L5-S1 Foraminal Stenosis Degeneration after L4-5 Lumbar Spinal Stenosis for TLIF: Impact of Preoperative Spinal Muscle Quality

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Research Article

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Abstract

Study design: Retrospective cohort analysis.

Objective: Our study aimed to investigate the effect of preoperative lumbar muscle quality (including muscle cross-sectional area (CSA) and muscle fatty infiltration rate (FIR) on L5-S1 foraminal stenosis degeneration after L4-5 TLIF.

Summary of Background Data: Adjacent segment degeneration (ASD) was a major spinal fusion complication. The paraspinal muscle had been proven to be an essential factor influencing the happening of ASD. However, few studies had investigated the association between paraspinal muscle and adjacent segment foraminal stenosis degeneration (ASD-FS).

Methods: One hundred-thirteen patients diagnosed with lumbar spinal stenosis at L4-5 were involved. Paraspinal muscle measurements were obtained preoperatively and bilaterally from axial T2-weighted MR images. The parameters included the, psoas cross-sectional area (p-CSA), erector spinae cross-sectional area (es-CSA), multifidus cross-sectional area (m-CSA), psoas fatty infiltration rate (p-FIR), erector spinae fatty infiltration rate (es-FIR), and multifidus fatty infiltration rate(m-FIR). The foraminal parameters were obtained in the Computed Tomography system bilaterally, including posterior disc height (PDH), disc-to-facet distance (D-F), foraminal height (FH), and foraminal area (FA). The association between muscle quality and ASD-FS had also been studied.

Results: At the last follow-up, the DF, FH, and FA were significantly decreased compared to pre-operation, and the decrease in FA was significantly positively related to es-FIR and m-FIR.

Conclusion: FIR for lumbar muscles preoperative was a predictor for L5-S1 ASD-FS after TLIF surgery, and patients who had higher es-FIR and higher m-FIR were more inclined to develop L5-S1 ASD-FS.

Background:

Lumbar spinal stenosis (LSS) was a common degenerative spinal disease in elderly individuals. After a detailed report of TLIF surgery by Harms et al[1] in 1998, TLIF surgery had become the major surgical treatment for LSS. Cole C D and McCall T D [1] reported that compared with PLIF, TLIF was more minimally invasive, had less structural exposure, and minimized lamina, facet, and pars dissection. Adjacent segment degeneration (ASD) was a major concern following fusion surgery. However, few studies had discussed adjacent segment degeneration of foramen.[3–6]

The pathology of lumbar foraminal stenosis was first reported in 1927.[7] It might cause be caused by posterolateral osteophytes, herniated discs, laterally bulging annulus fibrosus, subluxation of the facet, and hypertrophic ligamentum.[8] The concept of foraminal stenosis was defined as a lateral spinal stenosis. [7] The reconstructed sagittal images provided better visualization of the foramen. The foramen of L5-S1, because of its anatomical and functional features and the lumbosacral junction were more susceptible to significant loading from the trunk and tended to have a higher incidence of stenosis degeneration.[8]

The paraspinal muscles played an important role in the stability of the entire spine and the effectiveness of spine surgery. Muscle quality was evaluated using the muscle cross-sectional area (CSA) and fatty infiltration rate (FIR).

Previous studies had reported that the group with lower CSA and higher muscle FIR were more likely to have LBP, ASD, facet joint arthropathy, and spinal misalignment.[9–14]

To our knowledge, the correlation between spinal muscle quality and ASD-FS had not been investigated, and the purpose of our study was to investigate the effect of pre-operative spinal muscle CSA and FIR in the region of interest on foraminal stenosis degeneration of L5 -S1 after L4-L5 TLIF.

Table 1
Patients' Characteristics in Pre-operation

	LTA	**RTA**	
	Mean ± SD	Mean ± SD	p-value
sex	0.00	0.00	0.496
year	62.08 ± 0.09	62.93 ± 8.27	0.609
BMI	24.54 ± 2.50	23.43 ± 3.20	0.831
VAS	5.85 ± 1.69	5.67 ± 1.44	0.544
ODI	32.44 ± 5.13	32.22 ± 4.99	0.819

LTA: left transforaminal approach; RTA: right transforaminal approach.

$p < 0.05$ is marked by *, and $p < 0.01$ is marked by**.

Patients And Methods:

Participants

Between January 2018 and October 2021, 113 patients (54 males and 59 females) were hospitalized in When Zhou Medical University Affiliated First Hospital was included in this study. Based on the different transforaminal decompression approaches, we divided patients into the left transforaminal approach (LTA, men 30, women 29) and right transforaminal approach (RTA, men 24, women 30). All included patients had preoperative computed tomography scans and magnetic resonance imaging.

The study protocol was approved by the institutional review board of Wenzhou Medical University. The procedures were conducted in accordance with the ethical standards of the Declaration of Helsinki and approved by the local ethics committee. All participants provided informed consent to participate in this study. Participants' personal information was anonymized and deidentified before analysis.

Inclusion and Exclusion Criteria

All participants met the following inclusion criteria:(1) failure of conservative treatment after a minimum of 3 months, (2) age 40 years or above, (3) single-level TLIF surgery at the L4–L5, and (4) a follow-up period of 1 year. The exclusion criteria were: (1) surgery was performed by someone other than the corresponding author, (2) follow-up < 1 year, (3) any patient BMI ≥ $30kg/m^2$, (4) age < 40 years, (5) multilevel fusion surgery, (6) abnormal muscle activity or ambulation due to parkinsonism or neuromuscular disease, and (7) Lumbar spondylolisthesis, lumbar isthmic spondylolysis, spine scoliosis, lumbosacral transitional vertebrae and lumbar intervertebral instability in L5-S1(dynamic segment angle change > 5°).

Surgical Technique

All the patients were placed in the prone position. The segments were located using C-arm X-rays radiography before surgery. Lateral and anteroposterior images were obtained before the operation to determine the position of the pedicle of the surgical segment. We used a posterior median incision and then separated the natural cleavage plane between the multifidus and longissimus muscles to expose the bilateral facet joints. After identification of the traversing and exiting nerve roots, an aggressive full discectomy was performed in Kambin's triangle[18]. An appropriate height cage (Medtronic Sofamor Danek, Memphis, USA) filled with bone obtained from laminectomy, bone morphogenetic protein(rhBMP-2,4mg, from Hangzhou Jiu yuan, China) was inserted into the intervertebral space, and pedicle screws and rob system were implanted. Artificial bone or ilium was not used in any patients. Patents were asked to be in bed as much as possible for 1 month.

Clinical Measurements

Through the picture archiving and communication systems (PACS), of our hospital, the relevant imaging examination data of patients who met the above-mentioned inclusion conditions were measured.

Foraminal Parameters measurement

A 64-row multidetector computed tomography system (version 3.0; INFINITT Healthcare Co., Ltd., Seoul, South Korea, slice < 5 mm), was used in all patients preoperatively, 1-month post-operation, 6 months post-operation, and 12 months post-operation in our clinical follow-up.

The anatomical boundaries of the foramen were composed of: the adjacent superior-inferior vertebral pedicles, posteroinferior margin of the superior vertebral body, intervertebral disc, posterosuperior margin of the inferior vertebral body, and ligamentum flavum and facets joint as the posterior boundaries (Fig. 1a). We selected the bilateral L5/S1 nerve root entrances to the foramen, which appeared as the area between the medial edges of the superior and inferior pedicle cortical bone connection in the sagittal plane. The foraminal parameters included:

Posterior disc height (PDH, disc-to-facet distance (D-F), foraminal height (FH), and foraminal area (FA) (Fig. 1b).

Change in foraminal parameters (Δfp%) was defined as the absolute value of the rate: the foraminal parameters minus the foraminal parameters ahead and, then divided by the foraminal parameters ahead. The changes in foraminal parameters were expressed using the following formula:

$$\Delta fp\,\% = Abs\ \frac{\text{ForaminalParameters} - \text{ForaminalParametersatLastFollowup}}{\text{ForaminalParametersatLastFollowup}}$$

Paraspinal Muscle Measurements

We measured spinal muscle CSA and FIR to quantitatively evaluate muscle quality including the psoas, erector spinae, and multifidus on a 1.5-T MRI superconducting imaging system (Siemens, Avanto, Germany). Measurements of muscle CSA and FIR were observed by Image J software using the thresholding technique in T2-weighted axial images (Fig. 2,3). And we excluded the 'tent', which was defined as the region between the fascial plane and erector spinae[19,20]. All measurements were performed bilaterally at the level of L4-5. A region of interest (ROI) was used. Including: psoas cross-sectional area (p-CSA), erector spinae cross-sectional area (es-CSA), multifidus cross-sectional area (m-CSA), psoas fatty infiltration rate (p-FIR), erector spinae fatty infiltration rate (es-FIR), and multifidus fatty infiltration rate (m-FIR).

CSA was defined as the entire area of the region of interest. Similarly, using the thresholding technique, we obtained the area of fatty tissue in the muscle, which not only included the intermuscular but also the fatty tissue inside the muscles.

The muscle fatty infiltration rate (FIR) was expressed as the following formula:

Muscle FIR (%) = $\frac{\mathrm{TheAreaofFattyTissueinLumbarMuslce}}{\mathrm{CSAforLumbarMuslce}}$

Table 2
Foraminal Parameters in Pre-operation, 1-month Post-operation, 6 Months Post-operation, and 12 Months Post-operation in Groups.

		T0		T1		T2		T3	
groups		Mean ± SD		Mean ± SD		Mean ± SD		Mean ± SD	
		Left side	Right side	Left side	Right side	Left side	Right side	Left side	Right side
LTA	PDH(mm)	3.56 ± 1.22	3.51 ± 1.30	3.88 ± 1.40	3.63 ± 1.30	3.69 ± 1.27	3.51 ± 1.22	3.52 ± 1.25	3.34 ± 1.17
	D-F(mm)	5.60 ± 2.11	5.42 ± 1.60	5.47 ± 1.73	5.16 ± 1.49	5.27 ± 1.63	4.94 ± 1.39	4.91 ± 1.55	4.74 ± 1.37
	FH (mm)	21.05 ± 2.61	20.75 ± 2.63	20.80 ± 2.48	20.03 ± 2.62	20.02 ± 2.12	19.67 ± 2.38	19.13 ± 2.15*	19.05 ± 2.65
	FA (mm^2)	66.03 ± 26.10	64.53 ± 23.06	59.35 ± 22.41	57.85 ± 18.97	55.41 ± 20.23	54.32 ± 17.00	51.85 ± 19.21*	50.74 ± 16.05
RTA	PDH(mm)	3.09 ± 1.54	3.07 ± 1.57	3.54 ± 1.65	3.52 ± 1.61	3.33 ± 1.52	3.32 ± 1.52	3.14 ± 1.45	3.20 ± 1.48
	D-F (mm)	5.22 ± 1.86	5.51 ± 1.66	5.01 ± 1.72	5.46 ± 1.63	4.73 ± 1.66	5.25 ± 1.55	4.53 ± 1.59	5.01 ± 1.56
	FH (mm)	20.45 ± 2.88	20.25 ± 2.77	20.14 ± 2.67	20.09 ± 2.47	19.10 ± 2.41	19.49 ± 2.49	18.78 ± 2.40	18.49 ± 2.49
	FA (mm^2)	59.59 ± 24.38	60.22 ± 20.29	56.70 ± 21.12	57.63 ± 18.53	53.36 ± 19.29	53.75 ± 15.83	49.39 ± 17.69	51.05 ± 15.50

LTA: left transforaminal approach; RTA: right transforaminal approach;

T0: time of pre-operation; T1: time of 1-month post-operation; T2: time of 6 months post-operation; T3: time of 12 months post-operation.

PDH, posterior disc height; D-F, disc-to-facet distance; FH, foraminal height; FA, foraminal area.

Compared with outcomes in follow-up time point for ahead, $p < 0.05$ is marked by *, and $p < 0.01$ is marked by **.

Statistical Analysis

Statistical evaluation was performed using IBM SPSS Statistics 26 software (SPSS Inc., IBM Company Headquarters, Chicago, IL, USA). All values were expressed as mean standard deviation. Correlations between the paraspinal muscle and foraminal parameters were computed using Pearson correlation analysis. An independent sample t-test was performed to compare the differences in radiographic measurements. P-value < 0.05 is defined as statistical significance.

All parameters above were measured by an experienced orthopedics surgeon.

Table 3
Statistic Difference for Pre-operation and 12 Months Post-operation in Foraminal Parameters.

Foraminal parameter			T0	T3	
			Mean ± SD	Mean ± SD	P-value
LTA	PDH	Left side	3.56 ± 1.22	3.52 ± 1.25	0.851
		Right side	3.51 ± 1.30	3.34 ± 1.17	0.460
	D-F	Left side	5.60 ± 2.11	4.91 ± 1.55	0.043*
		Right side	5.42 ± 1.60	4.74 ± 1.37	0.014*
	FH	Left side	21.05 ± 2.61	19.13 ± 2.15	< 0.01**
		Right side	20.75 ± 2.63	19.05 ± 2.65	< 0.01**
	FA	Left side	66.03 ± 26.10	51.85 ± 19.21	< 0.01**
		Right side	64.53 ± 23.06	50.74 ± 16.05	< 0.01**
RTA	PDH	Left side	3.09 ± 1.54	3.14 ± 1.45	0.899
		Right side	3.07 ± 1.57	3.20 ± 1.48	0.788
	D-F	Left side	5.22 ± 1.86	4.53 ± 1.59	0.039*
		Right side	5.51 ± 1.66	5.01 ± 1.56	0.109
	FH	Left side	20.45 ± 2.88	18.78 ± 2.40	< 0.01**
		Right side	20.25 ± 2.77	18.49 ± 2.49	< 0.01**
	FA	Left side	59.59 ± 24.38	49.39 ± 17.69	0.014*
		Right side	60.22 ± 20.29	51.05 ± 15.50	0.010*

LTA: left transforaminal approach; RTA: right transforaminal approach;

T0: time of pre-operation; T3: time of 12 months post-operation;

PDH, posterior disc height; D-F, disc-to-facet distance; FH, foraminal height; FA, foraminal area.

$p < 0.05$ is marked by *, and $p < 0.01$ is marked by **.

Table 4
Statistic Difference for 1-month Post-operation and 12 Months Post-operation in Foraminal Parameters.

Foraminal parameter			T1	T3	
			Mean ± SD	Mean ± SD	P-value
LTA	PDH	Left side	3.88 ± 1.40	3.52 ± 1.25	0.139
		Right side	3.63 ± 1.30	3.34 ± 1.17	0.211
	D-F	Left side	5.47 ± 1.73	4.91 ± 1.55	0.063
		Right side	5.16 ± 1.49	4.74 ± 1.37	0.112
	FH	Left side	20.80 ± 2.48	19.13 ± 2.15	< 0.01**
		Right side	20.03 ± 2.62	19.05 ± 2.65	0.045*
	FA	Left side	59.35 ± 22.41	51.85 ± 19.21	0.050*
		Right side	57.85 ± 18.97	50.74 ± 16.05	0.030*
RTA	PDH	Left side	3.54 ± 1.65	3.14 ± 1.45	0.181
		Right side	3.52 ± 1.61	3.20 ± 1.48	0.273
	D-F	Left side	5.01 ± 1.72	4.53 ± 1.59	0132
		Right side	5.46 ± 1.63	5.01 ± 1.56	0.142
	FH	Left side	20.14 ± 2.67	18.78 ± 2.40	< 0.01**
		Right side	20.09 ± 2.47	18.49 ± 2.49	< 0.01**
	FA	Left side	56.70 ± 21.12	49.39 ± 17.69	0.050*
		Right side	57.63 ± 18.53	51.05 ± 15.50	0.048*

LTA: left transforaminal approach; RTA: right transforaminal approach;

T1: time of 1-month post-operation; T3: time of 12 months post-operation;

PDH, posterior disc height; D-F, disc-to-facet distance; FH, foraminal height; FA, foraminal area.

p < 0.05 is marked by *, and p < 0.01 is marked by **.

Results:

Patients Characteristics

There were no significant differences found in patient demographics, including sex, age (average LTA: 62.08 ± 0.09, RTA: 62.93 ± 8.27), BMI (average LTA: 24.54 ± 2.50, RTA: 23.43 ± 3.20), ODI, VAS score preoperative in two groups(p > 0.05) (Table 1).

Foraminal Parameters and Correlations

We did not find any significant changes in the data at 1-month post-operation vs. pre-operation and at 6 months post-operation vs. 1-month post-operation (Table 2). In the comparison between 12 months post-operation and 6 months post-operation, we saw a statistical difference in FH in LTA-left ($p = 0.025$) and FA in LTA-left ($p = 0.053$), but there were no more data to show that the changes in FH and FA were significant (Table 2). However, in the comparison between pre-operation and 12 months post-operation, we found significant decrease in D-F (LTA-left: **p = 0.043**, LTA-right: **p = 0.014**; RTA-left: **p = 0.039**), FH(LTA-left: **p < 0.01**, LTA-right: **p < 0.01**; RTA-left: **p < 0.01**,RTA-right: **p < 0.01**), and FA(LTA-left: **p < 0.01**, LTA-right: **p < 0.01**; RTA-left: **p = 0.014**, RTA-right: **p = 0.010**)(Table 3). Moreover in the comparison between 1-month post-operation and 12 months post-operation, we found a significant decrease in FH (LTA-left: **p < 0.01**, LTA-right: **p = 0.045**; RTA-left: **p < 0.01**, RTA-right: **p < 0.01**), and FA (LTA-left: **p = 0.053**, LTA-right: **p = 0.030**; RTA-left: **p = 0.054**, RTA-right: **p = 0.048**) (Table 4).

According to the independent sample T-test outcomes, we analyzed the relationship between foraminal parameter changes in muscle quality in pre-operation vs. 1-month post-operation, 1-month post-operation vs. 12 months post-operation, and pre-operation vs. 12 months post-operation. Correlations for spinal muscle CSA were presented in Table 5, and correlations for spinal muscle FIR were presented in Table 6. “-” for a negative relationship.

For 1-month post-operation, when compared with pre-operation, the change in PDH was negatively correlated with **p-CSA** and **es-CSA**, the change in D-F was positively correlated with **es-FIR** and **m-FIR**, the change in FH was negatively correlated with **es-CSA**, positively correlated with **es-FIR** and **m-FIR**, the change in FA was negatively correlated with **es-CSA**, and positively correlated with **es-FIR** and **m-FIR**.

In the analysis of the correlation between muscle quality and foraminal parameter changes in pre-operation vs. 12 months post-operation, we found that, regardless of LTA or RTA, the change in FA was positively related to **es-FIR** and **m-FIR.** However, no full correlations were observed for PDH, D-F, and FH.

For1-month post-operation vs. 12 months post-operation, no matter the LTA or RTA, we observed that the change of PDH, D-F, FH, and FA were positively correlated with **es-FIR** and **m-FIR**.

Table 5
Correlation (r) Between Change of Foraminal Parameters and Muscle CSA.

			PDH (%)		D-F (%)		FH (%)		FA (%)	
			left	right	left	right	left	right	left	right
LTA	T0 vs. T1	psoas	− .344**	− .306*	− .208	− .302*	− .190	− .210	− .226	− .363**
		erector spinae	− .262*	− .336**	− .229	− .324*	− .276*	− .332*	− .388**	− .269*
		multifidus	− .231	− .208	− .261*	− .140	− .224	− .159	− .210	− .186
	T1 vs. T3	psoas	− .309*	− .152	− .107	− .167	.006	− .238	− .212	− .103
		erector spinae	− .123	− .238	− .180	− .187	− .212	− .169	− .205	− .150
		multifidus	− .186	− .095	− .119	.049	− .049	− .207	− .215	− .115
	T0 vs. T3	psoas	− .226	− .155	− .061	.062	− .052	− .007	− .231	− .285*
		erector spinae	− .292*	− .148	− .167	− .011	− .054	.136	− .310*	− .306*
		multifidus	− .030	.005	− .317*	.032	.006	− .079	− .291*	− .071
RTA	T0 vs. T1	psoas	− .346*	− .403**	− .452**	− .150	− .188	− .338*	− .155	− .227*
		erector spinae	− .277*	− .293*	− .173	− .268*	− .461**	− .306*	− .166	− .223
		multifidus	− .442**	− .290*	− .188	− .145	− .202	− .094	− .169	− .057
	T1 vs. T3	psoas	− .236	− .342*	− .084	− .192	− .111	− .268*	− .138	− .119
		erector spinae	− .047	− .254	− .111	− .132	− .326*	− .216	− .152	− .147
		multifidus	− .009	− .236	− .198	− .147	.176	− .161	− .205	− .165
	T0 vs. T3	psoas	− .217	− .329*	− .332*	− .240	− .043	− .293*	− .060	− .261
		erector spinae	− .321*	− .205	− .081	− .185	− .191	− .078	− .088	− .212
		multifidus	− .329*	− .233	− .213	− .164	− .146	− .314*	− .100	− .234

CSA: cross-sectional area.

T0 vs. T1: pre-operation vs. 1-month post-operation; T1 vs. T3: 1-month post-operation vs.12 months post-operation; T0 vs. T3: pre-operation vs. 12 months post-operation;

PDH, posterior disc height; D-F, disc-to-facet distance; FH, foraminal height; FA, foraminal area;

$p < 0.05$ is marked by *, and $p < 0.01$ is marked by **.

Table 6
Correlation (r) Between Change of Foraminal Parameters and Muscle FIR.

			PDH (%)		D-F (%)		FH (%)		FA (%)	
			left	right	left	right	left	right	left	right
LTA	T0 vs. T1	psoas	0.195	0.009	.186	.186	.206	.150	.150	.150
		erector spinae	.158	.127	.273*	.389**	.405**	.436**	.350**	.494**
		multifidus	.054	.224	.260*	.357**	.279*	.380**	.431**	.461**
	T1 vs. T3	psoas	.183	− .081	.007	.219	− .017	.035	.215	.082
		erector spinae	.266*	.285*	.409**	.433**	.451**	.334**	.455**	.301*
		multifidus	.384**	.367*	.500**	.351**	.340*	.420**	.501**	.468**
	T0 vs. T3	psoas	− .022	.059	.052	.083	.204	.013	.157	.211
		erector spinae	.069	.080	.249	.256*	.374**	− .117	.462**	.451**
		multifidus	− .001	.082	.170	.354**	.390*	.270*	.554**	.495**
RTA	T0 vs. T1	psoas	− .009	− .042	.322*	.227	.059	.189	.221	.407**
		erector spinae	.129	− .019	.415**	.458**	.356**	.488**	.301*	.304*
		multifidus	.046	− .133	.474**	.395**	.293*	.476**	.282*	.371*
	T1 vs. T3	psoas	.274*	.166	.193	.170	.118	.187	.019	.134
		erector spinae	.326*	.392*	.354**	.363*	.298*	.383**	.378**	.343*
		multifidus	.410**	.492**	.431**	.409**	.276*	.430**	.331*	.330*
	T0 vs. T3	psoas	.127	− .036	.411**	.224	.148	.099	.060	.087
		erector spinae	− .021	− .052	.573**	.324*	.144	.415**	.447**	.452**
		multifidus	− .111	.269*	.516**	.472**	.088	.449**	.383**	.292*

FIR: fatty infiltration rate;

T0 vs. T1: pre-operation vs. 1-month post-operation; T1 vs. T3: 1-month post-operation vs.12 months post-operation; T0 vs. T3: pre-operation vs. 12 months post-operation;

PDH, posterior disc height; D-F, disc-to-facet distance; FH, foraminal height; FA, foraminal area;

$p < 0.05$ is marked by *, and $p < 0.01$ is marked by **.

Discussion:

As mentioned before, ASD was common after lumbar fusion surgery, and stenosis of the adjacent segment foramen was also often observed. Ryu D S et al [21]reported that reoperation was most likely for foraminal stenosis in patients with ASD (P = 0.001). Our study aimed to investigate the relevance of preoperative paraspinal muscle quality on the occurrence of L5-S1 ASD-FS after L4-5 fusion surgery.

Orita S et al [8] defined three major types of anatomical foramen stenosis: (1) vertical stenosis, (2) transverse stenosis, and (3) circumferential stenosis. Type 1 foraminal stenosis was mainly about foraminal height decrease, type 2 foraminal stenosis was about foraminal width decrease, and type 3 was a combination of the above pathological types. As we described previously, the lumbar foramen was a polygonal area, and reduction of any side would lead to stenosis of the lumbar foramen. In our study, we found a significant decrease in D-F, FH, and FA (pre-operation vs. 12 months post-), and in FH, FA (1-month post- vs. 12 months post-). There was no doubt that the FA decreased significantly during our follow-up, in other words, the foramen did become narrow, and that the decrease in FA might be due to the decrease in D-F and FH. The reason for the decrease in FH and D-F might be that fusion surgery accelerated degeneration in the facet joint, which could no longer maintain the foraminal height and even subluxation occurred.[10–13]

PDH was the only increase in foraminal parameters at 1-month postoperatively. However, to our knowledge, few studies had reported this finding. What caused this change? We speculated that the removal of the facet joints during the surgical procedure resulted in a temporary relaxation of the adjacent segmental disc and another factor that patients were asked to be on bed rest as much as possible for 1-month post-operation might not be ignored.

Correlations between foraminal parameter changes and muscle quality were analyzed. For 1-month post-operation versus pre-operation, the changes in PDH were negatively related to p-CSA and es-CSA, while the changes in FH and FA were negatively correlated not only with CSA (es-CSA) but positively with FIR (es-FIR, m-FIR), while a positive correlation for D-F was seen in muscle FIR(es-FIR, m-FIR), and at 1-month versus 12 months postoperatively, foraminal parameter changes were more associated with muscle FIR (es-FIR, m-FIR), rather than muscle CSA. Our results indicated that muscle CSA might significantly influence foraminal parameters to change in surgery. However, for the long-term process, the muscle FIR was a more predictive factor. Furthermore, in pre-operation versus 12 months post-operation, the result that the change in FA was closely related to FIR supported our hypothesis. Therefore, how the paraspinal muscles worked?

Spinal muscle quality influenced the effectiveness of surgery. Previous studies had reported that in patients undergoing posterior lumbar interbody fusion (PLIF), a smaller CSA was associated with a poorer fusion rate. [15,16] Wang W et al[17] pointed out that a smaller multifidus area and higher multifidus fatty infiltration rate on preoperative MRI scans were significantly associated with higher ODI scores, both preoperatively and postoperatively. In the lumbar muscle system, the psoas which was attached directly to the vertebral bodies anterolaterally acted as the primary flexor muscle group, and the multifidus, and erector spinae acted as strong extensor muscle groups. [22]They worked together to maintain the balance and stability of the lumbar spine. Fusion surgery increased the pressure in the disc and facet joint in the adjacent segments[1, 22–23,37]. The biomechanical pressure increase promoted disc degeneration, further disc herniation, extrusion of the lumbar foramen, and a decrease in foraminal height.[23,29–31] For erector spinae, McGill et al[24] pointed out that under external compression the erector spine reduced the compression force from 20–35% in a body experiment. When the multifidus was studied as individual muscles, they seem to act more as segmental stabilizers to enable the separate control of individual vertebrae. [25] Electromyography studies confirmed this result and found that the multifidus played a role in controlling intersegmental motion.[26–27] From the above, we more strongly believed that with a higher spinal muscle FIR especially in the multifidus and erector spinae, patients were more likely to develop ASD-FS after fusion surgery.

This study had several strong points. All surgical operations were performed in the natural cleavage plane between the multifidus and longissimus muscles to minimize the damage to the muscle. This approach had the advantages of less blood loss, fewer ASD rates, and fewer additional surgical procedures. [32,33]We took minimized damage to spinal muscle and patients. And we divided the spinal muscles into the left side and right side of the patient rather than evaluating them together in that chronic degenerative lumbar spine pathology was associated with muscle degeneration, the muscle quality on different sides in one varied and it was not reasonable enough to integrate them into the discussion.[34–36] Moreover, our measurements of the foramen area were comprehensive, including not only foraminal height but width, which could help us understand the ASD-FS in a 3-dimensional way. In addition, this study was the first to evaluate spinal muscle quality as a prognosticator of ASD-FS after TLIF surgery; thus, this study could be a cornerstone for further studies analyzing the factors influencing postoperative radiological foraminal stenosis in fusion surgery.

Why did we choose L5-S1 level as our research subjects? In terms of anatomical factors, the L5-S1 disc was at the lowermost part of the spine and was the most variable area of lumbar spine activity. The disc of L5-S1 was also more prone to be detected degeneration, in lumbar fusion and LBP patients.[38,39] Though the presence of preoperative disc degeneration did not show a significant correlation with the development of postoperative ASD.[40]

Finally, as with any study, this study also had some limitations, including its retrospective design, relatively small sample size, and short follow-up period. Furthermore, we were not able to distinguish fatty tissue intermuscular from that inside the muscles. Moreover, further studies were required to investigate the increase in PDH in L5-S1 foramen after fusion surgery.

Conclusion:

In our 1-year clinical follow-up, whether on the surgical or non-surgical side of TLIF surgery, we found that patients with a higher degree of spinal muscle fatty infiltration rate, especially for the erector spinae and multifidus, were more likely to develop ASD-FS.

Abbreviations:

Abbreviations	Definition
LSS	lumbar spinal stenosis
ASD	adjacent segment degeneration
CSA	cross-sectional area
FIR	fatty infiltration rate
ASD-FS	adjacent segment foraminal stenosis degeneration
es-CSA	erector spinae cross-sectional area
es-CSA	erector spinae cross-sectional area
m-CSA	multifidus cross-sectional area
p-FIR	psoas fatty infiltration rate
es-FIR	erector spinae fatty infiltration rate
m-FIR	multifidus fatty infiltration rate
PDH	posterior disc height
D-F	disc-to-facet distance
FH	foraminal height
FA	foraminal area
LTA	left transforaminal approach
RTA	right transforaminal approach
ODI	Oswestry Disability Index
VAS	Visual Analogue Score
$\Delta fp\%$	Change in foraminal parameters

Declarations:

Ethics approval and consent to participate: The study protocol was approved by the institutional review board of Wenzhou Medical University. The procedures were conducted in accordance with the ethical standards of the Declaration of Helsinki and approved by the local ethics committee. All participants provided informed consent to participate in this study. Participants' personal information was anonymized and deidentified before analysis.

Consent for publication: Not applicable.

Availability of data and materials: The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests: The authors declare that there are no competing interests.

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Authors' contributions: MH.C and HL.T participated in the design of the study and wrote the main body of the paper, P.Z collected the data, JX.L and WJ.Y and SK.F analyzed and supplemented the data, X.Y and YZ.H provided the tables and images, and all authors had read the article.

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Figures

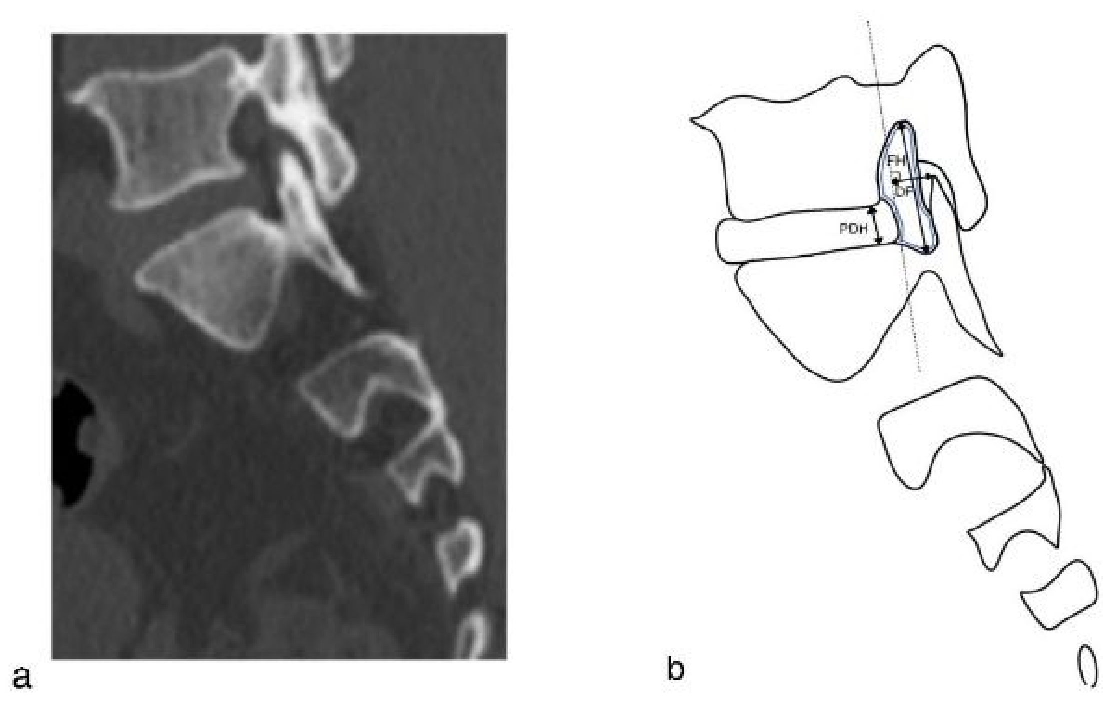

Figure 1

a: The anatomical boundaries of L5-S1 foramen boundaries for CT scan in the sagittal plane. **b**: Showing the measurements made on the disc and intervertebral foramen. Posterior disc height (PDH): The distance between the upper and lower endplates of the involved disc. The disc-to-facet distance (D-F): The vertical distance between the apex of superior articular process and vertical line which is defined as caudal end of bulging intervertebral disc to inferior endplate in the sagittal plane. Foraminal height (FH): The maximum distance between the inferior margin of the pedicle of the superior vertebra and the superior margin of the pedicle of the inferior vertebra.

Foraminal area (FA): FA is bounded by the surfaces of the upper and lower pedicles, the caudal end of the disk, and the anterior edge of the ligamentum flavum (the area circled by the blue line).

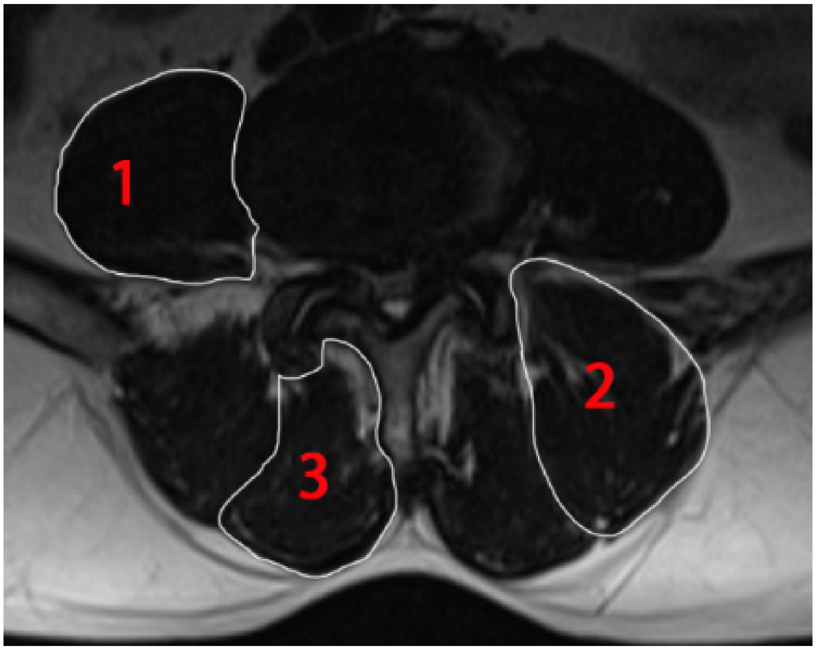

Figure 2

Region of interest(ROI) was used to measure the total cross-sectional area for the psoas, erector spinae, and multifidus. 1, psoas; 2, erector spinae muscle; 3, multifidus;

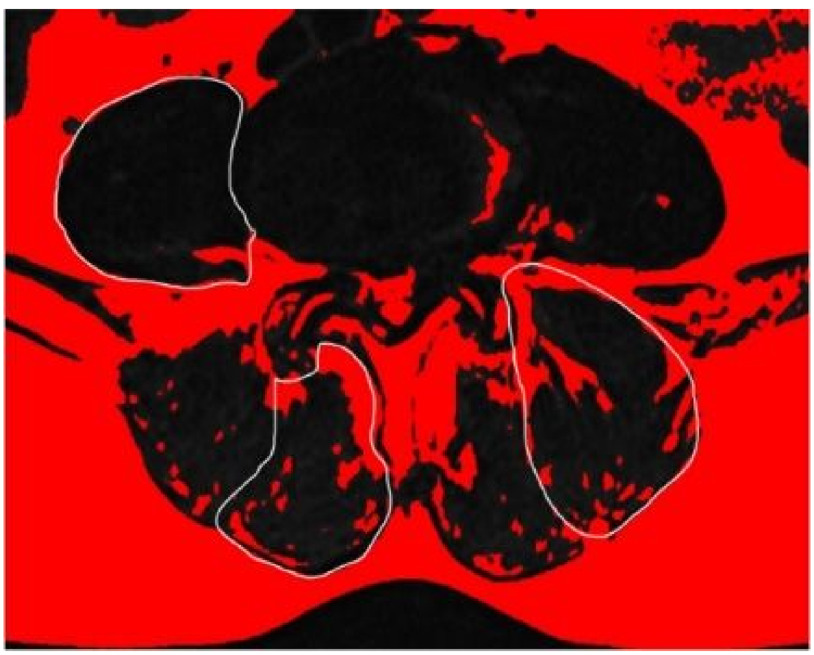

Figure 3

The thresholding technique was used to highlight the fatty tissue in the muscle in the region of interest.