Prediction of the Risk of C5 Palsy After Posterior Laminectomy and Fusion With Cervical Myelopathy Using Support Vector Machine: an Analysis of 184 Consecutive Patients

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Research Article

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Abstract

Background: This study aimed to predict the C5 palsy (C5P) after posterior laminectomy and fusion (PLF) with cervical myelopathy (CM) from routinely available variables by using support vector machine (SVM) method.

Methods: We conducted a retrospective investigation based on 184 consecutive patients with CM after PLF, and data was collected from March 2013 to December 2019. Clinical and imaging variables were obtained and imported into univariable and multivariable logistics regression analysis to identify risk factors for C5P. According to published reports and clinical experience, a series of variables was selected to develop an SVM machine learning model to predict C5P. The accuracy (ACC), area under the receiver operating characteristic curve (AUC) and confusion matrices were used to evaluate the performance of the prediction model.

Results: Among the total 184 consecutive patients, C5P occurred in 26 patients (14.13%). Multivariate analyses demonstrated the following 4 independent factors associated with C5P: electromyogram abnormal (odds ratio [OR] = 7.861), JOA recovery rate (OR = 1.412), modified Pavlov ratio (OR = 0.009), and presence of foraminal stenosis C4-C5 (OR = 15.492). The SVM model achieved an area under receiver operating characteristic curve (AUC) of 0.923 and ACC of 0.918. Meanwhile, the confusion matrix shown the classification results of the discriminant analysis.

Conclusions: The designed SVM model presented a satisfied performance in predicting C5P from routinely available variables. However, future external validation is needed.

1. Introduction

Postoperative C5 palsy (C5P) is a well-known and frequent complication of cervical surgery.[1] The main clinical manifestations of C5P include sensation disorder, persistent pain, muscle weakness and motor motion weakness in the innervation area of C5.[2-4] Although the low incidence and relatively long-term outcomes, C5P greatly influences the quantity of life, work productivity and patient-doctor trust during the recovery period[5, 6]. As noted in previous studies, the incidence of C5P is higher in patients after posterior laminectomy and fusion (PLF) than those who are treated with posterior laminoplasty (PLP) among the posterior cervical surgeries[7]. Despite this, there is still controversy regarding the high incidence of C5P in patients with PLF[8, 9]. Because the incidence of C5P is an essential indicator of the efficiency of cervical surgery, identification of the risk factors related to C5P and prediction of the risk of C5P following PLF are of major interest.

In general, posterior spinal decompression is the primary treatment for multi-segmental cervical myelopathy compared with anterior procedures[10]. PLP and PLF are the main procedures of spinal decompression that can be performed posteriorly[10]. In contrast to PLP, PLF can provide wider decompression, as well as avoids of kyphotic change and axial neck pain. However, the higher incidence of C5P in PLF remains dismal, which is the major disadvantage in PLF[7, 11]. In previous studies,

excessive posterior tractionor the tethering of the C5 root is recognized as vital causes. Up until now, most studies mainly focus on the incidence and imaging parameters. Unfortunately, the mechanism of C5P remains controversial, and the lack of a reliable prediction tool so far. In recent years, machine learning technology has received growing attention in medicine and healthcare.[12-14] Support vector machine (SVM), proposed by VAPNIK in 1997, is a linear and nonlinear classification method. Its basic idea is to map the data to be classified into a higher dimensional feature space with certain fault-tolerant conditions by using appropriate kernel functions[15]. The classification hyperplane categorizes the data. The supporting variable is the nearest sample point when determining the best classification hyperplane. At present, SVM has been widely used in the field of biomedicine and demonstrated good performance. [16, 17]

In this work, we aimed to predict the risk of C5 palsy after posterior LF with CM form routing available parameters using the SVM method.

2. Materials And Methods

2.1 Patients and clinical features

The study was granted ethics approval by the Ethics Committee of the Second Hospital of Jilin University (Project ID: 20151213002N). In this work, 214 consecutive patients who underwent PLF for nontraumatic CM between March 2013 to December 2019 are collected. A total of 214 patients were included from the medical record system and radiological information system. Based on our search strategy, cervical myelopathy was set as the keyword for the search, and they were eligible for the research if the patients were the kyphotic alignment of the cervical spine, segmental instability, and preoperative axial neck pain >5 in the pain visual analog scale (VAS, 0–10). All cases were operated on by the same orthopedic surgeon. We performed PLF using cervical lateral mass screw and/or cervical pedicle screw placement with localized local bone graft obtained from laminectomy. Foraminotomies at the symptomatic levels were performed, preserving more than 50% of the facet joints. Patients were divided into 2 groups, depending on the presence or absence of C5P (C5P and No-C5P group). C5P was defined as new onset of sensory disturbance and pain in the deltoid (< grade 3 or > grade 1 decrease from baseline) and C5 dermatome area 6 weeks after surgery. Finally, a total of 184 patients were enrolled in this study. All patients had a minimum follow-up of at least one year. To validate the model, the 10-fold cross-validation was adapted. After admission, patients' age, sex, BMI, history of hypertension, history of diabetes mellitus, and smoking were recorded. Parameters of physical examination and preoperative electromyography were included. Meanwhile, the preoperative, postoperative, and JOA recovery rate were collected. Finally, the number of levels decompressed and the number of fusion levels were documented, respectively.

2.2 Image acquisition and radiographic evaluation

All patients underwent Cervical radiography(X-ray), computer tomography (CT), and magnetic resonance imaging (MRI) detection at the Medical Imaging Center, Second Hospital of Jilin University before they received surgical treatment. The cervical curvature index (CCI) was measured as follows. The line between

C2 and the posteroinferior margin of C7 cervical vertebral body is made as line L. The vertical lines from the posteroinferior margin of each vertebral body from C3 to C6 to line A are x_1, x_2, x_3, and x_4, respectively. If the posteroinferior margin of C3 to C6 is located on the dorsal cervical side of line L, the value of a is recorded as a negative value. The CCI is the percentage of the sum of x_1 to x_4 and the value of L [$CCI = (x_1 + x_2 + x_3 + x_4)/L \times 100\%$] (Fig. 1A)[18]. The preoperative and postoperative CCI were calculated in this study. Next, preoperative and postoperative C2-7 sagittal vertical axis (C2-7 SVA) were measured using the following method. The distance between the center point through C2 and the vertical line of the posterosuperior corner of C7 was defined as C2-C7 SVA (Fig. 1B)[19]. The severe spinal cord compression was measured by the modified Pavlov ratio on sagittal T2-weighted magnetic resonance imaging (Fig. 1C, Fig. 1D)[20]. C4-C5 foramen stenosis is defined as 50% of normal or 50% of the mean value of upper and lower cervical foramina in the case of foramen stenosis on CT axial images (Fig. 1E).

2.3 Support vector machine

Recently, SVM has been used to solve various biomedicine problems. SVM is a supervised machine learning method based on structural risk minimization principles to minimize training and general error rates and establish a plane so that positive and negative samples can be distinguished in multidimensional space. SVM maps feature into a high-dimensional feature space by a kernel function. The radial basis function (RBF) kernel function was adopted in this work[21]. The input feature format can be recorded as "txt" or "xlsx" and uploaded to the support vector machine. The SVM in this paper adopts linear kernel with parameter C of 1.0. In this study, 10-fold cross-validation (The ratio of training and test set is 9:1 for one time. After all the data are applied for the test once, the evaluation process is over, which will show the SVM model's general capability.) was adapted to evaluate the performance of the SVM model. Open source, efficient, and free programming languages Python 3.7 and Scikit-learn 0.21.2 packages were used to build machine learning platforms.[22] The performance of SVM was evaluated by area under the receiver operating characteristic curve (AUC), accuracy (ACC), and confusion matrices. The ACC was determined by the following formula: ACC= (TP+TN)/(TP+TN+FP+FN). In this equation, TP: true positive; TN: true negative; FP: false positive; and FN: false negative.

2.4 Statistical analysis

Statistical analysis was performed using SPSS (IBM SPSS 26.0, SPSS Inc). Continuous variables were presented as means (SD) and categorical variables as frequency (percentage). If the normality of continuous variables was given, Student t-tests were applied. Controversy, if normality tests were failed, Mann–Whitney tests were used. For categorical variables, $\chi 2$ tests or Fisher exact tests were used for comparison of two groups. To better understand the relationship between the clinical and imaging parameters and C5P, logistics analysis was used to explore the independent risk factors for C5P. In this study, univariate analysis was performed to identify the potential risk factors. Then, variables with a value of $p < 0.2$ in the univariate analysis were included in a multivariate logistics regression model. Given the number of events available, the inclusion variables were set to make sure the final logistic regression model's parsimony. [23]Note that feature selection was utilized to select a subset of related features for

application in the machine that learned model for shorting training time, preventing dimensionality's curse, and making models simpler. Of note, the features selected for machine learning models do not necessarily need to be exactly the same as independent risk factors in multivariate regression analysis[24, 25].

3. Results

Among the total 184 consecutive patients, C5P occurred in 26 patients (14.13%) and did not occur in 158 patients. The mean age was 63.0 ± 11.4 years, and 760 patients (53.3 %) were male. There were no statistically significant differences in age, history of hypertension, history of smoking, or history of diabetes mellitus between C5P and No-C5P groups. Compare to No-C5P group, the BMI was higher that C5P group (P<0.01). We found a significantly higher proportion of abnormal electromyogram (EMG) results in group C5P (20/76.9%) group than No-C5P group (58/36.7%) (P<0.001). The pathological reflexes and postoperative JOA score did not show significant differences between the two groups. Notably, preoperative JOA score (median 12.9 [IQR 11.4, 14.8]) in C5P group significantly higher than No-C5P group (median 10.4 [IQR 8.1, 12.5]). Diatoms, the JOA recovery rate (median 61.3 [IQR 55.6, 68.6]) in C5P group significantly higher than No-C5P group (median 77.4 [IQR 72.4, 81.3]). The CCI change, preoperative, and postoperative C2-7 SVA did not differ significantly between C5P and No-C5P group. The modified Pavlov ratio was lower in C5P group [mean, SD. 0.31 (0.11)] than in No-C5P group [mean, SD. 0.34 (0.14)]. The proportion of presence of foraminal stenosis C4-C5 was significantly higher in C5P group (129/81.6%) than No-C5P group (4/15.4%) (p<0.001). The number of levels decompressed in C5P group [mean, SD. 3.2 (0.9)] was lower compared with [mean, SD. 3.8 (1.2)]. The number of fusion levels was observed significant difference between the C5P group [mean, SD. 3.9 (0.5)] and No-C5P group [mean, SD. 4.2 (0.6)]. The detailed results of the parameters were demonstrated in Table 1. The univariate and multivariate logistic regression analysis (Table 2) revealed that electromyogram abnormal, JOA recovery rate, modified Pavlov ratio, and presence of foraminal stenosis C4-C5 were independently associated with C5P.

Seven features were selected as the input of the SVM model, including electromyogram abnormal, preoperative CCI, JOA recovery rate, preoperative C2-7 SVA, modified Pavlov ratio, presence of foraminal stenosis C4-C5, and the number of levels decompressed. Based on the prediction results of 184 patients, the ROC curve of the prediction model was shown in Fig. 2A, and the AUC was 0.923. Meanwhile, the ACC of the prediction model was 0.918. Apart from that, the confusion matrix shown the classification results of the discriminant analysis. (Fig. 2B).

4. Discussion

In this study, the relationship between the clinical parameters and C5P was evaluated and the independent risk factors were identified by multivariate logistic regression analysis from 184 consecutive patients with CM after LF. An SVM model was established and applied to predict C5P. A range of evaluation indexes shown that our model had a good performance and promising clinical applications.

In patients with C5 nerve root palsy, approximately 50% of patients may experience hyperalgesia with or without pain and muscle weakness in the C5 innervation area, while the rest of the patients only experience motor weakness. C5 nerve root palsy is usually unilateral, while 5% to 7% of patients may present with bilateral symptoms.[26-28] It can occur from immediately after surgery to 2 months after surgery, and most patients occur one month after surgery. Some scholars emphasize that C5 nerve root palsy occurs 24 hours after surgery to distinguish intraoperative nerve injury.[29] Some scholars emphasize that C5 nerve root palsy occurs 24 hours after surgery to distinguish intraoperative nerve injury.[10, 29, 30] C5 nerve root palsy has a good prognosis, with about 70% of patients recovering within 3 to 6 months and the vast majority of patients (96%) recovering within two years, but 20% still have residual partial pain symptoms.[11, 30]

Noteworthy, C5P occurred in 26 (14.13%) out of 184 patients who underwent posterior cervical LF for the treatment of CM, which is in line with the previous study. In this study, the onset of C5P varied from 1 to 8 days postoperatively with a mean of 3.9 days. Nevertheless, there was no immediate postoperative neurological deficit. Thus, it is prudent to speculate that the occurrence of C5P may not be due to a direct injury caused by surgery but may be associated with multiple factors. Until now, there have been some additional studies on prediction for C5P. Frustratingly, it is difficult to accurately predict the incidence of C5P and identify related risk factors.[20, 31] In this research, we developed and validated an SVM model for C5P after LF in patients with CM based on a machine learning algorithm.

In this report, we identified 4 factors that were independently associated with C5P. Electromyogram abnormal was an independent predictor. In a study by Sasai *et al*[32], 111 patients with CM were divided into two groups and found out that electromyography was a sensitive predictor for predicting C5P after laminoplasty. In the present study, the proportion of electromyogram abnormal was significantly higher in the C5P group than in the No-C5P group. In parallel, multivariate logistic regression analysis showed electromyogram abnormal OR value of 7.861. This suggested that electromyogram abnormal was a critical risk factor to address in order to C5P. The electromyogram abnormal indicated that the patient had subclinical nerve root compression, which was the pathological basis for the occurrence of C5P. Although numerous previous studies have shown that preoperative, and postoperative JOA scores were not independent predictors of C5P, something interesting was observed in this study.[33-37] The JOA recovery rate was significantly higher in C5P group than that in the no-C5P group and was identified as an independent risk factor for C5P. In our clinical practice, the majority of patients with C5P had a good prognosis without specific treatment. However, it was easy to overlook the fact that the onset of C5P was often accompanied by significant motor weakness and pain, which could significantly impact the clinical outcome. Cervical lordosis has been considered as an essential factor in previous studies. Hence, we included this factor in the SVM model. Individual scholars have suggested that C5P was often associated with backward spinal cord drift. However, there were still many controversies in the previous literature.[38, 39] Therefore, there was currently still no clear evidence to confirm the inevitability of the degree of posterior displacement of the spinal cord in cervical lordosis and the occurrence of C5P. In this study, the difference between the preoperative CCI of the two groups was statistically significant, and the preoperative CCI was greater in the C5P group than in the No-C5P group. The CCI was reduced in both

groups postoperatively, but no statistically significant difference was observed between the two groups. These suggested that the greater the preoperative CCI, the higher the incidence of C5P.

Remarkably, we introduced the modified Pavlov ratio. The previous Torg-Pavlov ratio shows the canal-to-vertebral body ratio. [20]Although this provides a relatively concise method, false negatives frequently did occur. In order to investigate cord to actual compression mass including protruded disk, regardless of bony canal stenosis, a modified Pavlov ratio was introduced in this study. Pierre etc., firstly reported the application of modified Pavlov ratio in the evaluation of the state of spinal cord compression, which was a more accurate and reliable imaging parameter. The relationship between C2-C7 SVA and the incidence of C5P after cervical spine surgery has been reported in little previous literature.[19] In the present study, we found no significant difference between preoperative and postoperative C2-C7 SVA in the two groups. However, previous literature suggested that cervical sagittal balance on patients' postoperative quality of life cannot be ignored. [19]Therefore, we incorporated this parameter into the SVM model in a first attempt to explore the association between C2-C7 SVA parameters and C5P. Several studies have reported that preventive C4/5 foraminotomies decrease the incidence of C5P-LP.[40, 41] Although significance was not observed in this study, a higher incidence of C5P was found in patients with C4-5 foraminal stenosis than those without. More important, this variable was identified as an independent risk factor for C5P. The width of decompression in previous studies was considered to be an important risk factor for C5P.[39] However, little research on the effect of the number of levels decompressed on the incidence of C5P underwent LF. In the present study, the number of levels decompressed was significantly higher in the C5P group than in the No-C5P group. Although it was not statistically significant in the multifactorial logistic regression, we still clinically believe that the number of levels decompressed affects the distance of spinal cord drift backward and may increase the incidence of C5P.[42, 43] Therefore, we believe that the number of levels decompressed is an important parameter for the SVM model. One highlight of our work was using the SVM machine learning technique to predict the C5P after LF in patients with CM from routinely available variables. Our model achieved an AUC of 0.923, an ACC of 0.918, and a satisfying confusion matrix, which indicated that our model presented good performance in predicting C5P and might be widely applied in daily clinical practice.

There are some limitations to mention here. First, our study data were obtained from only a single centre, and the sample size was limited. Second, the conclusion of the study was restricted to the limitations of retrospective studies. Third, we only trained the SVM model by single-centre data, and we lack sufficient sample size for the external validation cohort. Thus, large multicenter trials are needed to improve the universality of results. Fourth, as a machine learning algorithm, this technique requires high computer hardware computing power, and the code related to the algorithm requires appropriate expertise, thus limiting the large-scale rollout. Finally, although we have attempted to collect more variables affecting the C5P potentially, it is possible that some important variables may have been neglected.

5. Conclusions

In conclusion, we conducted a multivariate logistics regression analysis of C5P's predictors in patients with CM after LF by using the SVM approach. The SVM model demonstrated satisfying performance in predicting C5P. Additionally, the variables incorporated in the SVM model are readily available to clinicians and researchers, and these facilitate routine clinical use. Those who are predicted to suffer C5P using the SVM model may benefit from the intervention. Meanwhile, the model can help us identify medium- and high-risk patients targeting important risk factors for modification and stratified management.

Abbreviations

C5P: C5 palsy; PLF: posterior laminectomy and fusion; CM: cervical myelopathy; SVM: support vector machine; ACC: accuracy; AUC: area under receiver operating characteristic curve; OR: odds ratio; JOA: Japanese Orthopaedic Association; BMI: body mass index; CCI: cervical curvature index; SVA: Sagittal vertical axis; CT: computer tomography; MRI: magnetic resonance imaging; RBF: radial basis function: TP: true positive; TN: true negative; FP: false positive; and FN: false negative.

Declarations

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Authors' contributions

HSW collected the data, analyzed the data, drafted the manuscript. YQ supervised the project and reviewed the manuscript. ZRT, WLL, TTF, JWZ, MYK and RPD conceived of the study, participated in its design and coordination, and helped to draft the manuscript. YQ was responsible for the whole project, designed the study, and supervised the study. All authors read and approved the final manuscript.

Availability of data and materials

The data set supporting the conclusion of this article is available on request to the corresponding author.

Ethics approval and consent to participate

The study was approved by an Institutional *Ethics Committee* at the Second Hospital of Jilin University (Ethics application number: 20151213002N). Considering that this work was a retrospective study, the ethics committee waived the requirement for informed consent from patients.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Tables

Table 1
Comparison of variables between the C5P group and No-C5P group.

	Total	No-C5P	C5P	p
Number of patients	184	158	26	
Age (years, %)				0.51
< 40	3 (1.6)	2 (1.3)	1 (3.8)	
40–50	20 (10.9)	16 (10.1)	4 (15.4)	
50–60	45 (24.5)	40 (25.3)	5 (19.2)	
60–70	61 (33.2)	54 (34.2)	7 (26.9)	
≥ 70	55 (29.9)	46 (29.1)	9 (34.6)	
Sex (%)				0.402
Female	86 (46.7)	76 (48.1)	10 (38.5)	
Male	98 (53.3)	82 (51.9)	16 (61.5)	
History of hypertension (%)				1
No	146 (79.3)	125 (79.1)	21 (80.8)	
Yes	38 (20.7)	33 (20.9)	5 (19.2)	
DM (%)				0.229
No	138 (75.0)	121 (76.6)	17 (65.4)	
Yes	46 (25.0)	37 (23.4)	9 (34.6)	
History of smoking (%)				0.345
No	160 (87.0)	139 (88.0)	21 (80.8)	
Yes	24 (13.0)	19 (12.0)	5 (19.2)	
BMI (kg/m^2, %)				0.003
≤ 18.4	3 (1.6)	0 (0.0)	3 (11.5)	
18.5–23.9	29 (15.8)	23 (14.6)	6 (23.1)	
24.0-27.9	42 (22.8)	37 (23.4)	5 (19.2)	
≥ 28.0	110 (59.8)	98 (62.0)	12 (46.2)	

Abbreviation: DM, diabetes mellitus; BMI, Body mass index; JOA, Japanese Orthopaedic Association; CCI: cervical curvature index; SVA: Sagittal vertical axis.

	Total	No-C5P	C5P	p
Electromyogram abnormal (%)				< 0.001
No	106 (57.6)	100 (63.3)	6 (23.1)	
Yes	78 (42.4)	58 (36.7)	20 (76.9)	
Pathological reflexes (%)				0.242
Strong positive	52 (28.3)	48 (30.4)	4 (15.4)	
Positive	89 (48.4)	76 (48.1)	13 (50.0)	
Weak positive	34 (18.5)	27 (17.1)	7 (26.9)	
Negative	9 (4.9)	7 (4.4)	2 (7.7)	
Preoperative JOA score	10.7 [8.5, 12.7]	10.4 [8.1, 12.5]	12.9 [11.4, 14.8]	< 0.001
Postoperative JOA score	13.1 [11.7, 14.7]	13.0 [11.7, 14.3]	14.6 [9.1, 17.3]	0.184
JOA recovery rate	75.5 [70.1, 80.6]	77.4 [72.4, 81.3]	61.3 [55.6, 68.6]	< 0.001
Preoperative CCI	6.3 [5.0, 7.6]	6.1 [4.9, 7.4]	7.4 [6.6, 8.3]	0.004
Postoperative CCI	10.5 [8.5, 12.3]	10.4 [8.3, 12.1]	11.3 [9.6, 14.1]	0.062
CCI Change	4.9 [3.8, 6.3]	4.7 [3.8, 6.1]	5.8 [3.7, 7.0]	0.134
Preoperative C2-7 SVA (mm)	23.4 [17.0, 27.4]	22.2 [16.9, 27.0]	23.8 [19.7, 29.0]	0.35
Postoperative C2-7 SVA (mm)	22.9 [19.5, 26.3]	22.9 [19.5, 25.7]	23.7 [19.0, 29.3]	0.422
Modified Pavlov ratio	0.32(0.1)	0.31(0.1)	0.34(0.09)	< 0.001
Presence of foraminal stenosis C4-C5 (%)				< 0.001
No	133 (72.3)	129 (81.6)	4 (15.4)	
Yes	51 (27.7)	29 (18.4)	22 (84.6)	
Number of levels decompressed	3.3 (1.0)	3.2 (0.9)	3.8 (1.2)	0.004
Number of fusion levels	3.9 (0.5)	3.9 (0.5)	4.2 (0.6)	0.014

Abbreviation: DM, diabetes mellitus; BMI, Body mass index; JOA, Japanese Orthopaedic Association; CCI: cervical curvature index; SVA: Sagittal vertical axis.

Table 2

Univariate and multivariate logistic regression model analyses of C5P in this study.

	Univariable Logistic Regression Analysis				**Multivariable Logistic Regression Analysis**			
	Odds ratio 95% Confidence interval P Value				Odds ratio 95% Confidence interval P Value			
Variable		Lower	Upper			Lower	Upper	
Age (years, %)	0.992	0.956	1.029	0.688				
Sex (%)	1.483	0.642	3.573	0.363				
History of hypertension (%)	0.902	0.284	2.411	0.847				
DM (%)	1.731	0.687	4.136	0.226				
History of smoking (%)	1.742	0.533	4.888	0.317				
BMI (kg/m^2, %)	0.973	0.899	1.047	0.471				
Electromyogram abnormal (%)	5.747	2.302	16.46	0.000399 ***	7.861	2.139	19.546	0.003674 **
Pathological reflexes (%)	1.569	0.957	2.577	0.0725				
Preoperative JOA score	0.718	0.620	0.798	0.07				
Postoperative JOA score	1.070	0.926	1.239	0.3636				
JOA recovery rate	1.371	1.168	1.637	0.000221 ***	1.412	1.111	1.879	0.008841 **
Preoperative CCI	1.400	1.124	1.776	0.00372 **	1.289	0.916	1.934	0.175568
Postoperative CCI	1.150	1.009	1.316	0.0375 *	1.138	0.935	1.399	0.199295
CCI Change	1.205	0.953	1.533	0.122				
Preoperative C2-7 SVA (mm)	1.021	0.972	1.074	0.406561				
Postoperative C2-7 SVA (mm)	1.043	0.974	1.117	0.218578				

Abbreviation: DM, diabetes mellitus; BMI, Body mass index; JOA, Japanese Orthopaedic Association; CCI: cervical curvature index; SVA: Sagittal vertical axis.

	Univariable Logistic Regression Analysis				Multivariable Logistic Regression Analysis			
Modified Pavlov ratio	0.012	0.0075	0.024	2.57e-05 ***	0.021	0.009	0.034	0.028964 *
Presence of foraminal stenosis C4-C5 (%)	8.231	4.124	13.214	3.76e-08 ***	15.492	3.961	21.654	0.000236 ***
Number of levels decompressed	1.850	1.205	2.901	0.00564 **	1.525	0.808	3.006	0.201100
Number of fusion levels	2.864	1.250	6.895	0.015492 *	0.994	0.339	3.115	0.992097
Abbreviation: DM, diabetes mellitus; BMI, Body mass index; JOA, Japanese Orthopaedic Association; CCI: cervical curvature index; SVA: Sagittal vertical axis.								

Figures

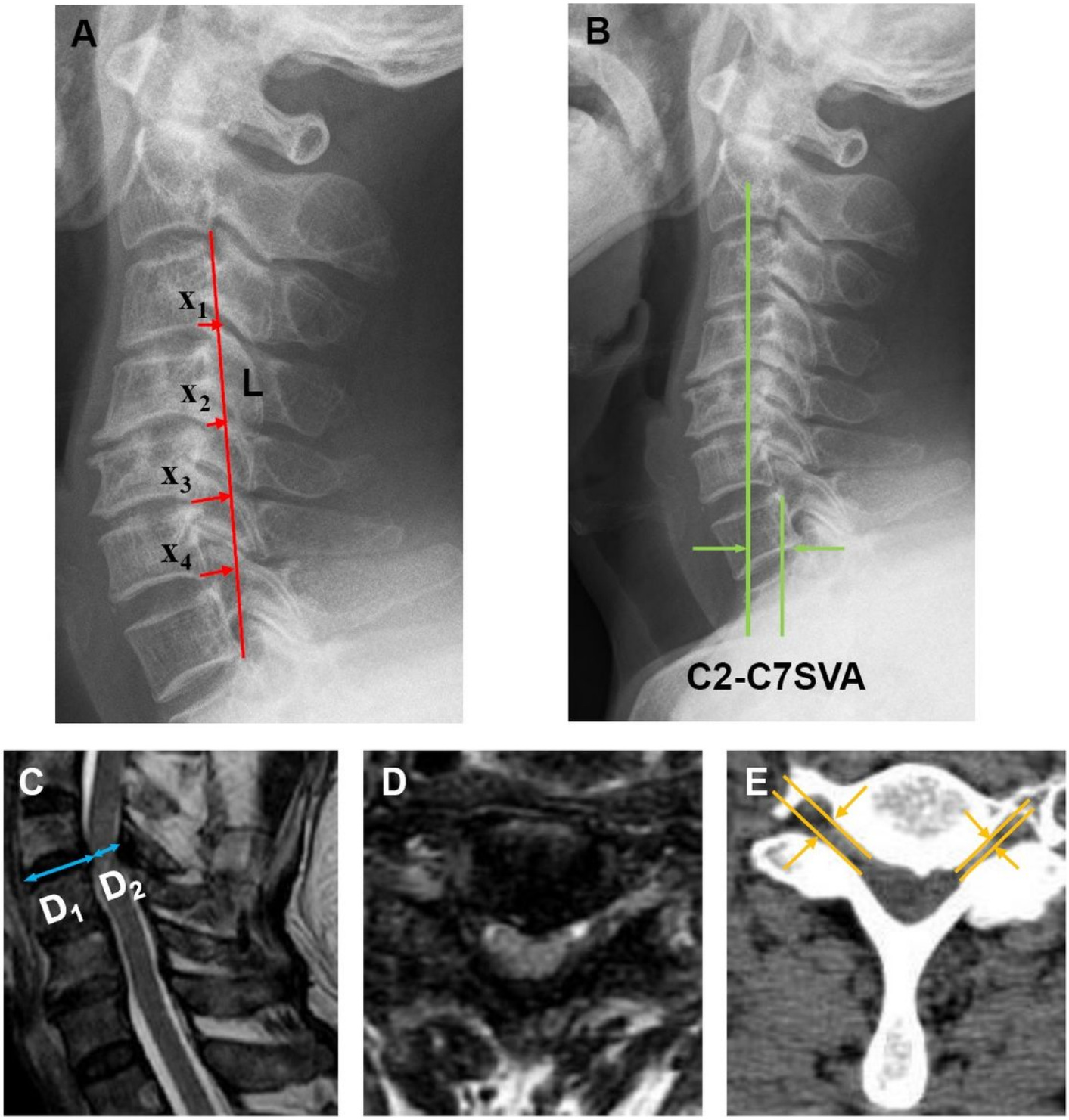

Figure 1

Radiographic evaluation. A, CCI on cervical spine X-rays. CCI: Line x the distance between the posterior inferior points of C2 and C7. The distance between the posterior inferior points of C3-C6 and the line L as called a1 to a4, respectively. The CCI is computed by this formula: CCI = (x1 + x2 + x3 + x4)/L × 100%. When posterior inferior points of C3-C6 are behind line L, the value of x1 to x4 are negative. B, C2-7 SVA on cervical spine X-rays. The distance between the center point through C2 and the vertical line of the

posterosuperior corner of C7 was defined as C2-C7 SVA. C, Modified Pavlov ratio on sagittal T2-weighted MRI. Pavlov ratio (= D1/D2, vertebral body spinal canal ratio). D, Presence of protruding lesions at the anterior portion of the spinal cord. E, Foraminal stenosis between C4 and C5 on axial CT image. The yellow arrows indicate foraminal dimension.

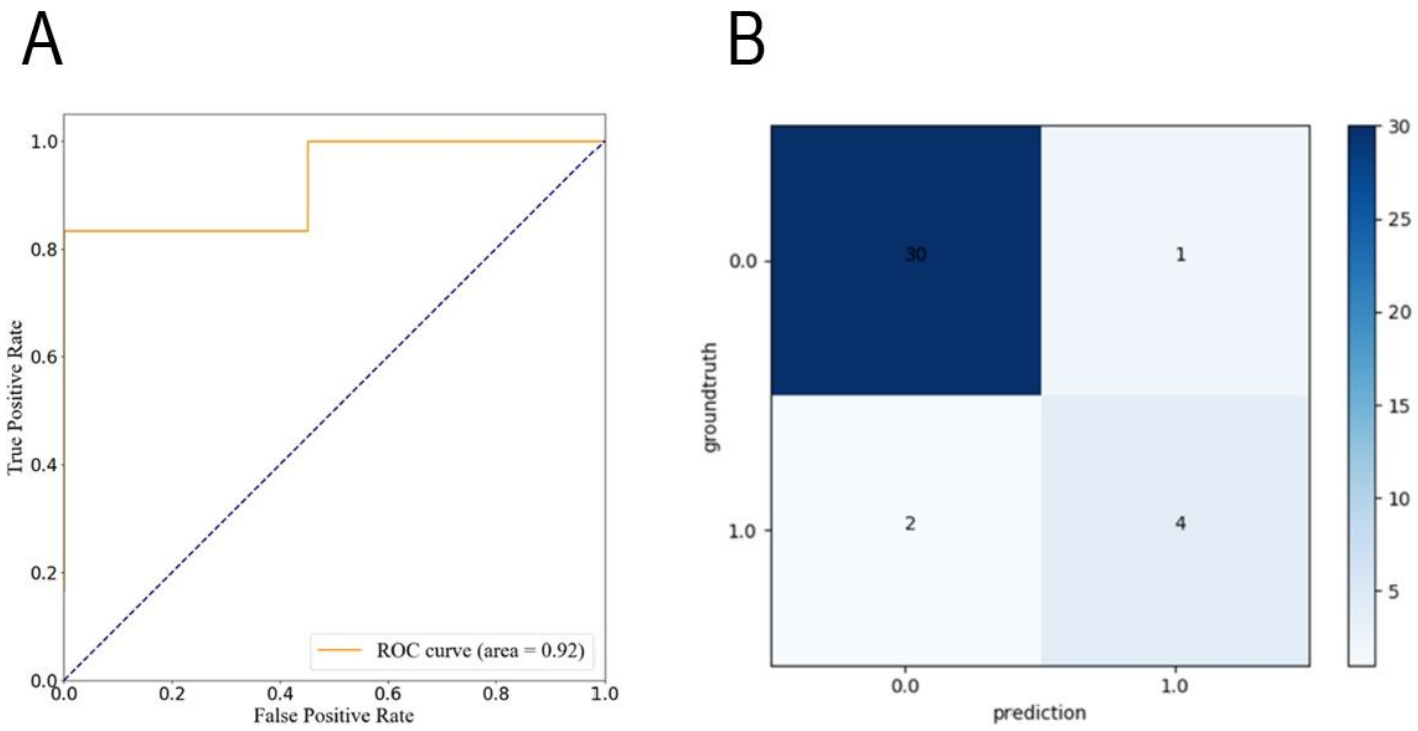

Figure 2

A, The results of the confusion matrix show a good predictive ability of the SVM model. B, The Receiver operating characteristic curve analysis of the SVM model.