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The clinical value of MRI scoring model in selecting surgical segments for lumbar spinal stenosis

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Abstract

Objective

This study aimed to investigate the association between MRI findings and clinical symptoms in patients with lumbar spinal stenosis (LSS), and to evaluate the utility of these findings in identifying the symptomatic level. We also assessed the performance of an MRI-based scoring model in assisting the selection of surgical levels in patients with LSS.

Methods

A retrospective, single-centre study was conducted involving 677 patients with LSS who underwent lumbar decompression surgery at Zhongda Hospital,affiliated with Southeast University, between January 2014 and January 2019. The MRI characteristics of all stenotic lumbar levels, together with relevant clinical data, were collected. Binary logistic regression analysis was used to identify independent factors associated with the responsible level, on the basis of which an MRI-based scoring model was developed and validated. The model's discriminative performance was evaluated using receiver operating characteristic (ROC) curve analysis in both the training and validation cohorts.

Results

No significant associations were observed between clinical symptoms and the quantitative MRI parameters used to assess stenosis severity at the surgically treated levels ($p > 0.05$). In contrast, significant associations were identified for the qualitative MRI parameters ($p < 0.05$). Binary logistic regression analysis demonstrated that the grades of central canal, lateral recess, and foraminal stenosis were independent predictors of the symptomatic level. Risk scores were assigned to each parameter according to its regression coefficient, resulting in a scoring system with a maximum total score of 9 points. The area under the receiver operating characteristic curve was 0.935. At an optimal cut-off value of 3 points, the sensitivity and specificity for identifying the symptomatic level were 86.9% and 90.9%, respectively.

Conclusion

This MRI-based morphological scoring system shows promising clinical utility for identifying symptomatic levels in patients with lumbar spinal stenosis. In the present study, decompression of stenotic levels with a total score of ≥3 was associated with superior clinical outcomes.

Key words

Lumbar spinal stenosis, magnetic resonance imaging, clinical symptoms, responsible segments, scoring model

Introduction

LSS is a clinical syndrome characterised by the proliferation of fibrous connective and osseous tissue, which reduces the space available for the lumbar dural sac, nerve roots, and blood vessels[1-3]. It is the most common indication for spinal surgery in individuals over 65 years of age[4]. The typical clinical manifestation of LSS is neurogenic intermittent claudication; some patients also experience radicular pain and sensory or motor deficits affecting both lower limbs[5]. MRI is currently the preferred imaging modality for diagnosing LSS[2]. LSS commonly presents with multilevel stenosis, involving the central spinal canal, bilateral lateral recesses, and intervertebral foramina[2]. However, not every stenotic level is symptomatic, even when the cross-sectional area of the dural sac is substantially reduced[6]. Blind decompression of all stenotic levels may result in excessive surgical exposure, prolonged operative times, and compromised lumbar stability, thereby increasing the risk of complications. Conversely, limited minimally invasive decompression may be insufficient and lead to unsatisfactory clinical outcomes. Consequently, more than one-third of patients fail to achieve substantial symptomatic relief after surgery[7]. Identifying MRI parameters that correlate with the severity of clinical symptoms is therefore clinically important. Nevertheless, the relationship between imaging findings and clinical symptoms in patients with LSS remains controversial[8-12]. In this study, we analysed MRI data from 677 patients with LSS who underwent lumbar decompression surgery at Zhongda Hospital,affiliated with Southeast University, between January 2014 and January 2019. We evaluated the associations between MRI findings and clinical measures, including visual analogue scale (VAS) scores for low back pain (LBP) and lower-limb pain (LLP), the Oswestry Disability Index (ODI), and subjective walking distance (SWD). The aim was to develop a scoring system capable of identifying symptomatic levels and thereby facilitating targeted decompression. This approach may provide a basis for determining the responsible levels and performing more precise decompression.

Methods

Patients

We retrospectively identified patients with LSS who underwent lumbar decompression surgery at our centre between January 2014 and January 2019. The inclusion criteria were as follows: (1) clinically significant symptoms of LSS, including low back pain, lower-limb pain, or neurogenic intermittent claudication, with MRI-confirmed spinal stenosis and compression of the dural sac and/or nerve roots; (2) failure to achieve substantial symptomatic relief after at least 3 months of standardised non-operative treatment, with symptoms significantly affecting quality of life; (3) intraoperative confirmation of lumbar spinal stenosis in patients undergoing lumbar decompression and fusion; (4) availability of complete preoperative MRI and clinical data; and (5) a 5-year postoperative follow-up with ODI assessment to evaluate symptomatic and functional outcomes. The exclusion criteria were as follows: (1) previous lumbar spine surgery; (2) lumbar fracture or spondylolisthesis; (3) spinal tumour, spinal tuberculosis, or ankylosing spondylitis; (4) cervicolumbar syndrome; and (5) lumbar scoliosis.

MRI

All patients underwent lumbar MRI on Siemens 1.5-T or 3.0-T superconducting scanners at our hospital within 6 months before surgery. The primary assessment method was morphological grading of the severity of lumbar spinal canal stenosis. Central canal stenosis was graded according to the Schizas morphological classification[13], which has demonstrated good intra- and interobserver reproducibility[14]. Lateral recess and intervertebral foraminal stenosis were assessed using the

grading systems proposed by Bartynski et al.[15] and Lee et al.[16], respectively; both systems are based on nerve-root morphology. For lateral recess and foraminal stenosis, the side with the higher grade was recorded. At the operated levels, the following quantitative MRI parameters were measured: spinal canal cross-sectional area (SCA), dural sac cross-sectional area (DSCA), lateral recess sagittal diameter (LRS), ligamentum flavum cross-sectional area (LFA), ligamentum flavum thickness (LFT), foraminal height (FHT), superior foraminal width (SFW), and foraminal cross-sectional area (FCA) (Fig. 1). Two spine surgeons independently performed each measurement twice, and the mean of the four measurements was used for subsequent analyses.

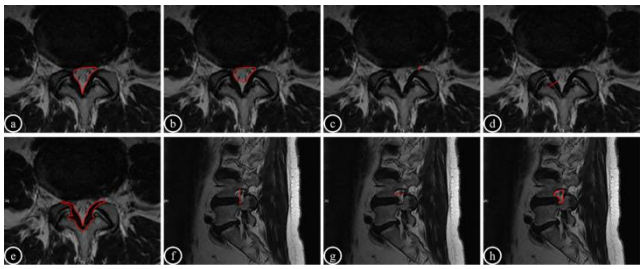


Fig.1 Axial and sagittal T2-weighted MRI sequences demonstrating standardized assessments of spinal canal structures at the lumbar level.(a-e) Axial views illustrating the measurement of spinal canal cross-sectional area (a), dural sac cross-sectional area (b), and ligamentum flavum cross-sectional area(e), as well as lateral recess sagittal diameter (c) and ligamentum flavum thickness (d).(f-h) Sagittal views showing linear measurements of the foraminal height (f), superior foraminal width(g), and the area of the foraminal cross-sectional area (h). Red outlines and lines indicate the regions of interest and measurement axes, respectively.

Pre-operative clinical assessment

The severity of LBP and LLP was assessed using the VAS, ranging from 0 (no pain) to 10 (worst imaginable pain). Patient-perceived disability was evaluated using the traditional Chinese version of the ODI 2.1. SWD was defined as the distance a patient could walk from the starting point until the onset of bilateral or unilateral buttock pain, lower-limb pain, heaviness, numbness, or weakness, and was extracted from the electronic medical records.

Statistical analysis

Statistical analyses were performed using SPSS version 26.0 (IBM Corporation, Armonk, NY, USA) and R version 4.2.1 (R Foundation for Statistical Computing, Vienna, Austria). Categorical variables were expressed as percentages and compared using the chi-square test. Continuous variables were reported as means ± standard deviations. Data distribution and homogeneity of variance were assessed before analysis; Student's t-test was used for normally distributed data, whereas non-parametric tests were applied when the assumptions of normality were not met. Intra-class correlation coefficients (ICC) were calculated to assess intraobserver reliability, based on repeated measurements by the same spine surgeon, and interobserver reliability, based on measurements by two spine surgeons. Spearman's rank correlation analysis was used to evaluate associations between MRI parameters, demographic characteristics, and preoperative ODI, VAS for LLP and LLP, and SWD. Multivariable linear regression analysis was then performed to identify potential determinants of ODI, VAS scores, and SWD. Unstandardised regression coefficients with 95% confidence intervals (95% CI) were reported. All tests were two-sided with $\alpha = 0.05$.Using segment responsibility as the dependent variable, logistic regression analysis was performed for MRI parameters that were significantly correlated with clinical symptoms, with the aim of identifying predictors of symptomatic segments. The model was comprehensively evaluated in terms of discrimination, calibration, and clinical utility using the area under the receiver operating characteristic curve (AUC),, decision curve analysis, and calibration curves.Predictor scores were assigned according to the magnitude of their β coefficients, and these scores were combined to develop a scale for localising responsible segments. The optimal cut-off value was determined using ROC curve analysis. The scoring system was subsequently applied to the validation cohort, and its diagnostic performance was assessed using the AUC and the Hosmer-Lemeshow goodness-of-fit test.

Results

Demographic data

Between January 2014 and January 2019, 677 patients with LSS underwent lumbar decompression and fusion at our center. Of these, 313 patients who underwent single-level lumbar decompression and achieved an ODI improvement rate of >50% at the 5-year follow-up, indicating substantial symptomatic improvement, were included in the modelling cohort. A further 113 patients who underwent single-level lumbar decompression and fusion constituted the validation cohort. In addition, 207 patients underwent multilevel lumbar decompression, while the remaining 44 patients underwent revision lumbar surgery. The baseline characteristics of the modelling cohort are presented in Table 1. This cohort comprised 161 men (51.4%) and 152 women (48.6%), with a mean age of 62.25 ± 11.1 years (range, 24–92 years) and a mean body mass index of 24.72 ± 3.01 kg/m².

Table 1 The preoperative clinical basic data and MRI parameters of the surgical segments of LSS patients in the modeling group

	N=313
Male gender（%）	51.4
Age (years)	65.25±11.11
Duration of symptoms(months)	54.04±75.77
Height(cm)	165.26±7.67
Weight(kg)	67.69±10.62
BMI (kg/m^2)	24.72±3.01
ODI (%)	57.71±14.67
SWD(m)	408.49±514.65
LBP VAS	5.80±2.59
LLP VAS	6.63±2.02
DSCA（mm^2）	72.3±37.42
SCA（mm^2）	111.67±53.78
DSCA/SCA	0.65±0.14
LRS（mm）	1.72±0.73
FHT（mm）	18.65±3.06
SFW（mm）	7.55±1.93
FCA（mm^2）	92.6±32.374
LFA（mm^2）	154.96±40.71
LFT（mm）	4.94±1.40
Central stenosis	
Grade A	115(36.7%)
Grade B	81(25.9%)
Grade C	102(32.6%)
Grade D	15(4.8%)
Lateral recess stenosis	
Grade 0	12(3.8%)
Grade 1	41(13.1%)
Grade 2	46 (14.7%)
Grade 3	214(68.4%)
Foraminal stenosis	
Grade 0	83(26.5%)
Grade 1	128(40.9%)
Grade 2	55(17.6%)
Grade 3	47 (15%)

Clinical symptoms

Among the 313 patients with LSS, the most common clinical manifestations were low back pain in 275 patients (87.9%), intermittent claudication in 302 (96.5%), radicular leg pain in 306 (97.8%), and lower-extremity weakness and/or hypoesthesia in 153 (48.9%). Preoperative VAS scores, ODI scores, and SWD are summarised in Table 1.

MRI evaluation of the surgical level

Among the 313 patients, the operated levels were distributed as follows: L1–L2 in 1 patient (0.3%), L2–L3 in 2 (0.6%), L3–L4 in 16 (5.1%), L4–L5 in 260 (83.1%), and L5–S1 in 34 (10.9%). The preoperative MRI findings are summarised in Table 1. Severe or greater central canal stenosis was present in 117 patients (37.4%), whereas severe lateral recess stenosis was observed in 214 (68.4%). In addition, 186 patients (59.4%) had a dural sac cross-sectional area (DSCA) of ≤75 mm².

Results of consistency test

Interobserver and intraobserver agreement for all quantitative MRI parameters was good to excellent, with ICC ranging from 0.71 to 0.91. For grading of central canal stenosis, interobserver agreement was excellent ($\kappa = 0.87$, 95% CI 0.80–0.91; $p < 0.01$). Intraobserver agreement was $\kappa = 0.92$ (95% CI 0.88–0.96; $p < 0.01$) for Observer 1 and $\kappa = 0.79$ (95% CI 0.75–0.84; $p < 0.01$) for Observer 2.For grading of lateral recess stenosis, interobserver agreement was also excellent ($\kappa = 0.91$, 95% CI 0.85–0.96; $p < 0.01$). The corresponding intraobserver agreement was $\kappa = 0.78$ (95% CI 0.73–0.84; $p < 0.01$) for Observer 1 and $\kappa = 0.85$ (95% CI 0.79–0.90; $p < 0.01$) for Observer 2. For grading of foraminal stenosis, interobserver agreement was substantial ($\kappa = 0.67$, 95% CI 0.61–0.72; $p< 0.01$), with intraobserver agreement of $\kappa = 0.77$ (95% CI 0.71–0.82; $p< 0.01$) for Observer 1 and $\kappa = 0.76$ (95% CI 0.70–0.81; $p< 0.01$) for Observer 2.

Correlation between baseline characteristics and clinical symptoms

Table 2 demonstrates a positive correlation between age and both the ODI score and LLP VAS score, with correlation coefficients of $r_s = 0.26$ ($p < 0.01$) and $r_s = 0.12$ ($p < 0.05$), respectively. Conversely, age was negatively correlated with SWD ($r_s = -0.22$, $p < 0.01$). These associations between age and ODI, LLP VAS, and SWD were confirmed by multiple regression analysis (Table 3). No significant correlations were observed between the other baseline characteristics, including sex, height, weight, BMI, and symptom duration, and the clinical outcomes (Table 2).

Table 2 Correlation of ODI, SWD, VAS and Baseline characteristics

Characteristic	ODI r_s	SWD r_s	LBP VAS r_s	LLP VAS r_s
Gender(male: female)	0.04	−0.06	0.09	0.06
Age(years)	0.26**	−0.22**	0.11	0.12*
Height(cm)	−0.02	0.04	0.00	0.04
Weight(Kg)	0.05	−0.05	0.07	0.10
BMI(kg/m^2)	0.08	−0.08	0.09	0.09
Duration of symptoms	−0.04	0.02	0.11	−0.11

Note:*p<0.05;**p<0.01； r_s：spearman correlation coefficient

Table 3 Multivariate linear regression analyses to identify factors associated with ODI, SWD and VAS

Variable	Variable			
	ODI	SWD	LBP VAS	LLP VAS
Age(years)	0.32**(0.18,0.46)	−5.81*(−10.40, −1.22)	0.02(−0.01,0.04)	0.02*(0.00, 0.04)
Central stenosis		-		
Grade A	Ref.	Ref.	Ref.	Ref.
Grade B	3.45 (−0.38,7.28)	−427.67**(−554.63, −300.70)	0.13 (−0.61,0.88)	−0.72**(−1.23, −0.22)
Grade C	7.55**(3.90,11.21)	−526.43**(-649.34, −403.52)	−0.03 (-0.75,0.68)	−0.31(−0.79,0.17)
Grade D	19.04**(11.77,26.31)	−661.39**(−899.86, −422.92)	0.32 (-1.09,1.74)	0.40 (−0.56,1.35)
Lateral recess stenosis 0~1 vs 2~3	4.38*(0. 35,8.41)	−115.95 (−251.57,19.68)	−0.13 (−0.92,0.65)	2.55**(2.02,3.08)
foraminal stenosis 0~1 vs 2~3	−0.60 (−3.89,2.69)	−78.85 (−188.42,30.71)	0.39 (−0.25,1.03)	0.24 (−0.19,0.68)

Note:*p<0.05; **p<0.01

Correlation between MRI parameters and clinical symptoms

No significant associations were observed between ODI, VAS, or SWD scores and any quantitative MRI parameter measured at the operated level, including SCA, DSCA, DSCA/SCA, LRS, LFA, LFT, FHT, SFW, and FCA (Table 4). In contrast, the grades of central canal and lateral recess stenosis were positively correlated with ODI scores, with correlation coefficients of $r_s = 0.35$ and $r_s = 0.18$, respectively (both $p< 0.01$).Furthermore, higher grades of central canal, lateral recess, and foraminal stenosis were negatively correlated with SWD ($r_s = -0.55$, $p < 0.01$; $r_s = -0.23$, $p< 0.01$; and $r_s = -0.12$, $p< 0.05$, respectively) and positively correlated with LLP VAS scores ($r_s = 0.12$, $p< 0.05$; $r_s = 0.42$, $p < 0.01$; and $r_s = 0.14$, $p < 0.05$, respectively). No significant correlation was found between LBP VAS scores and any MRI parameter ($p > 0.05$). Multivariable linear regression analysis showed that the grade of central canal stenosis was independently associated with

both ODI and SWD, whereas the grade of lateral recess stenosis was associated with ODI and LLP VAS scores (Table 4).

Table 4 Correlation of ODI, SWD, VAS and MRI Parameters

Parameters	ODI	SWD	LBP VAS	LLP VAS
DSCA	−0.03	0.10	0.01	0.09
SCA	−0.04	0.11	0.00	0.10
DSCA/SCA	0.03	−0.01	−0.03	0.00
LRS	−0.03	0.00	−0.02	0.00
FHT	−0.10	0.10	−0.05	−0.07
SFW	0.09	−0.02	0.01	−0.04
FCA	−0.03	0.075	−0.01	−0.08
LFA	−0.03	0.022	−0.03	0.04
LFT	−0.07	0.070	0.00	−0.05
Central stenosis	0.35**	−0.55**	0.09	0.12*
Lateral recess stenosis	0.18**	−0.23**	0.00	0.42**
Foraminal stenosis	0.05	−0.12*	0.08	0.14*

Note:*p<0.05;**p<0.01；r_s：spearman correlation coefficient

Univariate Logistic regression analysis

A total of 313 patients with LSS showed concordant clinical and MRI findings, and lumbar spinal stenosis was confirmed intraoperatively during single-level decompression. All patients achieved an ODI improvement of >50% at 5 years postoperatively, indicating substantial and sustained symptomatic relief. Accordingly, the 313 operated levels were classified as responsible segments.In addition, 165 non-operated stenotic levels identified on lumbar MRI in these patients were classified as non-responsible segments. Thus, 478 lumbar stenotic segments were included in the analysis. With segment status (responsible versus non-responsible) as the dependent variable, univariable logistic regression analysis was performed for variables previously shown to be associated with clinical symptoms, including age and the grades of central canal, lateral recess, and foraminal stenosis.Age was entered as a categorical variable. Grade A central canal stenosis comprised four subcategories (A1–A4); these subcategories were excluded from the logistic regression analysis because of the small number of cases in each group. For the same reason, grades C and D were combined. Similarly, grades 0 and 1 were combined for both lateral recess and foraminal stenosis. The analysis showed that the grades of central canal, lateral recess, and foraminal stenosis were significant predictors of responsible segments, whereas age was not statistically significant (Table 5).

Table 5 Univariate Logistic Regression Analysis

	non surgical segments, n=165	surgical segments, n=313	Regression β coefficient	Odds ratio	P value
Age(years)					
<60	26.67%	32.27%	Ref.	Ref.	
60-70	32.72%	32.27%	-0.205	0.815	0.407
>70	40.6%	35.5%	-0.326	0.722	0.170
Central stenosis					
Grade A	81.8%	36.7%	Ref.	Ref.	
Grade B	15.8%	25.9%	1.854	6.383	<0.001
Grade C+D	2.4%	37.4%	3.608	36.880	<0.001
Lateral recess stenosis					
Grade 0~1	92.7%	16.9%	Ref.	Ref.	
Grade 2	3.6%	14.7%	3.097	22.132	<0.001
Grade 3	3.6%	68.4%	4.634	102.962	<0.001
foraminal stenosis					
Grade 0~1	89.7%	67.7%	Ref.	Ref.	
Grade 2	7.9%	17.3%	1.151	3.163	0.01
Grade 3	2.4%	15%	2.111	8.258	<0.001

Multivariate Logistic regression analysis

A multivariable logistic regression model was developed to identify responsible segments, with segment status (surgical versus non-surgical) as the dependent variable. The independent variables were MRI parameters that had shown significant

associations with responsible-segment localisation in the univariable logistic regression analysis. As shown in Table 6, the grades of central canal, lateral recess, and foraminal stenosis were all significantly associated with the identification of responsible segments.The Hosmer–Lemeshow goodness-of-fit test yielded a χ^2 value of 10.023 (p= 0.124), indicating no significant discrepancy between the predicted and observed probabilities and suggesting good model calibration. The receiver ROC curve for the model is shown in Fig. 2. The area under the curve (AUC) was 0.936 (95% CI 0.912–0.959), demonstrating excellent discriminatory performance for localising responsible segments.The model's clinical utility was further evaluated using R version 4.2.1. Calibration curves were generated using bootstrap optimism correction based on 1,000 resamples to account for potential internal overfitting. The bias-corrected calibration curve closely approximated the ideal 45° line across the range of predicted risks, while the minimal divergence between the apparent and bias-corrected curves indicated negligible optimism in the model (Fig. 3). Decision curve analysis showed that the model provided a greater net benefit than conventional empirical judgement across a broad range of threshold probabilities, supporting its potential clinical utility (Fig. 4).

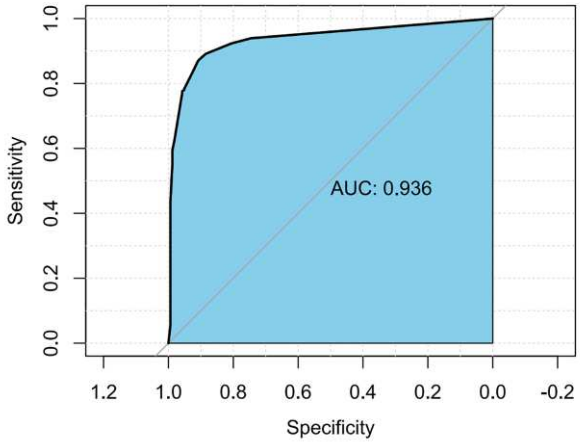


Fig. 2 ROC curve of the predictive model for responsible segment localization.

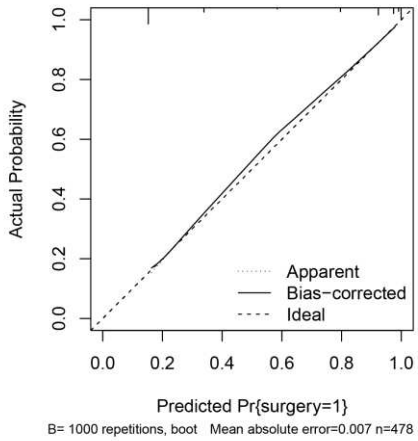


Fig. 3 Calibration curve of the prediction model

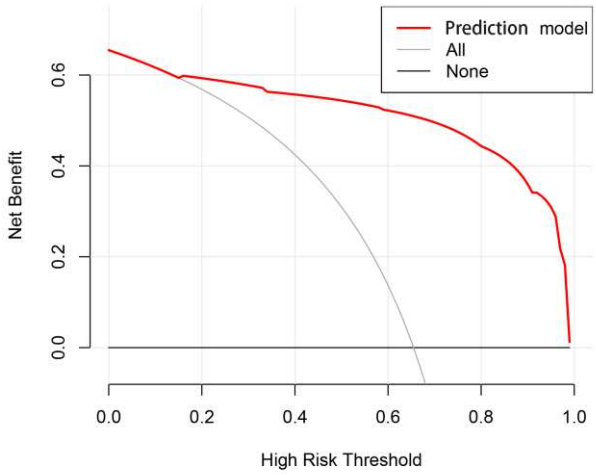


Fig. 4 Decision curve analysis of the prediction model.

A scoring model for assisting the localization of responsible segments

A scoring system was developed by assigning points to the identified risk factors. Each score was calculated by dividing the corresponding β coefficient by two-fifths of the sum of the two smallest β coefficients in the predictive model and rounding the result to the nearest integer (Table 6). Higher grades of central canal, lateral recess, and foraminal stenosis were associated with higher scores, yielding a maximum possible total score of 9 points.Using segment status as the outcome variable and the total score as the test variable, a ROC curve was constructed (Fig. 5). The AUC was 0.935, and the optimal cut-off value was 3 points. At this threshold, the sensitivity and specificity for identifying responsible segments were 86.9% and 90.9%, respectively. Lumbar segments with a total stenosis score of ≥3 points were more likely to represent responsible segments in patients with LSS, whereas segments with a total score of <3 points were rarely classified as responsible.

Table 6 Multivariate Logistic Regression Analysis

	Regression β coefficient	Odds ratio	95% CI	P value	points
Central stenosis					
Grade A	Ref.	Ref.			0
Grade B	1.456	4.291	1.953-9.430	<0.001	1
Grade C+D	2.612	13.633	4.181-44.450	<0.001	3
Lateral recess stenosis					
Grade 0~1	Ref.	Ref.			0
Grade 2	3.102	22.235	8.458-58.449	<0.001	3
Grade 3	4.160	64.091	25.998-158.002	<0.001	4
foraminal stenosis					
Grade 0~1	Ref.	Ref.			0
Grade 2	1.056	2.875	1.103-7.499	0.01	1
Grade 3	1.998	7.376	1.957-27.798	<0.001	2

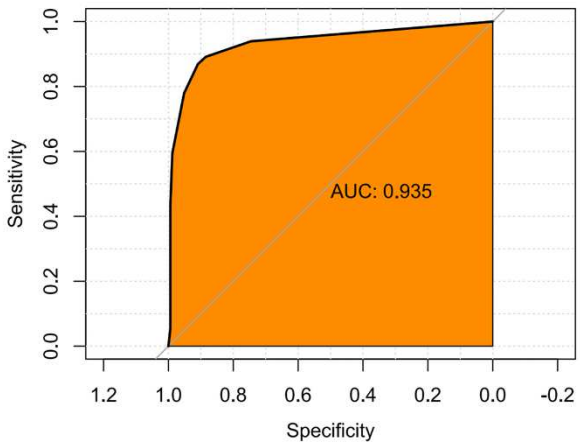


Fig. 5 ROC curve of the scoring model for localizing responsible segments in the modeling cohort.

Validation of the Scoring System

In the validation cohort, 113 patients underwent single-level lumbar decompression and were followed for more than 5 years postoperatively. Eleven patients (9.7%) did not achieve substantial improvement in LSS-related symptoms compared with their preoperative status; of these, two developed worsening symptoms accompanied by new lower-limb complaints. Sixteen patients (14.2%) reported residual mild lower-limb numbness, and 24 (21.2%) continued to experience mild low back and leg pain that was aggravated by walking. Overall, 102 patients (90.2%) experienced substantial symptomatic relief following surgery.Before surgery, the stenotic segments in the validation cohort were assigned scores according to the stenosis scoring model. The 5-year postoperative ODI improvement rate was used to define segment responsibility. An improvement rate of >50% was considered indicative of substantial symptomatic improvement, and the operated segment was therefore classified as the responsible segment; all other coexisting stenotic segments were classified as non-responsible. Conversely, an improvement rate of ≤50% indicated that the operated segment was not the responsible segment. In total, 222 lumbar stenotic segments were included in the analysis.A ROC curve was constructed using the stenosis score as the test variable and segment responsibility as the outcome variable. A cut-off score of 3 points provided high sensitivity and specificity for identifying responsible segments, with an AUC of 0.968 (Fig. 6). Lumbar stenotic segments with scores of ≥3 points were more likely to be responsible segments, and decompression of these segments was associated with favourable surgical outcomes.

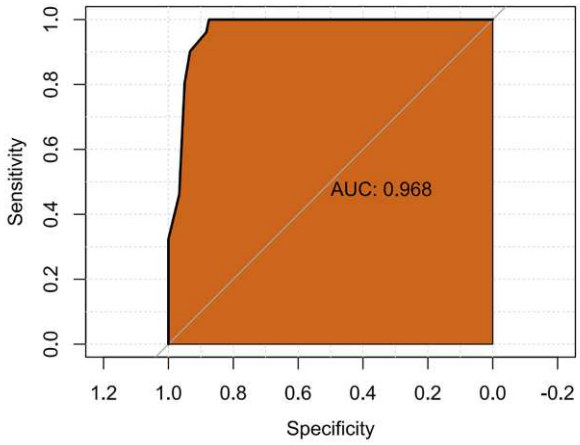


Fig. 6 ROC curve of the scoring model for localizing responsible segments in the validation model

Application of the Scoring Model in Patients Undergoing Multi-Level Decompression Surgery

We included 207 patients with LSS who had undergone multilevel lumbar decompression. The stenosis scoring model was applied to all lumbar stenotic segments identified on preoperative MRI. Segments with a score of <3 points that were not included in the decompression levels were assigned to Group A, whereas segments with a score of <3 points that nevertheless underwent decompression were assigned to Group B.Group A comprised 113 patients (60 women and 53 men) aged 32–87 years, with a mean age of 63.39 ± 10.78 years. The mean BMI was 24.57 ± 3.13 kg/m². Disease duration ranged from 6 to 240 months, with a mean of 51.88 ± 63.15 months, and the mean hospital stay was 10.96 ± 2.81 days. Group B comprised 94 patients (51 women and 43 men) aged 35–90 years, with a mean age of 66.13 ± 10.42 years. The mean BMI was 24.52 ± 2.87 kg/m². Disease duration ranged from 6 to 360 months, with a mean of 54.89 ± 82.56 months, and the mean hospital stay was 12.46 ± 2.84 days. No significant between-group differences were observed in the baseline clinical characteristics ($p > 0.05$).ODI scores were recorded preoperatively and at the 5-year follow-up, and the improvement rate was calculated using the prespecified formula. An improvement rate of >50% was considered indicative of a favourable surgical outcome, reflecting substantial relief of LSS-related symptoms and improvement in lumbar function sufficient to allow patients to resume their usual work and daily activities. An improvement rate of ≤50% was considered an unfavourable outcome, defined as minimal or no symptomatic improvement, or worsening of symptoms such as low back pain, leg pain, numbness, or weakness that substantially interfered with work and daily activities.As shown in Table 7, the proportion of patients achieving a favourable outcome was significantly higher in Group A than in Group B (93.8% vs. 85.1%; $\chi^2 = 4.260$,

p = 0.033). As shown in Table 8, there were no significant between-group differences in ODI scores either preoperatively or at the 5-year postoperative follow-up (p> 0.05). Similarly, preoperative VAS scores for low back pain and leg pain did not differ significantly between the groups (p > 0.05). However, the 5-year postoperative VAS score for low back pain was significantly lower in Group A than in Group B (1.19 ± 1.68 vs. 2.54 ± 2.34; p< 0.05). In contrast, no significant between-group difference was observed in the 5-year postoperative VAS score for leg pain (p> 0.05).

Table 7 Comparison of surgical Efficacy between the two groups of patients

	ODI improvement rate>50%	ODI improvement rate≤50%
Group A(n=113)	106(93.8%)	7(6.2%)
Group B(n=94)	80(85.1%)	14(14.9%)
$\chi 2$	4.260	
p	0.033	

Table 8 Comparison of clinical Scores between Group A and Group B patients

		Timing	ODI	LBP VAS	LLP VAS
Group A(n=113)		preoperative	58.82±12.43	6.27±2.09	6.5±2.14
		5-year postoperative	22.89±14.17	1.19±1.68	0.79±1.60
	t		22.461	21.814	19.858
	p		0.000	0.000	0.000
Group B(n=94)		preoperative	59.99±14.00	5.91±2.26	6.79±1.67
		5-year postoperative	24.66±14.90	2.54±2.34	0.97±1.67
	t		19.686	10.815	24.432
	p		0.000	0.000	0.000
	preoperative t		-0.634	1.187	-1.044
	preoperative p		0.527	0.236	0.298
	5-year postoperative t		-0.873	-4.813	-0.792
	5-year postoperative p		0.384	0.000	0.429

Prediction of Revision Surgery Using the Scoring Model

We retrospectively reviewed patients who underwent revision surgery at our center. The revision cohort comprised 22 patients (10 women and 12 men) aged 34–86 years, with a mean age of 69.00 ± 14.99 years and a mean BMI of 24.68 ± 4.01 kg/m². Revision surgery was indicated for degeneration, stenosis, or instability of adjacent segments. Patients with inadequate decompression at the index level, cage migration, implant failure, pseudarthrosis, or postoperative infection were excluded. The interval between the initial lumbar procedure and revision surgery ranged from 9 months to 10 years, with a mean of 4.15 ± 2.58 years.For comparison, 22 patients who had undergone primary multilevel lumbar decompression during the same period were randomly selected as controls. The control group comprised 11 women and 11 men aged 43–86 years, with a mean age of 62.68 ± 9.15 years and a mean BMI of 24.18 ± 3.07 kg/m². All control patients achieved a favourable outcome at the final follow-up and did not require revision surgery. No significant between-group differences were observed in baseline clinical characteristics (p> 0.05).In the revision cohort, the stenosis scoring model was applied to MRI scans obtained before the initial decompression to assess stenosis severity at the lumbar segments subsequently requiring revision surgery. In total, 32 revision segments were analysed. In the control cohort, stenotic segments adjacent to the operated levels were assessed, yielding 31 adjacent stenotic segments.A ROC curve was constructed using revision surgery as the outcome variable and the corresponding stenosis score as the test variable (Fig. 7). The AUC was 0.923 (95% CI 0.851–0.996). A cut-off score of 3 points yielded a sensitivity of 93.8% and a specificity of 87.1% for identifying segments requiring revision surgery. Thus, after lumbar decompression and fusion, adjacent segments with a total stenosis score of ≥3 points were more likely to require subsequent revision surgery.

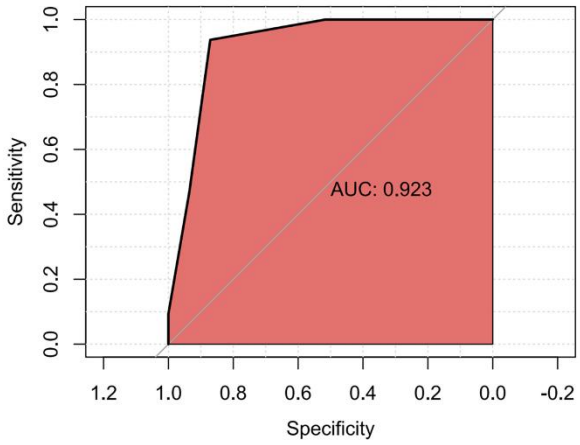


Fig. 7 ROC curve for predicting revision segments using the stenosis scoring system

Discussion

In this study, we found no significant association between symptom severity and any quantitative MRI parameter, consistent with previous reports[17-19]. Although one study[20] identified weak positive correlations between SCA, DSCA, and SWD ($r = 0.201$, $p = 0.045$; and $r = 0.198$, $p = 0.049$, respectively), more recent evidence suggests that quantitative measures of lumbar spinal stenosis are not consistently associated with clinical symptoms and have limited value in guiding treatment selection[6, 8, 9, 21]. Accordingly, quantitative MRI parameters should not be overemphasised when diagnosing LSS or determining the need for surgery.We believe that the use of quantitative parameters to assess the severity of lumbar spinal stenosis has several inherent limitations. First, a reduction in spinal canal diameter does not necessarily reflect the degree of dural sac or nerve-root compression and may not directly account for symptom generation, which could explain the weak association with clinical manifestations. Second, these measurements vary according to body habitus, ethnicity, sex, and age. Moreover, the morphology and dimensions of the spinal canal may differ between levels within the same individual, making it difficult to establish uniform diagnostic thresholds for stenosis[16]. Finally, the measurement of lumbar canal dimensions is time-consuming and subject to interobserver variability and measurement error[22]. These methodological limitations may partly explain the inconsistent findings reported in previous studies.

We observed a positive association between the grades of central canal and lateral recess stenosis and ODI scores. Using the Schizas grading system to assess central canal stenosis, Fushimi et al.[12] reported that severe central stenosis was strongly associated with clinical symptoms. Although several earlier studies[10, 11, 18, 23] found no clear relationship between the radiological severity of LSS and clinical manifestations, MRI-based morphological classification offers several advantages for assessing LSS. First, it captures the morphology and degree of compression of the dural sac and nerve roots. Second, unlike quantitative measurements, it is less influenced by individual characteristics such as ethnicity, sex, body habitus, and age. Third, it can be applied irrespective of the specific spinal level involved. Finally, morphological grading avoids the measurement errors and interobserver variability associated with quantitative canal-dimension measurements.

We identified a statistically significant negative correlation between the grade of central canal stenosis and the walking distance before the onset of claudication. More severe central stenosis was associated with a shorter walking distance. In contrast, previous studies[17, 18] reported no association between the grade of central canal stenosis and walking distance. Several factors may account for this discrepancy: (1) differences in the types of stenosis represented in the study populations; (2) limitations of the morphological grading systems used in earlier studies, which may not have comprehensively captured the severity of LSS; (3) the inclusion of patients with multilevel stenosis, meaning that the assessed segments were not necessarily the symptom-generating segments; and (4) insufficient sample sizes in previous investigations.

We observed a positive association between the grade of lateral recess stenosis and LLP VAS scores. Notably, LLP VAS scores were substantially higher when lateral recess stenosis was accompanied by nerve-root compression and morphological deformation. This finding may reflect the anatomical role of the lateral recess as the entry zone for the nerve root, where stenosis can readily result in nerve-root entrapment and consequent LLP.Our analysis of factors associated with LBP VAS

scores revealed no significant correlations with the MRI parameters, consistent with the findings of Minetama et al[24]. This suggests that LBP in patients with LSS is likely multifactorial and may arise from abnormalities involving the intervertebral discs, facet joints, sacroiliac joints, ligaments, vertebral bodies, neural structures, paraspinal muscles, and vertebral endplates, rather than being attributable solely to LSS.In the multiple linear regression analysis, MRI-based grading of foraminal stenosis was not significantly associated with symptom severity. One possible explanation is that MRI examinations were performed with patients in the supine position. Supine positioning reduces axial loading of the lumbar spine and may increase the dimensions of the intervertebral foramina, potentially attenuating or obscuring stenotic changes that would become more apparent under physiological loading.

Statistical analyses demonstrated significant associations between several qualitative MRI grading systems and clinical symptoms, particularly the Schizas[13], Bartynski[15], and Lee[16] grading systems. Using logistic regression, we developed a scoring system to aid identification of the symptom-generating segment. A stenotic segment with an MRI score of ≥3 points was considered highly likely to represent the responsible segment.Our analyses further indicated that prophylactic decompression of stenotic segments did not improve surgical outcomes and was instead associated with an increased risk of persistent postoperative low back pain. This may be explained by the fact that prophylactic decompression inevitably enlarges the surgical field and increases disruption of the posterior lumbar structures. Such disruption may result in injury, denervation, degeneration, and atrophy of the paraspinal muscles, potentially contributing to recurrent lumbar instability and iatrogenic spinal stenosis. These changes may promote residual low back pain and ultimately compromise the overall clinical benefit of surgery[25].

Studies[26, 27] have reported that 3–16% of patients experience no meaningful symptomatic improvement or even deterioration after lumbar spine surgery, potentially necessitating revision procedures. Common indications for revision include adjacent-segment degeneration, recurrent or residual stenosis, instability, inadequate decompression at the index level, cage migration, implant failure, pseudarthrosis, and postoperative infection. Revision surgery is technically demanding and carries an increased risk of complications because of extensive epidural scar formation and adhesions. These complications include nerve-root injury, dural tears, infection, haemorrhage, and postoperative myogenic pain.In the present study, we evaluated 32 revised segments in 22 patients who underwent revision surgery using the established scoring system. Our findings indicated that adjacent segments with an MRI score of ≥3 were more likely to require subsequent revision. However, the small number of patients undergoing revision substantially limits the statistical power and generalisability of these findings. Larger, prospective studies are therefore warranted to validate these preliminary observations.

Limitations of the study

This study has several limitations. First, its retrospective, single-centre design precludes the establishment of causal relationships between the imaging parameters and clinical symptoms. Independent external validation in larger, multicentre cohorts is required before this scoring system can be implemented in routine clinical practice. Second, MRI examinations were performed with patients in the supine position and may therefore not capture pathological changes that occur under physiological axial loading in the standing position. Third, the study population consisted exclusively of patients who underwent surgery for relatively severe symptoms and radiographic stenosis. The exclusion of patients managed conservatively and asymptomatic individuals from the comparative analysis may have introduced selection bias and limited the generalisability of the findings. Finally, the small revision cohort limits the statistical robustness of the analysis. Larger studies are warranted to validate these preliminary findings.

Conclusion

1. MRI-based morphological grading systems effectively assess the severity of lumbar spinal stenosis and show significant associations with clinical symptoms in patients with LSS. In contrast, quantitative MRI parameters do not appear to correlate significantly with symptom severity.

2. No MRI parameter was significantly associated with the severity of low back pain in patients with LSS. This finding supports the view that low back pain is multifactorial and cannot be attributed solely to spinal canal stenosis.

3. The scoring system developed from MRI-based morphological parameters may serve as an adjunctive tool for

identifying the symptomatic, or responsible, segment in patients with LSS. A stenotic lumbar segment with a score of ≥3 was highly likely to represent the responsible segment, and decompression at that level was generally associated with favourable clinical outcomes.

4. In patients with LSS, prophylactic decompression of stenotic segments with an MRI score of <3 was associated with a higher incidence of residual postoperative low back pain and may therefore reduce the overall effectiveness of surgery.

Declarations

Ethics approval and consent to participate

This study involving human participants was reviewed and approved by the Ethics Committee of the Affiliated Zhongda Hospital of Southeast University(ID:2023ZDSYLL309-P01).The reasons for exempting informed consent from the project are as follows:

1.This study is a study that utilizes medical records obtained from previous clinical diagnosis and treatment. The risk to the subjects is not greater than the minimum risk, and exempting informed consent will not have adverse effects on the rights and health of the subjects.

2. The data collected by the research institute can ensure that the privacy and identity information of the subjects are confidential and protected

3. This study does not utilize medical records and specimens that patients have previously explicitly refused to use.

4. The data obtained from this study is only for the purpose of this clinical study and is not intended for other purposes.

Consent for publication

Not applicable, because all individual patient data were anonymized and no identifiable individual information is included in this manuscript.All authors agreed to publish the paper.

Availability of data and materials

The data that support the findings of this study are available on request from the corresponding author.

Competing interests

The authors declare that they have no competing interests.

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