Spinal-pelvic sagittal imbalance and paraspinal muscle degeneration in patients with degenerative lumbar spinal stenosis: A monocentric, prospective and observational study

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Abstract. Degenerative lumbar spinal stenosis (DLSS) is a condition in which the body is held in a poor posture for a long period of time, resulting in a change in the stress structure of the lumbar spine that causes degenerative changes in the muscles of the spine. The sagittal balance of the spine and pelvis and the degeneration of the paravertebral muscles have been the focus of recent research. To explore the relationship between paraspinal muscle degeneration and changes in spine-pelvic sagittal parameters in patients with DLSS, 95 patients with DLSS (experimental group) and 70 healthy volunteers (control group) hospitalized in the Ordos Central Hospital between January 2020 and January 2022 were included as study subjects. All patients underwent lumbar magnetic resonance imaging and spinal X-ray using uniform criteria. The correlation between paravertebral muscle parameters and sagittal-pelvic sagittal parameters in patients with DLSS was obtained from two imaging examinations, and the data were organized and grouped in order to explore the correlation between these parameters. There was no significant difference in the general data between the two groups (P>0.05). In the L4-5 DLSS patient group, the ratio of fat infiltration in the right erector spinae (ES) muscle was negatively correlated with thoracic kyphosis (TK) (r=-0.536; P<0.05) but not significantly in the left side. The relative cross-sectional area of the left multifidus muscle (MF RCSA) was positively correlated with TK (r=0.685; r=0.615; P<0.05) but not significantly in the right side. In the L5-S1DLSS patient group, the right MF RCSA and right ES RCSA were significantly positively correlated with TK (r=0.685; r=0.615; P<0.05) but not significant in the left side. Thus, paravertebral muscle parameters were correlated with spinal-pelvic sagittal parameters in patients with DLSS.

Introduction

In China, middle-aged and elderly individuals ≥60 years old, accounted for 18.7% of all cases in the 7th census data. The proportion of elderly is growing, and the incidence of degenerative lumbar spinal stenosis (DLSS) is increasing annually (1).

DLSS refers to a chronic lumbar disease in which secondary degenerative changes of the vertebral body, intervertebral disc and paraspinal soft tissue occur due to stress imbalances in the lumbar spine, resulting in a series of back and leg pain and neurological symptoms caused by spinal canal volume change and dural sac stenosis (2). Parameters related to the sagittal position of the spine and pelvis can be used as criteria to evaluate the state of physical balance (3). The 'cone of economy', first described by Dubousset (4), indicates that the normal spinal and pelvic shape curve can enable individuals to fulfill the needs of physiological posture and daily activities with minimum energy consumption. Once the sagittal alignment of the spine is altered, balances of the spine require more energy from the surrounding tissues to maintain, resulting in muscle fatigue and paravertebral pain. Artificial muscle removal experiments have demonstrated that the lumbar spine can appear unstable under very mild loading without the support of the corresponding muscles (5).

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Abbreviations: DLSS, degenerative lumbar spinal stenosis; RCSA, relative cross-sectional area; CSA, cross-sectional area; FIR, fatty infiltration ratio; SVA, sagittal vertical axis; TK, thoracic kyphosis; LL, lumbar lordosis; PI, pelvic incidence; SS, sacral slope; PT, pelvic tilt; MRI, magnetic resonance imaging; MF, multifidus; ES, erector spinae; PS, psoas major; TE, echo time; TR, repetition time; DFOV, display field of view; NEX, number of excitations; PS, psoas major muscle

Key words: degenerative lumbar spinal stenosis, spinal-pelvic sagittal parameters, paravertebral muscles, fatty infiltration, magnetic resonance imaging

Therefore, paravertebral muscle mass is an important factor for the entire process of lumbar degeneration. Paravertebral muscle degeneration is associated with the development of a variety of lumbar diseases and the emergence of postoperative complications (6-9).

Previous studies on DLSS have mostly investigated the sagittal imbalance of the spine-pelvis or the degeneration of paravertebral muscles (10-13). However, the combination of the two has not been explored, to the best of the authors' knowledge, resulting in imperfect treatment options and ultimately affecting therapeutic outcomes. Therefore, the literature on DLSS, spinal-pelvic sagittal imbalance, and paravertebral muscle degeneration was reviewed and the present study was designed to analyze the link between lumbar paravertebral muscles and spinal-pelvic parameters in patients with DLSS by measuring the parameters associated with lumbar paravertebral muscles and spinal-pelvic sagittal position. The results obtained in the present study may provide a basis for the subsequent treatment and prognosis of DLSS.

Materials and methods

Study design. A total of 165 patients and healthy volunteers with lumbar spinal stenosis who were admitted to Ordos Central Hospital for treatment between January 2020 and January 2022 were included. Among all the patients (n=165) who participated in the present study, there were 72 men and 93 women, ranging in age from 53 to 80 years old, including 95 patients in the experimental group (patients with DLSS) and 70 patients in the control group (healthy volunteers). The present study was approved by the Ethics Committee of Ordos Central Hospital (Ordos, China; approval no. 2022-012). Informed consent was obtained from all subjects and/or their legal guardians for the present study.

Inclusion and exclusion criteria. The inclusion criteria consisted of a clinical diagnosis of DLSS including spondylolisthesis (I° or II°), with lumbar magnetic resonance imaging (MRI) and defined as single-segment stenosis, including central canal stenosis and/or lateral recess stenosis, spinal x-ray, radiating pain in the lower extremity and/or neurogenic claudication after a single trip of less than 100 m.

The exclusion criteria consisted of other spinal and soft tissue diseases, such as spinal trauma, spinal infection, spinal metastatic lesions, spondylolisthesis (III° or IV°), a history of spinal surgery, severe osteoarthritis of the hip and knee, lower limb paralysis, Parkinson's disease, multiple sclerosis, soft tissue tumors, or infections.

The inclusion criteria for the control group were individuals with lumbar MRI and spinal X-ray. No history of any lumbar disease, low back pain, radiation pain in the lower extremities, and neurogenic claudication. The exclusion criteria were the same as in the experimental group.

Imaging examination

Spinal X-ray. A universal digital radiography system (General Medical Merate S.p.A.) was used to obtain anteroposterior and lateral radiographs of the full-length spine. Lateral images were imported into Surgimap (v2.3.2.1; Nemaris, Inc.) to measure and calculate each sagittal parameter.

Lumbar MRI. MRI was performed using a Signa HDxt 3.0T magnetic resonance scanner (GE Healthcare). For conventional MRI scans of the sagittal fat-suppressed FSE T2WI, the following settings were used: Echo time (TE)=42.72; repetition time (TR)=3,246; display field of view (DFOV)=31x31 cm; slice thickness=4, interslice distance=5 and number of excitations (NEX)=2. For cross-sectional T2WI the following settings were used: TE=123.66; TR=2854; DFOV=20x20 cm; slice thickness=4; interslice distance=5; NEX=2. In the present study, the location and degree of compression of spinal stenosis were observed primarily through multiple angles in the axial and sagittal planes. The responsible lesion was confirmed in accordance with the medical history and clinical signs of the patients, and the cross-sectional MRI T2WI corresponding to the lesion was selected as the baseline image for measurement.

Evaluation indicators

Spine-pelvic parameters. Surgimap allowed the measurement of spine-related parameters. Lafage *et al* (14) confirmed that the application of Surgimap to calculate the relevant parameters had the advantages of shorter processing periods, less errors and easier data storage compared with traditional manual methods, and was thus suitable for clinical use. Full-length X-ray lateral images of the standard spine as JPG files were imported from the Radiology Department into Surgimap to measure the spinal sagittal parameters separately according to the corresponding operating criteria (Figs. 1 and 2).

Paraspinal muscle parameters. After image selection, a region of interest was drawn using ImageJ (v1.53c; National Institutes of Health) (Fig. 3), and the bilateral paravertebral muscles cross-sectional area (CSA) of the upper vertebral body at the lesion space, and subcutaneous fat extent were demonstrated and analyzed. The relative CSA (RCSA) was calculated using the following formula: Paravertebral muscle area/vertebral body area x 100% (the interindividual difference mostly decreased using this ratio). Furthermore, the software threshold technique (15) was used to measure the gray values of paravertebral muscles and the subcutaneous fat (Fig. 4), which were subsequently imported into Microsoft® Excel for Mac (v.16.48; Microsoft Corporation) and line graphs were created for analysis (Fig. 5). The ratio of the gray values of the coincident parts of the two to the gray values of paravertebral muscles was used to calculate the fatty infiltration ratio (FIR) (16). It is important to note that if the areas of interest of the multifidus and erector spinalis muscles cannot be drawn on the lumbar MRI, the case will be excluded. All parameters were measured using an independent attending physician.

Statistical analysis. Statistical analysis was performed using IBM SPSS Statistics (v.26.0; IBM Corp.). Continuous data are presented as the mean ± SD. An independent samples Student's t-test was used for comparison between two groups (two-tailed tests). A paired samples Student's t-test was used for comparison within a group (two-tailed tests). A one-way ANOVA was used for comparison between multiple groups (one-tailed tests). If the difference was statistically significant, Tukey's post hoc test was used for pound-wise comparison after the fact. Categorical data have been presented as frequencies (percentages). A Pearson's χ^2 test was used for comparison

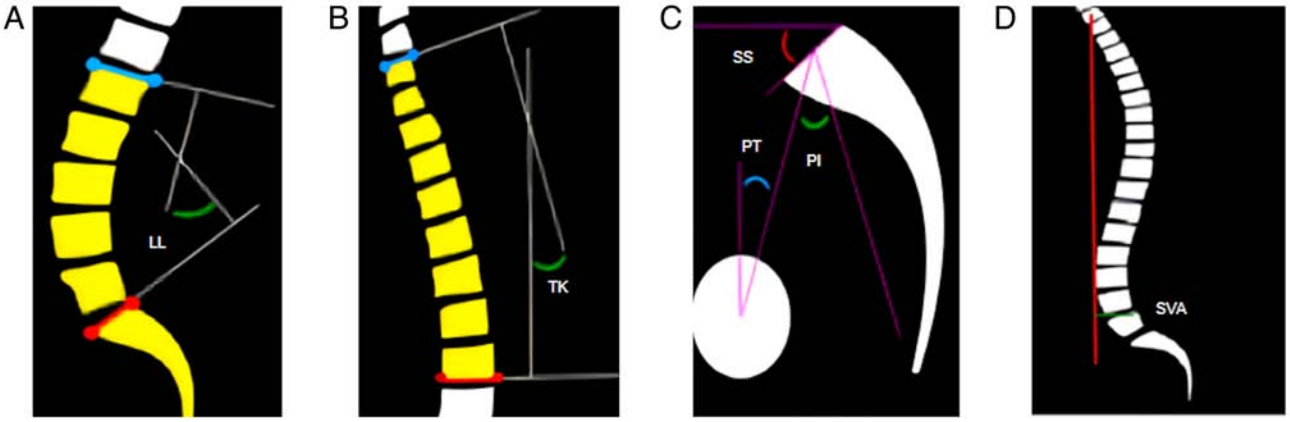

Figure 1. Measurement diagram developed using Surgimap. (A) LL, the angle formed by the tangent of the upper edge of the L1 vertebral body and the tangent of the upper endplate of the S1 vertebral body. (B) TK, the angle formed by the tangent of the upper edge of the T4 vertebral body and the tangent of the lower edge of the T12 vertebral body. (C) PT, passing through the middle of the upper endplate of S1, a straight line between the point and the midpoint of the line connecting the centers of the bilateral femoral heads was added in order to exhibit the angle formed by the straight line and the long axis of the body. SS, the angle formed by the tangent line of the upper endplate of S1 and the horizontal line. PI, a straight line through the midpoint of the line connecting the midpoint of the upper endplate of S1 and the center of the bilateral femoral heads was added. The angle formed by the vertical line of the upper endplate of S1 is depicted. (D) SVA, the distance between the plumb line of the seventh cervical vertebra and the posterior upper angle of the first sacrum. LL, lumbar lordosis; TK, thoracic kyphosis; PT, pelvic tilt; SS, sacral slope; PI, pelvic incidence; SVA, sagittal vertical axis.

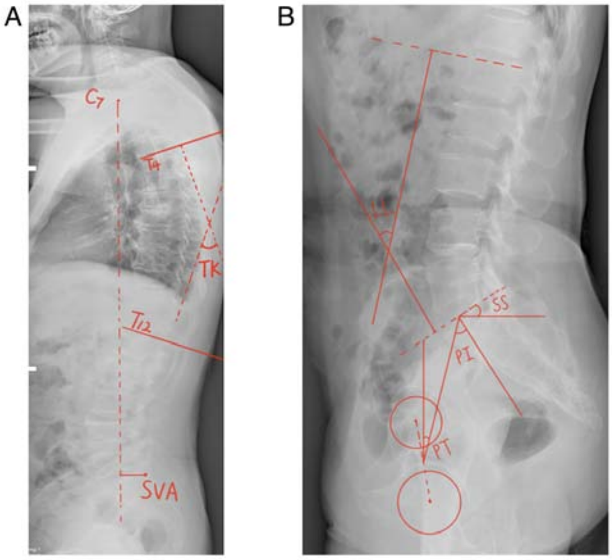

Figure 2. Spine-pelvic parameters measured using Surgimap. (A) TK, the angle formed by the tangent of the upper edge of the T4 vertebral body and the tangent of the lower edge of the T12 vertebral body. SVA, the distance between the plumb line of the seventh cervical vertebra and the posterior upper angle of the first sacrum. (B) LL, the angle formed by the tangent of the upper edge of the L1 vertebral body and the tangent of the upper endplate of the S1 vertebral body. PT, passing through the middle of the upper endplate of S1, a straight line between the point and the midpoint of the line connecting the centers of the bilateral femoral heads was created, and the angle formed by the straight line and the long axis of the body is depicted. SS, the angle formed by the tangent line of the upper endplate of S1 and the horizontal line. PI, a straight line through the midpoint of the line connecting the midpoint of the upper endplate of S1 and the center of the bilateral femoral heads was added. The angle formed by the vertical line of the upper endplate of S1 is revealed. LL, lumbar lordosis; TK, thoracic kyphosis; PT, pelvic tilt; SS, sacral slope; PI, pelvic incidence; SVA, sagittal vertical axis.

of the distribution between two groups (two-tailed tests). A Spearman's rank correlation analysis was used for correlation analysis (two-tailed tests). P<0.05 was considered to indicate a statistically significant difference.

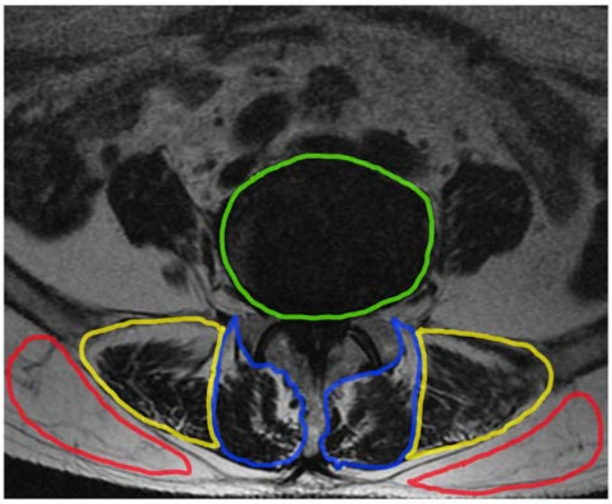

Figure 3. Example of the area of interest defined using ImageJ. Erector spinae CSA is indicated by yellow color, CSA of the target vertebral body is indicated by green, multifidus-CSA by blue and subcutaneous fat range by red. CSA, cross-sectional area.

Results

Analysis of general data results. A total of 165 subjects were included in the present study, including 70 subjects in the control group and 95 in the experimental group. The mean age of the experimental group (L4-5 group, 67.44±10.98 years; L5-S1 group, 64.17±4.9 years). The age range was 57-83 years. There were no statistically significant differences in age, sex, or body mass index amongst the three groups (P>0.05; Table I). In the experimental group, 66 patients had symptoms of low back pain, accounting for ~70% of the whole experimental group, and 33 patients revealed scoliosis on the spinal X-ray (Fig. 6).

Analysis of the spine-pelvis parameters. Pelvic incidence (PI), pelvic tilt (PT) and sagittal vertical axis (SVA) values were

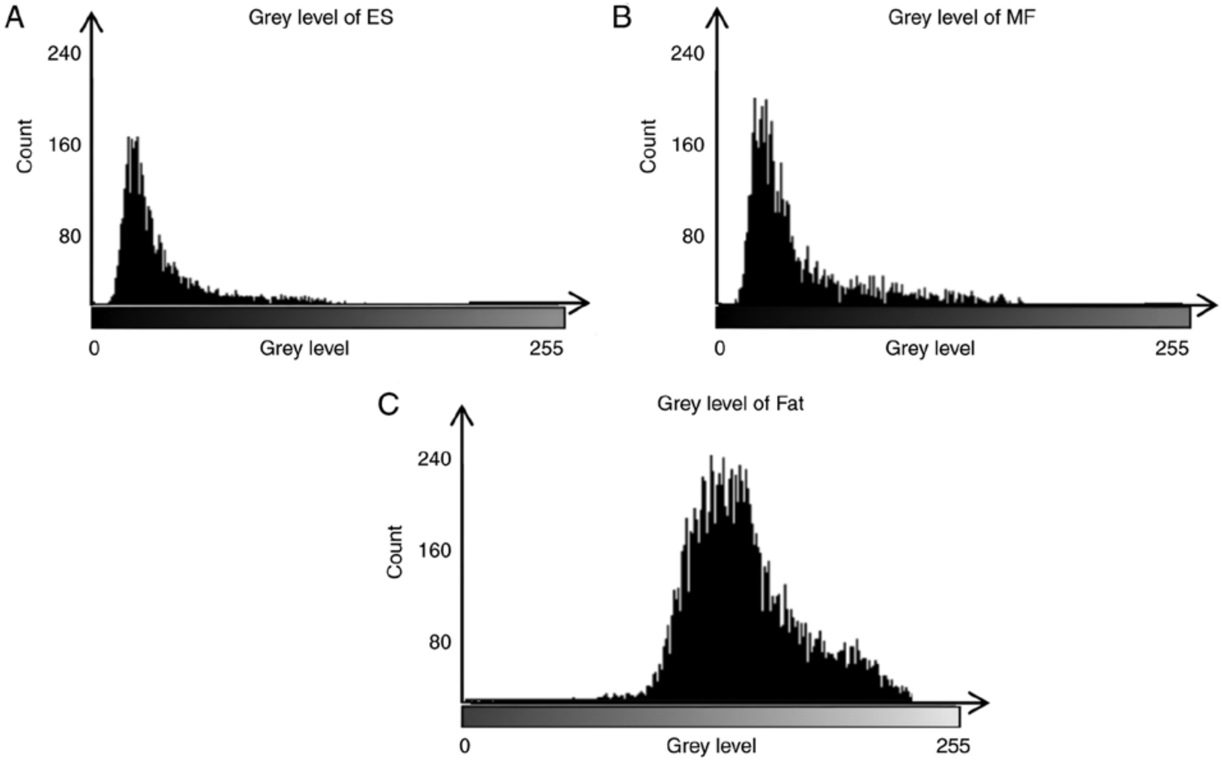

Figure 4. Grey-scale map of paravertebral muscle and subcutaneous fat constructed using ImageJ. (A) ES, (B) MF, (C) subcutaneous fat. MF, multifidus; ES, erector spinae.

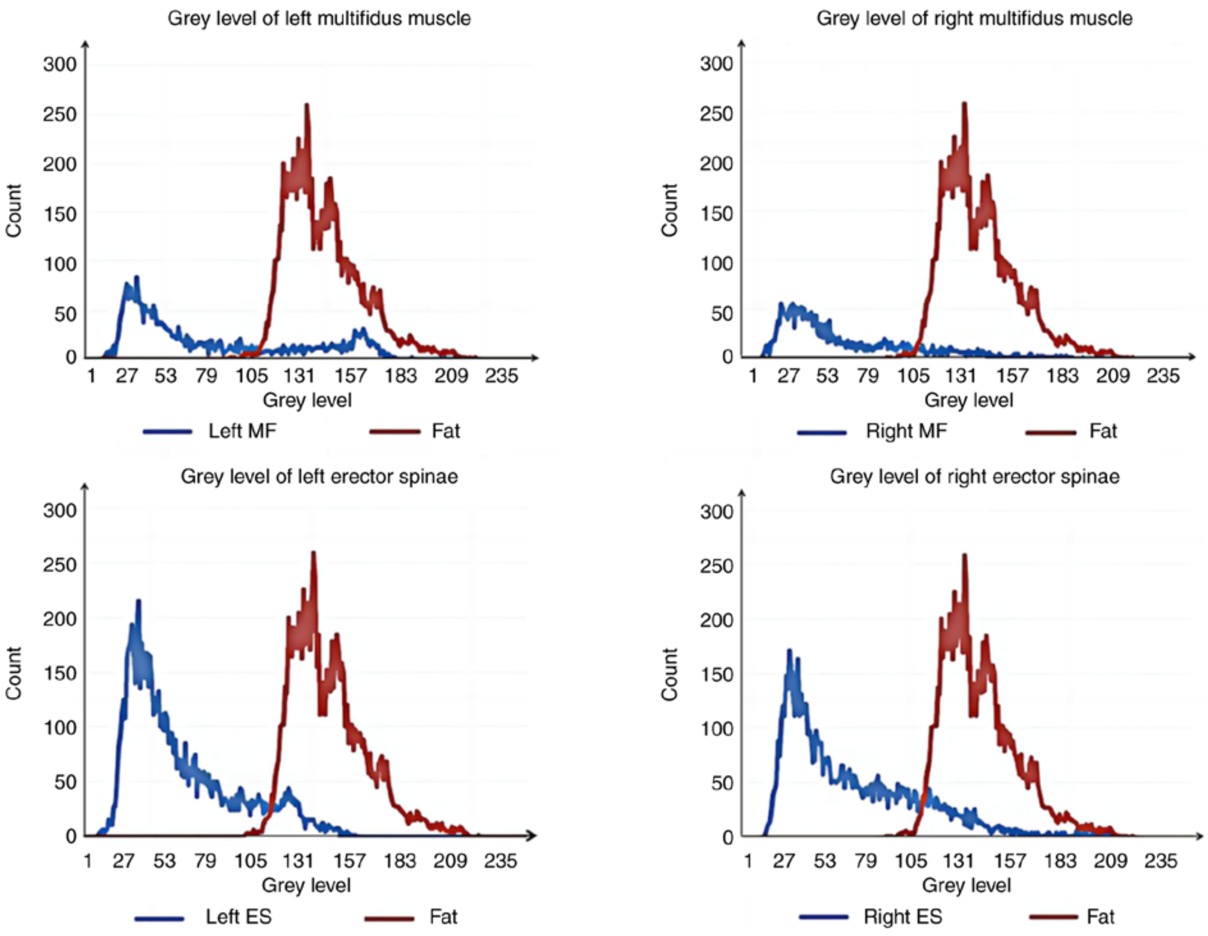

Figure 5. Gray Value Distribution Line Plot. Blue line, MF/ES muscle gray distribution; red, subcutaneous fat gray distribution. MF, multifidus; ES, erector spinae.

Table I. Clinicopathological characteristics of the study population

Clinicopathological characteristics	DLSS (L4-5)	DLSS (L5-S1)	Control group	χ^2/F	P-value
Male, n (%)	22 (44.9)	21 (45.7)	29 (41.4)	0.246	0.884
Female, n (%)	27 (55.1)	25 (54.3)	41 (58.6)		
Age, years	67.44±10.98	64.17±4.9	63.91±8.97	2.272	0.111
Body mass index (kg/m^2)[a]	21.68±3.3	22.66±2.83	22.95±2.32	2.651	0.074

[a]Mean ± SD. DLSS, degenerative lumbar spinal stenosis.

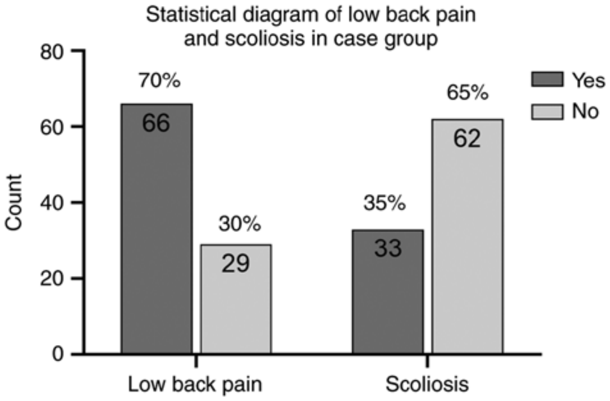

Figure 6. Statistical diagram of low back pain and scoliosis in case group. Low back pain and scoliosis is described by the X-axis while the number of people is revealed by the Y-axis.

significantly higher in patients with DLSS compared with the controls, in contrast, lumbar lordosis (LL) was significantly lower. Post-hoc test results revealed that there were no significant differences in all indexes between L4-5 and L5-S1 patients (all P>0.05; Table II).

Analysis of paravertebral muscle parameters. There were no significant differences in the bilateral multifidus (MF), the ratio of fat infiltration in the erector Spinus muscle (ES FIR), and RCSA within the control group (P>0.05).

Both right MF FIR and right ES FIR were significantly higher in patients with DLSS (L4-5) than in the ipsilateral controls, and the right MF FIR was higher than its contralateral (all P<0.05). The left and right MF-RCSA were significantly lower in patients with DLSS (L4-5) than in the ipsilateral ES-RCSA (P<0.05). In addition, left and right MF RCSA were significantly lower in the control group than in the ipsilateral ES RCSA as well (P<0.05). There was no significant difference in the CSA of the upper vertebral body between the DLSS patient group (L4-5) and the control group (P>0.05) (Table III).

The right MF-FIR in the DLSS (L5-S1) patients was significantly higher than that in the ipsilateral side of the control group (P<0.05). MF RCSA in both the left and right sides in DLSS patients was significantly higher than that in the ipsilateral side ES RCSA (P<0.05) MF RCSA in both the left and right sides in the control group was significantly higher than that in the ipsilateral ES RCSA (P<0.05). There was no significant difference in the upper vertebral body CSA values between patients with DLSS (L5-S1) and the control group (P>0.05) (Table IV).

Correlation analysis of the paraspinal parameters with the spinal-pelvic sagittal parameters. In the DLSS (L4-5) patient group, right ES FIR was negatively correlated with thoracic kyphosis (TK). Left MF RCSA was positively correlated with TK, whilst the left ES RCSA was negatively correlated with SVA (all P<0.05). In the DLSS (L5-S1) group, there was a significant positive correlation between the right MF RCSA and right ES RCSA with TK (both P<0.05) (Table V).

Discussion

DLSS is affected by spine-pelvis sagittal imbalances since the beginning and during the progression and outcome of the disease. The study of the relationship between DLSS and spine-pelvis sagittal imbalances is important for the prediction of the occurrence, development, prognosis, improvement and therapeutic management of the condition. A previous study demonstrated that spinal-pelvic sagittal balance should satisfy the following values: SVA <40 mm; PI-LL <10˚ and PT <20˚ (17). The quality of life scores of the patients were higher when SVA was <50 mm. However, when SVA was ≥50 mm, patients exhibited severe clinical symptoms, and quality of life scores also decreased notably. Thus, SVA ≥50 mm was considered indicative of spinopelvic sagittal imbalance. In the present study, patients with DLSS had an SVA value of >50 mm (64.10±34.40 mm), a PI-LL value of >10˚ (11.91˚±16.17˚) and a PT value of >20˚ (22.02˚±7.27˚), thus, indicating significant sagittal imbalance. This was inconsistent with Lim and Kim (18) who obtained normal PI values and favorable spinal-pelvic sagittal balance in patients with DLSS during comparative analysis of spinal-pelvic sagittal balance parameters between degenerative spondylolisthesis and patients with DLSS, possibly due to ethnic differences and differing lifestyles. The present study also observed that patients with DLSS had a larger PI. Amongst the sagittal parameters, PI is of special interest. Mac-Thiong *et a*l (19) identified that PI values were constant after skeletal development was completed in each person and that they did not change the posture in the receptor position. In the present study, the patient group had a larger PI value, indicating that a larger PI value may be one of the risk factors for DLSS.

In the present study, it was also revealed that patients with DLSS had a larger SVA, PT, PI and smaller LL than the

Table II. Spinal-pelvic sagittal parameters in the DLSS patients and control group.

	DLSS patient group		
Indicator	L4-5	L5-S1	Control group
SVA, mm	63.95±28.31[a]	64.3±42.56[a]	37.07±22.77
TK, °	32.49±13.77	30.73±4.87	31.9±10.85
LL, °	39. 20±11.83[a]	38.92±8.89[a]	46.83±10.72
PI, °	52.63±10.14[a]	49.62±8.92[a]	41.07±10
PT, °	22.39±6.94[a]	21.54±7.97[a]	11.64±7.28
SS, °	29.88±6.27	31.01±4	29.42±7.2

[a]$P<0.05$ vs. control group. DLSS, degenerative lumbar spinal stenosis.

control group, which was consistent with the study conducted by Barrey *et al* (20), and again demonstrated that patients with DLSS are likely to exhibit sagittal imbalances. Three bulges of the human spine, cervical anterior, and TK, can be clearly observed from lateral radiographs of the whole spine in normal population, and these are associated with the pelvis through LL. The lumbar spine is the link between the spine and the pelvis, and the imbalance of the spine in the sagittal position eventually affects the changes in pelvic parameters through the conduction of LL, thus, it is important to maintain the balance of the spinopelvic LL in the sagittal plane. Based on the results of the present study, LL was decreased compared with the healthy individuals; if LL is smaller, the physiological curvature of the lumbar spine is straighter in patients, which is reflected in the body posture by significant anteversion and forward movement of the center of gravity; the body has to compensate for pelvic retroversion in order to correct this posture, thus PT is increased. The physiological curvature of the lumbar spine disappears, the lumbar regions bear more burden from the body, and degeneration of the lumbar spine, facet joint hyperplasia, and ligamentum flavum hypertrophy occur over time. The results of the present study highlight certain avenues for future surgical treatment of DLSS, and surgery should not only decompress the spinal canal at the affected level, but also appropriately correct the imbalances in the sagittal position.

The psoas major muscle (PS) of the anterior group and MF and ES of the posterior group in the paravertebral muscles are often referred to as spinal dynamic stabilizers (21,22). PS maintains lumbar anteversion and curvature (23), MF aids rotational motion of the lumbar spine (24), and ES participates in lumbar flexion and extension (25). A previous study demonstrated that PS shows no obvious signs of fatty infiltration in either normal subjects or patients with lower back pain (26), thus, only MF and ES for FIR and RCSA were measured and compared. Paravertebral muscle degeneration, including decreased muscle fibers and increased fatty infiltration, is associated with the development and progression of a variety of lumbar diseases and the development of postoperative complications (9,27). The physiological function of an individual muscle is reflected in muscle CSA and density (28). Denervation and disuse decrease muscle CSA while increased fatty infiltration decreases muscle density (29). In the present study, it was identified that the right MF FIR was significantly higher in patients with DLSS than in ipsilateral controls, which is consistent with the findings of Lee *et al* (30) who exhibited a significantly higher degree of fatty infiltration in the paravertebral muscles of patients with spinal degeneration than in healthy subjects. Within muscle per unit area, the higher the degree of fat infiltration, the fewer the muscle fibers, and the lower the muscle strength. The maintenance of lumbar stability is inseparable from the action of paravertebral muscles. When the muscle strength decreases to a point where the muscle is insufficient to maintain lumbar stability, pain and discomfort are experienced in the lumbar region. Lower back pain was the primary symptom in 70% of the cases included in the present study. It was also observed that at the L4-5 group, the right MF FIR in patients with DLSS was higher than that in the contralateral side, indicating that the right MF muscle strength was lower than that in the left side, which is similar to the results of Jiang *et al* (16). However, Shafaq *et al* (31) revealed in their study that there were no significant differences in the CSA of bilateral MF and the degree of fat infiltration in patients with DLSS alone. Thus, it was hypothesized by the authors of the present study that when there is a different degree of fatty infiltration in the left and right lumbar muscles, the strength of the muscles on both sides is inconsistent, and this will result in significant left and right tilt in the lumbar region, followed by scoliosis and coronal imbalance. A total of 33 patients who were included in the present study, exhibited significant scoliosis on admission. A retrospective study observed that both DLSS (L4-5) and degenerative spondylolisthesis (L4-5) patients had a smaller PS CSA, MF CSA, and ES CSA at the lower edge of L3, L4, and L5 vertebral bodies than in the controls. However, the CSA studied failed to exclude deviations caused by individual body size. In the present study, the RCSA was calculated using an adjusted calculation method described by Urrutia *et al* (29), thus, eliminating the effect of individual differences on the results. However, no significant difference in RCSA was identified between the patient group and the control group, indicating that the degeneration of the paravertebral muscles was primarily due to fatty infiltration, and the RCSA of the muscles did not change notably. Patients with DLSS exhibited a greater degree of severe paravertebral muscle degeneration (greater degree of fatty infiltration), and lower functional scores (32,33). The results of the present study also demonstrated that right and left MF RCSA were significantly lower than ipsilateral ES RCSA at L4-5, while right and left MF RCSA was significantly higher than ipsilateral ES RCSA at L5-S1 in both patients with DLSS and controls, and this finding may be associated with natural morphological changes in human MF and ES. Fortin *et al* (33) observed similar results in their study.

A previous study revealed that standardized exercise of the paravertebral muscles slowed the progression of DLSS (34). The early symptoms of discomfort in patients with DLSS can be relieved by exercising the lower back muscles, using acupuncture, massaging, and other traditional Chinese medicine treatment methods to relieve paravertebral muscle fatigue, with small swallow fly and other movements to strengthen

Table III. Paravertebral muscle parameters in the DLSS patients (L4-5) and control group.

	DLSS patient group (L4-5)		Control group	
Indicator	Right	Left	Right	Left
MF-FIR, %	19.23±5.12[a,b]	15.23±7.38	15.45±3.82	14.89±3.86
ES-FIR, %	18.86±7.62[a]	12.6±13.46	12.70±2.26	12.53±1.00
MF-CSA, mm^2	738.95±307.57	707.46±295.31	927.47±167.98	948.92±219.73
ES-CSA, mm^2	1,092.77±389.81	1,099.69±337.68	898.4±110.42	932.76±107.48
MF-RCSA, %	41.08±21.44	43.17±16.64	39.64±7.95	40.25±7.87
ES-RCSA, %	52.65±12.84	56.73±16.41	48.64±8.47	49.99±5.43
Upper vertebral body CSA, mm^2	1,931.89±388.23	-	1,881.14±279.68	-

[a]P<0.05 vs. ipsilateral control group; [b]P<0.05 vs. contralateral value within the same group. MF, multifidus; ES, erector spinae; FIR, fat infiltration in the right; CSA, cross-sectional area; RCSA, relative CSA; DLSS, degenerative lumbar spinal stenosis.

Table IV. Paravertebral muscle parameters in DLSS patients (L5-S1) and control group.

	DLSS patient group (L5-S1)		Control group	
Indicator	Right	Left	Right	Left
MF-FIR, %	19.59±6.56[a]	18.42±3.41	14.98±3.43	15.84±2.82
ES-FIR, %	13.00±7.00	14.13±5.59	13.67±2.04	14.53±2.41
MF-CSA, mm^2	696.32±200.41	857.71±242.24	840.43±146.76	851.95±123.32
ES-CSA, mm^2	1,039.28±269.05	1,044.17±313.66	817.07±122.82	834.6±134.77
MF-RCSA, %	58.99±30.10	62.87±21.96	47.35±6.75	48.24±7.00
ES-RCSA, %	39.92±14.04	41.01±22.74	36.44±8.04	27.48±9.61
Upper vertebral body CSA, mm^2	1,914.92±310.66	-	1,781.91±251.36	-

[a]P<0.05 vs. ipsilateral control group. MF, multifidus; ES, erector spinae; FIR, fat infiltration in the right; CSA, cross-sectional area; RCSA, relative CSA; DLSS, degenerative lumbar spinal stenosis.

the strength of the core muscle groups in the lower back. Preoperative exercise of the lower back muscles can reduce the early clinical symptoms of patients with DLSS and the frequency of the disease. Postoperative exercises of the lower back muscles can improve the prognosis and improve the quality of life of patients. Notably, exercising the lower back muscles improves lumbar degenerative diseases, whilst healthy individuals should also strengthen the lower back muscles to prevent the occurrence of lumbar degenerative diseases.

The relationship between spinal-pelvic sagittal imbalance and paravertebral muscle degeneration has become a research hotspot in recent years. The results of the present study showed that the ratio of fat infiltration in the right ES FIR was negatively associated with TK in patients with DLSS at L4-5, similar to that observed by Jun *et al* (35), in which imaging data from 50 elderly patients were analyzed. They concluded that paravertebral muscle FIR was associated with TK. Thus, the imbalance in the sagittal position of the body (increased TK) requires greater muscle strength to correct, and greater muscle strength can only be demonstrated when the muscle FIR is smaller. Hiyama *et al* (36) detected that the mean CSAs of PS at L4 and L5 were negatively associated with PT by analyzing data from 140 patients with DLSS. Although PS was not studied in detail, MF RCSA and ES RCSA were identified to be positively associated with TK in patients with DLSS patients in the present study. When the lower lumbar spine loses its physiological curvature, LL becomes smaller, the body shows significant anteversion, the center of gravity moves forward, SVA and TK increase in order to maintain the overall balance of the body in the sagittal position, the pelvis compensates for retroversion. However, the pelvic retroversion is controlled by the paravertebral muscles, and the strength producing ability of the muscles is related to their physical size, and greater muscle strength is required to ensure the stability of the lumbar spine. Thus, when TK increases, the lower lumbar spine requires a larger RCSA. Overall, to the best of the authors' knowledge, there are no studies investigating the relationship between spinal-pelvic sagittal imbalance and paravertebral muscle degeneration in patients with DLSS, and it is expected that the results obtained in the present study will

Table V. Correlation analysis between the paravertebral muscle parameters and spinal-pelvic parameters in patients with DLSS .

	SVA		TK		LL		PI		PT		SS	
Indicator	L4-5	L5-S1	L4-5	L5-S1	L4-5	L5-S1	L4-5	L5-S1	L4-5	L5-S1	L4-5	L5-S1
MF-FIR, %												
Right	-0.087	-0.252	0.000	-0.21	0.082	0.189	0.238	0.140	0.077	-0.105	0.294	-0.091
Left	-0.075	0.231	-0.056	0.245	0.000	-0.035	-0.309	0.357	-0.372	0.336	-0.054	-0.315
ES-FIR, %												
Right	0.346	-0.021	-0.536[a]	0.392	-0.411	0. 224	0.172	-0.252	0.099	0.133	0.304	-0.063
Left	0.054	-0.14	-0.456	0.371	-0.272	0.566	0.119	-0.133	0.091	0.119	0.216	0.329
MF-RCSA, %												
Right	0.297	0.308	0.121	0.685[a]	0.156	-0.252	-0.241	-0.35	-0.376	0.245	0.118	0.308
Left	-0.224	-0.217	0.502[a]	-0.329	0.300	-0.028	0.021	-0.266	-0.146	0.098	-0.023	0.175
ES-RCSA, %												
Right	0.126	-0.028	0.182	0.615[a]	0.1 74	-0.112	-0.097	-0.203	-0.374	-0.042	0.077	0.343
Left	-0.504[a]	-0.168	0.393	0.154	0.1 50	-0.056	-0.186	0.231	-0.044	-0.238	-0.200	0.105
Upper vertebral body CSA, mm^2	-0.103	-0.098	0.097	-0.315	-0.044	-0.252	-0.009	-0.343	0.262	-0.035	-0.118	-0.434

[a] $P<0.05$. MF, multifidus; ES, erector spinae; FIR, fatty infiltration ratio; CSA, cross-sectional area; RCSA, relative CSA; DLSS, degenerative lumbar spinal stenosis; LL, lumbar lordosis; TK, thoracic kyphosis; PT, pelvic tilt; SS, sacral slope; PI, pelvic incidence; SVA, sagittal vertical axis.

highlight novel avenues for the improvement of the clinical basis for the treatment of DLSS.

The present study has several limitations. Due to the slow onset and long course of DLSS, the majority of patients opt for conservative treatment to manage the symptoms. However, surgical treatment is usually required for multi-segmental spinal stenosis. Therefore, fewer patients with single-level spinal stenosis were enrolled in the present study, and subsequent studies should include more cases and consider each type of DLSS. A complete study would include simple to complex DLSS. Through the results of the present study, the general path of the occurrence and development of DLSS was determined. However, treatment could not be performed based on a single aspect, and other factors related to DLSS are key to treatment. When the patient is determined to have surgical treatment, the patient should be informed of the correct way to perform lumbar and dorsal muscle exercises, and initiate these exercises sometime before the operation. In order to increase the chances of rapid postoperative recovery, the patients should continue to perform long-term postoperative lumbar and dorsal muscle exercises to strengthen the rehabilitation effect. The correction of the sagittal position line and lumbodorsal muscle fat removal are the two aspects of fusion treatment, which may result in an improved rehabilitation effect. However, the relationship between the start time of preoperative lumbar and dorsal muscle exercises and the time of elective surgery needs to be determined. Under the premise of ensuring no delay in treatment, preoperative lumbar and dorsal muscle exercise should be assisted to increase the chances of a quicker recovery and fine treatment of single-stage/multi-stage spinal stenosis.

In conclusion, FIR and RCSA in the paraspinal muscles of patients with DLSS were associated with TK. Therefore, a comprehensive assessment of the individual differences in performance is necessary for the prevention and treatment of DLSS. For patients requiring surgical treatment, a detailed surgical plan should be developed prior to surgery. The correction angle of the spinal and pelvic-related parameters is critical, and reasonable post-operative core muscle exercises are particularly important.

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Availability of data and materials

All data generated or analyzed during this study are included in this published article.

Authors' contributions

KZ and WY prepared and revised the manuscript, KZ and TB contributed to the collection and analysis of the data. KZ and TB confirm the authenticity of all the raw data. CW, BX, TW, FG, QZ, HL, XT, TZ and GG contributed to the collection and classification of the data. YW and WY designed and supervised the overall research and revised the manuscript. All authors have read and approved the final version of the manuscript.

Ethics approval and consent to participate

All methods were carried out in accordance with the relevant guidelines and regulations. All experimental protocols were approved by the Ethics Committee of Ordos Central Hospital, Inner Mongolia Medical University (Ordos, China; approval no. 2022-012). Informed consent was obtained from all subjects and/or their legal guardians for the present study.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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