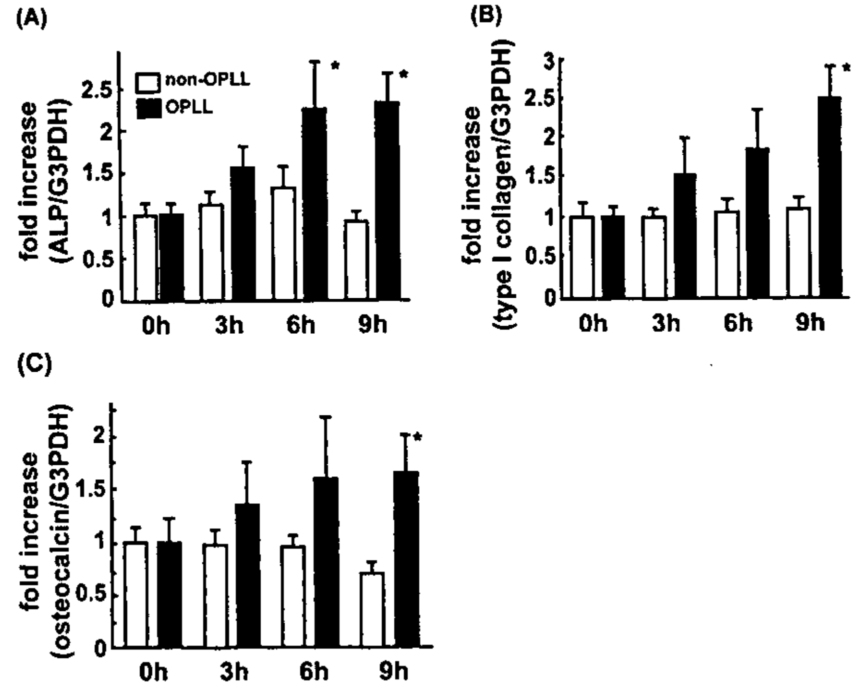

Fig. 3. RT-PCR analysis of ALP and type I collagen and osteocalcin mRNAs in spinal ligament cells from OPLL and non-OPLL patients (cases 1–10 and 15–24, respectively) following subjection to uni-axial cyclic stretch. The time courses of changes in the relative amounts of PCR products for the indicated time periods are shown. The densitometric quantification of the electrophoretic profiles of each gene was normalized to the corresponding G3PDH signal. The fold increases of ALP, type I collagen and osteocalcin mRNAs to 0 h are shown. ALP/G3PDH ± SEM at 0 h were non-OPLL; 1.11 ± 0.23 and OPLL; 1.14 ± 0.24. Type I collagen/G3PDH ± SEM at 0 h were non-OPLL; 1.28 ± 0.27 and OPLL; 1.16 ± 0.21. Osteocalcin/G3PDH ± SEM at 0 h were non-OPLL; 3.82 ± 0.55 and OPLL; 7.03 ± 1.52. *Significantly different from 0 h, $P < 0.05$.

regardless of their activation state to noncompetitively inhibit phosphorylation of ERK1/2. Therefore, we examined the effect of U0126 on the stretch-induced expressions of Cbfa1, ALP, type I collagen and integrin β1 mRNAs in OPLL cells (cases 10–14) and non-OPLL cells (cases 23–27). Cells were preincubated with or without 40 μM of U0126 for 10 min and then subjected to cyclic stretch for 9 h in the presence or absence of U0126. As shown in Figure 5A – 5E, the expressions of Cbfa1, ALP, type I collagen, osteocalcin and integrin β1 in OPLL cells were increased by the cyclic stretch by about 173% ($P < 0.05$), 274% ($P < 0.001$), 295% ($P < 0.05$), 181% (no significant difference) and 155% ($P < 0.05$), respectively, compared to the group without stretch or U0126, whereas no changes were observed in non-OPLL cells. U0126 suppressed the stretch-induced expressions of Cbfa1, ALP and type I collagen and osteocalcin to about 116%, 140%, 116%, 144%, respectively, compared to the group without stretch or U0126. The stretch-induced expression of integrin β1 was hardly suppressed by U0126 and it remained about 148% compared to the group without stretch or U0126. In non-OPLL cells, expression of integrin β1 was suppressed slightly by stretch (85%, $P < 0.01$), U0126 (84%, $P < 0.01$), stretch and U0126 (81%, $P < 0.001$) compared to the group without stretch or U0126.

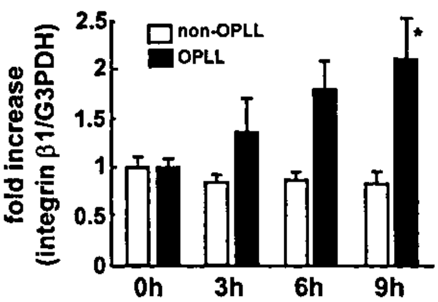

Fig. 4. RT-PCR analysis of the integrin β1 subunit mRNA in spinal ligament cells from OPLL and non-OPLL patients (cases 1–10 and 15–24, respectively) following subjection to uni-axial cyclic stretch. The time courses of changes in the relative amounts of PCR products for the indicated time periods are shown. The densitometric quantification of the electrophoretic profiles of each gene was normalized to the corresponding G3PDH signal. The fold increases of the integrin β1 subunit mRNA to 0 h (integrin β1 subunit/G3PDH ± SEM were non-OPLL; 1.55 ± 0.23 and OPLL; 1.67 ± 0.22) are shown. *Significantly different from 0 h, $P < 0.05$.

Discussion

Mechanical stress is known as a regulator of bone metabolism. It has been reported that mechanical stress increases the osteoblast cell number [36] and the expressions of alkaline phosphatase, type I collagen, osteopontin and osteocalcin, known as markers of osteoblast differentiation [37, 38]. Miyagawa et al. [39] and Tominaga [40] evaluated the relationship between the progression of ossification and the mobility of the cervical spine and reported that ossification tends to progress in patients with high mobility. Nakamura et al. [41] analyzed motions of the cervical spine and observed ossification area with excessive movements of the cervical spine. Based on these reports, OPLL may tend to progress at the area where abnormal strain exists, which is beyond physiological ranges.

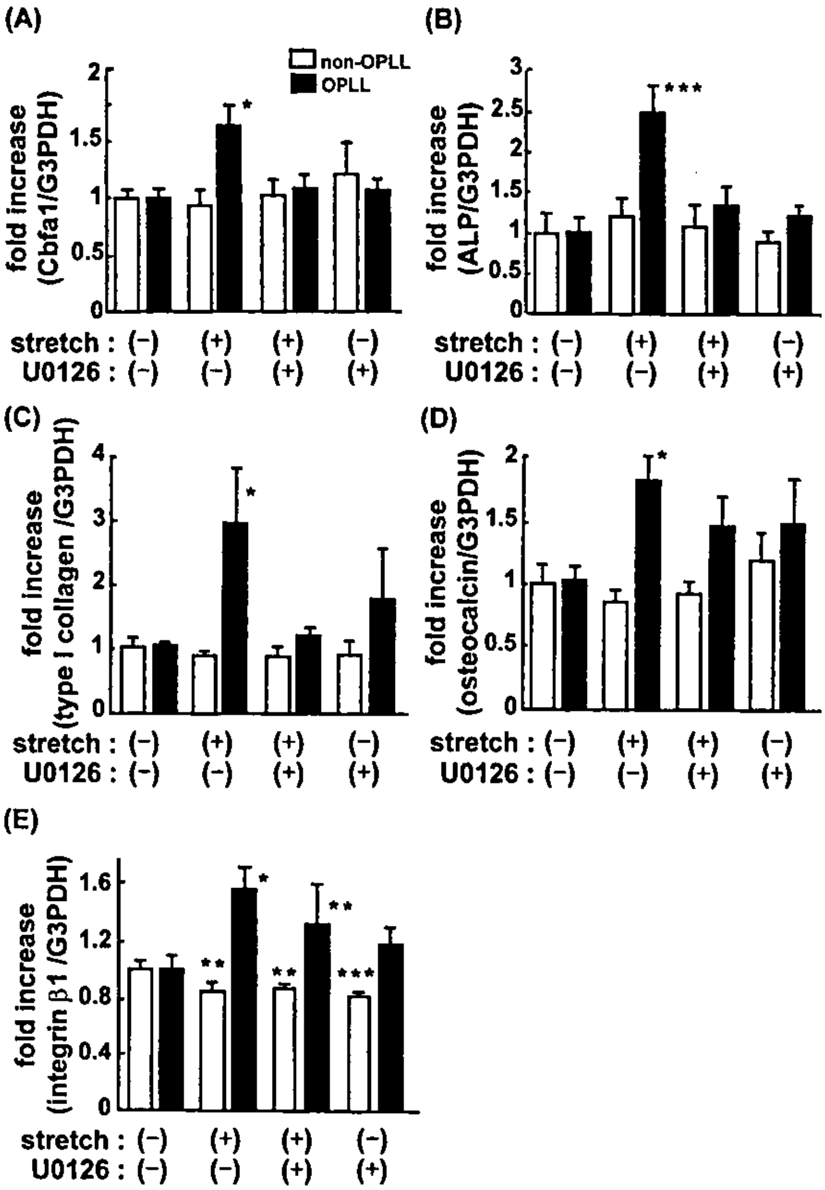

Fig. 5. Effect of MEK inhibitor U0126 on stretch-induced Cbfa1 type II, ALP, type I collagen, osteocalcin and integrin β1 expressions in OPLL cells. Cells derived from OPLL and non-OPLL patients (cases 10–14 and 23–27, respectively) were treated with 40 μM of U0126 for 12 h, and then subjected to 9 h of uni-axial cyclic stretch. After the stimulation, RT-PCR analysis of Cbfa1 type II (A), ALP (B), type I collagen (C), osteocalcin (D) and integrin β1 subunit (E) mRNAs in OPLL cells and non-OPLL cells were performed. The densitometric quantification of the electrophoretic profiles of each gene was normalized to the corresponding G3PDH signal. Each mRNA expressions/G3PDH ± SEM at stretch(−), U0126(−) cultures were non-OPLL; 0.94 ± 0.10, 1.27 ± 0.30, 1.23 ± 0.15, 1.95 ± 0.16, 1.55 ± 0.23 and OPLL; 1.03 ± 0.10, 1.31 ± 0.21, 1.26 ± 0.15, 3.63 ± 0.68, 1.67 ± 0.22. *Significantly different from stretch(−), U0126(−) cultures, $P < 0.05$. **Significantly different from stretch(−), U0126(−) cultures, $P < 0.01$. ***Significantly different from stretch(−), U0126(−) cultures, $P < 0.001$.

In this research, we used the extension ratio of 120% for mechanical stretch. We obtained the following data on various extension ratios (100–130%) for mechanical stretch: ALP/G3PDH were each 101.3 ± 3.5 (mean ± SEM), 108.5 ± 10.2, 128.1 ± 13.9, 154.4 ± 20.1, 203.7 ± 19.7, 215.9 ± 14.3 in cases of 100%, 105%, 110%, 115%, 120%, 130% extension ratio, respectively. The expression of ALP increased with increase of extension ratio and reached a plateau at 130% extension ratio. We used extension ratio 120% because damage occurred in the cell when extension ratio exceeded 130%. The present study showed that mechanical stress induced the mRNA expressions of Cbfa1, ALP, type I collagen and osteocalcin in OPLL cells. As mentioned above, Cbfa1 is the transcription factor of the major osteoblast-specific genes (*e.g.*, ALP, type I collagen and osteocalcin) and several studies have established the paramount importance of Cbfa1 in osteoblast differentiation and function [42, 43]. In addition, Cbfa1 is supposed to autoregulate itself by binding to the OSE2 element in its own promoter [23]. By immunohistochemistry, we observed Cbfa1 expression in many fibroblasts at the center of the ligaments of the stretched group which did not include the ossified site. In comparison, Cbfa1 expression in the unstretched spinal ligaments derived from the same OPLL patients tended to increase in the fibroblasts at the center of the stretched spinal ligaments. On the other hand, no change was observed in the non-OPLL ligaments. Moreover, it was reported that mechanical stress induced BMP2 and 4, their receptors and osteopontin which are known as specific markers of osteoblast differentiation in OPLL cells (Tanno et al. unpublished observation).

These results allow us to speculate that OPLL cells have the osteoblastic potential and that the metaplasia of OPLL cells into osteoprogenitor cells has already occurred in OPLL, consistent with other studies of OPLL pathogenesis [4–9]. This may be the reason why differing responsiveness to cyclic stretch was observed between the OPLL and non-OPLL cells. Cbfa1 was expressed in chondrocytes in both of OPLL and non-OPLL ligaments. This result supports the fact that Cbfa1 regulates the condrocytes differentiation [44].

It is well known that fibroblasts respond to the mechanical stress with type I collagen [45]. In this study the expression of type I collagen mRNA was upregulated only 110% by 9 h of mechanical stress in non-OPLL cells. However, after 18 h of stress, type I collagen mRNA tended to be upregulated about 130% compared to the unstretched group, suggesting lower sensitivity of non-OPLL cells for mechanical stress than OPLL cells (unpublished observation).

Recently, Ziros et al. [46] demonstrated that mechanical stress increased the mRNA and protein levels of Cbfa1 and induced DNA binding activity of endogenous Cbfa1 in osteoblasts via the activation of ERK. It was reported that U0126, a specific inhibitor of MEK, blocked phosphorylation of ERK1/2 and the expression of endogenous osteocalcin and bone sialoprotein mRNAs in osteoblasts [47]. U0126 also produced a down-regulation of Cbfa1 OSE2 element binding activity which was increased by mechanical stress in osteoblasts [46]. These reports substantiate the critical role assigned to the MAPK cascade in the osteoblast differentiation process in general. Based on these reports it was suggested that mechanical stress promotes the differentiation of osteoblasts by targeting Cbfa1 activated via the MAPK pathway. We demonstrated that U0126 suppressed the stretch-induced expressions of Cbfa1, ALP and type I collagen in OPLL cells. It is conceivable that in the OPLL cells, activation of MAPK by mechanical stress promotes the phosphorylation and then activates Cbfa1, in turn, binds to OSE2 elements in the Cbfa1, ALP and type I collagen promoters thereby upregulating the expression of these genes.

The MAPK pathway is an important transducer of integrin signals to the cell nucleus. Xiao et al. [47] recently showed that this pathway is required for Cbfa1-dependent transcription. Integrin receptors that mediate the interaction between cells and the extracellular matrix are supposed to act as mechanotransducers [29–33]. It was reported that the application of mechanical stress to the β1-integrin subunits of osteoblasts increases the activation of focal adhesion kinase (FAK) and MAPK [32, 33]. The present study showed that the integrin β1 subunit mRNA was expressed in both OPLL and non-OPLL cells. In OPLL cells, expression of the integrin β1 subunit was increased by mechanical stress. Carvalho et al. [48, 49] reported that mechanical stress increased the expression of the integrin β1 subunit in osteosarcoma cells. It is conceivable that the integrin β1 subunit transduces mechanical signals into intracellular signaling via the activated MAPK pathway in OPLL cells which have the osteoblastic phenotype. Moreover, α2β1 integrin interacts with the extracellular matrix type I collagen [50, 51]. Studies using function-perturbing integrin antibodies have shown that β1 integrin signaling is required for the induction of ALP in osteoblastic cells [52, 53]. These observations suggest that β1 integrin signaling interacts with type I collagen and also plays an important role as a mechanotransducer in the differentiation of osteoblasts.

These studies suggest that in OPLL cells, mechanical stress phosphorylates the MAPK pathway via the β1 integrin subunit which acts as the mechanotransducer and increases the transcriptional activity of Cbfa1. It may also suggest that the stretch-induced expression of type I collagen interacts with the β1 integrin subunit in OPLL cells. However, the exact mechanism of the integrin β1 subunit as a mechanotransducer in OPLL cells is unclear, and remains the subject of future study.

In conclusion, we showed that mechanical stress induced the expressions of Cbfa1, ALP and type I collagen in OPLL cells and that their expressions were blocked by a specific inhibitor of MEK. Mechanical stress also induced the expression of the integrin β1 subunit which is known as a mechanotransducer. Based on these observations, we propose that the increase in Cbfa1 expression induced by mechanical stress plays a key role in the progression of OPLL, at least in part, via the induction of osteogenic differentiation in spinal ligament cells through integrin β1 and the MAPK pathway. To clarify the detailed mechanism of Cbfa1 activation by mechanical stress and the role of Cbfa1 in progression of OPLL induced by mechanical stress, however, more direct evidence is needed. It may be obtained by functional knockout of Cbfa1 and/or MAPK.

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Long-term results of expansive open-door laminoplasty for ossification of the posterior longitudinal ligament of the cervical spine

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Object. Numerous surgical procedures have been developed for treatment of ossification of the posterior longitudinal ligament (OPLL) of the cervical spine, and these can be performed via three approaches: anterior, posterior, or combined anterior–posterior. The optimal approach in cases involving OPLL-induced cervical myelopathy, however, remains controversial. To address this issue, the authors assessed the benefits and limitations of expansive open-door laminoplasty for OPLL-related myelopathy by evaluating mid- and long-term clinical results.

Methods. Clinical results obtained in 72 patients who underwent expansive open-door laminoplasty between 1983 and 1997 and who were followed for at least 5 years were assessed using the Japanese Orthopaedic Association (JOA) scoring system. The mean preoperative JOA score was 9.2 ± 0.4; at 3 years postoperatively, the JOA score was 14.2 ± 0.3 and the recovery rate (calculated using the Hirabayashi method) was 63.1 ± 4.5%, both having reached their highest level. These favorable results were maintained up to 5 years after surgery. An increase in cervical myelopathy due to progression of the ossified ligament was observed in only two of 30 patients who could be followed for more than 10 years. Severe surgery-related complications were not observed. Preoperative JOA score, age at the time of surgery, and duration between onset of initial symptoms and surgery affected clinical results.

Conclusions. Mid-term and long-term results of expansive open-door laminoplasty were satisfactory. Considering factors that affected surgical results, early surgery is recommended for OPLL of the cervical spine.

KEY WORDS • **ossification of the posterior longitudinal ligament** • **expansive laminoplasty** • **cervical myelopathy**

IN Asian countries, including Japan, OPLL is a common cause of cervical myelopathy, as are cervical disc herniation and cervical spondylosis. Because the efficacy of conservative treatment for OPLL-related myelopathy is not certain, surgical treatment is chosen in most cases. Decompressive surgery for OPLL of the cervical spine comprises three types based on the directions of approach: anterior,[2,5,15,16] posterior,[8–10,17] and combined anterior–posterior. The ossified ligament can be removed directly via an anterior but not a posterior approach. On the other hand, a wide decompression can be easily achieved simultaneously by the posterior approach. Thus, the optimal approach for individual cases remains controversial.

In this study, we retrospectively reviewed clinical results obtained in 72 patients who underwent expansive open-door laminoplasty and were followed up for a minimum of 5 years to evaluate benefits and limitations of this procedure.

Clinical Material and Methods

Patient Demographics

At our hospital, expansive open-door laminoplasty was performed in 139 patients between 1983 and 1997. Of these, 72 patients who were followed for 5 years or more after surgery were involved in the present study. Of the remaining 67 patients, two patients died of unrelated causes, 20 had been referred to our hospital from different hospitals and returned to the original hospitals for follow-up examinations, and 45 underwent follow-up evaluations for less than 5 years' duration. The mean follow-up period was 9.5 years (range 5–18 years). There were 53 men and 19 women, whose mean age at the time of surgery was 57.9 years (range 37–77 years).

Operative Procedure

Laminoplasty was indicated for the majority of patients with OPLL-induced cervical myelopathy except for those

Abbreviations used in this paper: JOA = Japanese Orthopaedic Association; OPLL = ossification of the posterior longitudinal ligament; ROM = range of motion.

with single-level segmental OPLL without developmental cervical canal stenosis, who are the best candidates for anterior surgery.

The procedure for expansive open-door laminoplasty has been described in detail elsewhere.[8] Briefly, a midline exposure is made along the nuchal ligament down to the spinous process. The C2–T1 (or T-2) laminae are exposed bilaterally. Bone gutters at the medial margin of the facet joint are made bilaterally from C-3 to C-7 (or T-1) by using a high-speed drill. The drilling of the gutter in the open side is completed first, and then the hinge side is carefully drilled until the lamina door becomes slightly mobile when a gentle force is applied to the spinous process. After the removal of ligamenta flava at the C2–3 and C7–T1 interspaces, the lamina door is opened gradually until the lamina in the hinge side becomes almost horizontal. To maintain this position, sutures placed through facet joints are passed around the base of the corresponding spinous processes and securely tied. Sufficient space for decompression between the swollen dural tube and the ventral side of the lamina can be obtained at this stage. After placing a drainage tube, bilateral neck muscles are tightly sutured. The patient is kept in bed for 2 to 5 days after surgery and then allowed to ambulate while wearing a cervical brace, which is worn for 3 months.

Clinical Assessment

To assess the severity of myelopathy, the JOA scoring system was used (Table 1).[14] The total score for a healthy individual is 17. To evaluate the degree of symptomatic recovery after the surgical procedure, the recovery rate described by Hirabayashi, et al.,[7] was used: recovery rate (%) = (postoperative JOA score − preoperative JOA score)/(17 − preoperative JOA score) × 100. We also evaluated JOA scores of the upper-extremity and trunk functions separately from those of the lower-extremity and bladder functions (total score in a healthy individual 8 points), because lower-extremity and bladder functions are often disturbed by lumbar, knee, and prostate lesions in elderly patients. We also defined JOA score greater than 14 as indicating mild, 7 to 13 as indicating moderate, and below 6 as indicating severe myelopathy. The JOA scoring system was used to determine function at 1, 3, and 5 years postoperatively and at the final follow-up evaluation.

To assess surgery-related complications, the incidence and the extent of nuchal and shoulder pain as well as the restriction of neck ROM were investigated at the final follow-up evaluation by applying custom-made criteria (Table 2).

Radiographic Assessment

Lateral radiographs in flexion, extension, and neutral position were assessed. Ossification of the posterior longitudinal ligament was classified morphologically into three types: continuous, mixed, and segmental, according to a previously proposed scheme.[23] The ROM from C-2 to C-7 was measured on flexion–extension radiographs by using the method proposed by Satomi, et al.[21] Cervical alignment was classified on neutral radiographs into one of four types: lordosis, kyphosis, straight, or sigmoid (Fig. 1a). The extent of lordosis was expressed using the Ishihara curve index as shown in Fig. 1a.[12] Because the presence of OPLL affected the alignment of the spinal cord, the compensated curve index was defined as shown in Fig. 1b. The rate of OPLL affecting the spinal canal at each level (from C-2 to C-7) was measured on neutral x-ray films. Progression of OPLL was measured by comparing preoperative and final follow-up radiographs.

TABLE 1

Summary of the JOA scoring system for cervical myelopathy

Category	Score
motor function	
upper extremity	
unable to feed oneself w/ any tableware including chopsticks, spoon, or fork, &/or unable to fasten button of any size	0
can manage to feed oneself w/ spoon &/or fork but not w/ chopsticks	1
either eating w/ chopsticks or writing is possible but not practical, &/or large button can be fastened	2
either eating w/ chopsticks or writing is clumsy but practical, &/or cuff button can be fastened	3
normal	4
lower extremity	
unable to stand & walk by any means	0
unable to walk w/o 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	
upper extremity	
apparent sensory disturbance	1
minimal sensory disturbance	2
normal	3
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 &/or incontinence	0
sense of retention &/or dribbling &/or thin stream &/or incomplete continence urinary retardation &/or pollakiuria	1
normal	2

Statistical Analysis

Statistical analyses including unpaired t-test, Mann–Whitney U-test, and chi-square test were performed using StatView J-4.5 (Abacus Concepts, Inc., Berkeley, CA) running on a personal computer (Apple Computer, Cupertino, CA). Results are presented as the mean ± standard error of the mean.

Results

Expansive Open-Door Laminoplasty

The mean duration between the onset of initial symptoms and surgery was 41.3 months (range 1.8–170.4 months). The mean operative time was 130 minutes (range 73–223 minutes). The mean blood loss was 356 g (range 30–2200 g).

TABLE 2

Scoring system of nuchal and shoulder pain and the restriction of ROM of the neck

Factor	Score
nuchal pain & shoulder pain	
persistent severe pain requiring medication	0
persistent moderate pain requiring physical therapy	1
persistent mild pain requiring no treatment	2
occasional pain	3
no pain	4
restriction of neck ROM	
extension	
impossible to gargle	0
possible to gargle w/ some difficulty	1
normal	2
rotation	
impossible to turn face to person sitting adjacent	0
possible to turn face to person adjacent w/ some difficulty	1
normal	2
flexion	
impossible to look downstairs	0
possible to look downstairs w/ some difficulty	1
normal	2

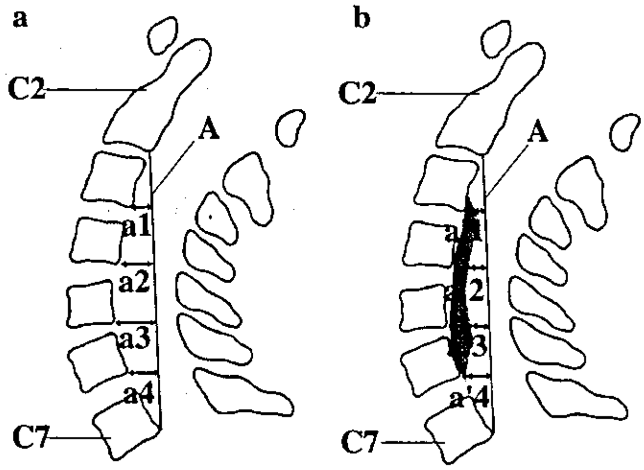

FIG. 1. Diagrams. a: A line is drawn between the lower posterior edge of C-2 and C-7 (this line is defined as A). Perpendicular lines are drawn from the lower posterior edge of the C3–6 vertebral bodies to this line, and the length of these lines is defined as a1–4. If every Line a1–4 is anterior to A and one of them is longer than 2 mm, the curvature is defined as lordotic. If every Line a1–4 is posterior to A and one of them is longer than 2 mm, the curvature is defined as kyphotic. If every Line a1–4 is less than 2 mm, the curvature is defined as straight. If line a1–4 exist anterior and posterior and one of them is more than 2 mm, the curvature is defined as sigmoid. The degree of curvature is calculated using the Ishihara index: index = (a1 + a2 + a3 + a4)/the length of A. b: Perpendicular lines are drawn from the lower posterior edge of the C3–6 to A, and the length between posterior margin of OPLL on each line and A is defied as Line a'1–4. The degree of curvature including the OPLL region is calculated as follows: index (OPLL) = (a'1 + a'2 + a'3 + a'4)/the length of A.

Clinical Results

The mean preoperative JOA score was 9.2 ± 0.4 (range 3–16). At 3 years the mean recovery rate and JOA score reached their highest levels (63.1 ± 4.5% and 14.2 ± 0.3, respectively). This favorable result was maintained up to 5 years after surgery. To evaluate the long-term results, the mean final follow-up recovery rate and JOA score were calculated separately in 30 patients who could be followed for more than 10 years (mean follow-up period 12.9 years). Final follow-up recovery rate and JOA score decreased to 41.3 ± 7.5% and 12.8 ± 0.4, respectively, in this population (Fig. 2). Upper-extremity and trunk function recovery rate, which was 63.9 ± 4.7% at 1 year, and that of the lower-extremity and bladder functions, which was 55.1 ± 6.0% at 1 year, decreased to 44.1 ± 9.2% and 27.2 ± 14.1%, respectively, at the final follow up (Fig. 2).

With respect to the severity of myelopathy, mild preoperative myelopathy was present in only 7% of all patients, whereas at final follow up severity of myelopathy was classified as mild in 51.4% overall. Before surgery, 14 patients (19.4%) suffered severe myelopathy. Symptoms improved to moderate in five patients and to mild in nine postoperatively. In comparing nine patients who experienced marked improvement with five patients who experienced moderate improvement, the mean preoperative JOA score was significantly higher (5.3 and 4, respectively; $p = 0.047$) and the mean age at the time of surgery was significantly lower (57.1 and 67.4, respectively; $p = 0.034$) in the former group; however, durations between the onset of initial symptoms and surgery, morphological types of OPLL, ROM and alignments of the cervical spine, curve index, compensated curve index, and the maximum occupancy rates of OPLL were not significantly different between the two groups (Table 3). Before surgery, 53 patients suffered moderate myelopathy, whereas postoperatively symptoms improved to mild in 39 and remained moderate in 14 patients. In comparing 39 patients who experienced marked improvement with 14 who experienced little or no improvement, the mean duration between the onset of initial symptoms and surgery was significantly shorter (30.7 and 70.4 months, respectively; $p = 0.003$) in the former; however, preoperative JOA scores, age at the time of surgery, morphological types of OPLL, ROM and alignments of the cervical spine, curve index, compensated curve index, and the maximum occupancy rates of OPLL were not significantly different between the two groups (Table 3).

Surgery-Related Complications

Segmental motor paralysis developed in five patients (6.9%): C-5 was paralyzed in four patients and C-7 in one. Except for one patient in whom preoperative deltoid muscle strength of Grade 2 (manual muscle testing), deteriorated to Grade 1, the preoperative strength of impaired muscles was normal, although it deteriorated to Grade 2 or 3 after surgery. In three patients paralysis was on the hinge side, and in two it was on the open side. Paralysis occurred 7 to 11 days after surgery, and four patients recovered to preoperative strength by 3 weeks after its development; however, the fifth patient required 2 years before muscle strength recovered to preoperative levels (it had decreased to Grade 3 after surgery). Postoperative computerized tomography scanning was performed in all patients. No obvious compressive lesion was observed in three patients; however, in two patients with paralysis at the C-5 level on the hinge side, dislodging of the C-4 lamina was demon-

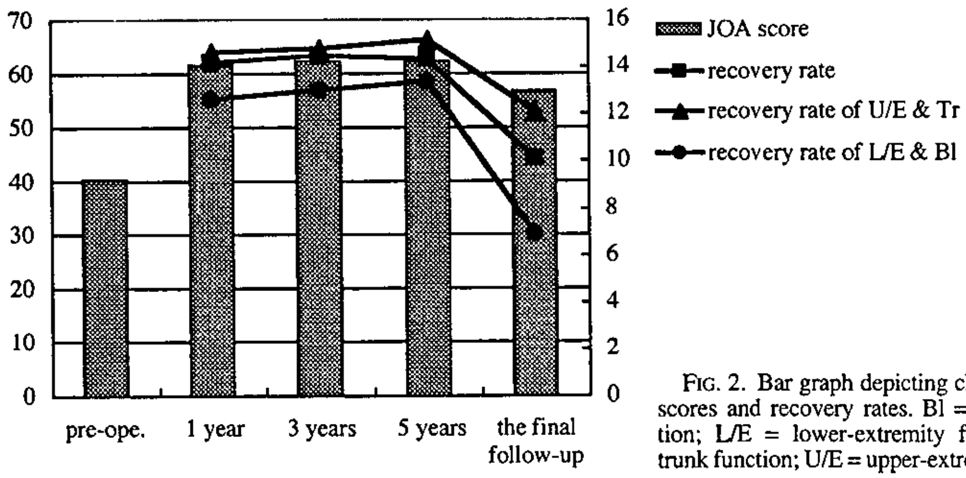

FIG. 2. Bar graph depicting changes in JOA scores and recovery rates. Bl = bladder function; L/E = lower-extremity function; Tr = trunk function; U/E = upper-extremity function.

strated. No additional operation was necessary because paralysis in all patients tended to resolve soon after onset.

The incidence and the extent of axial pain and the restriction of neck ROM postoperatively were evaluated in 43 patients whose final visits to our hospital were made after the year 2000, when our own criteria was established. Four patients (9.3%) suffered severe nuchal pain (0 or 1 point on our scoring system) and 13 patients (30.2%) suffered mild nuchal pain (2 or 3 points). Eight patients (18.6%) suffered severe shoulder pain (0 or 1 point) and 23 patients (53.5%) suffered mild shoulder pain (2 or 3 points) (Table 4). Neck ROM was limited (1 or 2 points) in 29 patients (67.5%) for extension, in 35 (81.5%) for rotation, and in 25 (58.2%) for flexion at the final follow-up examination (Table 4).

Late-Onset Deterioration

Because lower-extremity and bladder functions in elderly patients were often disturbed by lumbar, knee, and prostate lesions, we defined late deterioration of cervical myelopathy as a decrease of JOA scores of more than two points in upper-extremity and trunk functions. According to this definition, late-onset deterioration was observed in 11 patients, in whom progression of the ossified ligament was the cause in three patients. In two patients, progression was observed in the cervical spine (Fig. 3) and in one patient in the thoracic spine. In all of these cases, deterioration occurred more than 10 years after surgery. In another patient, the cause of late-onset deterioration was thought to be insufficient expansion of the laminae; in this case, the postoperative space available for the spinal cord at C-3 to C-5 was only 10 mm in anteroposterior diameter on lateral radiographs obtained immediately after surgery, and no cerebrospinal fluid space was present around the spinal cord on magnetic resonance imaging. Deterioration developed gradually between 5 and 10 years postoperatively, although progression of the ossified ligament was not observed. No additional operation was performed for these four patients.

TABLE 3
*Preoperative factors affecting surgical results**

	Severity of Myelopathy			
Factor	Sev–Mild	Sev–Mod	Mod–Mild	Mod–Mod
no. of patients	9	5	39	14
preop JOA score	5.3	4	9.9	9.6
age (yrs)	57.1	67.4	56.3	59.
duration (mos)	30.6	52.6	30.7	70.4
OPLL type				
continuous	4	1	16	3
mixed	5	3	15	6
segmental	0	1	8	5
ROM (°)	36.1	30.8	31.0	34.4
alignment				
lordotic	3	4	25	6
straight	5	0	5	4
kyphotic	1	0	7	1
sigmoid	0	0	2	3
curve index	0.51	1.27	0.63	0.31
compensated curve index	−0.88	−0.65	−0.58	−0.66
occupancy rate (%)†	49.8	55.3	45.9	38.9

* Mod = moderate; sev = severe.
† Occupancy rate indicates the maximum occupancy rate of OPLL affecting the spinal canal.

TABLE 4
Summary of surgery-related complications after open-door laminoplasty for OPLL

Factor	Grade (%)				
	0	1	2	3	4
incidence & degree of axial pain					
nuchal	1 (2.3)*	3 (7)	5 (11.6)	8 (18.6)	26 (60.5)
shoulder	5 (11.6)	3 (7)	13 (30.2)	10 (23.3)	12 (27.9)
restricted neck ROM					
extension	11 (25.6)	18 (41.9)	14 (32.6)		
rotation	8 (18.6)	27 (62.8)	8 (18.6)		
flexion	6 (14)	19 (44.2)	18 (41.9)		

Poor general condition was the reason in one patient, and others refused surgery despite our recommendation. In two other patients in whom late-onset deterioration occurred relatively early (between 1 and 3 years), severe spinal cord atrophy was observed despite sufficient decompression. The other causes were cerebral infarction and peripheral neuropathy due to diabetes mellitus in one patient each. In three patients, the cause was undetected because the patients refused to undergo further studies.

Radiographic Results

Continuous-, mixed-, and segmental-type OPLL was observed on preoperative lateral radiographs in 25 (34.7%), 33 (45.8%), and 14 patients (19.4%), respectively. Postoperative progression of the ossified ligament greater than 2 mm (range 2–60 mm, mean 26.3 mm, longitudinally; and range 2–10 mm, mean 3.9 mm, in thickness) was observed in 46 patients (63.9%).

Preoperative alignment of the cervical spine was lordotic in 42 patients (58.3%), kyphotic in 10 (13.9%), straight in 14 (19.4%), and sigmoid in six (8.3%). In comparing measurements in 42 patients with lordosis and those in 10 patients with kyphosis preoperatively, the highest postoperative JOA scores (14.7 and 14.7, respectively; $p = 0.993$), recovery rates (72.6 and 57.6%, respectively; $p = 0.253$), and incidence and the extent of nuchal pain (3.3 and 3.1, respectively; $p = 0.687$) were not significantly different; however, incidence and the extent of shoulder pain was significantly higher in patients with kyphosis (2.9 and 1.7 points, respectively; $p = 0.026$). A change in the cervical alignment was observed in 28 patients (38.9%) at the final follow up. In these patients, a change from lordosis to straight was most common (12 patients), whereas change from lordosis to kyphosis was observed in three patients only. Changes from other alignments to lordosis occurred in six patients. In comparing seven patients whose postoperative cervical alignment changed from lordosis or straight to kyphosis with 49 patients whose lordotic or straight alignment remained the same, both the highest mean JOA score (13.3 and 14.8, respectively; $p = 0.136$) and recovery rate (57.6 and 72.2%, respectively; $p = 0.226$) were not significantly different.

The ROM from C-2 to C-7 decreased from 31.8 ± 1.7 to 7.6 ± 1.1°. Spontaneous postoperative fusion of the laminae in more than one segment between C2–3 and C6–7 was observed in 70 patients (97.2%), and the mean number of fused segments was 3.2 ± 0.2 per patient.

Discussion

Benefits and Limitations of Expansive Laminoplasty

The overall recovery rate after expansive laminoplasty for OPLL has been reported to be approximately 60%.[1,6,11,13,19,20] In our study, the mean recovery rate was 62.1% at 1 year, and this level was maintained up to 5 years after surgery (Fig. 2). This finding means that mid-term results after expansive cervical laminoplasty for OPLL are satisfactory. In 30 patients who were followed for more than 10 years, however, the mean recovery rate had decreased to 41.3% at the last follow-up visit. In separating JOA scores into two functional groups, upper extremity/trunk, and lower extremity/bladder, the recovery rate decreased from 63.9 and 55.1% at 1 year to 44.1 and 27.2%, respectively, at the final follow up. The decrease in lower-extremity and bladder JOA scores was more prominent than that in the upper-extremity and trunk scores. This decrease may be caused partly by the aging of the patients during the follow-up period. Lower-extremity and bladder JOA scores could be decreased in relation to diseases in the lumbar spine, knee, and prostate, which often develop in elderly patients. Therefore, changes in the severity of the cervical myelopathy during a long-term period might not be correctly represented by total JOA score and recovery rate alone. In the present study, we endeavored to establish an accurate index for measuring the change of the severity of the pure cervical myelopathy during a long-term period more accurately; thus, late-onset deterioration was defined as a decrease in JOA scores of more than two points in the upper-extremity and trunk functions. According to this criterion, late-onset deterioration occurred in 11 of 72 patients. Reviewing the data obtained in these 11 patients, myelopathy was thought to be aggravated by progression of the cervical OPLL in only two patients, in whom deterioration developed more than 10 years after surgery. Thirty patients in this study underwent follow-up examination for longer than 10 years; therefore, the incidence of late-onset deterioration due to progression of OPLL was determined to be 6.7% (two of 30 cases). On the other hand, the incidence of radiographically documented progression of the ossified ligament was 63.9%. These findings underscore the effectiveness of decompression by expansive laminoplasty in preventing the recurrence of myelopathy due to progression of OPLL during a follow-up period of more than 10 years in the majority of the cases.

Analysis of these results indicates that mid- and long-

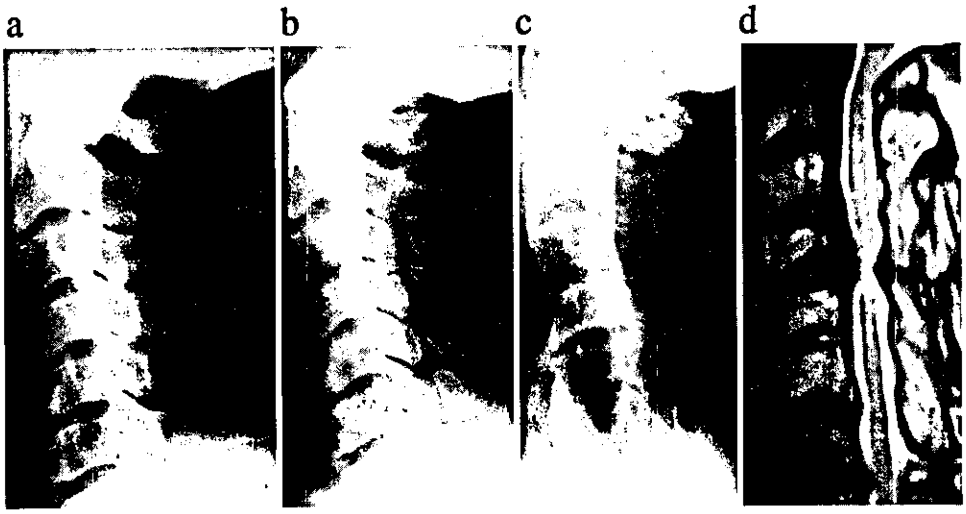

FIG. 3. Representative radiographs (a–c) and magnetic resonance image (d) obtained in a 55-year-old man who suffered late-onset deterioration caused by the progression of ossification. In this case, the cervical spine ankylosed at the C2–4 and C5–7 regions separately after surgery, and a 10-mm posterior progression of the ossified ligament was observed at the mobile C4–5 segment. Preoperative upper-extremity JOA and trunk score was 3, which improved to 8 at 1 year; however, it decreased to 5 at 10 years. The images were obtained before (a), 1 year after (b), and 10 years after (c and d) open-door laminoplasty.

term results after expansive open-door laminoplasty for cervical OPLL were satisfactory. The weakness of our study is the limited number of patients able to attend long-term follow up; however, we compared JOA scores and recovery rates at 1 and 3 years obtained in patients not included in this study and those obtained in our patients with adequate 5-year follow-up data, and no statistically significant differences were found (data not shown). Therefore, we believe that the results obtained in our patient population should represent those of the entire patient population.

In patients with severe myelopathy, two factors, preoperative JOA score and the age at the time of surgery, affected postoperative results, whereas in patients with moderate myelopathy the duration between the onset of initial symptoms and the surgery affected the clinical results. In patients with severe myelopathy whose JOA score improved to more than 14 points the mean preoperative JOA score was 5.3, whereas in those whose JOA score had improved but did not reach 14 points the mean preoperative JOA score was 4. This finding indicates that the optimal preoperative JOA score may be between 4 and 5 points for surgery to yield the best result. In addition, considering that age at time of surgery and duration between the symptom onset and surgery affected long-term outcomes adversely, early surgical treatment is recommended.

Late-Onset Deterioration

Although progression of the ossified posterior longitudinal ligament was observed in more than 50% of our patients, only two patients suffered late-onset deterioration of cervical myelopathy due to OPLL progression. One explanation could be that because the laminae were expanded one level above and below the regions where the spinal cord was already compressed, the spinal cord was not further compressed even if some progression of ossification occurred. Indeed, in one case of deterioration, spinal cord compression occurred at the C-2 lamina, which was excluded from expansion. When later-onset cord compression might occur at adjacent levels, these levels should also be surgically expanded. Another explanation is that progression of the ossified ligament as well as osseous union at the bone gutters led to a decrease in cervical ROM, which has protected the spinal cord by stabilizing the dynamic compressive forces. In fact, ROM in the C2–7 region decreased to 23.9% of its preoperative level, and fused segments were present in three of five expanded segments in our study. Therefore, spinal cord function was not disturbed, even if the spinal canal was constricted by progression of the lesion. In one case involving deterioration, because one segment escaped laminar fusion, mechanical stress concentrated there; the spinal cord became compressed due to focal progression of the ossified ligament and thickening of the ligamentum flavum (Fig. 3).

Insufficient widening of laminae was another cause of late-onset deterioration. Adequate expansion of all laminae is, therefore, important in this procedure.

Preoperative Alignment and Postoperative Changes

Iwasaki, et al.,[13] have suggested that laminoplasty was not contraindicated in patients with preoperatively established kyphotic deformity. We also found that clinical results were not significantly different between patients with lordotic and kyphotic cervical alignment except for the incidence and the extent of shoulder pain, although degree of kyphotic deformity was mild in our cases. Therefore, we believe that laminoplasty for OPLL is not contraindicated even in patients with mild kyphotic cervical alignment. The recovery rate in patients with kyphotic deformity, however, tended to be lower than that in patients with lordosis. It may be important to determine, in the future, what extent of kyphotic deformity is acceptable for this procedure. Changes in the alignment from lordotic or straight to kyphotic were observed in seven (12.5%) of 56 patients. Unlike cervical spondylotic myelopathy, in which changes in the alignment affect clinical results,[18] kyphotic deformity developing after surgery in patients with OPLL did not affect clinical results. This fact may be partly due to stabilization of the cervical spine by progression of OPLL.

Surgery-Related Complications

Several reports on segmental motor paralysis after expansive laminoplasty for cervical myelopathy have been published.[3,4,22,24,25] In these reports paralysis occurred in 5.2 to 10% of cases, an incidence similar to that in our study. Causes of this paralysis were reported to be nerve root lesions secondary to traumatic surgical techniques and/or tethering effect induced by excessive posterior shift of spinal cord. It has also been suggested that spinal cord lesions could be involved as a cause of this paralysis.[3,22] In our study, the cause of paralysis was considered to be compression initiated by a dislodged lamina in two patients. By improving surgical procedures, this can be prevented. Definite causes in the remaining three patients could not be determined. Although this paralysis is usually transient and recovers within several weeks, its incidence is not low. Further investigation is required to detect the exact mechanisms and to prevent this complication.

The incidences of nuchal and shoulder pain were 39.5 and 72.1%, respectively. The incidence of restricted neck ROM was also high. Although these complications are not fatal, they can significantly impair patients' quality of life. Prospective studies to develop novel surgical procedures and postoperative regimens for reducing incidence of such complications are ongoing at our hospital.

Conclusions

We recommend early surgical treatment for cervical OPLL even in patients with mild kyphotic deformity. A wide decompression and adequate expansion of laminae are extremely important to avoid recurrence of myelopathy due to postoperative progression of the ossified posterior longitudinal ligament.

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Cervical Myelopathy Due to OPLL

Clinical Evaluation by MRI and Intraoperative Spinal Sonography

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Background: Concerning the relationship between morphology and clinical outcome, there have been many reports using computed tomography/myelography but not so many using axial magnetic resonance imaging (MRI) of the spinal cord. This is the first report to correlate axial cord image, intensity changes in MRI, and cord expansion pattern using intraoperative ultrasonography.

Objective: The objectives were to correlate MRI studies, axial cord images/expansion, and changes in MRI intensity to see if there is a direct prognostic significance to these changes and to determine whether preoperative axial MRI images of the spinal cord predict recovery from compressive myelopathy.

Methods: Posterior cervical decompressions with laminoplasty were performed in 44 patients with cervical myelopathy due to ossification of the posterior longitudinal ligament. On T2-weighted MR images, the cross-sectional shape of the cord at the level of maximal compression was categorized as boomerang, teardrop, or triangle. Additionally, with use of intraoperative ultrasonography, the expansion pattern of the cord that occurred intraoperatively was contrasted with that seen on postoperative MR images.

Results: Clinical recovery rates were the worst for those with triangular, intermediate for those with boomerang, and the best for those with teardrop shape. Preoperative low T1 and high T2 signals were found in most cases with triangular cord configurations. Triangular cord configurations showed the least expansion among the three categorized spinal cords.

Conclusion: Patients with triangular deformity of the cord have atrophy as confirmed on MR studies where there is a low T1 and high T2 signal in the cord. Poor postoperative clinical recovery correlates with the lack of postoperative cord expansion on either MR or ultrasound evaluations. Those with either teardrop or boomerang deformities demonstrate a relatively good recovery rate.

Key Words: magnetic resonance images, intraoperative spinal sonography, cross-sectional shape of spinal cord

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Concerning the relationship between morphology and clinical outcome, there have been many reports using computed tomography (CT)/myelography. Yu et al[1–4] reported that considerable improvement was generally achieved after operative treatment in patients with a boomerang type (their A shape) as shown by CT/myelography, but not in patients with a triangular type (their D2 shape).

Kobayashi[5] divided the cross-sectional shape of the spinal cord into four types using CT/myelography and concluded that the triangle type (their type IV) shows poor results, whereas the boomerang type (their type I) shows good results. Fujiwara et al[6,7] also divided them into three types, namely, diffuse, unilateral, and central types, and concluded that the diffuse type (triangle type) shows small cross-sectional area of the spinal cord with poor clinical results, and the central type (boomerang type) presents a good clinical outcome.

Although previous morphologic analyses have been performed by using CT/myelography, our studies have been done by magnetic resonance imaging (MRI), and we could obtain more detailed information using three categories of spinal cord. On T2-weighted MR images, the cross-sectional shape of the cord at the level of maximal compression was categorized as boomerang, teardrop, or triangle. Additionally, with use of intraoperative ultrasonography, the expansion pattern of the cord that occurred intraoperatively was contrasted with that seen on postoperative MR images.[8] This study is the first report dealing with only patients with ossification of the posterior longitudinal ligament (OPLL) and pre-, intra-, and postoperative morphology of the cervical spinal cord. The objective of this study was to correlate MRI studies, axial cord images/expansion, and changes in MRI intensity to see if there was a direct prognostic significance to these changes and to determine whether preoperative axial MRI images of the spinal cord could predict recovery from compressive myelopathy due to OPLL.

MATERIALS AND METHODS

The diagnosis of OPLL was made in all 44 cases. Patients included 34 men and 10 women with an average age of 61 years (range 38–76 years). Overall duration of symptoms averaged 26 months.

Preoperative evaluations included MR studies. T2-weighted axial images at the level of maximal compression were classified as boomerang, teardrop, or triangular (Fig. 1). We defined three types of morphologic characteristics of compressed spinal cord on MRI. The boomerang type had a convex posterior surface and concave anterior surface with a smooth round corner; the teardrop type had a convex posterior surface and concave anterior surface with only one-sided smooth round corner; the triangular type had an angular lateral surface and a flat anterior surface.

These MRI findings were evaluated by radiologists who were independent of the surgery team. Surgical decompression included 22 French door[9] and 22 open door[9] laminoplasties. Intraoperative spinal sonography (IOSS) looking for cord expansion was also performed on all patients using an Echo Camera SSD 650 CL (Aloka) and a 7.5-MHz linear array transducer. This was then correlated with postoperative T2-weighted transaxial MR studies obtained 1 month postoperatively (Fig. 2). The authors then attempted to correlate postoperative outcome determined with the Japanese Orthopedic Association (JOA) score with cord expansion seen on these studies.

Correlations between MRI intensity changes of the spinal cord and the three types of deformed spinal cord were also evaluated.[10,11] Pre- and postoperative intensity changes were evaluated using a sagittal view by MRI. Recovery after surgery was evaluated with the formula suggested by Hirabayashi et al[12]:

$$\text{Recovery rate (\%)} = \frac{(\text{postoperative score} - \text{preoperative score}) \times 100}{17\ (\text{total score}) - \text{preoperative score}}$$

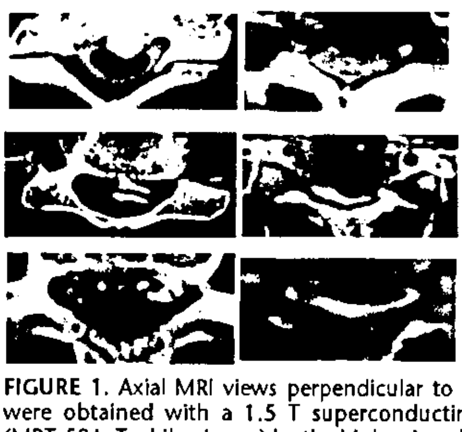

FIGURE 1. Axial MRI views perpendicular to the spinal cord were obtained with a 1.5 T superconducting MRI system (MRT-50A; Toshiba, Japan) by the high spin echo method (T2-weighted images were obtained at 2000-millisecond repetition time, 100-millisecond echo time, and a slice thickness of 5 mm). Morphologic characteristics of the boomerang type included a convex lateral surface and a concave anterior surface, the teardrop type a convex lateral surface and a partially concave anterior surface, and the triangular type an angular lateral surface and a flat anterior surface.

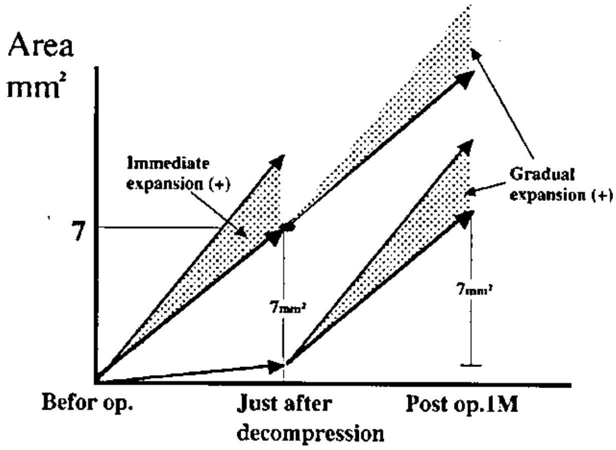

FIGURE 2. Definition of immediate expansion and gradual expansion of the spinal cord. If the cross-sectional area of the spinal cord was >7 mm^2 greater on IOSS compared with preoperative MRI, this was defined as immediate expansion. When the cross-sectional area of the spinal cord was >7 mm^2 greater at 1 month after surgery on MRI compared with IOSS, this was defined as gradual expansion.

The Wilcoxon *U* rank sum statistical test was used for comparing the preoperative and monthly postoperative JOA scores. For comparing the clinical recovery rate of each group, the Student *t* test was used to determine the significance of the differences.

RESULTS

Of 44 patients, 10 showed triangular, 13 teardrop, and 21 boomerang configurations of their spinal cords. There appeared to be no significant correlation between the cord shape and average age of the patients in any of the three groups studied.

Patients with the triangular shape of the cord had the longest symptom duration, those with the boomerang shape had intermediate duration, whereas those with the teardrop shape had the shortest symptom duration: 52, 22, and 13 months, respectively.

There was no statistical difference in preoperative JOA score and the shape of the cord. However, postoperatively, JOA scores were the worst for those with triangular, intermediate for those with boomerang, and the best for those with teardrop shapes. For those with triangular cord configurations, the preoperative cross-sectional area averaged 31.8 mm^2, intraoperative cross-sectional area averaged 36.5 mm^2, and postoperative cross-sectional area averaged 38.7 mm^2. They showed the least improvement. For those with teardrop cord configurations, the preoperative cross-sectional area averaged 39.0 mm^2, intraoperative cross-sectional area averaged 46.2

mm^2, and postoperative cross-sectional area averaged 54.7 mm^2. They showed the best improvement. For those with boomerang cord configurations, the preoperative cross-sectional area averaged 35.4 mm^2, intraoperative cross-sectional area averaged 41.9 mm^2, and postoperative cross-sectional area averaged 50.5 mm^2. They showed intermediate improvement.

As for longitudinal extension of the compression area, which is <30% in the compression ratio due to OPLL, those with triangular OPLL has the most extensive OPLL, covering an average of 2.4 vertebrae (Table 1).

For morphologic expansion of the spinal cord, the gradual expansion pattern, thought to be a good indicator of a good recovery rate, was found in 17 cases of the boomerang type, 11 cases of the teardrop type, and only 2 cases of the triangular type (Table 2).

Concerning pre- and postoperative intensity changes, in the boomerang type, high-intensity changes in T2-weighted images were observed in 10 of 21 cases preoperatively, and postoperatively, high-intensity changes in T2-weighted images were found also in 8 of 21 cases. In the teardrop type, high-intensity changes in T2-weighted images were found in 9 of 13 cases preoperatively, and postoperatively, high-intensity changes in T2-weighted images were seen in 9 of 13 cases. In the triangle type, low-intensity changes in T1-weighted images and high-intensity changes in T2-weighted images were found in 8 of 10 cases (Table 3).

DISCUSSION

Our studies have been done by MRI, and we could obtain more detailed information about the three categories of spinal cord. For intensity changes of MRI, 10 of the 21 boomerang types showed high intensity preoperatively and 8 showed high intensity postoperatively. Nine of the 13 teardrop cases showed high intensity preoperatively and also postoperatively. These results indicate that patients with only high-intensity T2-weighted images could have a good clinical recovery rate. In consideration of both the low intensity of T1-weighted images and the high intensity of T2-weighted images, considered to be good predictors of spinal cord atrophy, we found 8 of 10 triangular cases to exhibit these features. Regarding the poor clinical results for the triangular type, low intensity of T1-weighted images and high intensity of T2-weighted images might indicate a lack of plasticity in the spinal cord.

Matsuyama[8] studied cervical myelopathy by IOSS, preoperative CT/myelography, and 1-month postoperative CT/myelography and classified the expansion pattern after spinal cord decompression as gradual or immediate. They concluded that good clinical recovery is closely related to gradual expansion. The current study shows a close relationship between preoperative cross-sectional shape of the spinal cord and

TABLE 1. Summary of the Clinical Results for Each Type

	Boomerang	Teardrop	Triangle
No. of patients	21	13	10
Average age at op. (y)	57	61	67
Symptom duration (mo)	22	13	52
Preop. JOA (points)	11.1	10.5	9.9
Postop. JOA (points)	14.2	15.2	11.6
Recovery rate (%)	61.8	72.1	23
Cross-sectional area (preop.) (mm^2)	35.4	39.0	31.8
Cross-sectional area (intraop.) (mm^2)	41.9	46.2	36.5
Cross-sectional area (1 mo postop.) (mm^2)	50.5	54.7	38.7
Longitudinal extension (including nos. of vertebrae)	1.4	1.5	2.8

TABLE 2. Expansion Pattern of Each Type

	I(+) & G(+) (n)	I(+) & G(−) (n)	I(−) & G(+) (n)	I(−) & G(−) (n)
Boomerang	7	2	10	2
Teardrop	8	1	3	1
Triangle	2	0	0	8

I, immediate expansion; G, gradual expansion.

TABLE 3. Intensity Changes in MRI

	Preop. (n)	Postop. (n)
Boomerang		
T1: I & T2: H	10	8
T1: I & T2: I	11	12
T1: L & T2: H	0	1
Teardrop		
T1: I & T2: H	9	9
T1: I & T2: I	3	3
T1: L & T2: H	1	1
Triangle		
T1: I & T2: H	2	2
T1: I & T2: I	0	0
T1: L & T2: H	8	8

T1, T1 weighted; I, isointensity; T2, T2 weighted; L, low intensity; H, high intensity.

expansion pattern. The boomerang and teardrop types show immediate and gradual expansion patterns. Especially the gradual expansion pattern was detected in 17 of 21 boomerang cases and in 11 of 13 teardrop cases. However, 8 of 10 triangular cases did not show any immediate or gradual expansion pattern.

Two of 10 triangular cases showed immediate and gradual expansion pattern and had almost 70% good clinical recovery rate. Even if the case has the triangular type, if there is an immediate and gradual expansion pattern intraoperatively, we speculate that this case might have a good clinical recovery. When we think of the prognosis of the patients, we have to take into account the configuration of the spinal cord, MRI intensity, and expansion pattern. Indicators of a poor prognosis include the triangular type, low T1 and high T2, and no gradual and immediate expansion pattern. We recommend that patients with myelopathy due to OPLL have surgery before the cross-sectional shape of the spinal cord becomes triangular.

CONCLUSIONS

Patients with triangular deformity exhibit atrophy of the spinal cord and show the worst clinical recovery. However, teardrop and boomerang deformities demonstrate a relatively good recovery rate. Triangular deformity is closely related to low intensity of T1 and high intensity of T2 images and shows no immediate or gradual expansion. Immediate and gradual expansion pattern was also indicated good clinical results instead of image intensity and shape of spinal cord.

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Bath ankylosing spondylitis functional index (BASFI) evaluation of postoperative patients with OPLL

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Abstract Although surgical decompression of the involved spinal cord achieves a good recovery of neurological conditions, one of the most important complaints of patients with ossification of the posterior longitudinal ligament (OPLL) is disability as a result of spinal immobility. The activities of daily living (ADL) of postoperative patients with OPLL were examined. To evaluate the ADL of postoperative patients with OPLL in the cervical spine, we utilized the Bath Ankylosing Spondylitis Functional Index (BASFI), one of the most widely used functional indexes for ankylosing spondylitis. We investigated consecutive cases that underwent surgery for OPLL of the cervical spine in our department from 1978 to 1998. The latest and postoperative scores were compared to the preoperative Japanese Orthopaedic Association (JOA) scores (range, 0–17) to assess neurological recovery. We also evaluated ADL at the latest follow-up, using BASFI scores. Significant recoveries of JOA scores were confirmed; however, 77% of patients complained of disability. In BASFI, questions that seemed to reflect spinal condition received low scores in the present study. BASFI scoring was not sufficient in the present form; however, it is one of the candidate functional indexes for evaluating ADL in postoperative patients with OPLL. Establishment of an ideal functional index for such evaluation is needed.

Key words OPLL · BASFI · ADL · Functional index · Ankylosing spondylitis (AS)

Introduction

Ossification of the posterior longitudinal ligament (OPLL) of the spine is a common disease associated with cervical myelopathy in Japan.[7] Several surgical procedures have been established to decompress the involved area of the spinal cord.[1,10,15] Evaluation of postoperative condition is usually focused on neurological status using a scoring system, such as the Japanese Orthopaedic Association (JOA) scores (range, 0–17) (Table 1). However, postoperative patients with OPLL complain of long-term disability due to spinal immobility rather than neurological problems following surgery. Indeed, enlargement of ossification was observed several times in patents with OPLL who received surgery. Thus, a more fitting scoring system that is able to evaluate the activities of daily living (ADL) is needed to more accurately assess long-term condition.

Ankylosing spondylitis (AS) has common features with OPLL, such as marked ectopic ossification in the spinal ligaments, and occasionally results in so-called bamboo spine. These clinical similarities between AS and OPLL led us to employ the Bath Ankylosing Spondylitis Functional Index (BASFI),[3] which is one of the most widely used self-administered patient questionnaires that address physical function in AS, and from the results we evaluated ADL in postoperative patients with OPLL.

From our findings, we attempted to determine the usefulness of BASFI for evaluating ADL of postoperative patients with OPLL as well as the long-term results of their surgical treatment.

Materials and methods

From consecutive patients with OPLL in the cervical spine who underwent surgery in our department from 1978 to 1998, 22 (12 men, 10 women) agreed to direct examinations in our outpatient clinic for the present study. All exhibited myelopathy. The mean age at the time of operation was 58.6 years old (range, 48–71 years), and the mean term of follow-up at the latest follow-up was 93.6 months (range, 18–236 months). Anterior decompression and fusion (AD) were employed in 7 cases whereas posterior decompression

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Table 1. Japanese orthopaedic association scoring system (17-2) for cervical myelopathy

I. *Motor function*
1. Finger
0 = Unable to feed onself with any tableware including chopsticks, spoon or fork, and/or unable to fasten buttons of any size
1 = Can manage to feed oneself with a spoon and/or fork but not with chopsticks
2 = Either chopsticks-feeding or writing is possible but not practical, and/or large size buttons can be fastened
3 = Either chopsticks-feeding or writing is clumsy but practical, and/or cuff buttons can be fastened
4 = Normal
2. Shoulder and elbow (evaluated by MMT score of the deltoid or biceps muscles, whichever is weaker)
−2 = MMT 2 or less, −1 = MMT 3, −0.5 = MMT 4, 0 = MMT 5
3. Lower extremity
0 = Unable to stand up and walk by any means
0.5 = Able to stand up but unable to walk
1 = Unable to walk without a cane or other support on a level
1.5 = Able to walk without support but with a clumsy gait
2 = Walks independently on a level but needs support on stairs
2.5 = Walks with independently when going upstairs, but needs support when going downstairs
3 = Capable of fast walking but clumsy
4 = Normal

II. *Sensory function*
A. Upper extremely
0 = Complete loss of touch and pain sensation
0.5 = 50% or less normal sensation and/or severe pain or numbness
1 = More than 60% normal sensation and/or moderate pain or numbness
1.5 = Subjective numbness of a slight degree without any objective sensory deficit
2 = Normal
B. Trunk
Same as A

III. *Bladder function*
0 = Urinary retention and/or incontinence
1 = Sense of retention and/or dribbling and/or thin stream and/or incomplete continence
2 = Urinary retardation and/or pollakiuria
3 = Normal

Total score for a normal individual = 17
MMT, manual muscle test

(PD) was employed in 15. The number of fused segments was two in 1 case, three in 5 cases, and four in 1 case. The type of ossification were mixed type in 3, segmental type in 2, and continuous type in 2 cases in the AD group, and mixed type in 11, segmental type in 2, and continuous type in 2 cases in the PD group, respectively.

Neurological analysis

To evaluate the neurological condition of each patient, the JOA score (range, 0–17) was employed, and the preoperative, postoperative, and most recent scores at follow-up were assessed.

X-ray analysis

As the entire cervical spine angle, we measured the supplementary angle between the line parallel to the dorsal border of the second vertebra and the line parallel to that of the seventh vertebra (total angle; Fig. 1). A dynamic study was used for measuring range of motion

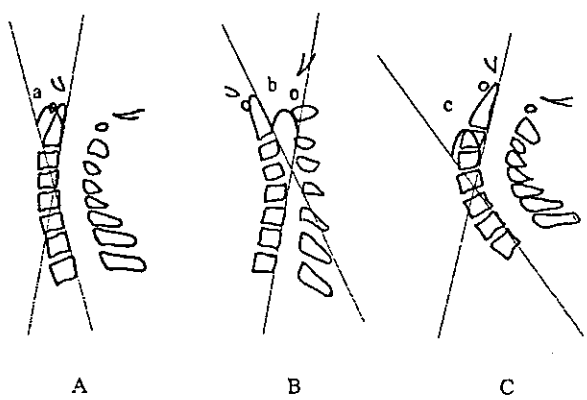

Fig. 1A–C. Radiographic measurements used for the cervical spine. **A** Measurement of the angle of the entire cervical spine (angle *a*, total angle) in the neutral position. Angle *a* was the supplementary angle between the line parallel to the dorsal border of the second vertebra and the line parallel to that of the seventh vertebra. **B, C** Technique for measuring range of motion (ROM); ROM = *b* + *c*

(ROM) of the cervical spine on the X-ray images (Fig. 1).

BASFI analysis

The BASFI was designed in 1994, through extensive discussion, by a team of rheumatologists, physiotherapists, and research associates with major input from patients with AS.[3] The BASFI consists of eight questions on activities relating to the functional anatomy of patients, and two additional questions that assess the patient's ability to cope with everyday life. The questions reflect ADL and include "putting on socks or tights without help or aids"; "bending forward from the waist to pick up a pen from the floor without an aid"; "reaching up to a high shelf"; "getting out of an armless dining-room chair without using your hands"; "getting up off the floor without help from lying on your back"; "standing unsupported for 10 minutes without discomfort"; "climbing 12–15 steps without using a handrail or walking aid"; "looking over your shoulder without turning your body"; "doing physically demanding activities (e.g., physiotherapy exercises, sports, and gardening)"; and "doing a full day's activities whether at home or at work" (Fig. 2). According to the method of a previous report,[3] each answer was plotted on a 10-cm visual analog scale (VAS) (Fig. 2). The patients assessed the ADL by themselves following the BASFI questionnaire. In the present study, "EASY" and "IMPOSSIBLE" answers received a score of 0 and 10, respectively. Thus, according to this scoring system, the best score (no disability) of the BASFI was 0 and the worst (total disability) was 100.

Please draw a mark on each line below to indicate your level of ability with each of the following activities.

1) Putting on your socks or tights without help or aids (e.g. sock aid)
EASY ________________________________ IMPOSSIBLE
2) Bending forward from the waist to pick up a pen from the floor without an aid
EASY ________________________________ IMPOSSIBLE
3) Reaching up to a high shelf without help or aids (e.g. helping hand)
EASY ________________________________ IMPOSSIBLE
4) Getting up out of an armless dining room chair without using your hands or any other help
EASY ________________________________ IMPOSSIBLE
5) Getting up off the floor without help from lying on your back
EASY ________________________________ IMPOSSIBLE
6) Standing unsupported for 10 minutes without discomfort
EASY ________________________________ IMPOSSIBLE
7) Climbing 12-15 steps without using a handrail or walking aid. **One foot on each step**
EASY ________________________________ IMPOSSIBLE
8) Looking over your shoulder without turning your body
EASY ________________________________ IMPOSSIBLE
9) Doing physically demanding activities (e.g. physiotherapy exercises, gardening or sports)
EASY ________________________________ IMPOSSIBLE
10)Doing a full days activities whether it be at home or at work
EASY ________________________________ IMPOSSIBLE

Fig. 2. A Bath Ankylosing Spondylitis Functional Index (BASFI) questionnaire

Statistical analysis

Mann–Whitney's U test and Wilcoxon signed-ranks test were applied when appropriate. P values less than 0.05 were regarded as significant. The software application used for the analysis was StatView-J 4.02 (Abacus Concepts, CA, USA).

Results

Because the different surgical procedures have influence on postoperative spinal mobility, especially in the cervical spine, we analyzed the results according to the surgical procedures. Also, as the distribution of follow-up term was wide (range, 18–236 months), we divided patients into two subgroups according to the follow-up time, equal to or less than 5 years or more than 5 years. The mean postoperative JOA score and that at the latest follow-up demonstrated significant recovery when compared with the mean preoperative JOA score in each subgroup (Table 2). However, most of the patients (17/22, 77%) in the present study still complained of stiffness and disability due to spinal immobility. The neck pain remained in 3 cases in the AD group and in 8 cases in the PD group, respectively.

For the BASFI, the score from each item as well as total scores at the latest follow-up are demonstrated in Table 3. The item that returned the lowest mean score was number 8 (looking over your shoulder without turning your body).

At the latest follow-up, ROM of the cervical spine was significantly restricted as compared with that before surgery (Wilcoxon signed-ranks test) (see Table 2). We divided the patients into two subgroups according to ROM in the cervical spine. Those who showed a greater than 10° loss of ROM of the cervical spine were considered as the limited ROM group, while those with a loss of 10° or less were the preserved ROM group. In the present study, the sample size was too small to find a significant difference concerning the JOA score and BASFI among these subgroups (data not shown). However, although progression of OPLL was found in 45% of these cases, there was no significant relationship between BASFI and the progression of OPLL (data not shown).

Table 2. Comparison of the JOA score and ROM of OPLL in the cervical spine

	Preoperation	Postoperation	Latest follow-up
AD (≦5y)(*n* = 2)			
JOA score (mean ± SD)	8.8 ± 6.7	9.8 ± 8.1	9.3 ± 6.7
P value	—	—	—
ROM (°) (mean ± SD)	36° ± 16°	—	16° ± 5.8°
P value	—	—	—
AD (>5y)(*n* = 5)			
JOA score (mean ± SD)	11 ± 3.6	15 ± 2.3	15 ± 2.4
P value	—	0.043*	0.043*
ROM (°) (mean ± SD)	36° ± 16°	—	16° ± 5.8°
P value	—	—	0.08*
PD (≦5y)(*n* = 6)			
JOA score (mean ± SD)	9.4 ± 4.0	13 ± 1.1	13 ± 1.3
P value	—	0.028*	0.046*
ROM (°) (mean ± SD)	37° ± 8.9°	—	18° ± 6.7°
P value	—	—	0.030*
PD (>5y)(*n* = 9)			
JOA score (mean ± SD)	10 ± 2.7	13 ± 3.0	12 ± 4.7
P value	—	0.018*	0.04*
ROM (°) (mean ± SD)	36° ± 9.9°	—	21° ± 16°
P value	—	—	<0.01*

JOA score, Japanese Orthopaedic Association score (range, 0–17); OPLL, ossification of the posterior longitudinal ligament; ROM, range of motion in the cervical spine; AD, anterior decompression group; PD, posterior decompression group; ≦5y, follow-up term after surgery equal or less than 5 years; >5y, follow-up term after surgery more than 5 years
* Significant by a Wilcoxon signed-ranks test

Table 3. BASFI score of OPLL in the cervical spine at the latest follow-up

	BASFI score (mean ± SD)			
	AD(≦5y)	AD(>5y)	PD(≦5y)	PD(>5y)
Question 1	2.5 ± 3.5	2.0 ± 2.7	3.2 ± 4.2	3.2 ± 4.2
Question 2	6.0 ± 5.7	2.6 ± 3.8	2.6 ± 4.3	2.6 ± 4.3
Question 3	4.0 ± 1.4	2.6 ± 4.3	4.3 ± 4.4	4.3 ± 4.4
Question 4	5.5 ± 3.5	1.4 ± 3.1	1.9 ± 3.8	1.9 ± 3.8
Question 5	5.0 ± 4.2	2.6 ± 3.0	2.6 ± 4.3	2.6 ± 3.5
Question 6	5.0 ± 7.1	1.6 ± 3.1	2.4 ± 3.5	2.4 ± 3.5
Question 7	5.0 ± 7.1	3.7 ± 5.1	5.0 ± 4.6	5.0 ± 4.6
Question 8	7.5 ± 3.5	4.4 ± 4.0	7.2 ± 3.3	7.2 ± 3.3
Question 9	3.5 ± 5.0	2.4 ± 2.9	3.6 ± 4.2	3.6 ± 4.2
Question 10	3.5 ± 5.0	2.2 ± 3.0	3.4 ± 4.1	3.4 ± 4.1
Total	48 ± 46	26 ± 30	36 ± 36	36 ± 36

BASFI, Bath Ankylosing Spondylitis Functional Index; OPLL, ossification of the posterior longitudinal ligament; AD, anterior decompression group; PD, posterior decompression group; ≦5y, follow-up term after surgery equal or less than 5 years; >5y, follow-up term after surgery more than 5 years

Discussion

Neurologically, the results of the present study demonstrated the usefulness of surgical decompression, as we found that a good recovery was maintained in most of the patients at the time of the latest follow-up. Nevertheless, most of the patients (17/22, 77%) in the present study still complained of stiffness and disability. We were not able to evaluate preoperative BASFI scores; thus, it was impossible to compare BASFI results before and after surgery. No significant correlation between BASFI and ROM of the cervical spine was demonstrated. This result showed that BASFI reflected not only the ROM of the cervical spine, which was measured in the present study, but also other ROM in cervical spine, such as rotation and lateral bending, as well as mobility of the total spine. As previously reported.[14] limited ROM of the cervical spine after surgery does not have an influence on neurological condition.