Small sagittal vertical axis accompanied with lumbar hyperlordosis as a risk factor for developing postoperative cervical kyphosis after expansive open-door laminoplasty

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OBJECTIVE Preoperative positive cervical sagittal imbalance and global sagittal imbalance are risk factors for postoperative cervical kyphosis after expansive open-door cervical laminoplasty (ELAP). The purpose of this study was to investigate the relationship between the incidence of postoperative cervical kyphosis after ELAP and the preoperative global sagittal spinal alignment in patients with cervical spondylotic myelopathy (CSM) without spinal sagittal imbalance.

METHODS Among 84 consecutive patients who underwent ELAP for CSM at the authors' hospital, 43 patients without preoperative cervical kyphosis ($C2-7$ angle $\geq 0^\circ$) and spinal sagittal imbalance ($C2-7$ sagittal vertical axis [SVA] ≤ 80 mm and $C-7$ SVA ≤ 95 mm) were included in the study. The global spinal sagittal parameters were measured on lateral whole-spine standing radiographs preoperatively and at 1 year postoperatively. The difference in preoperative global sagittal spinal alignment between the postoperative cervical lordosis group and the cervical kyphosis group was analyzed.

RESULTS The incidence of postoperative cervical kyphosis after ELAP was 25.6% (11 of 43 cases). Thirty-two patients (16 men and 16 women; mean age 67.7 ± 12.0 years) had lordosis, and 11 (7 men and 4 women; mean age 67.2 ± 9.6 years) had kyphosis. The preoperative $C-7$ SVA and pelvic incidence minus lumbar lordosis (PI-LL) in the kyphosis group were significantly smaller than those in the lordosis group ($p < 0.05$). The smaller $C-7$ SVA accompanied by a small PI-LL, the "truncal negative offset," led to postoperative cervical kyphosis due to posterior structural weakening by ELAP.

CONCLUSIONS In patients with CSM without preoperative cervical and global spinal sagittal imbalance, a small SVA accompanied by lumbar hyperlordosis is the characteristic alignment leading to postoperative cervical kyphosis after ELAP.

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KEYWORDS sagittal spinal alignment; cervical laminoplasty; cervical kyphosis; lumbar

EXPANSIVE open-door cervical laminoplasty (ELAP) has been widely performed for the treatment of patients with multilevel cervical spondylotic myelopathy (CSM). ELAP is thought to be an operation that preserves posterior elements (e.g., the ligamentous tension band)^{1,2} by a posterior approach. Cervical laminoplasty has several advantages in avoiding problems associated with laminectomy, including postoperative segmental instability, kyphosis, perineural adhesions, and late neurological

deterioration.¹¹ The theoretical advantage of laminoplasty is that it can preserve stability of the cervical spine, preventing postoperative kyphosis that can occur after laminectomy. Compared with laminectomy, the incidence of postoperative kyphosis is lower.¹¹

Postoperative cervical kyphosis can occur after ELAP even if the patient had sufficient preoperative cervical lordosis.^{1,19} Previous studies have shown a younger age at the time of surgery, laminectomy of 4 or more levels, surgery

ABBREVIATIONS CL = cervical lordosis; CSM = cervical spondylotic myelopathy; DISH = diffuse idiopathic skeletal hyperostosis; ELAP = expansive open-door cervical laminoplasty; LL = lumbar lordosis; OPLL = ossification of the posterior longitudinal ligament; PI = pelvic incidence; PT = pelvic tilt; SVA = sagittal vertical axis; TK = thoracic kyphosis.

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involving the C-2 lamina, performance of facetectomies, and increased preoperative range of motion as predictive factors.^{4,6} With the recent work investigating the outcomes after laminoplasty, positive global sagittal imbalance preoperatively was found to be associated with poor postoperative clinical outcomes,¹⁵ suggesting that cervical and global spinal sagittal balance should be taken into consideration when deciding whether to perform an ELAP. Because a previous study mentioned that positive cervical imbalance is a risk factor for postoperative cervical kyphosis,¹⁵ the indication of ELAP would be controversial for patients who have severe positive cervical imbalance preoperatively. In this study, we therefore focused on patients who do not have positive cervical and global sagittal imbalance. The purpose of this study was to investigate the relationship between the incidence of postoperative cervical kyphosis after ELAP and the preoperative total spinal sagittal alignment in selected patients whose cervical and global spinal sagittal alignment were not imbalanced.

Methods

Between January 2011 and December 2015, 138 consecutive patients underwent cervical operations for CSM; 84 consecutive patients underwent ELAP at our hospital (anterior decompression and fixation in 47 cases, posterior decompression with instrumentation in 5 cases, and anterior and posterior in 2 cases). Among them, 43 patients without preoperative cervical kyphosis (C2–7 angle $\geq 0^\circ$) and without spinal sagittal imbalance according to cervical spine deformity classification² and adult spinal deformity¹⁷ (C2–7 SVA ≤ 80 mm; C-7 SVA ≤ 95 mm) were included. There were 23 male patients and 20 female patients, with a mean age of 67.5 ± 13.7 years. The patients' preoperative measurements are summarized in Table 1. All patients provided written informed consent after explanation of the experimental protocol. This study was approved by the institutional review board of our institution. Patients with myelopathy caused by cervical disc herniation or cervical ossification of the posterior longitudinal ligament (OPLL), diffuse idiopathic skeletal hyperostosis (DISH), ELAP with posterior or anterior fusion, sigmoid curve of the cervical spine, occiput–C2 deformity, a history of previous cervical spine surgery, Parkinson disease, neurological disease, or patients who could not stand up without assistance were excluded.

The following parameters were measured on lateral whole-spine standing radiographs preoperatively and at 1 year postoperatively: the total distance from the plumb line of the pedicle center of the C-2 vertebra to the posterior superior corner of the C-7 vertebra (C2–7 sagittal vertical axis [SVA]); cervical lordosis (CL) assessed by the C2–7 Cobb angle (defined as the angle from the lower endplate of C-2 to the lower endplate of C-7); the angle between the T-1 upper endplate and the horizontal plane (T-1 slope); the angle between the T-4 upper edge and T-12 lower edge (thoracic kyphosis [TK]); the distance from the C-7 plumb line to the sacral posterior angle (C-7 SVA); the angle from the upper endplate of L-1 to the upper endplate of the sacrum (lumbar lordosis [LL]); the angle between the sacral plate and the horizontal plane (sacral slope);

TABLE 1. Preoperative total spinal sagittal alignment

Parameter	Mean $\pm$ SD
C2–7 SVA (mm)	14.6 $\pm$ 10.4
CL ($^\circ$)	27.6 $\pm$ 7.3
T-1 slope ($^\circ$)	31.8 $\pm$ 12.6
C-7 SVA (mm)	43.8 $\pm$ 13.2
TK ($^\circ$)	46.8 $\pm$ 12.2
LL ($^\circ$)	15.8 $\pm$ 6.5
PT ($^\circ$)	24.2 $\pm$ 11.0
PI ($^\circ$)	23.1 $\pm$ 49.9
PI-LL ($^\circ$)	3.0 $\pm$ 11.1

the angle between the line connecting the midpoint of the sacral plate to the axis of the femoral head and the gravity line (pelvic tilt [PT]); and the angle between the perpendicular to the sacral plate at its midpoint and the line connecting the point to the middle axis of the femoral head (pelvic incidence [PI])² (Fig. 1). Whole-spine anteroposterior and lateral radiographs were obtained using the digital slot-scanning radiography mode of the Sonialvision Safire fluoroscopy system (Shimadzu Corp.). An alignment of the C2–7 Cobb angle of 0° or more was defined as lordosis, and an alignment of the C2–7 Cobb angle less than 0° was defined as kyphosis.¹⁰ Based on the data obtained at 1 year after ELAP, the patients were divided into 2 groups as follows: the lordosis group and kyphosis group.

The clinical outcome was evaluated by the recovery rate according to the Japanese Orthopaedic Association scoring system for cervical myelopathy.⁵ Values are expressed as the mean $\pm$ standard deviation. Statistical analyses were performed using the JMP software package (version 10.0, SAS Institute Inc.). The Shapiro-Wilk W test was used for the goodness-of-fit to the normal distribution. The Student t-test was used to determine intergroup differences between the lordosis and kyphosis groups to evaluate the outcome measures of sagittal spinal parameters. The correlations between the variables of spinopelvic parameters were examined using Pearson's rank correlation coefficient. Stepwise single regression analysis was used to detect the postoperative CL by the preoperative spinal sagittal parameters. A p value < 0.05 was considered to indicate a statistically significant difference.

Results

Cervical kyphosis was present in 11 of 43 patients (25.6%) 1 year after ELAP. The lordosis group comprised 32 patients (16 men and 16 women; mean age 67.7 ± 12.0 years). The kyphosis group consisted of 11 patients (7 men and 4 women; mean age 67.2 ± 9.6 years) (Table 2). Regarding preoperative total sagittal spinal alignment of the kyphosis group, the C-7 SVA was significantly smaller than that of the lordosis group ($p < 0.05$) (Table 2). The PI-LL in the kyphosis group was significantly smaller than that of the lordosis group preoperatively and postoperatively (Table 3). The preoperative C-7 SVA and PI-LL had a positive correlation with postoperative CL (Table 4 and Fig. 2). The recovery rate according to the Japanese Or-

FIG. 1. Spinal and pelvic alignment measurements. T1S = T-1 slope. Copyright Kenji Endo. Published with permission.

thopaedic Association for cervical myelopathy score was $43.7\% \pm 13.2\%$ in the lordosis group and $38.2\% \pm 17.0\%$ in the kyphosis group.

Discussion

It is well known that cervical malalignment affects

the incidence of cervical myelopathy.¹⁴ Having sufficient preoperative cervical lordosis is a prerequisite for laminoplasty,¹⁸ and maintaining postoperative lordosis is important for spinal cord decompression.¹⁹ Postoperative cervical kyphosis is the most prevalent cervical spinal deformity secondary to cervical posterior decompression surgery.¹⁶ However, despite having sufficient preoperative lordosis, cervical laminoplasty often diminishes the lordosis.¹ For example, Lee et al. stated that the cervical lordosis

TABLE 2. Patient characteristics and preoperative parameters

Parameter	Lordosis Group	Kyphosis Group	p Value
Age (yrs)	67.7 ± 12.0	67.2 ± 9.6	0.91
Sex (M/F)	16/16	7/4	0.50
C2–7 SVA (mm)	23.8 ± 11.9	25.0 ± 8.7	0.75
CL (°)	16.6 ± 10.3	10.1 ± 8.9	0.05
T-1 slope (°)	28.4 ± 7.8	25.3 ± 5.8	0.23
C-7 SVA (mm)	33.7 ± 52.7	-5.7 ± 27.3	0.02
TK (°)	31.2 ± 13.1	33 ± 11.9	0.70
LL (°)	40.5 ± 10.1	49.5 ± 11.8	0.33
PT (°)	16.4 ± 6.9	13.3 ± 4.4	0.09
PI (°)	48.2 ± 13.0	38.9 ± 3.7	0.17
PI–LL (°)	5.4 ± 10.9	-4.5 ± 8.8	0.01

TABLE 3. Postoperative parameters

Parameter	Lordosis Group	Kyphosis Group	p Value
C2–7 SVA (mm)	24.6 ± 14.4	36.1 ± 13.4	0.02
CL (°)	14.5 ± 11.1	-7.6 ± 5.2	<0.0001
T-1 slope (°)	26.0 ± 10.1	27.8 ± 7.7	0.54
C-7 SVA (mm)	28.4 ± 45.7	-2.8 ± 24.7	0.04
TK (°)	27.8 ± 14.9	33.9 ± 10.8	0.16
LL (°)	41.4 ± 13.0	46.4 ± 12.6	0.16
PT (°)	15.9 ± 7.7	12.5 ± 5.4	0.17
PI (°)	48.2 ± 2.1	38.9 ± 3.9	0.04
PI–LL (°)	5.0 ± 9.2	-3.5 ± 6.0	0.01

TABLE 4. Correlations between the postoperative C2–7 angle and preoperative alignment parameters

	C2–7 SVA	C-7 SVA	CL	T-1 slope	TK	LL	PT	PI	PI–LL
Correlation	–0.23	0.42	0.65	0.36	0.10	–0.14	0.16	0.15	0.35
p value	0.13	<0.01	<0.01	0.02	0.51	0.36	0.30	0.32	0.02

decreased in 35 of 50 cases (70%) after ELAP.⁹ Sakai et al. explored factors associated with postoperative kyphosis and found that preoperative positive cervical sagittal imbalance was a risk factor for cervical kyphotic deformity after laminoplasty.¹⁵ Kim et al. also reported that uncompensated cervical sagittal spinal balance and the weight of the head will act as a continuous kyphotic force for cervical sagittal balance and patients with high T-1 slope and insufficient lordosis are subjected to a kyphotic force in the cervical spine.⁸ On the other hand, other studies have shown that postoperative kyphosis did not occur frequently in patients with a higher T-1 slope.^{3,7} Kim et al. reported that the incidence of postoperative cervical kyphosis after ELAP was 25.7% (9 of 35 cases) with a high T-1 slope and 20.7% (6 of 29 cases) with a low T-1 slope.⁷ The predictors of postoperative kyphosis have been unclear and a matter of debate in past studies. We hypothesized that this controversy may have been caused by analyzing only cervical regional alignment^{3,7,8} and that the evaluation of the “global sagittal balance” must be included for the analysis. Recently, Oshima et al.¹³ suggested that global sagittal balance and cervical regional alignment should be considered in evaluating clinical outcomes for patients undergoing ELAP.

In our current study, the kyphosis group exhibited a statistically significant smaller C-7 SVA preoperatively. The PI–LL was statistically small in the kyphosis group ($-4.5^\circ \pm 8.8^\circ$). We concluded that the characteristic preoperative distribution of sagittal spinal alignment in the kyphosis group was small CL, C-7 SVA, and PI–LL. However, the cutoff value of cervical lordosis for preventing postoperative cervical kyphosis is difficult to determine because cervical lordosis is affected by the global sagittal spinal alignment. Previously, the clinical significance of negative sagittal imbalance has not been clearly revealed. Our re-

sults suggest that patients who have a preoperative large LL with a small PI and truncal negative offset, so-called reciprocal change, will develop postoperative cervical kyphosis after the posterior structure is weakened by ELAP. From previous findings^{7,8,15} and our results, we propose that there could be 2 types of preoperative characteristic alignments leading to postoperative kyphosis after ELAP (Fig. 3). When performing ELAP in patients with normal spinal sagittal balance, the truncal negative offset associated with hyperlordosis (small PI–LL) is an important factor for predicting postoperative cervical kyphosis. Therefore, we may need to consider an additional procedure for these patients to avoid postoperative cervical kyphosis by performing either anterior or posterior fusion during ELAP.

This study has some limitations. The number of patients was relatively small due to the strict inclusion criteria, which excluded patients with spinal sagittal imbalance, OPLL, and DISH. If patients with OPLL and DISH were included, the rate of postoperative kyphosis might have been decreased further. In a future study, we should add more patients and conduct a study with longer follow-up.

Conclusions

In patients with CSM without cervical and global spinal sagittal imbalance, a small SVA with lumbar hyperlordosis is the characteristic alignment leading to postoperative cervical kyphosis after ELAP.

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FIG. 2. Correlations between postoperative C2–7 angle (A) and preoperative SVA (**left**) and preoperative PI–LL (**right**).

FIG. 3. A: Standard spinal sagittal balance. B: Positive C-7 SVA imbalance. C: Negative C-7 SVA imbalance. Copyright Kenji Endo. Published with permission. Figure is available in color online only.

received or will be received from any commercial party associated directly or indirectly with this study.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Endo, Matsuoka, Suzuki, Tanaka, Yamamoto. Acquisition of data: Endo, Matsuoka, Suzuki, Murata, Nishimura, Tanaka. Analysis and interpretation of data: Endo, Matsuoka, Suzuki, Sawaji, Murata, Nishimura. Drafting the article: Endo, Sawaji. Critically revising the article: Endo, Matsuoka, Sawaji. Reviewed submitted version of manuscript: Endo, Matsuoka, Suzuki, Sawaji, Yamamoto. Approved the final version of the manuscript on behalf of all authors: Endo. Statistical analysis: Endo, Matsuoka, Suzuki, Sawaji. Administrative/technical/material support: Endo. Study supervision: Endo, Suzuki, Sawaji, Yamamoto.

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