers quantitative and automatic volumetric calculations of abdominal fat using computed tomography, yielding excellent repeatability and reproducibility [38]. These software calculations use preexisting axial T2-weighted images from previous MRI studies and reduce the need for additional imaging and operating time.

We hypothesize that less paraspinal lean muscle and more intramuscular fat infiltration occur with increased age and are associated with vertebral compression fractures in postmenopausal women. With this study, we aimed to assess the relationship between vertebral compression fractures and paraspinal muscle mass and composition in an acute setting, uniquely using quantitative volumetric measurements.

Material and methods

This study was reviewed and approved by the Joint Institutional Review Board of Taipei Medical University (N201706022). The informed consent requirement was waived because this study was retrospective. All methods were performed following relevant guidelines and regulations.

Study population

All patient data were retrieved retrospectively from our institute’s radiology information system. We searched for patients who had received L-spine MRIs between May 2010 and March 2015, who were postmenopausal, and who had received DXA examinations within 2 years prior to or 3 months after the MRIs. These patients were divided into three groups.

Group 1 comprised those aged 60 to 80 years with osteoporosis or low bone mass and who experienced a single acute compression fracture as referred from either the emergency department or an outpatient department. All MRI images were reviewed for *acute* compression fractures of the L-spine, defined as compression fractures showing high signal change on T2-weighted fat-saturated images and the time of symptom onset/or time of a specific event (ex. fall, sneeze), as noted on medical records, within 14 days of MRI. Of the 116 consecutive patients who received L-spine MRIs and DXAs showing either low bone mass or osteoporosis, one patient was excluded due to missing images, and 104 had compression fractures. To avoid factors that could induce muscle atrophy or non-osteoporotic compression fractures, those with postoperative status or chronic fractures ($n = 43$), multiple compression fractures ($n = 37$), pathological compression fractures ($n = 5$), high-velocity energy trauma ($n = 8$), or known history of motor disabilities ($n = 3$) were excluded.

This group comprised eight postmenopausal women with single acute compression fractures and osteoporosis or low bone mass.

Group 2a was balanced across the same age range as group 1, and served as a control group. These women received L-spine MRIs for health examinations or low back pain assessments and had DXA measurements showing either low bone mass or osteoporosis. Those showing compression fractures, other pathologies, or deformities on imaging were excluded, resulting in 12 randomly selected postmenopausal women in the group.

Group 2b included postmenopausal women aged 40 to 59 years who received L-spine MRIs for general health examinations or low back pain assessments. Other inclusion criteria were the same as those for group 2a. Twelve women with osteoporosis or low bone mass were randomly selected.

On postero-anterior scans, BMD was measured in the lumbar region of the spine (L1–L4) and at bilateral proximal femurs. All measurements were performed using a single scanner (Lunar Prodigy, GE Healthcare). The WHO criteria were used to distinguish osteoporosis (T-score $\leqq -2.5$) from osteopenia ($-2.5 < T$-score < -1) and normal BMD (T-score $\geqq -1$) for all groups. The T-score was calculated using a standard formula: T-score = (BMD – reference value [peak BMD in a young normal population])/width of one standard deviation. Reference values for USA/Northern Europe were used as provided by manufacturers. The lowest T-score was chosen for diagnosis.

MRI and measurements

All MRI scans were performed using either of our two 1.5-T scanners (Avanto, Siemens Healthineers, or Signa, GE Healthcare). All patients underwent a routine MRI study of the L-spine in the supine position. Sagittal or coronal T2-weighted fat-saturated MRI images were used to assess acute vertebral compression fractures. Using a sagittal T2-weighted fast spin–echo pulse sequence as the localizer, axial T2-weighted fast spin–echo pulse sequence (repetition time, 2000–6000 ms; echo time, 80–130 ms; slice thickness, 4 mm; gap, 0–0.5 mm) images were acquired at the intervertebral disc (IVD) level parallel to the disc from L1–2 to L5–S1 using four 4-mm-thick slices. Two central axial sections from each of the L3–4, L4–5, and L5–S1 IVD spaces were identified using locating lines on sagittal images, and volumetric measurements of the paraspinal muscles were made (Fig. 1).

Sectional volumes of intramuscular fat and lean muscle were determined, and volume ratios of lean muscle to total muscle were calculated using automated planimetry software using a dedicated offline workstation (Virtual Place, AZE Inc.). Total muscle mass was defined as the total volume enclosed within the supposed epimysium for each muscle and included intramuscular fat and lean muscle fibers while avoiding intermuscular fat. For each image, the region of interest (ROI) was drawn using a computer mouse to separately outline the bilateral erector spinae (ES), MF, and psoas muscles (Fig. 1). The paraspinal muscle was defined as the combination of ES and MF as a muscle group. The operator paid special attention to avoid the posterior external vertebral venous plexus, intermuscular fat, and fat or connective tissue approximating the spinous process or lamina. The software then automatically quantified the separate tissue components within the ROI based on pixel intensity and calculated the lean muscle and intramuscular fat volumes between two consecutive axial images by taking the mean of the two axial areas and multiplying by the sum of the 2 slice and gap thicknesses.

Repeatability and reproducibility of MRI-based measurements

Ten randomly selected exams were used to assess intrarater repeatability and interrater reproducibility of intramuscular fat and lean muscle volumes using the AZE Virtual Place software. Two well-trained operators, a research assistant (rater A) with 3 years and a radiologic technologist (rater B) with 1 year of experience working with the equipment, performed the postprocessing tasks. To assess intrarater repeatability, each rater performed the measurements twice for lean muscle and intramuscular fat volumes for each muscle group at each IVD level; these replicates were performed 2 weeks apart. The first measurements for each of the 10 patients were compared across raters to assess interrater reproducibility.

Statistical analyses

Cronbach's alpha was used to assess measurement consistency in both intramuscular fat volume and lean muscle volume. The overall Cronbach's alpha was calculated for both raters across 10 randomly selected patients. Measurement of each muscle group was counted as a separate measurement; 3 muscles groups were measured per image with 2 images per IVD level, over 3 levels making a total of 18 measurements per patients. Intrarater repeatability was assessed using the intraclass correlation coefficient (ICC) for determining the reliability index.

Statistical analyses were performed using both Microsoft Excel and SPSS for Windows version 19.0 (SPSS Inc.). Between-group differences were calculated using the Student t test. Fisher exact test was used to calculate difference of osteoporosis/osteopenia in groups 1 and 2a. Statistical significance was recognized when $p < 0.05$.

A power analysis for intrarater reliability was conducted using G*Power software version 3.1.9.2 with 180 measurements across 10 patients; applying an alpha of 0.05 showed a power of 0.92.

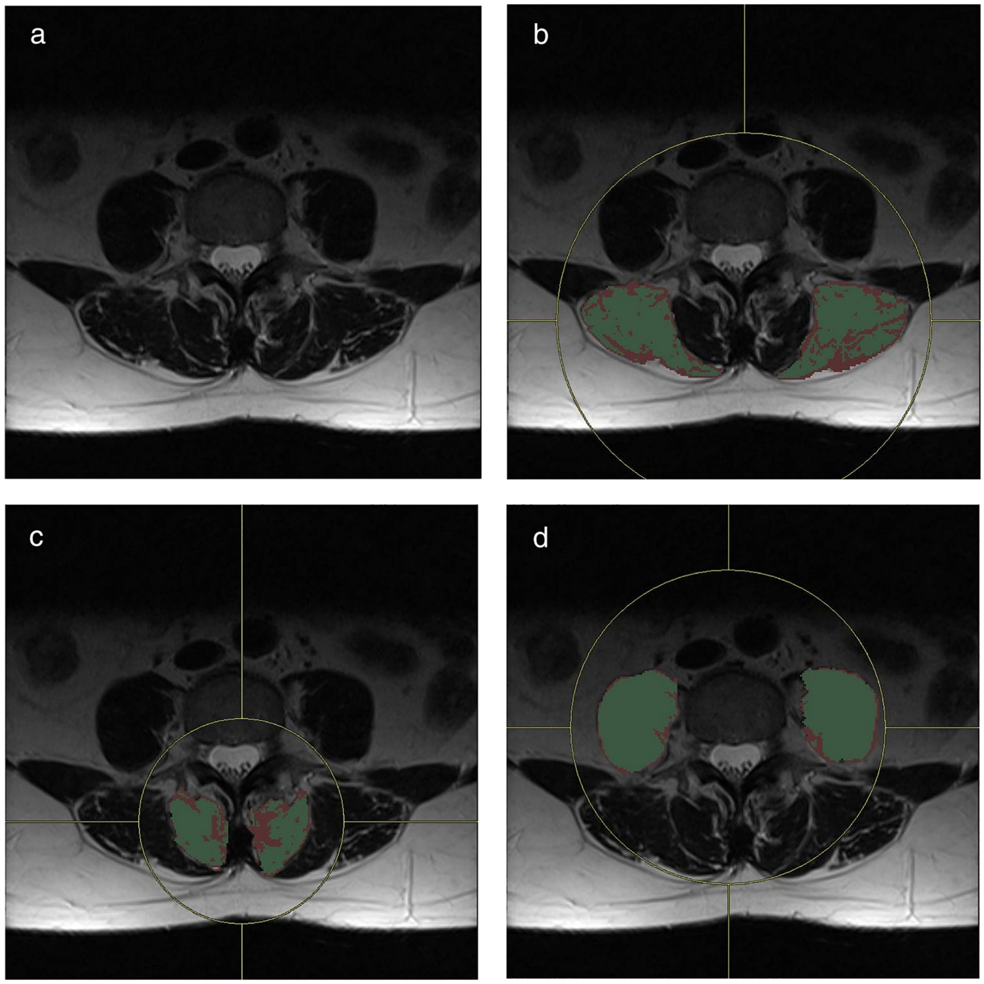

Fig. 1 Volumetric measurement of muscle using AZE software. **a** T2 axial images of each disc level from AZE software. Muscle boundaries were drawn using a computer mouse on images of the (**b**) erector spinae, **c** multifidus, and (**d**) psoas muscle. The AZE software then automatically calculated fat and lean muscle volumes within the selected regions of interest. Color-coded images show areas of intramuscular fat (pink) and lean muscle (green)

Results

In total, 32 patient images were included in this study: group 1 ($N = 8$; age 72.4 ± 6.0 years; range, 62–78 years), group 2a ($N = 12$; 69.0 ± 7 years; 60–79 years), and group 2b ($N = 12$; 53.9 ± 2.8 years; 49–58 years). There is no significant difference in osteoporosis/osteopenia between group 1 and group 2a. Significant differences in age or BMI were not found between groups 1 and 2a (Table 1). Time of symptom onset to MRI was an average of 4.25 days (range 1–9 days).

Comparisons of muscle volumes and compositions between the group with osteoporotic compression fractures (group 1) and the age-matched osteoporotic controls (group 2a)

After normalizing by BMI, the average muscle and fat fractions were compared between groups 1 and 2a (Table 2). Group 1 showed significantly lower lean muscle volumes for all muscle groups at the L5/S1 levels as well as the overall paraspinal and psoas muscle at all levels.

For most muscle groups, intramuscular fat volumes were also lower in group 1, reaching statistical significance at L3/4 and L5/S1 for the ES, L5/S1 for the paraspinal muscle, and the L3/4 for the psoas muscle ($p = 0.050$, 0.011, 0.033, and < 0.001, respectively). Only at L4/5 for the MF, ES, and overall paraspinal muscles were intramuscular fat volumes greater in group 1, but the difference was not significant.

Comparisons of muscle volumes and compositions between osteoporotic postmenopausal women of different age groups

Group 2 comprises 24 osteoporotic/osteopenic patients with low back pain or sciatica but no underlying systemic diseases. No significant difference was found in BMI between groups 2a and 2b (Table 1).

Group 2a showed smaller lean muscle volumes in all muscle groups, but statistical significance was reached only at the psoas muscle, L4/5 for all muscle groups and at L3/4 for the multifidus. The group also showed greater intramuscular fat volumes at all levels, reaching significance for the multifidus and paraspinal muscles. Overall, the ratio of lean muscle volume to total muscle

Table 1 Comparison of patient age, BMI, height, and BMD between groups (1 vs. 2a and 2a vs. 2b)

	Group 1	Group 2a	Group 2b
Age (year) [a]	72.4 ± 6.0	69.0 ± 7.0	53.9 ± 2.8*
BMI (kg/m^2) [a]	25.4 ± 5.0	24.4 ± 3.1	22.5 ± 2.7
Height (cm) [a]	152.1 ± 6.0	152.0 ± 6.3	159.3 ± 4.5*
BMD *T*-score (range, median)[b]	− 2.5 to − 4.3, − 2.85	− 1.2 to 3.3, − 2.45	− 1.3 to − 2.6, − 1.9

BMI, body mass index; *BMD*, bone mineral density

[a] Values of age, BMI, and height are presented as mean ± standard deviation

[b] Value of BMD was the lowest *T*-score from three skeletal sites (lumbar spine, bilateral femoral neck, and total femur) as examined by dual-energy X-ray absorptiometry. *T*-score represents the number of standard deviations from the mean value for healthy 30-year-old Caucasian women; therefore, direct comparisons cannot be made

*$p < 0.05$ between groups 2a and 2b

volume showed a significant decrease with age at all levels for all muscles except for the psoas at L5/S1 (Table 2).

Repeatability and reproducibility

The intrarater repeatability was good, evidenced by the Cronbach's alpha, which was 1 and 0.998 for lean muscle volume estimates and 0.998 and 0.991 for intramuscular fat volume estimates for rater A and rater B, respectively. The intrarater repeatability was better for the lean muscle volume estimates (ICC, 0.999 for rater A and 0.997 for rater B) than that for the intramuscular fat volume estimates (ICC, 0.995 for rater A and 0.982 for rater B).

Interrater reproducibility was good as well. Cronbach's alpha was 0.995 for lean muscle volume and 0.981 for intramuscular fat volume.

Discussion

These results provide the first quantitative evidence that smaller paraspinal muscles can be a potential contributing factor to osteoporotic compression fractures in postmenopausal women. This shows a smaller lumbar lean muscle mass overall in patients with acute compression fractures compared to healthy age-matched controls. Both muscle and bone are important in maintaining skeletal structure and strength. Paraspinal muscles help maintain integrity, stabilize the spine, and execute normal daily activities such as walking and maintaining balance. A previous study showed that decreased muscle mass is related to femoral neck fractures as a result of decreasing femoral neck strength relative to load. Therefore, skeletal muscle and bone have an interwoven relationship [39]. Our results show a relationship between smaller lean muscle volumes and compression fractures, possibly suggesting that those with smaller lean muscle volumes are more prone to traumatic events resulting from muscle dysfunction [40] or are more prone to osteoporotic compression fractures under any type of minor trauma. Further correlation with body composition using multivariable analyses can help determine the whole-body muscle status in these individuals and the mechanism by which small paraspinal muscle mass is associated with osteoporotic compression fractures.

Only one other study has investigated the relationship between muscle mass and vertebral compression fractures using qualitative analysis [16]. Kim et al observed significantly lower CSAs in paraspinal and psoas muscles and greater fat infiltration in those with compression fractures compared to counterparts without fractures [16]; however, the time lapse between MRI and onset of symptoms was not defined. This is important because it is well-known that disuse because of pain can itself cause muscle atrophy over time [41, 42]. In addition, quantitative measurements of muscle volume and fat infiltration were not performed. Our study is the first to investigate paraspinal muscle volume and its possible relationship with compression fractures using a quantitative and volumetric assessment.

Consistent with other studies [43–45], we found a decrease in lean muscle and an increase in intramuscular fat infiltration with aging. However, comparing group 1 to age-matched controls (group 2a), there was significantly less lean muscle volume, but intramuscular fat volume was not significantly greater, contrary to our hypothesis. This might indicate that while intramuscular fat increases with age, a change in lean muscle volume could be a more significant factor underlying changes in muscle function or structural strength.

Our results show the psoas muscle is the only muscle group with consistently lower total muscle mass and lean muscle volume throughout all IVD levels. This is true whether the scan was performed to study natural aging or the likelihood of fracture. The psoas muscle functions in hip flexion and other various movements of the spine and hip. It is important for walking and running, and it atrophies significantly with age [46]. This is likely a consequence of decline in physical activity among older adults [46, 47]. Only in the psoas muscle did we find that the total muscle mass differed significantly between the older and younger healthy patient groups, consistent with other studies. Moreover, when compared to healthy

Table 2 Comparison of average lean muscle, intramuscular fat, and muscle ratio between groups (1 vs. 2a and 2a vs. 2b)

	Group 1			Group 2a			Group 2b		
	L3/4	L4/5	L5/S1	L3/4	L4/5	L5/S1	L3/4	L4/5	L5/S1
Multifidus									
Lean muscle (cm^3)	0.24 ± 0.08	0.29 ± 0.06	0.29 ± 0.10*	0.22 ± 0.06†	0.34 ± 0.08†	0.40 ± 0.10	0.29 ± 0.07	0.41 ± 0.09	0.46 ± 0.09
Intramuscular fat (cm^3)	0.07 ± 0.04	0.11 ± 0.04	0.09 ± 0.06	0.07 ± 0.01†	0.10 ± 0.04†	0.12 ± 0.04†	0.06 ± 0.02	0.07 ± 0.02	0.09 ± 0.03
Muscle ratio (%)	77 ± 7	70 ± 7*	74 ± 20	75 ± 5†	77 ± 5†	76 ± 5†	84 ± 6	85 ± 3	83 ± 4
Erector spinae									
Lean muscle (cm^3)	0.75 ± 0.09	0.59 ± 0.08	0.16 ± 0.07*	0.80 ± 0.19	0.61 ± 0.15†	0.27 ± 0.13	0.82 ± 0.08	0.73 ± 0.09	0.34 ± 0.16
Intramuscular fat (cm^3)	0.16 ± 0.11*	0.22 ± 0.06	0.06 ± 0.05*	0.23 ± 0.06†	0.19 ± 0.06†	0.13 ± 0.05	0.19 ± 0.06	0.12 ± 0.04	0.11 ± 0.04
Muscle ratio (%)	82 ± 11	69 ± 9*	73 ± 17	77 ± 5†	76 ± 5†	67 ± 9†	81 ± 5	85 ± 5	75 ± 8
Paraspinal muscle									
Lean muscle (cm^3)	0.93 ± 0.16*	0.76 ± 0.10*	0.45 ± 0.12*	1.03 ± 0.23	0.94 ± 0.19†	0.67 ± 0.20	1.11 ± 0.09	1.14 ± 0.09	0.79 ± 0.15
Intramuscular fat (cm^3)	0.23 ± 0.10	0.33 ± 0.09	0.16 ± 0.11*	0.31 ± 0.07†	0.29 ± 0.09†	0.25 ± 0.07†	0.25 ± 0.07	0.20 ± 0.06	0.18 ± 0.07
Muscle ratio (%)	80 ± 9	70 ± 7*	74 ± 19	77 ± 5†	77 ± 4†	72 ± 5†	82 ± 5	85 ± 4	82 ± 7
Psoas									
Lean muscle (cm^3)	0.34 ± 0.08*	0.46 ± 0.08*	0.42 ± 0.06*	0.42 ± 0.11†	0.60 ± 0.14†	0.54 ± 0.13†	0.58 ± 0.09	0.77 ± 0.10	0.67 ± 0.14
Intramuscular fat (cm^3)	0.01 ± 0.01*	0.02 ± 0.01	0.01 ± 0.01	0.04 ± 0.01	0.04 ± 0.03†	0.01 ± 0.01	0.03 ± 0.01	0.02 ± 0.01	0.01 ± 0.02
Muscle ratio (%)	96 ± 3*	96 ± 3	97 ± 2	91 ± 4†	94 ± 4†	97 ± 2	95 ± 3	97 ± 1	98 ± 3

Muscle and fat volumes were normalized with body mass index; muscle ratio is the lean muscle portion of total muscle volume

*$p < 0.05$ between groups 1 and 2a; †$p < 0.05$ between groups 2a and 2b

age-matched controls, only the psoas muscles showed significant decreases in total muscle mass and lean muscle mass without significant increases in intramuscular fat. This was true at all levels in patients with compression fractures. Weakness of the psoas muscle has been found to lessen hip flexion velocity and cause gait disturbances [48]; it has also been closely related to falling when walking [47]. Therefore, our results suggest that a lower psoas muscle volume could contribute to an increased probability of compression fractures, though further study is needed to elucidate the mechanism.

A foundation method for manually defining the ROI and obtaining an accurate quantification of the paravertebral muscles and fat infiltration from axial MRIs has been described elsewhere [49]. This method was used with only minor alterations to the ROI for accurately defining the muscles. Factors considered when defining the ROI for each muscle group included considerations for adding areas involving the posterior external vertebral venous plexus, intermuscular fat, and connective tissue. Fat and connective tissue approximating the spinous process or lamina were also considered. Crawford et al and other researchers included these areas when defining the ROI [27, 31, 49]. We chose to exclude these areas because we believe these components should not be included as part of the muscle, particularly when total volume is the quantity of interest. We believe that expansions in these areas can suggest atrophy of adjacent muscles. Without sharp delineated margins, as seen in bony structures, it can be difficult to draw the ROI. Furthermore, the increased margins must be manually defined. Nevertheless, our results showed great interrater and intrarater correlations.

This study has a few limitations. First, the sample size of patients with compression fractures was small because we used strict inclusion criteria in this retrospective study. Second, although there was no statistically significant difference in age between group 1 and group 2a, group 1 showed higher age which might result in smaller volume of lean muscles. Third, although direct comparisons of BMD *T*-score cannot be made, group 1 showed slightly less BMD vs. the control group (2a) which could have contributed to a greater fracture risk. Finally, while we found a correlation between smaller lean muscle volume and compression fractures, we cannot conclude a causal relationship. The true etiology cannot be explained because this study is observational and retrospective. Spinal muscle atrophy might reflect only a portion of the patient's overall sarcopenic state, and this could then increase the probability of injury.

Conclusions

In conclusion, smaller paraspinal lean muscle volume is correlated with acute compression fractures when comparing patients with compression fractures to age-matched counterparts. Further longitudinal studies with larger cohorts are needed to verify this relationship. In addition, the older controls (healthy osteoporotic/osteopenic postmenopausal women) in this study had significantly less lean muscle volume and more intramuscular fat relative to the younger controls, consistent with other studies.

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Compliance with ethical standards

Guarantor The scientific guarantor of this publication is Professor Wing P. Chan.

Conflict of interest The authors of this manuscript declare no relationships with any companies whose products or services may be related to the subject matter of the article.

Statistics and biometry One of the authors in the manuscript, Yen-Kuang Lin, PhD, is a statistician.

Informed consent Written informed consent was waived by the Institutional Review Board.

Ethical approval Institutional Review Board approval was obtained.

Methodology
• Retrospective
• Observational
• Performed at one institution

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