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Paraspinal muscles atrophy on both sides and at multiple levels after unilateral lumbar partial discectomy

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Abstract

To identify the changes in cross-sectional areas (CSAs) and fatty infiltration of both sides of the paravertebral muscles and their associations with prognostic factors in patients who underwent unilateral lumbar discectomy. We retrospectively reviewed 27 patients who underwent magnetic resonance imaging before and after 1- or 2-level lumbar discectomy. The CSAs and functional cross-sectional areas of the paraspinal muscles were bilaterally measured from L1 to L2 to L5 to S1 based on T2-weighted axial images. These parameters were compared pre-and postoperatively. CSAs and functional cross-sectional areas decreased also in non-operative, non-surgical levels, not only in operated levels after discectomy. In the correlation analysis, the CSA of psoas major muscle at L1 to L2 was significantly decreased in patients with lower preoperative lordosis ($r = 0.598$, $P = .040$). The postoperative CSA of psoas major muscle at L4 to L5 was lower in those with the higher Pfirrmann grade ($r = -0.590$, $P = .002$); however, the CSA of quadratus lumborum muscle at L1 to L2 showed the opposite result ($r = 0.526$, $P = .036$). Similar results were also observed in the partial correlation adjusted for age and postoperative duration. Patients who underwent discectomy experienced overall paraspinal muscle atrophy in the lumbar region, including surgical and non-surgical sites. Such atrophic changes emphasized the need for core strengthening and lumbar rehabilitation from the early period after partial discectomy.

Abbreviations: CPSS = chronic pain after spinal surgery, CSA = cross-sectional area, ES = erector spinae, FCSA = functional cross-sectional area, ICC = interclass correlation coefficient, MF = multifidus, MRI = magnetic resonance imaging, PM = psoas major, PMA = paraspinal muscle atrophy, QL = quadratus lumborum, ROI = region of interest.

Keywords: diskectomy, laminectomy, muscular atrophy, paraspinal muscles, rehabilitation

1. Introduction

Paraspinal muscle atrophy (PMA) is commonly related to thoracolumbar pathologies after spinal surgeries.[1] PMA and fat infiltration contribute to sustained postoperatively low back pain in some patients (3%–36%).[2,3] Such muscle changes have been a common concern in terms of chronic pain after spinal surgery (CPSS), which was previously known as failed back surgery syndrome.[4,5]

PMA is thought to be associated with surgical retraction or dissection.[6] The 2 most common lumbar spine surgeries are decompression (laminectomy with/without discectomy) and spinal fusion.[7] Lumbar fusion surgeries induce more severe PMA than non-fusion procedures.[8] Furthermore, PMA is caused by non-fusion surgeries such as single or multiple laminectomies.[9] The paraspinal muscles even decrease after tubular discectomy or microdiscectomy, which are minimally invasive surgeries.[10] Most previous studies have focused on the paraspinal muscles of the surgical or adjacent levels.[9–11]

However, there are few studies analyzing the impact of partial lumbar discectomy on the paraspinal muscles at all lumbar spine levels and on both sides. Many studies have elucidated the relationships between PMA and different surgical approaches at the surgical and adjacent levels for fusion surgeries.[12–16] More extended PMA is related to less favorable surgical outcomes, emphasizing the importance of postoperative rehabilitation strategies.[17]

This study aimed to identify the changes in cross-sectional areas (CSAs) and fatty infiltration of individual paravertebral muscles at all lumbar levels after unilateral single- or 2-level lumbar partial discectomy. The relationship between these muscle changes and prognostic factors (preoperative Pfirrman grade and lumbar lordosis) was also analyzed.[1,18]

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The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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2. Materials and methods

2.1. Subjects

The patients who underwent lumbar spine surgeries with pre- and post-operative spine magnetic resonance imaging (MRI) scans between January 2011 and December 2020 were reviewed. Among them, only the patients with postoperative lumbar spine MRIs performed within 12 months after surgeries and who received 1- or 2-level unilateral lumbar partial discectomy with hemilaminectomy were included. Exclusion criteria were as follows: bilateral, fusion or revision surgeries; diagnosis of spinal infection, tumor, cord injury or myelitis; and post-operative MRI performed more than 12 months after surgery. Such strict inclusion criteria were supposed to control other confounding factors which could have impact on paraspinal muscle morphology. Our institutional review board approved this retrospective study protocol (approval no. 2021-06-020 by Institutional Review Board at CHA University, CHA Bundang Medical Center).

2.2. MRI acquisition

MRI scans were acquired with a 1.5- or 3.0-T MRI scanner (Signa HDxt; GE Medical Systems, Milwaukee, WI). T2-weighted turbo spin-echo axial images (repetition time/echo time, 3633.3–7500.0/84.0–125.0; field of view, 180 × 144–200 × 200 mm; matrix size, 320–512 × 185–256 mm) were obtained.

2.3. Image analysis

We acquired all T2-weighted lumbar axial images from the L1 to L2 to L5 to S1 levels at the center of each intervertebral disc. The paraspinal muscles (multifidus [MF], erector spinae [ES], quadratus lumborum [QL], and psoas major [PM]) were bilaterally measured. Total CSAs and functional cross-sectional area (FCSA), defined as fat-free muscle mass, were obtained by manually drawing the region of interest (ROI) over the boundaries of the right and left individual muscles using a pen mouse with ImageJ software (version 1.52; National Institutes of Health, Bethesda, MD; Fig. 1).[19] The measurements were performed twice by 2 physiatrists. The CSAs of each muscle were calculated by outlining the innermost fascial border surrounding the muscle, including all fat within the fascial boundary.[20] The FCSAs were estimated using a thresholding technique. The maximum signal intensity value acquired from the sample ROIs was used as the highest threshold to distinguish muscle tissue from fat. The minimum signal intensity value obtained from the ROI was standardized at 0 to reduce measurement errors and simplify the protocol. This technique was based on the difference in signal intensity between muscle (low signal) and fat (high signal) tissues, allowing for the differentiation between the 2 tissues.[19] Finally, the ratio of the FCSA to the total CSA of each paraspinal muscle was bilaterally calculated to estimate muscle composition and fatty infiltration.

2.4. Reliability

Interrater reliability was assessed through repeated measurements of all images by 2 authors. The interclass correlation coefficient (ICC) was calculated to determine the interrater reliability of the measurements. The interrater reliability ICC for the total CSA at all spinal levels was estimated to be excellent in the MF, ES, QL, and PM (0.83–0.97, 0.83–0.98, 0.95–0.99, and 0.96–0.99, respectively). In addition, the corresponding values of FCSA were calculated to be excellent in the MF, ES, QL, and PM. All ICCs were interpreted as follows: poor (<0.49), moderate (0.50–0.74), and excellent (0.75–1.00).[21]

2.5. Measurement of pre-operative Pfirrmann grading, and lumbar lordosis

Pre-operative Pfirrmann grading was assessed in sagittal T2WI MRI images. The structure, distinction of nucleus and annulus, signal intensity, and heights of the intervertebral discs from L1 to 2 to L5 to S1 were evaluated, and were divided into grades 1 to 5 according to the Pfirrmann grade classification (a higher score indicating more disc degeneration).[22] Pre-operative lumbar lordosis angle was determined based on lateral view of the lumbar X-ray images in standing position. The angle formed by the extension line connecting the upper plate of the vertebra body of L1 and the extension line connecting the lower plate of the vertebra body of L5 was measured.[23]

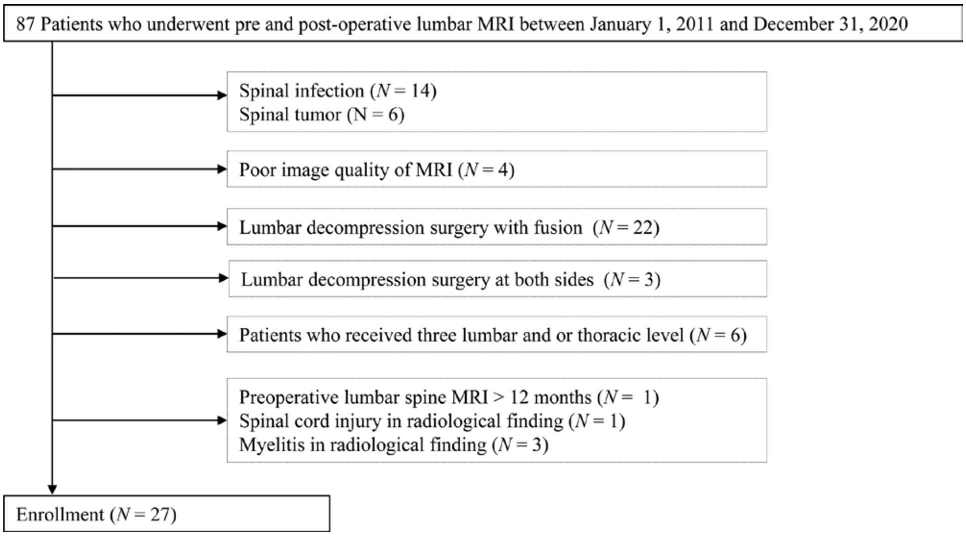

Figure 1. Measurement of the cross-sectional area (CSA) of the paraspinal muscles on magnetic resonance imaging. (Left) Measurement of the total CSAs of the paraspinal muscles at L3–L4. (Right) Functional CSAs of the muscles measured using a threshold method, represented by the area-extracting highlighted part in green. CSA = cross-sectional area, m1, m2 = multifidus, m3, m4 = erector spinae, m5, m6 = psoas major, m7, m8 = quadratus lumborum.

2.6. Statistical analysis

The Kolmogorov-Smirnov test for normal distribution was used before parametric or nonparametric statistical analysis was applied. As a result of the Kolmogorov-Smirnov test, except for the postoperative period and the non-parametric variable pfirmann scale grade, the paraspinal muscle area and clinical variables all showed a normal distribution ($P > .05$). Means and standard deviations were obtained for each variable. The Paired t test was used to compare the parameters between the operated and non-operated sides. Pearson's and Spearman`s correlation tests were used to determine the relationship between the paraspinal muscle areas (pre- and postoperative changes in the CSA and FCSA) and the clinical parameters (preoperative Pfirrmann grading and preoperative lumbar lordosis), with or without being adjusted by age and postoperative duration. For analysis of the relationship between preoperative lordosis and Pfirrmann grade and pre- and postoperative changes in the CSA of the paraspinal muscles on the operated side, relative changes in CSA were calculated to calibrate preoperative CSA. Relative changes in CSA can be interpreted as the ratios of atrophic change in individual paraspinal muscles, independent of preoperative CSA. The effect of different preoperative CSAs was taken into consideration using the following formula:

$$\text{relative changes in CSA} : \frac{(\text{postoperative CSA}) - (\text{preoperative CSA})}{\text{preoperative CSA}}.$$

Table 1

Patients' characteristics (N = 27).

Patient characteristics	Mean ± SD or (n = 27) (%)
Age	53.1 ± 13.2
Gender, Male	59.3%
BMI	24.7 ± 4.0
Post-operative duration (d)	87.7 ± 87.6
Diagnosis	
HIVD (Herniated intervertebral disc)	22 (81.5)
Spinal stenosis	5 (18.5)
Lumbosacral transitional vertebra	
Normal	24 (88.9)
Sacralization of L5	2 (7.4)
Lumbarization of S1	1 (3.7)
Partial hemi-laminectomy, segment	
L2/3	1 (3.7)
L4/5	13 (48.2)
L5/S1	10 (37.0)
L3/4 + L4/5	3 (11.1)
Partial hemi-laminectomy, direction	
Right	14 (51.9)
Left	13 (48.1)
Pre-operative Pfirrmann grade	
3	5 (18.5)
4	21 (77.8)
5	1 (3.7)
Pre-operative lumbar lordosis	44.4 ± 11.4

Data are mean ± standard deviation (SD), number, or percentage.
HIVD = herniated intervertebral disc, L = lumbar, S = sacrum.

SPSS version 21.0 for Windows (SPSS Inc., Chicago, IL) was used for data analysis. Results with a P value < .05 were considered statistically significant.

3. Results

The clinical and demographic characteristics of the patients are summarized in Table 1 and Table S1, Supplemental Digital Content, http://links.lww.com/MD/I338.

Of the 87 patients who underwent lumbar MRI between pre- and postoperative lumbar surgery, 27 were included in this study (60 were excluded; Fig. 2). Among them, 22 were diagnosed with herniated intervertebral discs, and 5 had spinal stenosis. Twenty-four patients underwent a single-level, and 3 underwent 2-level unilateral lumbar partial discectomy. On the operated side, the MF showed decreased CSAs and FCSAs at all 5 levels, from L1 to S1. The ES, QL, and PM muscles showed similar changes at most levels. These results were consistent in the paraspinal muscles of the non-operated side (Figs. 3a, b and 4a and b, and Supplementary Table S2, Supplemental Digital Content, http://links.lww.com/MD/I339 and Table S3, Supplemental Digital Content, http://links.lww.com/MD/I340). On the operated side, the ratios of FCSA-to-CSA were significantly decreased at most levels in the MF (L2–S1). On

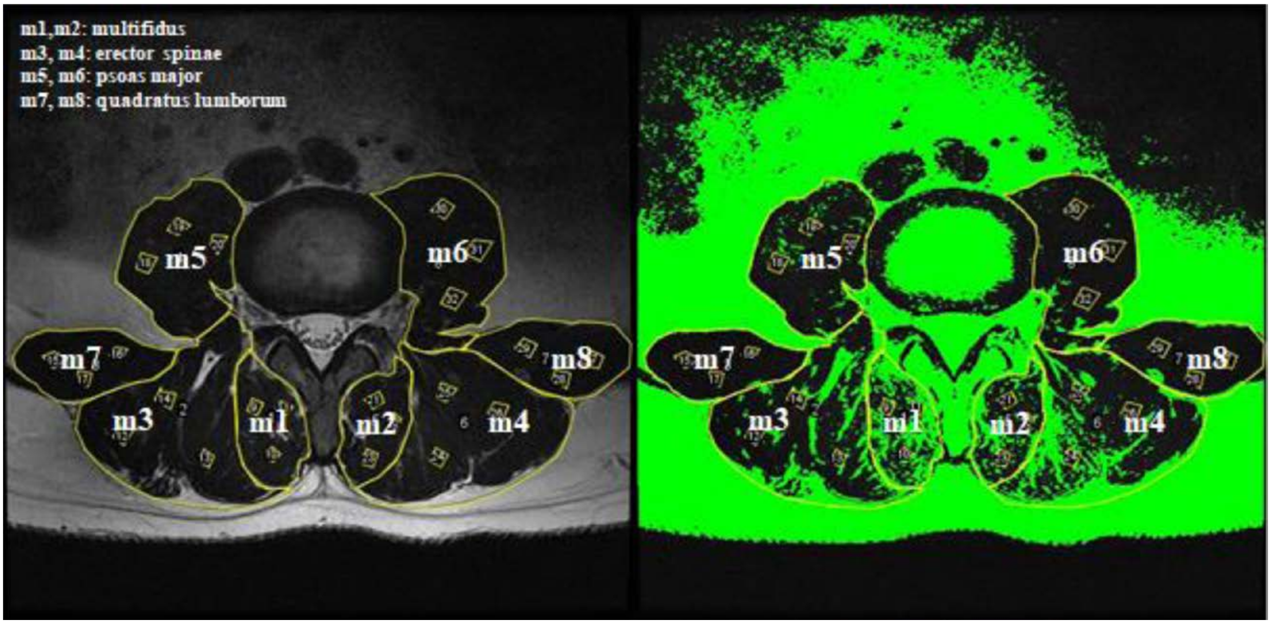

Figure 2. Flowchart of patient inclusion.

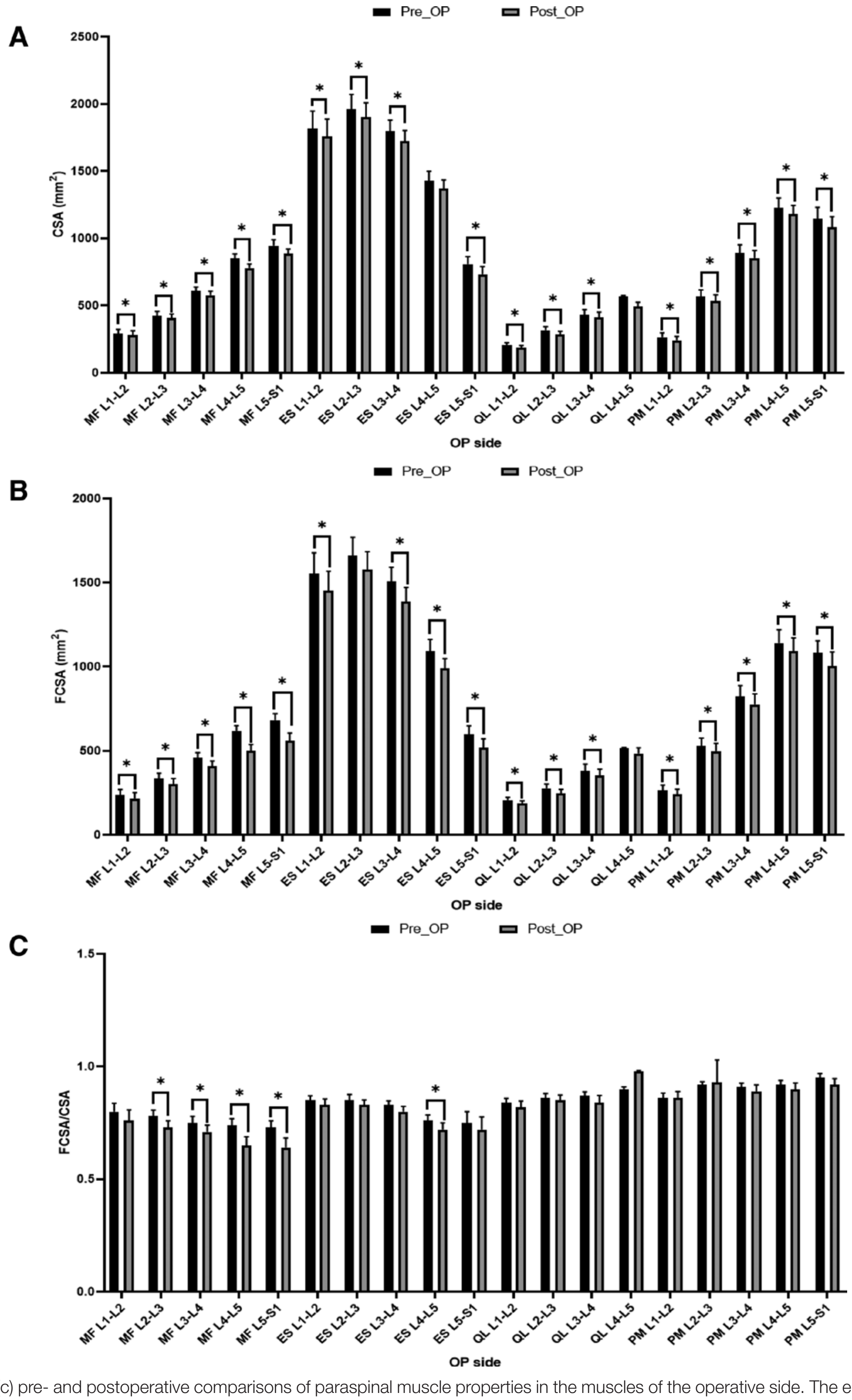

Figure 3. (a), (b), and (c) pre- and postoperative comparisons of paraspinal muscle properties in the muscles of the operative side. The error bars represent ± 1 standard deviation of the group measurements. *$P < .05$, by paired t-test. ES = erector spinae, MF = multifidus, PM = psoas major, QL = quadratus lumborum.

the non-operated side, the FCSA-to-total CSA ratio of the MF muscles was reduced only at the L3 to L4 level (Figs. 3c and 4c).

A correlation analysis was performed with clinical prognostic factors (age, postoperative duration, Pfirrmann scale grade, and preoperative lumbar lordosis; Fig. 5 and Table S4, Supplemental Digital Content http://links.lww.com/MD/I341). On the operative side, the negative delta values of the PM at L1 to L2 (relative changes, i.e., PMA) showed a significant association with preoperative lumbar lordosis ($r = 0.598$, $P = .040$) (Fig. 5A). The relative changes in CSA of PM at L4 to L5 were significantly decreased in patients with higher Pfirrmann scale grade ($r = –0.590$, $P = .002$) (Fig. 5B); however, CSA of QL at L1 to L2 was increased with higher Pfirrmann scale grade ($r = 0.526$, $P = .036$) (Fig. 5C).

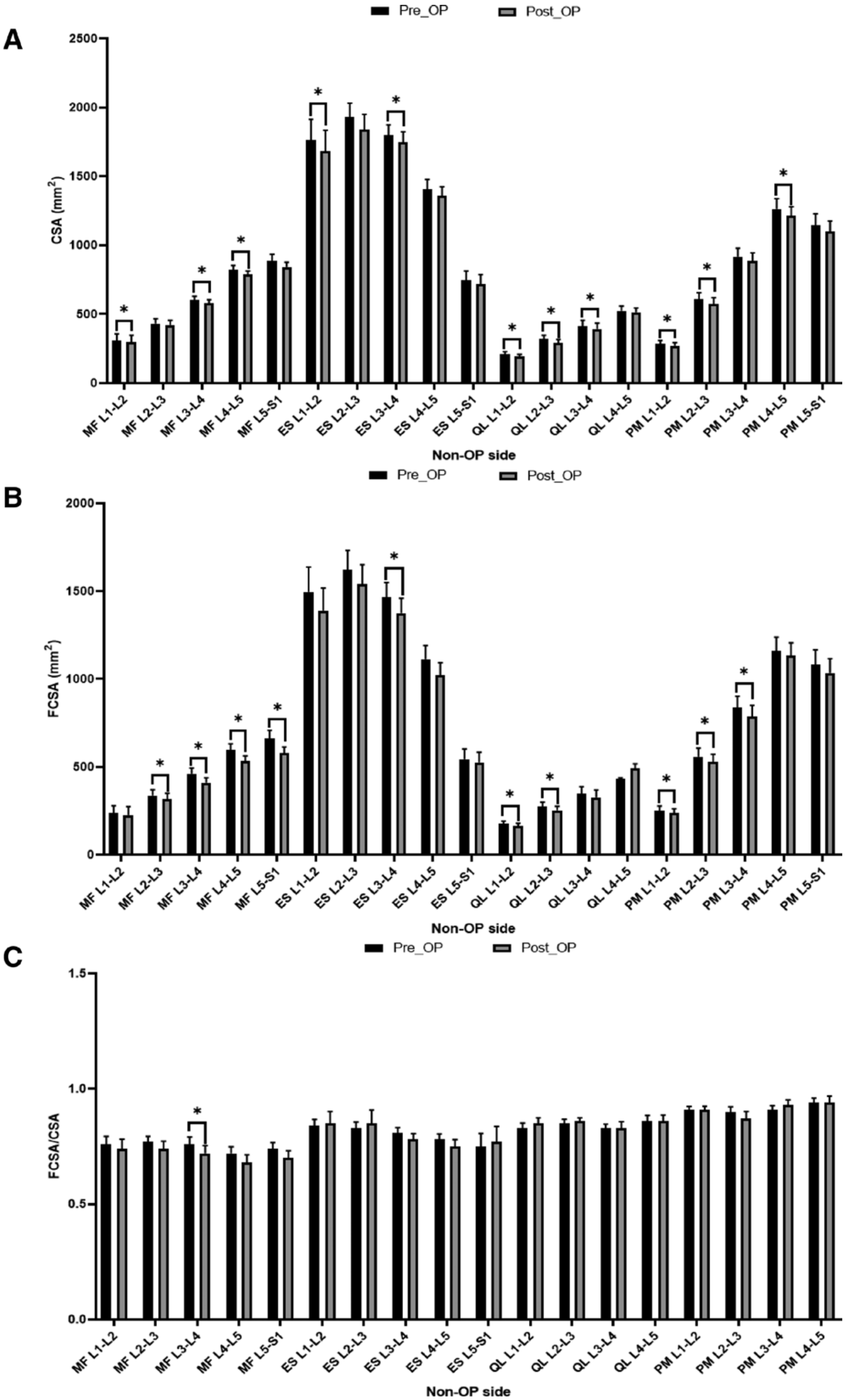

Figure 4. (a), (b), and (c) pre- and postoperative comparisons of paraspinal muscle properties in the muscles of the non-operative side. The error bars represent ± 1 standard deviation of the group measurements. *$P < .05$, by paired t-test. ES = erector spinae, MF = multifidus, PM = psoas major, QL = quadratus lumborum.

Further, we conducted a partial correlation analysis with preoperative lordosis (Table 2 and Table S5, Supplemental Digital Content http://links.lww.com/MD/I342) adjusted by age and postoperative duration. On the operative side, the relative changes in CSA of PM at L1 to L2 were significantly increased in patients with higher preoperative lumbar lordosis ($r = 0.709$, $P = .022$).

4. Discussion

4.1. Partial discectomy caused PMA bilaterally at all lumbar spine levels

We showed that PMA is not limited to the surgical level or operative side after unilateral partial laminectomy. In this study, even

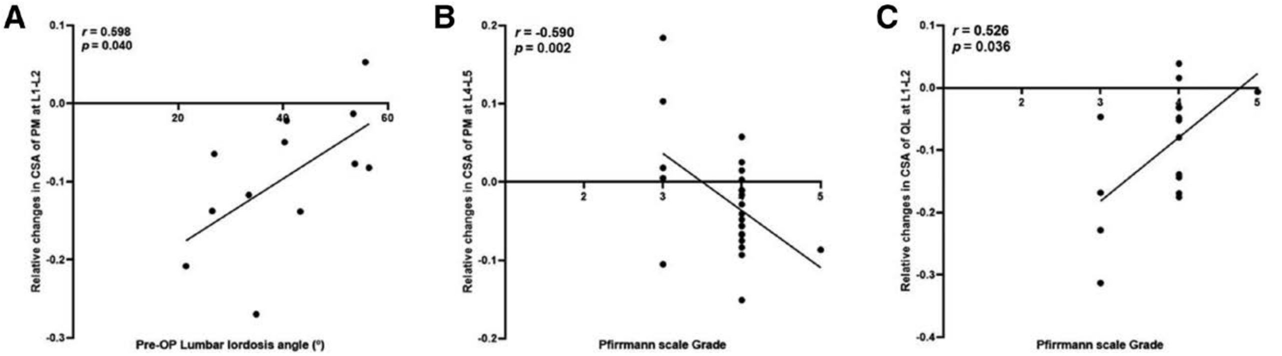

Figure 5. The correlation between preoperative lordosis and Pfirrmann grade and relative changes in the CSA of the paraspinal muscles on the operated side. Relative changes in CSA were calculated by subtracting the pre-operative value from the post-operative value and dividing by the preoperative value. The pre-operative lumbar lordosis angle was measured as the angle formed by the extension line of the upper plate of the L1 vertebra body and the extension line of the lower plate of the L5 vertebra body. The preoperative lordosis and relative changes in the CSA of the PM at L1–L2 (A). The Pfirrmann scale grade and relative changes in CSA of the PM at L4–L5 (B) and the QL at L1–L2 (C). *$P < .05$, by the Pearson's or Spearman`s correlation test. *r*, Pearson or Spearman correlation. CSA = cross-sectional area, ES = erector spinae, MF = multifidus, PM = psoas major, QL = quadratus lumborum.

Table 2

Pearson or spearman correlation and partial correlation among the relative changes in CSA of the paraspinal muscle properties between the pre and post operation and variables (age, post-op duration, lumbar lordosis and Pfirrmann grade) in OP side muscles.

	Relative changes in CSA of PM at L1–L2		Relative changes in CSA of PM at L4–L5		Relative changes in CSA of QL at L1–L2	
Variables	Correlation1	Partial correlation2	Correlation1	Partial correlation2	Correlation1	Partial correlation2
Age	$r = -0.027$ $P = .927$	–	$r = 0.210$ $P = .324$	–	$r = -0.040$ $P = .883$	–
Post-op duration	$r = 0.280$ $P = .332$	–	$r = -0.064$ $P = .766$	–	$r = -0.139$ $P = .609$	–
Lumbar Lordosis	$r = 0.598$ $P = .040$*	$r = 0.709$ $P = .022$*	$r = 0.001$ $P = .996$	$r = -0.048$ $P = .850$	$r = -0.309$ $P = .283$	$r = -0.391$ $P = .209$
Pfirrmann Grade	$r = 0.055$ $P = .853$	–	$r = -0.590$ $P = .002$*	–	$r = 0.526$ $P = .036$*	–

CSA = cross-sectional area, ES = erector spinae, MF = multifidus, PM = psoas major, QL = quadratus lumborum.

*$P < .05$.

1Pearson or Spearman correlation coefficients.

2Partial correlation coefficients adjusted for age and post-op duration of patients.

unilateral partial hemilaminectomy impacted general lumbar spinal muscles, as fusion surgeries where muscle changes in multiple levels were reported.[24,25] Atrophy of the MF at the surgical level was shown in other studies. Tabaraee et al suggested that ipsilateral MF changes were significantly higher than contralateral changes after minimally invasive lumbar discectomy.[26] Airaksinen et al noted that both the PM and ES reduced in size in computed tomography studies after laminectomy, suggesting that in addition to denervation, disuse or inactivity could have induced these atrophies.[27] To our knowledge, this is the first study to evaluate the effect of unilateral discectomy at all lumbar levels.

4.2. The general impact on the paraspinal muscles suggests whole paraspinal measurement

The general muscle changes we observed might indicate that whole muscle 3-dimensional volume analysis could better represent muscle geography than conventional CSAs in axial images as a surrogate marker for muscle structure. Changes at all levels indicate that the impact of surgery on paraspinal muscles should be viewed as an aggregate. This effort to represent muscle geography by 3-dimensional analysis has been reported (L3–S1).[28] Urrutia et al also suggested that multi-level evaluation of the paraspinal muscle should be performed.[29] Although we tried to reflect multiple lumbar spines, our images were obtained from single axial planes.

4.3. Implications for postoperative rehabilitation

Paraspinal muscles are the main target for rehabilitation in the multidisciplinary approach to treating patients with CPSS. Micro-laminectomy alone can cause CPSS (5%–50%), despite being less complex than fusion or stabilization surgeries.[7,30] Postoperative PMA with altered size and fatty infiltration is associated with chronic low back pain.[31,32] Back injuries affect muscle structure and function, and vice versa.[33] Decreased muscle size and fatty infiltration are linked to low back pain and physical dysfunction.[32] Such structural changes were observed generally, and were not limited to the surgical level.[34] This emphasizes the importance of postoperative rehabilitation, focusing on trunk strengthening programs.[35,36] Early rehabilitation from postoperative day 1 after microdiscectomy improved pain and function.[37] Moreover, our study suggested that, given the overall muscle degeneration at multiple sites, active core exercises targeting all the paraspinal muscles would be a prerequisite to improve surgical outcomes and prevent CPSS.

4.4. The MF, QL, PM, and ES muscles

The paraspinal muscles can be categorized into local and global muscles.[38] The MF, PM, and QL are local muscles responsible for postural, tonic, and segmental stabilization, and the ES muscle is a global muscle producing dynamic extension torque.[38] In our study, the MF consistently experienced PMA on both sides and at all lumbar levels (Figs. 3 and 4).

The MF muscle is the most vulnerable to injury during posterior spinal surgery, as it is innervated only by the medial branch of the dorsal ramus, with no intersegmental nerve supply as in the other paraspinal muscles. The medial branch of the dorsal rami is very vulnerable to compression due to lateral displacement of muscle mass during surgery, particularly where the nerve is relatively fixed as runs under the fibro-osseous mamilloaccessory ligament.[39] Our finding of consistent MF atrophy might be due to its innervation by the medial branch of the dorsal ramus of the spinal nerve inducing a reflex inhibitory mechanism associated with muscle reduction.[40,41]

In addition to the MF, other back muscles contribute to spine movement and coordination and are affected by spinal pathologies.[33] The PM (its primary function being the flexion of the hip and stabilizing the lumbar spine), QL, and ES also showed decreased size and fatty infiltration at multiple levels (Figs. 3 and 4).[1]

4.5. Association with preoperative lordosis and disc degeneration

The correlation analysis showed that lesser lumbar lordosis and severe disc degeneration were associated with greater PMA (Fig. 5). PMA can contribute to the loss of lumbar lordosis in the spinal degenerative change with aging.[42] Smaller lumbar lordotic angle has also been associated with disc herniation and spondylosis.[43] Sudhir et al noted that paraspinal muscle mass decreased and Pfirrman's grade increased with age.[44] Although PM at L4 to L5 decreased more with disc degeneration as expected, QL at L1 to L2 level showed the opposite trend (Fig. 5C). Absolute changes in QL also decreased post-surgery, it had a greater degree of atrophy with a lower Pfirmann grade. Such contradictory changes of PM and QL post-surgery might be due to differing effects of surgery based on their anatomic locations.[45] Further studies are required to explain the disparity in relationship between the PMA degree and its prognostic factors.

4.6. Limitations

There are several limitations to this study. First, the single-center study sample was small. In our study, detailed inclusion and exclusion criteria were established to more clearly demonstrate the postoperative paraspinal muscle atrophy, thus decreasing the number of patients. Second, our study had a retrospective design, and levels of physical therapy and exercise were not controlled. Third, MRI scans were obtained using 2 different scanners (1.5 and 3T), although they showed no difference in the evaluation of muscle/fat fractions.[46] Fourth, we only presented the changes in paraspinal muscles because of the lack of data for functional outcomes, such as pain or disability scales, as well as serum muscle enzymes associated with muscle damage such as creatine kinase (CK). Lastly, a causal link between muscle characteristics (CSA, fat infiltration, and asymmetry) and physical function was not established.[32]

5. Conclusion

Patients who underwent 1- or 2-level discectomy experienced bilateral paraspinal muscle atrophy at the non-surgical levels and on the non-operative side. Such atrophic changes were related to preoperative lordosis and disc degeneration, emphasizing the need for core strengthening and lumbar rehabilitation from the early period after discectomy surgery. Future studies can be planned as multicenter studies with a larger number of patients, and the effect on paraspinal muscle atrophy after surgery can be confirmed compared to a group of patients who did not undergo surgery.

Author contributions

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Writing – original draft: Doyoung Lee.

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