Osteoporosis and Sarcopenia 10 (2024) 84–88

Contents lists available at ScienceDirect

Osteoporosis and Sarcopenia

journal homepage: www.elsevier.com/locate/afos

Original article

Relation of bone mineral density with fat infiltration of paraspinal muscles: The Goutallier classification

Firuzan Fırat Ozer [a,*], Emel Güler [b]

[a] Division of Geriatrics, Department of Internal Medicine, Kayseri City Hospital, Kocasinan, 38080, Kayseri, Turkey
[b] Division of Algology, Department of Physical Medicine and Rehabilitation, Cumhuriyet School of Medicine, Cumhuriyet University, 58140, Sivas, Turkey

ARTICLE INFO

Keywords:
Osteoporosis
Goutallier classification
Muscle quality
Fat infiltration
Paraspinal muscles

ABSTRACT

Objectives: Muscle and bone tissue are interrelated throughout their developmental processes via paracrine and endocrine pathways. Osteosarcopenia has emerged with the growing data proving the high rate of simultaneous occurrence of sarcopenia and osteoporosis. We aimed to evaluate the relationship between osteoporosis, and muscle quality by grading the fatty infiltration in paraspinal muscles according to the Goutallier classification in magnetic resonance imaging (MRI).

Methods: Data of postmenopausal patients who underwent MRI for low back pain were analyzed retrospectively. Lumbar spine and femoral neck bone mineral density (BMD) were measured by using dual energy X-ray absorptiometry (DXA). Grade of paraspinal muscle fatty infiltration for each level of lumbar vertebrae including L1-L2, L2-L3, L3-L4, was evaluated separately according to Goutallier classification system.

Results: A total of 91 postmenopausal women were included in the study. The mean age of the study population was 60.5 ± 11. Lumbar vertebrae L1-L4 total T-scores and BMD g/cm^2 were lower in patients with higher grades of Goutallier classification ($P = 0.031$ and $P = 0.023$, respectively). The distribution of the severity of fatty degeneration was significantly higher in the osteoporosis/osteopenia group at all 3 disc levels. No significant correlation was observed between femoral neck BMD and paraspinal muscle fat infiltration.

Conclusions: There is a strong relationship between osteoporosis of the lumbar spine and paraspinal muscle quality, which can be considered as a reflection of osteosarcopenia. The Goutailler classification can be an effective and easy method in the evaluation of muscle quality with MRI.

1. Introduction

Bone and muscle are closely related tissues and there is a strong relationship between them in their development. Both bone and muscle mass peak in early adulthood, followed by a gradual decline after age 40 [1]. Osteoporosis and sarcopenia are two prevalent diseases and causes of morbidity and mortality among older adults and are associated with a significant increase in health care costs. Osteoporosis is a chronic disease characterized by low bone mass and deterioration of the micro-architecture of bone tissue [2]. Sarcopenia is defined by loss of muscle mass and function with advancing age [3]. Various imaging methods are available for the evaluation of bone and skeletal muscle mass and quality, both in osteoporosis and sarcopenia, and high-resolution imaging modalities have led us to understand the linear relationship between bone mineral content (BMC) and muscle mass [4]. The interdependence of sarcopenia and osteoporosis has led to the need for new definitions such as osteosarcopenia.

Major imaging modalities used to assess muscle mass include whole body dual-energy X-ray absorptiometry (DXA), computed tomography (CT), ultrasound, and magnetic resonance imaging (MRI) [5]. Although CT and MRI are the gold standard imaging methods for determining sarcopenia, no common criteria or thresholds, or indices specific to CT/MRI imaging methods have been clearly defined to assess skeletal muscle mass and diagnose sarcopenia. Various cut-off points have been proposed in studies for CT/MRI images to assess sarcopenia [6]. Fatty infiltration in skeletal muscle mass is a good indicator reflecting reduction in muscle mass and deterioration of muscle quality [7]. Among the imaging modalities, MRI shows the best contrast between fat and muscle tissue in the evaluation of muscle quality and myosteatosis [8]. The Goutallier classification is a visual system that grades fatty

Peer review under responsibility of The Korean Society of Osteoporosis.

* Corresponding author. Division of Geriatrics, Department of Internal Medicine, Kayseri City Hospital, Kocasinan, 38080, Kayseri, Turkey.
E-mail address: firuzozer@gmail.com (F.F. Ozer).

https://doi.org/10.1016/j.afos.2024.04.002
Received 11 December 2023; Received in revised form 25 February 2024; Accepted 14 April 2024
Available online 24 April 2024

infiltration in muscle tissue and enables to qualitative assessment of muscle tissue [9]. The Goutallier classification, originally projected for grading fatty degeneration of the rotator cuff muscles on CT, has been extended to MRI and assessment of other muscles, including the back muscles [10,11]. Magnetic resonance imaging enables the estimation of the morphology and composition of paraspinal muscles, including multifidus and erector spinae [9] In addition, it was emphasized that the Goutallier classification system for assessing muscle quality and mass could represent the first step towards standardized reporting in muscle assessment with MRI [12].

As a muscle quality biomarker, commonly, cross sectional area (CSA) has been used in MRI studies to evaluate the fatty degeneration of back muscles. In the majority of these studies, the relationship between vertebral pathologies, to a lesser extent bone mineral density (BMD), and fatty degeneration in the back muscles was examined [7,9–11]. Furthermore, no studies have investigated the relation of bone mineral density with quality of back muscles by applying the Goutallier classification. Therefore, this study aimed to investigate the relationship between the DXA revealed bone mineral density, and the fatty infiltration in the paraspinal muscles which was graded according to the Goutallier classification in MRI.

2. Methods

2.1. Study population

Data of postmenopausal patients who attended to the algalogy unit of a tertiary hospital with low back pain were analyzed retrospectively. Data of 91 postmenopausal patients with lumbar spine MR image, DXA measurements and serum 25 (OH) D levels, were obtained and included in the analysis. Body mass index was calculated by dividing weight with height in square meters. Exclusion criteria were defined as follows: (1) early menopause with age < 45 years old, (2) concomitant spinal disease (congenital, inflammatory, or infective), (3) history of lumbar spine surgery and/or injury, (4) ankylosing spondylitis, and (5) the inability to walk independently.

Informed consent form was obtained from the patients and ethical approval was obtained from the institution.

2.2. DXA measurements

Lumbar and femoral neck BMD were measured by using dual energy X-ray absorptiometry (DXA; Lunar Prodigy Advance, GE Lunar, Madison, WI, USA). Levels at L1-L2 T-score, L2-L3 T-score, L3-L4 T-score, L1-L4 total T-score, and lumbar vertebra total BMD gr/cm^2, femoral neck T-score and femoral neck BMD gr/cm^2 results from DXA measurements were included in the analysis. Osteoporosis is defined according to WHO criteria as a BMD that lies 2.5 standard deviations or more below the average value for young healthy women (a T-score of < -2.5). Osteopenia was defined as a T-score of < -1 and > -2.5.

2.3. Lumbar MRI

All patients were evaluated by MRI of the lumbar spine for nonspecific low back pain and images were achieved at our clinic (1.5 T MRI; Siemens, Erlangen, Germany). T2 axial image measurements were obtained from a single slice at the upper border of each disc at the level of the superior endplate of L1-L2, L2-L3 and L3-L4 for the evaluation of paraspinal muscle quality. All MRI images were viewed using the Eizo Radioforce Rx360 3 MP.

2.4. Assessment of parasipinal muscle quality

Grade of paraspinal muscle fatty infiltration for each level of lumbar vertebrae including L1-L2, L2-L3, L3-L4, was evaluated separately. Fatty infiltration was classified by evaluating the fat accumulation ratios of the spinalis, longissimus, and iliocostalis muscles, which are the 3 muscle groups that make up the paravertebral erector spinae muscle, in the T2 weighted images in lumbar MR. Fatty infiltration was classified according to Goutallier classification system [13] as Grade 0: No fatty infiltration; Grade 1: Minimal focal or linear fatty infiltration; Grade 2: less fatty infiltration than muscle tissue; Grade 3: equal amounts of fatty infiltration and muscle; Grade 4: More than 50% fatty infiltration (Fig. 1). All visible assessments of MRI were done by one reader (EG). The study population was divided into two groups according to the severity of fatty grades for analysis, dichotomized as ratio of fat deposition less than 25% (Grade 0 and Grade 1) and more than 25% (Grade 2, Grade 3, and Grade 4). While the degree of fatty degeneration in paravertebral muscles in all 3 vertebral levels (L1-L2, L2-L3, L3-L4) was determined separately, in both from left and right sides in all patients, the highest grade of fatty degeneration in any of the lumbar vertebral level selected for grouping the patients. Since, fatty infiltration quantified at each level probably affects the function of the whole muscle [9].

2.5. Statistical analysis

A descriptive analysis was performed. Histogram, q-q plots and Shapiro-wilk test were examined to assess the data normality. A two-sided independent samples *t*-test and Mann Whitney *U* test were conducted to compare the differences between continuous variables among the two groups. Variables regarding the DXA measurements were adjusted for age while comparing the groups. Binary logistic regression analysis was performed for adjustment with age. Pearson correlation coefficient was calculated to check the correlations between the grades of Gourtallier classification and vertebral T-scores at each disc level, separately. Comparisons between the grades of Goutallier classification and the osteoporosis/osteopenia group in each disc level were done by using Fisher's exact test. The Bonferroni corrections were applied for multiple comparisons. Friedman test was applied to compare the severity of fat infiltration between all three disc levels. Wilcoxon signed-rank test was performed for post hoc analysis. $P < 0.05$ was significant. Analyses were conducted using SPSS version 22.

Measurements showed good intrarater repeatability for the grading of Goutallier classification (intraclass correlation coefficient (ICC) = 0.999).

3. Results

A total of 91 postmenopausal women were included in the study. The mean age of the study population was 60.5 ± 11. According to Goutallier classification (fat deposition less than 25% and more than 25%) age was significantly correlated with fatty infiltration of paraspinal muscles ($P = 0.009$). Lumbar vertebrae L1-L4 total T-scores and BMD g/cm^2 were lower in patients with higher grades of Goutallier classification after adjusting by age ($P = 0.031$ and $P = 0.023$, respectively). The relation between the clinical characteristics of the patients and grades of Goutallier classification is represented in Table 1. The negative correlation between Goutallier grade and lumbar vertebra T-score was highest at L1-L2 level ($r = -0.211$, $P = 0.060$). Correlations between the Goutallier grades and lumbar vertebrae T-scores in each disc level (L1-L2, L2-L3, L3-L4) are presented with boxplot graphs in Fig. 2. After grouping the study population according to T-scores (osteoporosis/osteopenia and normal BMD values) distribution of Goutallier grades were significantly higher in osteoporosis/osteopenia group in all L1-L2, L2-L3 and L3-L4 disc levels (Table 2). The degree of fat infiltration was increasing towards the lower lumbar regions (Table 3).

4. Discussion

The close relationship between osteoporosis and sarcopenia is now well known with the emergence of the concept of osteosarcopenia [14]. In this study, we observed a significant relationship between decreased

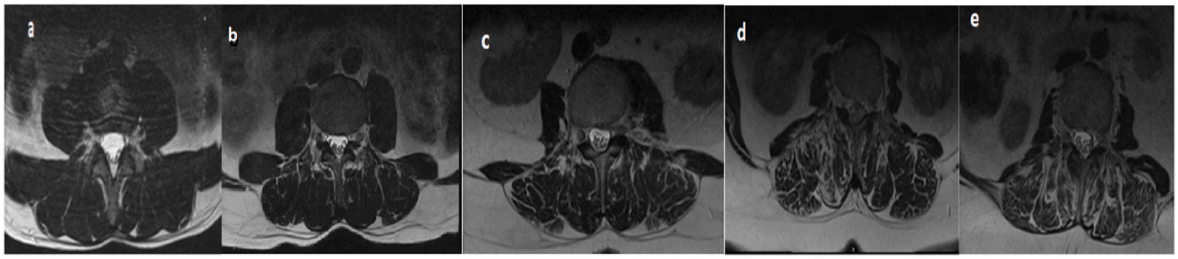

Fig. 1. MR images of paraspinal muscles representing fat infiltration according to Goutallier classification; Grade 0 (a), Grade 1(b), Grade 2(c), Grade 3 (d), and Grade 4 (e).

Table 1
Comparison of clinical factors of the study population according to fatty infiltration.

Variables	Total N = 91	Grade 0-1 N = 28 (30.8)	Grade 2-3-4 N = 63 (69.2)	P
Age, yrs	60.5 ± 11	56.0 ± 9.5	62.5 ± 11.1	0.009
BMI, kg/m²	32 ± 5.1	30.7 ± 4.9	32.5 ± 5.1	0.110
25(OH)D, ng/mL	20.05 (11.5–28.65)	20.8 (12.55–24.5)	19.7 (11.50–31)	0.953
BMD (spine T-score)	−1.4 ± 1.1	−0.9 ± 0.9	−1.7 ± 1.1	0.031*
BMD (spine g/cm²)	0.903 ± 0.134	0.967 ± 0.117	0.878 ± 0.132	0.023*
BMD (femoral neck T-score)	−0.2 ± 1.1	−0.1 ± 1.1	−0.3 ± 1.1	0.859*
BMD (femoral neck g/cm²)	0.887 ± 0.140	0.920 ± 0.154	0.872 ± 0.131	0.602*

$P < 0.05$ is significant, P* values adjusted for age, mean ± SD deviation, median (25th-75th percentiles), BMI, body mass index; BMD, bone mineral density.

bone mineral density and poor muscle quality. We evaluated the muscle quality with intramuscular fat infiltration, which is one of the main developmental mechanisms of sarcopenia, and we used the Goutallier classification to standardize this evaluation. In our results, fatty degeneration was closely associated with advanced age as expected, and decreased bone mineral density. Therefore, we corrected all of our analyses for age. When we compared the bone mineral density at femoral neck and at lumbar vertebra with Goutallier grading, low T-scores in the lumbar vertebra were closely associated with higher grades of fatty degeneration, but we did not observe a similar relationship in the femoral neck region. In the lumbar spine, when we separately correlated the DXA T-scores of all three disc levels with degree of fatty degeneration at the relevant levels, we observed the highest negative correlation in the L1-L2 level. This relationship was gradually decreasing at the lower disc levels. In patients with low bone mineral density (osteoporosis/osteopenia), the distribution of the severity of fatty degeneration according to disc levels was higher at all disc levels, with more pronounced at L1-L2 and L2-L3 levels, compared to the normal BMD group.

Sarcopenia is a clinical condition that points not only the decrease in muscle mass but also poor muscle performance and muscle strength. The main reason for its growing importance in recent years is that it is closely related to other clinical entities such as osteoporosis, which may cause unfavorable outcomes such as falls, hospitalization, and mortality [14, 15]. Muscle quality, which we evaluated by the help of fat infiltration, is actually a reflection of sarcopenia [12]. Although there is no standardization in MRI imaging, which is accepted as one of the gold standards for the evaluation of sarcopenia, the most frequently analyzed region was the thigh and less frequently the back muscles and mostly used cross sectional areas for assessments. It was also emphasized that the Goutallier classification could be a beginning for standardization in the evaluation of sarcopenia with MRI [12]. Moreover, the degree of fat infiltration assigned by the Goutallier classification showed a good correlation with quantitative method measurements and histological evaluations [9,16].

In our study, we observed a close relationship between the paraspinal muscles' fat infiltration and lumbar spine BMD. In studies, examined muscle-bone associations in lumbar region, an inverse relationship between fat infiltration of paraspinal muscles and lumbar BMD has been shown in consistent. Few studies have investigated muscle-bone associations in MRI and some investigated in quantitative computed tomography (QCT) with different quantitative and qualitative methods [17–20] One of these studies quantitatively evaluated fatty degeneration in paraspinal muscles with Proton density fat fractions (PDFF) [17] and the other, evaluated the paraspinal muscles as muscle functional cross-sectional area (FCSA) on magnetic resonance imaging (MRI) [18]. Han et al. [20] demonstrated that osteoporotic patients showed higher paraspinal muscle fat infiltration at L4-S level when compared with normal bone density group, however, no statistical difference was observed between osteoporosis, osteopenia and normal groups in terms of paraspinal muscle CSAs in patients who needed to undergo surgery for lumbar spinal stenosis, and they interpreted as the relationship between CSA and muscle strength was not as significant as that of fat infiltration. Yang et al. [21] compared CSA, fat infiltration of psoas and paraspinal muscles with lumbar spine BMD at the level of L3-L4, in a relatively young and large study population. As a result, only paraspinal muscle fat infiltration was independently associated with lower BMD scores in both sexes and they concluded that muscle quality plays more importance in bone muscle relationship than muscle size. In both of the above-mentioned studies, the importance of the linear relationship between back muscle fat infiltration and bone health was stated comparatively, in agreement with our results.

In our study, the femoral neck T-scores and BMD values tend to be lower in the group with high grade paraspinal muscle infiltration, though we did not observe a statistically significant difference. In a study with female osteoporotic hip fracture patients, total hip BMD measured by DXA was positively correlated with fatty degeneration of two mid-thigh muscles evaluated by CT [22]. These findings may be interpreted as muscle fat infiltration is more closely related to BMD at the localized skeletal site.

In our study, when each disc level was evaluated separately, the negative correlation between T-scores and fatty degeneration was strongest at L1-L2 level and this relationship decreased as downward. Huang et al. [23] evaluated the area between L3 and S1 for paraspinal lean mass and fat infiltration in three vertebral levels with quantitative and volumetric evaluation on MRI. While the lean mass was lower in osteoporotic fracture group than the age matched controls, most prominent L5-S1, they found no significant difference between the groups except for age related to fatty degeneration. In agreement with aforementioned study, corresponding to lower disc levels, although there was a positive correlation between the severity of fat infiltration and increasing age, we observed only a near significant negative correlation between fat infiltration and T-scores at L1-L2 level, not at lower levels. In addition, in accordance with previous studies, degree of fat infiltration was increasing towards lower levels of lumbar spine and was

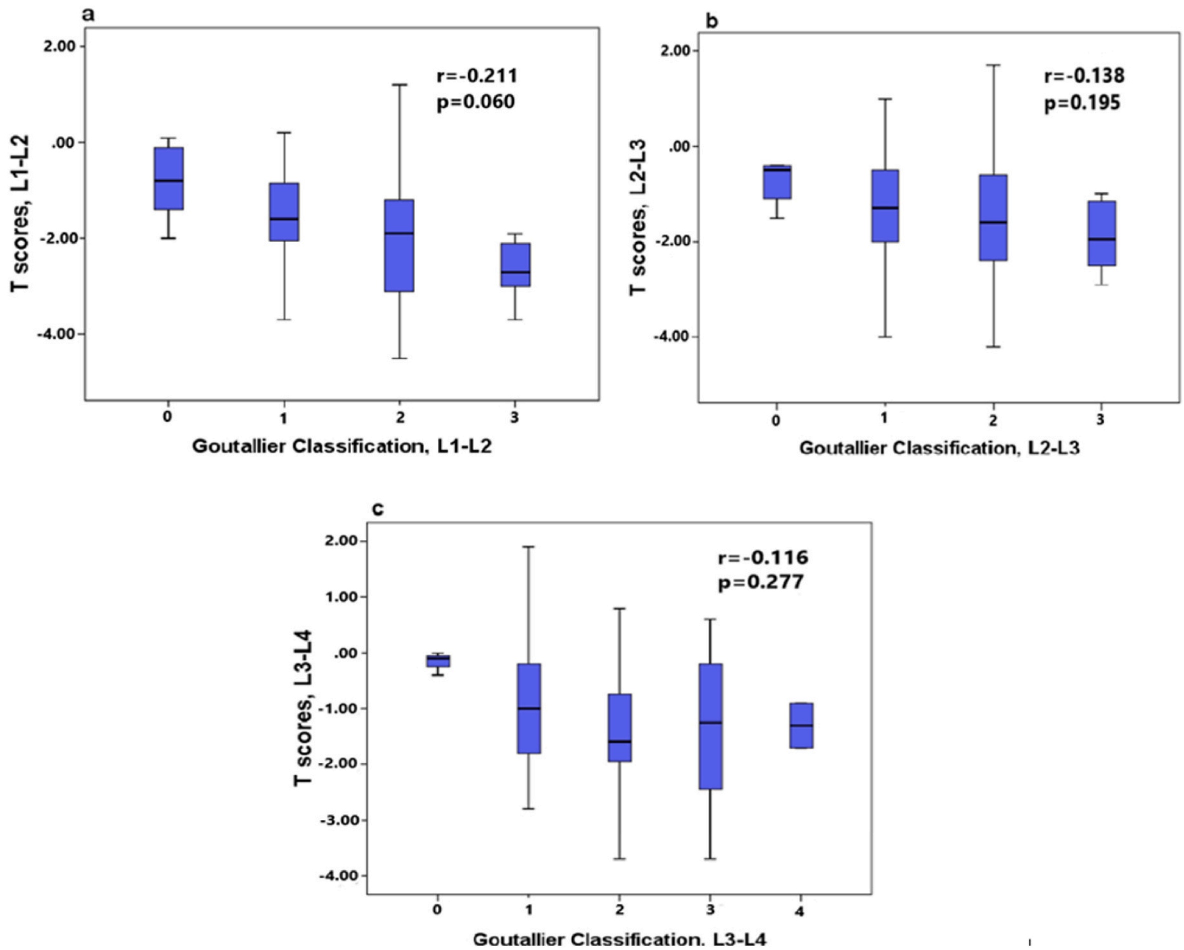

Fig. 2. Bar graphs represent the relation between the T-scores and the grades of Goutallier Classification at each disc level a)L1-L2, b)L2-L3, c)L3-L4. All r and P-values were adjusted by age.

Table 2
Comparison of Goutallier grades according to BMD status.

Goutallier clasification	Normal BMD values N = 33 (36.3)	Osteoporosis/ Osteopenia N = 58 (63.7)	*P
L1-L2			0.001
Grade 0	6 (18.2)[a]	0 (0)[b]	
Grade 1	18 (54.5)[a]	28 (48.3)[a]	
Grade 2	9 (27.3)[a]	23 (39.7)[a]	
Grade 3	0 (0)[a]	7 (12.1)[b]	
Grade 4	0	0	
L2-L3			0.002
Grade 0	6 (18.2)[a]	0 (0)[b]	
Grade 1	13 (39.4)[a]	21 (36.2)[a]	
Grade 2	13 (39.4)[a]	26 (44.8)[a]	
Grade 3	1 (3.0)[a]	11 (19)[b]	
Grade 4	0	0	
L3-L4			0.032
Grade 0	3 (9.1)[a]	0 (0)[b]	
Grade 1	14 (42.4)[a]	15 (25.9)[a]	
Grade 2	9 (27.3)[a]	28 (48.3)[b]	
Grade 3	7 (21.2)[a]	13 (22.4)[a]	
Grade 4	0 (0)[a]	2 (3.4)[a]	

Values are presented as number (%). *Fisher's exact test. [a,b]The same letters show similarity between pairwise comparisons.

highest at L3-L4 level [9]. In this case, we would like to speculate the question, whether the level of lumbar vertebrae has an emphasis on the evaluation of the relationship between paraspinal fat infiltration and lumbar BMD.

Table 3
Distribution of the severity of fat infiltration according to the level of the lumbar region.

Goutallier clasification	L1-L2 N = 91	L2-L3 N = 91	L3-L4 N = 91	*P
Grade 0	6 (6.6)	6 (6.6)	3 (3.3)	< 0.001
Grade 1	46 (50.5)	34 (37.4)	29 (31.9)	
Grade 2	32 (35.2)	39 (42.9)	37 (40.7)	
Grade 3	7 (7.7)	12 (13.3)	20 (22)	
Grade 4	0 (0)	0 (0)	2 (2.2)	
***Mean Ranks**	1.70[a]	1.97[b]	2.34[c]	

Goutallier grades, number (%), *Friedman test. [a,b,c]Post hoc analysis results with Wilcoxon signed-rank test. Different letters show the significant differences between pairwise comparisons.

This study has some limitations. First, the retrospective design of the study restricts our understanding of the linear causal relationship between muscle and bone tissue. Second, the relatively small number of patients and the study comprised of only postmenopausal women limit the generalizability of the results. Third, the parameters that have a direct effect on muscle and bone health, such as sex hormones and comorbidities, have not been evaluated.

5. Conclusions

Paraspinal muscle fat infiltration assessed with the Goutallier classification was observed to be closely associated with adjacent bone health, giving rise to thought the osteosarcopenia. Albeit, the intramuscular adiposity is a component of sarcopenia that has not yet been clearly defined, the Goutallier classification can be an effective and easy method in the evaluation of muscle quality with MRI. Considering that T2 weighted MRI image sections are frequently obtained in the clinics, the evaluation of paraspinal fat infiltration in routine practice may also be a guide for clinicians to evaluate bone and muscle health. It may help enhance to facilitate the way to diagnosis of osteosarcopenia.

CRediT author statement

Firuzan Fırat Ozer: Conceptualization, Methodology, Investigation, Formal analysis, Supervision, Writing – original draft. **Emel Güler:** Conceptualization, Investigation, Data curation, Writing – review & editing.

Conflicts of interest

The authors declare no competing interests.

Acknowledgments

ORCID Firuzan Fırat Özer: 0000-0001-7470-7488. Emel Güler: 0000-0002-5049-8770.

References

[1] Curtis E, Litwic A, Cooper C, Dennison E. Determinants of muscle and bone aging. J Cell Physiol 2015;230:2618–25.
[2] Wa P. Consensus development conference: diagnosis, prophylaxis, and treatment of osteoporosis. Am J Med 1993;94:646–50.
[3] Messina C, Maffi G, Vitale JA, et al. Diagnostic imaging of osteoporosis and sarcopenia: a narrative review. Quant Imag Med Surg 2018;8:86–99.
[4] Guerri S, Mercatelli D, Aparisi Gomez MP, et al. Quantitative imaging techniques for the assessment of osteoporosis and sarcopenia. Quant Imag Med Surg 2018;8:60–85.
[5] Boutin RD, Yao L, Canter RJ, Lenchik L. Sarcopenia: current concepts and imaging implications. AJR Am J Roentgenol 2015;205:W255–66.
[6] Lee K, Shin Y, Huh J, et al. Recent issues on body composition imaging for sarcopenia evaluation. Korean J Radiol 2019;20:205–17.
[7] Crawford RJ, Volken T, Valentin S, et al. Rate of lumbar paravertebral muscle fat infiltration versus spinal degeneration in asymptomatic populations: an age-aggregated cross-sectional simulation study. Scoliosis Spinal Disord 2016;11:21.
[8] Seabolt LA, Welch EB, Silver HJ. Imaging methods for analyzing body composition in human obesity and cardiometabolic disease. Ann N Y Acad Sci 2015;1353:41–59.
[9] Mandelli F, Nuesch C, Zhang Y, et al. Assessing fatty infiltration of paraspinal muscles in patients with lumbar spinal stenosis: Goutallier classification and quantitative MRI measurements. Front Neurol 2021;12:656487.
[10] Yanik B, Keyik B, Conkbayir I. Fatty degeneration of multifidus muscle in patients with chronic low back pain and in asymptomatic volunteers: quantification with chemical shift magnetic resonance imaging. Skeletal Radiol 2013;42:771–8.
[11] Kalichman L, Kim DH, Li L, et al. Computed tomography-evaluated features of spinal degeneration: prevalence, intercorrelation, and association with self-reported low back pain. Spine J 2010;10:200–8.
[12] Albano D, Messina C, Vitale J, Sconfienza LM. Imaging of sarcopenia: old evidence and new insights. Eur Radiol 2020;30:2199–208.
[13] Goodpaster BH, Chomentowski P, Ward BK, et al. Effects of physical activity on strength and skeletal muscle fat infiltration in older adults: a randomized controlled trial. J Appl Physiol 2008;105:1498–503.
[14] Reginster JY, Beaudart C, Buckinx F, Bruyere O. Osteoporosis and sarcopenia: two diseases or one? Curr Opin Clin Nutr Metab Care 2016;19:31–6.
[15] Cruz-Jentoft AJ, Bahat G, Bauer J, et al. Sarcopenia: revised European consensus on definition and diagnosis. Age Ageing 2019;48:601.
[16] Tamai K, Chen J, Stone M, et al. The evaluation of lumbar paraspinal muscle quantity and quality using the Goutallier classification and lumbar indentation value. Eur Spine J 2018;27:1005–12.
[17] Zhao Y, Huang M, Serrano Sosa M, et al. Fatty infiltration of paraspinal muscles is associated with bone mineral density of the lumbar spine. Arch Osteoporosis 2019;14:99.
[18] Chiapparelli E, Okano I, Adl Amini D, et al. The association between lumbar paraspinal muscle functional cross-sectional area on MRI and regional volumetric bone mineral density measured by quantitative computed tomography. Osteoporos Int 2022;33:2537–45.
[19] Li X, Zhang Y, Xie Y, et al. Correlation between bone mineral density (BMD) and paraspinal muscle fat infiltration based on QCT: a cross-sectional study. Calcif Tissue Int 2022;110:666–73.
[20] Han G, Zou D, Liu Z, et al. Paraspinal muscle characteristics on MRI in degenerative lumbar spine with normal bone density, osteopenia and osteoporosis: a case-control study. BMC Muscoskel Disord 2022;23:73.
[21] Yang Q, Yan D, Wang L, et al. Muscle fat infiltration but not muscle cross-sectional area is independently associated with bone mineral density at the lumbar spine. Br J Radiol 2022;95:20210371.
[22] Hahn MH, Won YY. Bone mineral density and fatty degeneration of thigh muscles measured by computed tomography in hip fracture patients. J Bone Metab 2016;23:215–21.
[23] Huang CWC, Tseng IJ, Yang SW, et al. Lumbar muscle volume in postmenopausal women with osteoporotic compression fractures: quantitative measurement using MRI. Eur Radiol 2019;29:4999–5006.