Table 1. Clinical Characteristics of Enrolled Patients

No. institutes	16
No. patients	156
Sex	Male: 104; female: 52
Age at the first visit (yr)	41~86 (mean 65.7)
Follow-up periods (yr)	5~23 (mean 10.3)
OPLL type*	
Segmental type	45 cases
Continuous type	55 cases
Mixed type	56 cases

*Classification by the Investigation Committee on the ossification of the posterior longitudinal ligaments of the Japanese Ministry of Public Health and Welfare.[1]

radiographic predictors for the development of myelopathy in patients with OPLL.

Materials and Methods

OPLL was evaluated in 156 patients (16 institutions) over an average 10.3-year period (Table 1). Enrollment criteria included radiograph, magnetic resonance, and computed tomography (CT) studies of the cervical spine, defining the different types of OPLL a minimum of 5 years of follow-up, and Institutional Review Board approval. Other critical variables included a history of trauma, documentation of >60% spinal canal stenosis, cervical range of motion (ROM), axial; CT/MR studies documenting the types of OPLL, and the neurologic confirmation of myelopathy. ROM was determined as the total angle of C2–C7 angles of at maxmum anterior and posterior position.

Statistical Analysis

A parametric statistical analysis was performed using the Student *t* test. Categorical variables were analyzed using χ^2 analysis. All values are expressed as means with 95% confidence intervals.

Results

Myelopathy was observed in all 39 patients with 60% or greater compromise of the cervical spinal canal/stenosis. Among the 39 patients, 19 patients had central type OPLL and the remaining 20 patients had lateral, deviated-type OPLL (Figure 1). A total of 57 (49%) of the remaining 117 patients with <60% canal compromise were myelopathic. Factors which seemed to contribute to myelopathy included: canal stenosis >60%, large ROM, and lateral-deviated type OPLL in axial view. (Table 2). Fifteen patients became acutely myelopathic secondary to trauma: 13 had mixed type OPLL and 2 had the segmental variant.

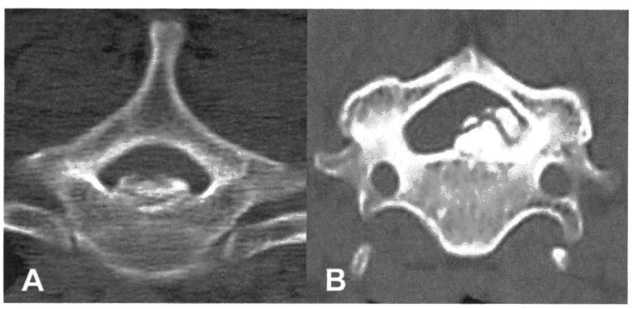

Figure 1. Axial ossified pattern of OPLL on CT or MRI. **A,** central type; **B,** lateral deviated type.

Table 2. Factors Contributing to Development of Myelopathy

	With Myelopathy	Without Myelopathy	
Maximum spinal			
Canal stenosis (%)			
≥60	39	0	
<60	57	60	
Cervical ROM (mean ± SE)	50 ± 18	38 ± 10	$P = 0.03$
Axial OPLL type (CT/MR)			$P = 0.021$
Central	12	39	
Lateral deviated	33	21	

Cervical ROM was analyzed in patients with <60% maximum spinal canal stenosis (N = 117). Axial OPLL type was analyzed in 105 patients with <60% maximum spinal canal stenosis, and patients with trauma induced myelopathy in this category were deleted.

Discussion

The static compression factor of the spinal cord seems to be a radiographic predictor of the development of myelopathy. All 39 patients with 60% or greater stenosis were myelopathic. In OPLL patients with less than 60% spinal canal stenosis, dynamic factors should be considered for the occurrence of myelopathy. A large range of motion of the cervical spine was a risk factor for the development of myelopathy. Similarly, Morio *et al*[2] also previously noted the existence of dynamic factor related to the development of myelopathy in patients with OPLL. The trauma-induced myelopathy cases have mixed or segmental type OPLL associated with large ROM. This finding also indicated the significance of dynamic factor for development of myelopathy. As for trauma-induced myelopathy, mixed-type OLL, in which the ossified ligament was partially interrupted, is a risk factor for the occurrence of myelopathy. The dynamic factor is mainly related to the occurrence of myelopathy in case of trauma.

In conclusion, static and dynamic factors were related to the development of myelopathy in OPLL. Sixty percent or greater maximum stenosis of the spinal canal, large range of motion of the cervical spine, and lateral deviated-type OPLL were radiographic risk factors for the development of myelopathy. Although we could not examine in the current study, the functional analysis of spinal cord by electrophysiological examination, such as spinal evoked potential in patients with OPLL might provide valuable information regarding the predictors of the development of myelopathy in future.

Key Points

- All patients with more than 60% spinal canal stenosis by OPLL exhibited myelopathy.
- The range of motion of the cervical spine was significantly larger in patients with myelopathy than in those without it.
- The frequency of myelopathy is significantly higher in patients with lateral deviated-type OPLL than in those with the central type.

- Trauma-induced myelopathy occurred more frequently in patients with mix-type OPLL.

Acknowledgment
The authors thank the members of this Committee for providing many cases for this multicenter study.

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Surgical Results and Related Factors for Ossification of Posterior Longitudinal Ligament of the Thoracic Spine

A Multi-Institutional Retrospective Study

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Study Design. Retrospective multi-institutional study

Objective. To describe the surgical outcomes in patients with ossification of the posterior longitudinal ligament in the thoracic spine (T-OPLL) and to clarify factors related to the surgical outcomes.

Summary of Background Data. Detailed analyses of surgical outcomes of T-OPLL have been difficult because of the rarity of this disease.

Methods. The subjects were 154 patients with T-OPLL who were surgically treated at 34 institutions between 1998 and 2002. The surgical procedures were laminectomy in 36, laminoplasty in 51, anterior decompression *via* anterior approach in 25 and *via* posterior approach in 29, combined anterior and posterior fusion in 8, and sternum splitting approach in 5 patients. Instrumentation was conducted in 52 patients. Assessments were made on (1) The Japanese Orthopedic Association (JOA) scores (full score, 11 points), its recovery rates, (2) factors related to surgical results, and (3) complications and their consequences.

Results. (1) The mean JOA score before surgery was 4.6 ± 2.0 and, 7.1 ± 2.5 after surgery. The mean recovery rate was 36.8% ± 47.4%. (2) The recovery rate was 50% or higher in 72 patients (46.8%). Factors significantly related to this were location of the maximum ossification (T1–T4) (odds ratio, 2.43–4.17) and the use of instrumentation (odds ratio, 3.37). (3) The frequent complications were deterioration of myelopathy immediately after surgery in 18 (11.7%) and dural injury in 34 (22.1%) patients.

Conclusion. The factors significantly associated with favorable surgical results were maximum ossification located at the upper thoracic spine and use of instrumentation. T-OPLL at the nonkyphotic upper thoracic spine can be treated by laminoplasty that is relatively a safe surgical procedure for neural elements. The use of instrumentation allows correction of kyphosis or prevention of progression of kyphosis, thereby, enhancing and maintaining decompression effect, and its use should be considered with posterior decompression.

Key words: thoracic spine, ossification of posterior longitudinal ligament, surgical outcome, spinal instrumentation. **Spine 2008;33:1034–1041**

Thoracic myelopathy caused by ossification of the posterior longitudinal ligament of the thoracic spine (T-OPLL) is usually progressive and responds poorly to conservative therapy, making surgery the only effective treatment option. Despite advancement in surgical techniques and tools employed for surgery of T-OPLL, favorable surgical results are not always achieved. Fujimura et al[1] investigated the surgical outcomes at a mean follow-up of 35 months after anterior decompression and fusion in 48 T-OPLL patients. They reported favorable overall results, but that the results were poorer in patients with a longer morbidity period, massive ossification, and ossification of other ligaments in association with T-OPLL. Matsuyama *et al*[2] investigated the surgical results in 21 patients with T-OPLL, and reported post-

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operative deterioration of thoracic myelopathy in 5 of these 21 patients.

According to a radiologic study conducted by Ohtsuka *et al*,[3] the prevalence of T-OPLL was 0.8% in 1058 subjects from the general population in a rural town in Japan, which was significantly lower than that of 3.2% for OPLL of the cervical vertebrae. Thus, since the T-OPLL is a rather uncommon condition[3–5] and the number of patients visiting a single institute is limited, detailed analysis of operated cases has been difficult. A Research Group for Ossification of the Spinal Ligament sponsored by the Japanese Ministry of Health, Labor and Welfare and constituted by members from major Japanese institutions engaged in the treatment of spinal diseases, conducted a multi-institutional retrospective survey of patients who underwent surgery for T-OPLL. This report describes the results of the analyses conducted by this group with regards to the surgical outcomes, factors related to the surgical outcomes, and perioperative complications in patients with T-OPLL.

Materials and Methods

The survey pertained to T-OPLL patients who underwent surgery during the 5-year period from 1998 to 2002 at any one of the 34 institutions where the members of the research group belonged. In July 2004, questionnaires were sent to each institution by the secretary office of the present survey. Each institution was requested to fill in the questionnaire. The data were recovered by the end of December 2004, and a total of 198 operated cases were collected. The analysis was conducted on the data obtained from 154 of 198 patients who had postoperative follow-up period of at least 1 year and whose important data including their sex, age, preoperative neurologic status, surgical methods and results, and major complications were not missing.

The study group consisted of 62 males and 92 females, with a mean age of 56.8 years (range, 27–79 years). The mean follow-up period was 3.0 years (range, 1–6 years).

The items investigated were the patients' demographic data, the underlying disease, presence/absence of comorbidity, details of the history of spinal surgery, radiologic findings [x-ray, magnetic resonance imaging (MRI), and computed tomography], surgical methods and surgical results, complications, and the surgical outcomes.

The morphology of the T-OPLL, level of the ossified lesions, and the kyphosis angle of the thoracic vertebrae (T3, 4 to T12) were determined radiologically. The morphology of T-OPLL was classified as the linear type, beaked type, continuous waveform type, continuous cylindrical type, or the mixed type (composed of at least 2 of these types), according to the classification established by the research group in 1993 (Figures 1–3).[6] The thoracic vertebral levels of the maximum ossification and maximum cord compression were determined by computed tomography and MRI, and the presence/absence of an intramedullary high-intensity lesion was assessed on T2-weighted MR images.

The surgical outcomes were assessed by the Japanese Orthopedic Association (JOA) score for thoracic myelopathy (total of 11 points), which was derived from the JOA scoring system for cervical myelopathy by eliminating the motor and sensory scores for the upper extremity (Table 1). The recovery rate was calculated using the preoperative JOA score (points) and the JOA score at the follow-up, according to the following formula; Recovery rate = (JOA score at follow-up − preoperative JOA score)/(11 − preoperative JOA score) × 100 (%). The Frankel classification modified by Bradford *et al*[7] was also used for evaluation of the surgical outcomes.

Statistical Analysis

Stata 9 software (Stata Corp., College Station, TX) was used for the statistical analysis. The surgical outcomes and the factors related to the outcomes were assessed by logistic regression analysis. Age- and sex-adjusted odds ratios and their 95% confidence intervals were demonstrated.

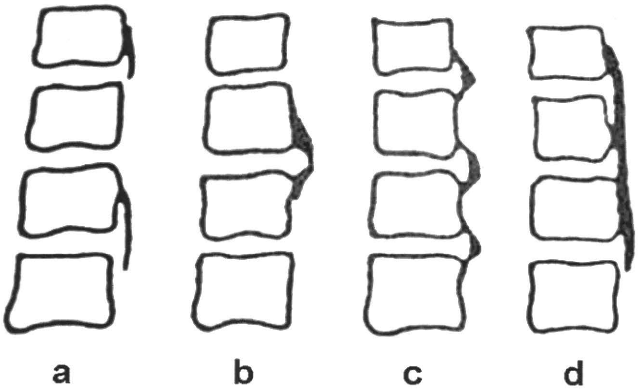

Figure 1. Classification of OPLL.[6] (**a**), linear type; (**b**) beaked type; (**c**), continuous waveform type; (**d**), continuous cylindrical type. Mixed type is defined as a combination of 2 or more different types.

Figure 2. Beaked type of OPLL compressing the spinal cord. Sagittal reconstruction of CAT scan of a 64-year-old man demonstrating a beaked type of OPLL.

Figure 3. Continuous cylindrical type of OPLL. Tomogram of a 48-year-old woman showing a continuous cylindrical type of OPLL.

Results

Clinical Data

The initial symptom was numbness of the lower extremities in 87 (56.5%), gait disturbance in 72 (46.8%),

Table 1. JOA Scoring System for Thoracic Myelopathy

Category	Score (Point)
Motor function	
Lower extremity	
Unable to stand and walk by any means	0
Unable to walk without a cane or other support on a level	1
Walks independently on a level but needs support on stairs	2
Capable of fast but clumsy walking	3
Normal	4
Sensory function	
Lower extremity	
Apparent sensory disturbance	0
Minimal sensory disturbance	1
Normal	2
Trunk	
Apparent sensory disturbance	0
Minimal sensory disturbance	1
Normal	2
Bladder function	
Urinary retention and/or incontinence	0
Sense of retention and/or dribbling and/or thin stream and/or incomplete continence	1
Urinary retardation and/or pollakiuria	2
Normal	3

Table 2. Demographics and Clinical Data of Patients

Sex	
Male	62
Female	92
Mean age	56.8 yr (range, 27–79)
Mean follow-up	3.0 yr (range, 1–6)
Mean morbidity period	24.3 mo (range, 1–183)
Initial symptoms	
Numbness in the lower extremities	87 (56.7)
Gait disturbance	72 (46.8)
Weakness of lower extremities	47 (30.5)
Sensation of trunk strangulation	23 (14.9)
Urinary disturbance	5 (3.2)

weakness of the lower extremities in 47 (30.5%), strangulating sensation of the trunk in 23 (14.9%), and urinary disturbance in 5 (3.2%) patients (some patients presented with multiple symptoms). The mean morbid period from the onset of the initial symptom to surgery was 24.3 months (range, 1–183 months). The prevalence of underlying diabetes mellitus was 22.1% (34 of 154). Twelve (7.8%) of the 154 patients had a history of decompression of the thoracic spine, and 29 (18.8%) of the 154 patients had a history of surgery in the spine other than the thoracic vertebrae; of these 29 patients, 23 had surgery for OPLL of the cervical spine, and the remaining 6 had surgery for lumbar spinal diseases (Table 2).

Radiologic Findings

The morphology of T-OPLL was classified as the linear type in 8 patients (5.2%), the beaked type in 45 patients (29.2%), the continuous waveform type in 46 patients (29.9%), the continuous cylindrical type in 26 patients (16.9%), and the mixed type in 29 patients (18.8%). The level of maximum ossification was located between the first to fourth thoracic vertebrae (T1–T4) in 69 patients, T5–T8 in 62 patients, and T9–T12 in 23 patients. The mean anteroposterior diameter of the lesion at the level of the maximum ossification was 6.7 ± 2.0 mm (range, 1.5–12.0 mm). On T2-weighted MRI, an intramedullary high-intensity lesion was recognized in 83 (63.8%) of the 130 patients in whom the lesion could be evaluated. With regard to association of T-OPLL with ossification of other spinal ligaments, cervical OPLL was recognized in 97 patients (63%), and ossification of the yellow ligament in the thoracic spine was recognized in 96 patients (62.7%).

Surgical Methods. Laminectomy was conducted in 36 patients, laminoplasty in 51 patients, anterior decompression and fusion *via* an anterior extrapleural or transpleural approach in 25 patients, anterior decompression *via* a posterior approach (the method reported by Ohtsuka *et al*[8]) in 29 patients, circumferential decompression and fusion *via* a combined anterior and posterior approach reported by Tomita *et al*[9] in 8 patients, and anterior decompression and fusion *via* a sternal splitting approach in 5 patients (Table 3).[10] When the surgical procedures selected for different morphologic types of T-OPLL were assessed, the linear type was most frequently treated by laminectomy, the beaked type by

Table 3. Type of OPLL and Surgical Methods

		Type of OPLL				
	No	Linear 8 (5.2)	Beaked 45 (29.2)	Continuous Waveform 46 (29.9)	Continuous Cylindrical 26 (16.9)	Mixed 29 (18.8)
Laminectomy	36	5 (62.5)	8 (17.8)	9 (19.6)	7 (26.9)	7 (24.1)
Laminoplasty	51	0	16 (35.6)	19 (41.3)	11 (42.3)	5 (17.2)
Anterior decompression *via* anterior approach	25	0	12 (26.7)	4 (8.7)	2 (7.7)	7 (24.1)
Anterior decompression *via* posterior approach	29	3 (37.5)	5 (11.1)	12 (26.1)	6 (23.1)	3 (10.3)
Circumferential decompression	8	0	2 (4.4)	2 (4.3)	0	4 (13.8)
Sternum splitting approach	5	0	2 (4.4)	0	0	3 (10.3)

Values inside parentheses indicate percentages.

laminoplasty, and anterior decompression and fusion *via* anterior approach, the continuous waveform type and the continuous cylindrical type by laminoplasty, and the mixed type by laminectomy, and anterior decompression and fusion *via* anterior approach.

When the procedures selected for different levels of maximum ossification were assessed, laminoplasty was conducted in 50% of all patients with maximum ossification at the level of T1–T4, laminectomy, laminoplasty, and anterior decompression and fusion *via* anterior approach were conducted at almost the same frequency in patients with maximum ossification at the level of T5–T8, whereas laminectomy was conducted in 52% of all the patients with maximum ossification at the level of T9–T12 (Table 4).

Augmentation by spinal instrumentation was conducted in 52 patients (33%), posterior instrumentation in 50 patients, and anterior instrumentation in the remaining 2 patients. Instrumentation was combined with laminectomy in 52.8%, with laminoplasty in 21.6%, with anterior decompression and fusion *via* anterior approach in 20.0%, with anterior decompression *via* posterior approach in 34.5%, with circumferential decompression and fusion in 87.5%, and with sternal splitting approach in none of the patients. The ossified lesion was excised in 48 patients (31.2%), thinned and floated in 25 patients (16.2%), and left untouched in 81 patients (52.6%). Intraoperative electrophysiologic monitoring was conducted in 77 patients (50.0%), and intraoperative ultrasonography was conducted in 51 patients (33.1%). Seven patients (4.5%) underwent additional decompression during the follow-up period.

Table 4. Level of OPLL and Surgical Methods

		Level of OPLL		
	No	T1–T4 69(44.8)	T5–T8 62 (40.3)	T9–T12 23(14.9)
Laminectomy	36	6 (8.7)	18 (29.0)	12 (52.2)
Laminoplasty	51	35 (50.7)	15 (24.2)	1 (4.3)
Anterior decompression *via* anterior approach	25	4 (5.8)	16 (25.8)	5 (21.7)
Anterior decompression *via* posterior approach	29	16 (23.2)	8 (12.9)	5 (21.7)
Circumferential decompression	8	3 (4.3)	5 (8.1)	0
Sternum splitting approach	5	5 (7.2)	0	0

Values inside parentheses indicate percentages.

Surgical Outcomes. The mean JOA score was 4.6 ± 2.0 before surgery, 6.9 ± 2.4 at 1 year after surgery, 7.0 ± 2.4 points at 3 years after surgery, and 7.1 ± 2.5 points at the final follow up, with a mean recovery rate of 36.8% ± 47.4% at the final follow-up. A mean recovery rate at the follow-up was 36.9% ± 23.3% in patients treated by laminectomy, 39.9% ± 39.6% by laminoplasty, 26.6% ± 46.8% by anterior decompression *via* anterior approach, 29.7% ± 53.3% by anterior decompression *via* posterior approach, 64.1% ± 28.2% by circumferential decompression, 48.1% ± 27.2% by sternum splitting approach.

The pre- and postoperative modified Frankel classification was tabulated in Table 5. The paralysis improved by at least one grade in 107 patients (69.5%), remained unchanged in 38 patients (24.7%), and deteriorated by at least one grade in 9 patients (5.8%).

Factors Related to the Surgical Outcomes. The recovery rate was 50% or higher in 72 patients (46.8%), and factors related to the recovery rate of 50% or higher were assessed, including age, sex, preoperative morbidity period, preoperative JOA score, morphologic type of the ossified lesion, anteroposterior diameter of the ossified lesion, kyphosis angle of the thoracic vertebra, intramedullary high-intensity lesion on T2 weighted MR images, level of maximum ossification, surgical method, combined use of instrumentation, and reoperation, and presence/absence of diabetes mellitus. The cut-off value of 50% was used, because the recovery rate of 50% or

Table 5. Surgical Outcomes

		Modified Frankel Classification						
	JOA Scores	A	B	C	D1	D2	D3	E
Preop.	4.6 ± 2.0	2	8	33	40	44	24	3
Follow-up	7.1 ± 2.4	1	4	7	13	38	67	24

The recovery rate of JOA scores was 36.8% ± 47.4%.
Improvement in Frankel grade was obtained in 107 patients (69.5%).

Table 6. Factors Related to Surgical Outcomes (50% or Higher Recovery Rate of JOA Scores)

Factors	% of Patients*	Odds Ratio (95% Confidence Interval)	P
Sex			
Female	48.8	1.00	
Male	47.5	0.95 (0.49–1.83)	0.877
Age			
<49	66.7	1.00	
50–59	46.7	0.44 (0.18–1.06)	0.067
60–69	41.0	0.35 (0.13–0.91)	0.032
≥70	29.4	0.21 (0.06–0.74)	0.015
Morbidity period			
<1 yr	58.5	1.00	
1–3	50.0	0.71 (0.31–1.59)	0.400
>3	34.0	0.46 (0.19–1.07)	0.073
Preop. JOA scores			
<5	51.4	1.00	
≥5	44.9	0.75 (0.38–1.46)	0.396
Type of OPLL			
Beaked/continuous wave form	51.2	1.00	
Mixed	65.4	1.87 (0.72–4.84)	0.196
Linear	16.7	0.20 (0.02–1.86)	0.157
Continuous cylindrical	34.6	0.61 (0.23–1.59)	0.311
Anteroposterior diameter of OPLL			
<5 mm	57.9	1.00	
5–10	46.9	0.73 (0.26–2.04)	0.551
≥10	70.0	1.81 (0.33–9.88)	0.492
Kyphosis angle on MRI			
<30 degrees	48.4	1.00	
≥30	51.5	1.10 (0.54–2.24)	0.794
Level of OPLL			
T1–4	59.7	1.00 *†	
T5–8	40.0	0.41 (0.19–0.87)	0.020
T9–12	31.8	0.24 (0.08–0.71)	0.010
Surgical methods			
Anterior decompression via anterior approach/Sternum splitting approach	46.7	1.00	
Anterior decompression via posterior approach	53.6	1.20 (0.40–3.43)	0.770
Circumferential decompression	87.5	8.20 (0.84–79.98)	0.071
Laminectomy/laminoplasty	43.5	0.90 (0.35–2.07)	0.727
Use of instrumentation			
No	38.7	1.00 *†	
Yes	63.0	3.40 (1.57–7.2	0.002
No. of surgeries			
Single	61.0	1.00	
Two or more	46.2	0.48 (0.14–1.69)	0.251
Diabetes mellitus			
No	47.4	1.00	
Yes	50.0	1.17 (0.53–2.60)	0.702
Intramedullary high-intensity lesion			
No	44.2	1.00	
Yes	51.8	1.40 (0.65–3.02)	0.391

Sex- and age-adjusted odds ratio and the 95% confidence interval is shown except that for sex and age.
*The numbers showing percentage of patients who obtained recovery rate of 50% or higher at the follow-up in each group.
†Statistically significant difference.

higher has been considered to be good to excellent surgical outcomes in the previous literature.[11] As a result, maximum ossification at T1–T4 [odds ratio; 1 for T1–T4 *vs.* 0.41 (95% confidence interval; 0.19–0.87, $P = 0.02$) for T5–T8 and 0.24 (0.08–0.71, $P = 0.01$) for T9–T12] and combined use of instrumentation with surgery [odds ratio; 1 for without instrumentation *vs.* 3.40 (1.57–7.2, $P = 0.002$) for with instrumentation] were associated significantly with the better outcomes (Table 6). None of the other factors was significantly related to the surgical outcome; however, the outcome tended to be favorable in patients treated by circumferential decompression and fusion and in patients with a morbidity period of less than 1 year, and in patients younger than 50 years of age.

Complications. The following perioperative complications were recognized: deterioration of thoracic myelopathy immediately after the surgery in 18 patients (11.7%); epidural hematoma in 3 patients (1.9%); dural injury resulting in cerebrospinal fluid leakage in 34 patients (22.1%); respiratory complications in 8 patients (5.2%); hoarseness in 2 patients; ileus, esophageal fistula, meningitis, myocardial infarction, and enteritis in 1 patient each.

In patients with neurologic deterioration, the grades of paralysis were Frankel A in 3 patients, B in 7, C in 4, D in 4, and surgical procedures employed were laminectomy in 3 patients (8.3%), laminoplasty in 2 (3.9%), anterior decompression *via* anterior approach in 5

(20.0%), anterior decompression and fusion *via* posterior approach in 6 (20.7%), and circumferential decompression in 2 (25.0%). In this group of patients, the ossified lesion was excised in 7 patients (*i.e.*, deterioration occurred in 14.2% of 48 patients who underwent excision), thinned and floated in 7 patients (*i.e.*, 28% of 25 patients who underwent thinning and floating), and left untouched in 4 patients (*i.e.*, 4.9% if 81 patients whose ossified lesion was left untouched). Thus, neurologic deterioration was observed more frequently in surgical procedures in which the ossified lesion was excised or thinned and floated than those in which the lesion was left untouched.

Measures against immediate neurologic deterioration were administration of steroid in 14 patients, surgical evacuation of hematoma in 2. In 12 patients (66.7%), the paralysis started to recovery in 5.6 days, on average (1–30 days), after the index surgery. The paralysis improved in 1 of 3 patients with Frankel A, 6 of 7 patients with Frankel B, 2 of 4 patients with Frankel C, and all 4 patients with Frankel D paralysis. Cerebrospinal fluid leakage was managed conservatively in 26 patients, and surgically in 8 patients.

■ Discussion

In the present study, improvement by at least one grade in the modified Frankel classification was obtained in 69.5% of the T-OPLL patients after surgical treatments, and mean recovery rate of the JOA score was 37%. Thus, moderate improvement of myelopathy was obtained after surgery in T-OPLL patients. However, compared with recovery rates of cervical OPLL reported in the literature, which ranged from 43% to 63%,[11–13] the recovery rates of T-OPLL were much lower. This is possibly attributable to the following reasons: (1) posterior decompression alone for T-OPLL is minimally effective because of kyphosis of the thoracic spine except in the upper thoracic spine where some lordosis exists; (2) the blood flow to the thoracic spinal cord is less than that to the cervical spinal cord; (3) anterior approach to the thoracic spine is more difficult than that to the cervical spine, making decompression surgery more technically demanding.

Fujimura *et al*[1,14] have identified several factors related to poor surgical results, including a long morbidity period, extensive OPLL, and ossification of other spinal ligaments. Matsuyama *et al*[2] have reported that many patients with the beaked-type of OPLL showed exacerbation of the neurologic symptoms after surgery. Tokuhashi *et al*[15] have reported that the efficacy of posterior decompression for OPLL may be poorer in patients with a large kyphosis angle on preoperative MRI. In the present survey, the factors that were found to be significantly related to the surgical outcomes were the level of maximum ossification at the upper thoracic spine and the combined use of instrumentation with decompression surgery.

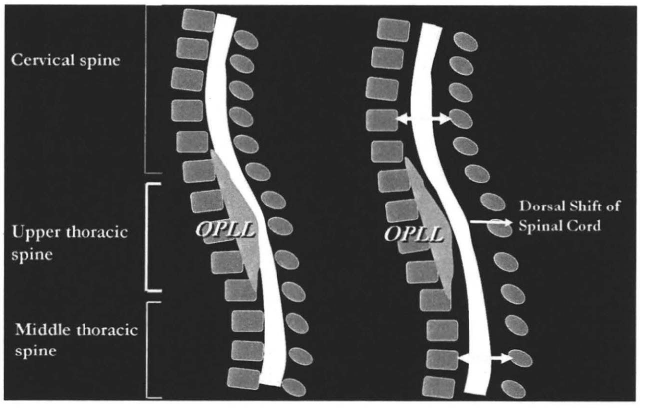

Figure 4. Schematic drawing describing the mechanism of decompression of the spinal cord by laminoplasty in patients with OPLL at the upper thoracic spine. Since the spinal curvature is usually lordotic or only slightly kyphotic at the cervicothoracic junction, dorsal shift and decompression of the spinal cord can be expected by posterior decompression alone.

Surgical method most frequently used for T-OPLL at the upper thoracic spine was laminoplasty. Since the spinal curvature is usually lordotic or only slightly kyphotic at the cervicothoracic junction, dorsal shift and decompression of the spinal cord can be expected by posterior decompression alone (Figure 4), and, therefore, T-OPLL at this level can be successfully treated by laminoplasty, which is relatively safe and is rarely associated with neurologic complications. The use of instrumentation allows correction of kyphosis or prevention of progression of kyphosis, and stabilization of the spine, thereby, enhancing and maintaining decompression effect.[16] Yamazaki *et al*[17] have reported a patient whose neurologic symptoms gradually deteriorated after laminectomy resulting in severe paraplegia. However, the patient obtained neurologic recovery after fusion with posterior instrumentation conducted 4 weeks after the initial decompression surgery. Nakanishi *et al*[18] have reported that a patient who had significant reduction of spinal evoked potential after laminectomy regained the potential level immediately after the addition of posterior instrumentation. Thus, the use of instrumentation should be considered when posterior decompression is conducted.

In the present study, there was no statistically significant difference in the surgical outcomes among patients treated by different surgical methods. Fujimura *et al*[1] and Ohtani *et al*[19] have reported that the anterior decompression is more radical and reasonable for T-OPLL in the kyphotic thoracic spine. On the other hand, Ohtsuka *et al*[8] and Tsuzuki *et al*[20] have reported that they have respectively obtained relatively favorable surgical outcomes using their posterior decompression procedures. Tomita *et al* reported the circumferential decompression method with good surgical outcomes. In the present study, although statistically not significant, the surgical outcomes of Tomita's method tended to be more favorable than those of other surgical methods. Further studies on a greater number of patients are necessary to determine the differences in the clinical outcomes among various surgical procedures.

Surgery for T-OPLL was associated with a high rate of complications. Exacerbation of neurologic symptoms immediately after the surgery and cerebrospinal fluid leakage caused by dural injury were major issues of concern. Diverse explanations have been proposed to explain the neurologic deteriorations immediately after the surgery, including direct spinal cord injury during excision of the ossified lesion, progression of kyphosis after posterior decompression, epidural hematoma, *etc.* There are also cases in which no specific cause can be identified. As described earlier in this article, laminectomy alone may lead to exacerbation of paralysis in some patients, leading to the recommended use of instrumentation in conjunction with posterior decompression. When complete excision is attempted, unexpected spinal cord injury or cerebrospinal fluid leakage caused by dural injury may develop. Thinning and floating of the ossified lesion, which have been considered to be safer than complete excision, did not reduce the incidence of neurologic complications. Some attempts to make surgery for T-OPLL safer and to improve the surgical outcomes have been made, including the uses of electrophysiologic monitoring, a navigation system during excision of the ossified lesion,[21] and intraoperative ultrasonography for confirmation of decompression during posterior decompression, *etc.* Although the frequency of neurologic deterioration immediately after the surgery was as high as 11.7%, paralysis can be expected to recover spontaneously to some extent, except for the patients who developed Frankel A paralysis.

The limitations of the present study included retrospective natures of the study, the small number of patients despite the large number of participating institutions, great variations of surgical methods among institutions, all of which may make reliable statistical analysis difficult. Nonetheless, this is the largest study of surgically treated patients with T-OPLL that is a rare disease, and the results are expected to provide some guidelines for selection of the surgical treatment method in the patients with different types and levels of T-OPLL. The results may also serve as basic data for prospective studies that are planned in the near future.

■ Key Points

- Multi-institutional retrospective study of surgically treated patients with ossification of posterior longitudinal ligament in the thoracic spine was conducted.
- The mean recovery rate of Japanese Orthopedic Association Scores was 36.8% ± 47.4%.
- Factors significantly related with favorable surgical outcomes were location of the maximum ossification at the upper thoracic spine and use of spinal instrumentation.

- Multi-institutional retrospective study of 154 surgically treated patients with ossification of posterior longitudinal ligament in the thoracic spine was conducted.
- Factors significantly related with favorable surgical outcomes were location of the maximum ossification at the upper thoracic spine and the use of spinal instrumentation.
- T-OPLL at the upper thoracic spine can be treated safely by laminoplasty.
- The use of instrumentation should be considered with posterior decompression for T-OPLL at the middle and lower thoracic spine.

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Postoperative changes in spinal cord signal intensity in patients with cervical compression myelopathy: comparison between preoperative and postoperative magnetic resonance images

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Object. Increased signal intensity of the spinal cord on magnetic resonance (MR) imaging was classified pre- and postoperatively in patients with cervical compressive myelopathy. It was investigated whether postoperative classification and alterations of increased signal intensity could reflect the postoperative severity of symptoms and surgical outcomes.

Methods. One hundred and four patients with cervical compressive myelopathy were prospectively enrolled. All were treated using cervical expansive laminoplasty. Magnetic resonance imaging was performed in all patients preoperatively and after an average of 39.7 months postoperatively (range 12–90 months). Increased signal intensity of the spinal cord was divided into 3 grades based on sagittal T2-weighted MR images as follows: Grade 0, none; Grade 1, light (obscure); and Grade 2, intense (bright). The severity of myelopathy was evaluated according to the Japanese Orthopedic Association (JOA) score for cervical myelopathy and its recovery rate (100% = full recovery).

Results. Increased signal intensity was seen in 83% of cases preoperatively and in 70% postoperatively. Preoperatively, there were 18 patients with Grade 0 increased signal intensity, 49 with Grade 1, and 37 with Grade 2; postoperatively, there were 31 with Grade 0, 31 with Grade 1, and 42 with Grade 2. The respective postoperative JOA scores and recovery rates (%) were 13.9/56.7% in patients with postoperative Grade 0, 13.2/50.7% in those with Grade 1, and 12.8/40.1% in those with Grade 2, and these differences were not statistically significant. The postoperative increased signal intensity grade was improved in 16 patients, worsened in 8, and unchanged in 80 (77%). There was no significant correlation between the alterations of increased signal intensity and surgical outcomes.

Conclusions. The postoperative increased signal intensity classification reflected postoperative symptomatology and surgical outcomes to some extent, without statistically significant differences. The alteration of increased signal intensity was seen postoperatively in 24 patients (23%) and was not correlated with surgical outcome.
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KEY WORDS • cervical compressive myelopathy • cervical expansive laminoplasty • magnetic resonance imaging • signal intensity

In patients with cervical compressive myelopathy, MR imaging can provide a variety of diagnostic information without x-ray exposure. Magnetic resonance imaging can show, not only the degree of spinal canal stenosis, but also the detailed intramedullary status of the spinal cord.[7] Increased signal intensity of the spinal cord on T2-weighted MR images and decreased signal intensity on T1-weighted MR images are well-known signal changes, and those signal changes are believed to reflect various intramedullary lesions. Increased signal intensity is also often seen in patients with cervical compressive myelopathy. The diagnostic significance of increased signal intensity values has, however, remained controversial.[5,9,10] With technical advances in MR imaging hardware and software, it has become possible for us to observe various degrees of increased signal intensity. Our previous report demonstrated that the classification of preoperative increased signal intensity in sagittal T2-weighted MR images was correlated with postoperative JOA scores and the postoperative recovery rate of the JOA score.[14]

After decompressive surgery, the disappearance or decrease of increased signal intensity has been observed in some cases. Unfortunately, to our knowledge, only a few studies have been performed to investigate changes of signal intensity of the spinal cord between pre- and postoperative MR imaging sequences. Such changes in signal intensity have not been thoroughly studied. Therefore, the purpose of the present study was to investigate the degree

Abbreviations used in this paper: JOA = Japanese Orthopaedic Association; MR = magnetic resonance.

and changes of increased signal intensity in patients with cervical compressive myelopathy before and after decompressive surgery and to elucidate whether postoperative increased signal intensity and its alteration reflect the postoperative severity of myelopathy and surgical outcomes in a prospective fashion.

Clinical Materials and Methods

Patient Population

One hundred and forty-two patients with cervical compressive myelopathy were studied prospectively from April 1995 to December 2000. Among these 142 patients, 104 were followed up for more than 12 months and were enrolled in the study. There were 67 men and 37 women, with a mean age of 61.0 years (range 34–79 years). The concomitant diagnoses causing cervical compressive myelopathy were cervical spondylotic myelopathy in 74 patients, ossification of the posterior longitudinal ligament in 20 patients, cervical disc herniation in 6 patients, and calcification of the yellow ligament in 4 patients. Patients with cerebral palsy, rheumatoid arthritis, or other spinal disease were excluded from this study. Patients who needed spinal instrumentation during surgery due to a kyphotic deformity or severe instability were excluded. Patients with a traumatic cervical cord injury without a bone lesion, a so-called "central cord injury," were also excluded. The mean duration of disease was 20 months (range 1–228 months) before surgery. Expansive laminoplasty from C-3 to C-7 was performed in all patients. All patients were followed up for more than 12 months, and the latest follow-up assessment was considered to be the time when the latest MR image was obtained.

Neuroimaging Assessment

All patients underwent high-resolution MR imaging using a 1.5-T Signa (GE Medical System) MR imaging unit before and after the decompressive surgery. Some patients underwent repeated postoperative MR imaging. In those cases, the final MR image was used in this study. The latest postoperative MR image was obtained more than 1 year after surgery (average 39.7 months, range 12–90 months) in all patients. A surface coil was used, and T1- and T2-weighted sagittal views of the cervical cord were obtained using a spin echo sequence system for T1-weighted images and a fast spin echo sequence system for T2-weighted images. The slice width was 4 mm, and the acquisition matrix was 512 × 256. The sequence parameters were TR 400 msec/TE 11 msec for T1-weighted images and TR 4000 msec/TE 126 msec for T2-weighted images. Using those sagittal T2-weighted images, the increased signal intensity of the spinal cord at the narrowest level was assigned 1 of 3 grades (Grade 0, 1, or 2) by 2 independent radiologists who were very experienced in spinal imaging. Grade 0 represented no increased signal intensity, Grade 1 represented light (obscure) increased signal intensity, and Grade 2 represented intense (bright) increased signal intensity (Fig. 1). The intense increased signal intensity (Grade 2) was defined as the intensity similar to the signal of cerebrospinal fluid. The concordance rate between the 2 observers in evaluating the signal changes in these T2-weighted images was 0.88 ($k = 0.80$, $p < 0.001$). The 2 observers determined the grades by consensus.

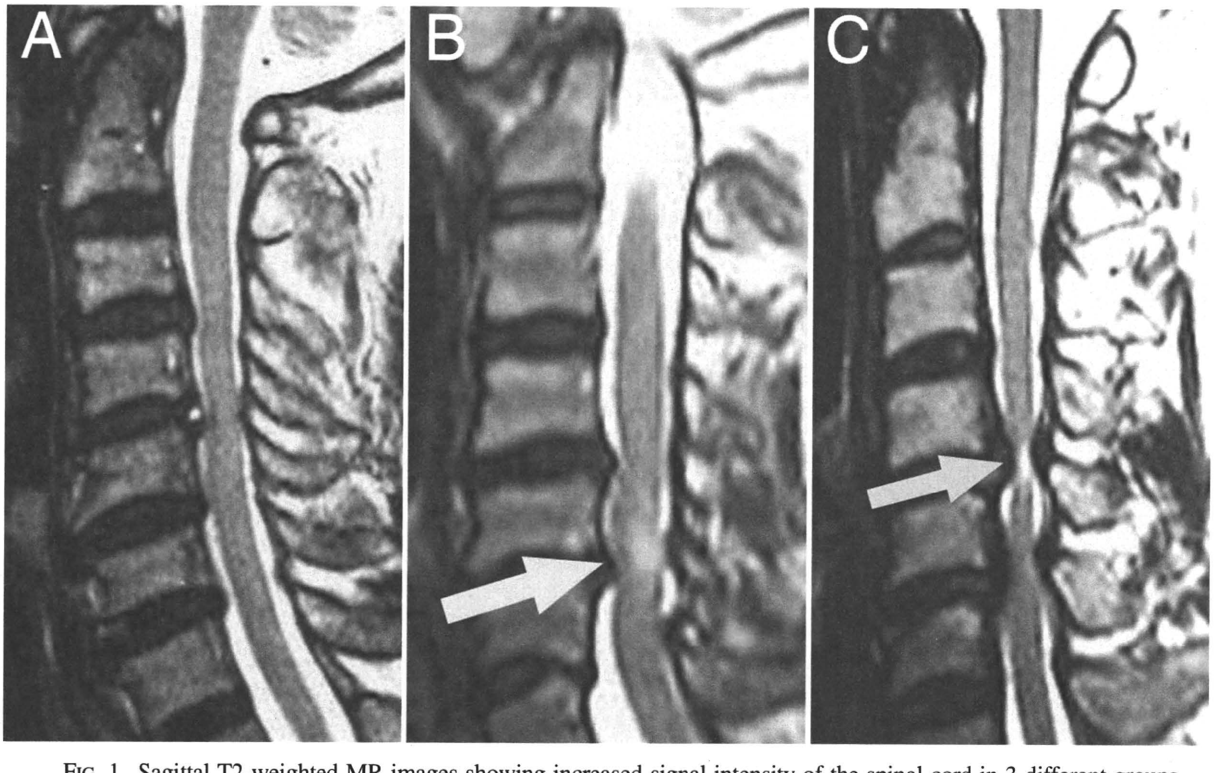

FIG. 1. Sagittal T2-weighted MR images showing increased signal intensity of the spinal cord in 3 different groups (A: Grade 0; B: Grade 1; C: Grade 2). *Arrows* indicate the site of the cervical compression myelopathy.

There was no patient preoperatively and only 1 patient postoperatively in whom low signal intensity was seen in sagittal T1-weighted images. Therefore, the signal change of sagittal T1-weighted images was not investigated in this study. Interpretation of postoperative MR images by the radiologist demonstrated that surgical decompression was appropriately performed in all patients.

Myelopathy and Recovery Assessment

The severity of myelopathy was evaluated preoperatively and postoperatively according to the JOA score for cervical myelopathy (Table 1). The improvement of postoperative symptomatology was evaluated using the recovery rate of the JOA score as assessed by the Hirabayashi method ([postoperative JOA score − preoperative JOA score] / [17 − preoperative JOA score] × 100%), with a recovery rate of 100% indicating the best postoperative improvement.

The multifactorial effects of variables such as age, duration of symptoms, preoperative JOA score, postoperative JOA score, recovery rate of JOA score, and preoperative increased signal intensity on MR imaging were studied.

Statistical Analysis

A standard StatView (SAS Institute) software package was used for statistical analysis. For nonparametric analysis, the Mann–Whitney U-test was used for analyzing differences between 2 groups, and the Kruskal–Wallis test followed by the Mann–Whitney U-test were used for analyzing differences among 3 groups. Repeated-measures analyses of variance in the same group were performed using the Wilcoxon signed-rank test. A probability value < 0.05 was considered statistically significant.

Results

The mean JOA score was 9.8 preoperatively, 13.4 at 1 year after surgery, and 13.2 at the final follow-up. The mean recovery rate of JOA score was 48.2% at the final follow-up.

In the preoperative MR imaging investigation, 86 patients (83%) had increased signal intensity of the spinal cord, whereas 18 patients (17%) did not. Preoperative MR imaging showed increased signal intensity Grade 0 in 18 patients, Grade 1 in 49, and Grade 2 in 37. Postoperatively, 73 patients (70%) showed increased signal intensity, and 31 patients (30%) did not. Postoperative MR imaging showed increased signal intensity Grade 0 in 31 patients, Grade 1 in 31, and Grade 2 in 42 (Table 2).

Among the 3 groups of patients with postoperative MR imaging Grades 0, 1, or 2, there were some differences in postoperative JOA scores and recovery rates. The respective postoperative JOA scores and recovery rates (%) were 13.9/56.7% in patients with postoperative Grade 0, 13.2/50.7% in those with Grade 1, and 12.8/40.1% in those with Grade 2, but these differences were not statistically significant. Significant differences were noted only in average patient age and duration of symptoms among those 3 groups (Table 3).

According to the grading system of increased signal intensity mentioned previously, the increased signal intensity grade was improved in 16 patients (15%), worsened in 8 (8%), and was unchanged in 80 (77%) after decompressive surgery. Among those 3 groups in whom the increased signal intensity grade was improved, worsened, or unchanged, there were no significant differences in average patient age, duration of symptoms, preoperative JOA score, postoperative JOA score, and recovery rate of JOA score (Table 4).

TABLE 1
Japanese Orthopaedic Association scale

JOA score
- I. Motor function of the upper extremity
  - 0. Impossible to eat with chopsticks or spoon
  - 1. Possible to eat with spoon, but not with chopsticks
  - 2. Possible to eat with chopsticks, but inadequate
  - 3. Possible to eat with chopsticks, but awkward
  - 4. Normal
- II. Motor function of the lower extremity
  - 0. Impossible to walk
  - 1. Needs cane or aid on flat ground
  - 2. Needs cane or aid only on stairs
  - 3. Possible to walk without cane or aid but slowly
  - 4. Normal
- III. Sensory function
  - A. Upper extremity
    - 0. Apparent sensory loss
    - 1. Minimal sensory loss
    - 2. Normal
  - B. Lower extremity (same as A)
  - C. Trunk (same as A)
- IV. Bladder function
  - 0. Complete retension
  - 1. Severe disturbance (sense of retension, dribbling, incomplete continence)
  - 2. Mild disturbance (urinary frequency, urinary hesitancy)
  - 3. Normal

Discussion

The purpose of this study was to classify increased signal intensity preoperatively and postoperatively in patients with cervical compressive myelopathy and to verify whether the postoperative classification and alterations of increased signal intensity could reflect the postoperative clinical features and surgical outcomes. The results demonstrated that the postoperative increased signal intensity classification reflected postoperative symptomatology and surgical outcomes to some extent, whereas the alteration of increased signal intensity did not correlate with surgical outcome.

Many authors have described the relationship between the existence of increased signal intensity and surgical outcomes. Some authors have reported that patients with in-

TABLE 2
Number of patients in each of 3 pre- and postoperative grades of increased signal intensity

Preop Grade	Postop Grade 0	Postop Grade 1	Postop Grade 2
0	18	0	0
1	13	28	8
2	0	3	34

TABLE 3

*Clinical features and surgical outcomes according to each grade of postoperative increased signal intensity**

Variable	Grade 0	Grade 1	Grade 2	p Value
all patients	31	31	42	
males	19	21	27	
females	12	10	15	
average age (yrs)	56.9 ± 9.4	62.2 ± 11.1	63.3 ± 7.9	0.016
duration of disease (mos)	10.2 ± 21.4	16.1 ± 21.2	31.0 ± 42.7	0.005
preoperative JOA score	10.1 ± 2.5	9.3 ± 2.8	9.9 ± 2.8	NS
postoperative JOA score	13.9 ± 2.5	13.2 ± 2.5	12.8 ± 2.6	0.129
recovery rate (%)	56.7 ± 26.5	50.7 ± 27.2	40.1 ± 34.7	0.109

* NS = nonsignificant.

creased signal intensity would show a poor prognosis after surgery,[3,8–11] but others could not find any such relationship.[5,12,13] Most of these investigators mention the existence of increased signal intensity on T2-weighted images and decreased signal intensity on T1-weighted images, but do not refer to the degrees of increased signal intensity. Only Mehalic and colleagues[3] report the grading scale (0 [none]–4 [very intense]) used to classify the relative increase in the signals from the spinal cord on T2-weighted images. Their grading scale, however, appears to be very meticulous for classifying these signal changes.

Therefore, we graded the changes in signal intensity into only 3 grades.[13] We have investigated whether the classification of increased signal intensity could be a predictor of surgical outcomes in an earlier study.[14] In that study, increased signal intensity on preoperative MR imaging was noted in 86 patients (83%); 49 patients were assessed as Grade 1, and 37 as Grade 2. The patients with preoperative increased signal intensity were significantly older, had a longer duration of symptoms, and improved less after decompressive surgery than the patients without preoperative increased signal intensity. We also found that the classification determined by preoperative MR imaging was significantly related to average patient age, duration of symptoms, postoperative JOA score, and recovery rate of JOA score. The patients with intense preoperative increased signal intensity had a longer duration of symptoms and the worst surgical outcomes.[14]

In this study, 73 patients (70%) had increased signal intensity postoperatively, and 31 patients (30%) did not. Postoperative MR imaging showed 31 patients as Grade 0, 31 as Grade 1, and 42 as Grade 2. It has been speculated that postoperative increased signal intensity is consistent with surgical outcomes. There was some difference in the postoperative JOA score and recovery rate according to the postoperative classification of increased signal intensity, but the difference was not statistically significant. There may be some reasons why we failed to see a significant difference. The image quality of postoperative MR im-aging is often deteriorated due to the surgical intervention. Although postoperative MR images were obtained in the same protocol, the slice obtained was slightly different from that used in the preoperative MR images. These imaging factors might influence the difference between preoperative and postoperative classification as a surgical predictor.

After the decompressive surgery, increased signal intensity grade was improved in 16 patients (15%), worsened in 8 (8%), and unchanged in 80 (77%); alteration of increased signal intensity was therefore observed in 24 patients (23%). Both the "worsened" and "unchanged" groups showed moderate postoperative clinical improvement, similar to the "improved" group. Several authors reported that the patients whose increased signal intensity decreased after surgery showed a better recovery rate postoperatively than the patients whose increased signal intensity increased further or did not change after surgery.[2,3,5,10,11] In contrast, others observed that postoperative alterations in increased signal intensity did not correlate with postoperative outcomes.[6,13] We could not find any significant differences in postoperative clinical symptoms and surgical results among the 3 groups (increased signal intensity grade im-

TABLE 4

*Clinical features and surgical outcomes according to 3 groups of postoperative alterations in increased signal intensity**

Variable	Improved	Unchanged	Worsened
all patients	16	80	8
males	8	53	6
females	8	27	2
average age (yrs)	58.8 ± 8.9	61.1 ± 10.1	64.5 ± 6.1
duration of disease (mos)	8.7 ± 6.6	22.8 ± 35.6	19.8 ± 32.0
preoperative JOA score	9.8 ± 2.6	9.7 ± 2.8	10.5 ± 2.6
postoperative JOA score	13.0 ± 2.8	13.2 ± 2.6	14.0 ± 1.4
recovery rate (%)	46.6 ± 26.7	48.0 ± 32.8	53.5 ± 16.6

*All differences between the groups in relation to average age, duration of disease, preoperative and postoperative JOA score, and recovery rate were not significant.

proved, worsened, or unchanged). The number of patients in both the improved and worsened groups was relatively small. The improved group had a preoperative increased signal intensity grade of 1 or 2, whereas the worsened group had a preoperative increased signal intensity grade of 0 or 1. Previous studies have shown that the signal intensity of the spinal cord changes from none to light increased signal intensity and finally to intense increased signal intensity with progression of the disease, and the recovery rate after surgery decreases accordingly. Although the classification of increased signal intensity was visually changed postoperatively, the surgical outcomes of the patients should have been influenced by the original increased signal intensity seen in preoperative MR imaging.

A neuropathological study showed that there appeared to be a common pattern of lesion progression in cervical spondylotic myelopathy, from mild alteration of the spinal cord to a severe alteration.[1] Other studies involving histopathological examination and MR imaging also showed that increased signal intensity without signal change on T1-weighted images nonspecifically appeared in mildly altered lesions, such as loss of nerve cells, gliosis and edema in gray matter, Wallerian degeneration, and demyelination and edema in white matter.[4,7] Increased signal intensity of the spinal cord on T2-weighted images has been understood to include a wide spectrum of compressive myelomalacic diseases and to reflect a wide range of spinal cord recuperative potentials.[5] In the present study, Grade 1 increased signal intensity, which had been noted preoperatively, disappeared postoperatively in 13 (27%) of 49 patients, whereas Grade 2 disappeared postoperatively in 3 (8%) of 37 patients. Based on our findings and previous studies, it can be concluded that light increased signal intensity reflects mild neuropathological alterations in the spinal cord and suggests greater recuperative potential, and intense increased signal intensity represents severe alterations and indicates less recuperative potential.

A potential limitation of the present study is that the signal changes of the spinal cord on sagittal T2-weighted images were investigated, but neither of the sagittal or axial T1-weighted images were studied. In this study, cases involving central spinal cord injury were excluded. There was no case that showed low signal intensity on preoperative sagittal T1-weighted images. Only 1 patient showed low signal intensity postoperatively. Because the spinal cord is severely compressed and its surface area is narrowed at the narrowest stenotic level, it is difficult to classify signal changes of the axial images at that level. Therefore, increased signal intensity of only sagittal T2-weighted images was investigated.

In this study, however, a relatively large number of patients who underwent the same single procedure (expansive laminoplasty) were investigated in a prospective fashion. Both preoperative and postoperative MR images were obtained in all patients, and postoperative MR imaging was performed at least 1 year after surgery.

Conclusions

Increased signal intensity of the spinal cord on T2-weighted MR imaging was classified pre- and postoperatively in patients with cervical compressive myelopathy. Postoperative increased signal intensity on sagittal T2-weighted MR images reflected postoperative symptoms and surgical results to some extent, but not as much as preoperative increased signal intensity. Alteration between preoperative increased signal intensity and postoperative increased signal intensity was observed in 24 patients (23%) and was not correlated with clinical features and surgical outcomes.

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Prediction of Clinical Results of Laminoplasty for Cervical Myelopathy Focusing on Spinal Cord Motion in Intraoperative Ultrasonography and Postoperative Magnetic Resonance Imaging

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Study Design. Retrospective analysis of preoperative imaging and clinical data from patients undergoing cervical expansive laminoplasty for cervical myelopathy.

Objective. To investigate preoperative parameters that predict 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), and to evaluate the association between clinical outcome and spinal cord floating.

Summary of Background Data. Intraoperative US has been used to evaluate the status of the spinal cord after cervical laminoplasty for cervical myelopathy. Few studies have evaluated the predictive preoperative parameters for intraoperative US results.

Methods. Imaging and clinical outcome data were collected from 101 consecutive patients who underwent cervical expansive laminoplasty for cervical myelopathy at Kaikoukai Nagoya Kyouritsu Hospital, Japan, from April 2004 to April 2008. The preoperative parameters associated with spinal cord floating in intraoperative US and postoperative MR images were investigated. Predictive parameters for the rate of recovery according to the Japanese Orthopedic Association score for cervical myelopathy at each follow-up session were also investigated.

Results. Predictive parameters for spinal cord floating after decompression in intraoperative US were the cervical vertebrae 2 to 7 (C2–C7) sagittal alignment in the standing neutral position on preoperative plain radiograph radiography (cut-off value = 3°) and the C5/6 "beak angle" in preoperative MRI (cut-off value = 20°). A predictive parameter for spinal cord floating in postoperative MRI was the C5/6 beak angle in preoperative MRI (cut-off value = 21°). The preoperative Japanese Orthopedic Association score and spinal cord floating at anterior elements of the cervical spine in intraoperative US were predictive parameters for clinical outcome.

Conclusion. Intraoperative US was more useful than postoperative MRI for predicting the clinical outcome of cervical expansive laminoplasty. Knowledge of the predictive parameters for spinal cord floating after cervical expansive laminoplasty could help evaluate the limitations of posterior decompression.

Key words: cervical myelopathy, intraoperative ultrasonography, laminoplasty. **Spine 2009;34:2634–2641**

Intraoperative ultrasonography (US) is a noninvasive imaging method that has been employed to evaluate the decompression status of the spinal cord[1–7] and the location of spinal tumors.[2,8,9] Intraoperative US has often been used in cervical expansive laminoplasty for cervical myelopathy, to identify successful spinal cord decompression. The success of posterior decompression is judged by the presence or absence of spinal cord floating at anterior elements of the spinal canal,[3,10] or by spinal cord morphology.[4,11] A previous study reported that detection of spinal cord floating at the anterior elements after posterior decompression resulted in a good clinical outcome in patients who underwent cervical expansive laminoplasty for cervical myelopathy.[10]

To our knowledge, no previous report has evaluated the predictive significance of preoperative parameters for the presence or absence of spinal cord floating in intraoperative US. Moreover, in posterior decompression of the cervical spine (without posterior fusion), fluoroscopic control of alignment of the cervical spine might not be performed in many institutions; therefore, the surgical alignment of the cervical spine might not correspond precisely to the neutral alignment in each case. We proposed that an analysis of the accumulating data would help to evaluate the predictive efficacy of intraoperative US of the spinal cord after posterior decompression.

Postoperative magnetic resonance imaging (MRI) can be used to evaluate the spinal cord status after posterior decompression. However, because it is performed using the same sized headrest in the supine position, the neutral alignment in each case cannot be reproduced. Furthermore, the weight of the spinal cord itself might affect the evaluation of spinal cord floating.

The current study explored preoperative parameters for predicting the floating status of the spinal cord in intraoperative US and postoperative MRI, and the asso-

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ciation with clinical outcome in patients who underwent expansive cervical laminoplasty for cervical myelopathy.

Materials and Methods

Study Design

This retrospective study evaluated preoperative imaging parameters and clinical data from patients who underwent cervical expansive laminoplasty of the cervical vertebrae 3 to 7 (C3–C7) for cervical myelopathy at Kaikoukai Nagoya Kyouritsu Hospital, Japan. All operations were performed by 2 trained spinal surgeons. One set of images was collected from preoperative MRI, plain radiograph radiography, postoperative MRI, and an intraoperative US movie file. Various image parameters were measured, and their significance to the spinal cord floating status in intraoperative US and postoperative MRI was evaluated. Clinical outcome was reviewed and the Japanese Orthopedic Association (JOA) score for cervical myelopathy was calculated at each follow-up session. The Hirabayashi recovery rate of each case was recorded and evaluated to determine the significant parameters for clinical outcome.

Inclusion/Exclusion Criteria

All adult patients who underwent cervical expansive laminoplasty at Kaikoukai Nagoya Kyouritsu Hospital from April 2004 to April 2008 were included. The study group comprised 101 consecutive patients (71 male and 30 female; mean age = 63.6 ± 11.6 years). The causes of cervical myelopathy were spondylosis (n = 71), ossification of the posterior longitudinal ligament (OPLL; n = 18), and disc herniation with multilevel canal stenosis due to spondylosis (n = 12). None of the patients had massive consequent-type OPLL that pressed on the spinal cord except at the intervertebral level.

Intraoperative US was performed in all 101 cases. Postoperative MRI was performed in 99 cases within 1 month of the operation.

Patients who had symptomatic neurologic disorders or were receiving hemodialysis (HD) were excluded from the evaluation of clinical outcome; in the latter case, this was because the function of the detrusor could not be evaluated and the JOA score includes this measure. In total, 26 patients were excluded for the following reasons: symptomatic lumbar canal stenosis (LSCS; n = 12), symptomatic LSCS with thoracic myelopathy (n = 2), symptomatic LSCS with thoracic OPLL (n = 2), symptomatic LSCS with thoracic vertebra 12 (Th12) late collapse (n = 1), symptomatic thoracic OPLL (n = 1), HD (n = 3), HD with symptomatic LSCS (n = 3), HD with carpal tunnel syndrome (n = 1), and brain tumor (n = 1). In total, 75 cases were included in the analysis of the association between clinical outcome and spinal cord floating in intraoperative US (mean follow-up period = 1.1 ± 0.3 years), and 73 in the analysis of the association between clinical outcome and spinal cord floating in postoperative MRI (mean follow-up period = 1.1 ± 0.3 years).

Surgical Procedure

Under general anesthesia, each patient was placed in a prone position. Head fixation was achieved using a Mayfield-type frame, with the same spinal surgeon holding the patient's head and adjusting the neck position to as neutral an alignment as possible in all 101 cases. There was no fluoroscopic control of alignment of the cervical spine. The skin incision was made at the C2–Th1 level, and the C3–Th1 laminas were exposed. The C3–C7 spinous processes were resected, then C3–C7 expansive laminoplasty (French door-open type) was performed using a surgical burr. Each lamina was opened to the bilateral side and 22-gauge needles (cut to 18 mm length) were placed in the gaps to prevent closure. Intraoperative US was performed using an EUB-6500 scanner (Hitachi, Japan) set at 13 Hz in B-mode with an EUP-L34T echo probe (Hitachi, Japan). For a midsagittal view, the probe was placed so the canalis centralis could be visualized. An axial view was also evaluated. The 22-gauge needle was then removed, and lamina spacers made from spinous process bone were applied between the C3–C7 split lamina. Two drains were positioned and the wound was closed layer-by-layer.

Data Collection

Summarized Results for Intraoperative US and Postoperative MRI. Data on the presence or absence of spinal cord floating at the anterior elements of the spine, and the distribution of the intervertebral level at which floating was not detected, were summarized. For cases with floating deficits at several intervertebral levels, each was summarized individually. For the intraoperative US midsagittal view, cases in which the spinal cord floating rhythmically corresponded to the patient's arterial pulsations and the echo-free space of the anterior of the spinal cord were defined as "complete floating (+) in US cases" (CF-US [+] cases). Cases with floating deficits of the spinal cord at any intervertebral level, or a seesaw-like motion of the spinal cord that indicated insufficiency of floating, were defined as "complete floating (−) in US cases" (CF-US (−) cases; Figure 1). The axial view was not included in the analysis because when complete spinal cord floating was observed on the midsagittal view it was also demonstrated in the axial view.

Data on the presence or absence of spinal cord floating at the anterior elements of the spine, and the distribution of the intervertebral level at which floating was not detected in postoperative MRI, were summarized in the same way. Postoperative MRI was performed using the 1.5 T MRI system (GE Medical System, Milwaukee, WI) in the supine position with the same head rest in all 99 cases. For the midsagittal view in postoperative MRI, cases that presented a high-intensity zone (≥1 mm) on T2-weighted images between the spinal cord and the anterior elements of the spine, with no hollow corresponding to protrusion of the anterior elements of the spine on the surface of the anterior aspect of the spinal cord, were defined as "complete floating (+) in MRI cases" (CF-MRI (+) cases; Figure 2). Cases that presented deficits of the high-intensity zone on T2-weighed images as described above at any intervertebral level, or remained hollow on the surface of the anterior aspect of the spinal cord, were defined as "complete floating (−) on MRI cases" (CF-MRI [−] cases; Figure 2).

The presence or absence of spinal cord floating in intraoperative US and postoperative MRI was also summarized, and the rate of coincidence was calculated.

Detection of Predictive Parameters for Spinal Cord Floating Status in Intraoperative US and Postoperative MRI. We investigated parameters that might predict the spinal cord floating status in intraoperative US and postoperative MRI. The preoperative parameters examined were the C2–C7 lordotic angle in the neutral standing position, the presence of local kyphosis, age, and gender. We also calculated and analyzed the "beak angle" in preoperative MRI at each intervertebral level, which might represent the degree of protrusion of the anterior elements of the spine, such as disc bulging and osteophytes (Figure

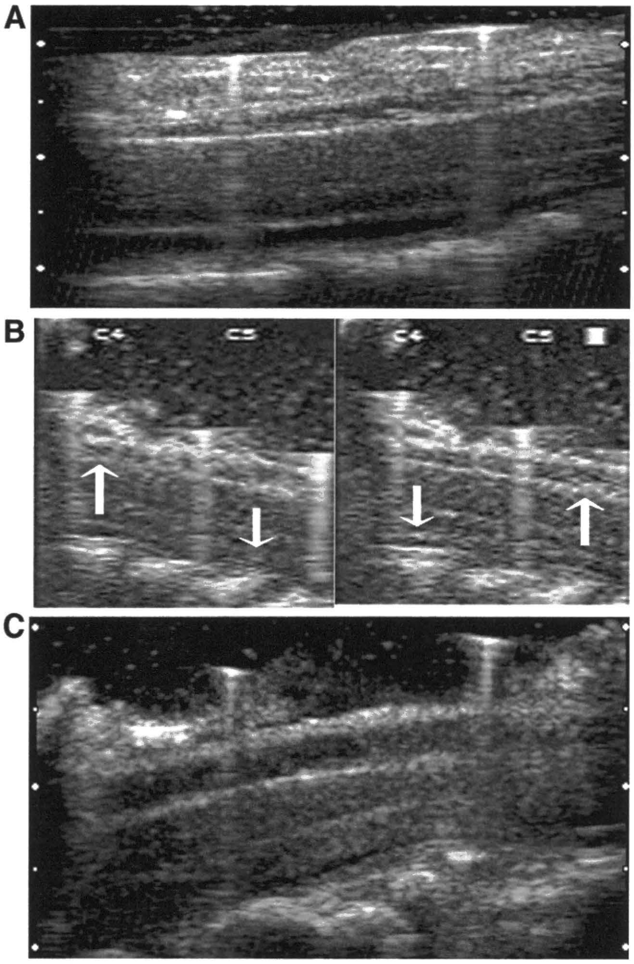

Figure 1. Intraoperative US images. **A,** CF-US (+) case. **B,** CF-US (−) case with seesaw-like motion of the spinal cord judged not to represent complete spinal cord floating. **C,** CF-US (−) case.

3). It might also reflect the local alignment at each level. If local lordosis decreases, the beak angle of the corresponding level increases. Decreased local lordosis might enhance the effect of protrusion of the anterior elements of the spine. We therefore established the beak angle to reflect both the degree of protrusion and the local alignment.

We also calculated the cut-off values of parameters that might affect the spinal cord floating status in intraoperative US and postoperative MRI.

In addition, we analyzed parameters that were predictive for the spinal cord floating status at each intervertebral level individually.

Evaluation of Beak Angles. The average beak angle at each intervertebral level was calculated and compared. We also evaluated the correlation between the beak angle and both the local alignment and the degree of protrusion of the anterior element of the spine to certify the propriety of our concept about the beak angle. To eliminate the differences of the size of the spine among the cases, the degree of the protrusion of the anterior element of the spine was indicated as the ratio to the average of the size of the upper and the lower vertebral bodies (Figure 3). The ratio was calculated by the formula as follows: $a/[(b + c)/2]$.

Furthermore, we examined the association between the beak angle at C5/6 and at other intervertebral levels.

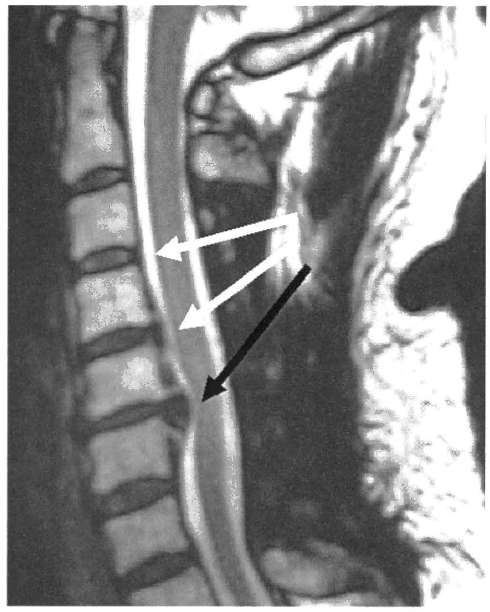

Figure 2. Postoperative MRI image. The white arrows indicate CF-MRI (+) lesions. The black arrow indicates a CF-MRI (−) lesion.

Association Between Clinical Outcome and Spinal Cord Floating or Other Parameters. We investigated the association between the rate of recovery of the JOA score at each follow-up session (1 month, 6 months, and 1 year after the operation) and the spinal cord floating status in intraoperative US and postoperative MRI. The patients were divided into 2 groups based on the JOA score recovery rate (≥50% or <50%). The preoperative JOA score was also examined.

Statistical Analysis

The significance of parameters was evaluated by monovariant logistic analysis, followed by multivariant analysis if several

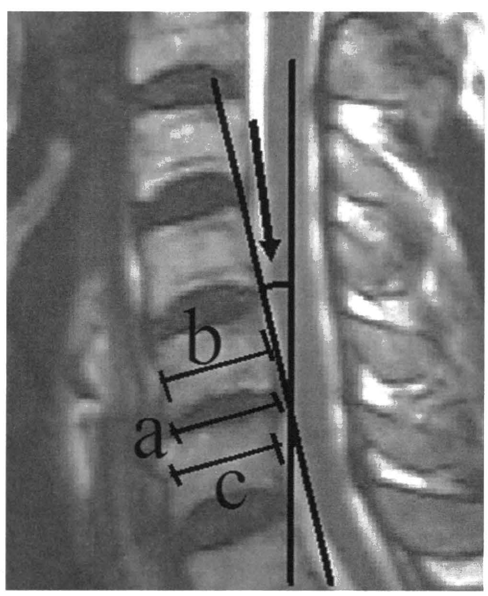

Figure 3. Schematic showing the beak angle. The arrow indicates the beak angle at the C5/6 intervertebral level. The degree of the protrusion of the anterior element of the spine was calculated by the formula as follows: $a/[(b + c)/2]$.

parameters showed significance. We also plotted receiver operating characteristic curves to investigate the cut-off value of each parameter shown to be statistically significant by logistic analysis. The Mann-Whitney *U* test was used to evaluate associations between 2 groups. Analysis of variance and the *post hoc* test (Bonferroni-Dunn) were used to evaluate associations between 3 or more groups. Correlation was evaluated using the Spearman's rank correlation coefficient. $P < 0.05$ was considered statistically significant.

■ Results

Summarized Results of Intraoperative US and Postoperative MRI

Intraoperative US detected 55 CF-US (+) cases and 46 CF-US (−) cases. Lesions where spinal cord floating could not be detected were seen at C2/3 (n = 1), C3/4 (n = 16), C4/5 (n = 18), C5/6 (n = 26), and C6/7 (n = 8). Deficits of complete spinal cord floating in intraoperative US were most frequent at the C5/6 intervertebral level. Postoperative MRI detected 59 CF-MRI (+) cases and 40 CF-MRI (−) cases. Lesions where spinal cord floating could not be detected were seen at C2/3 (n = 1), C3/4 (n = 13), C4/5 (n = 11), C5/6 (n = 21), and C6/7 (n = 4). Deficits of complete spinal cord floating in postoperative MRI were most frequent at the C5/6 intervertebral level.

The presence or absence of spinal cord floating in intraoperative US and postoperative MRI is summarized in Table 1 (n = 99). The rate of coincidence was 64.6%. The cases where the spinal cord floating status differed between intraoperative US and postoperative MRI were most frequently CF-US (−)/CF-MRI (+) (n = 26).

Detection of Predictive Parameters for Spinal Cord Floating Status in Intraoperative US and Postoperative MRI

Monovariant logistic analysis revealed the predictive parameters for spinal cord floating status in intraoperative US (n = 101; Table 2) as C2–C7 lordotic angle (P = 0.0002, odds ratio [OR] = 1.072, 95% confidence interval [CI] 1.034–1.111), presence of local kyphosis (P = 0.0182, odds ratio = 0.711, 95% CI 0.232–0.997), and C5/6 beak angle (P = 0.0158, OR = 0.956, 95% CI 0.921–0.991). Multivariant logistic analysis revealed C2–C7 lordotic angle (P = 0.0094, OR = 1.065, 95% CI 1.016–1.118) and C5/6 beak angle (P = 0.0293, OR = 0.955, 95% CI 0.915–0.995) to be statistically significant parameters for spinal cord floating in intraoperative US.

In postoperative MRI, monovariant logistic analysis revealed only the C5/6 beak angle as a statistically significant parameter (P = 0.0231, OR = 0.958, 95% CI

Table 1. Presence or Absence of Complete Floating of the Spinal Cord From the Anterior Elements of the Cervical Spine (n = 99)

	CF-MRI (+) Cases	CF-MRI (−) Cases
CF-US (+) cases	35	9
CF-US (−) cases	26	29

Table 2. Significant Parameters for Floating of the Spinal Cord

	P	OR	95% CI
Intraoperative US			
Monovariant			
C2–C7 lordotic angle	0.0002*	1.072	1.034–1.111
ROM: total	0.7711	0.996	0.969–1.023
Local kyphosis (+)	0.0182*	0.375	0.166–0.846
C3/4 beak angle	0.9890	1.000	0.969–1.032
C4/5 beak angle	0.9980	1.000	0.965–1.036
C5/6 beak angle	0.0158*	0.956	0.921–0.991
C6/7 beak angle	0.1384	1.033	0.990–1.078
Age	0.0041*	1.059	1.018–1.102
Gender	0.3084	1.562	0.662–3.684
Multivariant			
C2–C7 lordotic angle	0.0094*	1.065	1.016–1.118
Local kyphosis (+)	0.7142	1.203	0.448–3.229
C5/6 beak angle	0.0293*	0.955	0.915–0.995
Age	0.2812	1.025	0.980–1.074
Postoperative MRI			
Monovariant			
C2–C7 lordotic angle	0.3706	1.014	0.984–1.045
Local kyphosis	0.9103	1.048	0.466–2.354
C3/4 beak angle	0.1585	1.024	0.991–1.059
C4/5 beak angle	0.2504	0.979	0.943–1.015
C5/6 beak angle	0.0231*	0.958	0.923–0.994
C6/7 beak angle	0.4355	1.017	0.975–1.060
Age	0.9544	1.001	0.966–1.037
Gender	0.5972	0.791	0.331–1.889

*$P < 0.05$.

0.923–0.994) for the spinal cord floating status (n = 99; Table 2).

The cut-off value of each significant parameter for complete spinal cord floating in intraoperative US was 3° for C2/7 lordotic angle (Figure 4A) and 20° for C5/6 beak angle (Figure 4B). Monovariant logistic analysis confirmed the significance of the cut-off values of ≥3° for C2–C7 lordotic angle (P = 0.0049, OR = 4.000, 95% CI 1.500–10.500) and ≥20° for C5/6 beak angle (P = 0.0051, OR = 0.308, 95% CI 0.135–0.702).

The cut-off value of the significant parameter for complete spinal cord floating in postoperative MRI was ≥21° for C5/6 beak angle (Figure 4C). Monovariant logistic analysis confirmed the significance of this cut-off value (P = 0.0190, OR = 0.372, 95% CI 0.161–0.855).

We also investigated predictive parameters for spinal cord floating status at each intervertebral level individually.

Monovariant logistic analysis revealed the significant parameters for failure of spinal cord floating at the C3/4 level in intraoperative US as C3/4 beak angle (P = 0.0120, OR = 0.927, 95% CI 0.873–0.983) and C2–C7 lordotic angle (P = 0.0132, OR = 1.090, 95% CI 1.018–1.168; Table 3). Multivariant logistic analysis confirmed the significance of both C3/4 beak angle ($P <$ 0.0001, OR = 0.929, 95% CI 0.876–0.986) and C2–C7 lordotic angle (P = 0.0414, OR = 1.084, 95% CI 1.003–1.171; Table 3). Monovariant logistic analysis revealed only C4/5 beak angle as a significant parameter for failure of spinal cord floating at the C4/5 level in intraoperative US (P = 0.0399, OR = 0.934, 95% CI 0.875–0.997; Table 3), and only C6/7 beak angle as significant

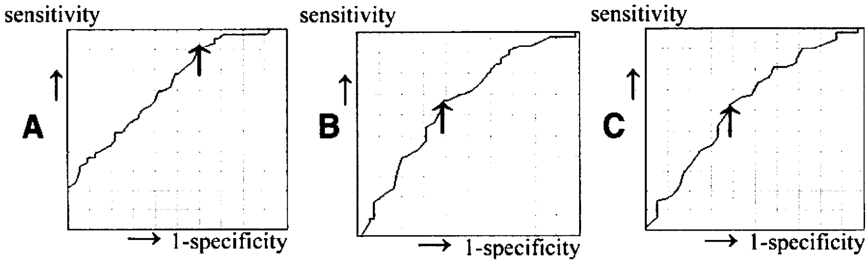

Figure 4. ROC curves analyzing cut-off values. **A**, C2–C7 lordotic angle in intraoperative US. **B**, C5/6 beak angle in intraoperative US. **C**, C5/6 beak angle in postoperative MRI. The arrows indicate the plotted points that determine cut-off values.

at the C6/7 level (P = 0.0051, OR = 0.887, 95% CI 0.815–0.965; Table 3).

Monovariant logistic analysis found the C3/4 beak angle to be a significant parameter for failure of spinal cord floating at the C3/4 level in postoperative MRI (P = 0.0002, OR = 0.870, 95% CI 0.808–0.937; Table 4), and the C5/6 beak angle to be significant for failure of spinal cord floating at the C5/6 level (P = 0.0010, OR = 0.921, 95% CI 0.878–0.967).

Evaluation of Beak Angles

As the beak angle was found to be an important parameter for spinal cord floating status in both intraoperative US and postoperative MRI, we investigated this factor in more detail.

The average beak angle was 16.4° ± 12.6° at C3/4, 17.4° ± 11.2° at C4/5, 21.0° ± 11.8° at C5/6, and 14.4° ± 9.7° at C6/7. The beak angle was more significant at C5/6 than at C3/4 (P = 0.0046), C4/5 (P = 0.0263), or C6/7 (P < 0.0001).

The beak angle significantly correlated with the local alignment at each intervertebral level (at C3/4; P < 0.0001, correlation coefficient = −0.502, at C4/5 level; P < 0.0001, correlation coefficient = −0.545, at C5/6 level; P < 0.0001, correlation coefficient = −0.647, at C6/7 level; P < 0.0001, correlation coefficient = −0.583, respectively). The beak angle also significantly correlated with the degree of the protrusion of the anterior element of the spine at each intervertebral level (at C3/4 level; P < 0.0001, correlation coefficient = 0.768, at C4/5 level; P < 0.0001, correlation coefficient = 0.681, at C5/6 level; P < 0.0001, correlation coefficient = 0.649, at C6/7 level; P < 0.0001, correlation coefficient = 0.653, respectively).

Among all 101 patients who underwent intraoperative US and all 99 patients who underwent postoperative MRI, the C5/6 beak angle was determined to be a significant parameter, even though cases with deficits of spinal cord floating at other intervertebral levels were included. To investigate this unexpected result further, the cases were divided into 2 groups based on whether the C5/6

Table 3. Individual Investigation of Predictive Parameters for Floating Status of the Spinal Cord in Intraoperative US at Each Intervertebral Level

	P	OR	95% CI
At C3/4: monovariant			
C3/4 beak angle	0.0120*	0.927	0.873–0.983
C2–C7 lordotic angle	0.0132*	1.090	1.018–1.168
Age	0.7438	0.989	0.927–1.055
Gender	0.2906	0.315	0.037–2.682
Local kyphosis (+)	0.1016	0.252	0.048–1.313
At C3/4: multivariant			
C3/4 beak angle	<0.0001*	0.929	0.876–0.986
C2–C7 lordotic angle	0.0414*	1.084	1.003–1.171
At C4/5: monovariant			
C4/5 beak angle	0.0399*	0.934	0.875–0.997
C2–C7 lordotic angle	0.2622	1.029	0.979–1.082
Age	0.6435	0.986	0.930–1.046
Gender	0.9827	1.016	0.244–4.226
Local kyphosis (+)	0.7659	0.820	0.222–3.029
At C5/6: monovariant			
C5/6 beak angle	0.1287	0.966	0.923–1.010
C2–C7 lordotic angle	0.0945	1.035	0.994–1.079
Age	0.1395	1.034	0.989–1.080
Gender	0.5811	1.364	0.453–4.104
Local kyphosis (+)	0.2327	0.525	0.182–1.513
C6/7: intraoperative US			
C6/7 beak angle	0.0051*	0.887	0.815–0.965
C2–C7 lordotic angle	0.5155	0.981	0.927–1.039
Age	0.8610	1.006	0.942–1.074
Gender	0.3720	0.374	0.043–3.246
Local kyphosis (+)	0.1207	5.510	0.638–47.567

*P < 0.05.

Table 4. Individual Investigation of Predictive Parameters for Floating Status of the Spinal Cord in Postoperative MRI at Each Intervertebral Level

	P	OR	95% CI
At C3/4: monovariant			
C3/4 beak angle	0.0002*	0.870	0.808–0.937
C2–C7 lordotic angle	0.1623	1.033	0.987–1.081
Age	0.7134	0.990	0.940–1.043
Gender	0.9282	1.060	0.299–3.751
Local kyphosis (+)	0.5213	0.682	0.212–2.196
At C4/5: monovariant			
C4/5 beak angle	0.2011	0.961	0.903–1.022
C2–C7 lordotic angle	0.9916	1.000	0.955–1.048
Age	0.7303	0.990	0.936–1.047
Gender	0.6098	1.407	0.379–5.215
Local kyphosis (+)	0.9949	1.004	0.286–3.530
At C5/6: monovariant			
C5/6 beak angle	0.0010*	0.921	0.878–0.967
C2–C7 lordotic angle	0.6848	1.007	0.972–1.044
Age	0.5048	1.014	0.973–1.056
Gender	0.1431	2.107	0.777–5.714
Local kyphosis (+)	0.4808	0.707	0.270–1.853
At C6/7: monovariant			
C6/7 beak angle	0.1012	0.926	0.845–1.015
C2–C7 lordotic angle	0.2677	1.046	0.966–1.133
Age	0.5860	1.023	0.943–1.110
Gender	0.8340	0.782	0.078–7.833
Local kyphosis (+)	0.4158	2.596	0.261–25.851

*P < 0.05.