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Pelvic muscle size and myosteatosis: Relationship with age, gender, and obesity

Thomas Pacicco[1], Shayna Ratner[1], Yin Xi[1], Takeshi Yokoo[1,2], David Fetzer[1], Orhan K Oz[1], Craig D Rubin[3], Avneesh Chhabra[1]

[1]Radiology, UT Southwestern Medical Center, [2]Advanced Imaging Research Center, UT Southwestern School of Medicine, [3]Geriatric Division, Internal Medicine, UT Southwestern Medical Center, Dallas, TX, USA

Correspondence: Dr. Avneesh Chhabra, UT Southwestern Medical Center, Dallas, TX 75022, USA.
E-mail: avneesh.chhabra@utsouthwestern.edu

Abstract

Purpose: To evaluate interreader performance in the measurement of the cross-sectional area and myosteatosis of pelvic skeletal muscles using fat quantification magnetic resonance imaging (MRI) and correlate with patient anthropomorphic characteristics. **Materials and Methods:** A Health Insurance Portability and Accountability Act–compliant retrospective cross-sectional study was performed. Between January and April 2016, 61 patients (26 males and 35 females) underwent a lumbosacral plexus 3T MRI with a modified three-dimensional spoiled gradient echo sequence dedicated to fat quantification (mDixon Quant; Philips Healthcare). Two independent reviewers outlined muscle cross-sectional area on axial images using a freehand region of interest tool and documented proton-density fat fraction (FF) and muscle area (cm^2) of the psoas, gluteus medius, gluteus maximus, and rectus femoris muscles on each side. Interreader agreement was assessed by intraclass correlation coefficient (ICC), and correlation between the measurements and subject's age, gender, and body mass index (BMI) was assessed using multiple linear regression analysis. **Results:** Excellent interreader agreement was obtained (ICC ≥0.74) for all muscle groups except for the left gluteus medius area and right psoas FF which showed good agreement (0.65 and 0.61, respectively). Statistically significant ($P \leq 0.05$) positive correlation was seen between the gluteal muscle FF and area with BMI, and rectus muscle FF with age and BMI. Statistically significant negative correlation between the rectus femoris area and age was also observed. **Conclusion:** Fat quantification MRI is a highly reproducible imaging technique for the assessment of myosteatosis and muscle size. Intramuscular FF and cross-sectional area were correlated with age and BMI across multiple muscle groups.

Key words: Adults; fat; measurement; MRI; muscular

Introduction

According to the Centers for Disease Control "Aging and Health in America," the United States will experience an unprecedented increase and proportion of older adults in the next 25 years. By 2030, the population of older adults will reach 72 million individuals, which is about 20% of the US population.[1] With an aging population, there would be an expected increase in the overall prevalence of diseases such as heart disease, diabetes mellitus, and various forms of cancer. In addition, elderly men and women suffer from an

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increased number of falls and hip fractures. Loss of muscle mass, also known as sarcopenia, has been shown to be a contributory factor to the fall risk of the elderly and is often associated with osteoporosis.[2] Increased fatty infiltration of muscle, also known as myosteatosis, has recently been documented as increasing as a person ages and as a risk factor for future morbidity and mortality including fall and fracture risk.[3,4] In addition to being an independent risk factors for fracture, sarcopenia and myosteatosis have been identified as risk factors for increased postsurgical morbidity and mortality.[5,6]

The current diagnostic imaging methods for the assessment of sarcopenia and myosteatosis in the elderly include dual energy X-ray absorptiometry, bioelectrical impedance analysis, magnetic resonance imaging (MRI), and computed tomography.[5-7] The use of computed tomography has been validated in predicting the risk of hip fracture by assessment of Hounsfield units of the mid-thigh muscle bundles and also for demonstrating a difference in gluteal muscle fatty infiltration between patients who are known fall risks (fallers) and those who are not (nonfallers).[7,8] MRI techniques for intramuscular fat assessment include conventional sequences (T1-weighted and T2-weighted), MR spectroscopy, and chemical shift imaging including two- or three-point Dixon techniques.[9-11] In particular, Dixon-based fat quantification MRI has been extensively used in evaluation of hepatic steatosis, as well as recently in assessment of intramuscular steatosis such as in the assessment of hip abductor and paraspinal skeletal muscle groups in healthy adults, and normative values have been published.[12,13] Fat quantification MRI techniques are also increasingly used to study posttraumatic and genetic musculoskeletal abnormalities.[14,15]

The aim of our study was to evaluate interreader performance in the measurement of cross-sectional area and myosteatosis of key functional skeletal muscle groups around the spine and hip using fat quantification MRI and to correlate with anthropomorphic features, such as patient age, gender, and body mass index (BMI).

Materials and Methods

Study design and patient population

This retrospective cross-sectional study was approved by the Institutional Review Board and was conducted in compliance with the Health Insurance Portability and Accountability Act. Between January and April 2016, 85 consecutive subjects underwent MRI of the lumbosacral plexus at 3T for pelvic or genital pain, which included a dedicated fat quantification sequence (details below) as per our institutional protocol. Exclusion criteria were presence of motion or metal artifact (n = 6), incomplete imaging (n = 10), underlying known muscular or neurogenic disorder (n = 1), presence of muscle edema suggested by hyperintense signal on T2-weighted imaging (n = 1), incomplete clinical data (n = 1), age less than 18 years (n = 1), and previous intra-abdominal surgical procedure intended for weight loss (gastric bypass or lap band) (n = 4). None of the included subjects had a systemic condition such as hereditary neuropathy, neurofibromatosis, or diffuse polyneuropathy such as chronic inflammatory demyelinating polyneuropathy. In all, 61 patients (35 females and 26 males), age range 18–84 years (mean = 51 years), met all the inclusion and exclusion criteria. Using electronic chart review, age, sex, and BMI of the subjects were recorded by a radiology resident in an Excel datasheet. There were four patients with diabetes mellitus type 2 who did not meet the inclusion criteria and were excluded based on the above criteria.

Imaging technique

All imaging examinations were uniformly performed on a 3T whole-body scanner (Philips Achieva, Ingenia, Best, Amsterdam, The Netherlands) using a 16-channel Torso XL coil linked to the posterior spine coils. A modified three-dimensional spoiled gradient echo sequence dedicated to fat quantification (mDixon Quant; Philips Healthcare, Amsterdam, The Netherlands) was performed in the axial plane from the level of L4 to the lesser trochanters. The key acquisition parameters were as follows: TR 11 ms, TE 1–1.34 ms, Delta TE 1 ms, matrix 292 × 292, and number of signal averages 1. Parallel imaging (SENSE) was used with phase-direction reduction of 1.5. The in-phase, opposed-phase, water-only, fat-only, and proton-density fat fraction (PDFF) images were automatically reconstructed on the scanner and sent to PACS Picture Archiving and Communications System; IntelliSpace; Philips Healthcare).

Image analysis

Image analysis was performed independently by two readers blinded to the demographic data, anthropomorphic, and clinical information using PACS. Under the supervision of a fellowship-trained musculoskeletal radiologist, a radiology resident and medical student evaluated the representative images through both psoas muscles (level of mid-L4 vertebral body), gluteus medius muscles (level of fibrous part of sacroiliac joints), gluteus maximus muscles (level of ischial tuberosities), and rectus femoris muscles (level of mid-lesser trochanters). On the axial PDFF images, the entire muscle cross-sectional area was outlined using a freehand region of interest (ROI) tool [Figures 1-4]. Careful attention was made to avoid inclusion of adjacent subcutaneous or retroperitoneal fat. For each ROI, FF mean and standard deviation (SD) and skeletal muscle area (SMA; cm^2) were recorded. Seven cases (about 10% of the imaging data set) were evaluated in consensus for training purposes 2 weeks before the final independent evaluations. Both readers performed the measurements independently following the initial training set of seven cases.

Figure 1: mDixon Quant sequence at the level of L4 with a representative freehand ROI of the right psoas muscle and subcutaneous fat of a 28-year-old male with a normal BMI (23 kg/m^2). Notice the right psoas muscle shows a fat fraction (FF) 1.53 ± 10.7% and adjacent subcutaneous fat shows a FF 90.14 ± 1.6%

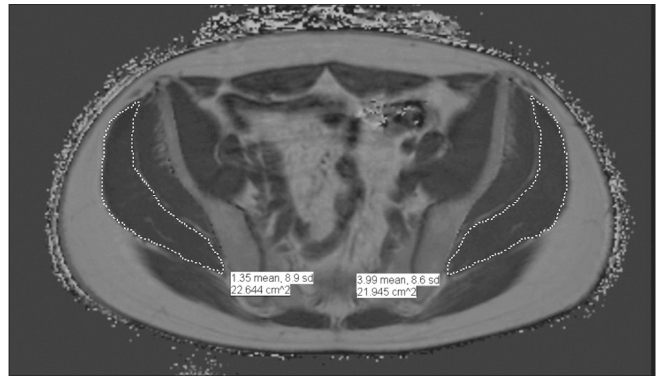

Figure 2: Representative freehand ROI of both gluteus medius muscles. Notice the right gluteus medius shows a fat fraction 1.35 ± 8.9% and muscle area 22.644 cm^2. The left gluteus medius shows a fat fraction 3.99 ± 8.6% and muscle area 21.945 cm^2

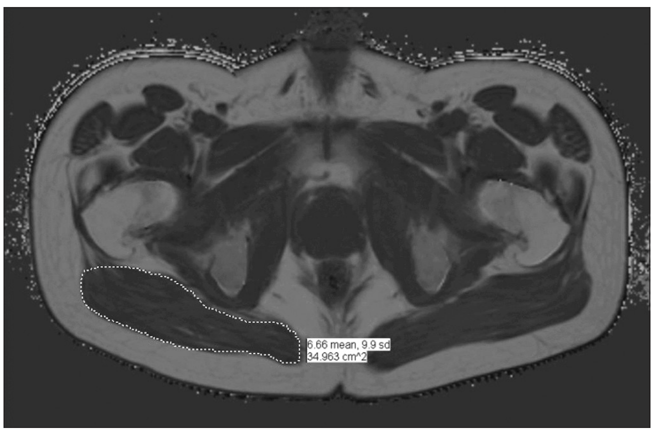

Figure 3: Representative right gluteus maximus ROI shows FF 6.66 ± 9.9% and area 34.96 cm^2

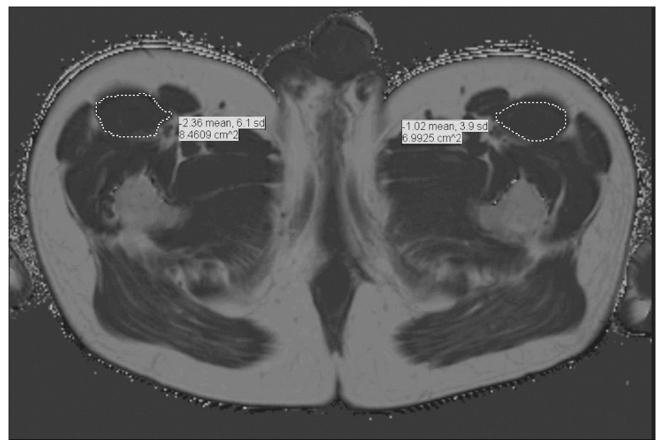

Figure 4: Freehand ROI of the bilateral rectus femoris shows the right rectus femoris −2.36 ± 6.1% and area 8.46 cm^2

Statistical analysis

Statistical analysis was performed by a statistician using SAS 9.4 (SAS Institute Inc., Cary, NC, USA). Descriptive statistics were used for demographic data and BMI and are expressed as mean and SD. QQ plot was used to verify the normality assumption (data point following a straight line indicating normality assumption is not violated).The interreader agreement of muscle FF and size measurements between the two readers was assessed by intraclass correlation coefficient (ICC). The ICC agreement was considered as poor for ICC values less than 0.40, fair for values between 0.40 and 0.59, good for values between 0.60 and 0.74, and excellent for values of 0.74 or greater.[16] The relationship of the measurements with BMI and age was individually assessed by Pearson's correlation coefficient. The difference in mean measurements between men and women was assessed by two-tailed unpaired t-test. Finally, the relationship between the measurements and subject's age, gender, and BMI was assessed simultaneously using multiple linear regression analysis. *p* value of less than 0.05 was considered statistically significant.

Results

Patient demographics

The summary statistics of age, gender, and BMI of the 64 study subjects (36 females and 25 males) are shown in Table 1. No significant difference was found between men and women in terms of age and BMI. The above-described muscle groups were felt to be adequately visualized on the PDFF images in all subjects to allow for respective measurements. QQ plots demonstrated that both age and BMI did not violate the normality assumption, and thus using mean and SD in describing their distribution were reasonable (supplemental files).

Mean muscle area and fat fraction

The mean measurements of SMA and FF of various groups are displayed in Table 2. The largest areas were observed in the gluteus muscles as would be expected in a healthy adult. There were significant differences in terms of mean FF between the right and left gluteus maximus, gluteus medius, and rectus femoris. The left gluteal muscles showed greater FF than the right muscles, and the right rectus femoris showed greater FF than the left. Without adjusting for age or BMI, the right and left muscle area and FF were positively correlated to each other with the greatest Pearson's correlation coefficient seen in the gluteus maximus muscles [Table 3 and Figure 5].

Interobserver agreement

Excellent agreement was obtained between the two readers for all measurements with ICC ranging from 0.74 to 0.98, except for the left gluteus medius area and right psoas FF, where it was good [Table 4]. The results indicate that reliable measurements of muscle area and exact FF can be obtained in multiple different muscle groups on mDixon quant sequence.

Relationship with BMI, age, and gender

The muscle areas and FF of both gluteus maximus and gluteus medius muscles as well as FF of both rectus femoris muscles were significantly and positively correlated with BMI [Table 5]. The FF of both rectus femoris muscles and the left gluteus medius muscle showed a statistically significant positive correlation, while the area of the rectus femoris showed statistically significant negative correlation with age. Muscle areas were significantly different between women and men among all muscle groups, while FF was only different between gluteus maximus and medius muscles [Table 6].

Using multiple regression analysis and following adjustments for gender and age, the FF of gluteus maximus, gluteus medius, and rectus femoris muscles as well as the area of the psoas muscles remained significantly correlated with BMI. The mean area of all muscle groups except rectus femoris ($P = 0.09–0.11$) also remained significantly correlated with BMI [Table 7]. Quantitatively, there was an average increase of muscle area by 0.95 cm^2 and 1% of FF per 1 kg/m^2 increase in BMI of the right and left gluteus maximus muscles [Table 7].

Table 1: Patient demographics

	Gender				Unpaired *T*-test
	Female		Male		
	Mean	Std	Mean	Std	*P*
BMI	27.29	5.81	25.18	3.91	0.1573
Age	53.06	15.42	49.85	15.59	0.2877

BMI: body mass index

Discussion

The current definition of sarcopenia which is most widely used is the European Working Group on Sarcopenia in Older People (EWGSOP) and depends on three factors: low skeletal muscle mass, inadequate muscle strength, and inadequate physical performance.[17] Class 1 sarcopenia is between 1 and 2 SDs below the mean of 18- to 40-year-old and class 2 sarcopenia is below 2 SDs. Diminished muscle size (sarcopenia) and myosteatosis have been independently shown to be important predictors of overall mortality, muscle function, and morbidity related to systemic diseases.[18-20] In addition to decreased muscle size, myosteatosis as assessed by cross-sectional imaging has been associated with increased morbidity and decreased functional status in the general population.[21-24] Myosteatosis has also been described as a risk factor for postoperative complications in gastric cancer population.[25]

As shown in this study, fat quantification MRI allows simultaneous quantitative assessment of SMA and myosteatosis in various muscle groups around the pelvis. The interreader performance for measuring muscle area and FF by PDFF was excellent in most muscle groups and good for the area of the left gluteus medius and the FF of the right psoas, confirming it to be a valid technique, similar to the study performed for the rotator cuff.[10] PDFF quantification has been shown to be accurate as judged by intramuscular biopsy fat quantification.[26,27] The discrepancy in FF of the right psoas muscle might be related to measurement error in freehand inclusion of retroperitoneal fat among the various slips of the muscles.

The psoas muscle cross-sectional area has been shown to be a marker on both CT and MRI to judge sarcopenia and risk of surgical morbidity and mortality in patients with cancer.[23,24] Given high reproducibility in muscle area

Table 2: Mean muscle area and FF of skeletal muscle groups

Muscle	Side	Cross-sectional area (cm^2)		*P* (left vs. right)	Intramuscular FF (%)		*P* (left vs. right)
		Mean	SD		Mean	SD	
Gluteus Maximus	Left	30.74	9.18	0.96	13.05	8.22	<0.01
	Right	30.77	9.02		10.48	8.23	
Gluteus Medius	Left	20.15	5	0.07	5.12	3.48	0.01
	Right	20.71	5.36		4.37	3.74	
Psoas	Left	8.04	3.24	0.74	3	3.9	0.34
	Right	8.1	3.06		2.54	3.85	
Rectus Femoris	Left	5.34	1.98	0.20	0.92	4.69	0.03
	Right	5.5	2.28		2.88	5.5	

FF: Fat fraction; SD: Standard deviation

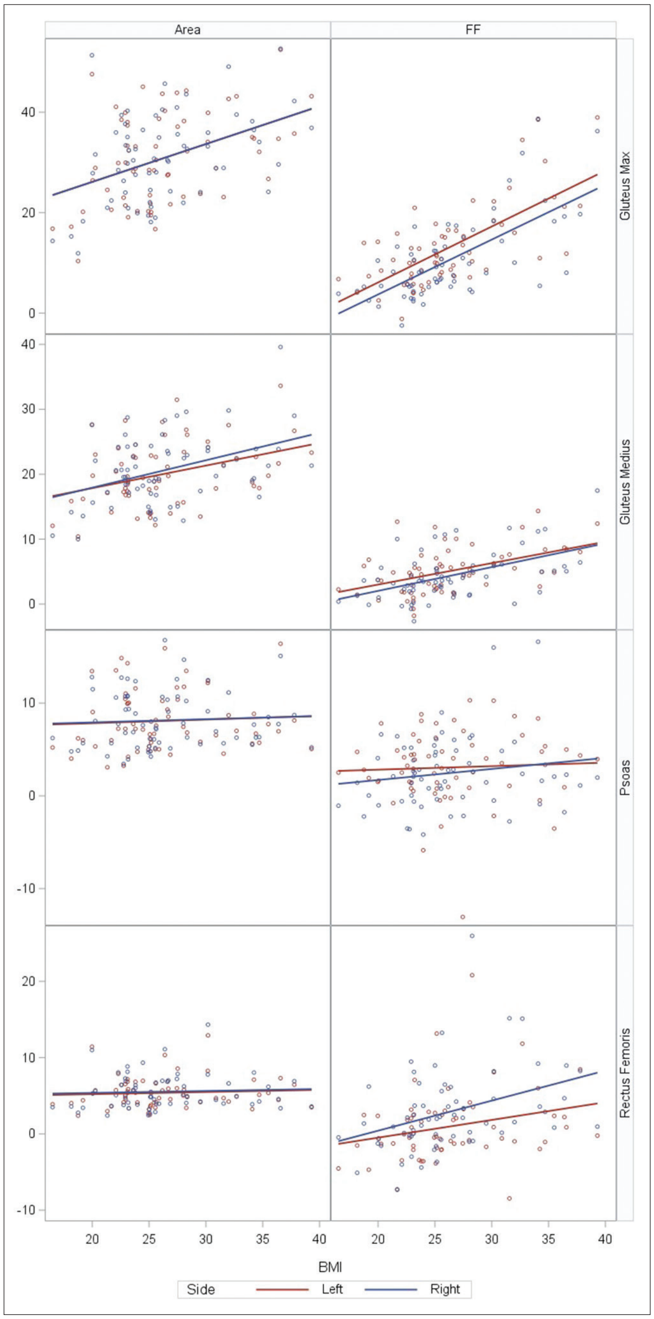

Figure 5: Scatter plot for area and FF of gluteus maximus, medius, psoas, and rectus femoris muscles

and FF measurements, fat quantification MRI of the psoas may prove to be a valuable prognostic tool in malignancy, rotator cuff disease, and systemic disease–related cachexia studies.[28,29]

Our study showed a nonstatistically significant negative correlation between the psoas muscle cross-sectional area and age and a statistically significant positive correlation between age and the FF of the left psoas muscle. Marcon *et al*.[12] demonstrated a significant correlation between hand dominance and female gluteal muscle FF. While hand dominance was not recorded due to the retrospective nature of this study, factor of hand dominance may account for some of the differences between left and right psoas FF.

Table 3: Pearson's correlation coefficient between left and right measurements

Region	Measurement	Pearson's correlation	*P*
Gluteus max	Area	0.94	<0.01
	FF	0.96	<0.01
Gluteus medius	Area	0.89	<0.01
	FF	0.79	<0.01
Psoas	Area	0.92	<0.01
	FF	0.52	<0.01
Rectus femoris	Area	0.9	<0.01
	FF	0.54	<0.01

FF: Fat fraction

Table 4: Interreader agreement of muscle area and FF

Region	Side	Intraclass correlation			
		Area	95% CI	FF	95% CI
Gluteus max	Left	0.90	(0.84, 0.94)	0.98	(0.97, 0.99)
	Right	0.85	(0.76, 0.91)	0.97	(0.95, 0.98)
Gluteus medius	Left	0.65	(0.48, 0.78)	0.83	(0.74, 0.9)
	Right	0.83	(0.73, 0.89)	0.87	(0.79, 0.92)
Psoas	Left	0.86	(0.78, 0.92)	0.81	(0.71, 0.88)
	Right	0.88	(0.8, 0.92)	0.61	(0.43, 0.75)
Rectus femoris	Left	0.74	(0.6, 0.84)	0.90	(0.84, 0.94)
	Right	0.83	(0.73, 0.9)	0.83	(0.73, 0.9)

FF: Fat fraction; CI: Confidence interval

Crawford *et al*.[13] and Marcon *et al*.[12] had earlier analyzed the volume of the paravertebral and gluteus medius and minimus muscles, respectively, in healthy volunteers age 20–62 years using fat- and water-signal-separated MR images with two- and three-point mDIXON sequences. Crawford *et al*. found that the fat content of the paravertebral muscles increased with age. Although no correlation with fat content and age was demonstrated in the gluteus muscles, they showed a positive correlation between BMI and gluteus medius and minimus FF. This was concurrent with our results, which showed statistically significant positive correlations between BMI and SMA as well as FF within the gluteus maximus and medius muscles. These results suggest that the gluteus muscles are prone to fatty infiltration with increased BMI.[30] A longitudinal increase in intramuscular fatty infiltration of the calf muscles has been associated with an increased risk of type 2 diabetes mellitus.[31] In addition, increased fatty infiltration of the gluteus maximus and reduced volume of the gluteus maximus and minimus have been identified in the affected side of patients with osteoarthritis when compared with a control population.[32]

The mid-thigh muscle sarcopenia has previously been shown to be correlated with hip fracture risk.[7] In this study, statistically significant negative correlation was

Table 5: Correlations of muscle area and FF with BMI and age when adjusted for gender

Pearson's correlation		Correlation with BMI				Correlation with age			
		Area	*P*	FF	*P*	Rho	Area	Rho	FF
Region	Side	Rho		Rho			*P*		*P*
Gluteus maximus	Left	0.42	<0.01	0.69	<0.01	0.05	0.86	0.19	0.14
	Right	0.43	<0.01	0.67	<0.01	0.05	0.85	0.18	0.17
Gluteus medius	Left	0.36	<0.01	0.49	<0.01	0.15	0.16	0.34	0.01
	Right	0.4	<0.01	0.5	<0.01	0.09	0.33	0.21	0.1
Psoas	Left	0.06	0.63	0.05	0.72	−0.16	0.17	0.09	0.46
	Right	0.06	0.65	0.16	0.20	−0.17	0.12	0.23	0.07
Rectus femoris	Left	0.07	0.58	0.25	0.05	−0.21	0.04	0.26	0.04
	Right	0.06	0.66	0.36	<0.01	−0.22	0.05	0.38	<0.01

FF: Fat fraction; BMI: Body mass index

Table 6: Statistical differences in area and FF among men and women

Region	Side	Area		*P*	FF		*P*
		Gender			Gender		
		Female	Male		Female	Male	
		Mean±SD	Mean±SD		Mean±SD	Mean±SD	
Gluteus max	Left	26.66±8.28	36.04±7.49	<0.01	16±8.91	9.21±5.25	<0.01
	Right	26.72±7.94	36.01±7.6	<0.01	13.17±9.23	6.99±5.02	<0.01
Gluteus medius	Left	18.11±4.36	22.86±4.56	<0.01	5.94±3.52	4.03±3.17	0.03
	Right	18.55±4.33	23.6±5.3	<0.01	5.29±4.12	3.13±2.78	0.02
Psoas	Left	6.1±1.66	10.63±3.03	<0.01	2.38±3.1	3.82±4.7	0.15
	Right	6.16±1.59	10.67±2.63	<0.01	2.03±3.59	3.23±4.15	0.22
Rectus femoris	Left	4.37±1.09	6.58±2.19	<0.01	0.94±4.59	0.9±4.9	0.97
	Right	4.35±1.29	6.99±2.44	<0.01	2.97±4.66	2.75±6.52	0.88

FF: Fat fraction; SD: Standard deviation

Table 7: Statistical significance of skeletal muscle area and mean FF correlated with BMI after adjusted for age and gender along with rate of increase in area and FF per 1 kg/m² increase in BMI

Region	Side	*P*		Rate of increase per 1 kg/m² in BMI	Rate of increase per 1 kg/m² in BMI
		Area	FF	Area	Mean FF
Gluteus maximus	Left	<0.01	<0.01	0.95±0.16	1.02±0.14
	Right	<0.01	<0.01	0.95±0.16	1.01±0.15
Gluteus medius	Left	<0.01	<0.01	0.47±0.09	0.32±0.07
	Right	<0.01	<0.01	0.55±0.1	0.34±0.08
Psoas	Left	0.03	0.48	0.13±0.06	0.07±0.1
	Right	0.02	0.09	0.12±0.05	0.16±0.09
Rectus femoris	Left	0.09	0.05	0.07±0.04	0.23±0.11
	Right	0.11	<0.01	0.08±0.05	0.4±0.12

FF: Fat fraction; BMI: Body mass index

found between both the right and left rectus femoris areas and age, and a statistically significant positive correlation was found between age and BMI and the rectus femoris FF. Thus, findings of loss of area and increased fatty infiltration of the thigh musculature with age possibly predict risk of fall and fracture risk.

The results of this study show that anthropomorphic variations in pelvic muscle groups should be taken into account in future studies of myosteatosis and sarcopenia using PDFF quantification. Psoas muscle FF measurements showed the least correlation with BMI. This finding suggests that psoas measurements can be used for the diagnostic and prognostic assessments of disease versus control states with minimal confounding by patient weight. In addition, if measurements were to be performed on gluteal muscles for such studies, one should consider that these muscles exhibit an average increase in area of 0.95 cm² and 1% unit of FF per 1 kg/m² increase in BMI.

The limitations of our study include the retrospective study design and inclusion of patients undergoing lumbosacral plexus MRI for pelvic and genital pain. While this population is not a representative sample of healthy subjects *per se*, we ensured that the population represents those with age- and gender-appropriate pelvic musculature, by excluding those with known primary neuromuscular disorder or imaging findings of neuromuscular disease. In addition, segmentation was manual and limited to single slices on different muscles, which could have potentially excluded the most functional areas of the muscles due to anatomic variations. However, both observers were diligent in avoiding mesenteric and subcutaneous fat during muscle area measurements and chose the same bony landmarks for independent calculations, which is reflected in the results that most of the muscle groups demonstrated excellent interobserver agreement.

Conclusion

Fat quantification MRI is a highly reproducible imaging technique for the assessment of intramuscular steatosis and muscle size. Intramuscular FF and muscle cross-sectional area were correlated with age and BMI across multiple muscle groups. Future studies should be geared toward the correlation of FF and muscle area with systemic disorders affecting the skeletal muscle, assessment of fall risk in at-risk populations, and postsurgical morbidity and mortality.

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Nil.

Conflicts of interest

There are no conflicts of interest. Unrelated conflicts of interest. AC- consultant- ICON Medical and Treace 3D Medical Inc. AC- book royalties- Wolters, Jaypee.

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