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CLINICAL ARTICLE

Relationships between Paraspinal Muscle and Spinopelvic Sagittal Balance in Patients with Lumbar Spinal Stenosis

Wei Wang, MD[1], Zhuoran Sun, MD[2,3,4], Weishi Li, MD[2,3,4], Zhongqiang Chen, MD[2,3,4]

[1]*Department of Orthopaedics, Tianjin Hospital, Tianjin and* [2]*Department of Orthopaedics, Peking University Third Hospital,* [3]*Beijing Key Laboratory of Spinal Disease Research and* [4]*Engineering Research Center of Bone and Joint Precision Medicine, Ministry of Education, Beijing, China*

Abstract

Objective: To investigate the relationships between measurements of paraspinal muscle and spinopelvic sagittal parameters and the predictive value of lumbar indentation value (LIV) on sagittal balance in patients with lumbar spinal stenosis.

Methods: It was a retrospective study. We collected the data of 110 patients, who were diagnosed as lumbar spinal stenosis from December 2018 to May 2019. The total cross-sectional area (tCSA), functional cross-sectional area (fCSA), and fatty infiltration (FI) of paraspinal muscle were measured. The spinopelvic sagittal parameters were also measured, including sagittal vertical axis (SVA), pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS), lumbar lordosis (LL), thoracic kyphosis (TK), and PI minus LL (PI-LL). Correlations between measurements of paraspinal muscle and sagittal parameters were investigated by Pearson correlation analysis. The multiple linear regression analysis was used to investigate the LIV, age, gender, and BMI for assessing spinopelvic sagittal balance. Receiver-operating characteristic (ROC) curve was used to find out the most optimum cut-off point of LIV for evaluating SVA.

Results: There were 42 males and 68 females in this study and the mean age was 59.9 ± 10.9 years old. By Pearson correlation analysis, MF tCSA showed significant association with LL ($r = 0.455$, $P < 0.01$) and PI-LL ($r = -0.286$, $P < 0.01$). MF fCSA had a significant correlation with LL ($r = 0.326$, $P < 0.01$) and PI-LL ($r = -0.209$, $P < 0.05$). LIV was also significantly correlated to spinopelvic sagittal parameters, including SVA ($r = -0.226$, $P < 0.05$), LL ($r = 0.576$, $P < 0.01$), TK ($r = 0.305$, $P < 0.01$), and PI-LL ($r = -0.379$, $P < 0.01$). By multiple linear regression analysis, LIV was independently associated with sagittal parameters, including PI-LL and SVA. The cut-off value of LIV for SVA ≤ 50 mm was 10.5 mm (AUC = 0.641). According to the best cut-off value, patients were divided into two groups. For patients with LIV ≤ 10.5 mm, the percentage of SVA ≤ 50 mm was 54.5% (18/33), while it was 83.1% (64/77) for patients with LIV >10.5 mm.

Conclusions: As a new index to evaluate paraspinal muscle atrophy, the LIV was independently correlated to spinopelvic sagittal balance. Degeneration of paraspinal muscle was associated with spinopelvic sagittal balance.

Key words: Cross-sectional area; Fatty infiltration; Lumbar indentation value; Multifidus; Paraspinal muscle; Spinopelvic sagittal parameter

Introduction

Lumbar spinal stenosis is the most common lumbar degenerative disease[1]. It is one of the most common diseases of the aging population that is associated with high social and economic burden[2]. The prevalence of relative and absolute acquired lumbar canal stenosis has been reported as

Address for correspondence Weishi Li, Department of Orthopaedics, Peking University Third Hospital, No. 49 North Garden Road, Haidian District, Beijing 100191, China. Email: puh3liweishi@163.com
Received 5 November 2020; accepted 21 March 2022

Orthopaedic Surgery 2022;14:1093–1099 • DOI: 10.1111/os.13264

Orthopaedic Surgery

22.5% and 7.3% of the normal population, respectively[3]. Neurogenic intermittent claudication is the typical symptom. The pathomechanism is that the decrease in the height of the intervertebral disks leads to bulging and tearing of the annulus fibrosus, foraminal stenosis, and overloading the facet joints. As a result, the dural sac is involved and the compression on nerve causes neurologic symptoms[4]. It is well-known that the patients with degenerative lumbar spinal stenosis have a forward-bending posture because epidural pressure is increased by upright posture and decreased by forward flexion[5].

Sagittal balance is a situation where the individual is able to maintain a stable standing position with minimal muscle effort. Spinopelvic sagittal alignment is important in lumbar degenerative diseases[6–11] and many studies investigated the spinopelvic sagittal parameters in standing position[12–15]. A previous comparative study found that the prevalence of sagittal imbalance was higher in patients with lumbar spine stenosis (LSS) compared with healthy people[16]. Spinal sagittal balance was important for the outcomes of patients with LSS[11,17]. Dohzono et al. investigated 88 patients with LSS and found that the low back pain was worse for patients with preoperative anterior translation of the C_7 plumb line than for those without. Lee *et al.* also found that the Oswestry Disability Index (ODI) and Visual Analog Score (VAS) showed greater improvement in the sagittal balance group than the sagittal imbalance group.

The sagittal balance of spine may be affected by the atrophy of paraspinal muscle, because paraspinal muscle plays an important role in maintaining stability. The cross-sectional area (CSA) and fatty infiltration (FI) are two keys in evaluating the paraspinal muscles[18–22], which represent the quantity and quality of paraspinal muscles, respectively. There was a significant correlation between the CSA of multifidus muscle (MF) and sagittal spinal alignment in patients with degenerative lumbar scoliosis[19]. Jun found that the quality of the paraspinal muscle may influence sagittal balance[23], while another study suggested that spinopelvic parameters had correlation with lumbar muscle volumes, but not with the FI of muscle for asymptomatic young adults[24]. There are disputes about the relationship between measurements of paraspinal muscle and spinopelvic sagittal parameters. The relationship between measurements of paraspinal muscle and spinopelvic sagittal balance in patients with LSS was unclear.

Besides, It is cumbersome to make sure the region of interest and measure the CSA and FI for evaluating the paraspinal muscle. Considering these factors, Takayama *et al.* introduced the lumbar indentation value (LIV) as a new index to evaluate paraspinal muscle degeneration[25]. It was easy and timesaving compared with the CSA and FI of paraspinal muscle.

So this study aimed (i) to investigate the correlations between measurements of paraspinal muscle and spinopelvic sagittal parameters, (ii) to investigate the correlations between the LIV and spinopelvic sagittal parameters, and (iii) to explore the predictive value of LIV on sagittal balance.

Methods

General Information

This was a single-institution retrospective study approved by the Ethics Committee of Peking University Third Hospital (No: M2019400). For this type of study, formal consent was not required. A total of 110 patients with LSS who underwent treatment in our hospital from 12 December 2018 to 12 May 2019 were included in this study. All of them presented with neurogenic claudication occasionally with concomitant radicular pain.

Inclusion and Exclusion Criteria

The inclusion criteria were (i) diagnosed was lumbar spinal stenosis, (ii) older than 18 years, (iii) had complete preoperative radiographic data. The exclusion criteria were (i) with neuromuscular diseases, (ii) with hip joint or knee joint disease, (iii) with history of former spinal surgery, (iiii) with neoplasm, infection, fracture, or spinal deformity.

Clinical Measurements

Spinopelvic Sagittal Parameters

A Discovery XR650 machine (General Electric Company) was used for all images. The radiographic parameters were measured by standing posteroanterior and lateral whole spine X-ray preoperatively. The parameters including sagittal vertical axis (SVA), thoracic kyphosis (TK), lumbar lordosis (LL), pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS), and PI minus LL (PI-LL) were measured by an experienced orthopaedic surgeon (Figure 1).

SVA was defined as the distance between the C_7 plumb line and posterior superior corner on the top margin of S_1, which reflected the overall sagittal balance of spine. TK was defined as the angle between the superior endplate of T_4 and the inferior endplate of T_{12}. LL was defined as the angle between the upper endplate of L_1 and the sacral plate. They reflected the local sagittal balance of spine. PI was defined as the angle between a perpendicular from the midpoint of upper endplate of S_1 and a line connecting the center of the femoral head to the center of the upper endplate of S_1. PT was defined as the angle between the vertical and the line through the midpoint of the sacral plate to femoral heads axis. SS was defined as the angle between the horizontal and the sacral plate. They reflected the pelvic morphology.

Paraspinal Muscle Measurements

Measurements of the MF and erector spinae muscle (ES) were obtained from T2-weighted images by Image J software. MRIs were required with Signa HDxt 3.0T (General Electric Company). Patients were placed in the supine position, with their legs straight and the lumbar spine

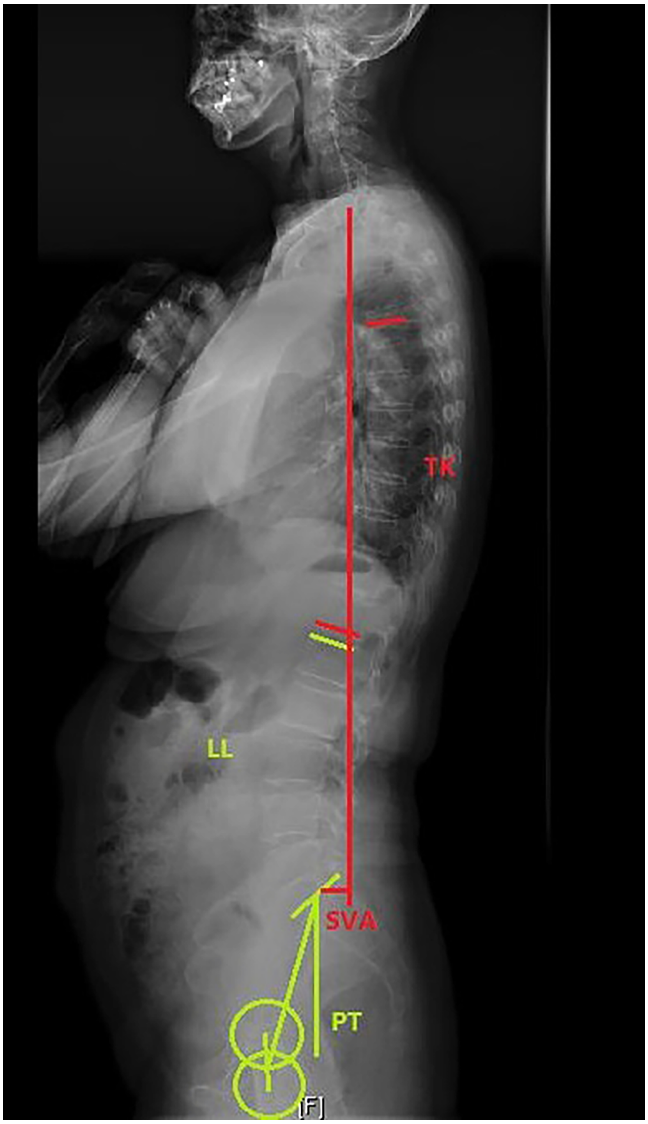

Fig. 1 Measurements of spinopelvic sagittal parameters, including SVA, PT, LL and TK. LL, lumbar lordosis; PT, pelvic tilt; SVA, sagittal vertical axis; TK, thoracic kyphosis

in a neutral posture. Axial MRI was parallel to the inferior endplate of the vertebral body. All muscles were measured bilaterally at the inferior vertebral endplate of L4. The mean value of left and right paraspinal muscle was calculated. Region of interest was used to measure muscular parameters, including total cross-sectional area (tCSA) (Figure 2), functional cross-sectional area (fCSA), and fatty infiltration (FI).

The fCSA was defined as the area of lean muscle tissue, which was measured by the thresholding technique (Figure 3). The FI was defined as the ratio of tCSA minus fCSA to tCSA. They reflected the degeneration of paraspinal muscles.

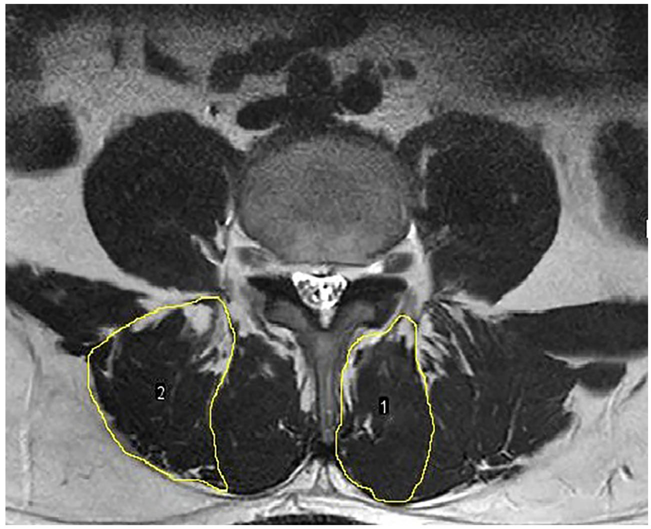

Fig. 2 Region of interest was used to measure the total cross-sectional area for the multifidus muscle and erector spinae muscle. 1, multifidus; 2, erector spinae muscle

Lumbar Indentation Value

Lumbar indentation value (LIV) was also an effective parameter for evaluating paraspinal muscle degeneration[25,26]. It was defined as the length of the line connecting the bilateral bulge of paraspinal muscles to the attachment of the spinous process (Figure 4). We measured LIV at L4 level using T2 axial MRI images. Compared with other paraspinal muscle parameters, it was easy and timesaving to measure.

Statistical Analysis

SPSS version 22.0 (IBM company) was used to analyze the collected data. All values were expressed as mean ± standard deviation. Age, BMI, paraspinal muscle parameters, and sagittal parameters were continuous variable while gender was a categorical variable. Correlations between measurements of paraspinal muscle and sagittal parameters were investigated by Pearson correlation analysis. The multiple linear regression analysis was used to investigate the LIV, age, gender, and BMI for assessing spinopelvic sagittal balance. To explore the predictive value of LIV on sagittal balance, we used receiver-operating characteristic (ROC) curve to find out the most optimum cut-off point that presented the largest Youden index. χ^2 test was done to compare categorical data in different groups. Statistical significance was set at P-value <0.05.

Results

General Data

There were 110 patients in this study, including 42 males and 68 females. The average age of patients was 59.9 ± 10.9 years with a range from 28 to 83 years. The

Fig. 3 Thresholding technique was used to highlight lean muscle area and obtain the functional cross-sectional area of paraspinal muscles. 1, multifidus; 2, erector spinae muscle

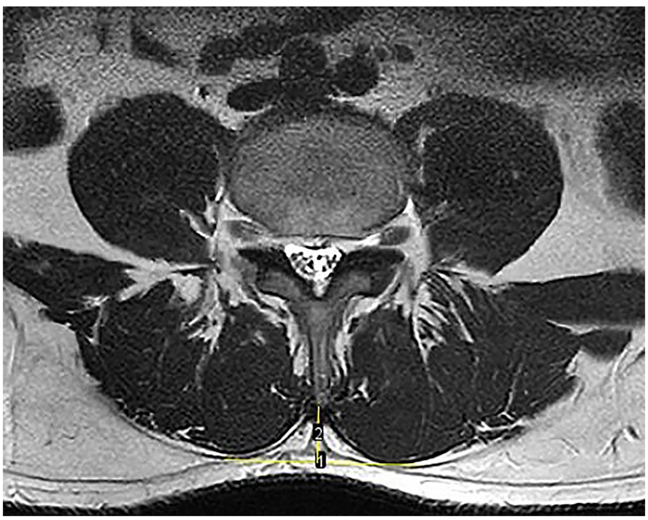

Fig. 4 Measurement of lumbar indentation value. 1, bulge of the paraspinal muscle. 2, the length of the bulge of paraspinal muscle to the attachment of the spinous process

mean value of body mass index (BMI) was 26.7 ± 3.2 kg/m^2. The mean Oswestry Disability Index scores were 56.7 ± 12.6. The mean Visual Analog Scale (VAS) was 5.8 ± 1.6. The mean and standard deviation of the different paraspinal muscle parameters and spinopelvic sagittal parameters are also presented in Table 1.

Correlations between Measurements of Paraspinal Muscle and Spinopelvic Sagittal Parameters

The association of paraspinal muscle parameters with spinopelvic sagittal parameters was measured by Pearson correlation analysis and the results were recorded in Table 2. MF tCSA showed significant association with LL ($r = 0.455$, $P < 0.01$) and PI-LL ($r = -0.286$, $P < 0.01$). MF fCSA had a significant correlation with LL ($r = 0.326$, $P < 0.01$) and PI-LL ($r = -0.209$, $P < 0.05$). LIV was also significantly correlated to spinopelvic sagittal parameters, including SVA ($r = -0.226$, $P < 0.05$), LL ($r = 0.576$, $P < 0.01$), TK ($r = 0.305$, $P < 0.01$), and PI-LL ($r = -0.379$, $P < 0.01$).

As shown in Table 2, we found that LIV showed the strongest correlations with SVA and PI-LL, which were important parameters to evaluate sagittal balance. To further investigate the effectiveness of LIV in predicting the sagittal balance, we used multiple linear regression analysis to evaluate the relationship between other factors and sagittal balance and the results were recorded in Table 3. LIV was independently associated with PI-LL ($P < 0.01$). With LIV decreasing, PI-LL increased. Similarly, we also evaluated the relationship for SVA. As showed in Table 4, age ($P = 0.001$), gender ($P = 0.004$), and LIV ($P = 0.011$) were independently correlated to SVA.

The Predictive Value of Lumbar Indentation Value on Sagittal Balance

To explore the predictive value of LIV on sagittal balance, we used ROC curves and calculated the Youden index. The patients were divided into sagittal balance group (SVA ≤ 50 mm) and sagittal imbalance group (SVA > 50 mm) (Figure 5). The best cut-off value of LIV for SVA was 10.5 mm (AUC = 0.641, sensitivity = 0.780, specificity = 0.536). According to the best cut-off value, patients were divided into two groups. For patients with LIV ≤ 10.5 mm, the percentage of SVA ≤ 50 mm was 54.5% (18/33), while it was 83.1% (64/77) for patients with LIV > 10.5 mm.

Discussion

Correlations between Cross-Sectional Area and Fatty Infiltration of Paraspinal Muscle and Spinopelvic Sagittal Parameters

Spinopelvic sagittal alignment is important in lumbar degenerative diseases[6–11]. In recent studies, paraspinal muscle's effect on sagittal balance was of great interest[23,24,27,28]. Jun *et al.* reviewed 50 elder patients' data and found a negative correlation between fatty degeneration of paraspinal muscle and LL[23]. But they only measured the whole paraspinal muscle rather than isolated muscle. Hiyama *et al.* found that the CSA of psoas major muscle correlated with PT[28]. Another study suggested that spinopelvic parameters had correlation with lumbar muscle volumes, but not with muscle fat infiltration for asymptomatic young adults[24]. There exist disputes for the relationship between paraspinal muscles and spinopelvic sagittal parameters, which was also unclear in patients with LSS.

In this study, we measured CSAs and FI of paraspinal muscles, which reflected the quantity and quality of them. We found that both MF tCSA and MF fCSA showed significant association with LL and PI-LL. It was consistent with previous results, which demonstrated that lumbar muscularity correlated with LL and PI-LL[23]. The results also showed that ES tCSA had a significant relationship to LL. The atrophy of paraspinal muscle was significantly associated with sagittal balance. Interestingly, measurements of MF showed a closer correlation with sagittal parameters than those of ES. We surmised that it may be related to the location of paraspinal muscle.

PT was also an important parameter for sagittal balance, reflecting the character of the pelvis. But in this investigation, it did not show any significant correlation with measurements of MF and ES. Measurements of MF and ES were significantly associated with spinal sagittal parameters, such as PI-LL and LL. It suggested that paraspinal muscles, including MF and ES, mainly affected curvature of spine rather than pelvis.

TABLE 1 Patients' characteristics

Variables	Value
Age (years)	59.9 ± 10.9
Gender (male/female)	42/68
BMI (kg/m^2)	26.7 ± 3.2
ODI	56.7 ± 12.6
VAS	5.8 ± 1.6
SVA (mm)	30.7 ± 42.1
PI (°)	47.7 ± 10.8
PT (°)	19.4 ± 8.0
SS (°)	28.3 ± 10.4
LL (°)	37.7 ± 14.8
TK (°)	27.7 ± 10.6
PI-LL (°)	10.0 ± 13.2
MF tCSA (mm^2)	927.8 ± 194.2
ES tCSA (mm^2)	1541.6 ± 344.3
MF fCSA (mm^2)	604.0 ± 197.3
MF FI (%)	35.6 ± 13.7
ES fCSA (mm^2)	1071.7 ± 316.5
ES FI (%)	30.9 ± 10.8
LIV (mm)	14.1 ± 5.9

Abbreviations: BMI, Body Mass Index; ES, erector spinae muscles; fCSA, functional cross-sectional area; FI, fatty infiltration; LIV, lumbar indentation value; LL, lumbar lordosis; MF, multifidus muscle; ODI, Oswestry Disability Index; PI, pelvic incidence; PI-LL, PI minus LL; PT, pelvic tilt; SS, sacral slope; SVA, sagittal vertical axis; tCSA, total cross-sectional area; TK, thoracic kyphosis; VAS, Visual Analog scale.

Relationship between the Lumbar Indentation Value and Spinopelvic Sagittal Parameters

LIV was also an effective parameter for evaluating paraspinal muscle degeneration[25,26], which equal to the length of the bulge of the muscle to the attachment of the spinous process. In this investigation, we found that there was a significant association between LIV and sagittal parameters, including SVA ($r = -0.226$, $P < 0.05$), LL ($r = 0.576$, $P < 0.01$), TK ($r = 0.305$, $P < 0.01$), and PI-LL ($r = -0.379$, $P < 0.01$). Compared with CSA and FI, LIV demonstrated a stronger correlation to sagittal parameters, such as PI-LL and SVA. Besides, it was easy and timesaving to measure LIV rather than CSA and FI.

To further evaluate the association of LIV with sagittal balance, we used multiple linear regression analysis to

TABLE 2 Correlations between measurements of paraspinal muscle and spinopelvic sagittal parameters

	SVA	PT	LL	TK	PI-LL
MF tCSA	−0.179	−0.131	0.455**	0.156	−0.286**
MF fCSA	−0.176	−0.138	0.326**	0.056	−0.209*
ES fCSA	0.064	−0.053	0.129	0.089	−0.111
ES tCSA	0.035	−0.041	0.191*	0.153	−0.163
MF FI	0.103	0.117	−0.075	0.095	0.064
ES FI	−0.081	0.065	0.019	0.045	−0.013
LIV	−0.226*	−0.043	0.576**	0.305**	−0.379**

Note: Correlations were investigated by Pearson correlation analysis. Data in the table present the correlation coefficient. Abbreviations: ES, erector spinae muscles; fCSA, functional cross-sectional area; FI, fatty infiltration; LIV, lumbar indentation value; LL, lumbar lordosis; MF, multifidus muscle; PI-LL, PI minus LL; PT, pelvic tilt; SVA, sagittal vertical axis; tCSA, total cross-sectional area; TK, thoracic kyphosis. * $P < 0.05$; ** $P < 0.01$.

TABLE 3 Results of multiple linear regression analysis in influencing factors of PI-LL

	Regression coefficient	Standardized coefficient	*T*-value	*p*-value
Age	0.150	0.123	1.352	0.179
Gender	−3.238	−0.119	−1.307	0.194
BMI	0.696	0.166	1.839	0.069
LIV	−0.939	−0.418	−4.572	<0.01**
Constant	0.890	—	0.072	0.943

Abbreviations: BMI, Body Mass Index; LIV, Lumbar indentation value. ** $P < 0.01$.

TABLE 4 Results of multiple linear regression analysis in influencing factors of SVA

	Regression coefficient	Standardized coefficient	*T*-value	*p*-value
Age	1.258	0.327	3.579	0.001**
Gender	−23.278	−0.270	−2.956	0.004**
BMI	1.007	0.076	0.837	0.405
LIV	−1.698	−0.238	−2.602	0.011*
Constant	−9.983	—	−0.254	0.800

Abbreviations: BMI, Body Mass Index; LIV, lumbar indentation value. * $P < 0.05$; ** $P < 0.01$.

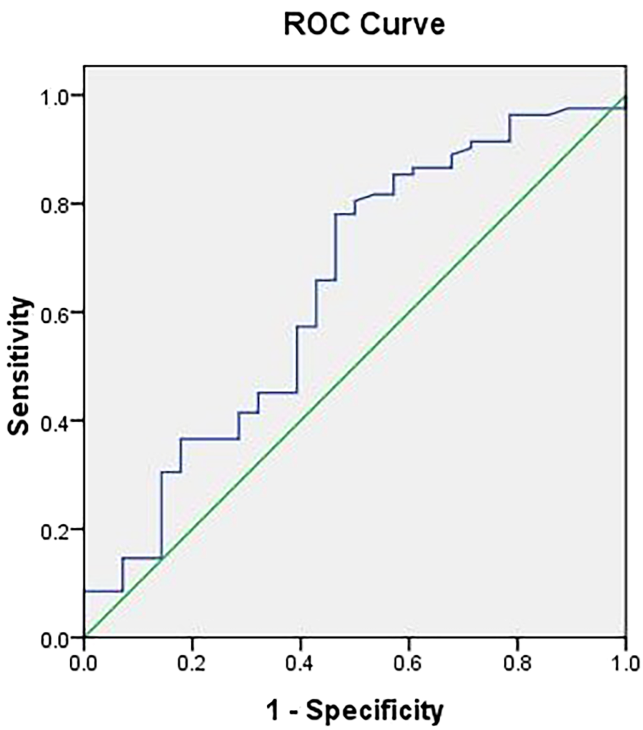

Fig. 5 ROC curve was used to find the optimum cut-off point of LIV to predict SVA

investigate the correlation between these factors, including age, gender, BMI, LIV, and sagittal balance. PI-LL and SVA are two key points to evaluate sagittal balance. Schwab *et al.* suggested that the ideal PI-LL should reach within ±10°, and the objectives of sagittal vertical axis (SVA) should be less than 50 mm[12,15], which had been widely used in clinical practice. Our results showed that LIV was independently associated with PI-LL and SVA (Tables 3 and 4), which demonstrated that the degeneration of paraspinal muscle was important for evaluating sagittal balance.

Based on SVA ≤ 50 mm, we calculated the best cut-off value of LIV for estimating sagittal balance. The best cut-off value of LIV for SVA was 10.5 mm. The percentage of SVA ≤ 50 mm was significantly higher in patients with LIV > 10.5 mm than that for patients with LIV ≤ 10.5 mm. From these results, LIV was a good parameter to evaluate spinal sagittal balance.

Limitations of the Study

In this study, we found that LIV was independently associated with sagittal balance. Similar to previous studies[29,30], we measured paraspinal muscle at L_{4-5} level. There were still some limitations to our investigation. Firstly, it was only a single-center retrospective study, which might have led to selection bias. Therefore, a multicenter prospective study is needed to further evaluate the paraspinal muscle's effect on spinopelvic sagittal balance. Besides, the sample size was relatively small. But as a novel and effective index for measuring paraspinal muscle degeneration, we found that LIV was valid for evaluating spinopelvic sagittal balance, which may be helpful for future investigations.

Conclusions

Both MF tCSA and MF fCSA showed significant relationships to LL and PI-LL. As a new index to evaluate paraspinal muscle atrophy, LIV was independently correlated to spinopelvic sagittal parameters, including SVA and PI-LL. It was suitable to evaluate spinopelvic sagittal balance. Degeneration of paraspinal muscle was associated with spinopelvic sagittal balance.

Conflict of Interest

The authors declare that they have no conflicts of interest.

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