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ORIGINAL ARTICLE

# Factors associated with postoperative axial symptom after expansive open-door laminoplasty: retrospective study using multivariable analysis

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## Abstract

**Purpose** The aim of the present study was to investigate the factors associated with axial symptom using multivariable analysis.

**Methods** The authors retrospectively assessed 249 patients treated by open-door laminoplasty. The patients were classified into two groups: axial symptom and no axial symptom group. The possible factors included demographic variables (age, sex, BMI, smoking, heart disease, diabetes, preoperative neck pain, preoperative JOA scores, preoperative NDI, course of disease and pathogenesis) and surgical and radiological variables [operation time, intraoperative blood loss, collar wear time, preoperative cervical curvature, postoperative cervical curvature, T1 slope, preoperative and postoperative C2 sagittal vertical axis (C2 SVA)].

**Results** The prevalence of axial symptom was 34.9% (89/249). The collar wear time, preoperative and postoperative C2 SVA were risk factors for axial symptom. A cutoff value of 22.6 mm for preoperative C2 SVA and 3.5 weeks for collar wear time predicted the development of axial symptom.

**Conclusions** The longer collar wear time, larger preoperative and postoperative C2 SVA were positively correlated with the higher incidence of axial symptom.

**Keywords** Axial symptom · Expansive open-door laminoplasty · C2 sagittal vertical axial · Risk factors

## Introduction

Expansive open-door laminoplasty (EOLP) has been widely used as posterior cervical surgery. Axial symptom, a well-known complication after laminoplasty, leads to pain and/or stiffness around the posterior neck or suprascapular areas and poor quality of life [1, 2]. Postoperative axial symptom could affect the recovery of Japanese Orthopaedic Association (JOA) and Neck Disability Index (NDI). A recent study showed that the change of JOA for 2.5 and NDI for 4.2 among patients undergoing cervical laminoplasty was one of the most important psychometric parameters for assessing the postoperative results of spinal surgery [3]. Therefore, it is very important to reduce the occurrence of axial symptoms after laminoplasty. Causative mechanisms that have been proposed for axial symptom include lamina open-door angles ˃ 30° [4], range of motion [5], less neck muscle strength [6], older age (˃ 63 years) and preservation of muscles attached at the C2 spinous process [7]. The exact risk factors for axial symptom remain unclear. However, multiple factors are likely to be involved. In recent year, cervical sagittal balance has attracted more attention. The cervical sagittal balance has been associated with neck pain and poor health-related quality of life [8, 9]. What is more, cervical sagittal balance has been recognized as one of the important factors affecting the outcomes of cervical spine surgery [10]. However, there is no study on the correlation between axial symptom and cervical sagittal balance.

Therefore, we included cervical sagittal balance variables and aimed to investigate the mechanisms underlying the development of axial symptom in patients treated with EOLP, using multivariable analysis to reduce the influence of confounding factors.

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## Materials and methods

### Inclusion of patients

Between July 2008 and July 2018, a total of 249 patients (120 men and 129 women) needed operative managements were examined prospectively. The inclusion criteria were the following: multilevel cervical disk herniation (≥ 3 levels) with neurological dysfunctions; ossification of posterior longitudinal ligament (OPLL). The exclusion criteria were the presence of infection, trauma and tumor.

### Surgical procedures

Surgery was performed according to the modified Hirabayashi method [11]. A midline incision was made on the posterior neck skin. The bilateral paravertebral muscles were detached from the spinous processes. The spinous processes were cut away, and gutters were created on the bilateral laminae at the border of the laminae and facets using a high-speed drill. One side of the lamina was completely cut and used as the open side. The side chosen was based on the side with more significant clinical symptoms. The other side of the lamina was partially cut with the ventral cortex preserved to form the hinge side. All surgical procedures were performed by the same surgeon.

### Study variables

The demographic variables, radiography variables and surgical-related variables were the possible risk factors. The following are the demographic variables collected at baseline: age, sex, BMI, smoking, heart disease, diabetes, preoperative neck pain, preoperative JOA scores, preoperative NDI scores, course of disease and pathogenesis. The surgical and radiological variables include the following: operation time, intraoperative blood loss, collar wear time, preoperative cervical curvature, postoperative cervical curvature, T1 slope, preoperative and postoperative C2 sagittal vertical axis (C2 SVA).

Cervical sagittal alignment was evaluated using 3 parameters on a cervical lateral radiograph in standing position: C2 sagittal vertical axis (C2 SVA), defined as the distance between the C2 plumb line and the superior–posterior aspect of the C7 vertebra; cervical curvature, defined as the angle tangential to the lower endplate of the C2 vertebra and upper endplate of the C7 vertebra; T1 slope, defined as the angle tangential to the upper endplate of the T1 vertebra and horizontal line (Fig. 1).

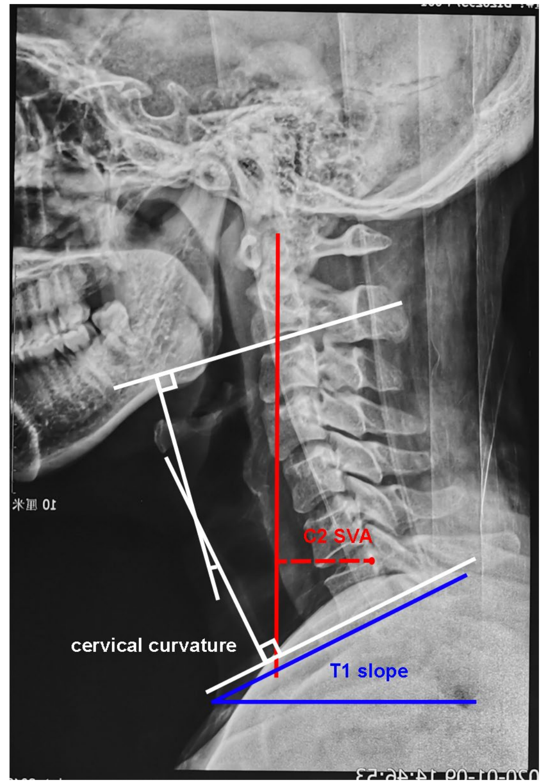


**Fig. 1** Measurement of cervical sagittal alignment parameters. The white lines indicate cervical curvature, defined as the angle tangential to the lower endplate of the C2 vertebra and upper endplate of the C7 vertebra; the red lines indicate C2 SVA, defined as the distance between the C2 plumb line and the superior–posterior aspect of the C7 vertebra; the blue lines indicate T1 slope, defined as the angle tangential to the upper endplate of the T1 vertebra and horizontal line

### Axial symptoms evaluation

The axial symptoms are defined as more than 1 month persistent cervical or shoulder pain after expansive open-door laminoplasty. Neck or shoulder pain occurring within 1 month after surgery is not defined as axial symptom. Based on the postoperative axial symptom evaluation, the patients were classified into two groups: the axial symptom group, including patients with obvious pain and related pain treatment, and no axial pain or with slight discomfort and without treatment.

### Statistical analysis

Comparative analysis with postoperative axial symptom as the dependent variable was done using independent samples t tests and Chi-square test. Age, BMI, preoperative JOA scores, preoperative NDI, duration of symptoms, operation time, blood loss, collar wear time, preoperative cervical curvature, postoperative cervical curvature, T1 slope, preoperative and postoperative C2 SVA were analyzed by independent samples t tests, and sex, smoking, heart disease, diabetes, preoperative neck pain and pathogenesis were analyzed using Chi-square test. The retrieved clinical variables were interrogated using multivariate analysis to identify risk factors. Only variables with $p < 0.20$ in the univariate analysis were included in the multivariate logistic regression model building process. Probability values < 0.05 were considered statistically significant. The OR and 95% CI were also determined. To identify the cutoff value of risk factors for predicting axial symptom, we used receiver operating characteristic (ROC) curve. We selected the cutoff point that maximized the value of Youden index, in which specificity is high and *p* values of less than 0.05 were considered to be statistically significant. Commercially available software (SPSS 20.0, Inc., Chicago, IL, USA) was used for all statistical analysis.

**Table 1** Main demographic variables of patients before the surgery

| | Axial symptom ($n = 87$) | No axial symptom ($n = 162$) | *p* values |
|---|---|---|---|
| Age (years) | 60.9 ± 7.3 | 60.3 ± 7.7 | 0.557 |
| Sex (male/female) | 49/38 | 71/91 | 0.060 |
| BMI (kg/m$^2$) | 25.8 ± 4.0 | 26.1 ± 4.1 | 0.681 |
| Smoking (yes/no) | 29/58 | 39/123 | 0.118 |
| Diabetes (yes/no) | 47/40 | 79/83 | 0.429 |
| Heart disease (yes/no) | 39/48 | 72/90 | 0.954 |
| Preoperative neck pain (yes/no) | 19/68 | 35/137 | 0.140 |
| Preoperative JOA | 9.3 ± 2.1 | 9.4 ± 2.3 | 0.599 |
| Preoperative NDI | 7.6 ± 3.1 | 7.9 ± 3.4 | 0.481 |
| Course of disease (months) | 10.5 ± 2.8 | 10.7 ± 3.0 | 0.552 |
| Pathogenesis | | | 0.403 |
| Multilevel cervical disk herniation | 51 | 86 | |
| OPLL | 36 | 76 | |

## Results

We analyzed data from 249 patients (120 male and 129 female) with a mean age of 60.5 ± 7.6 who underwent expansive open-door laminoplasty. Among these patients, 87 patients were in the axial symptom group and the other patients ($n = 162$) were in the no axial symptom group; the prevalence of axial symptom was 34.9%. The follow-up was from 12 to 108 months; the median follow-up was 24 months. The demographic, clinical and radiological variables are shown in Tables 1, 2.

There was no significant difference found on age, sex, body mass index (BMI), smoking, heart disease, diabetes, preoperative JOA and preoperative NDI. For surgical-related variables, the collar wear time ($p < 0.0001$) had a significant difference between the two groups, while no significant differences were found in course of disease, operation time and blood loss. According to the analyses of radiological variables, the preoperative C2 SVA ($p = 0.023$) and postoperative C2 SVA ($p = 0.009$) had significant difference between the two groups; however, there was no significant difference in T1 slope, preoperative and postoperative cervical curvature (Table 2).

The univariate analysis showed that the sex, smoking, preoperative neck pain, course of disease, operation time, collar wear time, preoperative and postoperative C2 SVA might be related to axial symptoms ($p < 0.20$). The multivariate analysis showed that collar wear time, preoperative C2 SVA and postoperative C2 SVA were independent risk factors for this complication. However, sex, smoking, operation time and preoperative neck pain were nor significantly associated with axial symptom.

We estimated the optimal cutoff value for the collar wear time, preoperative and postoperative C2 SVA for predicting axial symptom using the ROC curve (Fig. 2). As shown in Table 4, the area under the ROC curves were 0.594 (preoperative C2 SVA), 0.606 (postoperative C2 SVA) and 0.625 (collar wear time). According to Youden index analysis, the cutoff values were 22.9 mm

**Table 2** Radiological and surgical variables of patients

| | Axial symptom | No axial symptom | *p* values |
|---|---|---|---|
| Preoperative cervical curvature (°) | 19.8 ± 9.5 | 20.6 ± 8.3 | 0.475 |
| Postoperative cervical curvature (°) | 15.8 ± 8.8 | 15.0 ± 13.1 | 0.574 |
| T1 slope (°) | 26.1 ± 7.5 | 25.8 ± 8.3 | 0.770 |
| Preoperative C2 SVA (mm) | 21.2 ± 10.6 | 17.7 ± 11.6 | 0.023 |
| Postoperative C2 SVA (mm) | 25.6 ± 9.0 | 22.7 ± 6.3 | 0.009 |
| Operation time (min) | 98.8 ± 18.9 | 102.4 ± 18.7 | 0.148 |
| Blood loss (ml) | 147.6 ± 41.3 | 150.0 ± 39.3 | 0.655 |
| Collar wear time (weeks) | 4.4 ± 1.9 | 3.5 ± 1.8 | < 0.001 |

**Table 3** Multivariate analysis of factors associated with axial symptom

| | OR | 95% CI | *p* values |
|---|---|---|---|
| Sex | 1.511 | 0.790–2.890 | 0.212 |
| Smoking | 1.362 | 0.667–2.782 | 0.397 |
| Preoperative neck pain | 1.854 | 0.911–3.776 | 0.089 |
| Operation time | 1.006 | 0.990–1.021 | 0.468 |
| Collar wear time | 0.789 | 0.679–0.917 | 0.002 |
| Preoperative C2 SVA | 0.970 | 0.945–0.995 | 0.019 |
| Postoperative C2 SVA | 0.943 | 0.907–0.981 | 0.003 |

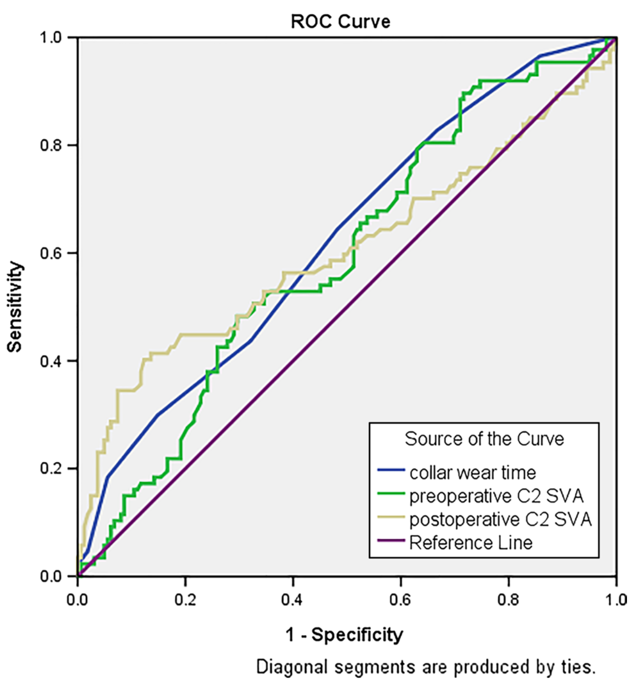


**Fig. 2** Receiver operating characteristic (ROC) curve of the collar wear time, preoperative C2 SVA and postoperative C2 SVA for predicting axial symptom

(preoperative C2 SVA), 29.6 mm (postoperative C2 SVA) and 3.5 weeks (collar wear time) (Table 3).

## Discussion

Axial symptom is a common complication in posterior cervical surgery, at an incidence rate from 5% to about 60% [12, 13]. Our data showed that the prevalence of this complication was 34.9% (87/249). Some risk factor reported thus far includes loss of cervical motion [14], decreased strength and atrophy of cervical muscle [6, 15], collar wear time [16, 17], preoperative neck pain [18, 19], spring-back phenomenon or nonfusion hinge [20, 21]. However, these results were inconsistent [13]. First, previous studies might have included some confounding factors, such as underlying divergent pathology or nonuniform surgical procedure. Second, the definition of axial symptom varies in different studies. Third, these risk factors were identified using various statistics analyses.

Several studies have been reported that modified traditional surgical procedure could reduce postoperative incidence of axial symptoms [22–25]. However, there is no study on the relationship between cervical sagittal alignment-related parameters and the incidence of postoperative axial symptoms. Therefore, we evaluated the factors associated with uniform defined axial symptom in patients treated with fixed surgical procedure (EOLP), using multivariable analysis to reduce the influence of confounding factors. As far as we know, this study is the largest multivariate analysis of axial symptom in recent years. The results of this study showed that collar wear time, preoperative and postoperative C2 SVA were independent risk factors of axial symptom for patients treated with EOLP.

More studies pay attention to cervical sagittal balance, which is related to postoperative outcomes, higher quality of life and prevention of disability [26–28]. Cervical sagittal balance is important for the maintenance of neutral head posture and horizontal gaze [29]. Tang et al. showed that cervical sagittal imbalance was associated with higher rated of disability following multilevel posterior cervical fusion [10]. Diebo et al. confirmed that the cascade of changes to cervical sagittal alignment could be detrimental to overall quality of life [30]. The compensation mechanisms that maintain neutral head posture and horizontal gaze often

**Table 4** Receiver operating characteristic (ROC) of the independent risk factors for predicting axial symptom

| | Area under ROC | 95% CI | *p* values | Cutoff value | Sensitivity | Specificity |
|---|---|---|---|---|---|---|
| Preoperative C2 SVA (mm) | 0.594 | 0.521–0.667 | 0.015 | 22.9 | 0.483 | 0.813 |
| Postoperative C2 SVA (mm) | 0.606 | 0.526–0.685 | 0.006 | 29.6 | 0.123 | 0.721 |
| Collar wear time (weeks) | 0.625 | 0.553–0.697 | 0.001 | 3.5 | 0.481 | 0.837 |

involve a cascade of changes, which lead to fatigue and neck pain [31]. Cervical sagittal balance can be quantified by measuring a variety of different parameters. At present, the most common cervical sagittal balance parameters are C2 SVA and T1 slope, which were also included in this study [29, 32, 33].

In this study, our results showed both the preoperative and postoperative C2 SVA were risk factors of axial symptom in patients undergoing EOLP. The preoperative and postoperative C2 SVA of the axial symptom group was larger than those of no axial symptom group, respectively (preoperative: 21.2 ± 10.6 mm (axial) vs. 17.7 ± 11.6 mm (no axial); postoperative: 25.6 ± 9.0 mm (axial) vs 22.7 ± 6.3 mm (no axial)). Bao et al. [34] found C2 SVA in symptomatic subgroup was larger than that in asymptomatic subgroup. Smith et al. [35] also found that larger C2 SVA had a correlation with worse myelopathy severity score. Tang et al. [10] showed that measures of C2 SVA greater than 4 cm have been correlated with worse outcomes following cervical spine surgery. The larger C2 SVA might lead to higher intramedullary cord pressure [36, 37]. The higher intramedullary cord pressure had been shown to result in substantial histologic changes in the spinal cord, including neuronal loss and atrophy of the anterior horn, demyelination and decreased vascular distribution, which might be the cause of spinal dysfunction and neurological deterioration [38, 39].

Cervical osseoligamentous compartment merely play as some facets of a multifactorial matrix in development of axial symptom. Panjabi et al. [40] showed that the osseologamentous only contributed about 20% to the mechanical stability of the cervical spine, while the neck musculature contributes the remaining 80%. The posterior cervical spine helps stabilize the head, keep the alignment of the cervical spine and play key role in neck pain [41]. Patients with larger C2 SVA lead to suboccipital muscles shortened, if the contracted states prolonged, which might result in neck pain [32]. Other researchers suggested that excess suboccipital muscle contraction might cause neck pain by placing chronic tension on the pain-sensitive dura mater via myodural bridges [42, 43]. The cutoff values of preoperative and postoperative C2 SVA were 22.9 mm and 29.6 mm, respectively. Therefore, in the future, if we performed EOLP for patients with preoperative C2 SVA >22.9 mm and/or postoperative C2 SVA >29.6 mm, we should pay attention to reducing the incidence of postoperative axial symptom.

In this study, collar wear time was another independent risk factor of axial symptom in EOLP. Patients in axial symptom had a longer collar wear time, which was consistent with previous reports [13]. For EOLP, collar might be helpful to protect the hinge, reduce risks of hinge fractures and avoid spring-back phenomena. However, too much collar wear time might cause or aggravate atrophy of cervical posterior extensor muscles, which could lead to fatigue and neck pain [16, 17]. Besides, the collar use might dramatically reduce cervical range of motion [44], which was closely related to the occurrence of axial symptom [14, 45]. The ROC analysis of collar wear time showed that the cutoff value was 3.5 weeks. Cheung et al. reported that the use of collar led to less axial neck pain within 3 weeks after surgery [46]. Wang et al. included 20 articles and the results showed that the axial symptom prevalence was 34% (319/874) after collar wear time ˃8 weeks, while 26% (339/1312) after collar wear time ≤ 4 weeks [13]. Therefore, we recommended that collar wear time should be limited within 4 weeks in order to reduce the incidence of postoperative axial symptom.

In this study, we confirmed statistically significant correlations between the incidence of axial symptom and preoperative, postoperative C2 SVA and collar wear time and demonstrated the cutoff threshold for these factors that predicts development of axial symptom. However, our study has some inherent limitations. First, due to its retrospective design, only a part of variables was selected to study which may lead to exist selection bias. Second, different patients may have different subjective feelings about the axial symptom because of the different environment. Third, the effect of other postoperative complications on the postoperative axial symptom was not taken into account. Going forward, prospective and well-designed studies will be necessary to control these factors, thereby establishing the predictive or causal factors associated with axial symptom more reliably.

## Conclusion

The larger preoperative, postoperative C2 SVA and longer collar wear time were positively correlated with the higher incidence of axial symptom following expansive open-door laminoplasty. ROC analysis showed that the preoperative C2 SVA of 22.9 mm, postoperative C2 SVA of 29.6 mm and collar wear time of 3.5 weeks could be a possible threshold for predicting the development of axial symptom. These results could lead to new insights into preventing axial symptom after cervical laminoplasty.

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### Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

## References


1. Takeuchi K, Yokoyama T, Aburakawa S, Saito A, Numasawa T, Iwasaki T, Itabashi T, Okada A, Ito J, Ueyama K, Toh S (2005) Axial symptoms after cervical laminoplasty with C3 laminectomy compared with conventional C3-C7 laminoplasty: a modified laminoplasty preserving the semispinalis cervicis inserted into axis. Spine 30(22):2544–2549. https://doi.org/10.1097/01.brs.0000186332.66490.ba
2. Kawakami M, Tamaki T, Yoshida M, Hayashi N, Ando M, Yamada H (1999) Axial symptoms and cervical alignments after cervical anterior spinal fusion for patients with cervical myelopathy. J Spinal Disord 12(1):50–56
3. Kato S, Oshima Y, Matsubayashi Y, Taniguchi Y, Tanaka S, Takeshita K (2019) Minimum clinically important difference in outcome scores among patients undergoing cervical laminoplasty. Eur Spine J 28(5):1234–1241. https://doi.org/10.1007/s00586-019-05945-y
4. Zhang H, Lu S, Sun T, Yadav SK (2015) Effect of lamina open angles in expansion open-door laminoplasty on the clinical results in treating cervical spondylotic myelopathy. J Spinal Disord Tech 28(3):89–94. https://doi.org/10.1097/BSD.0b013e3182695295
5. Motosuneya T, Maruyama T, Yamada H, Tsuzuki N, Sakai H (2011) Long-term results of tension-band laminoplasty for cervical stenotic myelopathy: a ten-year follow-up. J Bone Joint Surg Br 93(1):68–72. https://doi.org/10.1302/0301-620X.93B1.24532
6. Fujibayashi S, Neo M, Yoshida M, Miyata M, Takemoto M, Nakamura T (2010) Neck muscle strength before and after cervical laminoplasty: relation to axial symptoms. J Spinal Disord Tech 23(3):197–202. https://doi.org/10.1097/BSD.0b013e3181a1a73e
7. Kato M, Nakamura H, Konishi S, Dohzono S, Toyoda H, Fukushima W, Kondo K, Matsuda H (2008) Effect of preserving paraspinal muscles on postoperative axial pain in the selective cervical laminoplasty. Spine 33(14):E455–E459. https://doi.org/10.1097/BRS.0b013e318178e607
8. Smith JS, Shaffrey CI, Lafage V, Blondel B, Schwab F, Hostin R, Hart R, O'Shaughnessy B, Bess S, Hu SS, Deviren V, Ames CP, International Spine Study G (2012) Spontaneous improvement of cervical alignment after correction of global sagittal balance following pedicle subtraction osteotomy. J Neurosurg Spine 17(4):300–307. https://doi.org/10.3171/2012.6.SPINE1250
9. Villavicencio AT, Babuska JM, Ashton A, Busch E, Roeca C, Nelson EL, Mason A, Burneikiene S (2011) Prospective, randomized, double-blind clinical study evaluating the correlation of clinical outcomes and cervical sagittal alignment. Neurosurgery 68(5):1309–1316. https://doi.org/10.1227/neu.0b013e31820b51f3 **discussion 1316**
10. Tang JA, Scheer JK, Smith JS, Deviren V, Bess S, Hart RA, Lafage V, Shaffrey CI, Schwab F, Ames CP (2015) The impact of standing regional cervical sagittal alignment on outcomes in posterior cervical fusion surgery. Neurosurgery 76(Suppl 1):S14–S21. https://doi.org/10.1227/01.neu.0000462074.66077.2b **discussion S21**
11. Hirabayashi K, Watanabe K, Wakano K, Suzuki N, Satomi K, Ishii Y (1983) Expansive open-door laminoplasty for cervical spinal stenotic myelopathy. Spine 8(7):693–699. https://doi.org/10.1097/00007632-198310000-00003
12. Wang SJ, Jiang SD, Jiang LS, Dai LY (2011) Axial pain after posterior cervical spine surgery: a systematic review. Eur Spine J 20(2):185–194. https://doi.org/10.1007/s00586-010-1600-x
13. Wang M, Luo XJ, Deng QX, Li JH, Wang N (2016) Prevalence of axial symptoms after posterior cervical decompression: a meta-analysis. Eur Spine J 25(7):2302–2310. https://doi.org/10.1016/j.spinee.2016.04.018
14. Jiang JL, Li XL, Zhou XG, Lin H, Dong J (2012) Plate-only open-door laminoplasty with fusion for treatment of multilevel degenerative cervical disease. J Clin Neurosci 19(6):804–809. https://doi.org/10.1016/j.jocn.2011.09.021
15. Hosono N, Sakaura H, Mukai Y, Yoshikawa H (2007) The source of axial pain after cervical laminoplasty-C7 is more crucial than deep extensor muscles. Spine (Phila Pa 1976) 32(26):2985–2988. https://doi.org/10.1097/brs.0b013e31815cda83
16. Iizuka H, Nakagawa Y, Shimegi A, Tsutsumi S, Toda N, Takagishi K, Shimizu T (2005) Clinical results after cervical laminoplasty: differences due to the duration of wearing a cervical collar. J Spinal Disord Tech 18(6):489–491
17. Heller JG, Edwards CC 2nd, Murakami H, Rodts GE (2001) Laminoplasty versus laminectomy and fusion for multilevel cervical myelopathy: an independent matched cohort analysis. Spine (Phila Pa 1976) 26(12):1330–1336. https://doi.org/10.1097/00007632-200106150-00013
18. Sakai Y, Matsuyama Y, Inoue K, Ishiguro N (2005) Postoperative instability after laminoplasty for cervical myelopathy with spondylolisthesis. J Spinal Disord Tech 18(1):1–5
19. Ohnari H, Sasai K, Akagi S, Iida H, Takanori S, Kato I (2006) Investigation of axial symptoms after cervical laminoplasty, using questionnaire survey. Spine J 6(3):221–227. https://doi.org/10.1016/j.spinee.2005.10.014
20. Hosono N, Yonenobu K, Ono K (1996) Neck and shoulder pain after laminoplasty. A noticeable complication. Spine 21(17):1969–1973
21. Tanaka N, Nakanishi K, Fujimoto Y, Sasaki H, Kamei N, Hamasaki T, Yamada K, Yamamoto R, Nakamae T, Ochi M (2008) Expansive laminoplasty for cervical myelopathy with interconnected porous calcium hydroxyapatite ceramic spacers: comparison with autogenous bone spacers. J Spinal Disord Tech 21(8):547–552. https://doi.org/10.1097/BSD.0b013e31815c85bd
22. Hosono N, Sakaura H, Mukai Y, Fujii R, Yoshikawa H (2006) C3-6 laminoplasty takes over C3-7 laminoplasty with significantly lower incidence of axial neck pain. Eur Spine J 15(9):1375–1379. https://doi.org/10.1007/s00586-006-0089-9
23. Nori S, Shiraishi T, Aoyama R, Ninomiya K, Yamane J, Kitamura K, Ueda S (2018) Muscle-preserving selective laminectomy maintained the compensatory mechanism of cervical lordosis after surgery. Spine 43(8):542–549. https://doi.org/10.1097/BRS.0000000000002359
24. Shiraishi T, Kato M, Yato Y, Ueda S, Aoyama R, Yamane J, Kitamura K (2012) New techniques for exposure of posterior cervical spine through intermuscular planes and their surgical application. Spine 37(5):E286–E296. https://doi.org/10.1097/BRS.0b013e318239cc7e
25. Riew KD, Raich AL, Dettori JR, Heller JG (2013) Neck pain following cervical laminoplasty: does preservation of the C2 muscle attachments and/or C7 matter? Evid Based Spine Care J 4(1):42–53. https://doi.org/10.1055/s-0033-1341606
26. Youn MS, Shin JK, Goh TS, Kang SS, Jeon WK, Lee JS (2016) Relationship between cervical sagittal alignment and health-related quality of life in adolescent idiopathic scoliosis. Eur Spine J 25(10):3114–3119. https://doi.org/10.1007/s00586-016-4488-2
27. Scheer JK, Tang JA, Smith JS, Acosta FL Jr, Protopsaltis TS, Blondel B, Bess S, Shaffrey CI, Deviren V, Lafage V, Schwab F, Ames CP, International Spine Study G (2013) Cervical spine alignment, sagittal deformity, and clinical implications: a review. J Neurosurg Spine 19(2):141–159. https://doi.org/10.3171/2013.4.SPINE12838
28. Mesfin A, Bakhsh WR, Chuntarapas T, Riew KD (2016) Cervical scoliosis: clinical and radiographic outcomes. Global Spine J 6(1):7–13. https://doi.org/10.1055/s-0035-1554776
29. Tang R, Ye IB, Cheung ZB, Kim JS, Cho SK (2019) Age-related changes in cervical sagittal alignment: a radiographic analysis. Spine 44(19):E1144–E1150. https://doi.org/10.1097/brs.0000000000003082

30. Diebo BG, Challier V, Henry JK, Oren JH, Spiegel MA, Vira S, Tanzi EM, Liabaud B, Lafage R, Protopsaltis TS, Errico TJ, Schwab FJ, Lafage V (2016) Predicting cervical alignment required to maintain horizontal gaze based on global spinal alignment. Spine (Phila Pa 1976) 41(23):1795–1800. https://doi.org/10.1097/brs.0000000000001698
31. Rajnics P, Templier A, Skalli W, Lavaste F, Illes T (2002) The association of sagittal spinal and pelvic parameters in asymptomatic persons and patients with isthmic spondylolisthesis. J Spinal Disord Tech 15(1):24–30
32. Patwardhan AG, Khayatzadeh S, Havey RM, Voronov LI, Smith ZA, Kalmanson O, Ghanayem AJ, Sears W (2018) Cervical sagittal balance: a biomechanical perspective can help clinical practice. Eur Spine J 27(Suppl 1):25–38. https://doi.org/10.1007/s00586-017-5367-1
33. Jouibari MF, Le Huec JC, Ranjbar Hameghavandi MH, Moghadam N, Farahbakhsh F, Khadivi M, Rostami M, Kordi R (2019) Comparison of cervical sagittal parameters among patients with neck pain and healthy controls: a comparative cross-sectional study. Eur Spine J. https://doi.org/10.1007/s00586-019-06117-8
34. Bao H, Varghese J, Lafage R, Liabaud B, Diebo B, Ramchandran S, Day L, Jalai C, Cruz D, Errico T, Protopsaltis T, Passias P, Buckland A, Qiu Y, Schwab F, Lafage V (2017) Principal radiographic characteristics for cervical spinal deformity: a health-related quality-of-life analysis. Spine (Phila Pa 1976) 42(18):1375–1382. https://doi.org/10.1097/brs.0000000000002144
35. Smith JS, Lafage V, Ryan DJ, Shaffrey CI, Schwab FJ, Patel AA, Brodke DS, Arnold PM, Riew KD, Traynelis VC, Radcliff K, Vaccaro AR, Fehlings MG, Ames CP (2013) Association of myelopathy scores with cervical sagittal balance and normalized spinal cord volume: analysis of 56 preoperative cases from the AOSpine North America Myelopathy study. Spine(Phila Pa 1976) 38(22 Suppl 1):S161–170. https://doi.org/10.1097/brs.0b013e3182a7eb9e
36. Winestone JS, Farley CW, Curt BA, Chavanne A, Dollin N, Pettigrew DB, Ct Kuntz (2012) Laminectomy, durotomy, and piotomy effects on spinal cord intramedullary pressure in severe cervical and thoracic kyphotic deformity: a cadaveric study. J Neurosurg Spine 16(2):195–200. https://doi.org/10.3171/2011.10.SPINE11377
37. Chavanne A, Pettigrew DB, Holtz JR, Dollin N, Ct Kuntz (2011) Spinal cord intramedullary pressure in cervical kyphotic deformity: a cadaveric study. Spine 36(20):1619–1626. https://doi.org/10.1097/BRS.0b013e3181fc17b0
38. Shimizu K, Nakamura M, Nishikawa Y, Hijikata S, Chiba K, Toyama Y (2005) Spinal kyphosis causes demyelination and neuronal loss in the spinal cord: a new model of kyphotic deformity using juvenile Japanese small game fowls. Spine 30(21):2388–2392
39. Milhorat TH, Capocelli AL Jr, Kotzen RM, Bolognese P, Heger IM, Cottrell JE (1997) Intramedullary pressure in syringomyelia: clinical and pathophysiological correlates of syrinx distension. Neurosurgery 41(5):1102–1110. https://doi.org/10.1097/00006123-199711000-00014
40. Panjabi MM, Cholewicki J, Nibu K, Grauer J, Babat LB, Dvorak J (1998) Critical load of the human cervical spine: an in vitro experimental study. Clin Biomech (Bristol, Avon) 13(1):11–17
41. Okada E, Matsumoto M, Ichihara D, Chiba K, Toyama Y, Fujiwara H, Momoshima S, Nishiwaki Y, Takahata T (2011) Cross-sectional area of posterior extensor muscles of the cervical spine in asymptomatic subjects: a 10-year longitudinal magnetic resonance imaging study. Eur Spine J 20(9):1567–1573. https://doi.org/10.1007/s00586-011-1774-x
42. Fakhran S, Qu C, Alhilali LM (2016) Effect of the suboccipital musculature on symptom severity and recovery after mild traumatic brain injury. AJNR Am J Neuroradiol 37(8):1556–1560. https://doi.org/10.3174/ajnr.A4730
43. Alix ME, Bates DK (1999) A proposed etiology of cervicogenic headache: the neurophysiologic basis and anatomic relationship between the dura mater and the rectus posterior capitis minor muscle. J Manipulative Physiol Ther 22(8):534–539. https://doi.org/10.1016/S0161-4754(99)70006-0
44. Whitcroft KL, Massouh L, Amirfeyz R, Bannister G (2010) Comparison of methods of measuring active cervical range of motion. Spine (Phila Pa 1976) 35(19):E976–980. https://doi.org/10.1097/brs.0b013e3181cd6176
45. Fujimori T, Le H, Ziewacz JE, Chou D, Mummaneni PV (2013) Is there a difference in range of motion, neck pain, and outcomes in patients with ossification of posterior longitudinal ligament versus those with cervical spondylosis, treated with plated laminoplasty? Neurosurg Focus 35(1):E9. https://doi.org/10.3171/2013.4.focus1394
46. Cheung JPY, Cheung PWH, Law K, Borse V, Lau YM, Mak LF, Cheng A, Samartzis D, Cheung KMC (2019) Postoperative rigid cervical collar leads to less axial neck pain in the early stage after open-door laminoplasty-a single-blinded randomized controlled trial. Neurosurgery 85(3):325–334. https://doi.org/10.1093/neuros/nyy359