Adjacent Segment Stenosis after Muscle-Preserving Selective Laminectomy: A Retrospective Study of Patients with a Minimum 10-Year Follow-Up

Ryoma Aoyama[1)], Tateru Shiraishi[1)], Junichi Yamane[2)], Ken Ninomiya[3)], Yuichiro Takahashi[1)], Kazuya Kitamura[4)], Satoshi Nori[5)] and Satoshi Suzuki[5)]

1) Department of Orthopedics, Tokyo Dental College Ichikawa General Hospital, Chiba, Japan
2) Department of Orthopedics, Murayama Medical Center, Tokyo, Japan
3) Department of Orthopedics, Shizuoka City Shimizu Hospital, Shizuoka, Japan
4) Department of Orthopedics, National Defense Medical College, Saitama, Japan
5) Department of Orthopedics, Keio University, Tokyo, Japan

Abstract:

Introduction: The present study aimed to understand the characteristics of adjacent segment stenosis post-surgery by examining the status of adjacent segment stenosis in patients with long-term follow-up after muscle-preserving selective laminectomy (SL).

Methods: We examined 43 patients who underwent muscle-preserving SL at a single academic institution and were followed up for >10 years. The C2-C7 angle, C2-C7 sagittal vertical axis, range of motion, and C7 slope were measured using an X-ray lateral view. The anterior-posterior diameter of the spinal cord (AP of SC) and anterior-posterior diameter of the dural tube (AP of dura) at adjacent segment were measured using magnetic resonance imaging T2-weighted sagittal section. Residual space for the spinal cord at the adjacent segment (SAC) was calculated as the difference between AP of SC and AP of dura.

Results: Four cases had cephalad adjacent segment stenosis at the last follow-up (upper stenosis (US) group), 9 cases had caudal adjacent segment stenosis (lower stenosis (LS) group), and 30 cases had no stenosis (none (N) group). AP of SC, AP of dura, and SAC at the upper adjacent segment were significantly lower in the US group. AP of dura and SAC at the lower adjacent segment were significantly lower in the LS group. Multivariate logistic regression analysis revealed that the small AP of dura in the upper adjacent segment and small SAC in the lower adjacent segment were risk factors for developing a new stenosis.

Conclusions: Decompression should be considered beforehand in adjacent segments with small AP of SC and small AP of dura when performing cervical decompression.

Keywords:

Adjacent segment, stenosis, laminectomy, laminoplasty, muscle-preserving

Spine Surg Relat Res 2022; 6(2): 115-122
dx.doi.org/10.22603/ssrr.2021-0076

Introduction

Adjacent segment stenosis after cervical spine surgery is an unpleasant complication that leads to poor postoperative outcomes and lowers the patient and surgeon satisfaction with the surgery[1-9)]. Both natural history and surgical invasion are considered to be involved in the development of adjacent segment stenosis after cervical spine surgery[6)].

In particular, there have been various previous studies on adjacent segment stenosis after cervical spine fusion, and the mechanism of its occurrence is much understood[2,3,5-7)]. Alternatively, in the case of adjacent segment stenosis after cervical decompression surgery, the mechanism of adjacent segment stenosis due to surgical invasion is less likely to occur because the postoperative range of motion (ROM) is less restricted, and there are fewer reports of the occurrence of ad-

Corresponding author: Ryoma Aoyama, aoyamar@tdc.ac.jp
Received: April 8, 2021, Accepted: May 19, 2021, Advance Publication: June 30, 2021

jacent segment stenosis after cervical decompression surgery[8-13]. Therefore, the pathogenesis of adjacent segment stenosis after cervical decompression surgery is not well understood because of the lack of studies. In addition, there are reports that adjacent segment stenosis after cervical fusion is not much different from that after decompression, and that the adjacent segment stenosis is caused by the natural aging process[4,6,7]. Therefore, the fact that the difference in the pathogenesis of the occurrence of adjacent segment stenosis depends on the surgical technique is still unclear.

Muscle-preserving selective laminectomy (SL) that preserves as much of the soft tissue in the posterior cervical spine as possible and the postoperative limitation of cervical ROM with this procedure is less than other techniques[14-16]. The current study aimed to understand the mechanism of adjacent segment stenosis by examining the status of adjacent segment stenosis in patients with long-term follow-up after muscle-preserving SL.

Materials and Methods

Subjects

From July 2005 to March 2010, 267 patients with cervical myelopathy underwent muscle-preserving SL at our single academic institution. Our inclusion criteria for SL were as follows: symptomatic disease (at least one clinical sign of myelopathy) and evidence of spinal canal stenosis on cervical magnetic resonance imaging (MRI) or myelogram-computed tomography (CT). To determine the decompression level, the intervertebral disk level with the disappearance of the subarachnoid space in the cervical extended position was used as the decompression level. Myelography was performed in almost all surgical patients, and the disappearance of the subarachnoid space was determined by myelogram-CT in the cervical extended position performed preoperatively. However, for patients who could not undergo myelography due to allergies, etc., preoperative MRI was performed in the neutral and extended positions on the same day, and the intervertebral disk level where the subarachnoid space disappeared on MRI in the extended position was used as the decompression level. SL was not performed in patients who had a local kyphosis of >20°, a spondylolisthesis of >3.5 mm, and an occupying ratio of ossification of the posterior longitudinal ligament (OPLL) of >60%[14-16]. Of these 267 patients, 43 patients who were observed for >10 years were examined in the current study. The average follow-up period was 10 years and 11 months.

The definition of stenosis in the present study was stenosis on imaging, regardless of the presence or absence of symptoms. Stenosis was defined as the area where there was a loss of the subarachnoid space on MRI, which was taken 10 years or more after surgery. The adjacent segment in the current study was defined as the intervertebral space craniocaudal to the decompression site that was not decompressed and was closest to the decompression site. For example, in the case of a mono-laminectomy of C5, the cephalad adjacent segment is the C3/4, and the caudal adjacent segment is the C6/7 (Fig. 1).

The three groups were divided according to whether there was imaging stenosis at the adjacent segment on the cephalad or caudal sides at the last follow-up: the US (upper stenosis) group was the group with stenosis at the cephalad adjacent segment; the LS (lower stenosis) group included eight cases with stenosis at the caudal adjacent segment and one case with stenosis at the one caudal adjacent intervertebral space of the caudal adjacent segment; and the N (none) group was the group without stenosis at the adjacent segment.

Analysis of radiological findings

Two spinal surgeons independently performed the radiological evaluation, using a DICOM viewer (Synapse version 4.1.0; FUJIFILM Medical, Tokyo, Japan). Standing lateral view plain radiographs were obtained with the neck in a neutral posture, preoperatively, and at the final follow-up. For neutral posture, lateral radiographs were obtained with the patient standing in a comfortable position, with the head facing forward for horizontal gaze. The C2-C7 angle was measured as the Cobb angle between the C2 and C7 vertebral bodies. We defined the C2-C7 sagittal vertical axis (SVA) as the distance between the C2 plumb line and the posterior superior corner of the C7 vertebral body. Pre- and postoperative ROM was calculated as the difference between the C2 and C7 angles during flexion and extension motion. C7 slope was determined as the angle between the superior endplate of C7 and a horizontal line[14]. Disk angle was measured as the Cobb angle at the adjacent intervertebral space of decompression. Disk ROM was calculated as the difference between the disk angle during flexion and extension motion.

At the adjacent segment of the decompression level, the anterior-posterior diameter of the spinal cord (AP of SC) and the anterior-posterior diameter of the dural tube (AP of dura) were measured on a T2-weighted sagittal section of MRI in the neck-neutral position (Fig. 1). This measurement was made at the site with the least residual space for the spinal cord (space available for the spinal cord, SAC) at the disk level and was done in a line orthogonal to the spinal cord. Residual SAC was calculated as the difference between AP of SC and AP of dura. The disk heights of the adjacent segments were also measured by MRI T2-weighted sagittal section in the neck-neutral position.

Statistical analysis

Statistical analysis was performed using SPSS software (version 25.0; SPSS, Chicago, IL, USA). All values are expressed as mean ± standard deviation and were considered significant when $P<0.05$. A comparison of each independent variable among the three groups was performed using one-way analysis of variance for continuous variables and Kruskal-Wallis test for discrete variables. Logistic regression

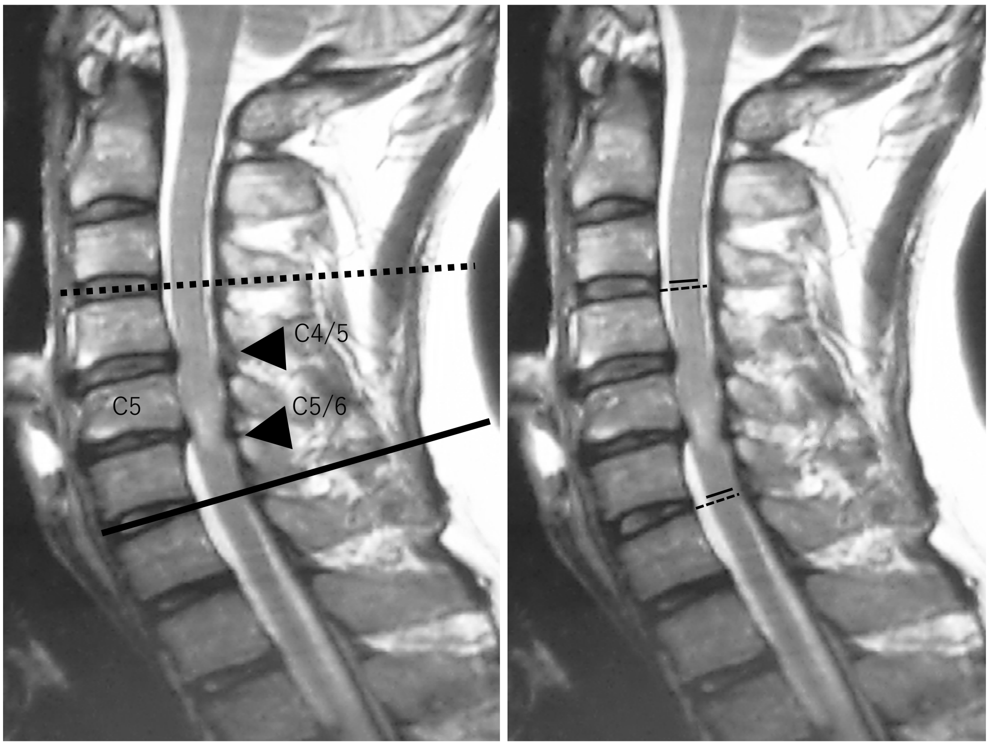

Figure 1. Definition of the adjacent segment and measurement of the anterior–posterior diameter. The left picture shows the MRI of a patient who underwent a single laminectomy of C5 for two-level stenosis at C4/5 and C5/6 (arrowhead). Here, the upper adjacent segment is C3/4 (dotted line), and the lower adjacent segment is C6/7 (solid line). The right picture shows the measurement of the anterior–posterior diameter of the spinal cord (solid line) and the anterior–posterior diameter of the dural tube (dotted line) at the adjacent segment. The measurements were taken orthogonal to the spinal cord and at the site with the least residual space for the spinal cord at the disk level.

analysis was used for risk factor analysis. First, a univariate analysis was used to determine the significance of various parameters. Factors with $P<0.25$ in the univariate analysis were then included in the multivariate analysis.

Results

Demographics of patients

Of the 43 cases reviewed, 4 cases had cephalad adjacent segment stenosis at the last follow-up, 8 cases had caudal adjacent segment stenosis, 1 case had two intervertebral caudal adjacent segment stenosis, and 30 cases had no adjacent segment stenosis (Table 1).

Four patients with cephalad adjacent segment stenosis were included in the US group, 9 patients with caudal and two caudal adjacent vertebral stenoses were included in the LS group, and 30 patients with no stenosis were included in the N group. At the final follow-up, there was only one case of stenosis outside the adjacent segment in the LS group (a case of stenosis one adjacent intervertebral space of caudal adjacent segment), and no new stenosis appeared in the other segments among the three groups. There were no significant differences in mean age, sex ratios, the type of disease, or the number of lamina resections between the three groups. The details of cases with adjacent segment stenosis at the final follow-up are shown in Table 2.

Three of the four patients in the US group required reoperation due to myelopathy caused by cephalad adjacent segment stenosis during the follow-up period. Two of the nine patients in the LS group required reoperation due to myelopathy caused by caudal adjacent segment stenosis.

C2-C7 angle, C2-C7 SVA, C7 slope, and ROM

There were no significant differences in C2-C7 angle, C2-C7 SVA, C7 slope, or ROM between the three groups (Table 1). The C2-C7 angle tended to be lower in the US group, with a mean value of −3°, indicating that there were more cases of kyphosis in the US group.

AP of SC, AP of dura, residual SAC, disk angle, and disk ROM at the adjacent segment

When examining the upper adjacent segment, the AP of SC, AP of dura, and residual SAC were all predominantly lower in the US group (Table 1). The disk height at the adjacent segment was not significantly different between the three groups. The disk angle at the adjacent segment was the same among the three groups. The disk ROM at the adjacent segment was significantly lower in the N group.

When examining the lower adjacent segment, no signifi-

Table 1. Demographics of Patients and Radiological Findings.

	US group	LS group	N group	*P*-value
No. of patients	4	9	30	
Mean age	60.0±6.7	57.3±12.4	63.3±9.5	0.266
Male/female	3/1	8/1	23/7	0.731
CSM/OPLL	3/1	4/5	18/12	0.072
No. of laminectomy	2.3±1.0	2.8±0.7	3.0±0.9	0.209
C2–C7 angle	−3±5.5	11.6±11.0	9.8±11.0	0.07
C2–C7 SVA (mm)	18.9±5.0	18.9±5.8	24.7±13.5	0.359
ROM	39.5±13.8	36.9±11.3	33.4±16.23	0.299
C7 slope	16.8±1.5	23.0±7.3	23.3±6.2	0.678
Post C2–C7 angle	10.0±5.2	10.7±14.6	15.8±12.8	0.487
Post ROM	28.0±12.1	19.8±11.0	23.0±12.2	0.678
Upper adjacent segment				
AP of SC (mm)	**5.2±1.0**	6.7±0.9	6.1±0.8	**0.016**
AP of dura (mm)	**7.0±0.6**	10.4±1.5	9.7±1.9	**0.006**
SAC (mm)	**1.8±0.4**	3.6±0.6	3.7±1.6	**0.034**
Disc height (mm)	5.4±1.3	6.3±1.6	6.0±0.75	0.404
Disc angle	2.5±6.6	9.3±11.7	2.4±4.6	0.131
Disc ROM	12.5±11.0	10.7±4.6	**4.4±3.3**	**0.011**
Lower adjacent segment				
AP of SC (mm)	5.8±0.5	5.7±0.9	5.4±0.5	0.26
AP of dura (mm)	10.0±0.6	**8.2±1.4**	9.7±1.1	**0.009**
SAC (mm)	4.2±0.4	**2.6±0.7**	4.3±1.0	**<0.001**
Disc height (mm)	5.4±0.5	6.3±1.6	5.6±0.7	0.14
Disc angle	2.3±4.3	8.0±3.2	5.3±3.7	0.136
Disc ROM	4.3±3.4	2.3±1.7	2.5±3.2	0.579

US group, upper adjacent segment stenosis group; LS group, lower adjacent segment stenosis group; N group, none stenosis group; CSM, cervical spondylotic myelopathy; OPLL, ossification of the posterior longitudinal ligament; SVA, sagittal vertical axis; ROM, range of motion; AP of SC, anterior–posterior diameter of the spinal cord; AP of dura, anterior–posterior diameter of the dural tube; SAC, space available for the spinal cord
The groups in bold are significantly different from the others.

Table 2. Demographics of Patients with New Stenosis.

	Group	Age at first surgery	Gender	Disease	Level of laminectomy at first surgery	Level of new stenosis	Preoperative SAC at adjacent segment with stenosis	Preoperative AP of dura at adjacent segment with stenosis	Duration for second surgery from first surgery	Level of laminectomy at second surgery
Reoperation cases	US	56	Male	CSM	C4, C5, C6	C2/3	1.2	7.7	11 years 8 months	C3
	US	69	Male	CSM	C4, C5, C6	C2/3, C1/2	2.2	7.1	12 years 8 months	C1, C3
	US	59	Female	OPLL	C5, C6	C3/4	2.0	6.2	6 years	C3
	LS	35	Male	CSM	C3, C4, C5	C6/7	2.6	6.9	11 years	C6
	LS	63	Male	OPLL	C4, C5, C6	C7/Th1	2.4	7.6	3 years	C7
Only stenosis cases	US	54	Male	CSM	C6	C4/5	1.6	6.9		
	LS	57	Male	CSM	C3	C5/6 (not adjacent)	3.8 (C4/5)	10.7 (C4/5)		
	LS	62	Male	CSM	C4, C5, C6	C7/Th1	1.1	5.9		
	LS	45	Male	OPLL	C3, C4, C5	C6/7	3.0	8.7		
	LS	68	Female	OPLL	C5, C6	C7/Th1	2.6	8.3		
	LS	60	Male	CSM	C4, C5, C6	C7/Th1	2.9	8.7		
	LS	50	Male	OPLL	C3, C4, C5	C6/7	2.6	9.5		
	LS	76	Male	OPLL	C2, C3, C4	C5/6	2.0	7.9		

SAC, space available for the spinal cord; AP of dura, anterior–posterior diameter of the dural tube; US, upper adjacent segment stenosis; LS, lower adjacent segment stenosis; CSM, cervical spondylotic myelopathy; OPLL, ossification of the posterior longitudinal ligament

Table 3. The Risk Factor Analysis for New Stenosis.

		OR	95% CI	*P*-value	OR	95% CI	*P*-value
Upper adjacent segment	Age			0.918			
	Male/female			0.834			
	CSM/OPLL			0.998			
	No. of laminectomy			*0.106*			0.334
	C2–7 angle	0.816	0.671–0.992	**0.042**			0.305
	C2–7 SVA (mm)			0.481			
	ROM			0.501			
	C7 slope			*0.05*			0.327
	AP of SC (mm)			*0.053*			0.148
	AP of dura (mm)	0.114	0.019–0.693	**0.018**	0.128	0.021–0.785	**0.026**
	SAC (mm)			*0.15*			0.148
	Disc height (mm)			*0.172*			0.192
	Disc angle			0.643			
	Disc ROM			*0.051*			0.075
Lower adjacent segment	Age			*0.121*			0.197
	Male/female			0.415			
	CSM/OPLL			0.65			
	No. of laminectomy			0.618			
	C2–7 angle			0.395			
	C2–7 SVA (mm)			0.259			
	ROM			0.635			
	C7 slope			0.8			
	AP of SC (mm)			0.259			
	AP of dura (mm)	0.319	0.129–0.788	**0.013**			0.158
	SAC (mm)	0.08	0.013–0.505	**0.007**	0.008	0.013–0.528	**0.008**
	Disc height (mm)			*0.05*			0.096
	Disc angle			*0.098*			0.199
	Disc ROM			0.558			

OR, odds ratio; CI, confidence interval; CSM, cervical spondylotic myelopathy; OPLL, ossification of the posterior longitudinal ligament; SVA, sagittal vertical axis; ROM, range of motion; AP of SC, anterior–posterior diameter of the spinal cord; AP of dura, anterior–posterior diameter of the dural tube; SAC, space available for the spinal cord
Significant risk factors are shown in bold. The risk factors used in multivariate analysis are shown in italics.

cant differences in the AP of SC and disk height were observed between the three groups. The AP of dura and the residual SAC were significantly lower in the LS group. The disk angle and the disk ROM at the adjacent segment were statistically the same between the three groups.

Risk factor analysis for new stenosis

Multivariate logistic regression analysis revealed that the small diameter of the dural tube in the upper adjacent segment and small SAC in the lower adjacent segment were risk factors for developing new stenosis (Table 3). The univariate logistic regression analysis revealed that lower C2-C7 angle in the upper adjacent segment and lower AP of dura were risk factors for developing new stenosis.

Incidence of new stenosis according to the size of SAC and AP of dura

The incidence of new stenosis at the adjacent segment was examined according to the distribution of the AP of dura and the residual SAC because these two factors showed significant differences in the examination of the upper and lower adjacent segments (Table 4).

The incidence of new stenosis at the cephalad adjacent segment was >50% in patients with a spinal residual space of <2.5 mm and a dural tube diameter of <8 mm. For the caudal adjacent segment, >50% of new stenosis occurred in patients with a spinal residual space of <3.5 mm and dural tube anterior-posterior diameter of <8.5 mm.

Discussion

After muscle-preserving SL, adjacent segment stenosis appeared in 30% of patients with more than a 10-year follow-up, and surgery was required in 12%. Previous studies showed that the incidence rates of symptomatic adjacent segment stenosis after cervical fusion surgery are approximately 3% per year, 26% at 10 years, and 12% at 20 years[1,2,6]. The results of the current study do not differ much from these past papers on fusion surgery and can be said to have much more incidence than those of the previous reports on decompression surgery.

We expected that muscle-preserving selective decompres-

Table 4. The Incidence of New Stenosis According to the Size of the Residual Space for the Spinal Cord (SAC) and Anterior–Posterior Diameter of the Dural Tube.

	No. of patients (total of 43 patients)	No. of patients with new stenosis	Rate of new stenosis (%)
Upper adjacent segment			
SAC<2.0 mm	3	3	100
SAC<2.5 mm	7	4	***57.1***
SAC<3.0 mm	14	4	28.6
AP of dura<7.5 mm	5	3	60
AP of dura<8.0 mm	6	4	***66.7***
AP of dura<8.5 mm	11	4	36.4
Lower adjacent segment			
SAC<2.5 mm	3	3	100
SAC<3.0 mm	12	8	66.7
SAC<3.5 mm	14	8	***57.1***
SAC<4.0 mm	21	9	42.9
AP of dura<7.5 mm	2	2	100
AP of dura<8.0 mm	5	4	80
AP of dura<8.5 mm	10	5	***50***
AP of dura<9.0 mm	16	7	43.8

SAC, space available for the spinal cord; AP of dura, anterior–posterior diameter of the dural tube
Data for the threshold at which the rate of new stenosis exceeds 50% for the first time are shown in bold italic.

sion would result in less adjacent spinal stenosis because of its ability to preserve a cervical ROM. In fact, in the present study, the ROM after long-term follow-up was 34.9° preoperatively and 22.8° postoperatively, which is 65.3% of the remaining ROM, whereas the long-term follow-up of expansive open-door laminoplasty was reported to be 44° preoperatively and 14° postoperatively, which is 31.8% of the remaining ROM, and that of double-door laminoplasty was 36° preoperatively and 8° postoperatively, which is 22.2% of the remaining ROM[17,18]. The ROM of patients who underwent SL was found to remain well even in the long term. However, in fact, SL may result in more adjacent spinal stenosis than other techniques.

In the present study, only patients with cervical myelopathy who underwent decompression were included, so it is possible that the selection bias resulted in the study of a group that was originally prone to age-related changes. The low follow-up rate may have contributed to the higher restenosis rate.

In addition, SL decompresses only the intervertebral space in which the subarachnoid space disappears in the cervical extension position[14-16], whereas conventional laminoplasty decompresses a uniformly wide area, such as C3-C7[17,19]. It is possible that conventional laminoplasty decompressed potential stenotic areas that would not have been decompressed by SL. In addition, because the ROM is preserved in muscle-preserving SL[14-16], the load caused by the movement of the adjacent segment continues, and the potential stenosis site may be prone to the appearance of new stenosis. According to the report that there is no difference in adjacent intervertebral stenosis after cervical fusion and decompression, the incidence rates of adjacent segment stenosis with symptoms after posterior decompression are 3% per year and 9% at 3 years[4], and the incidence rate of degeneration on imaging of adjacent segments after posterior decompression is 50% at 5 years[7]. Compared with these, the incidence of adjacent segment stenosis in the current study was not much different, and therefore this study also supports that adjacent segment stenosis after cervical spine surgery is probably a natural process[6].

Based on these results, in the current SL, in addition to the intervertebral space where there is loss of the subarachnoid space in the cervical extension position, when the SAC is <2.5 mm cephalad and 3.5 mm caudal to the adjacent segment, we have selected them as a decompression level. Therefore, for patients with developmental spinal canal stenosis, the method of decompression that also decompresses the narrowed part of the spinal canal derived from the present study is probably the same extent of decompression as conventional laminoplasty. This speculation needs to be investigated in the future.

Adjacent segment stenosis after muscle-preserving SL was found to be more common caudally in the current study. There are few reports of adjacent segment stenosis after cervical decompression surgery, as much as we have been able to discover, with two cases occurring cephalad and nine cases occurring caudal[8-13]. The results of the present study are consistent with these findings. Because there are only a few reports of adjacent segment stenosis after decompression surgery, the mechanism of its occurrence is often unclear. However, it is often speculated that reduced ROM after decompression causes a type of load on the caudal intervertebral segment. It has been reported that adjacent segment stenosis after cervical fusion is more common on the cephalad side[3]; however, caudal adjacent segment stenosis was more common after cervical decompression in the current study and previous reports[8-13], suggesting a difference in the mechanism of stenosis between fusion surgery and decompression surgery. We have reported that after muscle-preserving SL, the lower cervical spine becomes kyphotic, and the upper cervical spine alignment becomes compensatory lordotic, thus maintaining the alignment of the entire cervical spine[14]. This change in alignment after muscle-preserving SL may have been a factor in the acceleration of age-related changes to the caudal adjacent segment.

The cases of stenosis of the cephalad adjacent segment after muscle-preserving SL appeared in the segment with a small AP of dura in the present study and were found to be more likely to occur in cervical kyphotic cases. Although there are reports of poor postoperative results in kyphosis cases after cervical laminoplasty[20], to the best of our knowledge, no previous study has shown that postoperative cephalad stenosis is more likely to occur in kyphosis cases. It is possible that a load of forward bending due to kyphosis is easily applied to the adjacent segment on the cephalad side, accelerating the aging process, but due to the small number of cases in the current study, further study is necessary to clarify the truth. Although no significant difference was found in the present study, the disk ROM was significantly decreased in the N group when the cephalad adjacent segment stenosis was examined, and the possibility that segmental instability at the adjacent segment was involved in adjacent segment stenosis on the cephalad side was also speculated, as it has been shown that dynamic factors affect the development of cervical myelopathy[21].

Limitations of this Study

As this was a retrospective study of a small number of patients, the possibility of selection bias cannot be ruled out. Selection bias cannot be ruled out due to the poor follow-up rate. In addition, the absence of a control group for comparison precludes an accurate evaluation of the natural course and changes due to surgical intervention. Because we only evaluated cases of decompression using a single technique and did not compare it with fusion or other techniques of decompression, we cannot clarify the difference in the occurrence of adjacent segment stenosis due to differences in the surgical invasion. Since CSM and OPLL with different pathologies were analyzed simultaneously in the present study, we cannot exclude the effect of the difference in pathologies even if there was no difference in the disease ratio among the three groups. A prospective comparative study with a large number of patients is desirable to elucidate the mechanism of adjacent segment stenosis.

Conclusion

After muscle-preserving SL, new stenosis appeared in the adjacent segment with less spinal residual space, and it occurred more frequently in the caudal adjacent segment.

Prophylactic decompression of the adjacent segment may be effective to avoid this new adjacent stenosis. Decompression should be considered beforehand in adjacent segments with small residual SAC and a small AP of dura. We recommend prophylactic decompression if residual SAC is <2.5 mm cephalad and 3.5 mm caudal, and if the AP of dura is <8.0 mm cephalad and 8.5 mm caudal.

Conflicts of Interest: The authors declare that there are no relevant conflicts of interest.

Sources of Funding: None

Author Contributions: Ryoma Aoyama wrote and prepared the manuscript. All authors participated in the study design. All authors have read, reviewed, and approved the manuscript.

Ethical Approval: This study was approved by the IRB of Tokyo Dental College Ichikawa General Hospital (approval no. 254).

References

1. Hilibrand AS, Carlson GD, Palumbo MA, et al. Radiculopathy and myelopathy at segments adjacent to the site of a previous anterior cervical arthrodesis. J Bone Joint Surg Am. 1999;81(4):519-28.
2. Xu R, Bydon M, Macki M, et al. Adjacent segment disease after anterior cervical discectomy and fusion: clinical outcomes after first repeat surgery versus second repeat surgery. Spine (Phila Pa 1976). 2014;39(2):120-6.
3. Baba H, Furusawa N, Imura S, et al. Late radiographic findings after anterior cervical fusion for spondylotic myeloradiculopathy. Spine (Phila Pa 1976). 1993;18(15):2167-73.
4. Henderson CM, Hennessy RG, Shuey HM, Jr., et al. Posterior-lateral foraminotomy as an exclusive operative technique for cervical radiculopathy: a review of 846 consecutively operated cases. Neurosurgery. 1983;13(5):504-12.
5. Lawrence BD, Hilibrand AS, Brodt ED, et al. Predicting the risk of adjacent segment pathology in the cervical spine: a systematic review. Spine (Phila Pa 1976). 2012;37(22 Suppl):S52-64.
6. Hilibrand AS, Robbins M. Adjacent segment degeneration and adjacent segment disease: the consequences of spinal fusion? Spine J. 2004;4(6 Suppl):190S-4S.
7. Herkowitz HN, Kurz LT, Overholt DP. Surgical management of cervical soft disc herniation. A comparison between the anterior and posterior approach. Spine (Phila Pa 1976). 1990;15(10):1026-30.
8. Shiokawa T, Ohta H, Matsumoto Y, et al. [A comparison of adjacent segmental disorders after cervical laminoplasty between ossification of cervical posterior longitudinal ligament and cervical spondylotic myelopathy]. J Spine Res. 2019;10(12):1605-8. Japanese.
9. Wada K, Hatta S, Murata Y, et al. Adjacent segment disease following C3-C7 en block laminoplasty and long-term follow-up of surgical treatment by T1-T3 laminoplasty. J Orthop Sci. 2014;19(3):511-4.
10. Wang MY, Green BA, Vitarbo E, et al. Adjacent segment disease: an uncommon complication after cervical expansile laminoplasty: case report. Neurosurgery. 2003;53(3):770-2; discussion 2-3.
11. Koda M, Furuya T, Rokkaku T, et al. Drop finger as an adjacent segment disease after cervical expansive laminoplasty. Neurol India. 2013;61(6):695-6.
12. Tsunoda K, Matsuo T, Nagata I. [Lower adjacent segment disease following cervical laminoplasty]. Spinal Surgery. 2014;28(2):182-6. Japanese.
13. Takagi H, Kawaguchi Y, Kanamori M, et al. T1-2 disc herniation following an en bloc cervical laminoplasty. J Orthop Sci. 2002;7(4):495-7.
14. Nori S, Shiraishi T, Aoyama R, et al. Muscle-preserving selective laminectomy maintained the compensatory mechanism of cervical lordosis after surgery. Spine (Phila Pa 1976). 2018;43(8):542-9.
15. Shiraishi T. A new technique for exposure of the cervical spine laminae. Technical note. J Neurosurg. 2002;96(1 Suppl):122-6.
16. Shiraishi T, Kato M, Yato Y, et al. New techniques for exposure of posterior cervical spine through intermuscular planes and their surgical application. Spine (Phila Pa 1976). 2012;37(5):E286-96.
17. Chiba K, Ogawa Y, Ishii K, et al. Long-term results of expansive open-door laminoplasty for cervical myelopathy--average 14-year follow-up study. Spine (Phila Pa 1976). 2006;31(26):2998-3005.
18. Seichi A, Takeshita K, Ohishi I, et al. Long-term results of double-door laminoplasty for cervical stenotic myelopathy. Spine (Phila Pa 1976). 2001;26(5):479-87.

19. Ratliff JK, Cooper PR. Cervical laminoplasty: a critical review. J Neurosurg. 2003;98(3 Suppl):230-8.

20. Suda K, Abumi K, Ito M, et al. Local kyphosis reduces surgical outcomes of expansive open-door laminoplasty for cervical spondylotic myelopathy. Spine (Phila Pa 1976). 2003;28(12):1258-62.

21. Sumi M, Kataoka O, Sawamura S, et al. Radiological pathophysiology of cervical spondylotic myelopathy. Rinsho Seikeigeka. 1998;33(11):1277-86. Japanese.