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Original Article

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Predicting Neck Dysfunction After Open-Door Cervical Laminoplasty — A Prospective Cohort Patient-Reported Outcome Measurement Study

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Objective: To analyze the predictive factors for neck pain and cervical spine function after laminoplasty for degenerative cervical myelopathy (DCM) using K-means for longitudinal data (KML).
Methods: In this prospective cohort study, we collected clinical and radiographic data from patients with DCM who underwent cervical laminoplasty. A novel index of surgical outcome, "neck function," which comprises neck pain and cervical spine function according to the Japanese Orthopedic Association Cervical Myelopathy Evaluation Questionnaire, was proposed. We treated surgical outcomes as longitudinal rather than cross-sectional data and used KML for analysis. Patients were categorized as having good or poor outcomes based on the KML graph of neck pain and cervical spine function.
Results: From 2016 to 2020, 104 patients underwent laminoplasty for DCM; however, 35 patients were excluded because of loss to follow-up or incomplete data. The authors found that central canal stenosis (odds ratio [OR], 17.93; 95% confidence interval [CI], 1.26–254.73; $p=0.03$) and preoperative neck pain (OR per 1 point increase = 1.49; 95% CI, 1.12–1.99; $p=0.006$) were 2 negative predictive factors and that a positive K-line during flexion was a positive predictive factor (OR, 0.11; 95% CI, 0.01–0.87; $p=0.036$) for neck function after laminoplasty.
Conclusion: Central canal stenosis, preoperative neck pain and a K-line during flexion were found to be predictive of postoperative neck pain and cervical spine function after laminoplasty. To achieve better surgical outcomes for neck function, the authors suggest the utilization of these determinants as a guiding framework for the selection of surgical approaches for DCM.

Keywords: Spinal cord compression, Spondylosis, Ossification of posterior longitudinal ligament, Laminoplasty

INTRODUCTION

Degenerative cervical myelopathy (DCM) is a comprehensive term that refers to all degenerative changes that cause spinal cord compression, including cervical spondylotic myelopathy (spondylosis, disc herniation, and facet hypertrophy), hypertrophy or ossification of the ligamentum flavum or posterior longitudinal ligament, and subluxation.[1,2] DCM, which is characterized by progressive degeneration, is the most common cause of spinal cord dysfunction or myelopathy in adults.[3,4] A wide spectrum of neurological signs and symptoms, including hyperreflexia, muscle atrophy, muscle weakness, gait dysfunction, dysesthesia, chest and neck pain, and increased spasticity, occur due to spinal cord compression.[5] Surgical intervention is considered necessary due to stepwise worsening of the natural course of cervical myelopathy. Decompression of the spinal cord, restoration of sagittal alignment, and stabilization of the spine are the major goals of surgery.[6] There are 3 different surgical approach options: the anterior approach, the posterior approach, and the combined anterior and posterior approach. Several factors,[7] including surgeon preference and familiarity, sagittal alignment, location and levels of the compressive pathology, patient comorbidities, and the value of the K-line, are considered when surgeons make decisions about surgical approaches.[8,9]

Laminoplasty is one of the most commonly performed posterior approaches. It allows for wider decompression,[10] comprising direct decompression via removal of posterior compressive pathologies and indirect decompression occurring when the cervical spinal cord drifts away from anterior compressive pathologies. Progressive neck pain, kyphotic deformity and delayed instability have been reported as the main disadvantages.[11,12] However, laminectomy combined with lateral mass fixation leads to new problems such as neck motion limitation and potential adjacent degeneration. Most of the studies on surgical outcomes have reported the modified Japanese Orthopedic Association (mJOA) score and pain scale score as the major indicators. To study the aforementioned disadvantages of laminoplasty, we propose a novel index of surgical outcome, "neck function," which comprises neck pain and cervical spine function according to the Japanese Orthopedic Association Cervical Myelopathy Evaluation Questionnaire (JOACMEQ); both neck pain and cervical spine function are patient-reported outcome measures.

K-means is a useful clustering algorithm used to group data points into distinct clusters based on their similarity. However, traditional K-means methods are designed for cross-sectional data, where each data point is independent of others. When dealing with longitudinal data, where data points are collected over time from the same subjects or entities, traditional K-means may not be suitable. Common parameters for surgical outcome studies, i.e., either the pain scale score or neurological function, are relatively subjective and reported from the doctor's perspective. In addition, most studies regarding surgical outcomes have measured and analyzed such outcomes at certain (e.g., preoperative, postoperative 1 month, and postoperative 3 months) time points. In other words, these parameters may be affected by instant physical and psychological conditions. We believe that surgical outcomes involve longitudinal data that vary and change with time; therefore, we applied a novel K-means for longitudinal data (KML) method to identify factors associated with good surgical outcomes. In this prospective cohort study, we collected clinical and radiographic data from patients with DCM who underwent cervical laminoplasty and identified potential factors for predicting postoperative neck function.

MATERIALS AND METHODS

1. Patient and Surgical Intervention

Between 2016 and 2020, 104 adult participants were prospectively enrolled in this study. The inclusion criteria were as follows: (1) ≥18 years of age, (2) symptomatic DCM, and (3) magnetic resonance imaging (MRI) revealing cervical spinal cord compression. Patients with cervical radiculopathy alone, cervical trauma, subluxation, infection, tumor or autoimmune spondylopathy were excluded. All patients underwent cervical Hirabayashi type[13,14] expansive open-door laminoplasty. The segment and level of surgical intervention were determined with the signal change of myelopathy and/or cervical cord compression presented on the preoperative MR image. The side of the hinge or opening was mostly determined according to the patient's symptoms and signs. We opened the much more severe side for better decompression. Thirty-five patients were excluded because of less than 1 year of follow-up (3 patients), incomplete or missing data (4 patients without preoperative mJOA and 22 patients without preoperative JOACMEQ) or unsatisfactory images (6 patients because of blocked view at C7 level) (Fig. 1). All surgeries in this study were performed by the same senior surgeon at the time of authorship. This study was approved by National Taiwan University Hospital Research Ethics Committee under protocol (#201505093RINA). The protocol adhered to the principles of the Declaration of Helsinki, and all methods were conducted in accordance with the relevant guidelines and regulations. A written informed consent was obtained from all subjects.

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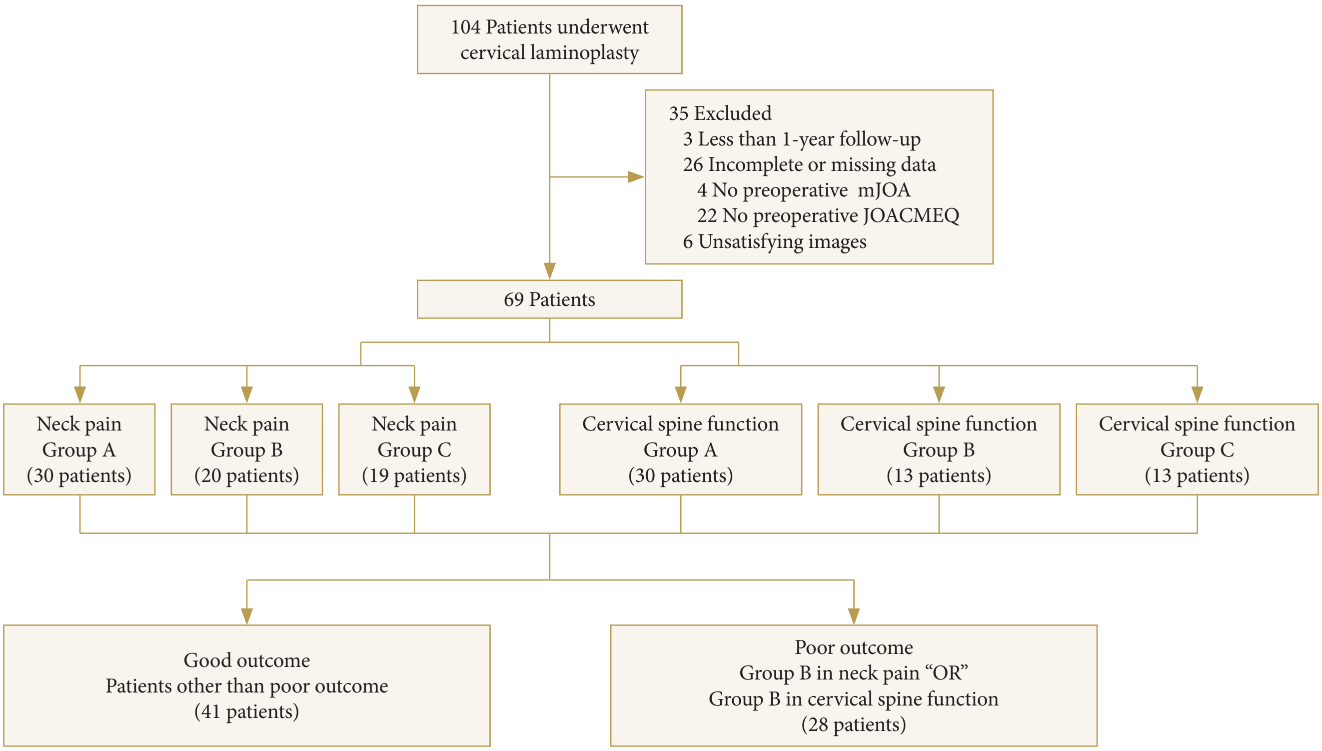

Fig. 1. The study design and flowchart. This study aimed to compare good and poor outcomes in terms of neck function. The poor outcome group (28 patients) was defined as either group B patients with neck pain or group B patients with poor cervical spine function based on the results of Fig. 3. Other patients (41 patients) were grouped into good outcomes. mJOA, modified Japanese Orthopedic Association; JOACMEQ, Japanese Orthopedic Association Cervical Myelopathy Evaluation Questionnaire.

2. Data Collection

We collected data on patient demographics (age, sex, weight, height, body mass index, smoking status) and comorbidities (diabetes mellitus, abnormal liver function, moderate-to-severe chronic kidney disease, chronic obstructive pulmonary disease, congestive heart failure, myocardial infarction, coronary artery disease, stroke, peptic ulcer disease, acquired immunodeficiency syndrome, dementia) for each patient. From the preoperative MR images, we recorded the levels of the operated segments (for example, laminoplasty at C3 to C6 was recorded as 4), and then we assessed the extent of the disease by using Kang grading of central canal stenosis[15] and Kim grading system of neural foramen stenosis[16] at the most severe segment. The severity of disease and functional impairment were evaluated with the mJOA score, Neck Disability Index (NDI), and Japanese Orthopedic Association Cervical Myelopathy Evaluation Questionnaire (JOACMEQ) at baseline and at 1-, 3-, 6-, and 12-month intervals after the operation. The severity of myelopathy was defined by the total mJOA score: <12 was severe, 12–14 was moderate, and ≥ 15 was mild. In addition, we measured 12 radiographic parameters (the McGregor angle, C2 slope, C7 slope, C0–2 angle, C2–7 angle, C0–7 angle, global cervical angle, C1–7 sagittal vertical axis (SVA), C2–7 SVA, range of motion, K-line at extension and K-line at flexion) of lateral, flexion and extension radiographs of the cervical spine at baseline and at 12 months after the operation (Fig. 2).

3. Data Analysis

Among the variables in the JOACMEQ, we focused on cervical spine function and neck pain, defining them as "neck function." The degrees of cervical spine function and neck pain experienced by patients were clustered using the K-means method for longitudinal data with the kml package implemented in R ver. 3.4.2 (R Foundation for Statistical Computing, Vienna, Austria), and detailed R code was provided in Supplementary File 2. There were missing data if patients did not adhere to regular follow-up appointments. Values that were missing in the middle and at the end of the study period were imputed using the previous nonmissing values.

Fig. 3A shows that in group A, there was no obvious neck pain before or after surgery. Patients in group B indicated that their neck pain did not change after surgery. Group C patients re-

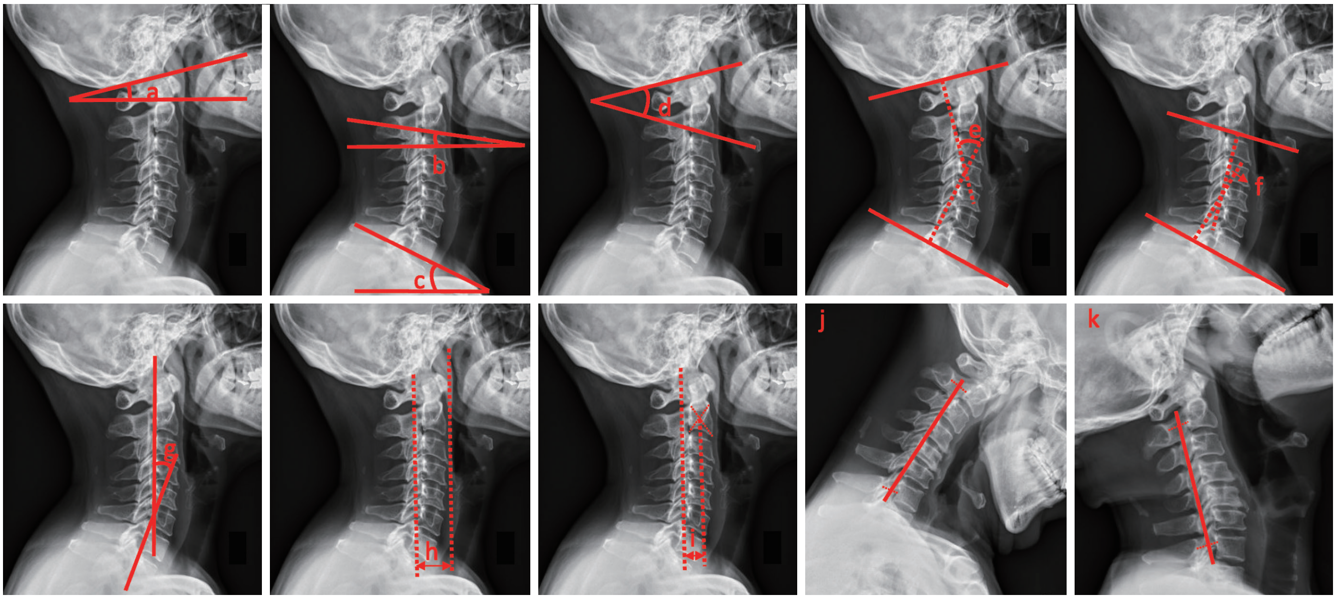

Fig. 2. Radiographic parameters measured in our study. The McGregor angle (a) is the angle between McGregor line (the line connecting the posterior edge of the hard palate to the most caudal portion of the occipital curve) and the horizontal plane. The C2 slope (b) is the angle between the C2 lower endplate and the horizontal plane, and the C7 slope (c) is the angle between the C7 lower endplate and the horizontal plane. The C0–2 angle (d) is the angle between McGregor's line and the C2 lower endplate. The C2–7 angle (e) is the angle between the C2 lower endplate and the C7 lower endplate. The C0–7 (f) angle is the angle between McGregor line and the C7 lower endplate. The global cervical angle (g) is the angle between the 2 lines, one parallel to the posterior margin of the C2 vertebral body and the other parallel to the posterior margin of the C7 vertebral body. The C1–7 sagittal vertical axis (h) is the distance between a plumb line from the anterior tubercle of C1 and the posterior superior corner of C7, and the C2–7 (i) sagittal vertical axis is the distance between a plumb line from the center of the C2 body and the posterior superior corner of C7. The K-line is a straight line that connects the midpoints of the spinal canal at C2 and C7 on a lateral plain film during extension (j) or flexion (k).

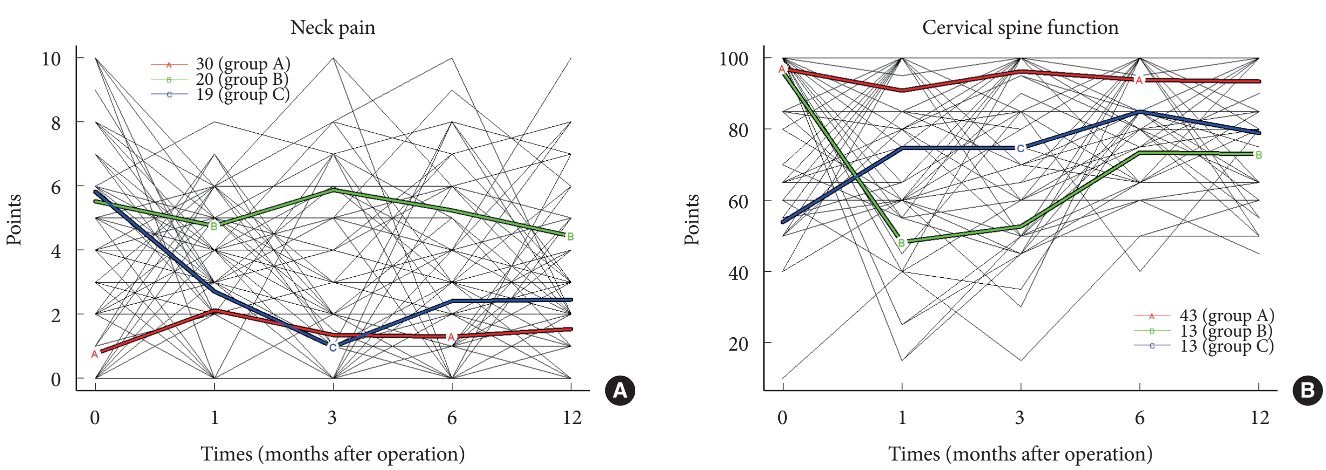

Fig. 3. K-means for longitudinal data curves for neck pain (A) and cervical spine function (B). (A) Group A reported that there was no obvious neck pain before or after surgery. Group B reported that the neck pain did not change after surgery. Group C exhibited a remarkable improvement in neck pain after surgery, which further improved gradually during regular follow-up. (B) Group A patients maintained fair cervical spine function before and after surgery. Group B experienced deteriorated cervical spine function after surgery; although there was some improvement during regular follow-up, the patients' cervical spine function was poorer than that preoperatively. Group C exhibited improved cervical spine function after surgery.

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ported a remarkable improvement in their neck pain after surgery, which further improved gradually during regular follow-up. Fig. 3B shows that group A patients had fair cervical spine function before and after surgery. Group B patients exhibited deteriorated cervical spine function after surgery. Although there was some improvement during regular follow-up, the patients' cervical spine function was poorer than that preoperatively. Group C patients exhibited an improvement in cervical spine function after surgery. We defined patients with poor neck function as either group B patients with neck pain or group B patients with poor cervical spine function; other patients were considered to have good outcomes.

The analysis population comprised eligible patients who had completed at least 12 months of follow-up. All the characteristics of the patients in the good outcome and poor outcome groups were compared using a descriptive statistical method. Categorical data are presented as counts and percentages with the chi-square test used for comparisons; continuous data are presented as the means (standard deviation) with Student t-test for analysis. Univariate and multivariate analyses were performed with logistic regression. A p-value < 0.05 was regarded as statistically significant. Statistical analysis was performed using SPSS ver. 9.4 (SPSS Inc., Chicago, IL, USA).

RESULTS

1. Patient Demographics

A total of 69 patients were enrolled in this study. Fig. 3A (neck pain) shows that 44.3% of the patients were in group A, 28.4% were in group B and 27.3% were in group C. Fig. 3B (cervical spine function) shows that 61.4% of the patients were in group A, 19.3% were in group B and 19.3% were in group C. There were 28 patients in the poor outcome group, defined as group B for neck pain or group B for cervical spine function; the other 41 patients were in the good outcome group. The basic patient characteristics of the good outcome and poor outcome groups are listed in Table 1. There were no statistically significant differences in age (61.17 ± 10.30 vs. 60.11 ± 7.18), body height (163.05 ± 8.82 vs. 161.49 ± 7.39), body weight (70.62 ± 15.26 vs. 70.60 ± 14.18), body mass index (26.41 ± 4.20 kg/m^2 vs. 26.94 ± 4.30 kg/m^2), or proportion of smokers (14.6% vs. 21.4%) between the good outcome group and the poor outcome group. Similarly, the difference in underlying comorbid diseases was not significant (Supplementary Table 1). However, the proportion of male patients was significantly higher in the good outcome group (78.1% vs. 50%, p = 0.015).

Table 1. Patient demographics

Variable	Good outcome (n = 41)	Poor outcome (n = 28)	p-value
Age (yr)	61.17 ± 10.30	60.11 ± 7.18	0.669
Male sex	32 (78.1)	14 (50.0)	0.015
Height (cm)	163.05 ± 8.82	161.49 ± 7.39	0.444
Weight (kg)	70.62 ± 15.26	70.60 ± 14.18	0.996
BMI (kg/m^2)	26.41 ± 4.20	26.94 ± 4.30	0.612
Smoking	6 (14.6)	6 (21.4)	0.527
Operated segment	2.68 ± 0.65	3.14 ± 0.71	0.165
Complication	2 (4.9)	2 (7.1)	0.538
Grading of central canal stenosis			0.022
1	0 (0)	0 (0)	
2	10 (24.4)	1 (3.6)	
3	31 (75.6)	27 (96.4)	
Grading of neural foramen stenosis			0.247
1	4 (9.8)	2 (7.1)	
2	19 (46.3)	8 (28.6)	
3	18 (43.9)	18 (64.3)	
Preoperative mJOA grade			0.057
Mild	21 (51.2)	12 (42.8)	
Moderate	17 (41.5)	8 (28.6)	
Severe	3 (7.3)	8 (28.6)	
Preoperative JOACMEQ score			
Neck pain	2.75 ± 2.79	4.80 ± 2.31	0.005
Chest pain	1.29 ± 2.31	1.52 ± 2.14	0.692
Arm pain	3.11 ± 3.11	3.12 ± 3.03	0.985
Leg pain	2.71 ± 2.79	4.12 ± 2.77	0.054
Cervical spine function	87.63 ± 18.22	87.40 ± 23.46	0.965
Upper limb function	87.53 ± 15.11	80.42 ± 20.64	0.146
Lower limb function	79.67 ± 24.32	75.27 ± 27.40	0.507
Bladder function	83.39 ± 19.35	78.75 ± 15.83	0.332
Quality of life	61.81 ± 18.74	55.42 ± 17.48	0.179
Neck disability index	16.66 ± 17.59	18.00 ± 17.30	0.755

Values are presented as mean ± standard deviation or number (%).
BMI, body mass index; mJOA, modified Japanese Orthopedic Association; JOACMEQ, Japanese Orthopedic Association Cervical Myelopathy Evaluation Questionnaire.

The operated segment was 2.68 ± 0.65 levels in the good outcome group and 3.14 ± 0.71 in the poor outcome group, yet there was no statistically significant difference. One patient in the poor outcome group underwent another surgery of anterior cervical discectomy and fusion (ACDF) 2 weeks after laminoplasty because of persistent symptoms of radiculopathy and myelopathy. The pathology of this patient revealed 3-level cervical spondylosis, and one of the affected levels revealed severe cord compression by the herniated disc and hypertrophic ligamentum flavum. Because preoperative MRI revealed severe compression from both the anterior and posterior aspects, the patient was comprehensively informed about the high possibility of a second surgery before laminoplasty was performed. There was a total of 4 patients who experienced complications after laminoplasty, with 2 patients in each group. Two patients, one in each group, experienced muscle weakness after surgery. Both patients recovered well after undergoing aggressive rehabilitation for 1 month. One patient in the good outcome group experienced intraoperative cerebrospinal fluid (CSF) leakage, which was repaired immediately, and there was no accompanying discomfort afterward. One patient in the poor outcome group had massive intraoperative blood loss, and that patient was sent to the intensive care unit for transfusion therapy and temporary inotropic agent support. In our series, there was no postoperative C5 palsy, which is a common and disabling complication following laminoplasty.

2. Disease Extent and Severity

The comparison of disease extent and severity between the 2 groups were also listed in Table 1. The grading of foraminal stenosis was 9.8% for grade 1, 46.3% for grade 2, 43.9% for grade 3 in the good outcome group, 7.1% for grade 1, 28.6% for grade 2, and 64.3% for grade 3 in the poor outcome group. According to the preoperative mJOA score, 51.2% of the patients in the good outcome group had mild disease severity, 41.5% had moderate disease severity, and 7.3% had severe disease severity; 42.8% of the patients in the poor outcome group had mild disease severity, 28.6% had moderate disease severity, and 28.6% had severe disease severity. Moreover, in the poor outcome group, there were longer segments involved, a greater proportion of patients with severe high-grade foraminal stenosis and more patients with moderate-to-severe disease. However, these 3 parameters did not reach statistical significance (operated segment $p=0.165$, foraminal-stenosis grade $p=0.247$, and mJOA score $p=0.057$). In contrast, the degree of central canal stenosis was more severe in the poor outcome group, with 3.6% having a grade of 2 and 96.4% having a grade of 3, while in the good outcome group, 24.4% of patients had a grade of 2, and 75.6% had a grade of 3 ($p=0.022$).

3. Radiographic Parameters

A comparison of the radiographic parameters is presented in Table 2. The McGregor angle, C2 slope, C7 slope, C0–2 angle, C2–7 angle, C0–7 angle, global cervical angle, C1–7 SVA, C2–7 SVA and range of motion were 19.88 ± 10.48 and 21.54 ± 10.60, 12.20 ± 9.09 and 10.50 ± 7.84, 24.95 ± 9.13 and 22.75 ± 7.12, 30.31 ± 10.94 and 31.64 ± 9.99, 14.54 ± 11.03 and 13.79 ± 8.87, 45.12 ± 12.67 and 44.61 ± 12.81, 16.15 ± 11.47 and 15.96 ± 9.40, 2.90 ± 1.65 and 2.84 ± 1.49, 1.75 ± 1.22 and 1.54 ± 1.21, 37.90 ± 12.58 and 38.75 ± 14.99 in the good outcome and poor outcome groups, respectively. There was no significant difference in any of these parameters. The proportions of K-lines (+) in the good outcome group and poor outcome group were 90.2% and 78.6% during extension and 36.6% and 7.1% during flexion, respectively. The proportion of K-lines (+) during flexion significantly differed ($p=0.005$).

Table 2. Radiographic parameters

Parameter	Good outcome (n = 41)	Poor outcome (n = 28)	p-value
Cervical angle (°)			
McGregor angle	19.88 ± 10.48	21.54 ± 10.60	0.523
C2 slope	12.20 ± 9.09	10.50 ± 7.84	0.425
C7 slope	24.95 ± 9.13	22.75 ± 7.12	0.288
C0–2 angle	30.31 ± 10.94	31.64 ± 9.99	0.611
C2–7 angle	14.54 ± 11.03	13.79 ± 8.87	0.765
C0–7 angle	45.12 ± 12.67	44.61 ± 12.81	0.869
Global cervical angle	16.15 ± 11.47	15.96 ± 9.40	0.945
Sagittal vertical axis (cm)			
C1–7 sagittal vertical axis	2.90 ± 1.65	2.84 ± 1.49	0.874
C2–7 sagittal vertical axis	1.75 ± 1.22	1.54 ± 1.21	0.476
Range of motion (°)	37.90 ± 12.58	38.75 ± 14.99	0.800
K-line			
Extension			0.296
(–)	4 (9.8)	6 (21.4)	
(+)	37 (90.2)	22 (78.6)	
Flexion			0.005
(–)	26 (63.4)	26 (92.9)	
(+)	15 (36.6)	2 (7.1)	

Values are presented as mean ± standard deviation or number (%).

4. Univariable and Multivariable Analyses

According to the univariate logistic regression analysis in Table 3, several factors correlated with poor outcomes, including female sex (odds ratio [OR], 3.10; 95% confidence interval [CI], 1.10–8.75; $p=0.03$), central canal stenosis (OR, 6.54; 95% CI, 1.02–42.0; $p=0.048$), severe myelopathy according to the mJOA score (OR, 6.54; 95% CI, 1.30–32.96; $p=0.02$), and preoperative

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Table 3. Univariable analysis

Variable	Odds ratio (95% CI)	p-value
Sex		
Male	1.00	-
Female	3.10 (1.10–8.75)	0.03
Smoking	1.27 (0.84–5.79)	0.76
Grading of central canal stenosis		
Grade 2	1.00	
Grade 3	6.54 (1.02–42.0)	0.048
Grading of neural foramen stenosis		
Grade 1	1.00	
Grade 2	0.92 (0.15–0.88)	0.93
Grade 3	1.80 (0.30–10.81)	0.52
Preoperative mJOA grade		
Mild	1.00	
Moderate	0.84 (0.28–2.50)	0.75
Severe	6.54 (1.30–32.96)	0.02
Preoperative JOACMEQ score		
Neck pain	1.33 (1.09–1.64)	0.04
Chest pain	1.07 (0.85–1.34)	0.57
Arm pain	1.03 (0.87–1.21)	0.73
Cervical spine function	0.99 (0.97–1.02)	0.65
Upper limb function	0.98 (0.95–1.01)	0.16
Bladder function	0.98 (0.95–1.01)	0.10
Quality of life	0.98 (0.95–1.01)	0.19
Neck Disability Index	1.01 (0.98–1.04)	0.57
C2–7 angle	1.00 (0.95–1.05)	0.99
C2–7 sagittal vertical axis	0.94 (0.64–1.41)	0.78
Range of motion	1.01 (0.97–1.05)	0.64
K-line extension		
(–)	1.000	-
(+)	0.05 (0.11–1.75)	0.25
K-line flexion		
(–)	1.000	-
(+)	0.24 (0.07–0.90)	0.03

CI, confidence interval; mJOA, modified Japanese Orthopedic Association; JOACMEQ, Japanese Orthopedic Association Cervical Myelopathy Evaluation Questionnaire.

neck pain (OR, 1.33; 95% CI, 1.09–1.64; p = 0.04). A positive K-line during flexion was found to be associated with a good outcome (OR, 0.24; 95% CI, 0.07–0.90; p = 0.03). According to the multivariable logistic regression analysis in Table 4, central canal stenosis (OR, 17.93; 95% CI, 1.26–254.73; p = 0.03) and preoperative neck pain (OR per 1 point increase = 1.49; 95% CI, 1.12–1.99; p = 0.006) were 2 predictive factors for poor outcomes. A positive K-line during flexion was a predictor of a good outcome (OR, 0.11; 95% CI, 0.01–0.87; p = 0.036).

Table 4. Multivariate analysis

Variable	Odds ratio (95% CI)	p-value
Sex		
Male	1.00	-
Female	2.61 (0.61–11.22)	0.20
Grading of central canal stenosis		
Grade 2	1.00	-
Grade 3	17.93 (1.26–254.73)	0.03
Preoperative mJOA grade		
Mild	1.00	-
Moderate	0.92 (0.20–4.14)	0.92
Severe	4.38 (0.56–34.29)	0.16
Preoperative JOACMEQ score		
Neck pain	1.49 (1.12–1.99)	0.006
K-line flexion		
(–)	1.00	-
(+)	0.11 (0.01–0.87)	0.036

CI, confidence interval; mJOA, modified Japanese Orthopedic Association; JOACMEQ, Japanese Orthopedic Association Cervical Myelopathy Evaluation Questionnaire.

DISCUSSION

In this study, the pathologies of the enrolled patients were mainly multilevel (≥ 3 level) cervical spondylosis or herniated intervertebral disc (HIVD), ossification of the posterior longitudinal ligament (OPLL), or a combination of cervical spondylosis and OPLL. We predominantly performed laminoplasty instead of anterior cervical corpectomy and fusion (ACCF) or laminectomy with posterior fixation on these patients for several reasons: preservation of the cervical range of motion; relatively high risk of complications in ACCF, including cord damage, dura tears, cerebrospinal fluid leakage, prolonged operative time, etc.; potential adjacent segment diseases after fusion surgery; and the reconstruction material, such as expandable body cages or mesh, which are not covered by the National Health Insurance in Taiwan. We also preferred laminoplasty instead of ACDF, particularly for older patients or patients with significant comorbidities, to avoid the possible risk associated with a prolonged operative time. In this cohort, only 2 patients had pure cervical spondylosis. One of them received an additional ACDF surgery 2 weeks after laminoplasty. The etiologies of the other

67 patients were either pure OPLL or a combination of cervical spondylosis and OPLL.

We determined the surgical level of laminoplasty according to the preoperative MRI findings. During the operation, we aimed to preserve the insertion of the nuchal ligament at the C7 level in order to maintain supportive strength and prevent further kyphotic changes.[17-19] Therefore, if the compressive pathology extended to the C2 or C7 level, decompression would be achieved by partial laminectomy or removal of the undermined bony structure or ligamentum flavum instead of laminoplasty. Fig. 4 shows a typical plain radiograph and MR images before and after laminoplasty. Postoperative MR images demonstrated that good decompression could be achieved by indirect decompression. In our series, only one patient in the poor outcome group underwent both ACDF and laminoplasty due to significant circumferential cord compression. Although the postoperative MRI usually revealed satisfactory cord decompression after laminoplasty, some patients complained of cervical discomfort after laminoplasty, which is usually regarded as one of the drawbacks of laminoplasty. In clinical studies, most of the literature has used the mJOA score and pain score at certain durations after surgery as the major indicators of surgical outcome. However, these parameters are usually reported from the surgeon's perspective. The use of the NDI or other patient-reported outcome measurements is based on the patient's perspective; however, such data are usually drifting and unsteady. To evaluate the clinical presentation of these disadvantages, we considered neck pain and cervical spine function (questions 1–1 to 1–4 in the JOACMEQ) to be representative, and we proposed these parameters as a novel index of surgical outcome: "neck function." Because it is common for a patient with a degenerative cervical spine to also have a degenerative lumbar spine, we hypothesized that lower limb function or bladder function in the JOACMEQ may not be a precise outcome indicator after cervical spine surgery.

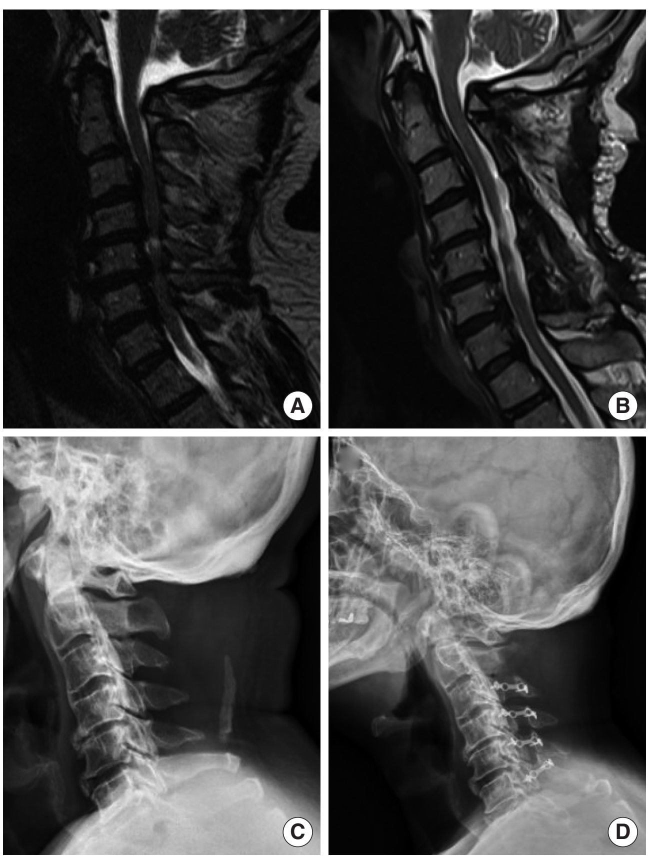

Fig. 4. Typical magnetic resonance images (MRIs) and plain radiographs before (A & C) and after (B & D) laminoplasty. (A) The preoperative MRI revealed severe spinal cord compression at C3 to C6 level with signal change of myelopathy at C5 level. (C) Both ossification of the posterior longitudinal ligament and spondylosis were the leading etiologies. The patient underwent C3 to C6 Hirabayashi type expansive open-door laminoplasty (D), and the postoperative MRI (B) demonstrated a satisfied decompression after the surgery.

The duration of symptoms[20-24] and preoperative myelopathy[24-32] are widely accepted as 2 major predictive factors. The mJOA score has been widely applied in different studies to represent disease severity. In our study, we evaluated the severity of disease and preoperative functional impairment with the mJOA score, NDI, and JOACMEQ. In the good outcome group, the proportion of patients with mild-to-moderate myelopathy was greater than that in the poor outcome group. However, the difference did not reach statistical significance. Although our results were not compatible with those of previous studies, the p-value of 0.057 was close to 0.05, which might indicate insufficient statistical power because of the relatively small sample size.

Another notable outcome indicator in our study was the score for neck pain on the JOACMEQ, which was significantly greater in the poor outcome group. Similarly, Ghasemi and Behfar[33] proposed that laminoplasty not be recommended for patients with significant preoperative axial neck pain. Invasion of nuchal muscle and ligament, especially at C2 and C7, postoperative neck stiffness or fibrosis, and nerve root traction after cord shifting are possible reasons of neck pain.[34-37] Nevertheless, there were still about only 28% (19/69, group C in Fig. 3A) of the patients were clustered to have relieving neck pain after laminoplasty, which might be benefit from cord decompression. Although the surgical response to neck pain was relatively unconvincing, we did not find any patient cluster in our cohort with

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noticeably aggravated neck pain after the surgery. Stephens et al.[38] also reported that laminoplasty did not lead to worsening axial neck pain. These results suggested that when treating patients with neck pain as the chief complaint, surgeons must carefully consider whether laminoplasty is appropriate.

In addition, we evaluated disease severity by preoperative MRI grading of central canal and neural foramen stenosis. Significance of central canal stenosis was noted, indicating that the extent of stenosis affects the surgical outcome. Previous studies have seldom mentioned the importance of central canal stenosis. Generally, the degree of central canal stenosis is intuitively correlated with the severity of myelopathy. As a result, it is reasonable that patients with more stenotic central canals had more severe symptoms and possibly worse surgical outcomes. However, our study revealed that only the severity of central canal stenosis was associated with poor "neck function" outcomes, while the severity of myelopathy, measured by the mJOA score, was not. Theoretically, the severity of myelopathy has strong correlation with nerve function, including upper limb, lower limb and bladder function in the JOACMEQ. To some extent, the severity of myelopathy is also associated with quality of life. The illustrative case in Fig. 4 represented a common clinical scenario where the signal change of myelopathy is usually located at one of the stenotic levels, but not necessarily at the most stenotic level. In this study, we mainly investigated neck pain and cervical spine function via the JOACMEQ. The major reasons for stenotic cervical spinal canal are OPLL, osteophytes, HIVD and facet arthropathy, all of which can cause limited range of motion and neck pain, resulting in poor cervical spine function. Consequently, we considered the degree of central canal stenosis to be a reasonable predictive factor of "neck function."

Older age has been reported to be associated with worse surgical outcomes in many studies.[39-41] Merali et al.[24] used a machine learning approach to confirm the effect of age. Two cohort studies reported that elderly patients had a higher incidence of cervical myelopathy and delayed diagnosis.[42,43] However, several studies have reported the opposite findings.[44,45] Whether age is an important predictor of surgical outcome is still controversial.[46,47] In our series, we did not find older age to be a significant predictor either. Smoking status and the presence of comorbidities were also mentioned in many studies.[27,41,48-51] However, the associations between smoking status and comorbidities were inconclusive according to those studies. Our study revealed a nonsignificant correlation between smoking status or other comorbidities and neck function after laminoplasty. C2–7 lordosis and the C2–7 SVA are 2 important radiographic parameters recognized as predictors of surgical outcome.[52,53] Nevertheless, in our study, we did not find any specific radiographic parameter that was correlated with the surgical outcome of neck function.

The K-line, proposed by Fujiyoshi et al.,[8] is a straight line that connects the midpoints of the spinal canal at C2 and C7 on a lateral plain film of the cervical spine. K-line positivity indicates that the OPLL or compressive pathology is not beyond the K-line but is negative when the OPLL is beyond the K-line. Many scholars have reported that the surgical outcome of laminoplasty for treating patients with negative K-lines is poorer.[54-56] Under these circumstances, anterior decompression and fusion surgery are recommended because they are more effective for neurological improvement and can maintain good sagittal alignment of the cervical spine.[57] However, there are still controversial arguments about the importance of the K-line, and several studies have revealed its uncertainty and limitations. Tsujimoto et al.[58] reported that favorable outcomes could be recorded in K-line-negative patients when the OPLL was in the upper cervical region or the K-line became positive during neck extension. Liu et al.[59] reported a more precise modified K-line specified in C4–6 because they considered that a longer OPLL would affect the K-line results and decrease its predictive value. Unlike the aforementioned studies that aimed to compare neurological recovery, by assessing mJOA scores before and after surgery, we analyzed "neck function" after surgery. Interestingly, our series revealed that a positive K-line during neck flexion strongly indicated a better surgical outcome with respect to neck function after laminoplasty; however, the K-line during extension did not have a significant impact. In contrast to many previous studies[54-56] reporting that laminoplasty was not a suitable surgical plan for patients with a negative K-line in the neutral neck position, our results revealed that the value of the K-line during flexion might be more decisive. In other words, even with a negative K-line in the neutral neck position, laminoplasty might be a reasonable surgical option in selective cases with a positive K-line during neck flexion.

Another novelty of this study is the use of KML. It is a statistical technique designed for analyzing longitudinal data and serves as an extension of the K-means clustering method. Compared to traditional K-means, KML is better suited for handling data that evolve over time, such as long-term surgical outcome assessments in the medical field. The advantages of this method include the following: First, the KML method captures the changing trends in data over time by accounting for the temporal dependence between different time points, which is a crucial aspect of longitudinal data analysis. Second, during long-term tracking studies, variations between individuals may exist, and KML can effectively handle such heterogeneity, aiding in identifying patterns among different individuals or groups. Third, unlike traditional K-means, KML does not require a priori determination of the number of clusters. It automatically determines the optimal number of clusters based on the data's characteristics, making it advantageous for gaining initial insights into data patterns.

Despite these advantages, using KML may also present some challenges. First, longitudinal data often have high dimensionality and may contain missing values and outliers. Proper data preprocessing is necessary before applying KML to ensure the reliability of the results. Second, although KML does not require prespecification of the number of clusters, it still requires the selection of some initial parameters that can influence the stability and effectiveness of the results. Therefore, when using KML, it is essential to try different parameter combinations and to compare their outcomes. Third, an adequate evaluation of the clustering results obtained with KML is necessary. This analysis involves using internal evaluation metrics (e.g., SSE - sum of squared errors) and external evaluation metrics (e.g., ARI - adjusted Rand index) to assess the quality of the clustering.

To our knowledge, this is the first study to investigate the predictive factors for neck pain and decreased cervical spine function, which were previously acknowledged to be drawbacks after laminoplasty. In addition, surgical outcomes should be time dependent, so we applied a novel method, KML, to analyze the surgical outcome instead of evaluating them at certain time points after surgery. Third, surgical indications for all patients were quite similar, and our analyses were based on patient-reported outcome measures, which are regarded as more objective. Finally, comparisons between good- and poor-outcome groups avoided bias from different surgical approaches or techniques.

Our study has several limitations. First, this single-center, single-surgeon study recruited only 69 patients. The limited patient numbers might have led to the wide range of 95% CIs for the ORs, indicating the uncertainty of our results. Second, progressive kyphosis after laminoplasty has been fully discussed in previous studies.[11,12] However, a short follow-up duration might obscure the long-term effect of kyphosis on neck function. Furthermore, there were patients who had only mild stationary neck pain (groups A and B in Fig. 3A) or who had poor cervical spine function (group A in Fig. 3B) before and during the follow-up. We hypothesized that some of these patients had symptoms that were too minor to be detected or that the current evaluation tools were not sensitive enough. Additionally, when selecting surgical methods, we tended to choose patients with cervical myelopathy caused by OPLL or those with longer levels of cervical spondylosis; consequently, our findings can only be applied to these patients. Finally, due to the disadvantages of the KML mentioned above, 35 patients were excluded because of loss to follow-up, incomplete data or images (usually unmeasurable cervical parameters) in our study, which might have affected the reliability of our results. We acknowledge that our current clustering approach may not fully capture the nuance of individual postoperative outcomes, especially in cases of postoperative deterioration or complex trajectories. A larger dataset and more detailed clustering could enhance the robustness and clinical applicability of our findings, allowing for a finer classification that better accommodates the variability in individual patient outcomes. In summary, the results of this study lack generalizability and can be applied only to a specific population. Because of these limitations, the present findings should be interpreted with caution. Further research is warranted to confirm the feasibility of these predictive factors when making decisions about surgical methods.

CONCLUSION

KML is a powerful method that is particularly suitable for analyzing longitudinal data and can help surgeons understand patterns and trends in surgical outcomes. Through the utilization of KML, this study demonstrated that the severity of central canal stenosis, preoperative neck pain, and the K-line value during neck flexion were predictive factors for neck function after laminoplasty for DCM patients. We found that central canal stenosis and preoperative neck pain were negative predictive factors, while a positive K-line during flexion was a positive predictive factor for postoperative neck function. We hope that these findings can guide spine surgeons in selecting suitable DCM patients for laminoplasty.

NOTES

Supplementary Materials: Supplementary Table 1 and File can be found via https://doi.org/10.14245/ns.2448620.310.

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Supplementary Table 1. Patient demographics

Variable	Good outcome (n = 41)	Poor outcome (n = 28)	p-value
Preoperative mJOA grade			
Motor_upper	4.37 ± 0.80	3.75 ± 1.08	0.217
Motor_lower	5.37 ± 1.18	5.18 ± 1.31	0.459
Sensory	2.12 ± 0.46	2.00 ± 0.54	0.884
Sphincter	2.56 ± 0.59	2.50 ± 0.69	0.289
Diabetes mellitus	7 (17.1)	7 (25.0)	0.42
Abnormal liver function	3 (7.3)	3 (10.7)	0.68
Moderate-to-severe CKD	1 (2.4)	1 (3.6)	1.00
Malignancy	7 (17.1)	5 (17.9)	1.00
Congestive heart failure	0 (0)	1 (3.6)	0.41
Myocardial infarction	0 (0)	0 (0)	NA
AIDS	0 (0)	0 (0)	NA
COPD	0 (0)	1 (3.6)	0.41
Stroke	3 (7.3)	1 (3.6)	0.64
Dementia	0 (0)	0 (0)	NA
Peptic ulcer disease	1 (2.4)	2 (7.1)	0.56

Values are presented as mean ± standard deviation or number (%).
mJOA, modified Japanese Orthopedic Association; CKD, chronic kidney disease; AIDS, acquired immunodeficiency syndrome; COPD, chronic obstructive pulmonary disease; NA, not available.

Supplementary: R code

```
### Neck Pain for example
mydata_Neck_Pain = mydata[,c("idnumber","name","Neck_Pain_pre","Neck_Pain_1m","Neck_Pain_3m","Neck_Pain_6m","Neck_Pain_12m")]
head(mydata_Neck_Pain)
names(mydata_Neck_Pain)
imputation(as.matrix(mydata_Neck_Pain[,3:7]),method = "linearInterpol")
cld_mydata_Neck_Pain < -cld(mydata_Neck_Pain,timeInData = 3:7)
cld_mydata_Neck_Pain
kml(cld_mydata_Neck_Pain,3,parAlgo = parALGO(distance = function(x,y)cor(x,y),saveFreq = 10),nbRedrawing = 3,toPlot = "both")
try(choice(cld_mydata_Neck_Pain))
mydata$Neck_Pain_clusters < -getClusters(cld_mydata_Neck_Pain,3)
mydata
```


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