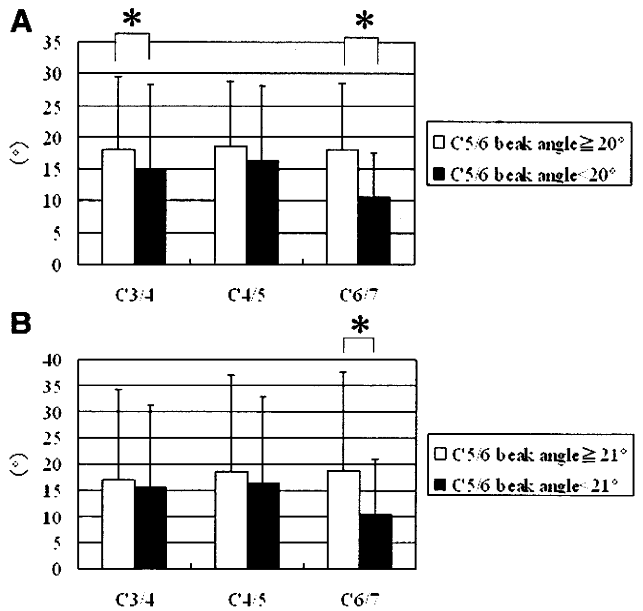

Figure 5. Comparison of beak angle at each intervertebral level in cases grouped by C5/6 cut-off value. **A**, Intraoperative US. **B**, Postoperative MRI. Bars indicate mean ± SD. *$P < 0.05$.

beak angle was more or less than the cut-off value, and were compared at each intervertebral level. When all 101 cases were divided by the cut-off value for spinal cord floating in intraoperative US (20°), the beak angles at C3/4 and C6/7 differed significantly between the 2 groups. The average beak angle at C3/4 for cases with a C5/6 beak angle ≥20° was 18.0° ± 11.6° and that for cases with a C5/6 beak angle <20° was 15.0° ± 13.5°; this difference was statistically significant (P = 0.039; Figure 5A). The average beak angle at C6/7 for cases with a C5/6 beak angle ≥20° was 8.0° ± 10.7° and that for cases with a C5/6 beak angle <20° was 10.6° ± 6.9°; this difference was statistically significant (P = 0.0006; Figure 5A). When all 99 cases were divided by the cut-off value for spinal cord floating in postoperative MRI (21°), the beak angle at C6/7 differed significantly between the groups. The average beak angle at C6/7 for cases with a C5/6 beak angle ≥20 was 18.8° ± 10.7° and that for cases with a C5/6 beak angle <20° was 10.5° ± 6.8°; this difference was statistically significant (P = 0.0139; Figure 5B).

Association Between Clinical Outcome and Spinal Cord Floating or Other Parameters

The JOA score recovery rate for the 75 cases at each follow-up session was 37.3% ± 27.8% at 1 month, 45.1% ± 26.7% at 6 months, and 40.4% ± 30.8% at 1 year after the operation. The preoperative JOA score was a significant parameter for a JOA score recovery rate of ≥50% at 1 month (P < 0.0001, OR = 2.411, 95% CI 1.560–3.727), 6 months (P = 0.0013, OR = 1.672, 95% CI 1.222–2.288), and 1 year (P = 0.0093, OR = 1.369, 95% CI 1.080–1.674; Table 5). Complete spinal cord floating in intraoperative US was a significant parameter 1 year after the operation (P = 0.0017, OR = 5.067, 95% CI 1.839–13.956). Multivariant logistic analysis revealed both preoperative JOA score (P = 0.0004, OR = 10.323, 95% CI 2.811–37.916) and complete spinal cord floating in intraoperative US (P = 0.0019, OR = 1.645, 95% CI 1.202–2.252) to be significant predictive parameters for a recovery rate of ≥50% at 1 year after the operation (Table 5).

Table 5. Significant Parameters for Clinical Outcome (Recovery Rate of JOA Score ≥50%)

	Follow-up Period	P	OR	95% CI
Monovariant				
Spinal cord-floating from anterior elements on US	1 mo	0.7784	0.861	0.304–2.440
	6 mo	0.1786	2.012	0.726–5.573
	1 yr	0.0017*	5.067	1.839–13.956
Spinal cord-floating from anterior elements on MRI	1 mo	0.6637	0.792	0.276–2.270
	6 mo	0.2139	0.522	0.187–1.456
	1 yr	0.8696	1.086	0.407–2.898
C2–C7 lordotic angle	1 mo	0.2875	0.980	0.943–1.018
	6 mo	0.9901	1.000	0.965–1.036
	1 yr	0.6132	1.009	0.975–1.043
Local kyphosis (+)	1 mo	0.1458	0.444	0.149–1.326
	6 mo	0.9371	0.960	0.351–2.626
	1 yr	0.8788	0.929	0.359–2.401
Age	1 mo	0.2474	0.976	0.936–1.017
	6 mo	0.5403	0.987	0.946–1.029
	1 yr	0.7619	0.994	0.957–1.033
Gender	1 mo	0.5236	1.500	0.431–5.215
	6 mo	0.2401	0.516	0.171–1.556
	1 yr	0.3076	0.571	0.195–1.674
Preoperative JOA score	1 mo	<0.0001*	2.411	1.560–3.727
	6 mo	0.0013*	1.672	1.222–2.288
	1 yr	0.0093*	1.369	1.080–1.734
C3/4 beak angle	1 mo	0.2216	0.972	0.930–1.017
	6 mo	0.8132	1.005	0.965–1.046
	1 yr	0.3023	1.022	0.981–1.065
C4/5 beak angle	1 mo	0.1257	0.964	0.920–1.010
	6 mo	0.7710	1.007	0.963–1.051
	1 yr	0.7257	1.007	0.967–1.050
C5/6 beak angle	1 mo	0.9540	1.001	0.958–1.046
	6 mo	0.4167	1.018	0.975–1.063
	1 yr	0.3545	0.981	0.941–1.022
C6/7 beak angle	1 mo	0.9224	1.003	0.953–1.055
	6 mo	0.9623	1.001	0.953–1.052
	1 yr	0.6981	0.991	0.944–1.039
Multivariant				
Spinal cord-floating from anterior elements on US	1 yr	0.0004*	10.323	2.811–37.916
Preoperative JOA score	1 yr	0.0019*	1.645	1.202–2.252

*$P < 0.05$.

■ Discussion

Few previous reports have discussed the predictive value of intraoperative US for the clinical outcome of spinal surgery.[4,10,11] This is particularly true for predictive preoperative parameters of spinal cord floating status after cervical laminoplasty, and for comparisons between intraoperative US and postoperative MRI.[11]

Spinal cord floating at the anterior elements of the spine after posterior decompression might affect the clinical outcome; however, the association between spinal cord floating status and clinical outcome has remained controversial.[3,10] Both intraoperative US and postoperative MRI are performed without adjusting the neutral alignment of the cervical spine in each case; therefore, further reports are required to evaluate the predictive efficacy of these techniques.

In the current study, spinal cord floating after posterior decompression was demonstrated to be valuable for predicting clinical outcome. However, its significance was detected only 1 year after the operation. Spinal cord recovery after decompression is often relatively slow, which could explain this result.

Morphology of the spinal cord in the axial view was not evaluated in the current study. A previous work reported an association between clinical outcome and spinal cord morphology after posterior decompression.[4,11] Although it could be useful to evaluate spinal cord morphology, it is difficult to classify and to assess morphology accurately without bias. Therefore, we evaluated the presence or absence of spinal cord floating in intraoperative US and postoperative MRI.

Few previous reports have compared imaging parameters between intraoperative US and postoperative MRI.[11,12] In the current study, the rate of coincidence of the spinal cord floating status was relatively poor (64.6%). Most cases with differing results for intraoperative US and postoperative MRI were CF-US (−)/CF-MRI (+). Conversely, postoperative MRI tended to produce "false-positive" results for the evaluation of spinal cord floating status. One explanation is that MRI was performed in the supine position, so the weight of the spinal cord might have caused it to shift and separate from the anterior elements of the spine. Another possibility is that the height of the head rest used in MRI increased lordosis, especially in older patients whose whole spine alignment was often kyphotic, thereby enhancing the posterior shift of the spinal cord. Furthermore, the dynamics of the spinal cord can be visualized with intraoperative US, which might allow the spinal cord floating status to be evaluated more precisely than with postoperative MRI.

The C2–C7 lordotic angle was shown to be a significant parameter for spinal cord floating in intraoperative US only when all 101 cases were analyzed. Increasing lordosis could result in enhancement of the posterior shift of the spinal cord after posterior decompression. However, the alignment of the cervical spine was not under fluoroscopic control. Our result suggested that the preoperative neutral alignment of the cervical spine could be a significant predictive parameter for spinal cord floating status in intraoperative US without the precise reproduction of alignment. It was not clear why the analysis of the postoperative MRI results did not demonstrate significance of the C2–C7 lordotic alignment. However, 1 explanation is that MRI was performed using the same head rest in all patients, which might have generated a greater change of alignment than intraoperative US in each patient.

The C2–C7 lordotic angle was not a significant parameter for clinical outcome. A previous study reported that kyphosis of >13° resulted in a poor clinical outcome of cervical laminoplasty.[13] However, several other reports demonstrated no association between sagittal alignment and clinical outcome in cervical laminoplasty.[14,15] The current study suggested that C2–C7 sagittal alignment was a predictive parameter only for spinal cord floating status, and was not directly associated with clinical outcome.

The significance of the C5/6 beak angle in both intraoperative US and postoperative MRI, even when cases with failure of spinal cord floating at other intervertebral levels were included, was unexpected. The beak angle at other intervertebral levels also showed significance for individual lesions in the individual analysis. This suggested that the beak angle was an important predictor for spinal cord floating status, even though there were some exceptions. Furthermore, we certified the beak angle to be a useful parameter that could represent both the local alignment and the degree of the protrusion of the anterior element of the spine. When the cases were divided into 2 groups according to the cut-off value of the C5/6 beak angle for spinal cord floating status, the beak angles at other intervertebral levels tended to increase in cases with a C5/6 beak angle larger than the cut-off value. One explanation for this is that the C5/6 beak angle might represent the degree of other beak angles at other intervertebral levels, at least partially. Particularly in spondylotic cases, it was possible that degenerative change at each intervertebral level might advance to a similar degree. The average C5/6 beak angle in this research was larger than that of any other intervertebral level, and the C5/6 was apex of lordosis of cervical spine generally, which might have had some influence on our results.

The preoperative JOA score was a significant parameter for clinical outcome at all follow-up time points. A previous study reported that preoperative neurologic status affected clinical outcome.[16] This could be attributable to the fact that the functional recovery of the spinal cord depends on the irreversible change. It was noteworthy that the spinal cord floating in intraoperative US was a predictive parameter for clinical outcome in the individual analysis; this indicated that its strength as a predictive factor was not affected by the preoperative JOA score, which was another strong predictor.

Intraoperative US is a simple and noninvasive imaging technique. Our study shows that intraoperative US evaluation can predict clinical results without alignment control by fluoroscopic methods. Moreover, the identification of parameters that predict the spinal cord floating status in intraoperative US might help to predict the limitations of posterior decompression.

■ Conclusion

Significant predictive parameters for spinal cord floating status were C2–C7 lordotic angle (cut-off value = 3°) and C5/6 beak angle (cut-off value = 20°) in intraoperative US, and C5/6 beak angle (cut-off value = 21°) in postoperative MRI. Significant parameters for clinical outcome were preoperative neurologic status and spinal cord floating status in intraoperative US.

■ Key Points

- The predictive parameters for the floating status of the spinal cord at the anterior elements of the cervical spine in both intraoperative ultrasonography (US) and postoperative magnetic resonance imaging (MRI) were investigated.
- The association between clinical outcome and floating status of the spinal cord in imaging also evaluated.
- Statistically significant parameters for spinal cord floating in intraoperative US were the cervical vertebrae 2 to 7 sagittal alignment in the standing neutral position on preoperative plain radiograph radiography and C5/6 "beak angle" in preoperative MRI.
- The preoperative JOA score and spinal cord floating at anterior elements of the cervical spine in intraoperative US were predictive parameters for clinical outcome.
- Intraoperative US was more useful than postoperative MRI for predicting the clinical outcome of cervical expansive laminoplasty.

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Technical Note

Anterior pedicle screw fixation for multilevel cervical corpectomy and spinal fusion

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Summary

Background. Prevention of graft dislodgement in multilevel cervical corpectomy and fusion has been an unresolved problem. Anterior plate fixation has a significant failure rate. External support with a halo-vest is uncomfortable for patients. In the present study, we report a new surgical technique of anterior pedicle screw (APS) fixation for multilevel cervical corpectomy and spinal fusion, and describe the safety and utility of the system.

Method. After cervical corpectomy, the pedicles on the right side were visualised under oblique fluoroscopy. Guide wires were inserted into the pedicles from the inner wall of the excavated vertebral body until they were hidden in the pedicles. After a fibula autograft was placed, the graft was penetrated in the reverse direction by the guide wires. After drilling and tapping, cannulated screws were inserted into the pedicles through the grafted fibula along the guide wires.

Findings. In 9 patients with cervical myelopathy, the surgery was accomplished with a fibula autograft using APS fixation. A total of 22 APSs were inserted, and 21 screws were placed precisely in the pedicles. There were no neurovascular complications. Patients were allowed to ambulate without a halo-vest on the second day after the surgery. Post-operatively, no dislodgement of the grated fibula occurred, and all patients improved neurologically.

Conclusions. The insertion of APSs is feasible and safe. APS fixation enables us to obtain rigid fixation anteriorly, and we propose that APS fixation is an attractive option for multilevel cervical corpectomy and fusion.

Keywords: Pedicle screw; anterior surgery; cervical spine; corpectomy; vertebral artery.

Introduction

Previous reports have shown that surgical outcomes of multilevel cervical corpectomy with spinal fusion are superior to those of laminoplasty in patients with cervical myelopathy, especially when the alignment of the cervical spine is kyphotic, and the spinal cord is severely compressed anteriorly [16, 20, 25, 26, 29].

Previous studies have shown that such problems as post-operative neck pain and stiffness, are less prominent after multilevel cervical corpectomy with spinal fusion when compared with those after laminoplasty [8, 15, 28].

Despite pre-operative information showing good surgical outcomes associated with anterior surgery, many patients (especially elderly patients) have selected posterior surgery [20]. The major reason for this selection is that the post-operative course of anterior surgery is often complicated. In particular, prevention of graft dislodgement in multilevel cervical corpectomy with spinal fusion has been an unresolved problem. Anterior plate fixation has a significant failure rate [5, 23, 27]. External

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support with a halo-vest decreases the dislodgement of the grafted bone, but application of the support is uncomfortable for patients [20]. Anterior and posterior plate fixation increases the stability of the constructs [6, 24], but requires a longer anaesthesia and is very laborious, including a change of the patient's surgical position.

We previously reported data showing the safety of anterior pedicle screw (APS) insertion in the cervical spine in an experimental study using cadavers (presented at the 19th annual meeting of the Cervical Spine Research Society-European Section, 2004). Based on those results, we began investigating the clinical application of APS fixation for multilevel cervical corpectomy with spinal fusion. In the present study, we describe the operative technique of APS fixation and report on its outcome.

Materials and methods

Patient population

From June 2004 to June 2006, 9 patients with cervical compression myelopathy underwent multilevel cervical corpectomy and spinal fusion with an autologous fibula graft using APSs (Table 1). The patients included 7 males and 2 females (average age at time of surgery = 56.3 years; range, 40–71 years). The average follow-up period was 16 months (range, 6–25 months). The cause of myelopathy were classified as ossification of the posterior longitudinal ligament (OPLL) in 4 patients, cervical spondylotic amyotrophy in 2, multilevel cervical disc herniation in 2, and cervical disc herniation accompanied by canal stenosis in the other patient. The fusion level was C3–C7 in 4 patients, C4–C7 in 3, C3–C6 in 1, and C5-T1 in 1.

Surgical technique of anterior pedicle screw fixation

As a representative example, we describe the surgical procedures for a patient (Number 3, Table 1), who underwent corpectomy of C5 and C6 and a fibula autograft fixed with APSs through the right C5 and C6 pedicles. The patient was placed in the supine position, and the patient's head was fixed with Mayfield's three pin system. With the patient in this position, we could obtain enough working space for surgery at the patient's nuchal area. Draping was performed so that the anterior and posterior aspects of the patient's neck were contained to the operative field.

Pre-operatively, we set the fluoroscopy angle at approximately 45° oblique to the floor and along the axis of the pedicles of C5 and C6. With such oblique fluoroscopy, we could detect the round-shaped cortex of the C5 and C6 pedicles on the right side of the cervical spine clearly.

A transverse collar incision of approximately 8 cm was made at the left side of the neck. The surgical approach extended along the esophagus and left carotid sheath, and the anterior aspect of the cervical vertebrae was exposed. After discectomy of C4/5, C5/6 and C6/7, cervical corpectomy of C5 and C6 was performed. Decompression of the spinal cord was confirmed by intraoperative spinal ultrasonography.

At the caudal aspect of C4 and the cranial aspect of C7, the endplate was removed by an air drill, and a graft bed for the strut fibula was prepared. The length required for the strut bone was measured. A piece of the left fibula was harvested from the patient's leg and prepared as a free strut graft to the site of corpectomy.

The right C6 pedicle was visualised under oblique fluoroscopy. A guide wire, with both ends sharpened, was inserted into the pedicle from the inner wall of

Table 1. *Summary of data for 9 patients who underwent surgery with anterior pedicle screw fixation*

Case no.	Age (y)/ gender	Diagnosis	Fusion level	APS level	Follow-up period (mo)	JOA score		Solid graft union/period (mo)
						Before surgery	At follow-up	
1	44/M	OPLL	C4–C7	C5, C6	25	7.5	15	yes (12)
2	50/F	CDH&CS	C3–C6	C4, C5	24	12	16.5	yes (9)
3	64/M	CSAM	C4–C7	C5, C6	24	14.5	15.5	yes (14)
4	48/M	OPLL	C3–C7	C4, C5*, C6	18	1	7.5	yes (15)
5	40/M	MCDH	C4–C7	C5, C6	18	n.d.	n.d.	yes (12)
6	71/F	MCDH	C5–Th1	C6, C7	12	6	12	yes (12)
7	57/M	CSAM	C3–C7	C4, C5, C6	12	13	17	not yet
8	66/M	OPLL	C3–C7	C4, C5, C6	9	8	13.5	not yet
9	67/M	OPLL	C3–C7	C4, C5, C6	6	13	15	not yet

APS Anterior pedicle screw, *JOA* Japanese Orthopaedic Association, *OPLL* ossification of the posterior longitudinal ligament, *CDH&CS* cervical disc herniation and canal stenosis, *CSAM* cervical spondylotic amyotrophy, *MCDH* multilevel cervical disc herniation, *n.d.* not detected.

* The screw penetrated the lateral wall of the pedicle.

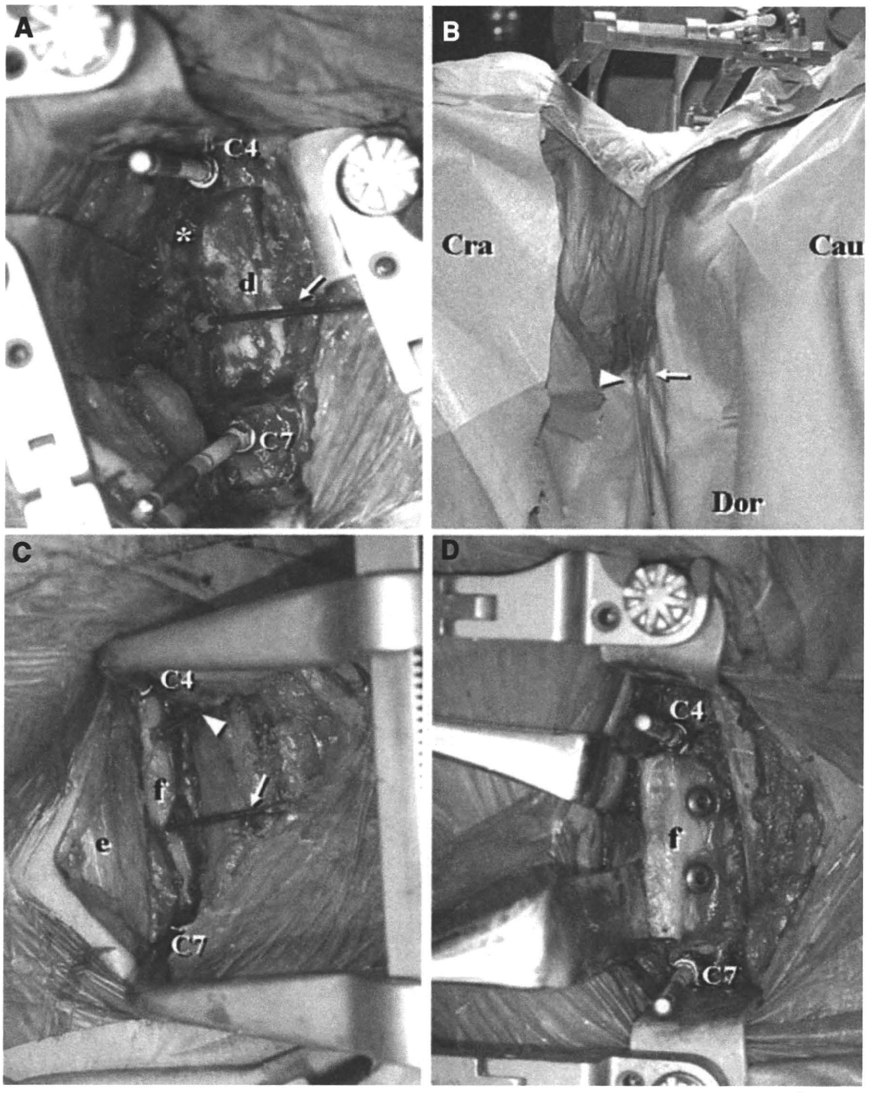

Fig. 1. Intra-operative photographs showing the process of anterior pedicle screw fixation for C5–C6 corpectomy and C4–C7 spinal fusion in a patient with cervical myelopathy (Patient 3). After corpectomy of C5 and C6, the right C6 pedicle was visualized under oblique fluoroscopy. (A) A guide wire (*arrow*) was inserted into the right C6 pedicle from the inner wall of the excavated vertebral body. The asterisk indicates the insertion point of the C5 pedicle screw. *d* Dura mater. (B) Guide wires were inserted deeply until they were hidden completely in the C5 and C6 pedicles. At this stage, the guide wires pass through the C5 pedicle (*arrowhead*) and the C6 pedicle (*arrow*) perforated the skin at the posterolateral area of the neck. The cranial side (*Cra*), caudal side (*Cau*) and dorsal side (*Dor*) of the patient are indicated. (C) After a fibula autograft (*f*) was placed, the graft was penetrated in the reverse direction by the guide wires through the C5 pedicle (*arrowhead*) and the C6 pedicle (*arrow*). *e* Esophagus. (D) After drilling and tapping, cannulated screws were inserted into the C5 and C6 pedicles through the grafted fibula (*f*) along the guide wires

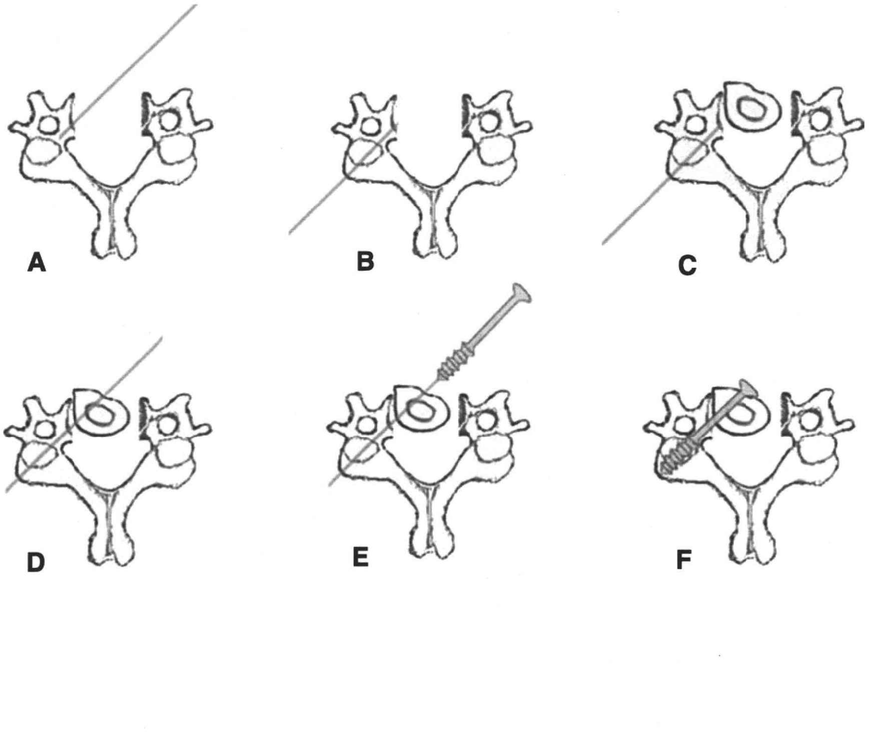

Fig. 2. Schematic drawings (A–F) showing the process of anterior pedicle screw fixation for multilevel cervical corpectomy and fusion

the excavated vertebral body under fluoroscopic guidance (Figs. 1A and 2A). It was inserted deeply, until it was hidden completely in the pedicle (Fig. 2B). At this stage, the guide wire perforated the skin at the posterolateral area of the neck (Fig. 1B). Another guide wire was placed similarly at the right C5 pedicle. The fibular autograft was tapped gently into place without interference by the guide wires (Fig. 2C). The graft was penetrated in the reverse direction by the guide wires (Figs. 1C and 2D). After drilling and tapping, a cannulated screw was inserted into the C6 pedicle through the graft along the guide wire (Fig. 2E, F). The length of the screw was determined pre-operatively by measuring the axial CT images. Similarly a screw was inserted at C5 (Fig. 1D).

On the second day after surgery, the patient was allowed to ambulate with a Philadelphia collar. At 6 weeks after surgery, a soft collar was used instead of the Philadelphia collar, and at 8 weeks after surgery, the soft collar was removed.

Clinical assessment

The Japanese Orthopaedic Association (JOA) scoring system was used to evaluate the severity of cervical myelopathy [20]. In 8 patients, the JOA scores before surgery and at the final follow-up after surgery were evaluated, and the recovery rate calculated. In patient 5, it was difficult to evaluate sensory and motor loss precisely, because the patient was mentally retarded.

Radiographic assessment

Accuracy of the insertion of the APSs was evaluated with CT reconstruction images. We determined that

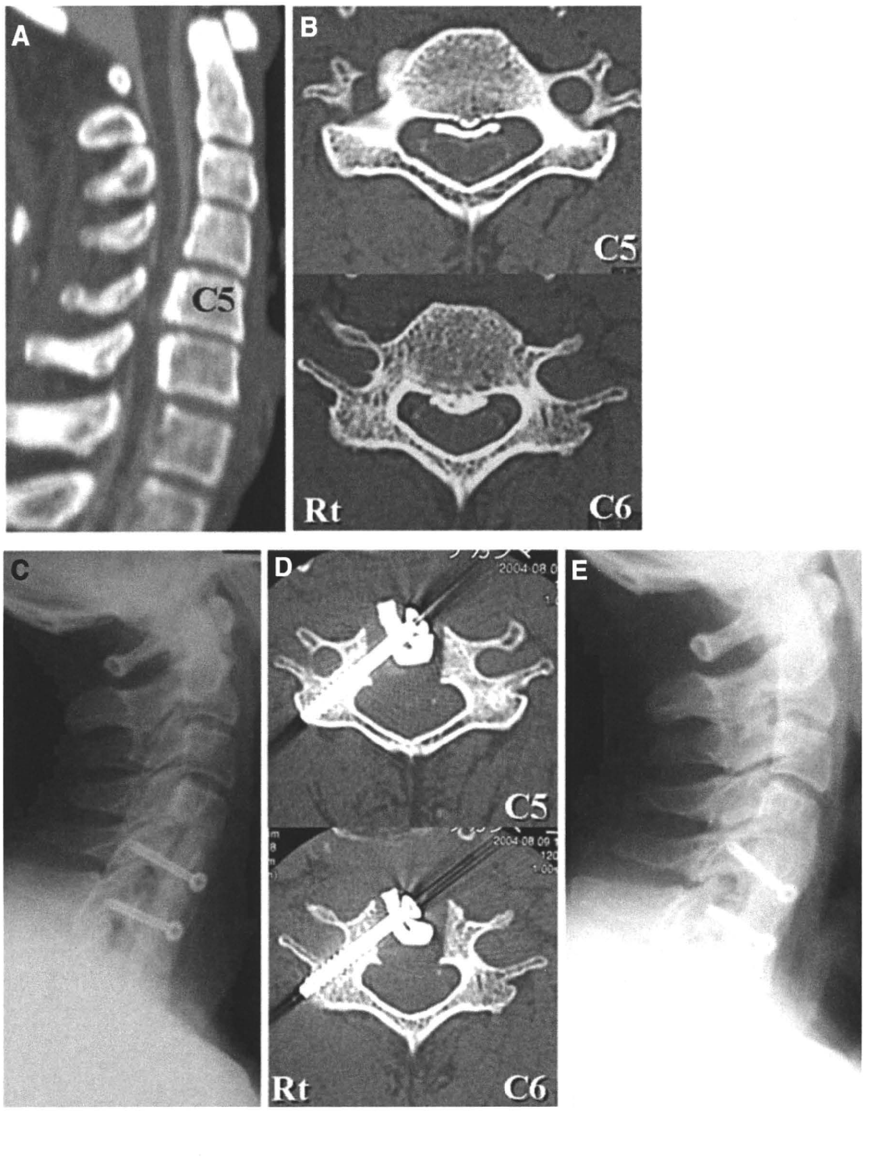

Fig. 3. Pre-operative midsagittal reconstruction image (A) and axial images at the C5 and C6 pedicles (B) of a CT myelogram of a 44-year-old man (Patient 1) showing OPLL at C4–C6 with compression of the spinal cord anteriorly at C5–C6. Post-operative lateral radiographic image (C) and axial views of CT (D) two weeks after surgery, indicating that the screws were inserted accurately through the grafted fibula autograft and the C5 and C6 pedicles. A lateral radiographic image two years after surgery (E), showing complete spinal fusion at C4–C7

the graft union was complete when intersegmental mobility within the fused segment was absent. A solid fusion was defined as ≤1 mm of change between flexion and extension radiographs in the interspinous distance across a grafted segment and by continuous osseous trabeculation at the site of the arthrodesis.

Results

A total of 22 APSs was inserted in this series. Among them, 21 screws were inserted precisely in the pedicles, and 1 screw perforated the lateral wall of the pedicle (C5 of patient 4). Thus, the pedicle perforation rate in this series was 4.5%. There were no neurovascular complications.

All 9 patients improved neurologically. The mean JOA score was 9.4 points before surgery and 14.0 points at the final follow-up, and the mean recovery rate was 64.4%.

There was no loosening or dislodgement of screws. No displacement of the grafted fibula occurred. Among 7 patients who were followed for more than 1 year after surgery, solid spinal fusion was detected in 6. The mean time to solid spinal fusion was 12.3 months (range, 9–15 months) after surgery.

Clinical presentations

Patient 1

A 44-year-old man presented with bilateral numbness in his upper and lower extremities and a spastic gait. The pre-operative JOA score was 7.5/17 points. Radiological examinations with CT myelogram and MR images showed C4–C6 OPLL associated with compression of the spinal cord anteriorly at C5–C6 (Fig. 3A, B).

At surgery, we first performed corpectomy of C5 and C6, extirpated the OPLL, and decompressed the spinal cord. We then harvested the fibula from his left leg and grafted it between C4 and C7. We inserted two APSs through the grafted fibula and the right C5 and C6 pedicles. Post-operative radiographs and CT images confirmed that the screws were inserted accurately through the pedicles (Fig. 3C, D), and no dislodgement of the grafted fibula was seen. At the final follow-up of 25 months, the patient's JOA score was 15/17 points (recovery rate: 79%), and complete spinal fusion was confirmed (Fig. 3E).

Patient 2

A 50-year-old woman presented with bilateral numbness and clumsiness in her hands. Her pre-operative JOA score was 12/17 points. Radiological examination with CT myelogram and MR images showed a central-type soft disc herniation at C4/5 and disc bulging at C5/6, which compressed the spinal cord anteriorly (Fig. 4A). She also had canal stenosis at the cervical spine; the anterior–posterior diameter of the spinal canal was 13 mm at C3, 12 mm at C4, 11.5 mm at C5, 13 mm at C6 and 13.5 mm at C7.

At operation, we first performed corpectomy of C4 and C5, extirpated the herniated discs, and decom-

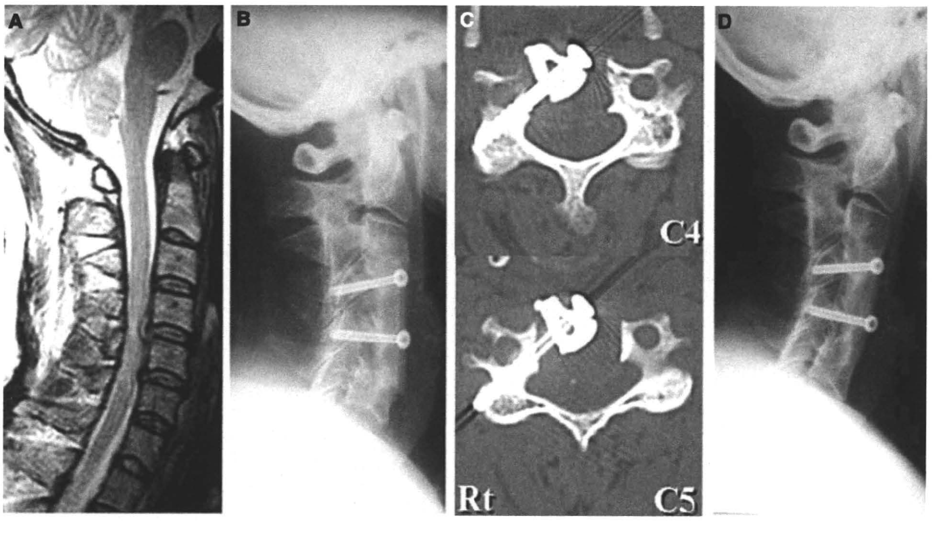

Fig. 4. Pre-operative T2-weighted MRI at the midsagittal plane (A) of a 50-year-old woman (patient 2) showing soft disc herniation at C4/5 and disc bulging at C5/6, which compressed the spinal cord anteriorly. Post-operative lateral radiographic image (B) and axial views of CT (C) two weeks after surgery, indicating that the screws were inserted accurately through the grafted fibula autograft and at the C4 and C5 pedicles. A lateral radiographic image two years after surgery (D), indicating that spinal fusion with the fibula autograft was complete at C3–C6

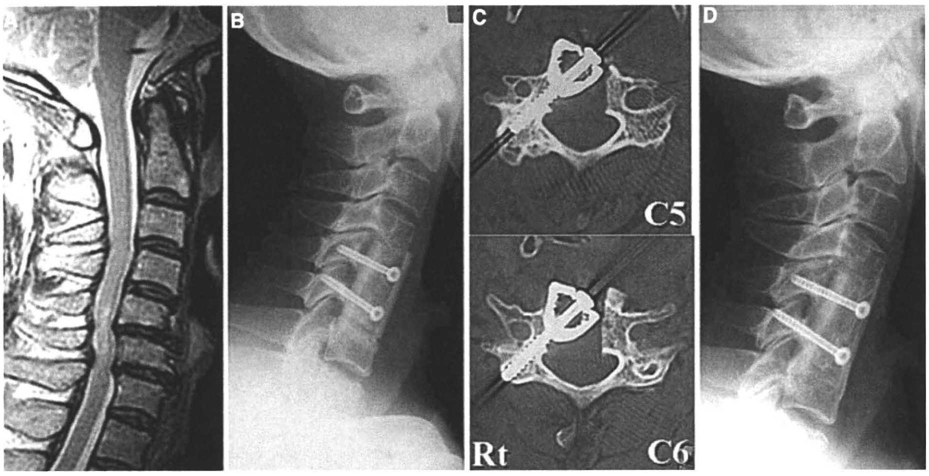

Fig. 5. Pre-operative T2-weighted MRI at the midsagittal plane (A) of a 64-year-old man (Case 3) showing osteophytes at C5/6 and C6/7, which compressed the spinal cord anteriorly. Post-operative lateral radiographic image (B) and axial views of CT (C) two weeks after surgery, indicating that the screws were inserted accurately through the grafted fibula autograft and the C5 and C6 pedicles. A lateral radiographic image two years after surgery (D), indicating that spinal fusion with the fibula autograft was complete at C4–C7

pressed the spinal cord. We then harvested the fibula from the left leg and grafted it between C3 and C6. We inserted two APSs through the grafted fibula and the right C4 and C5 pedicles. Post-operative radiographs and CT images confirmed that the screws were inserted accurately through the fibula autograft and the pedicles (Fig. 4B, C). At the final follow-up of 24 months, the patient's JOA score was 16.5/17 points (recovery rate: 90%), and complete spinal fusion was completed with an adequate alignment of the cervical spine (Fig. 4D).

Patient 3

A 64 year old man presented with muscle weakness and dysaesthesiae of his right upper extremity. His pre-operative JOA score was 14.5/17 points. Radiological examination with CT myelogram and MR images showed instability at C4/5 and osteophytes at C5/6 and C6/7, which compressed the spinal cord anteriorly (Fig. 5A).

At surgery, we first performed corpectomy of C5 and C6, extirpated the osteophytes and decompressed the spinal cord. We then harvested the fibula from his left leg and grafted it between C4 and C7. We inserted two APSs through the grafted fibula and the right C5 and C6 pedicles. Post-operative radiographs and CT images confirmed that the screws were inserted accurately through the pedicles (Fig. 5B, C). At the final follow-up of 24 months, the patient's JOA score was 15.5/17 points (recovery rate: 40%), and complete spinal fusion was confirmed without any dislodgement of the grafted fibula (Fig. 5D).

Discussion

Pedicle screws are useful tools for posterior fixation of the cervical spine [1–3]. The insertion of pedicle screws, however, has the potential risk of screw misplacement that causes damage to the spinal cord, nerve roots, or vertebral artery [4]. Previous studies have shown that the ratio of correct placement of ordinary posterior pedicle screws at the cervical spine ranges from 12.5 to 97% [4, 12–14, 18, 19, 21, 22]. Abumi *et al.* reported that the misplacement ratio of cervical posterior pedicle screws was 6.7% in their series (45 of 669 screws) [4]. Neo *et al.* inserted 86 pedicle screws in degenerative cervical vertebrae from the posterior direction, and 25 of them (29%) breached the pedicle walls [21].

In our APS fixation method, the vertebral artery is located at the lateral aspect of the entrance point, and the dura is directly visible in the surgical field. In addition, the ideal anterior entrance point of the APS can be identified using oblique fluoroscopy, which enables us to insert the APS into the pedicle accurately. When we compare the procedure for the placement of the APS with that of the posterior pedicle screw, the entrance point of the APS is closer to the pedicle (Fig. 6). Thus, the safety area at the insertion of the APS was larger than that of posterior pedicle screws. In fact, in the present series, 21 of 22 APSs were placed correctly in the pedicles, even though they were inserted into degenerative vertebrae. In this series, therefore, the misplacement ratio of APSs was 4.5%, which is principally lower than that of previously reported posterior pedicle screws [4, 21].

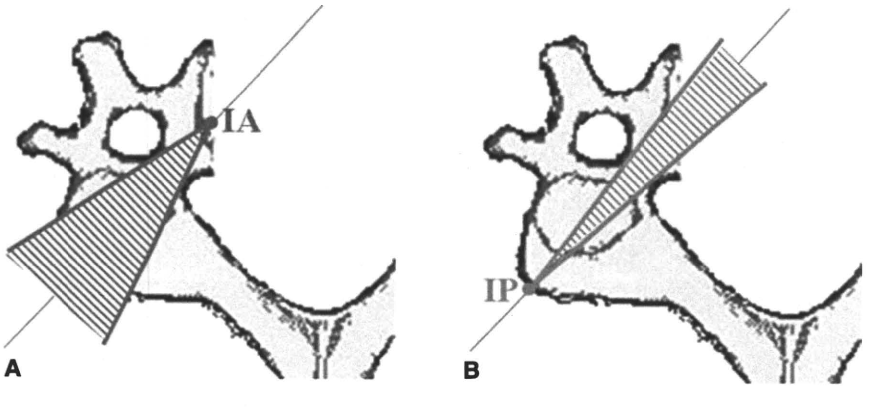

Fig. 6. Schematic drawings comparing the screw insertion points and the safety areas of the trajectory of an anterior pedicle screw (A) and a posterior pedicle screw (B). The safety area at the insertion of the anterior pedicle screw is larger than that of the posterior pedicle screw. The insertion points of the anterior (*IA*) and posterior (*IP*) pedicle screws are indicated

Fixation with an anterior plate and screws has several problems. The screws of the anterior construct are short and inserted monocortically to a vertebral body, which is sometimes made of fragile cancellous bone. Thus, anterior plating alone excessively loads the graft even with small degrees of motion, which may promote piston movement and failure of the anterior plate construct [7]. In particular, graft sinking is a major risk factor, which causes the failure of the anterior plate construct.

In contrast, fixation with APSs has several advantages. First, the pedicle is a strong anchor, even in osteoporotic patients [2]. Previous reports have proved biomechanical superiority of pedicle screws to conventional anterior and/or posterior cervical instrumentation methods [11, 17]. Another advantage is that the APS method does not fix the junction between the grafted bone and the vertebral body. This suggests that graft sinking does not reduce the stability of the construct.

Based on the considerations described above, we have begun clinical application of APS fixation. The present results showed that the insertion of APSs was safe, and no technical difficulty existed. Although a halo-vest was not applied post-operatively in this series, no dislodgement of the grafted fibula occurred. Graft sinking occurred to some extent during the follow-up period; however, bone union at the junction between the grafted fibula and the vertebral body progressed successfully. In this series, solid spinal fusion was detected 9–15 (mean 12.3) months after surgery. Previous reports showed that when multilevel cervical anterior fusion was performed with a fibular strut graft and post-operative halo-vest fixation, graft union was achieved at an average of 12 months after surgery [9, 10]. In the present series, the period for obtaining solid spinal fusion was almost the same as that in those previous reports. Thus, APS fixation can provide a rigid anterior fibula graft with minimum post-operative external support.

In conclusion, the present data demonstrates that insertion of APSs is feasible and safe. APS fixation could become a useful tool for obtaining rigid fixation of the grafted bone anteriorly when performing multilevel cervical corpectomy and spinal fusion.

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Comment

Aramomi *et al.* have analyzed a small series of patients who underwent anterior pedicle screw fixation for multilevel cervical corpectomy and spinal fusion. The anterior insertion of screws into the pedicles has been introduced as feasible and safe. The new anterior surgical approach was expected to increase stability and lower the risk of failures by using conventional anterior fixation methods. Even though the outcome in this small series was quite good, long-term results of much larger series will have to confirm this assumption. Nevertheless, this technical note is a nice introduction into a new fixation method performed from anteriorly. We agree that Halo-vests are very uncomfortable for patients who underwent cervical corpectomies and should be used only in special cases with significant morbidity. In fact, even Philadelphia collars can be avoided in most cases and a soft collar should be sufficient, provided intraoperative stability and screw firmness are confirmed. Although we would prefer iliac bone grafts instead of fibular grafts, this certainly would not change the overall idea of this paper. We are looking forward to see the reports of larger series from other groups using this elegant anterior fixation method.

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A New Concept for Making Decisions Regarding the Surgical Approach for Cervical Ossification of the Posterior Longitudinal Ligament

The K-Line

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Study Design. To report a new index, the K-line, for deciding the surgical approach for cervical ossification of the posterior longitudinal ligament (OPLL).

Objective. To analyze the correlation between the K-line-based classification of cervical OPLL patients and their surgical outcome.

Summary of Background Data. Previous studies showed that kyphotic alignment of the cervical spine and a large OPLL are major factors causing poor surgical outcome after laminoplasty for cervical OPLL patients. However, no report has evaluated these 2 factors in 1 parameter.

Methods. The K-line was defined as a line that connects the midpoints of the spinal canal at C2 and C7. Twenty-seven patients who had cervical OPLL and underwent posterior decompression surgery were classified into 2 groups according to their K-line classification. OPLL did not exceed the K-line in the K-line (+) group and did exceed it in the K-line (−) group. By intraoperative ultrasonography, we evaluated the posterior shift of the spinal cord after the posterior decompression procedure. The Japanese Orthopedic Association scores before surgery and 1 year after surgery were evaluated, and the recovery rate was calculated.

Results. Eight patients were classified as K-line (−), and 19 patients were classified as K-line (+). The mean recovery rate was 13.9% in the K-line (−) group and 66.0% in the K-line (+) group ($P < 0.01$). Ultrasonography showed that the posterior shift of the spinal cord was insufficient in the K-line (−) group.

Conclusion. The present results demonstrate that a sufficient posterior shift of the spinal cord and neurologic improvement will not be obtained after posterior decompression surgery in the K-line (−) group. Our new index, the K-line, is a simple and practical tool for making decisions regarding the surgical approach for cervical OPLL patients.

Key words: K-line, surgical approach, ossification of posterior longitudinal ligament, cervical myelopathy, laminoplasty. **Spine 2008;33:E990–E993**

Regarding the factors causing poor surgical outcomes after laminoplasty for cervical ossification of the posterior longitudinal ligament (OPLL), previous reports have described 2: (1) the alignment of the cervical spine is kyphotic,[1] and (2) the size of the OPLL is large.[2,3] Previous studies evaluated these 2 factors independently, and, to the best of our knowledge, no report has analyzed them in 1 parameter. In the present study, we proposed a new index that can evaluate the cervical alignment and the OPLL size in 1 parameter. We named this index the K-line. The "K" stands for "kyphosis." According to the K-line, we classified cervical OPLL patients who underwent posterior decompression surgery, and evaluated the relationship between their surgical outcome and the K-line-based classification. In addition, we used intraoperative ultrasonography (US) to evaluate the posterior shift of the spinal cord from the OPLL and analyzed the relationship between the decompression status of the spinal cord and the K-line classification.

Materials and Methods

Patients

From May 1990 through December 2005, 27 patients with cervical myelopathy due to OPLL underwent posterior decompression surgery. The patients included 23 males and 4 females. Their mean age at surgery was 63.3 years (range, 46–81 years). The surgical method included cervical enlargement laminoplasty in 19 patients and posterior decompression with instrumented fusion in 8 patients. Our cervical enlargement laminoplasty consisted of a C3 to C7 *en bloc* laminoplasty (Itoh's method).[4,5] From April 2003, when cervical OPLL patients have massive OPLL and evident intersegmental mobility at the cord compression level, we performed posterior instrumented fusion of the cervical spine using a lateral mass and rod system associated with laminectomy or laminoplasty as described previously.[5] All patients had undergone follow-up evaluation for a period of 1 year or longer after surgery.

Clinical and Radiographic Assessments

The Japanese Orthopedic Association scoring system was used to evaluate the severity of cervical myelopathy.[5] The Japanese Orthopedic Association scores before surgery and 1 year after surgery were evaluated, and the recovery rate was calculated.[5]

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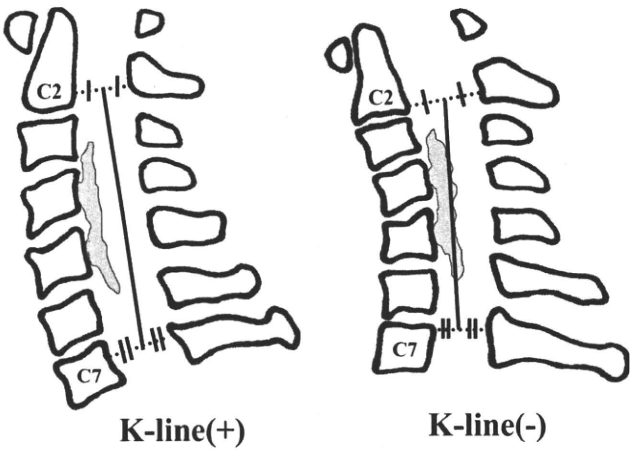

Figure 1. Schematic drawings of the "K-line." The K-line is a straight line that connects the midpoints of the spinal canal at C2 and C7 on the lateral cervical radiographs. Patients with cervical ossification of the posterior longitudinal ligament (OPLL) are divided into 2 groups according to the K-line. OPLL does not exceed the K-line in the K-line (+) group and does exceed it in the K-line (−) group.

Before surgery, the cervical lordotic angle (C2–C7 angle) was measured on lateral radiographs.[5] The occupation ratio of the ossified mass at the most stenotic level of the spinal canal was examined with computed tomography (CT) and defined as follows: OPLL occupation ratio = (thickness of OPLL/anteroposterior diameter of the bony spinal canal) × 100.[5]

Definition of K-Line

To draw the K-line, we used principally the lateral view of the cervical radiograph in the neutral position. In cases whose C7 vertebrae were occluded by the shadow of the patients' shoulders, we evaluated the midsagittal view of the T2-weighted magnetic resonance image. We first decided the midpoints of the spinal canal at C2 and C7 and then connected them (Figure 1). According to the K-line, OPLL cases were divided into 2 groups: a K-line (+) group and a K-line (−) group (Figure 1). In the K-line (+) group, the OPLL did not exceed the K-line and stayed within the ventral area of the K-line. Because there is a space between the K-line and OPLL, we named this group "plus" (Figure 2A). In the K-line (−) group, OPLL exceeded the K-line and had grown beyond the K-line (Figures 2B, C). When the size of OPLL was large, many cases were classified as K-line (−) (Figure 2B). Even though the OPLL size was not large, some OPLL cases were classified as K-line (−) when the alignment of the cervical spine was kyphotic (Figure 2C).

Intraoperative Spinal US

By means of intraoperative US, we recorded the movement of spinal cord by an animation mode and assessed the posterior shift of the spinal cord from the anterior ossified mass. Immediately after the posterior decompression procedure, we evaluated the presence of the subarachnoid space at the ventral side of the spinal cord. We then classified the decompression status into 3 types: a noncontact type, a contact and apart type, and a contact type.[6] In the noncontact type, the spinal cord does not touch the OPLL, and the subarachnoid space can always be seen between the OPLL and the spinal cord. In the contact and apart type, the spinal cord touches and is apart from the OPLL, depending on the pulsation. In the contact type, the spinal cord always touches the OPLL, and no subarachnoid space appears between the OPLL and the spinal cord.

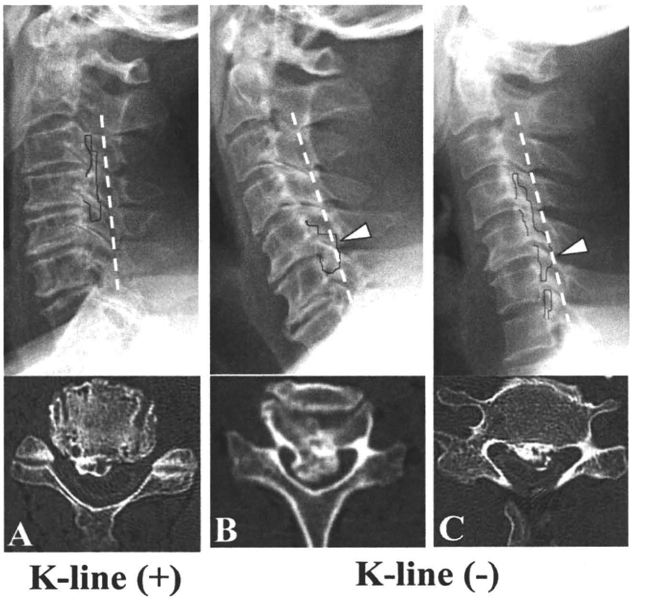

Figure 2. Representative cervical radiographs and computed tomography (CT) images of the K-line (+) **(A)** and the K-line (−) **(B, C)**. **A,** The size of OPLL is not large (the occupation ratio of the spinal canal by OPLL is 36.3%, and the OPLL thickness is 4 mm at C4/5), and the OPLL stays at the ventral area of the K-line. **B,** The OPLL size is large (the occupation ratio is 85%, and the thickness is 11 mm at C5/6), and the OPLL extends beyond the K-line. **C,** The OPLL size is intermediate (the occupation ratio is 48.4%, and the thickness is 5 mm at C5/6), but the OPLL exceeds the K-line because the alignment of the cervical spine is kyphotic. Arrowheads in **(B)** and **(C)** indicate the site where the OPLL exceeds the K-line.

Statistical Analysis

Statistical analysis was performed using the Mann-Whitney *U*-test, the Scheffe's F test and Fisher's exact probability test. A $P < 0.05$ was considered statistically significant. Results are presented as the mean ± standard error of the mean.

Results

Of the 27 OPLL patients analyzed in the present study, 19 were classified as K-line (+), and 8 were classified as K-line (−). Preoperative and postoperative clinical data are summarized in Table 1. The mean recovery rate was 66.1% in the K-line (+) group and 13.9% in the K-line (−) group. Thus, neurologic improvement after surgery was far better in the K-line (+) group than in the K-line (−) group ($P < 0.01$).

Five patients were classified as the contact type by intraoperative US, 12 patients were classified as the contact and apart type, and 10 patients were classified as the noncontact type. The mean recovery rate was 10.5% in patients of the contact type, 54.2% in patients of the contact and apart type, and 66.5% in patients of the noncontact type. Thus, neurologic improvement in patients of the contact type was inferior to those of the contact and apart type and the noncontact type ($P < 0.05$).

Of the 19 patients in the K-line (+) group, 9 patients were classified as the contact and apart type, and 10 patients were classified as the noncontact type. Of the 8 patients of the K-line (−) group, 5 patients were classi-

Table 1. Clinical Data According to the K-Line Classification

K-Line Group	K-Line (+) (n = 19)	K-Line (−) (n = 8)
JOA score (points)*		
Before surgery	8.9 ± 0.7 (4–14)	7.3 ± 0.7 (4.5–9.5)
After surgery	13.8 ± 0.6 (10–17)	8.9 ± 0.8† (5–12)
Recovery rate (%)*	66.1 ± 5.2 (33.3–100)	13.9 ± 12.2† (−50–52)
Age at surgery (yr)*	60.7 ± 1.9 (46–78)	69.5 ± 3.6 (54–81)
Occupation ratio of OPLL (%)*	52.3 ± 2.9 (28.6–72.7)	63.8 ± 5.0 (45.4–90)
Thickness of OPLL (mm)*	6.7 ± 0.4 (3–9)	8.4 ± 0.6 (6–11)
C2–C7 Lordotic angle (degrees)*	12.4 ± 1.9 (−3–26)	13.7 ± 5.9 (−12–32)
Ultrasonography type (n)		
Contact	0	5
Contact and apart	9	3
Noncontact	10	0

*Values are expressed as mean ± standard error, with the range in parentheses.
†Statistically different from the K-line (+) group ($P < 0.01$).
JOA indicates Japanese Orthopaedic Association.

fied as the contact type and 3 patients were classified as the contact and apart type (Table 1). Thus, the incidence of the contact type was significantly higher in the K-line (−) group ($P < 0.01$). In contrast, the incidence of the noncontact type was significantly higher in the K-line (+) group ($P < 0.05$).

■ Discussion

Batzdorf *et al*[7] analyzed the degree of spinal curvature in patients with cervical spondylotic myelopathy and reported the relation between the degree of curvature and the postoperative clinical outcome after laminectomy. Taking into account their study design, in the present study, we advocated the K-line as an index for deciding the surgical approach for cervical OPLL patients. By using the K-line, we can evaluate the alignment of the cervical spine and the size of OPLL in 1 parameter. In addition, the method of patient classification according to the K-line is simple and practical.

With surgeries from the posterior approach for cervical OPLL patients, we can evaluate the posterior shift of the spinal cord immediately after the posterior decompression procedure by using intraoperative US. Mihara *et al*[8] analyzed the findings of intraoperative spinal US in cervical myelopathy patients who underwent laminoplasty. They reported that better neurologic recovery was obtained in patients in whom the subarachnoid space appeared at the ventral side of the spinal cord. This is consistent with the findings of our present study that, in patients whose intraoperative US findings were the contact type, neurologic improvements after surgery were inferior to those of the contact and apart type and the noncontact type.

When we perform surgeries for cervical OPLL patients, we expect complete decompression of the spinal cord. Thus, the most desirable intraoperative US finding immediately after the posterior decompression procedure is the noncontact type. In the K-line (−) group in the present study, no patient was a noncontact type. This indicates that the posterior shift and the decompression of the spinal cord from the anterior ossified mass will be insufficient in the K-line (−) group. In contrast, in the K-line (+) group, 10 patients were the noncontact type, and no patient was the contact type. This indicates that, in many cases in the K-line (+) group, a sufficient posterior shift decompression of the spinal cord will be expected, even after surgeries from the posterior approach. If we select posterior surgeries for cervical OPLL patients of the K-line (−) group, an adequate posterior shift of the spinal cord will not occur after surgery, and a sufficient neurologic improvement will not be expected. Thus, we suggest that, for patients of the K-line (−) group, selection of surgeries from the posterior approach is not appropriate. For such patients, we recommend anterior decompression surgery as the first choice.

In conclusion, the present results demonstrate that a sufficient posterior shift and decompression of the spinal cord will not be obtained with surgeries from the posterior approach for cervical OPLL patients of the K-line (−) group. Our new index, the K-line, is a simple and practical tool for making decisions regarding the surgical approach for cervical OPLL patients.

■ Key Points

- We proposed a new index, the K-line, which can evaluate cervical alignment and OPLL size in 1 parameter.
- Cervical OPLL patients who underwent posterior decompression surgery were classified into 2 groups: K-line (+) and K-line (−).
- Sufficient posterior shift of the spinal cord and neurologic improvement were not obtained after posterior decompression surgery in the K-line (−) group.
- The K-line is a simple and practical tool for making decisions regarding the surgical approach for cervical OPLL patients.

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Risk factors for closure of lamina after open-door laminoplasty

Clinical article

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Object. This retrospective study was conducted to evaluate the prevalence and clinical consequences of postoperative lamina closure after open-door laminoplasty and to identify the risk factors.

Methods. Eighty-two consecutive patients with cervical myelopathy who underwent open-door laminoplasty without plates or spacers in the open side (Hirabayashi's original method) were included (62 men and 20 women with a mean age of 62 years and a mean follow-up of 1.8 years). In 67 patients the cause of cervical myelopathy was spondylotic myelopathy, and in 15 it was caused by ossification of posterior longitudinal ligament. Radiographic measurements were made of the anteroposterior diameters of the spinal canal and vertebral bodies from C3–6, and the presence of kyphosis were assessed. Lamina closure was defined as ≥ 10% decrease in the canal-to-body ratio at the final follow-up compared with that immediately after surgery at ≥ 1 vertebral level. The impact of lamina closure on neck pain, patient satisfaction, Japanese Orthopaedic Association scores, and recovery rates were also evaluated.

Results. The mean canal-to-body ratio at C3–6 was 0.69–0.72 preoperatively, 1.25–1.28 immediately after surgery, and 1.18–1.24 at the final follow-up examination. Lamina closure was observed in 34% of patients and was not associated with sex, age, or cause of myelopathy, but was significantly associated with the presence of preoperative kyphosis ($p = 0.014$). Between patients with and without lamina closure, there was no significant difference in preoperative (9.7 ± 3.1 vs 10.6 ± 2.5) and postoperative (13.7 ± 2.4 vs 13.1 ± 2.7) Japanese Orthopaedic Association scores, recovery rates (53.9 ± 29.9% vs 44.3 ± 29.5%), neck pain scores (3.5 ± 0.7 vs 3.3 ± 1.0), or patient satisfaction level (4.0 ± 1.4 vs 4.8 ± 1.0).

Conclusions. Lamina closure at ≥ 1 vertebral level occurred in 34% of patients. Although patients with lamina closure obtained equivalent recovery from myelopathy in a short-term follow-up, they tended to be less satisfied with surgery compared with those who did not have closure. The only significant risk factor identified was the presence of preoperative cervical kyphosis, and preventative methods for lamina closure, therefore, should be considered for patients with preoperative kyphosis. *(DOI: 10.3171.SPI.2008.4.08176)*

Key Words • **cervical myelopathy** • **lamina closure** • **laminoplasty**

Open-door laminoplasty was developed by Hirabayashi in 1977 and has been widely used since as a decompression method for multilevel cervical compressive myelopathy.[1,5–7,16,19] In Hirabayashi's original method, the laminae are kept open by stay sutures placed between the laminae and the muscles around the facet joint at the same level.[6,7] Although it is a simple, less time consuming and cost-effective surgical method for most patients with cervical myelopathy, it is associated with several problems including the development of postoperative axial pain,[9,10] C-5 motor palsy,[2] and closure of the opened laminae (lamina closure) among others.[21,22] Among these problems, lamina closure is a concern because it may result in suboptimal decompression of the spinal cord. Satomi et al.[21] reported that neurological deterioration due to postoperative lamina closure was observed in 2 of 51 patients with compressive cervical myelopathy who underwent a mean follow-up of 7.8 years after open-door laminoplasty. Although it has not been clarified whether postoperative lamina closure really results in suboptimal neurological recovery or causes later deterioration of cervical myelopathy, or, if so, how much

Abbreviations used in this paper: CBR = canal-to-body ratio; CI = confidence interval; JOA = Japanese Orthopaedic Association; OPLL = ossification of posterior longitudinal ligament; SD = standard deviation; VB = vertebral body.

degree of closure is clinically inacceptable, we all intuitively believe that lamina closure should be prevented.

To prevent lamina closure, several modifications to Hirabayashi's original method have been reported including the use of anchor screws adjacent to the facet joints on the hinge side,[1,15,25,27] and the use of bone grafts, spacers,[12,22] and titanium plates bridging between the laminae and the facet joints in the open side.[17,20] However, these additional procedures may increase surgical time, medical costs, risk of dislodgement and infection, and should be reserved for use in specific patients in whom these additional procedures are absolutely necessary. The purposes of this study were to evaluate the prevalence and clinical consequences of postoperative lamina closure after open-door laminoplasty and to identify its risk factors.

Methods

Eighty-two consecutive patients who underwent open-door laminoplasty for cervical myelopathy in the period between 2004 and 2005 were enrolled in this study. The patients included 62 men and 20 women with a mean age of 62.7 years (range 20–80 years). The mean follow-up period was 1.8 years (range 1–3.3 years). Sixty-seven patients had spondylotic myelopathy and 15 had OPLL. An open-door laminoplasty was used in which the lamina was dissected on the left side with a high-speed drill making the hinges on the right side. To enhance the stability of the lamina, 2.2-mm titanium anchor screws (Smith and Nephew) were placed into the facet joints on the hinge side in 68 patients (83%) who underwent treatment in the later stage of this study. The anchor screws were placed in every other level, and conventional stay sutures were used in the remaining levels. No spacer or plate was used in the open side. The day after surgery, all patients were allowed to sit up without a brace, and if possible, to stand and walk. All patients were encouraged to start range of motion exercises and isometric muscle strengthening exercise of the neck as early as possible. Therefore, all patients except those with postoperative complications followed the same clinical path after surgery.

Lateral sitting radiographs with the patient in the neutral position were obtained before surgery, immediately after surgery, at 3 months and 1 year postoperatively, and at the final follow-up. Measurements on the radiographs of the anteroposterior diameters of the VBs and spinal canal from C3–6 were made by an orthopedic surgeon (K.W.) using an electric caliper with 0.01-mm accuracy (Mitsutoyo). The kyphosis angle was defined as the angle formed by the 2 tangential lines to the posterior wall of the C-2 and C-6 VBs. To eliminate the magnifying effect of radiography, the CBR was assessed by dividing the anteroposterior diameter of the spinal canal by the diameter of the VB at each level (Fig. 1). The measurements were repeated twice and the results were averaged. To assess the intra- and interobserver reliability of measurements, radiographs obtained at the final follow-up in 25 patients were chosen in a random fashion and were measured again by the first examiner ~ 2 weeks after his first measurement and also by another orthopedic surgeon (M.M.). The intra- and interobserver reliability were statistically tested using an interclass correlation coefficient. The data presented in the *Results* section are based only on the measurements obtained by the first examiner (K.W.).

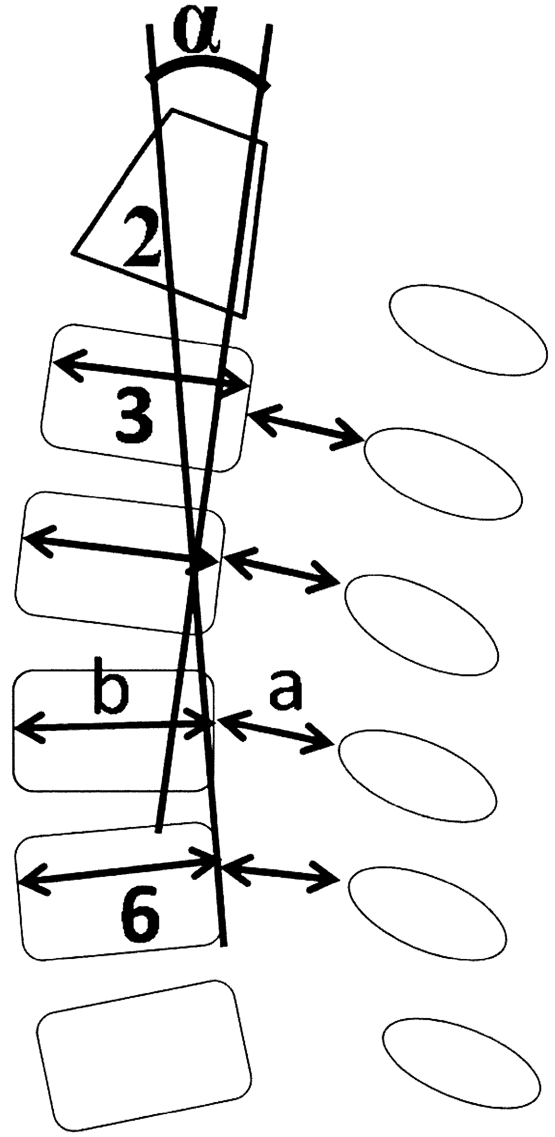

FIG. 1. Schematic of the radiologic measurements. The anteroposterior diameters of the spinal canal and the VBs were measured from C3–6. The CBR was determined by dividing the anteroposterior diameter of the spinal canal (a) by that of the VB (b). The kyphosis angle (α) was the angle formed by the 2 tangential lines to the posterior wall of the C-2 and C-6 VBs.

Because no objective methods to evaluate lamina closure have been reported, we established a quantitative method to evaluate lamina closure. If the CBR measured immediately after surgery decreased by ≥ 10% at the final follow-up at ≥ 1 vertebral level, it was considered as lamina closure (Fig. 2). The cutoff value of a ≥ 10% decrease in CBR was determined based on the mean and range of decrease in CBR. Using radiographs of patients with lamina closure, we examined correlations between the quantitative evaluation using the CBR and conven-

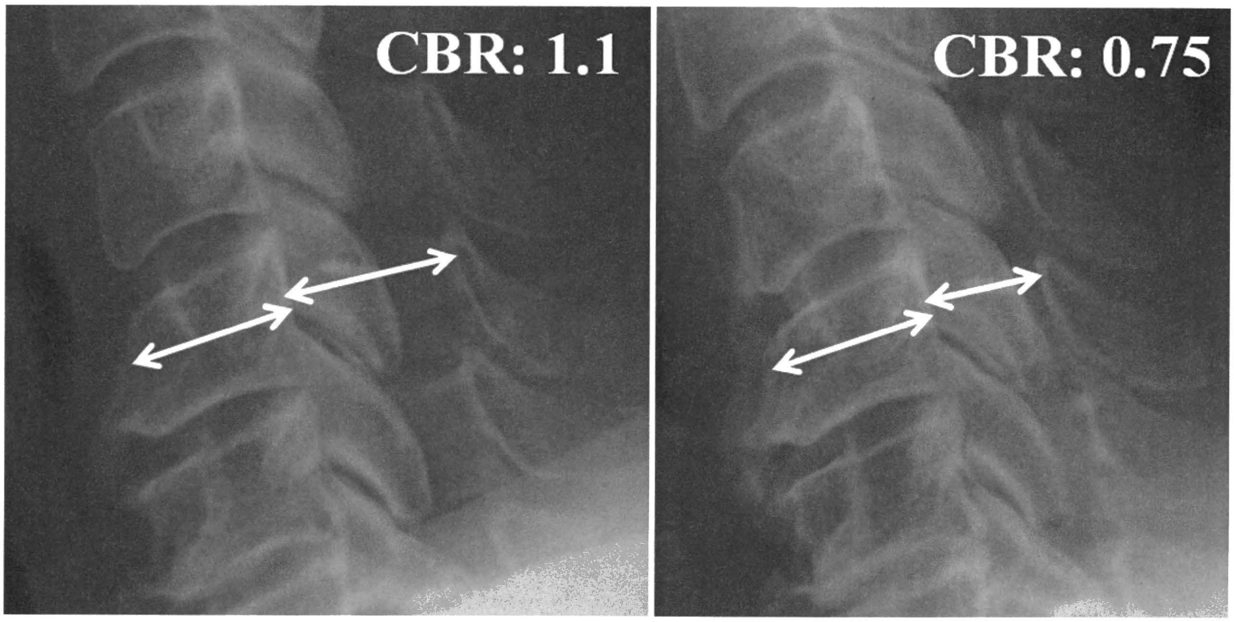

FIG. 2. Representative radiographs of lamina closure. A 32% decrease in CBR from the image obtained immediately after surgery *(left)* to the final follow-up image *(right)* is shown, indicating the presence of lamina closure.

tional qualitative evaluation, in which 2 orthopedic spine surgeons without knowledge of the results of the quantitative evaluation cooperatively made subjective judgments on whether lamina closure was present or not.

The chi-square test was used to evaluate relationships between lamina closure and factors including sex, age (< 60 or ≥ 60 years old), cause of myelopathy (spondylosis or OPLL), and the existence of preoperative cervical kyphosis.

Neurological status was evaluated using the JOA scale for cervical myelopathy (a 17-point scale),[13] and the recovery rate was calculated using the following formula established by Hirabayashi: (postoperative JOA score – preoperative JOA score) / (17 – preoperative JOA score) × 100%. Neck pain was evaluated using a 5-point scale (4 = no pain, 3 = slight pain needing no treatment, 2 = moderate pain needing occasional analgesia, 1 = pain needing a frequent analgesia, and 0 = severe pain needing daily analgesia). Patient satisfaction with surgery at follow-up was also evaluated using a 7-point grading scale (6 = very satisfied, 5 = satisfied, 4 = slightly satisfied, 3 = intermediate, 2 = slightly dissatisfied, 1 = dissatisfied, and 0 = very dissatisfied).

For statistical analyses, including the t-test, chi-square test, and Pearson and intraclass correlation coefficient, SPSS software (15.1J, SPSS Inc.) was used and probability values < 0.05 were considered statistically significant.

Results

Changes in CBR

The mean (± SD) CBRs were 0.72 ± 0.10 at C-3, 0.69 ± 0.11 at C-4, 0.71 ± 0.13 at C-5, and 0.71 ± 0.12 at C-6 before surgery; 1.25 ± 0.16 at C-3, 1.26 ± 0.11 at C-4, 1.28 ± 0.11 at C-5, and 1.27 ± 0.10 at C-6 immediately after surgery; 1.17 ± 0.10 at C-3, 1.20 ± 0.11 at C-4, 1.22 ± 0.11 at C-5, and 1.23 ± 0.10 at 1 year postoperatively; and 1.18 ± 0.10 at C-3, 1.20 ± 0.10 at C-4, 1.24 ± 0.17 at C-5, and 1.23 ± 0.10 at C-6 at the final follow-up (Fig. 3). The mean (± SD) decrease in CBR at the final follow-up compared with immediately after surgery was 5.58 ± 7.47% (range 0–52.9%) at C-3, 5.40 ± 5.13% (range 0–18.8%) at C-4, 4.93 ± 5.87% (range 0–22.6%) at C-5, and 4.83 ± 4.4% (range 0–19%). Thus, the CBRs increased significantly immediately after surgery but decreased slightly at the final follow-up at all vertebral levels. The cutoff value of a 10% decrease in CBR for determination of lamina closure was chosen because it approximately corresponded to a mean value plus a 1-SD decrease in CBR at each intervertebral level.

For intraobserver reliability of measurements, intraclass correlation coefficients for the CBR and kyphosis angle were 0.94 (95% CI 0.86–97) at C-3, 0.96 (95% CI 0.91–0.98) at C-4, 0.92 (95% CI 0.82–0.97) at C-5, 0.91 (95% CI 0.90–0.96) at C-6, and 0.99 (95% CI 0.98–0.99) for the angle of kyphosis ($p < 0.001$). Interobserver reliability was 0.83 (95% CI 0.52–0.94) at C-3, 0.85 (95% CI 0.58–0.95) at C-4, 0.90 (95% CI 0.74–0.96) at C-5, 0.85 (95% CI 0.58–0.95) at C-6, and 0.98 (95% CI 0.96–0.99) for the angle of kyphosis ($p < 0.001$). The intra- and interobserver reliability was acceptably good.

Lamina Closure

Lamina closure defined by a 10% decrease in CBR at the final follow-up was observed in 28 patients (34%). The percentage of the closed laminae per level was 25.9%

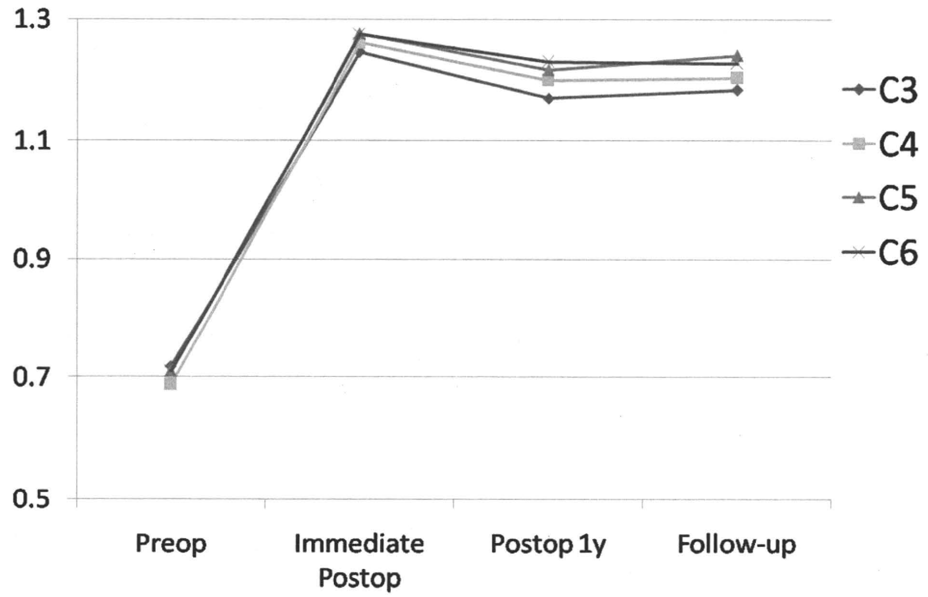

FIG. 3. Graph demonstrating the change in CBR in all patients over time. The CBRs increased significantly immediately after surgery and then decrease slightly at the final follow-up.

at C-3, 19.8% at C-4, and 23.5% at C-5, but 14.8% at C-6. The average number of closed laminae was 1.9 per patient who had lamina closure. After reading radiographs of these 28 patients, the 2 orthopedic surgeons judged that lamina closure was present in 22 of 28 patients (78.6%). When the cutoff value for lamina closure was set as a 15% decrease in CBR, 11 patients (13.4%) were identified. The orthopedic surgeons judged that lamina closure was present in 9 (81.8%) of these patients.

Chronological evaluation of CBRs in patients with lamina closure revealed that lamina closure was observed no later than 3 months after surgery at all levels (Fig. 4). Compared with patients without lamina closure, those with lamina closure demonstrated a significant decrease in CBRs at all levels ($p < 0.01$, paired t-test; Fig. 5). However, all patients with or without lamina closure had a higher CBR at follow-up than before surgery at all vertebral levels, indicating that even in cases of lamina closure, these patients obtained some decompressive effect.

Clinical Outcomes

The mean pre- and postoperative JOA scores in all patients were 10.3 ± 2.7 and 13.4 ± 2.6, respectively, and the mean recovery rate was 47.3 ± 29.8%. The JOA scores

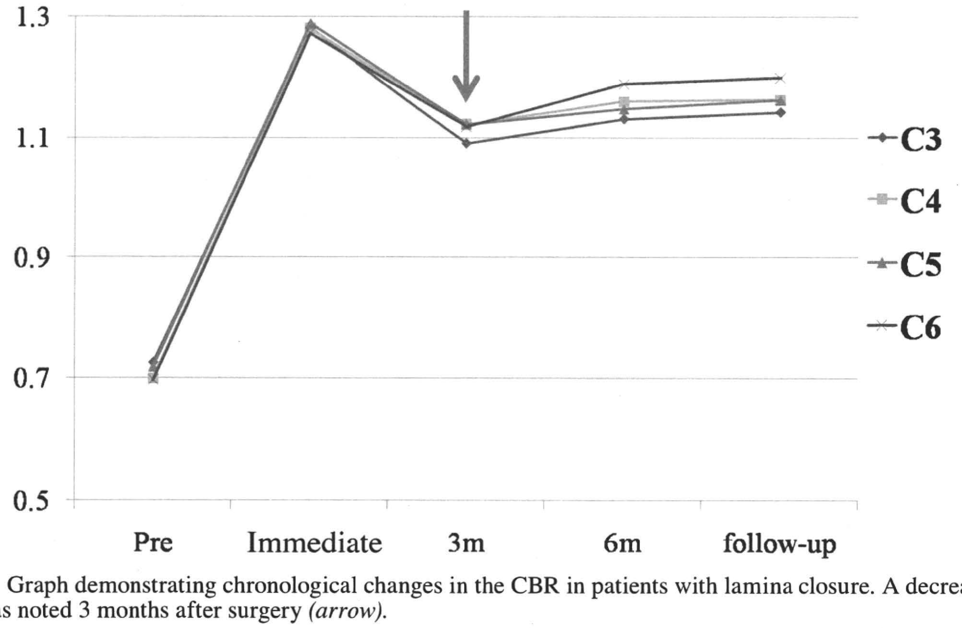

FIG. 4. Graph demonstrating chronological changes in the CBR in patients with lamina closure. A decrease in the CBRs was noted 3 months after surgery *(arrow)*.

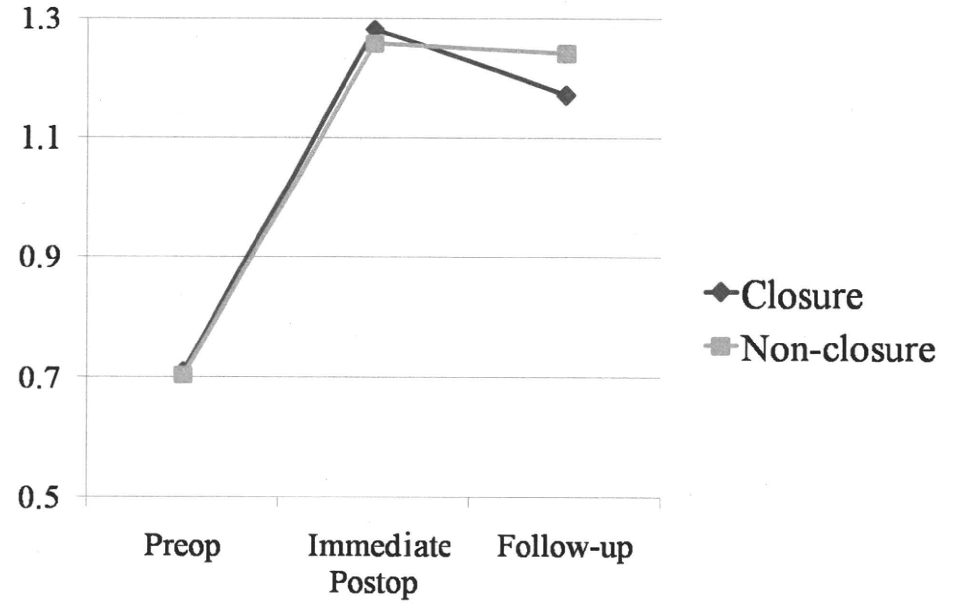

FIG. 5. Graph comparing the mean CBR between the lamina closure and nonclosure groups. The lamina closure group had a more marked decrease in mean CBR compared with the nonclosure group. The CBRs for C3–6 were averaged to obtain a mean CBR.

before surgery and at follow-up, and the recovery rates were not significantly different between the patients with lamina closure and those without (Table 1), although the patients with lamina closure tended to demonstrate a better recovery rate than those without (p = 0.19). There was no significant correlation between the degree of lamina closure (largest decrease in CBR at 1 of the 4 vertebral levels from C3–6) and the recovery rate (Pearson correlation coefficient = 0.29, p = 0.80). The patients with lamina closure were less satisfied with surgical outcomes than those without closures, although the difference was not statistically significant (mean satisfaction score 4.0 ± 1.4 for patients with closure vs 4.8 ± 1.0 for patients without; p = 0.10). There was no significant difference in neck pain score between the 2 groups (3.5 ± 0.7 with lamina closure vs 3.3 ± 1.0 without; p = 0.62).

One patient required revision surgery for a postoperative hematoma, but no patient required additional decompressive surgery for neurological deterioration secondary to lamina closure during the follow-up period of this study.

Factors Associated With Lamina Closure

Patient sex, age, cause of myelopathy, and the use of anchor screws were not significantly correlated with the occurrence of lamina closure. However, the existence of preoperative cervical kyphosis was significantly associated with lamina closure (Fig. 6). Preoperative kyphosis was observed in 14 patients (17.1%), and a mean angle of kyphosis was 13.9° (range 7–22°). Nine (64.3%) of the 14 patients with preoperative kyphosis developed postoperative lamina closure (p = 0.014) compared with 19 (27.9%) of 68 patients without kyphosis.

Discussion

Lamina closure has been noted as a problem associated with open-door laminoplasty. However, its prevalence and clinical consequences have not been reported in detail, partly because objective criteria for what constitutes lamina closure have not been established. In the present study, we developed the quantitative criteria assessing lamina closure in which a ≥ 10% decrease in CBR at ≥ 1 level was defined as lamina closure. These criteria may be too sensitive for detection of lamina closure because there was some disagreement between the quantitative and qualitative evaluation of lamina closure. The orthopedic spine surgeons judged that lamina closure was present in only 79% of patients with a 10% decrease in CBR at the final follow-up examination. One reason for this discrepancy is that the cutoff value of 10% may be

TABLE 1
*Summary of clinical results in patients with and without lamina closure**

Parameter	Closure Group	Nonclosure Group	p Value†
JOA score			
preop	9.7 ± 3.1	10.6 ± 2.5	0.18
at final FU‡	13.7 ± 2.4	13.3 ± 2.7	0.55
recovery rate (%)	53.9 ± 29.9	44.3 ± 29.5	0.19
neck pain score	3.5 ± 0.7	3.3 ± 1.0	0.62
patient satisfaction	4.0 ± 1.4	4.8 ± 1.0	0.10

* Data are given as means ± SDs. Neck pain score and patient satisfaction scores are based on 5- and 7-point scales, respectively, and are described in *Methods*. Abbreviations: FU = follow-up; preop = preoperative.

† Unpaired t-test.

‡ Mean time to final follow-up was 1.8 years.