North American Spine Society Journal (NASSJ) 20 (2024) 100570

Contents lists available at ScienceDirect

North American Spine Society Journal (NASSJ)

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

Clinical Studies

Association between modifiable and nonmodifiable risk factors with paralumbar muscle health in patients with lower back pain

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ARTICLE INFO

Keywords:
Muscle health
Paralumbar
Lumbar spine
Spine surgery
Sarcopenia
Goutallier
multifidus
Erector spinae
Cross-sectional area

ABSTRACT

Background: Prior studies have linked sarcopenia and fat infiltration in paraspinal muscles with lumbar pain, spinal pathology, and adverse postoperative outcomes in lumbar spine surgery. A recent magnetic resonance imaging (MRI)-based method for assessing muscle health, incorporating parameters such as Goutallier Classification (GC) and the Paralumbar Muscle Cross-Sectional Area to Body Mass Index ratio (PL-CSA/BMI), has shown that higher muscle grades correlate with significant improvements in patient-reported outcomes. Despite these advancements, there is limited research on the associations between paralumbar muscle health and factors such as age, BMI, walking tolerability, and spondylolisthesis. Our study aimed to evaluate such associations.
Methods: This Institutional Review Board-approved retrospective cohort study included patients aged 18 or older presenting with back pain symptoms who underwent lumbar spine MRI within 12 months of presentation to a single orthopedic surgeon. Patients with incomplete imaging, cancer pathology, or trauma-induced injuries were excluded. MRI-based measurements of Lumbar Indentation Value (LIV), Goutallier Classification (GC), and PL-CSA/BMI were used as outcome measures. Paralumbar muscles on axial T2-weighted lumbar MRIs were outlined using ImageJ to determine the PL-CS and LIV through the L1–L5 disc spaces, with GC classified by the primary author. Quantile regression analysis was used for continuous variables, and negative binomial regression with an estimated ancillary parameter was applied for ordinal variables, with statistical significance set at $p<.05$.
Results: Our analysis found that increasing age was associated with increased GC, decreased PL-CSA, and CSA/BMI at all lumbar levels. Age was associated with increased LIV at L1/L2. We found that increasing BMI was associated with increased LIV and PL-CSA and decreased CSA/BMI at all lumbar levels while it was only associated with increased GC at L1/L2, L2/L3 and L3/L4. Higher grade spondylolisthesis was associated with worse GC at all lumbar spinal levels except L3/L4 and with decreased LIV at L1/L2. An inability to walk > 1 block predicted LIV and GC at L2/L3 while predicting CSA/BMI at L4/L5. Increasing age was associated with decreased CSA at L1/L2, L2/L3 and L4/L5 while it was associated with decreased CSA/BMI and increased GC at all lumbar levels. Age was only associated with decreased LIV at L1/L2, L2/L3. Lastly, increasing BMI was associated with increased CSA,

Abbreviations: Magnetic resonance imaging, (MRI); Goutallier classification, (GC); paralumbar muscle cross-sectional area, (PL-CSA); body mass index, (BMI); lumbar indentation value, (LIV); Oswestry Disability Index, (ODI).

FDA device/drug status: Not applicable.

Author disclosures: ***JF:*** Nothing to disclose. ***JS:*** Nothing to disclose. ***MR:*** Nothing to disclose. ***JS:*** Nothing to disclose. ***ADK:*** Nothing to disclose. ***AN:*** Nothing to disclose. ***ST:*** Nothing to disclose. ***BJ:*** Nothing to disclose. ***AS:*** Nothing to disclose. ***MS:*** Nothing to disclose. ***JZ:*** Nothing to disclose. ***JS:*** Nothing to disclose. ***DE:*** Nothing to disclose. ***SQ:*** Nothing to disclose. ***SV:*** Nothing to disclose.

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https://doi.org/10.1016/j.xnsj.2024.100570
Received 18 September 2024; Received in revised form 26 October 2024; Accepted 29 October 2024
Available online 2 November 2024

LIV, and decreased CSA/BMI at all lumbar levels and associated with increased GC at all lumbar levels except L4/L5. All statistically significant associations had p-values<.05.

Conclusions: Our analysis determined that increasing age, increased BMI, spondylolisthesis, and walking intolerability are significantly associated with poor paralumbar muscle health. Alongside these findings we discovered that increased age, BMI, spondylolisthesis and walking intolerability were significantly associated with varying degrees of increased Goutallier classification and LIV. Future research is required to determine whether there can be individual alterations in paralumbar muscle health following changes in modifiable risk factors. Additionally future efforts should focus on elucidating the impact of the underlying mechanism behind certain nonmodifiable risk factors such as age on Goutallier classification and poorer paralumbar muscle health.

Introduction

A growing elderly population and increasing incidence of lumbar spine pathology has warranted research evaluating risk factors associated with degenerative spine disease [1]. Decreased muscle strength in particular has been shown to be associated with lumbar pathology, and recent studies have correlated sarcopenia with increased lower back pain [2–5]. Additionally, age has been shown to be associated with increased fat infiltration in paraspinal muscles, which may be a risk factor for lumbar pathology [6,7] and poor postoperative outcomes in lumbar spine surgery [8].

A novel approach has been developed to evaluate muscle health via several parameters including Goutallier classification (GC), and paralumbar muscle cross-sectional area (PL-CSA) normalized by body mass index (BMI). In this study higher muscle grades were associated with statistically significant improvements in patient-reported outcomes [9]. The literature currently lacks studies evaluating how these parameters vary with age and other risk factors.

The purpose of this study was to evaluate associations between patients' paralumbar muscle health scores and their associations with age, BMI, spondylolisthesis, and walking tolerability. We hypothesized that muscle health scores would reveal a decrease with age, BMI, spondylolisthesis, and decreased walking tolerability.

Methods

This retrospective study investigating the patient records and imaging of a single surgeon was conducted following approval from the senior author's institutional review board. Inclusion criteria included patients presenting with lower back pain and available lumbar MRI imaging alongside clinical information for assessment. Exclusion criteria included patients with incomplete demographic, radiographic, or clinical data, and patients with a history of trauma, infection, or neoplasm. Additionally, cases lacking interpretable MRI scans by the authors were excluded. Assessment included an examination of various patient characteristics such as age, BMI, the presence and grade of degenerative spondylolisthesis, and the level of walking tolerability. The grade of spondylolisthesis was reported based on the Meyerding classification [10]. The level of walking tolerability was self-reported by the patient and quantified based on the number of blocks the patient could independently ambulate.

Axial T2-weighted lumbar MRIs were evaluated using 3 parameters including paralumbar cross-sectional area, Goutallier classification, and lumbar indentation value (LIV) [11]. PL-CSA was determined by tracing the boundary of the combined bilateral multifidus and erector spinae muscles using ImageJ software (ImageJ, National Institutes of Health, Bethesda, MD). This method in evaluating PL-CSA has been used in previous studies and has been shown to be an efficient process by which measurements can be determined [8,9,12,13]. An example PL-CSA measurement is shown in Fig. 1.

PL-CSA measurements were normalized by the patient's BMI. Goutallier classification was graded on a scale from 0 to 4 based on a qualitative assessment of fatty degeneration of the paralumbar muscles. Goutallier classes were defined as follows: 0-no fatty streaks, 1-minimal fatty streaks, 2-fat evident but more muscle present, 3-equal amounts of fat and muscle, and 4-higher quantity of fat than muscle [11]. An example of Goutallier classification is depicted in Fig. 2. Lastly, LIV was measured as the perpendicular distance between the spinous process and a line tangential to the paralumbar muscle bulges. An example LIV measurement is depicted in Fig. 3.

Muscle health measurements for each patient were conducted by 2 independent observers. Measurements were collected by medical students and an orthopedic surgery resident. The senior author assessed each researchers' initial measurements for accuracy. Each researcher responsible for data collection was trained in the methodology of how to accurately collect measurements. Additionally, articles that defined methodology were reviewed by those performing measurements during the training process to ensure competency during data collection.

Statistical analysis

All statistical analyses were performed using SPSS (version 28, IBM, Armonk, New York). For each categorical variable, the frequency and proportion were recorded. Descriptive statistics including mean and standard deviation were calculated for continuous variables. A quantile regression analysis was performed for continuous variables and a negative binomial regression with estimated ancillary parameter was used for ordinal variables. The criterion for statistical significance was set at $p<.05$.

Results

A total of 615 patients were assessed from the senior author's practice with a lumbar MRI between June 2020 and June 2021 the mean age was 57.6 years old ±15.9 with a majority female (60.8%). Full demographic characteristics of our patient cohort can be found in Table 1. The inter-rater reliability assessments for the MRI-based muscle health measurements indicated excellent reliability at all levels (intraclass correlation >0.9).

Table 1
Patient demographics.

Characteristics	*N*	%
N of subjects	615	100.0%
Age (years), means ±SD	57.6±15.9	
Female sex	374	60.8%
Race		
American Indian or Alaskan Native	6	1.0%
Asian	64	10.4%
Black or African American	227	19.0%
Native American or Pacific Islander	3	0.3%
White	255	41.5%
Other	123	20.0%
Unknown/Declined to answer	48	7.8%
Ethnicity		
Hispanic	64	10.4%
Not Hispanic	496	80.7%
Unknown/Declined to answer	55	8.9%

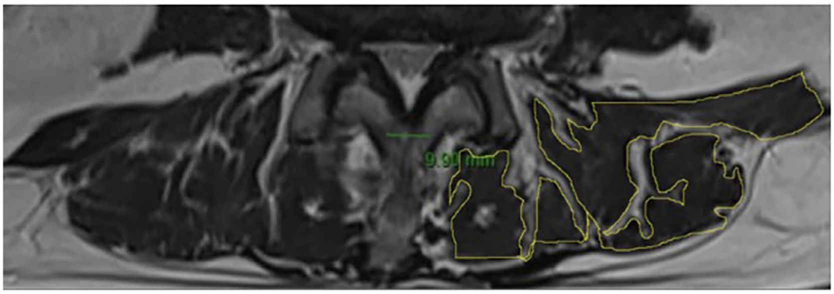

Fig. 1. Sample tracing combined bilateral multifidus and erector spinae muscles to calculate paralumbar muscle cross-sectional area on axial T2-weighted MRI performed using ImageJ software.

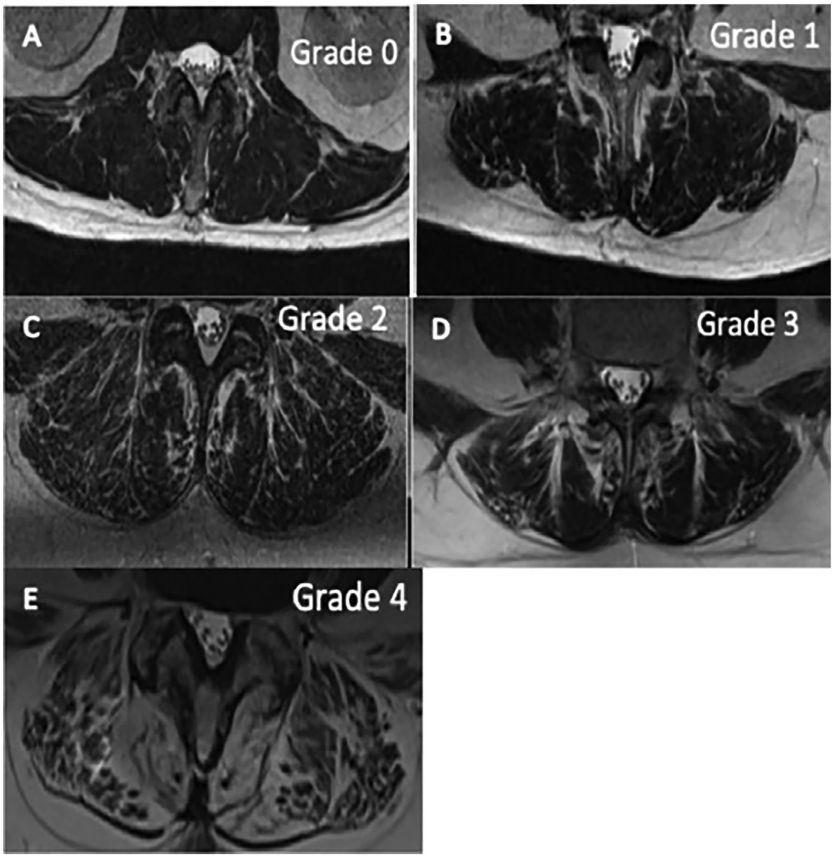

Fig. 2. Sample Goutallier classification based on quantity of fat relative to muscle using axial T2-weighted MRI.

Of these patients, 89 were identified to have a history of spine surgery for the treatment of degenerative lumbar spine disease. Diagnoses indicating surgery included lumbar spinal stenosis, degenerative disc disease, degenerative spondylolisthesis, foraminal stenosis, and lateral recess stenosis. The most common categories of surgical procedures performed were lumbar decompression (35 patients, 39.3%) and posterior lumbar fusion (29 patients, 32.6%), all performed using traditional open techniques. Seven patients underwent revision spine procedures while no patients underwent multiple revision surgeries.

Increasing age was significantly associated with an increased Goutallier grade at L1/L2 (OR:1.028, [95%CI: 1.02,1.03], $p<.001$), L2/L3 (OR: 1.028, [1.02,1.03], $p<.001$), L3/L4 (OR:1.026, [1.02,1.03], $p<.001$), and L4/L5 (OR: 1.027, [1.02,1.03], $p<.001$). Increasing age was also significantly associated with decreased PL-CSA at L1/L2 (-26, [-34, -17], $p<.001$), L2/L3 (-24, [-32, -16], $p<.001$), L3/L4 (-24, [-31, -16], $p<.001$), and L4/L5 (-32, [-39, -25], $p<.001$). Increasing age was significantly associated with decreased CSA/BMI at L1/L2 (-0.9, [-1.2,-0.6], $p<.001$), L2/L3 (-0.8, [-1.1,-0.5], $p<.001$), L3/L4 (-0.9, [-1.1,-0.6], $p<.001$) and L4/L5 (-1.1, [-1.4,-0.8], $p<.001$) Lastly, increasing age was significantly associated with decreasing LIV at the L1-L2 level only (-0.1, [-0.1,-0.01], $p=.009$) (Table 2).

Our analysis found that increasing BMI by 1 point was significantly associated with an increased LIV at L1/L2 (0.3, [95%CI: 0.2,0.4], $p<.001$), L2/L3 (.2, [0.1,0.3], $p<.001$), L3/L4 (0.2, [0.1, 0.3], $p<.001$), and L4/L5 (0.1, [0.02,0.2], $p=.014$). Increasing BMI by 1 point was significantly associated with increased PL-CSA at L1/L2 (61.2, [42.1,80.3], $p<.001$), L2/L3 (50, [35.2, 71.2], $p<.001$), L3/L4 (49.8, [32.5,67.0], $p<.001$) and L4/L5 (38.5[20.2, 56.8], $p<.001$). Increasing BMI by 1 point was also found to be significantly associated with decreasing CSA/BMI at L1/L2 (-2.1, [-2.7,-1.4], $p<.001$), L2/L3 (-2.2, [-2.8,-1.6], $p<.001$) L3/L4 (-2.3, [2.9,-1.7], $p<.001$), and L4/L5 (-2.4, [-3.1,-1.8], $p<.001$). Lastly increasing BMI by 1 point was significantly associated with an increased Goutallier grade at L1/L2 (OR:1.017, [1.01,1.03], $p=.003$), L2/L3 (OR:1.017, [1.01, 1.03], $p=.002$) L3/L4 (OR: 1.011, [1.0,1.02], $p=.031$) (Table 3).

Higher grade of spondylolisthesis was significantly associated with worse Goutallier classification scores at L1/L2 (OR=1.341 [95% CI: 1.115, 1.612], $p=.002$), L2/L3 (OR=1.341 [1.139, 1.510], $p<.001$),

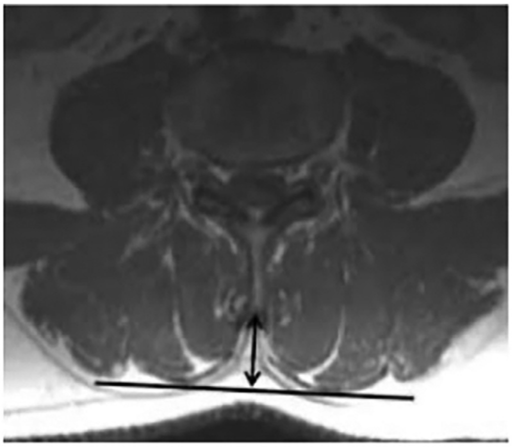

Fig. 3. Sample lumbar indentation value measurement on axial T2-weighted MRI performed using ImageJ software.

L3/L4 (OR=1.188, [1.065, 1.324], *p*=.002, and L4/L5 (OR=1.117, 95% CI: 1.006,1.240 *p*=.039). A L1/L2 spondylolisthesis was also found to be significantly associated with a decreased LIV at spinal level L1/L2 (OR=-3.330[-5.311, -1.349], *p*=.001). No significant association between spondylolisthesis and LIV was determined at all other lumbar spinal levels. Finally, spondylolisthesis was not found to be significantly associated with PL-CSA/BMI at all lumbar spinal levels (Table 4).

Next, when evaluating walking tolerability, we found an inability to walk ≥ 1 block predicted GC at spinal level L2/L3 (OR=1.252, [95% CI: 1.055,1.485], *p*=.010); no other significant association was found at all other measured spinal levels. Moreover, an inability to walk ≥ 1 block predicted LIV at spinal level L2/L3 (+1.950 points, [0.367,3.533], *p*=.016); no other significant associations were found at all other measured spinal levels. Finally, an inability to walk ≥ 1 block predicted PL-CSA/BMI at spinal level L4/L5 (-14.61 points, [-27.094, -2.134], *p*=.022); no other significant associations were found at all other measured spinal levels (Table 5).

Further stratification of our sample showed that patients aged ≥ 65 years old were associated with a significantly decreased CSA at L1/L2 65 (-600 points, [95%CI: -794, -406], *p*<.001), L2/L3 (-692 points, [-885, -500], *p*<.001), L3/L4 (-628 points, [-805,-452], *p*<.001), and L4/L5 (-791 points, [-984,-598], *p*<.001.) Additionally, CSA/BMI was significantly decreased at L1/L2 (-19 points, [-25, -12], *p*<.001), L2/L3 (-21 points, [-28, -25], *p*<.001), L3/L4 (-21 points, [-28, -14], *p*<.001), L4/L5 (-22 points, [29, -15], *p*<.001). Also, patients aged ≥ 65 years old were associated with a significantly increased odds of increased GC at L1/L2 (1.9, [1.6, 2.1], *p*<.001), L2/L3 (1.9, [1.6, 2.2], *p*<.001), L3/L4 (1.8, [1.6,2.1], *p*<.001) and L4/L5 (1.9, [1.7,2.1], *p*<.001) and decreased LIV at L1/L2 (-1.8, [-3.1,-0.5], *p*=.009) and L2/L3 (-1.4, [-2.6,-0.2], *p*=.024.) (Table 6).

Lastly, we discovered that obesity (defined as BMI ≥ 30 kg/m^2) was associated with significantly increased CSA at L1/L2 (724 points, [95%CI: 536, 911], *p*<.001), L2/L3 (591 points, [405, 778], *p*<.001), L3/L4 (477 points, [307,648], *p*<.001), L4/L5 (342 points, [155,529], *p*<.001), decreased CSA/BMI at L1/L2 (-17, [-23,-10], *p*<.001), L2/L3 (-22, [-28,-16], *p*<.001), L3/L4 (-29, [-35,-22], *p*<.001), L4/L5 (-29,[-36,-22], *p*<.001) and increased LIV at L1/L2 (4.7, [3.4,6], *p*<.001), L2/L3 (3.2, [2,4,] *p*<.001), L3/L4 (2.8, [1.6,4], *p*<.001) and L4/L5 (2.3, [1.1,3.6], *p*<.001). Obesity was also associated with increased odds of increased GC at L1/L2 (1.3, [1.1,1.7], *p*=.001), L2/L3 (1.3, [0.8,1.6], *p*=.001), L3/L4 (1.2, [1, 1.4,] *p*=.008) (Table 6).

Discussion

Our study aimed to identify potential associations between paralumbar muscle health, LIV, Goutallier classification, and patient characteristics such as age, BMI, spondylolisthesis and walking tolerability. We found that increasing age was associated with increased Goutallier classification, decreased CSA, CSA/BMI, and LIV. Alongside this finding we saw that increasing BMI was associated with decreased CSA/BMI and increased CSA, LIV and Goutallier classification. Next, we saw that limited walking tolerability was associated with increased LIV, and Goutallier classification and decreased CSA/BMI at distinct lumbar spinal levels. Our remaining variables analyzed determined that increasing spondy-

Table 2
Age-related changes in LIV, CSA, and Goutallier grading.

	Mean ± SD	R	95% C.I.		S.E.	*p*-value
			Lower	Upper		
LIV (mm)[*]						
L1–L2	16.2 ± 10.1	**-0.06**	-0.11	-0.016	0.024	**.009**
L2–L3	11.9 ± 6.4	-0.04	-0.08	0.001	0.021	.059
L3–L4	46.1 ± 12.6	-0.03	-0.071	0.015	0.022	.199
L4–L5	21.7 ± 14.4	-0.03	-0.071	0.019	0.023	.256
PL-CSA (mm^2)[†]						
L1–L2	4198.2 ± 2593.8	**-25.8**	-34.298	-17.302	4.32	**<.001**
L2–L3	4277.8 ± 1716.0	**-24.2**	-32.082	-16.411	3.98	**<.001**
L3–L4	4157.4 ± 1612.9	**-23.8**	-31.468	-16.207	3.88	**<.001**
L4–L5	3834.1 ± 1247.0	**-32.1**	-39.481	-24.769	3.74	**<.001**
PL-CSA/BMI[‡]						
L1–L2	145.5 ± 102.7	**-0.9**	171.16	206.91	0.15	**<.001**
L2–L3	147.6 ± 55.2	**-0.8**	-1.14	-0.59	0.16	**<.001**
L3–L4	143.8 ± 51.8	**-0.9**	-1.13	-0.59	0.14	**<.001**
L4–L5	133.5 ± 127.7	**-1.1**	-1.39	-0.84	0.14	**<.001**
Goutallier Grade	≥ 3	B	Exp(B) with 95% CI (Lower/Upper)		S.E.	*p*
L1–L2	1 (0.2%)	**0.028**	1.028 (0.136/0.281)		0.0029	**<.001**
L2–L3	48 (7.8%)	**0.028**	1.028 (1.023/1.033)		0.0026	**<.001**
L3–L4	77 (12.5%)	**0.026**	1.026 (1.026/1.021)		0.0024	**<.001**
L4-L5	124 (20.4%)	**0.027**	1.027 (1.022/1.032)		0.0023	**<.001**

Bold values represent significant values ($p < 0.05$).
[*] Lumbar indentation value.
[†] Paralumbar—cross sectional area
[‡] Paralumbar—cross sectional area/ body mass index.

Table 3
Body mass index-related changes on LIV, CSA, and Goutallier grades.

	Mean ± SD	R	95% C.I.		S.E.	*p*-value
			Lower	Upper		
LIV (mm)*						
L1–L2	16.2 ± 10.1	**0.31**	0.194	0.418	0.057	**<.001**
L2–L3	11.9 ± 6.4	0.20	0.11	0.288	0.045	<.001
L3–L4	46.1 ± 12.6	0.18	0.079	0.28	0.051	<.001
L4–L5	21.7 ± 14.4	0.12	0.024	0.218	0.049	.014
PL-CSA (mm^2)†						
L1–L2	4198.2 ± 2593.8	**61.2**	42.146	80.338	9.7237	**<.001**
L2–L3	4277.8 ± 1716.0	**53.2**	35.156	71.164	9.1679	**<.001**
L3–L4	4157.4 ± 1612.9	**49.8**	32.544	66.973	8.7657	**<.001**
L4–L5	3834.1 ± 1247.0	**38.5**	20.171	56.757	9.3145	**<.001**
PL-CSA/BMI‡						
L1–L2	145.5 ± 102.7	**-2.1**	-2.75	-1.40	0.34	**<.001**
L2–L3	147.6 ± 55.2	**-2.2**	-2.81	-1.57	0.32	**<.001**
L3–L4	143.8 ± 51.8	**-2.3**	-2.93	-1.73	0.31	**<.001**
L4–L5	133.5 ± 127.7	**-2.4**	-3.06	-1.82	0.32	**<.001**
Goutallier Grade	≥ 3	B	Exp(B) with 95% CI (Lower/Upper)		S.E.	*p*-value
L1–L2	1 (0.2%)	**0.017**	1.017(1.006/1.029)		0.0057	**.003**
L2–L3	48 (7.8%)	**0.017**	1.017(1.006/1.027)		0.0052	**.002**
L3–L4	77 (12.5%)	**0.011**	1.011(1.001/1.021)		0.005	**.031**
L4–L5	124 (20.4%)	0.003	1.003(.993/1.013)		0.0049	.535

Bold values represent significant values ($p < 0.05$).
* Lumbar indentation value.
† Paralumbar—cross sectional area.
‡ Paralumbar—cross sectional area/ body mass index.

Table 4
Spondylolisthesis grade-related changes in LIV, CSA, and Goutallier grading.

	Mean ± SD	R	95% C.I.		S.E.	*p*-value
			Lower	Upper		
LIV (mm)*						
L1–L2	16.2 ± 10.1	**-3.33**	-5.311	-1.349	1.009	**.001**
L2–L3	11.9 ± 6.4	-0.79	-2.14	0.56	0.688	.251
L3–L4	46.1 ± 12.6	1.19	-0.015	2.395	0.614	.053
L4–L5	21.7 ± 14.4	1.02	-0.123	2.168	0.584	.08
PL-CSA (mm^2)†						
L1–L2	4198.2 ± 2593.8	-172.8	-533.434	185.834	183.1247	.343
L2–L3	4277.8 ± 1716.0	**-297.2**	-571.136	-23.264	139.4895	**.034**
L3–L4	4157.4 ± 1612.9	-156.9	-370.512	56.712	108.7719	.15
L4–L5	3834.1 ± 1247.0	-204.8	-424.176	14.643	111.7226	.067
PL-CSA/BMI‡						
L1–L2	145.5 ± 102.7	-4.1	-16.29	8.04	6.19	.505
L2–L3	147.6 ± 55.2	-4.1	-14.29	6.08	5.19	.429
L3–L4	143.8 ± 51.8	-4.8	-12.54	3.00	3.96	.229
L4–L5	133.5 ± 127.7	-4.9	-13.76	4.04	4.53	.284
Goutallier Grade	≥ 3	B	Exp(B) with 95% CI (Lower/Upper)		S.E.	*p*-value
L1–L2	1 (0.2%)	**0.293**	1.341(1.115/1.612)		0.0941	**.002**
L2–L3	48 (7.8%)	**0.271**	1.311(1.139/1.510)		0.0721	**<.001**
L3–L4	77 (12.5%)	**0.172**	1.188(1.065/1.324)		0.0555	**.002**
L4–L5	124 (20.4%)	**0.111**	1.117(1.006/1.240)		0.0535	**.039**

Bold values represent significant values ($p < 0.05$).
* Lumbar indentation value.
† Paralumbar—cross sectional area.
‡ Paralumbar—cross sectional area/ body mass index.

lolisthesis was associated with increased Goutallier classification at all levels of the lumbar spine and associated with decreased CSA at L2-L3 and decreasing LIV at L1-L2.

Our study utilized a MRI based technique using paralumbar cross sectional area and Goutallier classification, which was found to be associated with health-related quality of life scores for patients with spinal pathology, to perform our analysis [9]. A 2020 study by Wang et. al using this same novel technique determined that a reduced functional cross-sectional area of the multifidus muscle and increased fatty infiltration of the multifidus on preoperative MRI scans was associated with worse Oswestry Disability Index (ODI) scores in both pre- and postoperative evaluations. Additionally, this group found that erector spinae fatty infiltration was positively correlated to ODI scores and that a relationship existed between atrophy of these paraspinal muscles and functional status [14]. These findings correlate with our own discovery that poor walking tolerance, which can be an indicator of functional status, was negatively correlated with CSA/BMI and Goutallier classification, a system designed to quantify fatty infiltration. Our analysis additionally found an association between walking intolerance and LIV at certain lumbar levels. Wang et. al also determined that fatty infiltration was

Table 5
Walking tolerance-related changes in LIV, CSA, and Goutallier grading.

	Mean ± SD	R	95% C.I.		S.E.	*p*-value
			Lower	Upper		
LIV (mm)*						
L1–L2	16.2 ± 10.1	1.48	-0.489	3.449	1.003	.14
L2–L3	11.9 ± 6.4	**1.95**	0.367	3.533	0.806	**.016**
L3–L4	46.1 ± 12.6	1.57	-0.169	3.309	0.885	.077
L4–L5	21.7 ± 14.4	1.06	-0.656	2.776	0.874	.226
PL-CSA (mm^2)†						
L1–L2	4198.2 ± 2593.8	-154.2	-497.166	188.766	174.6378	.378
L2–L3	4277.8 ± 1716.0	-110.7	-434.586	213.186	164.9241	.502
L3–L4	4157.4 ± 1612.9	-94.0	-398.231	210.231	154.9155	.544
L4–L5	3834.1 ± 1247.0	-227.3	-566.149	111.549	172.5402	.188
PL-CSA/BMI‡						
L1–L2	145.5 ± 102.7	-1.1	-12.84	10.55	5.95	.848
L2–L3	147.6 ± 55.2	-3.5	-15.38	8.33	6.03	.56
L3–L4	143.8 ± 51.8	-6.4	-16.98	4.27	5.41	.24
L4–L5	133.5 ± 127.7	**-14.6**	-27.09	-2.13	6.35	**.022**
Goutallier Grade	≥ 3	B	Exp(B) with 95% CI (Lower/Upper)		S.E.	*p*-value
L1–L2	1 (0.2%)	0.119	1.127(.929/1.367)		0.0986	.226
L2–L3	48 (7.8%)	**0.224**	1.252(1.055/1.485)		0.0873	**.01**
L3–L4	77 (12.5%)	0.139	1.149(.976/1.352)		0.0831	.095
L4–L5	124 (20.4%)	0.096	1.100(.941/1.287)		0.08	.231

Bold values represent significant values ($p < 0.05$).
* Lumbar indentation value.
† Paralumbar—cross sectional area.
‡ Paralumbar—cross sectional area/ body mass index.

associated with change in ODI representing functional status and therefore preoperative fatty infiltration could be representative of a patient's postoperative functional status change potential [14]. Our findings are important given the uncovered relationship between paralumbar CSA, fatty infiltration and functional status postoperatively because it gives spine surgeons an objective metric to discuss with patients when weighing the risks against benefits before undergoing surgical intervention.

The association between obesity, as determined by BMI, muscular fatty infiltration and back pain characteristics has been repeatedly shown in recent studies [15–17] A 2022 study by Shi et al found a relationship between lumbar disc degeneration and associated low back pain with fatty infiltration of the multifidus and surmised this could potentially be due to fatty infiltration related inflammation [18]. This relationship has been further implicated by our analysis which shows a stepwise increase in Goutallier classification with increasing BMI. The importance of this finding is significant given BMI's modifiable nature and its relationship with physical inactivity. With this knowledge spine surgeons can discuss with patients the objective benefits to weight loss on their functional status and muscle health. Patients who were previously thought inoperable could potentially become quality surgical candidates with reduction in BMI preoperatively.

A study by Teichtahl et. al found a dose dependent relationship in sedentary community-based adults between physical inactivity and fat infiltration of the multifidus and increased intensity of back pain [19]. A randomized control trial by Santanasto et. al took thirty-six overweight to moderately obese, sedentary older adults and found that the physical activity and weight loss cohort lost significant amounts of total muscle mass, fat cross sectional area and demonstrated a significant decrease in the lipid content of their musculature [20]. This study shows that with weight loss there is a potential to reduce fatty infiltration; however, the benefits must be compared to the concerns of decreased muscle mass in certain vulnerable populations.

An additional consideration with the weight reduction approach is that it reinforces the importance of physical therapy for patients, which is often an area of contention due to pain associated with it. Conversations can be had with patients explaining the importance of physical therapy's role in building muscle mass while decreasing fatty infiltration even if patients are not planning on having surgery for an extended period. A previous study by this group found there to be no significant association between chronicity of back pain symptoms and Goutallier classification; however, the mean BMI of the chronic back pain cohort was significantly higher and surpassed the obesity threshold [21]. These findings when viewed together highlight the complex and still not fully understood impact of BMI on low back pain and its objective muscular manifestation. Overall, BMI is a modifiable risk factor that our study has shown correlates with paraspinal muscle health. Further research is required to analyze paraspinal muscle health post weight reduction in patients with low back pain and to quantify postoperative outcomes in this cohort of patients.

Unlike obesity, age is a nonmodifiable risk factor that has also repeatedly been shown to correlate with decreasing CSA of paraspinal muscle, poor paraspinal muscle health and function [22,23]. Our study further exposed this relationship by showing increasing age was associated with increased Goutallier classification, decreased CSA, CSA/BMI and LIV. These findings are important for spine surgeons because they could potentially deconstruct the previously accepted albeit changing adage that older patients are less likely to benefit from spine surgery.

Recent studies have shown that older patients are likely to benefit from deformity correcting spinal surgery [24,25]. However, given previously reported findings that increased Goutallier classification and decreased paraspinal muscle health leads to poorer functional outcomes postoperatively with increased rate of postoperative complications our findings create conflicting points of view [26–28]. If decreased paralumbar muscle health is associated with increasing age, older patients would be less likely to benefit from spinal surgery, yet the opposite appears to be true. This could be a result of the baseline functional deficits present in this cohort in addition to the pathophysiology by which fatty infiltration increases in older patients. If older patients increased Goutallier classification and decreased CSA represents a physiologic adaptation of aging it could potentially lead surgeons to think they are less likely to benefit from surgical intervention when viewed through the lens of a younger cohort. This discrepancy is highlighted in a study by Song et al. which found that history of spine surgery was associated with decreased

Table 6
Age >65 and Obesity-related changes in LIV, CSA, and Goutallier grading.

LIV (mm)*		R	95% CI Lower	95% CI Upper	p-value
L1–L2	Age >65	**-1.8**	-3.146	-0.454	**.009**
	Obesity	**4.74**	3.439	6.041	**<.001**
L2–L3	Age >65	**-1.375**	-2.568	-0.182	**.024**
	Obesity	**3.215**	2.063	4.367	**<.001**
L3–L4	Age >65	-1.1	-2.367	0.167	.089
	Obesity	**2.81**	1.587	4.033	**<.001**
L4–L5	Age >65	-0.85	-2.142	0.442	.197
	Obesity	**2.37**	1.123	3.617	**<0.001**
PL-CSA (mm²)†		**R**	**95% CI Lower**	**95% CI Upper**	**p-value**
L1–L2	Age >65	**-600**	-794	-406	**<.001**
	Obesity	**724**	536	911	**<.001**
L2–L3	Age >65	**-692**	-885	-500	**<.001**
	Obesity	**591**	405	778	**<.001**
L3–L4	Age >65	**-628**	-804.7	-452.1	**<.001**
	Obesity	**477.7**	307.02	648.473	**<.001**
L4–L5	Age >65	**-790.7**	-983.8	-597.5	**<.001**
	Obesity	**342**	155.2	528.9	**<.001**
PL - CSA/BMI‡		**R**	**95% CI Lower**	**95% CI Upper**	**p-value**
L1–L2	Age >65	**-18.697**	-25.204	-12.19	**<.001**
	Obesity	**-16.621**	-22.912	-10.331	**<.001**
L2–L3	Age >65	**-21.242**	-27.901	-14.584	**<.001**
	Obesity	**-22.047**	-28.491	-15.603	**<.001**
L3–L4	Age >65	**-20.978**	-27.686	-14.27	**<.001**
	Obesity	**-28.572**	-35.069	-22.075	**<.001**
L4–L5	Age >65	**-22.449**	-29.435	-15.463	**<.001**
	Obesity	**-29.018**	-35.776	-22.261	**<.001**
Goutallier Class		**Exp(B)**	**95% C.I. Lower**	**95% C.I. Upper**	**p-value**
L1–L2	Age >65	**1.865**	1.594	2.181	**<.001**
	Obesity	**1.296**	1.107	1.516	**.001**
L2–L3	Age >65	**1.902**	1.649	2.193	**<.001**
	Obesity	**1.277**	1.107	1.473	**.001**
L3–L4	Age >65	**1.828**	1.601	2.087	**<.001**
	Obesity	**1.195**	1.047	1.365	**.008**
L4–L5	Age >65	**1.875**	1.653	2.126	**<.001**
	Obesity	1.122	0.989	1.274	.073

Bold values represent significant values ($p < 0.05$).
* Lumbar indentation value.
† Paralumbar—cross sectional area.
‡ Paralumbar—cross sectional area/ body mass index.

paralumbar CSA, CSA/BMI, and increased Goutallier grade without any difference in mean age between cohorts [13]. This finding alongside ours could indicate a distinction between pathologic and physiologic muscular degeneration and fatty infiltration. Future research is required to further investigate the possibility of these 2 pathways leading to appearingly similar manifestations but with potentially different implications for back pain treatment.

Our analysis also found that increasing spondylolisthesis was associated with increased Goutallier classification at all levels of the lumbar spine and associated with decreased CSA at L2–L3 and decreasing LIV at L1–L2. These findings further verify an association recently published between decreased muscular health and spondylolisthesis in patients with operative lumbar stenosis [12]. These findings represent the importance of spondylolisthesis when evaluating patients with low back pain. Further investigation into the biomechanical relationship between spondylolisthesis and degenerating paralumbar muscle health can help spine surgeons when determining the best management techniques for patients with low back pain and these features. Additionally, our findings can aid future research on the potential impact of varying surgical techniques on paralumbar muscle health. A previous study by Song et al. showed the importance of this association when it found that patients with a history of lumbar spinal surgery had significantly impacted muscle health [13]. This study sought to incorporate a comprehensive analysis on patient muscle health in order to most effectively illustrate its relationship with modifiable and nonmodifiable patient characteristics. By understanding known associations between muscle health and variables such as BMI, age, and functional status surgeons will be able to perform a more nuanced evaluation of how surgery impacts muscle thus improving patient care.

This analysis included several limitations, the first of which is that it is a retrospective study that only included patients from a single Orthopedic Spine surgeon at one institution. For this reason, the study may not be generalizable to all patient populations. Further investigation utilizing data from multi-centered patient populations is necessary in confirming these findings. However, it is important to note that the institution involved in the analysis does act as a healthcare access point to a diverse patient population and therefore may be more generalizable than the average healthcare entity. Second, this study did not use a quantitative, standardized method for assessing patients' pain characteristics. Although not standardized, an informal subjective questionnaire was utilized in the analysis which asked patients what their primary concern was, the exact anatomical location affected, their ability to walk a specified number of blocks, if symptoms improved when leaning forward and what previous therapies the patients had undergone.

Another limitation of the study was the lack of serial imaging. It is difficult to adequately determine alterations in paralumbar muscle health in each individual with only MRI's indicating their musculature's appearance at one moment in time. For this reason, patients' muscle health could not be correlated to their longitudinal health parameters such as change in weight, walking tolerability and age. Although a limitation this reflects the reality of what imagining spine surgeons will have access to when making decisions regarding therapeutics for their patients. Lastly, this study did not investigate specific patient parameters that could influence paralumbar muscle health such as activity level, occupation, lifestyle risk factors, family history and previous spinal surgery. We relied on patient reported ability to walk a block which may not be accurate.

Conclusion

Our current analysis used a previously validated method for determining paraspinal muscle health via PL-CSA and determined that increasing age, increased BMI, spondylolisthesis, and walking intolerability are significantly associated with poor paralumbar muscle health. Alongside these findings we discovered that increased age, BMI, spondylolisthesis and walking intolerability were significantly associated with varying degrees of increased Goutallier classification and LIV. Future research is required to determine whether there can be individual alterations in paralumbar muscle health following changes in modifiable risk factors. Additionally future efforts should focus on elucidating the impact of the underlying mechanism behind certain nonmodifiable risk factors such as age on Goutallier classification and poorer paralumbar muscle health.

Declarations 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.

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