Journal of Biomechanics 163 (2024) 111928

Contents lists available at ScienceDirect

Journal of Biomechanics

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

The assessment of paraspinal muscle epimuscular fat in participants with and without low back pain: A case-control study

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ARTICLE INFO

Keywords:
Low back pain
Magnetic resonance imaging
Paraspinal muscles
Epimuscular fat

ABSTRACT

It remains unclear whether paraspinal muscle fatty infiltration in low back pain (LBP) is *i)* solely intramuscular, *ii)* is lying outside the epimysium between the muscle and fascial plane (epimuscular) or *iii)* or combination of both, as imaging studies often use different segmentation protocols that are not thoroughly described. Epimuscular fat possibly disturbs force generation of paraspinal muscles, but is seldomly explored. This project aimed to 1) compare epimuscular fat in participants with and without chronic LBP, and 2) determine whether epimuscular fat is different across lumbar spinal levels and associated with BMI, age, sex and LBP status, duration or intensity. Fat and water lumbosacral MRIs of 50 chronic LBP participants and 41 healthy controls were used. The presence and extent of epimuscular fat for the paraspinal muscle group (erector spinae and multifidus) was assessed using a qualitative score (0–5 scale; 0 = no epimuscular fat and 5 = epimuscular fat present along the entire muscle) and quantitative manual segmentation method. Chi-squared tests evaluated associations between qualitative epimuscular fat ratings and LBP status at each lumbar level. Bivariate and partial spearman's rho correlation assessed relationships between quantitative and qualitative epimuscular fat with participants' characteristics. Epimuscular fat was more frequent at the L4-L5 ($X^2 = 13.781$, $p = 0.017$) and L5-S1 level ($X^2 = 27.825$, $p < 0.001$) in participants with LBP compared to controls, which was not found for the higher lumbar levels. The total qualitative score (combined from all levels) showed a significant positive correlation with BMI, age, sex (female) and LBP status ($r = 0.23$–0.55; $p < 0.05$). Similarly, the total area of epimuscular fat (quantitative measure) was significantly correlated with BMI, age and LBP status ($r = 0.26$–0.57; $p < 0.05$). No correlations were found between epimuscular fat and LBP duration or intensity. Paraspinal muscle epimuscular fat is more common in chronic LBP patients. The functional implications of epimuscular fat should be further explored.

1. Introduction

Low back pain (LBP) is a well-known public health concern (Buchbinder et al., 2018; Foster et al., 2018). The average annual direct and indirect costs of LBP per population range between 3.4 and 3.6 billion US dollars and 3.2 million to 13.2 billion US dollars, respectively (Fatoye et al., 2023). Additionally, impairments in paraspinal muscle strength (Rissanen et al., 1995; Holmes et al., 1996), flexibility (Rainville et al., 1992; Mayer et al., 1987), endurance (van der Velde and Mierau, 2000), and obesity (Tsuritani et al., 2002) are well-documented in chronic LBP. A link between paraspinal muscle morphological changes (e.g. atrophy, fatty infiltration (FI), asymmetry) and LBP (Ranger et al., 2017; Cuellar

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https://doi.org/10.1016/j.jbiomech.2024.111928
Accepted 3 January 2024

et al., 2017; Danneels et al., 2000; Kulig et al., 2009; Mengiardi et al., 2006), may result in trunk/paraspinal muscle impairments and spinal instability (Prins et al., 2018). Particularly, the lumbar multifidus (MF) and erector spinae (ES) muscles provide lumbar stability while supporting the upper trunk (Ward et al., 2009; Bogduk et al., 1992; Bergmark, 1989).

Magnetic resonance imaging (MRI) is a reliable and gold standard imaging method to assess paraspinal muscle morphometry, from its high resolution, soft tissue contrast, and landmarks visualization (Hu et al., 2011; Fortin and Battié 2012; Sasaki et al., 2017; Paalanne et al., 2011; Ranson et al., 2006). MRI studies investigating paraspinal muscle composition show positive correlations with LBP, FI as well as pain intensity and disability (Kjaer et al., 2007; D'Hooge et al., 2012; Fischer et al., 2013; Kalichman,Carmeli,and Been, 2017; Sions et al., 2017; Teichtahl et al., 2015). Decreased functional muscle tissue from FI likely hinders a muscle's force production capability and spinal stability (Airaksinen et al., 1996). However, it remains unclear whether paraspinal muscle FI in LBP is solely intramuscular, is lying outside the epimysium between the muscle and fascial plane (epimuscular) or both, as imaging studies often use different segmentation protocols not thoroughly described.

Two common segmentation methods for defining the region of interest (ROI) of lumbar paraspinal muscles either "*include*" or "*exclude*" the epimuscular fat "tent" between the MF or ES muscle and fascia, when present (Berry et al., 2018). Berry et al. (2018) compared both methods and found excellent inter-rater reliability for cross-sectional areas (CSA) and fat signal fraction (FSF) in LBP patients, justifying their use to measure lumbar paraspinal musculature. However, including epimuscular fat in the ROI led to larger CSA and FSF values compared to excluding epimuscular fat (Berry et al., 2018). Variations in segmentation methods likely contribute to inconsistent findings, and to date, it remains unknown whether epimuscular fat is an important feature of LBP. Additionally, epimuscular fat possibly disturbs the mechanical relationship between neighboring paraspinal muscles by influencing muscle interactions and force generation on the skeleton (Finni,de Brito Fontana,and Maas, 2023). Finni et al. (2023) state that connective tissue linkages between muscles affect their function. Therefore, a fat layer could weaken epimuscular force transmissions, the transmission of forces from a muscle to the skeleton, especially at the extramuscular level, where force is transmitted between the epimysium of a muscle and adjacent non-muscular structures.

While epimuscular fat alone is understudied, studies report the relationship between FI in paraspinal muscles and age, sex, body mass index (BMI) and LBP status. Older age is independently associated with FI (Urrutia et al., 2018; Shahidi et al., 2017) with increased FI in women compared to men (Sions et al., 2017; Kalichman,Carmeli,and Been, 2017; Urrutia et al., 2018). Kjaer et al. (2007) found that MF FI is strongly associated with LBP, higher in women, but not influenced by BMI. Sex also plays a role in muscle shape variations (Xiao et al., 2018; Xiao et al., 2021). While a recent *meta*-analysis concluded that chronic LBP patients have a significantly higher amount of FI and a smaller CSA in the MF muscle compared to controls (Seyedhoseinpoor et al., 2022), further investigations on epimuscular fat are warranted.

The literature discussing the presence and extent of epimuscular fat in LBP compared to controls is scarce, and whether epimuscular fat plays a role in LBP, or is associated with important factors such as spinal level, BMI, age, sex, pain duration, or pain intensity is unclear. Therefore, this study aimed to 1) examine the presence and extent of the epimuscular fat "tent" in participants with chronic LBP as compared to healthy controls and 2) determine if the amount/surface area of epimuscular fat is associated with spinal level (e.g., L1 to L5), BMI, age, sex, symptoms duration (pain), or symptom intensity.

2. Materials and methods

2.1. Study design

This was a retrospective multicentre case-control study.

2.2. Participants

Lumbar MRI images of 50 chronic LBP participants and 41 healthy controls were retrospectively reviewed from 3 different institutions (Concordia University, University of Veterinary Medicine Vienna, Université de Sherbrooke). All participants underwent lumbosacral MRI scan for research purposes, including a DIXON or IDEAL fat–water axial sequences. Included participants with LBP had non-specific chronic LBP ($\geq$3 months), defined as pain between the lower ribs and gluteal folds, with or without leg pain, had a "moderate" (21–40 %) or "severe" (41–60 %) score on the modified Oswestry LBP Questionnaire. Excluded participants were aged below 18 or above 65 years old, had evidence of nerve root compression or reflex motor sign deficits (e.g. weakness, reflex changes, or sensory loss with same spinal nerve), had a history of spinal surgery or vertebral fractures, had major lumbar spine abnormalities (e.g., spondylolysis, spondylolisthesis, or lumbar scoliosis $> 10^\circ$), were pregnant or had comorbidities preventing them to participate in an exercise program. The Numerical pain rating scale (NPRS) was used to assess the degree of pain experienced by participants with LBP on a scale from 0 to 10, with 0 being no pain and 10 being extreme pain. The scale is a self-reported rating system for pain intensity that is a reliable and valid method of detecting significant changes in perceived pain (Jensen et al., 1999; Childs, Piva, and Fritz 2005). The Oswestry LBP and NPRS questionnaires were completed on paper in person during the baseline MRI session. Healthy controls did not have current LBP or a history of LBP for at least 3 months with no previous history of spinal surgery or trauma, or neurological disease. Research ethics board approval at each institution, from the Central Ethics Committee of the Quebec Ministry of Health and Social Services (CCER-15–16-17), the Medical University of Vienna Ethics Committee (1609/2012) and by the institutional review board of the Centre intégré universitaire de santé et de services sociaux de l'Estrie – Centre hospitalier universitaire de Sherbrooke (CIUSSS de l'Estrie – CHUS, 2021–3861). Written consent from all participants was obtained. Ethics approval was obtained.

2.3. Paraspinal muscle measurements

Paraspinal muscle measurements of the MF and ES were obtained for each participant from DIXON or IDEAL fat–water sequenced axial images. In accordance with Hodges et al. (2021), all available lumbar levels (L1 to L5) were investigated and analysed separately. Muscles were combined in a single ROI representing the total paraspinal muscle CSA (tCSA) and manually segmented bilaterally using two different segmentation methods to quantitatively examine the surface area (in cm^2) of epimuscular fat, as illustrated in Fig. 1:

Method 1 (including epimuscular fat): The medial border of the MF was outlined by the spinous process from its most superficial to deep aspect where it adjoins the lamina. The anterior and deep border of the MF was between the lateral aspect of the lamina to the anterior feature of the mammillary process and zygapophyseal joint. It joined with the anterior, deep border of the ES where it continued along the lateral aspect of the transverse process. The posterior ES border was defined by using the fascial plane and *including* the epimuscular fat between the longissimus and iliocostalis when present. Epimuscular fat that was lateral to the iliocostalis and under the lumbosacral fascia was also *included* in the ROI (Berry et al., 2018; Crawford et al., 2017) (Fig. 1).

Method 2 (excluding epimuscular fat): The medial border of the MF and anterior border of ES were the same as defined above in Method 1. Segmentation for the posterior borders of the MF and ES muscle was based on the epimysial plane. When epimuscular fat was present

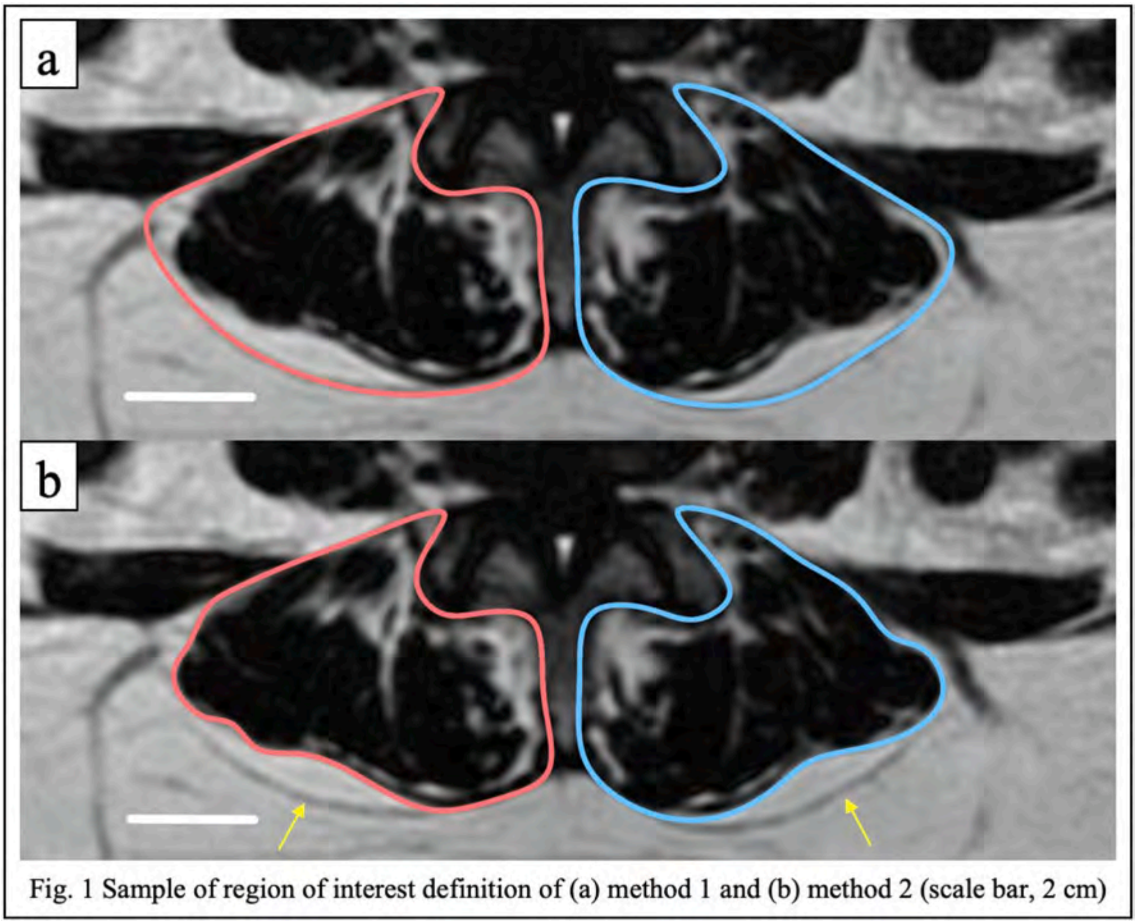

Fig. 1. Sample of region of interest definition of (a) method 1 and (b) method 2 (scale bar, 2 cm).

between the longissimus and iliocostalis, it was *excluded* from the ROI. Epimuscular fat that was lateral to the iliocostalis and under the lumbosacral fascia was also *excluded* from the ROI (Crawford et al., 2017; Berry et al., 2018) (Fig. 1).

All tCSA muscle measurements for both methods were obtained on corresponding mid-disc fat–water axial images at each lumbar level using the HOROS software (version 4.0.0). The ROI representing tCSA of interest was traced on the fat image and then copied on the corresponding water image.

Muscle measurements were performed by two raters (Rater 1, honors student, J.B. and Rater 2, PhD student, B.R.); both raters were trained by a senior researcher (M.F.) with over 14 years of experience in spine imaging analysis of paraspinal muscles. To test the reliability for muscle measurements and qualitative ratings, the MR images of 10 participants were randomly selected by each rater and measured independently. After at least 5 days, the same measurements were repeated.

2.4. *Quantitative rating of epimuscular fat "Tent"*

A quantitative measure of the epimuscular fat "tent" was analysed per participant by calculating the difference between the tCSA of *methods 1* and *2* bilaterally at each level, resulting in a total quantitative epimuscular fat area after summing the measurements.

2.5. *Qualitative rating of epimuscular fat "Tent"*

Each participant received a qualitative rating that assessed the presence and extent of epimuscular fat along the border of ES and MF. Ratings were acquired for each lumbar level, bilaterally, totaling 10 qualitative ratings per participant. The total qualitative rating score was calculated by summing the epimuscular fat ratings.

The ratings consisted of a 5-point scale, with a rating of 0 indicating no presence of epimuscular fat. Then, for every 25 % increase in epimuscular fat along the posterior border of the ES muscle only, an additional point was given. More specifically, a rating of 1 indicates epimuscular fat present along 1/4th of the ES muscle, a rating of 2 indicates epimuscular fat present along half of the ES muscle, a rating of 3 indicates epimuscular fat present along 3/4th of the ES muscle, a rating of 4 indicates epimuscular fat present along full length of the ES muscle. Finally, a rating of 5 indicates epimuscular fat present along full length of both the MF and ES muscle (Fig. 2).

Altogether, a total qualitative rating score and total quantitative area of epimuscular fat for all levels was calculated by summing 10 qualitative and quantitative measurements (two sides, five levels), separately.

2.6. *Statistical analysis*

All statistical analyses were performed with IBM SPSS ver. 28.0 (IBM Corp., Armonk, NY, USA). Intra-class correlation coefficients (ICCs) were used to assess intra-rater and inter-rater reliability of the quantitative epimuscular fat area; $ICC_{(2,1)}$ were calculated using a 2-way random-effects model, single-measurement, and absolute agreement and the following agreement interpretation guidelines (i.e., $<0.50 =$ poor, $0.50–0.75 =$ moderate, $0.75–0.90 =$ good, and $> 0.90 =$ excellent) (Koo and Li, 2016). Cohen's Weighted Kappa assessed the intra-rater and inter-rater reliability of the qualitative rating using the following guidelines (i.e., $< 0 =$ no agreement, $0.01–0.20 =$ none to slight, $0.21–0.40 =$ fair, $0.41–0.60 =$ moderate, $0.61–0.80 =$ substantial, $0.81–1.00 =$ almost perfect agreement) (Landis and Koch, 1977). Means and standard deviations were calculated for participants'

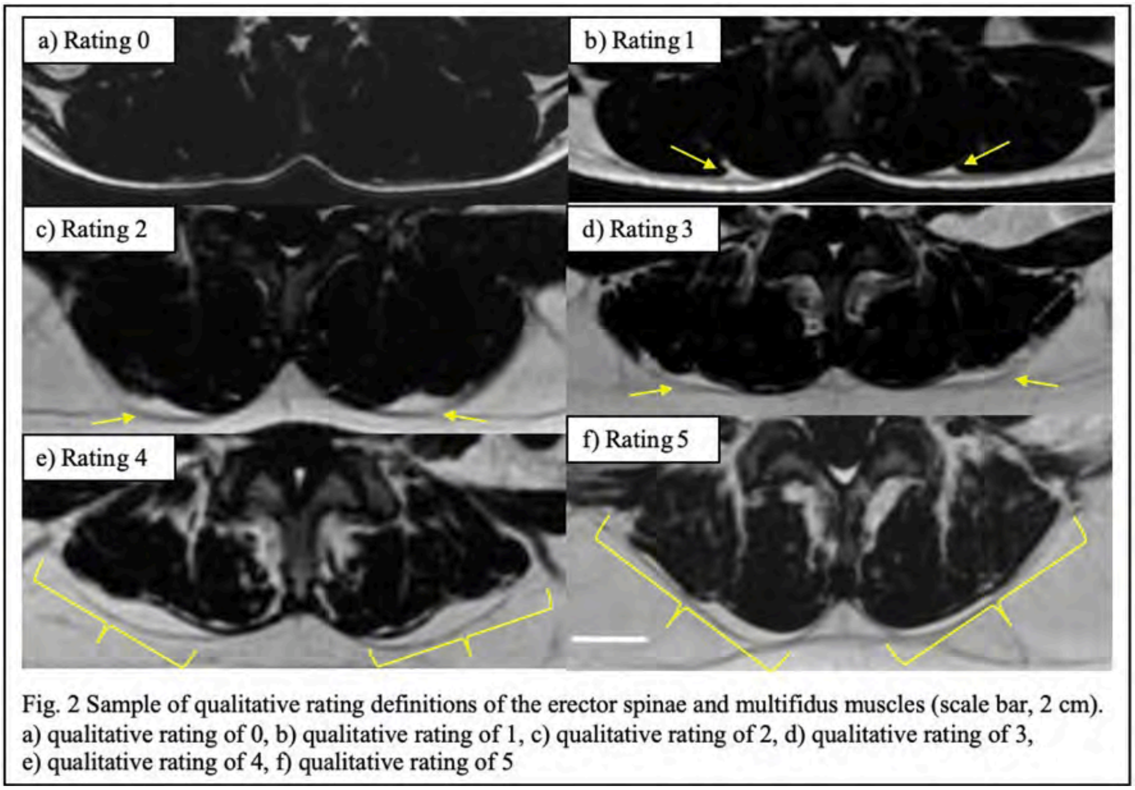

Fig. 2. Sample of qualitative rating definitions of the erector spinae and multifidus muscles (scale bar, 2 cm). a) qualitative rating of 0, b) qualitative rating of 1, c) qualitative rating of 2, d) qualitative rating of 3, e) qualitative rating of 4, f) qualitative rating of 5.

characteristics, and comparison of means was analyzed using an independent sample *t* test. Chi-squared tests evaluated associations between qualitative epimuscular fat ratings and LBP status, at each lumbar level and side. Spearman's rho correlation assessed relationships between quantitative and qualitative epimuscular fat at each lumbar level and side with participants' BMI, age, sex, LBP status, LBP duration and LBP intensity (NPRS). Furthermore, adjusted partial correlations were also performed between quantitative and qualitative epimuscular while adjusting for participants' BMI, age, sex, and LBP status. Spearman's rho correlation coefficients were interpreted using the following correlation guidelines (i.e., $0.1 < r < 0.3$ = small/weak, $0.3 < r < 0.5$ = medium/moderate, $0.5 < r < 1.0$ = large/strong) (Cohen, 1988). As not all participants had the L1-L2 level available, Spearman's rho analysis was performed twice. One analysis included 72 participants from L1-L5 (n = 50 LBP, n = 22 controls), and the second included 87 participants from L2-L5 (n = 50 LBP, n = 37 controls). Each analysis generated almost identical findings, leading to identical overall conclusions, and therefore only the L2-L5 results were reported.

3. Results

3.1. Participants

Participants' characteristics are presented in Table 1. All characteristics were comparable between LBP and controls except for BMI. BMI was significantly higher in the LBP group.

3.2. Reliability

Overall, good to excellent intra-rater reliability (ICCs > 0.75) was observed for all tCSA measures for each rater, and excellent reliability (ICCs > 0.90) for %FSF for both methods. As seen in Table 2, moderate to perfect intra-rater agreement was observed for all qualitative ratings

Table 1
Participants' Characteristics.

	LBP (*n* = 50)	Control (*n* = 41)	P-*Value*
Age (y)	41.8 ± 11.5	39.7 ± 13.8	0.445
Range	(21–63)	(22–60)	
Female, *n* (%)	35 (70)	22 (54)	0.109
Height (cm)	169.7 ± 9.5	171.7 ± 11.0	0.343
Weight (kg)	73.5 ± 14.5	70.1 ± 11.8	0.229
BMI (kg/m^2)	25.6 ± 4.6[a]	23.6 ± 2.3	**0.011**
Range	(15.4–36.2)	(19.6–28.1)	
LBP Duration (months)[*]	81.9 ± 92.2		
LBP NPRS (0–10) [**]	5.7 ± 1.8		
ODI	29.0 ± 10.6		

Values are presented as means ± standard deviations, unless otherwise denoted. BMI: body mass index; LBP: lower back pain; NPRS: Numerical Pain Rating Scale, ODI: Oswestry Disability Index.

[a] – $p < 0.05$.

[*] – Two missing data from LBP group.

[**] – Seven missing data from LBP group.

Table 2
Intra-rater and inter-rater reliability of qualitative epimuscular fat ratings.

	Side	Intra-rater Reliability Weighted Kappa	Inter-rater Reliability Weighted Kappa
L1-L2	Right	0.773	0.842
	Left	1.000	0.854
L2-L3	Right	1.000	1.000
	Left	1.000	0.634
L3-L4	Right	1.000	0.917
	Left	1.000	0.731
L4-L5	Right	1.000	0.772
	Left	1.000	0.764
L5-S1	Right	1.000	0.822
	Left	1.000	0.864

for each rater, with substantial to perfect inter-rater agreement for all qualitative ratings (weighted Kappa ranging between 0.634 and 1.000).

3.3. Association between qualitative epimuscular fat ratings and LBP status at each lumbar level

Associations between qualitative epimuscular fat ratings and LBP status at all lumbar levels are presented in Table 3 for each side. As exhibited in Fig. 3, a qualitative rating of 4–5 was most observed at the two lower lumbar levels in LBP participants compared to healthy controls. Chi-squared tests revealed a statistically significant association between qualitative ratings and LBP status at both L4-L5 and L5-S1 and both sides.

3.4. Correlation between total qualitative epimuscular fat rating scores (L2-L5) and BMI, Age, Sex, and LBP status

Crude and adjusted partial correlations between *total qualitative epimuscular fat rating scores* and BMI, age, sex and LBP status are presented in Table 4. BMI, sex (female) and LBP status were all significantly and positively correlated to *total qualitative epimuscular fat rating scores* both in the crude and adjusted analyses (Table 4). There was also a weak positive correlation between age and *total qualitative epimuscular fat rating scores* in the crude analysis, but this correlation was not significant when adjusting for BMI, sex and LBP status. The correlation between total qualitative epimuscular fat rating score and BMI is illustrated in Fig. 4.

3.5. Correlation between total quantitative epimuscular fat area (L2-L5) and BMI, Age, Sex, and LBP status

Crude and adjusted partial correlations between the *total quantitative epimuscular fat area* and BMI, age, sex, and LBP status are presented in Table 4. BMI and age were both significantly and positively correlated to the total area of epimuscular fat in the crude and adjusted analyses. Sex was not correlated to the total quantitative area of epimuscular fat. Finally, a weak correlation between LBP status and the total area of epimuscular fat was identified in the crude analysis, but did not remain significant in the adjusted analysis.

3.6. Correlation between total qualitative epimuscular fat ratings and quantitative epimuscular fat area (L2-L5) and LBP duration and LBP intensity

There was no correlation between LBP duration or LBP intensity with the *total qualitative rating scores* or *total quantitative area* of epimuscular fat (Table 5).

4. Discussion

Using both qualitative and quantitative measures, our study provides novel findings about the relationship between the presence of epimuscular fat and LBP status along the lumbar spine. Our results showed weak-to-moderate positive correlations between qualitative and quantitative epimuscular fat measures and LBP status, as well as BMI, age and sex. To our knowledge, no other studies have investigated epimuscular fat in patients with LBP compared to controls. Our findings also revealed, using qualitative epimuscular fat ratings, that the presence of a large epimuscular fat tent was more frequent at L4-L5 and L5-S1 in participants with LBP compared to controls.

Table 3
Association (Chi-Square Test) between qualitative epimuscular fat ratings (score 0–5) and LBP status (LBP vs. healthy controls) at each lumbar level (L1-L5).

	Right		Left	
	Chi-Square	P-*Value*	Chi-Square	P-*Value*
Epimuscular				
L1-L2[*]	0.269	0.874	1.649	0.438
L2-L3	2.183	0.823	2.113	0.833
L3-L4	4.536	0.475	5.766	0.330
L4-L5[‡]	13.781	**0.017**	12.026	**0.034**
L5-S1[‡]	27.825	**<0.001**	26.971	**<0.001**

[*] – Fifteen missing data from L1-L2 Epimuscular Fat Rating ($n = 76$).

[‡] Illustrated inFig. 3.

4.1. Effect of LBP status and spinal level

We found significant positive correlations between qualitative and quantitative measure of epimuscular fat with LBP status, which remained significant after adjusting for BMI, age, and sex (e.g., qualitative measure). Indeed, there is growing body of evidence suggesting that LBP is associated with a decrease in paraspinal muscle size (Fortin and Macedo, 2013), which may be due to disuse, muscle denervation, and/or reflex inhibition (Fortin and Macedo, 2013; Noonan and Brown, 2021). Berry et al., (2018, 2020) suggested that such paraspinal atrophy may be linked to a concomittent increased epimuscular fat; as the size of the ES and MF muscle decreases, fat may accumulate between the epimysium and lumbosacral fascia. Using a large cohort of 412 adults, Kjaer et al. (2007) also reported a strong association between MF FI and LBP. However, as paraspinal muscle segmentation methods and related FI measurements protocols are often not clearly defined in past studies, it not always clear whether FI measurements solely considered intramuscular, epimuscular fat (outside the epimysial plane), or both.

Our results also suggests that epimuscular fat was more frequent at the L4-L5 and L5-S1 level in participants with LBP compared to controls, which was not found for the higher lumbar levels. This finding is in accordance with a previous 15-year longitudinal study, which reported greater changes in paraspinal muscle morphology (e.g., atrophy and increase in and FI) at L5-S1 relative to L3-L4 over time (Fortin et al., 2014). More recently, Berry et al. (2020) also reported that the epimuscular "fatty tent" was primarily present in the lower lumbar levels and dissipated at the higher levels. Indeed, most bodyweight is tolerated at the L5-S1 level, which induces larger stress and more movement at that level (Fortin et al., 2014). It is thus not surprising that L4-L5 and L5-S1 are the spinal levels most implicated in failure, with higher incidence of spinal pathology and degeneration (Donnally,Hanna,and Varacallo, 2022; Saleem et al., 2013). Therefore, paraspinal muscle atrophy at the lower lumbar levels likely contributes to the presence and extent of epimuscular fat at L4-L5 and L5-S1 in patients with LBP. While a few studies demonstrated an association between FI and decreased muscle function (e.g., decreased strength and contraction) (Fortin et al., 2017; Goubert et al., 2017; Schlaeger et al., 2019), whether the presence of *intramuscular* or *epimuscular* fat at L4-L5 and L5-S1 plays a greater role in muscle function warrants further investigation.

4.2. Demographic correlates (BMI, age, sex) of epimuscular fat

While the relationship between paraspinal muscle FI with BMI, age, and sex has been examined, literature discussing the relationship between epimuscular fat and these factors is scarce and inconsistent (Hodges et al., 2021). Our findings revealed strong positive correlations between qualitative and quantitative epimuscular fat measures and BMI, which remained significant after adjusting for age, sex, and LBP status. We are not aware of any other study that has specifically examined the association between epimuscular fat and BMI. However, Hildebrandt et al. (2017) found no correlation between the extent of MF FI and BMI in individuals with LBP. Similarly, Kalichman et al. (2017) reported no association between paraspinal intramuscular FI and BMI. The authors stated that an increased in percentage body fat (e.g., greater BMI) does not typically translate in greater paraspinal muscles FI only at the lower two lumbar levels, but instead FI naturally disperses throughout the

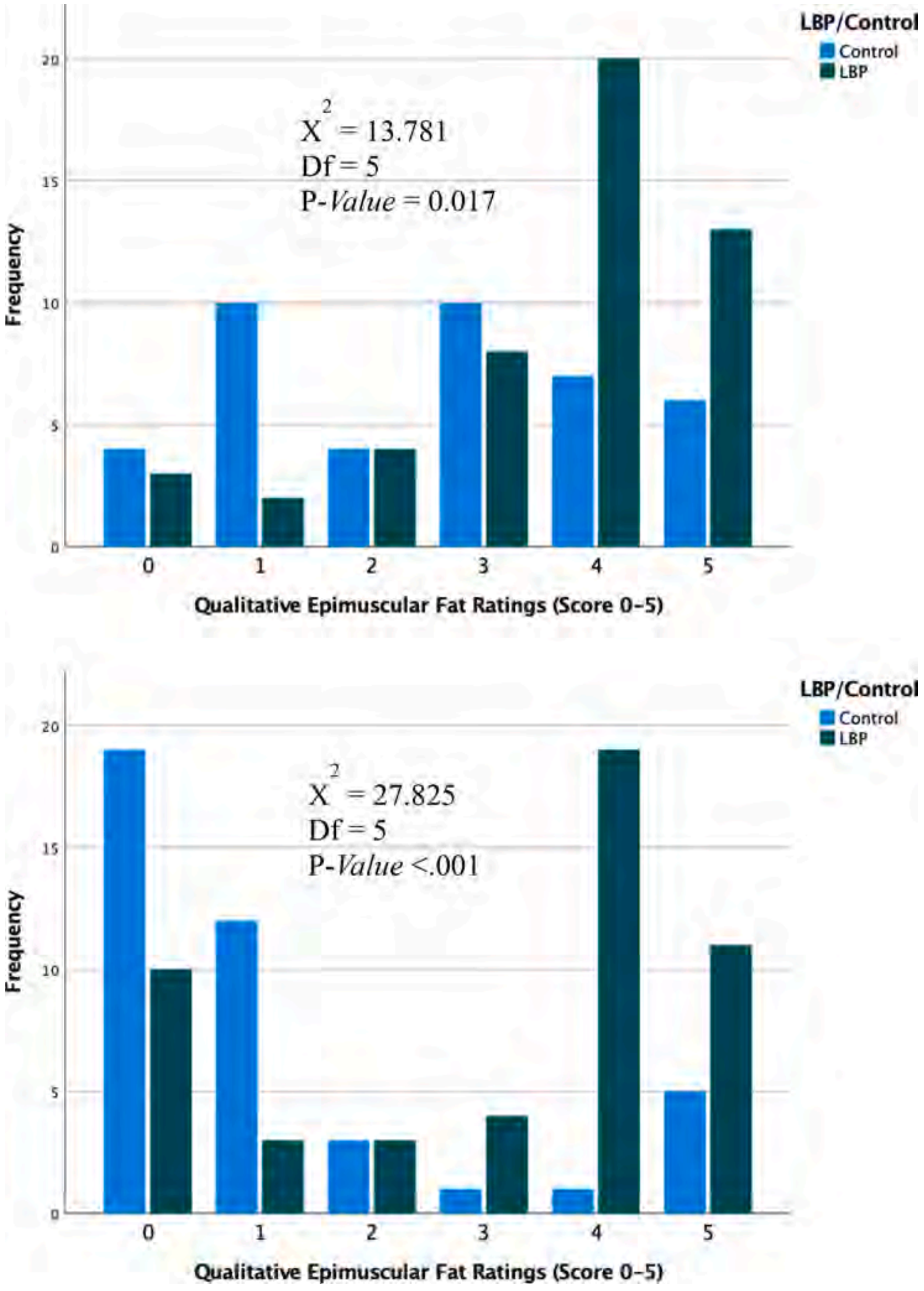

Fig. 3. Bar graphs showing the frequency of qualitative ratings (score 0–5) for LBP and healthy controls at the L4-L5 (top image) and L5-S1 (bottom image) lumbar level, on the right side.

entire lumbar spine (Kalichman et al., 2017). As paraspinal muscle FI is primarily present at the two lower lumbar levels in individuals with chronic LBP, it is likely spinal degeneration that initiate such changes in these problematic areas (Kalichman,Carmeli,and Been, 2017). The same authors also reported that lumbar paraspinal muscle density, an indicator of lean muscle tissue and force generation capability, decreases as BMI increases (Kalichman et al., 2010). Interestingly, Fortin et al. (2014) reported a significant association between ES FI (which included both *epimuscular* and *intramuscular* FI) and BMI in a 15-year longitudinal MRI study of 99 adult male twins.

Qualitative and quantitative epimuscular fat measures also had weak-to-moderate positive correlations with age, even after adjusting for BMI, sex, and LBP status for the quantitative measure. Our findings corroborate with previous imaging studies suggesting that age is independently associated with MF and ES FSF values in patients with spinal symptoms (Urrutia et al., 2018; Shahidi et al., 2017). Additional studies also reported a positive significant association between lumbar MF FI and age in a general population (Fortin et al., 2014) and in individuals with LBP (Hildebrandt et al., 2017). However, as highlighted before, there are important variations in measurements protocols, and some are not described in enough details to determine whether FI and FSF measures included were solely intramuscular, epimuscular, or both (Hodges et al., 2021).

Surprisingly, only the qualitative epimuscular fat measure had a weak positive correlation with sex, which remained significant after adjusting for BMI, age, and LBP status. While no direct comparions can be made with our study as we only investigated epimuscular fat, our findings are in according with previous studies showing that women

Table 4
Crude and adjusted partial correlations between total qualitative epimuscular fat rating score, total quantitative epimuscular fat area (cm^2) and BMI, age, sex and LBP status.

	Correlation	*P*-value	Correlation	*P*-value
	Crude		**Adjusted***	
Total Qualitative epimuscular Fat Rating Score from L2-L5 (*N* = 87)				
BMI	0.55	**<0.001**	0.54	**<0.001**
**Adjusted for age, sex, LBP status*				
Age	0.23	**0.032**	0.13	0.230
**Adjusted for BMI, sex, LBP status*				
Sex	0.24	**0.025**	0.28	**0.010**
**Adjusted for BMI, age, LBP status*				
LBP Status	0.34	**0.001**	0.22	**0.041**
**Adjusted for BMI, age, sex*				
Total Quantitative Epimuscular Fat Area (cm^2) from L2-L5 (*N* = 87)				
BMI	0.57	**<0.001**	0.53	**<0.001**
**Adjusted for age, sex, LBP status*				
Age	0.30	**0.004**	0.26	**0.016**
**Adjusted for BMI, sex, LBP status*				
Sex	0.01	0.902	−0.01	0.937
**Adjusted for BMI, age, LBP status*				
LBP status	0.26	**0.024**	0.15	0.181
**Adjusted for BMI, age, sex*				

Spearman's rho correlation used for all variables.

have higher paraspinal muscle FI as compared to men (Sions et al., 2017; Kalichman,Carmeli,and Been, 2017; Hildebrandt et al., 2017). In the same vein, other studies also found a correlation between paraspinal muscle FSF and sex, with men having a lower FSF values than women (Dahlqvist et al., 2017; Urrutia et al., 2018). Hidebrandt et al (2017) showed that woman had significantly greater MF FI than men in a sample of participants with acute and chronic LBP. Overall, our findings suggest that epimuscular fat along the posterior border of the ES and MF is associated with increased age and BMI, and possibly sex. However, because only the qualitative epimuscular fat measure showed a correlation (weak) with sex, further work is needed.

4.3. *Influence of LBP duration and intensity*

We found no correlation between qualitative and quantitative epimuscular fat measures with LBP duration or intensity. This is consistent with past cross-sectional studies reporting no associations between LBP intensity and paraspinal muscle FI (Mengiardi et al., 2006; Dahlqvist et al., 2017) or size (Ploumis et al., 2011; Ranger et al., 2019). Fortin

Table 5
Correlation between Total Qualitative Epimuscular Fat Rating Score, Total Quantitative Epimuscular Fat Area (cm^2), and LBP Duration and Intensity.

	Correlation [95 % CI]	*P*-value
***N* = 48**		
Total Qualitative Epimuscullar Fat Rating Score from L2-L5		
LBP Duration	−0.06 [-0.33, 0.25]	0.698
LBP Intensity*	0.05 [-0.30, 0.39]	0.765
Total Quantitative Epimuscular Fat Area (cm^2) from L2-L5		
LBP Duration	−0.02 [-0.32, 0.27]	0.880
LBP Intensity*	−0.10 [-0.44, 0.22]	0.514

Spearman's rho correlation (r_s) used for all variables.
CI: Confidence interval.
* – Five missing data from LBP Intensity variable (*n* = 43).

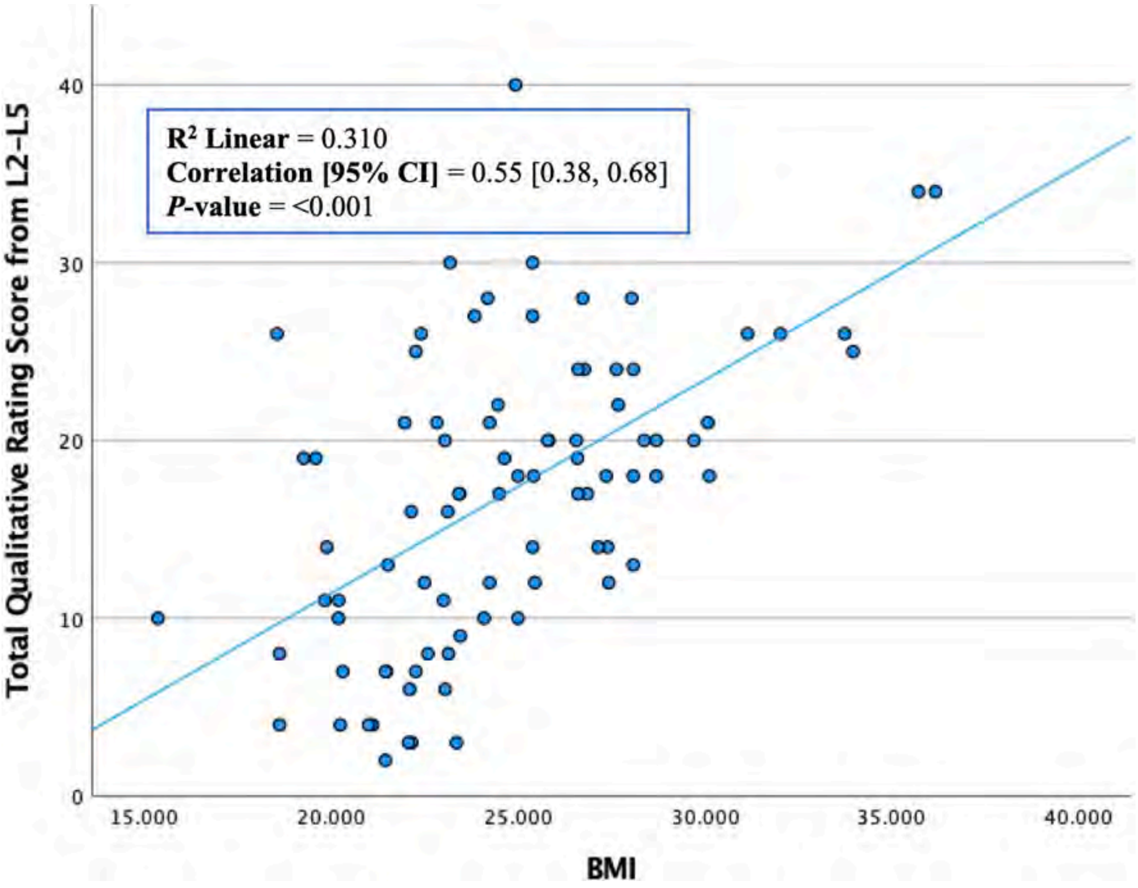

Fig. 4. Scatter plot graph showing the correlation between total qualitative rating score (L2-L5) for epimuscular fat and BMI.

et al. (2014) also reported no association of LBP history, which included LBP frequency and intensity in the previous year, with changes in paraspinal muscle morphology (size) or composition (FI). However, it is important to consider that the non-significant findings in our study and previous studies may be related to the relatively small range in pain duration. While the relationship between epimuscular fat and pain duration remain largely unknown, animal model studies (e.g. inducing disc and nerve lesions) revealed that only a short amount of time (e.g. 6 days) is needed to induce intramuscular FI (Hodges et al., 2006). It may be the case that this would also apply to epimuscular fat, but more research is needed to confirm this theory.

4.4. Limitations

Due to differences in MRI protocols that was not standardized between sites, it was not possible to correct the slice orientation perpendicular to mid-disc by 3D reconstruction from L4-S1. Therefore, the muscle was not always sliced perpendicular to the direction of its muscle fibers at these levels. Furthermore, this study assessed participants aged between 21 and 63 years. Elderly individuals may exhibit different morphological changes along the spine, potentially yielding different results, such as increased FI and decreased muscle CSA (Fortin et al., 2014). Additionally, the control group sample size is relatively small and smaller than our LBP group. Despite participants' characteristics being comparable between groups, BMI was higher in the LBP group.

5. Conclusion

Our findings showed that a novel qualitative epimuscular fat measure had a significant positive correlation with BMI, age, sex (female) and LBP status. Similarly, the quantitative measure of epimuscular fat was significantly correlated with BMI, age and LBP status. Paraspinal muscle epimuscular fat was more frequent at the L4-L5 and L5-S1 levels in participants with LBP compared to controls, but no correlations were found between epimuscular fat and LBP duration or intensity. Functional implications of epimuscular fat should be further explored, especially in LBP and at the lower lumbar spinal levels.

Institutional review board Statement:

Ethics approval was obtained from the Central Ethics Committee of the Quebec Ministry of Health and Social Services (CCER-15–16-17), the Medical University of Vienna Ethics Committee (1609/2012) and by the institutional review board of the Centre intégré universitaire de santé et de services sociaux de l'Estrie – Centre hospitalier universitaire de Sherbrooke (CIUSSS de l'Estrie – CHUS, 2021–3861).

Informed consent Statement:

Written informed consent has been obtained from the patients to publish this paper.

CRediT authorship contribution statement

Brent Rosenstein: Investigation, Methodology, Formal analysis, Data curation, Writing – original draft. **Jessica Burdick:** Investigation, Methodology, Data curation, Writing – review & editing. **Alexa Roussac:** Investigation, Writing – review & editing. **Meaghan Rye:** Investigation, Writing – review & editing. **Neda Naghdi:** Investigation, Writing – review & editing. **Stephanie Valentin:** Resources, Investigation, Writing – review & editing. **Theresia Licka:** Resources, Investigation, Writing – review & editing. **Monica Sean:** Investigation, Data curation, Writing – review & editing. **Pascal Tétreault:** Resources, Investigation, Writing – review & editing. **Jim Elliott:** Resources, Writing – review & editing. **Maryse Fortin:** Conceptualization, Project administration, Investigation, Supervision, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

The authors would like to thank all the participants and MRI technical staff for their collaboration in this study. Support was received from The Quebec Bioimaging Network and the Austrian Science Fund (FWF) project P24020. MF is supported by Fonds de Recherche du Québec – Santé (FRQS).

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