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ORIGINAL ARTICLE

Extremely high preoperative C7 slope limits compensatory cervical lordosis after muscle-preserving selective laminectomy

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Abstract

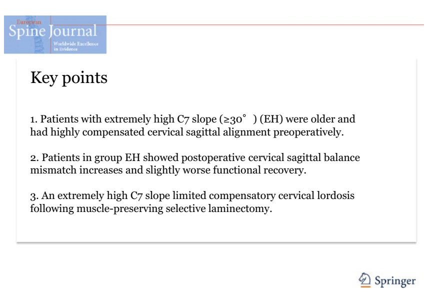
Purpose A high C7 slope induces C2–C7 lordosis to compensate for cervical sagittal balance adjustments. A muscle-preserving selective laminectomy (SL) can maintain this compensation postoperatively. This study evaluated the effect of an extremely high C7 slope on C2–C7 lordotic compensation following SL.

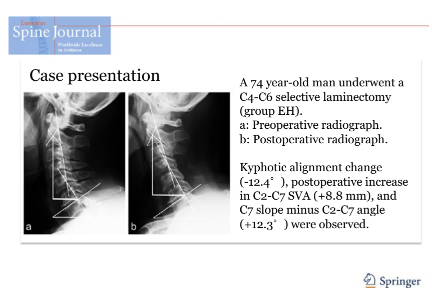
Methods This study enrolled 151 cervical compressive myelopathy patients who underwent SL. Lateral cervical spine radiographs were taken before surgery and during final follow-up. Patients were divided into extremely high C7 slope ($\geq 30°$) (EH) and non-high C7 slope ($< 30°$) (NH) groups and the influence of a high C7 slope on radiological and surgical outcomes was examined.

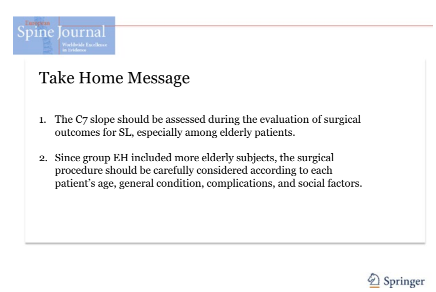
Results Mean age was higher in group EH ($p < 0.001$). Preoperatively, patients in group EH had a larger C2–C7 sagittal vertical axis (SVA) ($p = 0.001$) and greater cervical lordosis ($p < 0.001$). Although C2–C7 SVA increased after surgery, mean C2–C7 angle of group EH decreased. Mismatches between C7 slope and C2–C7 angle increased for group EH postoperatively ($p = 0.015$). Postoperative Japanese Orthopedic Association (JOA) score and recovery rate (RR) were slightly lower in group EH ($p = 0.001$ and $p = 0.006$, respectively). Multiple linear regression analyses revealed that extremely high C7 slope, not age, affected the RR of JOA score ($p = 0.006$).

Conclusions Patients in group EH were older and had highly compensated cervical sagittal alignment preoperatively. They demonstrated postoperative cervical sagittal balance mismatch increases and slightly worse functional recovery. An extremely high C7 slope limited compensatory cervical lordosis following SL.

Graphical abstract These slides can be retrieved under Electronic Supplementary Material.







Keywords Cervical sagittal balance · C7 slope · Surgical outcome · Cervical compressive myelopathy · Selective laminectomy

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Introduction

Cervical sagittal alignment is a determining factor of surgical and radiological outcomes of cervical spine surgery [1–3]. The T1 slope contributes to cervical and global sagittal alignment [4]. Likewise, the C7 slope is a marker of overall spinal sagittal alignment by linking the occipitocervical and thoracolumbar spine [5]. Few studies have examined the relationship between preoperative T1 (C7) slope and radiological or functional outcomes [6–8]. These studies divided patients by median preoperative T1 (C7) slope (above vs below). Two studies determined more postoperative kyphotic changes in laminoplasty patients with a higher preoperative T1 slope [6, 8]. Among patients undergoing muscle-preserving selective laminectomy (SL), more postoperative lordotic changes and greater comparable functional recovery were observed in patients with a higher C7 slope [7]. SL, in which decompression laminae are selected without disturbing the deep extensor muscles (DEMs) or facet joints, has been used to decompress cervical compressive myelopathy (CCM) at our institution for > 12 years. SL minimizes the surgical invasiveness of the cervical posterior structure and maintains cervical spine alignment [7, 9].

As C7 slope increases, C2–C7 angle compensates into lordotic alignment to adjust cervical sagittal balance or horizontal gaze [7, 10, 11]. We speculated that patients with an "extremely" high C7 slope (≥ average + 1 SD, 30°) whose cervical sagittal alignments were highly compensated by preoperative C2–C7 hyper-lordosis would reveal the limitations of cervical lordosis as a postoperative compensator. We divided our patients into extremely high C7 slope (EH) and non-high C7 slope (NH) groups and examined the impact of an extremely high C7 slope on radiological and functional outcomes.

Materials and methods

Subjects

Between April 2010 and December 2013, 278 consecutive patients underwent SL for CCM at our academic institution. The study's inclusion criteria were: age ≥ 18 years, symptomatic CCM (at least one clinical sign of myelopathy), and evidence of CCM on cervical myelography–computed tomography (CM–CT). Patients who presented with radiculopathy without myelopathy; underwent foraminotomy or previous cervical spine surgery; or had ankylosing spondylitis, rheumatoid arthritis, infection, tumors, or trauma were excluded. Our surgical indications for SL patients were: (1) local kyphosis < 20° [7]; (2) spondylolisthesis < 3.5 mm [12]; and (3) occupying ratio of ossification of the posterior longitudinal ligament (OPLL) < 60% [13]. Preoperative CM–CT was performed for all patients to reveal OPLL presence and type. Since the most common surgically treated level was C6, patients whose SL included C6 were selected. The study involved 151 CCM patients who underwent C6 SL (12 cases), C5–C6 SL (38 cases), C4–C6 SL (74 cases), and C3–C6 SL (27 cases).

Operative procedure

We performed SL as previously described [7, 9, 14]. Selective mono-laminectomy was used to decompress two adjacent intervertebral levels [7, 9, 14]. For C3–C6 SL, the C2–C3, C3–C4, C4–C5, C5–C6, and C6–C7 interlaminar spaces were exposed through the bilateral interspinalis muscles [9]. The C3, C4, C5, and C6 spinous processes were split longitudinally using a high-speed drill and divided at the base without damaging the bilateral DEMs. The C3, C4, C5, and C6 laminae, upper half of the C7 lamina, and yellow ligament of the ventral aspect of the C2 lamina were removed. Adjacent five-level (C2–C3, C3–C4, C4–C5, C5–C6, and C6–C7) decompression was accomplished. The split fragments of the C3, C4, C5, and C6 spinous processes were sutured together.

Prior to surgery, decompression levels were determined through complete obstruction of the subarachnoid space in the preoperative CM–CT with the patients' necks in neutral and extended positions. To determine laminectomy width, we measured spinal cord width at the upper edge of each lamina using CM–CT. Laminectomy width was up to 2–3 mm wider than spinal cord width [7, 14]. The mean laminectomy width was 15–19 mm; we never exposed the bilateral facet joints during the procedure.

Patient characteristics and outcome measures

Patients' clinical characteristics including age, sex, diagnosis, operative level, and perioperative complications were recorded. The Japanese Orthopedic Association (JOA) score system for cervical myelopathy was used to measure outcomes preoperatively and at final follow-up (> 1 year after surgery). Hirabayashi's method was used to calculate recovery rate (RR) of the JOA score [15].

Evaluation of radiological findings

Standing lateral, flexion, and extension radiographs of the cervical spine were measured preoperatively and at final follow-up. A neutral lateral radiograph of the cervical spine was obtained with patients in comfortable standing positions facing forward with horizontal gaze. The

C7 slope was determined as angle between the superior end plate of C7 and a horizontal line. C7 slope was used instead of T1 slope because of difficulty measuring T1 slope in many patients [7, 16, 17]. C2–C5, C5–C7, and C2–C7 angles were obtained by measuring the tangential lines along the posterior borders of the C2 and C5, C5 and C7, or C2 and C7 vertebral bodies. The C2–C7 sagittal vertical axis (SVA) was the distance between the C2 plumb line and the posterior superior corner of the C7 vertebral body. Cervical range of motion (ROM) was the difference in C2–C7 angle during flexion and extension. Materials were sub-analyzed by C7 slope magnitude (preoperative C7 slope ≥ 30° vs < 30°). Two independent spinal surgery specialists analyzed the images using a DICOM viewer (RadiAnt version 3.2.3, Meixant, Poznan, Poland; or Synapse version 4.1.0, FUJIFILM Medical, Tokyo, Japan). The interobserver reliabilities analyzed by the interclass correlation coefficient (ICC) (2, 1) demonstrated strong correlations of > 0.8 for each radiological parameter.

Statistical analysis

SPSS software (version 22.0; IBM Corporation, Armonk, NY, USA) was used for the statistical analyses. Continuous variables are shown as mean ± SD. Statistical analyses comparing pre- and postoperative radiological parameters were performed using an unpaired *t* test. Correlations between C7 slope and age or radiological factors were analyzed using Pearson's correlation coefficient. Each independent variable was compared between groups EH and NH using an unpaired t-test for continuous variables and a Chi-square test or Mann–Whitney *U* test for discrete variables. Selected factors with $p < 0.05$ on univariate analysis between groups EH and NH were examined via multiple linear regression analysis of RR of JOA score. The interobserver reliabilities of the radiography measurements were analyzed using ICC. Differences were considered significant at $p < 0.05$.

Table 1 Pre- and postoperative radiological parameters

	Preoperative	Postoperative	*p* value
C2–C7 angle (°)	10.9 ± 12.4	12.3 ± 12.6	0.351
C2–C5 angle (°)	5.9 ± 11.5	10.5 ± 11.3	0.001
C5–C7 angle (°)	4.8 ± 8.6	1.6 ± 10.0	0.004
C7 slope (°)	21.4 ± 8.2	21.2 ± 9.0	0.852
C2–C7 SVA (mm)	18.0 ± 15.3	19.6 ± 15.9	0.402
Cervical ROM (°)	35.0 ± 12.2	29.4 ± 12.5	< 0.001

SVA sagittal vertical axis, *ROM* range of motion

Results

Patient demographic and radiological parameters

This study involved 151 patients (96 males, 55 females). The mean follow-up period was 27.2 ± 11.5 months.

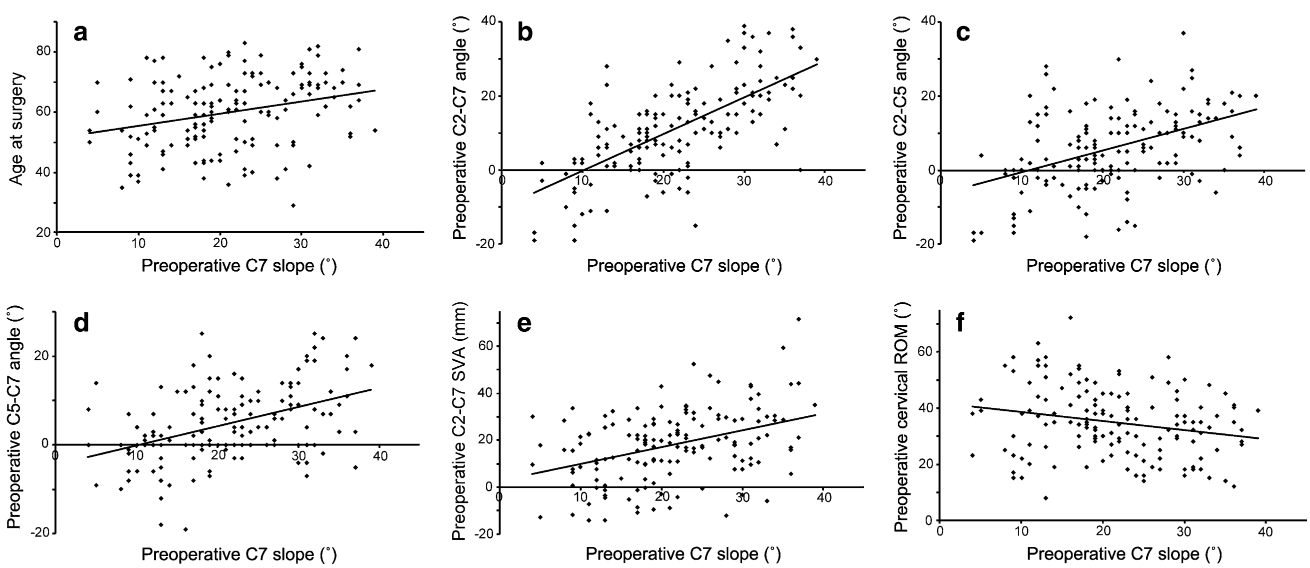

Fig. 1 Correlation analyses. **a** Correlation between preoperative C7 slope and age at surgery ($r = 0.280$, $p < 0.001$). **b** Correlation between preoperative C7 slope and preoperative C2–C7 angle ($r = 0.672$, $p < 0.001$). **c** Correlation between preoperative C7 slope and preoperative C2–C5 angle ($r = 0.442$, $p < 0.001$). **d** Correlation between preoperative C7 slope and preoperative C5–C7 angle ($r = 0.423$, $p < 0.001$). **e** Correlation between preoperative C7 slope and preoperative C2–C7 SVA ($r = 0.391$, $p < 0.001$). **f** Correlation between preoperative C7 slope and preoperative cervical ROM ($r = -0.219$, $p = 0.007$)

Table 2 Correlation between C7 slope and age and radiological factors

	r	p value
Preop. C7 slope vs.		
Age at surgery	0.280	< 0.001
Preop. C2–C7 angle (°)	0.672	< 0.001
Preop. C2–C5 angle	0.442	< 0.001
Preop. C5–C7 angle	0.423	< 0.001
Preop. C2–C7 SVA (mm)	0.391	< 0.001
Preop. cervical ROM	− 0.219	0.007
Postop. C7 slope vs.		
Age at surgery	0.467	< 0.001
Postop. C2–C7 angle (°)	0.659	< 0.001
Postop. C2–C5 angle	0.424	< 0.001
Postop. C5–C7 angle	0.375	< 0.001
Postop. C2–C7 SVA (mm)	0.372	< 0.001
Postop. cervical ROM	− 0.203	0.012

SVA sagittal vertical axis, *ROM* range of motion

Perioperative complications included two cases of C5 palsy (1.3%), one of superficial infection (0.7%), and one of spinal epidural hematoma (0.7%). Postoperative C2–C5 lordotic changes ($p = 0.001$) and postoperative C5–C7 kyphotic changes ($p = 0.004$) were observed. Mean cervical ROM decreased slightly postoperatively ($p < 0.001$) (Table 1).

Correlation between C7 slope and age and radiological factors

Age at surgery was correlated with C7 slope pre- and postoperatively. C7 slope was also correlated with C2–C7 angle, C2–C5 angle, C5–C7 angle, C2–C7 SVA, and cervical ROM pre- and postoperatively (Fig. 1, Table 2).

Effect of preoperative C7 slope on patient characteristics and radiological parameters

Patients were divided by C7 slope based on average measurements + 1 SD ($21.4 + 8.2 = 29.6° \approx 30°$). The preoperative C7 slope was ≥ 30° in 31 patients (group EH) and < 30° in 120 patients (NH group). Mean age was greater in group EH than in group NH ($p < 0.001$). Mean postoperative JOA score and RR of JOA score were greater for group NH than group EH ($p = 0.001$ and $p = 0.006$, respectively). No significant intergroup differences existed in other patient characteristics (Table 3).

Mean preoperative C7 slope was 33.1 ± 2.6 in group EH and 18.4 ± 6.2 in group NH ($p < 0.001$). Group EH patients had greater lordotic C2–C7, C2–C5, and C5–C7 angles than group NH patients pre- ($p < 0.001$, $p < 0.001$, and $p = 0.001$, respectively) and postoperatively ($p < 0.001$, $p = 0.011$, and $p < 0.001$, respectively). Mean C2–C7 angle decreased in group EH but increased in group NH postoperatively ($p = 0.003$). Although postoperative kyphotic

Table 3 Patients' characteristics as affected by preoperative C7 slope

	Preop. extremely high C7 slope (≥ 30°, EH group)	Preop. non-high C7 slope (< 30°, NH group)	p value
Number of cases	31	120	
Age at surgery	67.5 ± 9.5	58.2 ± 11.8	< 0.001
Sex (male, %)	74.1	60.8	0.168
OPLL (%)	22.6	27.5	0.580
JOA score			
Preop.	11.4 ± 2.2	12.2 ± 2.2	0.096
Postop.	13.3 ± 2.0	14.6 ± 1.7	0.001
RR (%)	35.1 ± 20.4	49.1 ± 25.9	0.006
Surgical factors			
The number of CLs surgically treated	2.9 ± 1.0	2.7 ± 0.8	0.315
Op. time (min)	141.3 ± 36.9	128.9 ± 28.3	0.091
Blood loss (g)	9.4 ± 18.4	10.7 ± 29.3	0.813
Operative level (n: cases)			0.095
C6 SL	4	8	
C5–C6 SL	4	34	
C4–C6 SL	14	60	
C3–C6 SL	9	18	

SL selective laminectomy, *OPLL*, ossification of posterior longitudinal ligament, *JOA* Japanese Orthopedic Association, *RR* recovery rate, *CLs* consecutive laminae changes in C5–C7 angle were comparable between the groups, a greater lordotic change in C2–C5 angle was observed in NH ($p<0.001$). Mean C2–C7 SVA was greater in group EH than in group NH both pre- ($p<0.001$) and postoperatively ($p=0.003$). C2–C7 SVA increased in both groups postoperatively ($p=0.243$). Cervical ROM was better in NH than EH patients both pre- ($p=0.016$) and postoperatively ($p=0.003$). C7 slope minus C2–C7 angle increased in group EH but decreased in group NH postoperatively ($p=0.015$) (Table 4).

Multiple linear regression analysis of RR of JOA score

We analyzed the factors influencing RR of JOA score using multiple linear regression analysis. An extremely high preoperative C7 slope affected RR of JOA score (β = -0.223, $p=0.006$); patient age did not ($p=0.185$) (Table 5).

Case presentation

A 74-year-old man underwent C4–C6 SL (Fig. 2). Preoperative C2–C7 angle, C7 slope, C7 slope minus C2–C7 angle, and C2–C7 SVA were 23.6°, 35.4°, 11.8°, and 28.8 mm, respectively (group EH). Two years and 1 month after surgery, C2–C7 angle, C7 slope, C7 slope minus C2–C7 angle, and C2–C7 SVA were 11.2°, 35.3°, 24.1°, and 37.6 mm, respectively. Preoperative JOA, postoperative JOA, and RR of JOA score were 10, 10.5, and 7.1%. Kyphotic alignment change, postoperative increase in C2–C7 SVA, and C7 slope minus C2–C7 angle were observed.

Discussion

In the current study, patients with an extremely high C7 slope were older, more likely to have lordotic cervical alignment, and had larger preoperative C2–C7 SVA. After

Table 4 Patients' radiological parameters as affected by preoperative C7 slope

	Preop. extremely high C7 slope (≥ 30°, EH group)	Preop. non-high C7 slope (< 30°, NH group)	*p* value
C2–C7 angle (°)			
Preop.	23.9 ± 9.6	7.6 ± 10.8	< 0.001
Postop.	22.2 ± 11.0	9.7 ± 11.7	< 0.001
Postop. minus Preop.	− 1.8 ± 5.8	2.2 ± 6.5	0.003
C2–C5 angle (°)			
Preop.	14.1 ± 10.1	3.8 ± 10.9	< 0.001
Postop.	15.1 ± 9.6	9.4 ± 11.4	0.011
Postop. minus Preop.	1.0 ± 6.4	5.5 ± 6.1	< 0.001
C5–C7 angle (°)			
Preop.	10.0 ± 9.9	3.4 ± 7.7	0.001
Postop.	7.7 ± 10.2	0.0 ± 9.4	< 0.001
Postop. minus Preop.	− 2.3 ± 6.0	− 3.4 ± 5.4	0.354
C7 slope (°)			
Preop.	33.1 ± 2.6	18.4 ± 6.2	< 0.001
Postop.	32.3 ± 6.9	18.3 ± 7.1	< 0.001
Postop. minus Preop.	− 0.8 ± 6.7	0.0 ± 5.4	0.496
C7 slope minus C2–C7 angle (°)			
Preop.	9.2 ± 10.2	10.8 ± 9.0	0.391
Postop.	10.2 ± 10.6	8.6 ± 9.2	0.420
Postop. minus Preop.	1.0 ± 6.5	− 2.2 ± 6.3	0.015
C2–C7 SVA (mm)			
Preop.	25.8 ± 17.5	16.0 ± 14.0	0.001
Postop.	29.2 ± 20.1	17.1 ± 13.6	0.003
Postop. minus Preop.	3.4 ± 12.5	1.0 ± 9.4	0.243
Cervical ROM (°)			
Preop.	30.3 ± 10.4	36.2 ± 12.4	0.016
Postop.	23.6 ± 9.7	30.9 ± 12.7	0.003
Postop. minus Preop.	− 6.7 ± 12.5	− 5.3 ± 14.4	0.624

SVA sagittal vertical axis, *ROM* range of motion surgery, C2–C7 SVA increased and C2–C7 angle decreased in EH patients. Moreover, a postoperative increase in mismatch between C7 slope and C2–C7 angle was observed in those patients. Surgical outcome was slightly worse among EH patients. Multiple linear regression analysis revealed that only an extremely high C7 slope affected RR of JOA score. An extremely high preoperative C7 slope limited the compensatory cervical lordosis after SL.

C7 slope is an important marker of overall spinal sagittal alignment and links the occipitocervical and thoracolumbar spine [5]. An advantage of studying the C7 slope is that it is easier to determine the superior endplate of C7 than that of T1 [5]. The C7 slope is correlated with C2–C7 angle, occiput–C2 angle, sacral slope, and C7 SVA [5]. Another study also reported the correlation of C7 slope with C2–C7 angle and C2–C7 SVA [7]. Significant correlations between C7 slope and C2–C7 angle, C2–C5 angle, C5–C7 angle, C2–C7 SVA, and cervical ROM were observed in this study. A previous report demonstrated a gradual increase in T1 slope as age increased in an asymptomatic population [11]; we observed a similar correlation between C7 slope and age.

Unlike the previous study analyzing the relationship between preoperative "relatively" high (≥ median) C7 slope and surgical outcome [7], this study separated patients with "extremely" high (≥ average + 1 SD) C7 slope from those with less extreme C7 slope into group EH and group NH. Patients in group NH demonstrated postoperative lordotic changes in C2–C7 angle and increases in C2–C7 SVA. EH patients underwent kyphotic changes in C2–C7 angle and increases in C2–C7 SVA. These findings indicate that the compensatory C2–C7 lordotic change that occurred in NH patients was absent in EH patients, suggesting that extremely high preoperative C7 slope limits the compensatory mechanism of cervical lordosis after surgery. We previously observed that SL including lower cervical lamina(e) frequently caused a slight postoperative C5–C7 kyphotic change along with the compensatory C2–C5 lordotic change. In this study, EH patients with a higher preoperative C2–C5 angle showed smaller postoperative lordotic changes in C2–C5 angle than NH patients, which affected their postoperative C2–C7 kyphotic changes.

Table 5 Multiple linear regression analysis of RR of JOA score

Characteristic	β	p value
Preop. extremely high C7 slope (≥ 30°)	− 0.223	0.006
Age at surgery		0.185
C2–C7 angle (°)		
Preop.		0.245
Postop.		0.382
Postop. minus Preop.		0.735
C2–C5 angle (°)		
Preop.		0.245
Postop.		0.298
Postop. minus Preop.		0.871
C5–C7 angle (°)		
Preop.		0.947
Postop.		0.528
C7 slope minus C2–C7 angle (°)		
Postop. minus Preop.		0.282
C2–C7 SVA (mm)		
Preop.		0.419
Postop.		0.778
Cervical ROM (°)		
Preop.		0.643
Postop.		0.942

RR recovery rate, *JOA* Japanese Orthopedic Association, *SVA* sagittal vertical axis, *ROM* range of motion

T1 slope minus C2–C7 angle is considered the cervical analog to the pelvic incidence minus lumbar lordosis mismatch [8, 18]. A higher T1 slope minus C2–C7 angle indicates uncompensated cervical alignment or a kyphotic cervical spine [8, 18]. In this study, group NH experienced postoperative decreases in C7 slope minus C2–C7 angle, suggesting that the cervical alignment was well compensated after surgery. A postoperative kyphotic change in C2–C7 angle affected change in C7 slope minus C2–C7 angle, which increased postoperatively in extremely high C7 slope patients. The limited cervical lordotic compensation in group EH caused these postoperative increases in cervical sagittal alignment mismatch.

In this study, slightly worse functional recovery was observed in group EH. Whether surgical decompression of CCM is equally effective for patients of all ages remains under debate; some studies reported that older patients have a lower RR of JOA score [19, 20] while other studies did not [21, 22]. Since group EH included more elderly subjects, we conducted a multiple linear regression analysis of RR of JOA score. The results indicated that the lower RR of JOA score in group EH resulted from the preoperative extremely high C7 slope, not from the advanced age. The C7 slope should be assessed during the evaluation of surgical outcomes for SL, especially among elderly patients. Sielatycki et al. reported that creating greater lordosis and decreasing C2–C7 SVA by cervical fixation surgery (CFS) were not associated with improved myelopathy and health-related quality of life (HRQOL) in patients with non-kyphosis [23]. Since we did not directly compare SL and CFS, it was difficult to conclude whether CFS improved the surgical outcomes of group EH. CFS is generally considered a more invasive surgery than posterior cervical decompression without fixation [24, 25]. Since group EH included more elderly subjects, the surgical

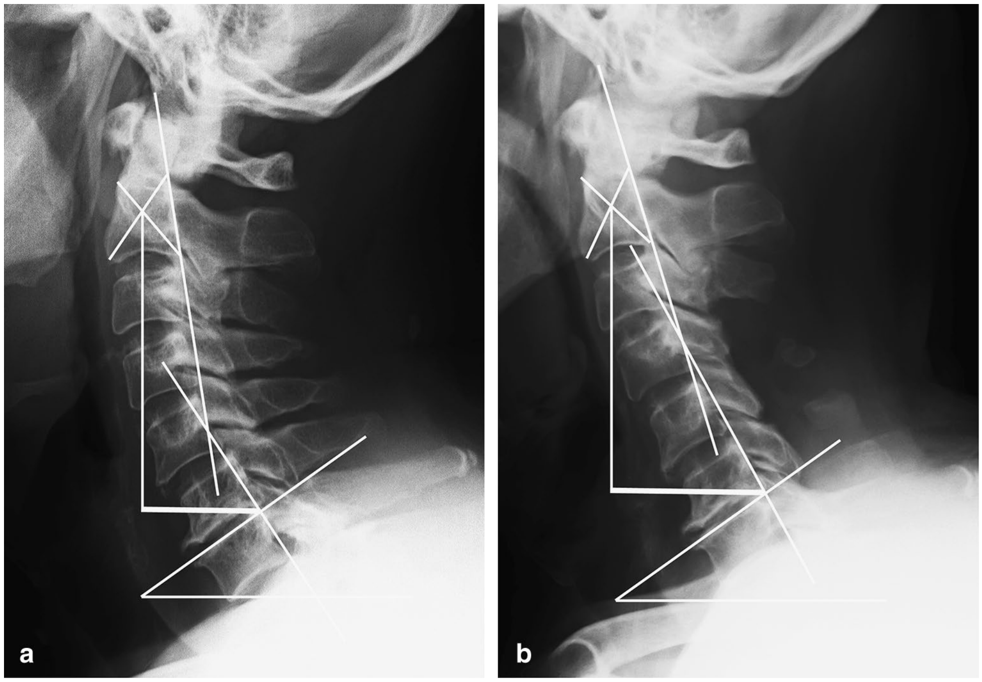

Fig. 2 Case presentation. A 74-year-old man underwent a C4–C6 selective laminectomy. **a** Preoperative C2–C7 angle, C7 slope, C7 slope minus C2–C7 angle, and C2–C7 SVA were 23.6°, 35.4°, 11.8°, and 28.8 mm, respectively (group EH). **b** Two years and 1 month after surgery, C2–C7 angle, C7 slope, C7 slope minus C2–C7 angle, and C2–C7 SVA were 11.2°, 35.3°, 24.1°, and 37.6 mm, respectively. Note that kyphotic alignment change (− 12.4°), postoperative increase in C2–C7 SVA (+ 8.8 mm), and C7 slope minus C2–C7 angle (+ 12.3°) were observed

procedure should be carefully considered according to each patient's age, general condition, complications, and social factors.

The current study is limited in several ways. First, it was retrospective, making selection bias unavoidable. Second, due to the small number of patients, several confounding factors may have influenced the results. Third, radiography of the entire spine was not performed, so we could not evaluate the relationship between cervical parameters and thoracolumbar or spinopelvic parameters. Since we did not acquire the patients' HRQOL outcomes, we could not examine the influence of a high C7 slope. Prospective studies with larger populations that include radiography of the entire spine and HRQOL are required to evaluate the full influence of high C7 slope on surgical outcomes after SL.

Conclusion

Older patients with an extremely high preoperative C7 slope ($\geq 30°$) whose cervical sagittal alignment was highly compensated preoperatively demonstrated postoperative increases in cervical sagittal balance mismatch. An extremely high preoperative C7 slope limited the compensatory cervical lordosis after SL.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

Funding This study had no funding source.

Ethical approval This article does not involve any studies with human participants performed by any of the authors.

Informed consent Informed consent was obtained from all participants included in the study.

References

1. Tang JA, Scheer JK, Smith JS, Deviren V, Bess S, Hart RA, Lafage V, Shaffrey CI, Schwab F, Ames CP (2012) The impact of standing regional cervical sagittal alignment on outcomes in posterior cervical fusion surgery. Neurosurgery 71:662–669. https://doi.org/10.1227/neu.0b013e31826100c9 **(discussion 669)**
2. Oe S, Togawa D, Nakai K, Yamada T, Arima H, Banno T, Yasuda T, Kobayasi S, Yamato Y, Hasegawa T, Yoshida G, Matsuyama Y (2015) The influence of age and sex on cervical spinal alignment among volunteers aged over 50. Spine (Phila

Pa 1976) 40:1487–1494. https://doi.org/10.1097/brs.0000000000001071
3. Protopsaltis TS, Scheer JK, Terran JS, Smith JS, Hamilton DK, Kim HJ, Mundis GM Jr, Hart RA, McCarthy IM, Klineberg E, Lafage V, Bess S, Schwab F, Shaffrey CI, Ames CP (2015) How the neck affects the back: changes in regional cervical sagittal alignment correlate to HRQOL improvement in adult thoracolumbar deformity patients at 2-year follow-up. J Neurosurg Spine 23:153–158. https://doi.org/10.3171/2014.11.spine1441
4. Knott PT, Mardjetko SM, Techy F (2010) The use of the T1 sagittal angle in predicting overall sagittal balance of the spine. Spine J 10:994–998. https://doi.org/10.1016/j.spinee.2010.08.031
5. Nunez-Pereira S, Hitzl W, Bullmann V, Meier O, Koller H (2015) Sagittal balance of the cervical spine: an analysis of occipitocervical and spinopelvic interdependence, with C-7 slope as a marker of cervical and spinopelvic alignment. J Neurosurg Spine 23:16–23. https://doi.org/10.3171/2014.11.spine14368
6. Kim TH, Lee SY, Kim YC, Park MS, Kim SW (2013) T1 slope as a predictor of kyphotic alignment change after laminoplasty in patients with cervical myelopathy. Spine (Phila Pa 1976) 38:E992–E997. https://doi.org/10.1097/brs.0b013e3182972e1b
7. Nori S, Shiraishi T, Aoyama R, Ninomiya K, Yamane J, Kitamura K, Ueda S (2017) Muscle-preserving selective laminectomy maintained the compensatory mechanism of cervical lordosis after surgery. Spine (Phila Pa 1976). https://doi.org/10.1097/brs.0000000000002359
8. Kim B, Yoon DH, Ha Y, Yi S, Shin DA, Lee CK, Lee N, Kim KN (2016) Relationship between T1 slope and loss of lordosis after laminoplasty in patients with cervical ossification of the posterior longitudinal ligament. Spine J 16:219–225. https://doi.org/10.1016/j.spinee.2015.10.042
9. 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 (Phila Pa 1976) 37:E286–E296. https://doi.org/10.1097/brs.0b013e318239cc7e
10. Ames CP, Blondel B, Scheer JK, Schwab FJ, Le Huec JC, Massicotte EM, Patel AA, Traynelis VC, Kim HJ, Shaffrey CI, Smith JS, Lafage V (2013) Cervical radiographical alignment: comprehensive assessment techniques and potential importance in cervical myelopathy. Spine (Phila Pa 1976) 38:S149–S160. https://doi.org/10.1097/brs.0b013e3182a7f449
11. Chen Y, Luo J, Pan Z, Yu L, Pang L, Zhong J, Li Z, Han Z, Cao K (2017) The change of cervical spine alignment along with aging in asymptomatic population: a preliminary analysis. Eur Spine J. https://doi.org/10.1007/s00586-017-5209-1
12. White AA 3rd, Johnson RM, Panjabi MM, Southwick WO (1975) Biomechanical analysis of clinical stability in the cervical spine. Clin Orthopaed Relat Res 109:85–96
13. Fujimori T, Iwasaki M, Okuda S, Takenaka S, Kashii M, Kaito T, Yoshikawa H (2014) Long-term results of cervical myelopathy due to ossification of the posterior longitudinal ligament with an occupying ratio of 60% or more. Spine (Phila Pa 1976) 39:58–67. https://doi.org/10.1097/brs.0000000000000054
14. Nori S, Aoyama R, Ninomiya K, Yamane J, Kitamura K, Ueda S, Shiraishi T (2017) Cervical laminectomy of limited width prevents postoperative C5 palsy: a multivariate analysis of 263 muscle-preserving posterior decompression cases. Eur Spine J. https://doi.org/10.1007/s00586-017-5202-8
15. Hirabayashi K, Miyakawa J, Satomi K, Maruyama T, Wakano K (1981) Operative results and postoperative progression of ossification among patients with ossification of cervical posterior longitudinal ligament. Spine (Phila Pa 1976) 6:354–364
16. Sakai K, Yoshii T, Hirai T, Arai Y, Torigoe I, Tomori M, Sato H, Okawa A (2016) Cervical sagittal imbalance is a predictor of kyphotic deformity after laminoplasty in cervical spondylotic myelopathy patients without preoperative kyphotic alignment. Spine (Phila Pa 1976) 41:299–305. https://doi.org/10.1097/brs.0000000000001206
17. Sakai K, Yoshii T, Hirai T, Arai Y, Shinomiya K, Okawa A (2017) Impact of the surgical treatment for degenerative cervical myelopathy on the preoperative cervical sagittal balance: a review of prospective comparative cohort between anterior decompression with fusion and laminoplasty. Eur Spine J 26:104–112. https://doi.org/10.1007/s00586-016-4717-8
18. Ames CP, Smith JS, Eastlack R, Blaskiewicz DJ, Shaffrey CI, Schwab F, Bess S, Kim HJ, Mundis GM Jr, Klineberg E, Gupta M, O'Brien M, Hostin R, Scheer JK, Protopsaltis TS, Fu KM, Hart R, Albert TJ, Riew KD, Fehlings MG, Deviren V, Lafage V (2015) Reliability assessment of a novel cervical spine deformity classification system. J Neurosurg Spine 23:673–683. https://doi.org/10.3171/2014.12.spine14780
19. Zhang P, Shen Y, Zhang YZ, Ding WY, Wang LF (2011) Significance of increased signal intensity on MRI in prognosis after surgical intervention for cervical spondylotic myelopathy. J Clin Neurosci 18:1080–1083. https://doi.org/10.1016/j.jocn.2010.12.023
20. Zhang YZ, Shen Y, Wang LF, Ding WY, Xu JX, He J (2010) Magnetic resonance T2 image signal intensity ratio and clinical manifestation predict prognosis after surgical intervention for cervical spondylotic myelopathy. Spine (Phila Pa 1976) 35:E396–E399. https://doi.org/10.1097/brs.0b013e3181c6dbc4
21. Iwasaki M, Okuda S, Miyauchi A, Sakaura H, Mukai Y, Yonenobu K, Yoshikawa H (2007) Surgical strategy for cervical myelopathy due to ossification of the posterior longitudinal ligament: Part 1: clinical results and limitations of laminoplasty. Spine (Phila Pa 1976) 32:647–653. https://doi.org/10.1097/01.brs.0000257560.91147.86
22. Yamazaki T, Yanaka K, Sato H, Uemura K, Tsukada A, Nose T (2003) Cervical spondylotic myelopathy: surgical results and factors affecting outcome with special reference to age differences. Neurosurgery 52:122–126 **(discussion 126)**
23. Sielatycki JA, Armaghani S, Silverberg A, McGirt MJ, Devin CJ, O'Neill K (2016) Is more lordosis associated with improved outcomes in cervical laminectomy and fusion when baseline alignment is lordotic? Spine J 16:982–988. https://doi.org/10.1016/j.spinee.2016.04.009
24. 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) 26:1330–1336
25. Varthi AG, Basques BA, Bohl DD, Golinvaux NS, Grauer JN (2016) Perioperative outcomes after cervical laminoplasty versus posterior decompression and fusion: analysis of 779 patients in the ACS-NSQIP Database. Clin Spine Surg 29:E226–E232. https://doi.org/10.1097/bsd.0000000000000183

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