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Psoas muscle measurement as a predictor of recurrent lumbar disc herniation

A retrospective blind study

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Abstract

Paraspinal (erector spinae and multifidus) and psoas muscles contribute to spinal stability, but no study has yet examined the relationship between muscle mass and recurrent lumbar disc herniation (rLDH).

The purpose of this study was to investigate the effect of psoas and paraspinal muscle mass on recurrent Lumbar disc herniation (LDH).

This retrospective study included 49 patients with LDH (22 men, 27 women; mean age: 59.9 years; range 32–80) who underwent discectomy and partial laminectomy without fusion and underwent both pre- and postoperative magnetic resonance imaging. The presence of rLDH was determined using medical records and postoperative magnetic resonance imagings. Patients were divided into an rLDH group (26 patients) and a without-rLDH group (23 patients). Clinical characteristics, segmental motion, and paraspinal and psoas muscle mass were compared between the groups. Using ImageJ software, the cross-sectional area (CSA), lean muscle mass (LMM), and skeletal muscle index (SMI) were measured on T2 axial preoperative magnetic resonance images at L2-L3, L3-L4, and L4-L5 disc levels to represent muscle mass. Univariate and multivariate logistic regression analyses were performed.

In the rLDH group, patients were younger (52.6 years vs 68.2 years; $P = .001$), segmental instability was more common (50.0% vs 4.3%; $P = .001$), and the CSA, LMM, CSA_{SMI}, and LMM_{SMI} of psoas muscles were larger (5851.59 mm^2 vs 4264.93 mm^2, 5456.59 mm^2 vs 4044.77 mm^2, 18.77 cm^2/m^2 vs 13.86 cm^2/m^2, and 17.52 cm^2/m^2 vs 12.98 cm^2/m^2; $P < .01$ for all 4 variables). On multivariate logistic regression, age and segmental instability were independent risk factors for rLDH (odds ratio 0.886 and 18.527; $P = .01$ and $P = .02$, respectively).

In middle-aged and elderly patients with lumbar disc herniation, relatively younger age, segmental instability, and greater psoas muscle mass may be risk factors for recurrence.

Abbreviations: BMI = body mass index,CI = confidence interval, CSA = cross-sectional area, CT = computed tomography, DICOM = Digital Imaging and Communications in Medicine, ICC = intraclass correlation coefficient, LMM = lean muscle mass, MRI = magnetic resonance imaging, OR = odds ratio, rLDH = recurrent lumbar disc herniation, SMI = skeletal muscle index,

1. Introduction

Sarcopenia, defined as skeletal muscle loss due to aging, is associated with both functional loss and frailty.[1–3] Previous studies have shown that sarcopenia also increases morbidity and mortality.[3–5] To quantitatively assess muscle mass, the cross-sectional area (CSA) of muscles measured using computed tomography (CT) or magnetic resonance imaging (MRI) has been used as a biomarker,[6–20] as the decrease in muscle mass is objectively demonstrated on medical images. Fatty degeneration of muscles is also found in cases of sarcopenia and assessed as decreased muscle attenuation on CT and increased fat fraction (decreased LMM) on MRI.[4,11,13,20]

Paraspinal (erector spinae and multifidus) and psoas muscles contribute to spinal stability as dynamic stabilizers.[21,22] Lumbar disc herniation (LDH) is one of the most common spinal diseases, and there have been studies suggesting that sarcopenia may be related to LDH.[15] During surgery for LDH, the disc and posterior column, which serve as spinal stabilizers, are partially resected. We assumed that the paraspinal and psoas muscles would compensate after the surgery and contribute more to the stability of the spine. Therefore, we hypothesized that sarcopenia of the paraspinal and psoas muscles would increase postoperative spinal instability and that it is a risk factor for recurrent LDH. Although controversial, the currently known risk factors for recurrent LDH include younger age,[23] older age,[24] male sex,[25] severe[26] or minor disc degeneration,[27] diabetes mellitus,[28] smoking,[29] absence of regular exercise,[30] overweight,[31] underweight,[32] intense

The datasets generated during and/or analyzed during the current study are not publicly available, but are available from the corresponding author on reasonable request.

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employment,[25,29] and segmental motion.[33] However, no study has yet examined the relationship between muscle mass and the recurrence of LDH. Therefore, in this study, we investigated the effect of psoas and paraspinal muscle mass on the recurrence of LDH.

2. Methods

This retrospective blind study was approved by the Institutional Review Board of the National Health Insurance Service Ilsan Hospital. Due to its retrospective nature, the requirement for informed consent was waived.

2.1 Patient selection and characteristics

We examined the data of patients who underwent discectomy and partial laminectomy (laminotomy, partial hemilaminectomy, or subtotal laminectomy in surgical records) for disc herniation at the National Health Insurance Service Ilsan Hospital from January 2011 to December 2019. Among them, 247 patients who had both a preoperative MRI within 1 month before the surgery and a follow-up MRI 6 months or more after the surgery were included. We excluded patients who underwent lumbar spinal fusion (185 patients), had MRI artifacts that hindered accurate muscle measurement (3 patients), infectious spondylitis (4 patient), underwent reoperation due to recurrence at the index surgery (2 patient), and had equivocal diagnosis of recurrent LDH on postoperative MRI (4 patients). Finally, 49 patients were selected. We gathered data regarding sex, age, height, weight, body mass index, presence of diabetes, smoking history, and regular exercise status from the medical records of all patients.

On the preoperative MRIs, we evaluated intervertebral disc herniation level, location (right or left; zonal anatomy: central, subarticular, foraminal, or extraforaminal), shape (protrusion, extrusion, or sequestration), degree of disc degeneration, and muscle mass. The degree of disc degeneration was assessed using the Pfirrmann classification.[34] Of the 49 included patients (22 men, 27 women; mean age: 59.9 years; range 32–80), 7 patients had disc herniation at L3-L4, 20 patients at L4-L5, and 22 patients at L5-S1. Extrusion was the most common disc shape: protrusion (n = 11), extrusion (n = 36), sequestration (n = 2). Based on the Pfirrmann classification for disc degeneration, 7 patients had grade III and 42 had grade IV. That is, all patients had substantial disc degeneration, but the height of the intervertebral disc was not severely collapsed. None of the patients had profound scoliosis causing apparent muscle asymmetry. The mean time from the day of surgery to the postoperative MRI was 46.9 months (range: 9–103 months).

2.2 Patient grouping

Patients were divided into a recurrent LDH group and a nonrecurrent LDH according to the results of the follow-up MRI. Recurrent LDH was defined as both symptomatic recurrence after an improvement period of at least 6 months after the discectomy and MRI confirmation. Disc herniation that occurred at the same level as the previous operation was regarded only as recurrence. Twenty-six patients (14 men, 12 women; mean age 52.6 years) had recurrence and 23 (8 men, 15 women; mean age 68.2 years) had no recurrence. Demographics of both cohorts are shown in Table 1. Among the 26 patients with recurrence, 7 required fusion operations, 17 were referred to pain clinics for nerve block treatment, and 2 patients were lost to follow-up.

2.3 Image analyses

Segmental motion was measured using lateral flexion-extension radiography performed within 1 month of the postoperative

Table 1

Demographics and preoperative magnetic resonance imaging findings.

		Recur (n = 26)	Nonrecur (n = 23)	*P*
Sex	Men	14 (53.8)	8 (34.8)	.18[c]
	Women	12 (46.2)	15 (65.2)	
Age (years, mean ± SD)		52.6 ± 11.90	68.2 ± 8.72	.001[a]*
Height (cm, mean ± SD)		165.0 ± 9.54	160.0 ± 7.85	.05[b]
Weight (kg, mean ± SD)		68.4 ± 12.0	62.2 ± 9.07	.05[a]
BMI (kg/m^2, mean ± SD)		25.2 ± 3.47	24.4 ± 3.12	.38[a]
DM	Present	1 (3.8)	3 (13.0)	.24[d]
	Absent	25 (96.2)	20 (87.0)	
Smoking	Present	9 (34.6)	3 (13.0)	.08[d]
	Absent	17 (65.4)	20 (87.0)	
Regular Exercise	Present	6 (23.1)	4 (17.4)	.62[d]
	Absent	20 (76.9)	19 (82.6)	
Disk level	L3-L4	2 (7.7)	5 (21.7)	.11[d]
	L4-L5	14 (53.8)	6 (26.1)	
	L5-S1	10 (38.5)	12 (52.2)	
Laterality	Right	11 (41.7)	13 (44.4)	.31[c]
	Left	15 (58.3)	10 (55.6)	
Zone	Central	11 (42.3)	14 (60.9)	.19[c]
	Subarticular	15 (57.7)	9 (39.1)	
Morphology	Protrusion	6 (23.1)	5 (21.7)	.38[d]
	Extrusion	18 (69.2)	18 (78.3)	
	Sequestration	2 (4.1)	0 (0.0)	
Pfirrmann grade	III	5 (19.2)	2 (8.7)	.29[d]
	IV	21 (80.8)	21 (91.3)	

Data are number (%) of patients, otherwise indicated.
[a] by Student *t* test;
[b] by Mann-Whitney *U* test;
[c] by Pearson chi-squared test;
[d] by Fisher's exact test.
* Statistically significant at $P < .05$.

MRI. For the assessment of segmental instability, 5 patients were excluded due to the lack of dynamic radiography within 1 month. Sagittal-plane angulation and translation at the recurrent LDH level were measured. There have been various diagnostic criteria for lumbar segmental instability; we used >3 mm translation and 10° angulation from L1 to L5 and >20° angulation from L5-S1.[35]

Both pre- and postsurgical MRI examinations were obtained using one of two 3-T scanners (Skyra [Siemens Healthcare] and Achieva [Philips Healthcare]). For quantitative muscle mass evaluation on the preoperative MRI, we used a method similar to that described by Chang et al.[11] The paraspinal muscle was further divided into erector spinae muscle and multifidus muscle. Using picture archiving and communication system workstations (Centricity Radiology RA100, GE Healthcare), axial T2-weighted magnetic resonance images of L2-L3, L3-L4, and L4-L5 disc levels were saved as Digital Imaging and Communications in Medicine (DICOM) files. The CSA of the muscle was measured at each level using the ImageJ software (version 1.53a, National Institutes of Health, USA). The areas of muscle and fat were divided by setting the threshold signal intensity, and lean muscle mass (LMM) was calculated as the CSA multiplied by the fat fraction (Fig. 1). The skeletal muscle index (SMI) was calculated to normalize the height values by dividing the muscle mass by the square of the patient's height (cm^2/m^2). For the CSA and LMM, sums of the measurements at the 3 levels (L2-L3, L3-L4, and L4-L5) on both sides were used as the muscle-mass variables. Image analysis was performed independently by a musculoskeletal radiologist (fellowship trained with 4 years of clinical experience) and an anesthesiologist who was a fellow at the pain clinic. Before the analysis, the pain clinician was trained in the anatomy of the paraspinal and psoas muscles using spine MRIs not included in the study. Each specialist received only the DICOM files and measured the muscle mass in random order blinded to the patient groups. In addition, measurement was repeated after 8 weeks to evaluate intraobserver reliability. Only the first evaluation by the radiologist was used for statistical analyses.

2.4 Statistical analyses

For data analysis, we used R software (Version 4.0.3; R Foundation for Statistical Computing, Vienna, Austria) and R studio (Version 1.3.959). For continuous variables in the univariate analysis, if normal distribution was not shown in the Shapiro-Wilk test, the Mann–Whitney *U* test was performed; if the variables followed a normal distribution, according to the F-test of equality of variances, Welch's *t* test was performed for variables with unequal variances and Student's *t* test was performed for features with equal variances. For categorical variables, Fisher's exact test and Pearson's chi-squared test were performed. Multivariate logistic regression analysis was then performed with variables that were meaningful in the univariate analysis. The intraclass correlation coefficient was used to evaluate the interobserver and intraobserver agreement for the muscle-mass measurements. $P < .05$ was judged to indicate statistical significance.

3. Results

The mean age of the recurrent LDH group was significantly lesser than that of the nonrecurrent LDH group (52.6 years vs 68.2 years, respectively; $P = .001$). There seemed to be no bias due to relatively long follow-up duration causing younger age to be mistaken for a risk factor, as there was no difference in the follow-up duration between the groups (46.8 months in the recurrent group vs 47.1 months in the nonrecurrent group, $P = .98$). There were no statistical differences between the groups in sex, height, weight, body mass index, presence of diabetes, smoking history, regular exercise status, or preoperative MRI findings (disc herniation level, location, shape, or disc degeneration grade).

The recurrent LDH group showed more segmental instability (50.0% vs 4.3%; $P = .001$) according to the above-mentioned instability criteria (i.e., >3 mm translation and 10° angulation at L1-L5 and >20° angulation for L5-S1). According to a stricter criteria put forth by White and Panjabi[36] (>4.5 mm displacement or angulation >15° at L1-L4, >20° at L4-L5, and >25° at L5-S1), none of the patients had instability; all 44 patients showed sagittal-plane rotation ranging from 2° to 15.4° and translation of 0–4 mm. The measured angles and displacement values themselves did not differ significantly between the groups. The results of the segmental instability evaluation are presented in Table 2.

Regarding muscle mass evaluation using the preoperative MRIs, the CSA and LMM of the psoas muscles were significantly larger in the recurrent group (5851.59 mm^2 vs 4264.93 mm^2; $P = .003$ and 5456.59 mm^2 vs 4044.77 mm^2; $P = .01$, respectively; Figure 2). The SMI was significantly larger in the psoas muscle CSA$_{SMI}$ and LMM$_{SMI}$ of the recurrent group as well (18.77 cm^2/m^2 vs 13.86 cm^2/m^2; $P = .004$ and 17.52 cm^2/m^2 vs 12.98 cm^2/m^2; $P = .01$, respectively). The paraspinal muscles did not differ significantly between the groups. The results are shown in Table 3.

Significant continuous variables in univariate analysis including age, CSA, LMM, CSA$_{SMI}$, and LMM$_{SMI}$ of psoas muscle were presented in Figure 3 with scatter and box plots. Multivariate

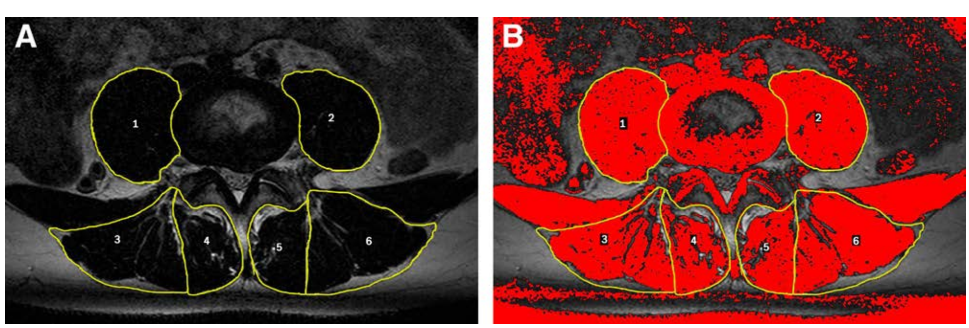

Figure 1. A 57-year-old man with L4-L5 disk protrusion and recurrence. (A) On the axial T2-weighted image, the muscle mass seems sufficient. (B) Fat and muscle areas were divided, and the fat fraction was measured using the threshold signal intensity setting in ImageJ. The CSA and lean muscle mass of the psoas (1 plus 2; 5735.62 mm^2 and 5349.11 mm^2, respectively), erector spinae (3 plus 6; 9260.10 mm^2 and 7615.37 mm^2, respectively), and multifidus (4 plus 5; 4174.20 mm^2 and 2944.84 mm^2, respectively) muscles were measured and calculated. The skeletal muscle indexes of CSA and LMM were 18.41 cm^2/m^2 and 17.17 cm^2/m^2 for psoas muscles, 29.72 cm^2/m^2 and 24.44 cm^2/m^2 for erect spinae, 13.40 cm^2/m^2 and 9.45 cm^2/m^2 for multifidus, respectively. CSA = cross-sectional area, LMM = lean muscle mass.

Table 2

Segmental motion at recurrence.

		Recur (n = 24)	Nonrecur (n = 20)	*P*
Segmental angulation (degrees, mean ± SD)		8.42 ± 3.2	7.04 ± 3.17	.49[a]
Segmental translation (mm, mean ± SD)		1.32 ± 1.27	0.67 ± 1.04	.17[b]
Segmental in stability (number [%] of patients)	Present	13 (54.2)	1 (5.5)	.001[c]*
	Absent	11 (45.8)	19 (95.0)	

note –

[a] by Student *t* test;

[b] by Mann-Whitney *U* test;

[c] by Fisher's exact test.

* Statistically significant at $P < .05$.

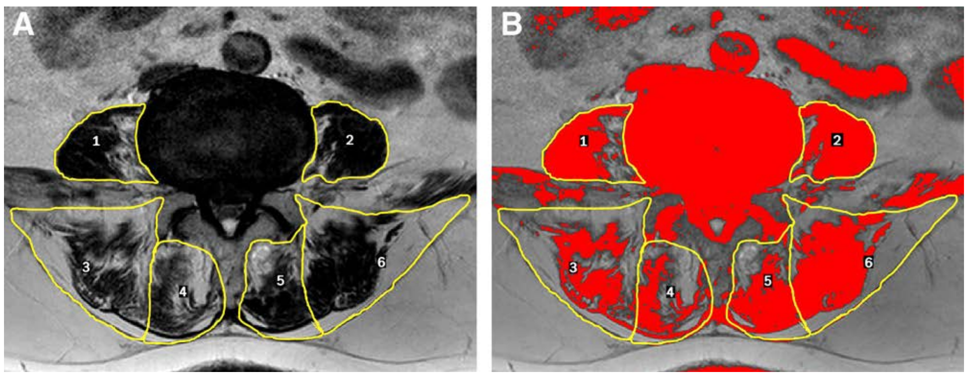

Figure 2. A 61-year-old woman with L4-L5 disk protrusion without recurrence. (A) A small CSA and prominent fatty degeneration of the psoas and paraspinal muscles observed on the axial T2-weighted image. (B) The CSA and lean muscle mass of the psoas (1 plus 2; 2836.76 mm^2 and 2686.01 mm^2, respectively), erector spinae (3 plus 6; 9281.32 mm^2 and 5064.77 mm^2, respectively), and multifidus (4 plus 5; 2950.79 mm^2 and 1591.78 mm^2, respectively) muscles were measured and calculated using Image J. Skeletal muscle index of CSA and LMM were 9.11 cm^2/m^2 and 8.62 cm^2/m^2 for psoas muscles, 29.79 cm^2/m^2 and 16.26 cm^2/m^2 for erect spinae, 9.47 cm^2/m^2 and 5.11 cm^2/m^2 for multifidus, respectively. CSA = cross-sectional area, LMM = lean muscle mass.

Table 3

Muscle mass measurement on preoperative MRI.

	Recur (n = 26)	Nonrecur (n = 23)	*P*
Cross-sectional area (CSA, mm2) of			
Psoas	5851.59 ± 2130.80	4264.93 ± 1247.26	.003[a]*
Erector spinae	10,702.74 ± 2079.55	10,009.54 ± 1634.44	.21
Multifidus	3687.58 ± 879.07	3244.38 ± 645.86	.05
Lean muscle mass (LMM, mm2) of			
Psoas	5456.59 ± 2090.77	4044.77 ± 1204.82	.01[a]*
Erector spinae	7955.17 ± 2140.37	7047.51 ± 1515.70	.09
Multifidus	2588.76 ± 883.94	2155.71 ± 606.57	.05
CSASMI (cm2/m2) of			
Psoas	18.77 ± 6.84	13.86 ± 4.02	.004[a]*
Erector spinae	34.34 ± 6.68	32.08 ± 5.23	.19
Multifidus	11.84 ± 2.82	10.43 ± 2.08	.05
LMMSMI (cm2/m2) of			
Psoas	17.52 ± 6.71	12.98 ± 3.86	.01[a]*
Erector Spinae	25.53 ± 6.87	22.53 ± 4.83	.09
Multifidus	8.31 ± 2.84	6.92 ± 1.95	.06

All values are mean ± SD.

[a] Welch's t-test, others are all by Student *t* test.

* Statistically significant at $P < .05$.

SMI = skeletal muscle index.

logistic regression analysis was performed with the significant variables. Among 4 muscle mass variables, CSA of the psoas muscle was only included in regression analysis due to high collinearity. In the logistic regression analysis, age and presence of segmental instability were factors that significantly influenced LDH recurrence (odds ratio [OR] = 0.886, confidence interval [CI] = 0.811–0.994, *P* = .01 and OR = 18.527, CI = 1.546–221.989, *P* = .02, respectively).

The interobserver and intraobserver agreements of muscle-mass measurements were excellent (ICC of 0.944 and 0.987 for CSA and 0.921 and 0.946 for LMM, respectively).

4. Discussion

The results of this study showed that psoas muscle mass was larger in the recurrent LDH group on preoperative MRI. In our

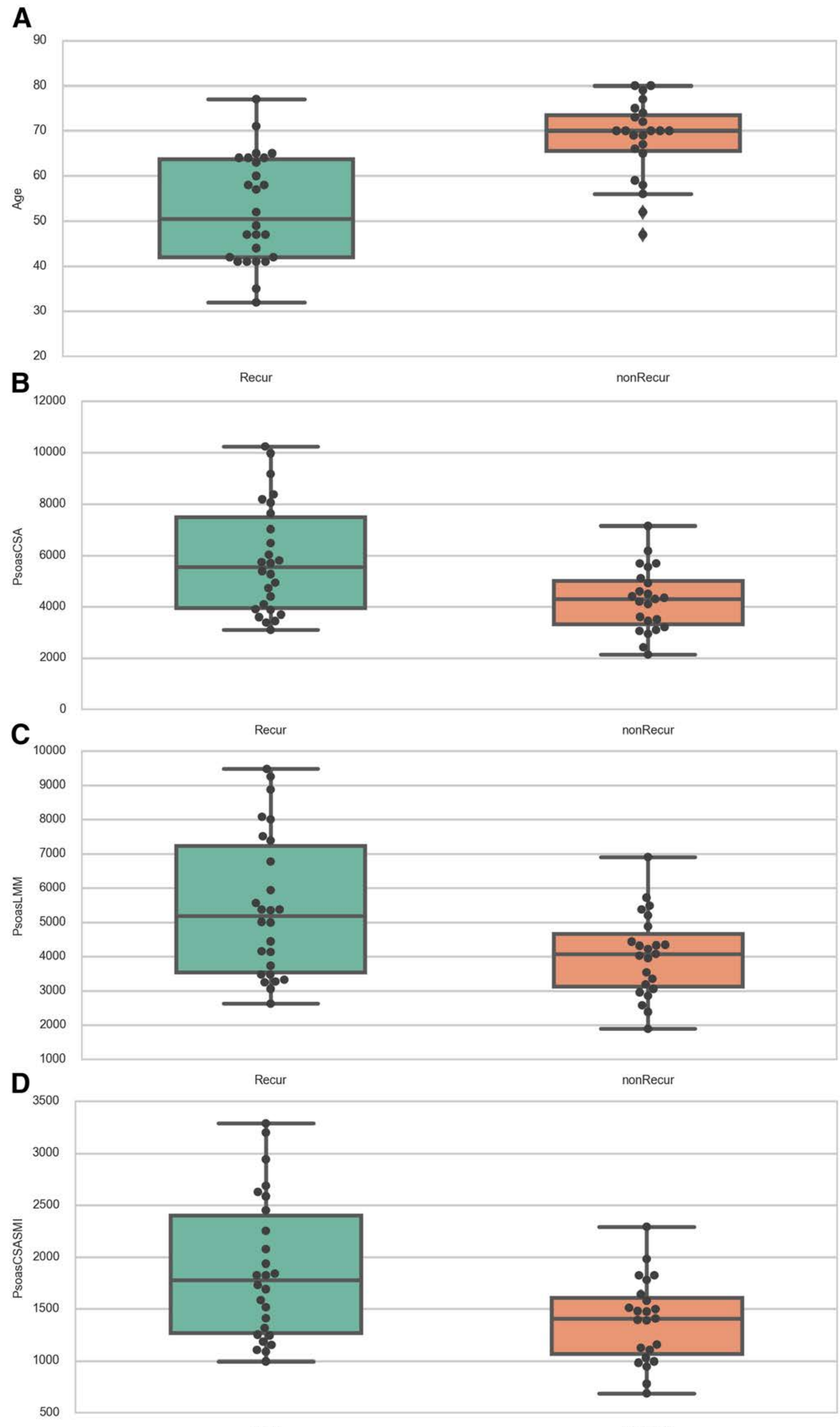

Figure 3. Scatter and box plots of significant continuous variables. (A) Age. (B) Cross-sectional area of the psoas muscle. (C) Lean muscle mass of the psoas muscle. (D) CSA_{SMI} of the psoas muscle. (E) LMM_{SMI} of the psoas muscle. CSA_{SMI}, skeletal muscle index of cross-sectional area, LMM_{SMI} = skeletal muscle index of lean muscle mass.

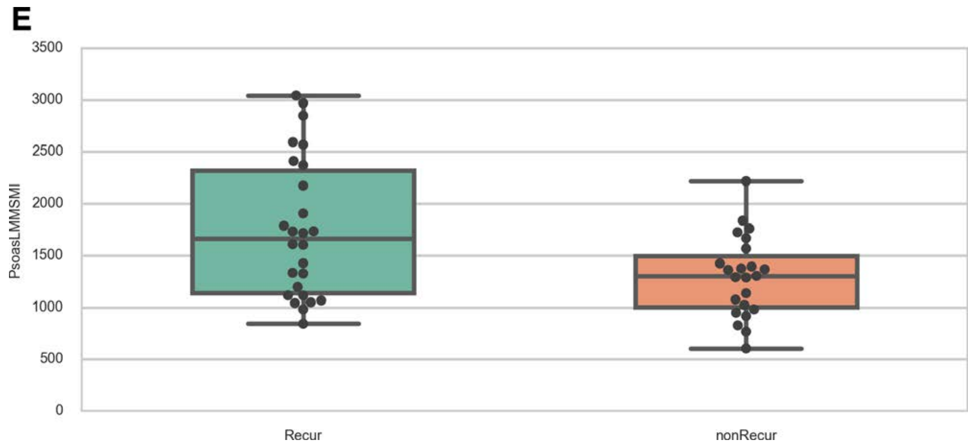

Figure 3. Continued

middle-aged and elderly patients, younger age was an independent risk factor for LDH recurrence. Segmental instability also was shown to be an important independent predictor of recurrent LDH.

Many studies have used muscle mass as a biomarker on CT or MRI. According to a recent review[7]; however, measurement methods are highly variable and have not been standardized. The most commonly used method is to obtain the SMI by measuring the CSA of the total muscle mass, including the abdominal wall, at the L3 level. Another frequently used method is to measure only the psoas muscle, but anatomical levels have also been diverse; at the L3,[6,9,18] L4,[10] and L4-L5.[13,17] Amini et al[8] proposed that total psoas volume may be a better tool to evaluate sarcopenia than a single axial image at the L3 level. As the middle portion of the vertebra and pedicle levels were not included in routine axial lumbar spine magnetic resonance images, we measured the adjacent disc levels (L2-L3, L3-L4, and L4-L5) instead. Paraspinal muscle measurements have also been used frequently in studies of spine MRIs, but the measurement location also varied, including L3-L4,[16] L4-L5,[11,15] and multilevel summation.[12,14,19] Urrutia et al[20] stated that single-level paraspinal muscle measurement is not representative of the entire muscle. Therefore, we evaluated both psoas muscles and paraspinal muscles at the L2-L3, L3-L4, and L4-L5 levels with 3-level summation to represent the muscle mass.

Contrary to our initial hypothesis that paraspinal and psoas sarcopenia may cause recurrent LDH, large psoas muscle mass was common in the recurrent LDH group in our study. To elucidate the reason for this, we focused on different biomechanics of the psoas and paraspinal muscles. A review by Hansen et al[37] demonstrated that the psoas major exerts large compression and shear force on the lumbar joints and stabilizes the spine by making it stiff. Psoas muscles act as hip flexors and aid in forward flexion of the spine. Schmidt et al[38] reported the highest intradiscal pressure occurred during lumbar flexion. Considering these biomechanics of the psoas muscle, it is plausible that a large psoas muscle mass imposes large compressive force, raises intradiscal pressure, and makes the partially resected disc susceptible to recurrent LDH. In contrast, the multifidus and erector spinae act more as stabilizers than movers of the vertebral column.[37] Therefore, sufficient multifidus muscle mass seems to be a preventive factor for recurrent LDH. Our study results, however, did not reveal significant differences in paraspinal muscle mass between the groups. There have been many studies concerning paraspinal muscle atrophy after lumbar spine surgery. As we included patients with partial laminectomy, from minimally invasive laminotomy to subtotal laminectomy, variable degrees of muscle atrophy resulted from the first discectomy surgery and seemed to contribute to the recurrence of disc herniation. Therefore, in this sample, paraspinal muscle mass in preoperative MRI may have been inadequate to verify the protective effect of paraspinal muscle mass on recurrent LDH.

There is still controversy regarding the relationship between age and recurrent disc herniation. A previous study showed that age is irrelevant,[39] whereas another showed that recurrence is common among the elderly.[24] In our study, recurrence of LDH decreased by 11 % with each year of age increase, which is consistent with the findings of a previous study by Jansson et al[40] They evaluated the hazard ratio of reoperation and rehospitalization due to recurrent back pain after disc herniation surgery, according to age. They demonstrated that, compared with patients younger than 39 years of age, the hazard ratio peaked to 1.16 times in patients in their 40s, 1.07 times in patients in their 50s, then gradually decreased to 0.74 times in patients in their 60s, and 0.67 times in patients in their 70s or older. Kim et al[24] revealed that old age was a risk factor; however, the average age of the recurrent group was 47.4 years and that of the nonrecurrent group was 34.4 years, similar to the findings of Jansson et al As the elderly but relatively healthy population increases, there would be increased chance to perform discectomy only without fusion like our elderly study population. A relatively younger age seems to be an important risk factor for recurrent LDH in those middle-aged and elderly patients.

According to our results, patients with segmental instability were 18 times more likely to have recurrent LDH than those without. However, we did not find a significant difference in the angulation measurement itself between the groups. Kim et al[33] revealed that 1° increments in sagittal range of motion raised the recurrence risk 2.03 times. This difference is attributed to the vigorous pain management employed in their study. They routinely used a nonopioid analgesic injection, and, if needed, intravenous fentanyl was added to assess full range of motion. Considering the mean angulation of 11.3° in the patients with L4-L5 recurrent disc herniation, it seems inappropriate in this postoperative setup to reference the 15–25° cutoff values proposed by White and Panjabi.[36] Even though angulation and translation measurements did not differ significantly in our patients, the presence of segmental instability (according to the more than 3 mm or 10° for L1-L5 and 20° for L5-S1 criteria) was an independent risk factor for recurrence.

This study had several limitations. The main limitation was its retrospective design and the small number of patients. As the patients in our hospital include elderly individuals, a majority of the patients who had posterior fixation together with discectomy and partial laminectomy were excluded from the study. The small patient population hindered analysis of the bone resection degree, which may be attributed to postsurgical segmental instability. The small sample size also hampered comparison of the levels of herniated intervertebral discs, at which the muscle's contribution to spinal stability may vary. However, a meta-analysis revealed that the level and side of LDH did not correlate with recurrence.[39] Even though our study population was small, we verified our results with power analysis, which confirmed adequate study power level (0.8). We are also the first to suggest that psoas muscle mass is a risk factor for LDH recurrence, and further studies with large populations and age- and level-matched prospective designs are warranted. As there are many other risk factors for recurrent disc herniation, the mere presence of larger psoas muscles does not justify the fusion operation due to high recurrence risk. Clinically, it would be beneficial to inform patients of the correlation between recurrent disc herniation and large psoas muscle mass and advise them to avoid excessive psoas exercise.

In conclusion, in middle-aged or elderly patients with LDH, a relatively younger age, segmental instability, and larger psoas muscle mass may be risk factors for recurrent disc herniation.

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Author contributions

Tae Yang Choi: formal analysis, funding acquisition, data curation, software, writing.
Min-Yung Chang: conceptualization, data curation, formal analysis, investigation, methodology, writing.
Seung Hyun Lee: conceptualization, data curation, validation, writing-review and editing.
Joung Goo Cho: Supervision, Data curation, conceptualization.
Sumin Lee: writing—review and editing.

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