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The association between spondylolisthesis and decreased muscle health throughout the lumbar spine for patients with operative lumbar spinal stenosis

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Abstract

Purpose—There are data underlining the relationship between muscle health and spine related pathology, but little data regarding changes in paralumbar muscle associated with lumbar spondylolisthesis. We aimed to define changes in paralumbar muscle health associated with spondylolisthesis.

Methods—A retrospective review was performed on consecutive patients with lumbar spine pathology requiring an operation. A pre-operative lumbar MRI was analysed for muscle health measurements including lumbar indentation value (LIV), paralumbar cross-sectional area divided by body mass index (PL-CSA/BMI), and Goutallier classification of fatty atrophy. All measurements were taken from an axial slice of a T2-weighted image at lumbar disc spaces. Baseline health-related quality of life scores (HRQOLs), narcotic use and areas of stenosis were tracked. We performed Chi-square analyses and student's t test to determine statistically significant differences between cohorts.

Results—There were 307 patients (average age 56.1 ± 16.7 years, 141 females) included within our analysis. 112 patients had spondylolisthesis. There were no differences in baseline HRQOLs between the spondylolisthesis cohort (SC) and non-spondylolisthesis cohort (non-SC). There were significantly worse PL-CSA/BMI at L2–L3 ($p = 0.03$), L3–L4 ($p = 0.04$) and L4–L5 ($p = 0.02$) for the SC. Goutallier classification of paralumbar muscle was worse for SC at L1–L2 ($p = 0.04$) and

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at L4–L5 ($p < 0.001$). Increased grade of spondylolisthesis was associated with worse PL-CSA at L1–L2 ($p = 0.02$), L2–L3 ($p = 0.03$) and L3–L4 ($p = 0.05$). Similarly, there were worse Goutallier classification scores associated with higher-grade spondylolisthesis at all levels ($p < 0.05$).

Conclusion—There are significant detrimental changes to paralumbar muscle health throughout the lumbar spine associated with spondylolisthesis.

Keywords

Muscle health; Spondylolisthesis; Lumbar spine surgery; Patient-reported outcomes; Lumbar spinal stenosis

Introduction

There have been substantial data showing that chronic low back pain is associated with paraspinal muscle wasting and patients with lumbar spondylolisthesis have associated atrophy of their multifidus muscle [1–3]. Our study group has also shown that worse muscle health as measured by a Goutallier classification and the ratio of paralumbar muscle cross-sectional area divided by body mass index (BMI) correspond to worse health-related quality of life scores (HRQOLs) [4]. The pathophysiology creating the link between muscle degeneration and lumbar spine pathology is not yet determined. This relationship may be multifactorial dealing with age, the changing biomechanics of the lumbar spine in relation to spondylolisthesis, patient's activity level and other factors [5–7].

Lumbar spondylolisthesis impacts the lumbar spine and surrounding soft tissue in a variety of ways. Abnormal motion as measured by the change in position of one vertebra in relation to another can be significant and is in multiple planes [8]. The impact of this motion of an unstable spondylolisthesis or the impact of abnormal alignment associated with a stable spondylolisthesis on paralumbar muscle health has not been investigated throughout the lumbar spine.

There has been limited study of muscular changes associated with lumbar spondylolisthesis for patients requiring an operative procedure for lumbar spine pathology. Thakar et al. [3] were able to quantify the muscular changes associated with isthmic spondylolisthesis for patients with isthmic spondylolisthesis compared with age- and sex-matched controlled nonlisthetic patients. Wang et al. [9] showed that the multifidus muscle atrophy was associated with lumbar degenerative spondylolisthesis. Park et al. [10] investigated the correlation between cross-sectional area of lumbar paraspinal muscles and slip percentage for patients diagnosed with lumbar spondylolisthesis. In our review of the literature, there has been no investigation of patients with debilitating symptoms associated with their spondylolisthesis and the muscle changes within patients requiring an operative procedure. Nor has there been any study looking at our combination of muscle health measurements.

Our study aimed to quantify the changes associated with lumbar spondylolisthesis throughout the lumbar spine. Specifically, we wanted to compare two similar patient cohorts requiring an operation for lumbar radicular symptoms from spinal stenosis with or without spondylolisthesis. A level-by-level comparison was performed to elucidate whether

there were specific muscle health measurement changes associated with spondylolisthesis. We also wanted to determine whether worse spondylolisthesis based upon Meyerding classification was associated with worse muscle health [11]. This study will allow for greater understanding on the changing biomechanical forces on the lumbar spine of a patient with spondylolisthesis.

Materials and methods

After obtaining approval from our institutional review board, we performed a retrospective review of patients requiring an operation for lumbar spine pathology. The patients included within this analysis were collected from the senior author's surgical clinic where less than 50% of new patient's require surgical treatment. We only included patients with a diagnosis of lumbar spinal stenosis with imaging correlating with symptomatology on both radiographs and magnetic resonance imaging (MRI). Patients with back/leg pain that did not have moderate to severe spinal stenosis on MRI which corresponded to their clinical examination were not included within our study. The degree of stenosis at the level of operation was quantified using dural tube cross-sectional area at the intervertebral level at which the level was operated upon [12,13]. Only patients over 18 years old were included within our study. Only patients with debilitating pain were considered for surgery as well. Patients with a history of trauma, neoplasm, previous lumbar spinal surgery were excluded from our study. Only patients that had undergone a course of non-operative treatment including but not limited to physical therapy, steroid injections, non-steroidal anti-inflammatory drugs, or chiropractor were included within this operative cohort. Those patients without MRI or radiographs available for interpretation by the authors were excluded from the study as well. Basic demographic data were collected for all patients including age, sex and body mass index (BMI).

We first delineated patients based on whether they had a lumbar spondylolisthesis. This was done by examining standing lateral radiographs and determining if there was any forward displacement of a cephalad vertebra in relation to a caudal vertebra. This was then graded based on the previously reported Meyerding classification [11]. Both of these findings were confirmed by two authors within the study.

We measured cross-sectional area of paralumbar muscles (PL-CSA) using a specially designed free online software called ImageJ [14]. ImageJ (Image J, National Institutes of Health, Bethesda, MD) allowed us to trace out the boundary of the combined multifidus and erector spinae muscles. A sample of this measurement is shown in Fig. 1. In order to correct for a patient's habitus when evaluating the absolute value of PL-CSA, we divided PL-CSA (mm^2) with the BMI of the patient (kg/M^2). In Fig. 1, the yellow outline shown with this axial cross-sectional T2 weighted image shows the manner in which paralumbar cross-sectional area was measured for each patient. These axial cross-sectional slices were in line with the disc space of interest (Fig. 1). The muscle health measurements that were selected for this study were specifically designed to be easy to measure without the use of complex software/coding that would be difficult to use in a busy clinical setting when evaluating patients.

We also measured muscle health with a newly described, validated measurement of muscle bulk/degeneration named the lumbar indentation value (LIV) [14]. A higher lumbar indentation value corresponds to better muscle health according to previously published literature [14]. Other studies did not find that LIV corresponded to better muscle quality [15]. Figure 2 provides an example measurement of LIV. This measurement is the perpendicular distance between the spinous process and a line tangential to the paralumbar muscle bulges.

In Fig. 2, the LIV is shown in blue within this figure (Fig. 2). It quantifies the distance between a perpendicular line between lumbar muscle humps and a spinous process.

The Goutallier classification of the paralumbar muscle was graded on a scale based on a qualitative assessment of fat atrophy of the muscle [15]. A 1 out of 4 was defined as having minimal to no fatty streaks in muscle, a 2 out of 4 as having fat evident but more muscle present, a 3 out of 4 meant equal fat and muscle and a 4 out of 4 was more fat than muscle. All measurements were done on an axial T2 weight cut from the MRI at each disc space within the lumbar spine except for L5–S1. L5–S1 was excluded due to the fact that both multifidus and erector spinae anatomy are too variable for reliable comparison across patients [14]. All measurements were done using Sectra Medical Imaging (Sectra AB, Linkoping, Sweden). In order to properly compare cohorts using a Chi-square analysis, we defined a “good” Goutallier classification score as 1 or 2 and a “bad” Goutallier classification as 3 or above.

All measurements were done by either a fellowship-trained spine surgeon, resident in orthopaedic surgery or medical student. Measurements performed by the medical student and orthopaedic surgery resident were checked by a fellowship-trained spine surgeon to ensure proper accuracy. Researchers were trained on the methodology of measuring paralumbar muscle (cross-sectional area, lumbar indentation value and Goutallier classification) over the course of a day. Relevant articles describing the methods for measurement were reviewed in detail with the medical students/residents as well [14,16,17].

All patients were also asked to fill out questionaire related to their symptoms to gauge baseline level of disability stemming from their lumbar spine pathology. These questionnaires were the visual analog pain scale back (VAS-back), visual analog pain scale leg (VAS-leg), patient-reported outcomes measurement physical health (PROMIS) scores, Oswestry disability index (ODI), short-form 12 mental health score (SF-12 MHS), and short-form 12 physical health score (SF-12 PHS). We also catalogued pre-operative narcotic use at the initial office visit. These data were then converted into morphine equivalent units [18]. The presence or absence of moderate to severe central canal stenosis was also noted for each patient and compared between the cohorts. The presence or absence of severe foraminal stenosis was also noted for each patient and compared between the cohorts.

Statistical analysis

In order to compare cohorts within our study we used SPSS statistics software (IBM Corp., Armonk, NY). We used an independent student’s *t*-test to compare cohorts. We used a

Chi-square analysis in order to compare cohorts when examining Goutallier classification scores given the fact that the Goutallier classification is a non-continuous variable. When performing multiple comparisons between groups, we did use a Bonferroni correction factor to ensure the accuracy of our results. Statistical significance was defined as $p < 0.05$.

Results

There were 307 patients included in our study. The basic demographic information for this group of patients is shown in Table 1. In Table 2, there is a breakdown of frequency of level involved in spondylolisthesis for the spondylolisthesis cohort.

There were no statistically significant differences in terms of HRQOLs between patients with or without spondylolisthesis. The pre-operative results of VAS-leg, VAS-back, SF-12 MHS, SF-12 PHS, ODI and PROMIS between the cohorts are shown in Table 3. There were no statistically significant differences in terms of narcotic use based on average morphine equivalent daily doses between cohorts. There was a statistically significant higher rate of both central canal stenosis (75.0% vs. 50.0%, $p < 0.001$) and foraminal stenosis (73.2% vs. 44.5%, $p < 0.001$).

Muscle health measurements between our two cohorts of patients are shown in Table 4. Clearly, there are numerous measurements that show statistically significant differences in muscle health between the two cohorts at various levels. The average BMI for each cohort was not significantly different ($p = 0.14$). The muscle health measurements were worse for those with spondylolisthesis in terms of PL-CSA/BMI and Goutallier classification. The LIV measurements, however, were larger for the cohort with spondylolisthesis.

Comparison of muscle health measurements within spondylolisthesis cohort

We compared muscle health measurements based on the degree of slip for patients with spondylolisthesis. We separated patients based on whether they had grade 1 slip versus grade 2 or 3 anterolisthesis based on the Meyerding classification. None of our patients had an anterolisthesis above grade 3. The results of this analysis are shown in Table 5. As is clear, there are worse PL-CSA/BMI and Goutallier classification figures for patients with higher grade slips. Those patients with an anterolisthesis at L4–L5 were compared to patients with an anterolisthesis at L5–S1 to determine if muscle health measurements differed on the level that the spondylolisthesis occurred at as well. There were no statistically significant differences in terms of PL-CSA/BMI, LIV or Goutallier classification between patients with an anterolisthesis at L4–L5 versus those with an anterolisthesis at L5–S1 (all $p > 0.05$).

Discussion

Our study demonstrates the significant changes in paralumbar muscle health associated with lumbar spondylolisthesis. There is obvious decreased muscle health with worse PL-CSA/BMI measurements and Goutallier classification scores associated with lumbar spondylolisthesis throughout the lumbar spine. The morphology of muscle associated with

spondylolisthesis likely changes as well, given the unexpected increase in LIV associated with anterolisthesis. Greater slip was also associated with worse muscle measurements in terms of PL-CSA/BMI and Goutallier classification which further demonstrates the likely pathophysiologic changes of musculature associated with spondylolisthesis.

The conclusions regarding muscle health measurements should be viewed in the context of similar health related quality of life scores among both those with and those without spondylolisthesis. Clearly both those with and without spondylolisthesis are dealing with significant pain/disability. As previous studies have shown, however, the pathophysiology causing these drops in HRQOLs is likely a multifactorial problem [19]. Spondylolisthesis and associated bony/anatomical changes directly related to the change in vertebral alignment and muscle health changes are likely two of many other issues associated with disability for this subsegment of the population.

Our findings have several important implications in terms of treatment of patients with lumbar spondylolisthesis. Recent literature has shown how that global spinal alignment correlates with fatty infiltration of paravertebral musculature [20]. The authors discuss the “spiraling cascade” which describes excessive muscle stress or injury related to spinal deformity could contribute to muscle remodelling [21]. A similar mechanism of action may occur for patients with spondylolisthesis. Treatments geared toward strengthening/stretching lumbar paravertebral muscles may impact clinical outcomes for patients with spondylolisthesis by preventing abnormal muscle remodelling. This is an important avenue for future research.

The biomechanics of lumbar spine instability likely play a role in both pain/disability associated with lumbar spondylolisthesis as well as the muscle health changes found within this article. In a study by Crawford et al. an in vitro model of grade one degenerative spondylolisthesis was created by sequentially dissecting out bony/disc and soft tissue structures from a vertebral segment [22]. They found that resection of both disc and ligamentous structures to the vertebral bodies was necessary for slippage between vertebrae. Our study might corroborate this biomechanical study as this process may occur with spondylolisthesis. Another in vitro study also demonstrated that destabilization of facet complex likely also plays a role in the development of spondylolisthesis [23]. Further research is required to understand the precise pathophysiologic steps in terms of disc degeneration, facet complex arthropathy and paralumbar muscle atrophy/shrinking which contribute to lumbar spondylolisthesis. We also found that patients with spondylolisthesis had higher rates of both central and foraminal stenosis. How this impacts muscle health (i.e. the degree of stenosis) likely warrants further research as well.

The altered biomechanics of the lumbar spine with spondylolisthesis might relate to worse paralumbar muscle health by exacerbating the reflex inhibition and changes in coordination in trunk muscles typically associated with low back pain [24]. Different recruitment patterns of motor neurons associated with low back pain likely may be altered further by the increased translation at a level with an unstable lumbar spondylolisthesis [25]. Studies examining the pathophysiology of this process have begun to show how degenerative spine

conditions are associated with muscle degeneration, inflammation, and decreased vascularity [26].

Previous studies of the lumbar spine have found that altered alignment is associated with altered paralumbar muscle morphology and our findings are consistent with this conclusion. Hyun et al. [27] have shown that degenerative lumbar kyphosis was associated with increased fatty changes in both the erector spinae and multifidus muscles. Similarly, Wagner et al. have shown that degenerative spondylolisthesis is associated with decreased psoas cross-sectional area [28]. Our results mirror these findings in that paralumbar muscle health worsens with the altered alignment associated with spondylolisthesis. Furthermore, in situations where the alignment is worse (i.e. higher grade slips) we have shown that that fatty atrophy worsens (i.e. worse Goutallier classification scores).

The finding that LIV increases with spondylolisthesis was surprising given the fact that LIV directly correlates with better muscle health. LIV can be used as a quick reference to estimate paralumbar muscle cross-sectional area [14]. Our results, however, likely are related to the changing muscle morphology associated with disruption of normal lumbar alignment for patients with spondylolisthesis. This likely alters the relationship of the two paralumbar muscle humps to the spinous process of the caudal vertebra and increasing the LIV without necessarily corresponding to an increase in muscle cross-sectional area. The authors would recommend keeping this fact in mind when evaluating the utility of the LIV measurement for patients with spondylolisthesis.

There are several important limitations in relation to our study. It is retrospective nature and includes only patients with surgical lumbar spine pathology. Further research on the muscle health measurements of asymptomatic controls would be necessary for a better understanding of how the muscle health changes we measure correspond to lumbar spine symptoms. Patients with solely back pain without imaging/clinical findings warranting surgery may have their own unique set of muscle health measurements. This was not examined within our study and is an additional area of research. We have also not controlled or examined in detail the segmental instability associated with lumbar spondylolisthesis. Similarly, we did not break down whether the precise level of spondylolisthesis impacts the amount of muscle health changes that occur or whether/how lateral listhesis changes muscle morphology/size. These are both areas warranting further study. There may be a subset of patients with significant motion on flexion/extension radiographs that may have worse muscle health changes. This analysis of dynamic instability and muscle health is an area of future research that could demonstrate significant findings in terms of the pathophysiology of lumbar spondylolisthesis. Furthermore, there may be a component of back pain associated with dynamic instability that may be present for patients with no spondylolisthesis on neutral radiographs [29]. The precise nature of low back pain and/or radiating leg pain may significantly impact muscle health, and this is likely a topic for future research. We also did not control for the duration of symptoms, nor did we control for the activity level/occupation of patients between the two cohorts. This may significantly impact the severity of muscle health changes associated with lumbar spinal stenosis and may be a confounding factor in our analysis. To date, we have not established inter- and intra-rater reliability for our set of measurements and this is an important limitation for our study.

While we did not examine specifically differences in sagittal alignment between the cohorts, there are data that show spondylolisthesis is associated with changes in sagittal profile and degenerative scoliosis [30]. There are likely significant correlations/associations between scoliosis, spondylolisthesis and muscle health that require further research and are beyond the scope of this manuscript.

Our analysis demonstrates the significant association between spondylolisthesis and paralumbar muscle health for those patients dealing with symptomatic lumbar spinal stenosis. This association is reflected in lower PL-CSA/BMI and Goutallier classification scores for patients dealing with both lumbar spinal stenosis and lumbar spondylolisthesis. Furthermore, these changes are exacerbated by higher grade slips. More research is required to understand the precise timing/pathophysiology of these changes in paralumbar muscles as spondylolisthesis develops for each individual patient.

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References

1. Belavy DL, Armbrecht G, Richardson CA, Felsenberg D, Hides JA (2011) Muscle atrophy and changes in spinal morphology: is the lumbar spine vulnerable after prolonged bed-rest? Spine 36(2):137–145 [PubMed: 20595922]
2. Cooper RG, St Clair Forbes W, Jayson MI (1992) Radiographic demonstration of paraspinal muscle wasting in patients with chronic low back pain. Br J Rheumatol 31(6):389–394 [PubMed: 1534505]
3. Thakar S, Sivaraju L, Aryan S, Mohan D, Sai Kiran NA, Hegde AS (2016) Lumbar paraspinal muscle morphometry and its correlations with demographic and radiological factors in adult isthmic spondylolisthesis: a retrospective review of 120 surgically managed cases. J Neurosurg Spine 24(5):679–685 [PubMed: 26771373]
4. Virk S, Wright-Chisem J, Sandhu M, Vaishnav A, Albert TJ, Gang CH, Qureshi S (2021) A novel magnetic resonance imaging-based lumbar muscle grade to predict health-related quality of life scores among patients requiring surgery. Spine (Phila Pa 1976) 46(4):259–267. 10.1097/BRS.0000000000003833 [PubMed: 33273441]
5. Lee SH, Park SW, Kim YB, Nam TK, Lee YS (2017) The fatty degeneration of lumbar paraspinal muscles on computed tomography scan according to age and disc level. The Spine Journal 17(1):81–87 [PubMed: 27497888]
6. Joszko K, Gzik M, Wolański W, Gzik-Zroska B, Kawlewska E (2018) Biomechanical evaluation of human lumbar spine in spondylolisthesis. J Appl Biomed 16(1):51–58
7. Teichtahl AJ, Urquhart DM, Wang Y et al. (2015) Physical inactivity is associated with narrower lumbar intervertebral discs, high fat content of paraspinal muscles and low back pain and disability. Arthritis Res Ther 17(1):114 [PubMed: 25947906]
8. Dombrowski ME, Rynearson B, LeVasseur C et al. (2018) ISSLS PRIZE IN BIOENGINEERING SCIENCE 2018: dynamic imaging of degenerative spondylolisthesis reveals mid-range dynamic lumbar instability not evident on static clinical radiographs. Eur Spine J 27(4):752–762 [PubMed: 29470715]
9. Wang G, Karki SB, Xu S et al. (2015) Quantitative MRI and X-ray analysis of disc degeneration and paraspinal muscle changes in degenerative spondylolisthesis. J Back Musculoskelet Rehabil 28(2):277–285 [PubMed: 25096310]

10. Park J-H, Kim K-W, Youn Y et al. (2019) Association of MRI-defined lumbar paraspinal muscle mass and slip percentage in degenerative and isthmic spondylolisthesis: a multicenter, retrospective, observational study. Medicine (Baltimore) 98(49):e18157 [PubMed: 31804327]
11. Meyerding HW (1932) Spondylolisthesis. Surg Gynecol Obstet 54:371–377
12. Hamanishi C, Matukura N, Fujita M, Tomihara M, Tanaka S (1994) Cross-sectional area of the stenotic lumbar dural tube measured from the transverse views of magnetic resonance imaging. J Spinal Disord 7(5):388–393 [PubMed: 7819638]
13. Copay AG, Glassman SD, Subach BR, Berven S, Schuler TC, Carreon LY (2008) Minimum clinically important difference in lumbar spine surgery patients: a choice of methods using the oswestry disability index, medical outcomes study questionnaire short form 36, and pain scales. Spine J 8(6):968–974 [PubMed: 18201937]
14. Takayama K, Kita T, Nakamura H et al. (2016) New predictive index for lumbar paraspinal muscle degeneration associated with aging. Spine 41(2):E84–90 [PubMed: 26335668]
15. Tamai K, Chen J, Stone M et al. (2018) The evaluation of lumbar paraspinal muscle quantity and quality using the Goutallier classification and lumbar indentation value. Eur Spine J 27(5):1005–1012 [PubMed: 29396765]
16. Bang WS, Lee DH, Kim KT et al. (2018) Relationships between vitamin D and paraspinal muscle: human data and experimental rat model analysis. Spine J 18(6):1053–1061 [PubMed: 29355791]
17. Battaglia PJ, Maeda Y, Welk A, Hough B, Kettner N (2014) Reliability of the Goutallier classification in quantifying muscle fatty degeneration in the lumbar multifidus using magnetic resonance imaging. J Manipulative Physiol Ther 37(3):190–197 [PubMed: 24630770]
18. Svendsen K, Borchgrevink P, Fredheim O, Hamunen K, Mellbye A, Dale O (2011) Choosing the unit of measurement counts: the use of oral morphine equivalents in studies of opioid consumption is a useful addition to defined daily doses. Palliat Med 25(7):725–732 [PubMed: 21378066]
19. Battie MC, Jones CA, Schopflocher DP, Hu RW (2012) Health-related quality of life and comorbidities associated with lumbar spinal stenosis. The Spine Journal 12(3):189–195 [PubMed: 22193054]
20. Elysee JC, Lovecchio F, Lafage R et al. (2021) The relationship of global sagittal malalignment to fatty infiltration in the aging spine. Eur Spine J 10.1007/s00586-021-06759-7
21. Hyun S-J, Kim YJ, Rhim S-C (2016) Patients with proximal junctional kyphosis after stopping at thoracolumbar junction have lower muscularity, fatty degeneration at the thoracolumbar area. Spine J 16(9):1095–1101 [PubMed: 27217332]
22. Crawford NR, Çagli S, Sonntag VKH, Dickman CA (2001) Biomechanics of Grade I degenerative lumbar spondylolisthesis. Part 1: In vitro model. J Neurosurg 94(Suppl 1):45–50 [PubMed: 11147867]
23. Melnyk AD, Kingwell SP, Zhu Q et al. (2013) An In Vitro Model of Degenerative Lumbar Spondylolisthesis. Spine (Phila Pa 1976) 38(14):E870–E7 [PubMed: 23558441]
24. Danneels LA, Vanderstraeten GG, Cambier DC, Witvrouw EE, De Cuyper HJ (2000) CT imaging of trunk muscles in chronic low back pain patients and healthy control subjects. Eur Spine J 9(4):266–272 [PubMed: 11261613]
25. Panjabi MM (1992) The stabilizing system of the spine. Part I. Function, dysfunction, adaptation, and enhancement. Journal of Spinal Disorders. 5(4):383–9 [PubMed: 1490034]
26. Shahidi B, Hubbard JC, Gibbons MC et al. (2017) Lumbar multifidus muscle degenerates in individuals with chronic degenerative lumbar spine pathology. J Orthop Res 35(12):2700–2706 [PubMed: 28480978]
27. Hyun SJ, Bae CW, Lee SH, Rhim SC (2016) Fatty degeneration of the paraspinal muscle in patients with degenerative lumbar kyphosis: a new evaluation method of quantitative digital analysis using MRI and CT scan. Clin Spine Surg 29(10):441–447 [PubMed: 27879506]
28. Wagner SC, Sebastian AS, McKenzie JC et al. (2018) Severe lumbar disability is associated with decreased psoas cross-sectional area in degenerative spondylolisthesis. Global Spine J 8(7):716–721 [PubMed: 30443482]
29. Basques BA, Espinoza Orias AA, Shifflett GD et al. (2017) The kinematics and spondylosis of the lumbar spine vary depending on the levels of motion segments in individuals with low back pain. Spine 42(13):E767–E774 [PubMed: 27831966]

30. Labelle H, Roussouly P, Berthonnaud É et al. (2004) Spondylolisthesis, pelvic incidence, and spinopelvic balance: a correlation study. Spine (Phila Pa 1976) 29(18):2049–54 [PubMed: 15371707]

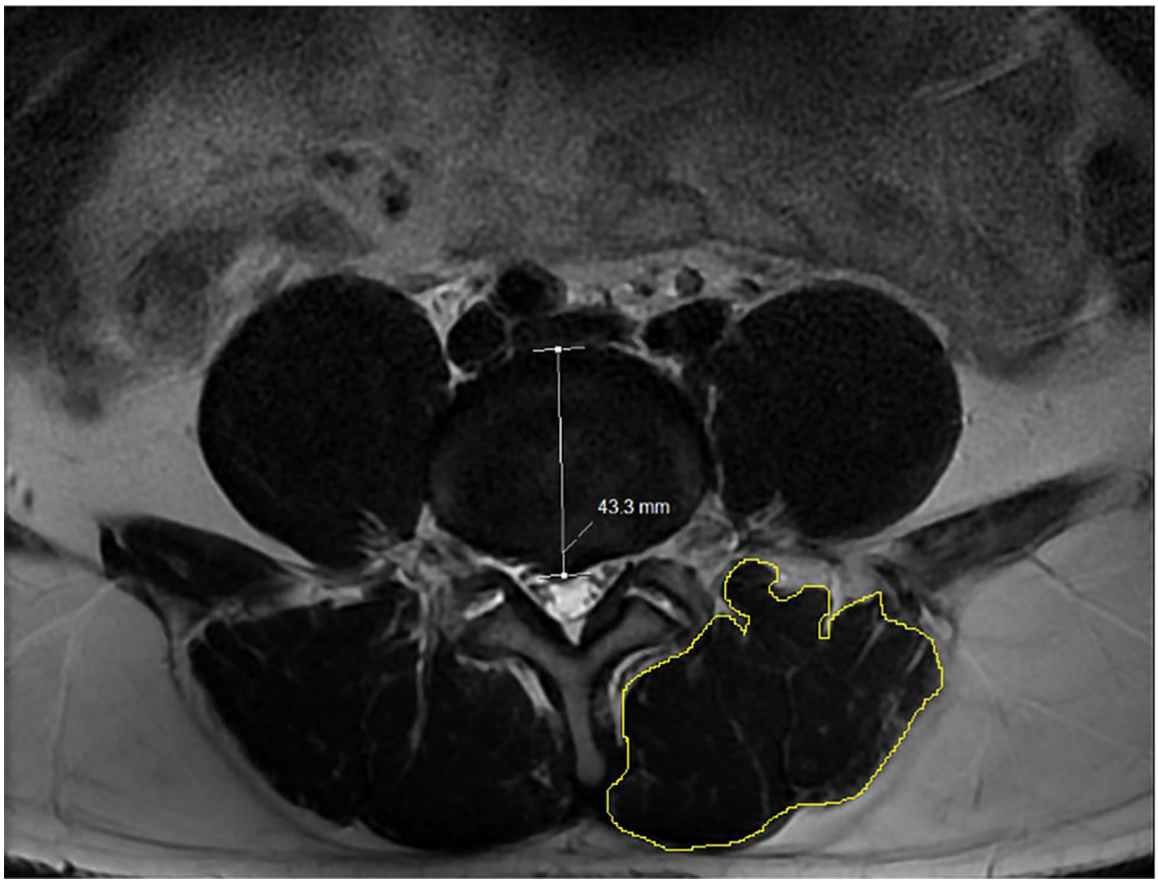

Fig. 1.

The yellow outline shown with this axial cross-sectional T2 weighted image shows the manner in which paralumbar cross-sectional area was measured for each patient. These axial cross-sectional slices were in line with the disc space of interest

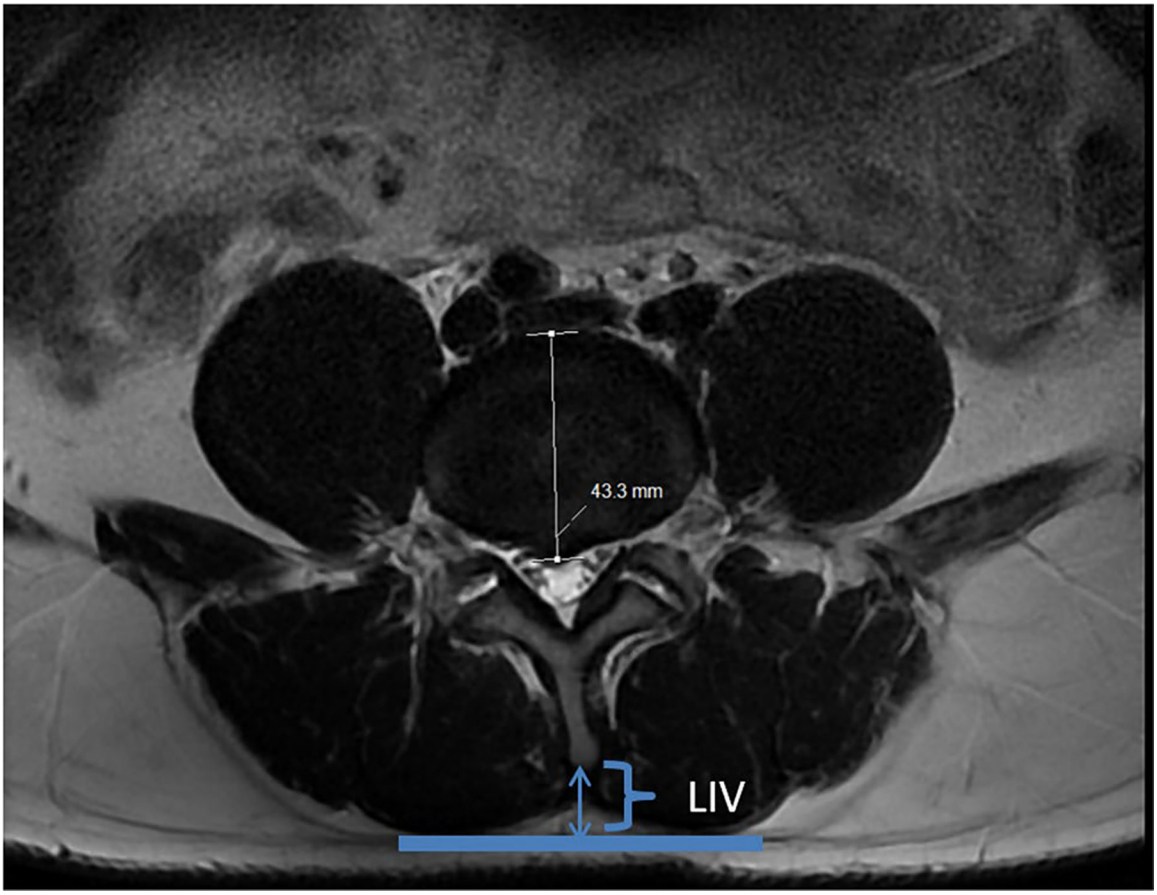

Fig. 2.

The lumbar indentation value (LIV) is shown in blue within this figure. It quantifies the distance between a perpendicular line between lumbar muscle humps and a spinous process

Table 1

Basic demographic data for patients included within our study. Averages are listed with associated standard deviations

Demographic data	
Number of patients	307
Spondylolisthesis cohort (number of patients)	112
Non-spondylolisthesis cohort (number of patients)	195
Gender	
Male (number of patients)	166
Female (number of patients)	141
Age (years)	56.1 ± 16.7
Body mass index (kg/m^2)	26.9 ± 5.8

VAS–back, visual analog pain scale back; VAS–leg, visual analog pain scale leg; ODI, Oswestry disability index; SF-12 MHS, short-form 12 mental health score; SF-12 PHS, short-form 12 physical health score; PROMIS, patient-reported outcomes measurement physical health scores

Table 2

Breakdown of levels where spondylolisthesis present among our cohort of patients

Level of spondylolisthesis	Number of patients (percentage of total patients in the spondylolisthesis cohort)
L2–L3	2 (1.8%)
L3–L4	10 (8.9%)
L4–L5	60 (53.5%)
L5–S1	21 (18.8%)
Multilevel spondylolisthesis	19 (16.9%)

Table 3

The pre-operative health-related quality of life scores were not different between the two cohorts of patients. This was across both pain scores and disability scores. A comparison of pre-operative narcotic use between patient cohorts was done with morphine equivalents per day being compared.

	Non-spondylolisthesis cohort	Spondylolisthesis cohort	*p* value
Health related quality of life score			
VAS – Back	5.2 ± 4.2	4.9 ± 4.1	0.49
VAS – Leg	8.2 ± 2.6	8.0 ± 2.7	0.53
ODI	52.1 ± 29.5	45.5 ± 28.9	0.09
SF-12 MHS	48.0 ± 12.9	49.8 ± 14.5	0.31
SF-12 PHS	30.5 ± 7.0	29.9 ± 7.9	0.60
PROMIS	20.4 ± 15.9	16.7 ± 16.2	0.08
Narcotic use (morphine equivalents per day)	5.33 ± 15.2	3.4 ± 13.3	0.24

Table 4

The muscle health measurements at each vertebral level for our two cohorts are shown below. Of note PL-CSA/BMI refers to paralumbar cross-sectional area (mm^2) divided by BMI (kg/M^2). LIV refers to lumbar indentation value. Each continuous measurement is listed as an average with ± standard deviation. Goutallier classification is listed as percentage with a score of 2 or lower. Numbers listed in bold met our threshold for statistical significance ($p < 0.05$)

Muscle health measurement	Level	Non-spondylolisthesis cohort	Spondylolisthesis cohort	*p* value
BMI		28.0 ± 4.9	29.2 ± 5.0	0.14
PL–CSA/BMI	L1–L2	141.2 ± 52.8	134.5 ± 47.3	0.27
	L2–L3	158.3 ± 40.2	147.4 ± 40.6	**0.03**
	L3–L4	157.5 ± 41.8	147.1 ± 39.4	**0.04**
	L4–L5	143.0 ± 36.6	132.1 ± 39.7	**0.02**
LIV (mm)	L1–L2	9.8 ± 6.5	11.4 ± 5.8	**0.03**
	L2–L3	11.0 ± 5.7	12.6 ± 5.5	**0.02**
	L3–L4	12.4 ± 6.3	14.4 ± 5.8	**0.01**
	L4–L5	14.1 ± 6.0	15.9 ± 6.1	**0.02**
Goutallier classification (percentage of patients with score of 2 or lower)	L1–L2	96.4%	91.1%	**0.04**
	L2–L3	88.7%	83.9%	0.23
	L3–L4	75.4%	66.9%	0.11
	L4–L5	71.8%	51.8%	< **0.001**

Table 5

A comparison of muscle health measurements between patients with grade 1 slip versus grade 2 or 3 slip within the spondylolisthesis cohort. Each continuous measurement is listed as an average with ± standard deviation. Goutallier classification is listed as percentage with a score of 2 or lower. Numbers listed in bold met our threshold for statistical significance ($p < 0.05$)

Muscle health measurement	Level	Grade 1 anterolisthesis	Grade 2 or 3 anterolisthesis	*p* value
PL–CSA/BMI	L1–L2	140.0 ± 48.6	108.9 ± 42.0	**0.02**
	L2–L3	153.3 ± 40.7	127.8 ± 34.2	**0.03**
	L3–L4	152.0 ± 39.9	128.9 ± 33.2	**0.05**
	L4–L5	136.4 ± 40.8	118.0 ± 29.2	0.14
LIV (mm)	L1–L2	11.2 ± 5.9	12.4 ± 5.6	0.81
	L2–L3	12.3 ± 5.6	13.9 ± 5.4	0.54
	L3–L4	14.1 ± 6.0	15.7 ± 5.2	0.44
	L4–L5	15.7 ± 6.3	16.2 ± 5.7	0.80
Goutallier classification (percentage of patients with score of 2 or lower)	L1–L2	94.5%	73.6%	**< 0.001**
	L2–L3	81.1%	73.7%	**0.003**
	L3–L4	94.5%	68.4%	**0.004**
	L4–L5	88.4%	57.9%	**0.011**