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Effectiveness of multiple-level decompression in laminoplasty and simultaneous C1 laminectomy for patients with cervical myelopathy

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Abstract A retrospective study to investigate the relationship between the surgical levels and decompression effects was performed in patients with cervical myelopathy who had undergone Tension-band laminoplasty (TBL) with/without simultaneous C1 laminectomy. One hundred and sixty-eight patients (115 males, 53 females; age: 31–80 years, average 58.9 years; follow-up period: 12–120 months, average 20 months) were divided into three groups according to the range of the surgical levels: seventy-two patients in group A underwent TBL at the C2–C7 levels with C1 laminectomy; 60 patients in group B underwent TBL at the C2–C7 levels; 36 patients in group C underwent TBL at the C3–C7 levels. Neurological evaluation was performed by using the Japanese Orthopedic Association (JOA) scoring system. The alignment changes of the spinal column and the spinal cord were analyzed using pre- and post-operative roentgenograms and MRIs. The differences in the pre- and post-operative anterior subarachnoid spaces (D-ASAS), the spinal cord diameters (D-CORD), and the dural sleeve diameters (D-DURA) at

the C1–C7 levels were also analyzed by using MRIs. The JOA scores improved in all groups. As for the spinal alignment, neither significant changes between pre- and post-operation in any group nor significant differences among the three groups were found. The lordosis of the cervical spinal cord was decreased in all groups. D-ASAS of group A was larger than that of group B at the C1–C5 levels ($P < 0.05$), as were those of D-CORD and D-DURA at the C1–C2 and C4–C5 levels ($P < 0.05$). D-ASAS of group A was larger than that of group C at the C1–C4 levels ($P < 0.05$), as were those of D-CORD and D-DURA at the C1–C5 levels ($P < 0.05$). In conclusion, laminoplasty including the C2–C7 levels with simultaneous C1 laminectomy was proven to allow the most posterior shift of the spinal cord within the widened dural sleeve at C5 or higher levels without significantly changing the spinal alignment.

Keywords Cervical myelopathy · Decompression · Laminoplasty · MRI · Spinal cord

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Introduction

Cervical myelopathy is usually a pathological condition in which the cervical spinal cord and the nerve roots are compressed due to degenerative changes of the spinal column, resulting in a variety of neurological symptoms

and signs. Herniated disc, vertebral bony spur, and ossification of the posterior longitudinal ligament (OPLL) impart pressure on the spinal cord from the anterior or anterolateral directions [18, 8, 24]. If spinal canal stenosis and unfolding of the yellow ligament are combined, the compression is more aggravated [1, 7].

Table 1 Details of the 168 patients in the present study

	Group	Total number	Gender		Age (years) Mean (range)	Disease	
			Male	Female		CSM	OPLL
<i>CSM</i> , cervical spondylotic myelopathy; <i>OPLL</i> , ossification of the posterior longitudinal ligament	A	72	46	26	57 (31–76)	48	24
	B	60	43	17	61 (40–80)	44	16
	C	36	26	10	58 (38–78)	30	6

Decompression surgery for patients with cervical myelopathy has been performed via anterior or posterior approaches [4, 15, 6, 3]. Using the anterior approach, the spinal cord is decompressed anteriorly by directly resecting or frontward floating the compressing pathognomonic materials. This requires removing the intervertebral disc and part of the vertebral body; thus, intervertebral fusion is accordingly mandatory after decompression [19]. On the other hand, using the posterior approach (mostly laminoplasty), the spinal cord is decompressed posteriorly by moving backward and away from the compressing materials [21, 11, 5, 12, 20, 14].

In the posterior approach, it is ideal to separate the spinal cord from the compressing materials as completely as possible in order to obtain maximum decompression effectiveness. Extensive laminoplasty provides a wide range of decompression for the spinal cord to move in the posterior direction while maintaining the skeletal structures of the posterior spinal column. However, in some patients, good neurological recovery could not be acquired, since the narrow range of surgical levels limited the movement of the spinal cord. As such, the questions are how many surgical levels are enough for each patient and how far the decompression effect extends. The purpose of the present study was to retrospectively investigate the relationship between the surgical levels and the decompression effects in patients who had undergone Tension-band laminoplasty (TBL) [22] at different spinal levels.

Materials and methods

One hundred and sixty-eight patients (follow-up period: 12–120 months, average 20 months) (Table 1) who had undergone TBL between 1990 and 2001 were selected for the present study with inclusion criteria as follows: The patient had a clear history of functional loss despite conservative management. They were followed up with a successive record of roentgenograms, MRIs, and neurological assessments. TBL was performed for the patients in groups A, B, and C at the C2–C7 levels with simultaneous C1 laminectomy, C2–C7 levels, and C3–C7 levels, respectively. There were no significant differences in the distributions of age, gender, and diagnosis among these groups.

Surgical technique

The TBL was performed as previously reported [22]. Briefly, the patient was placed in the prone position with the cervical spine at a slight extension and the head supported by a Mayfield skull fixator. A mid-dorsal vertical incision from the base of the skull to the C7 spinous process was made deep to the nuchal ligament. The ligamentous complex was isolated and preserved. Muscles attached to the C2 spinous process, including the semispinalis and rectus capitis, were detached and each end was marked by suturing thread. The paravertebral muscles (PVMs) were detached bilaterally from the laminae and longitudinal grooves were thereafter made along the lamina facet junction bilaterally at the C2–C7 levels for patients in groups A and B and C3–C7 levels for patients in group C. The groove on one side (usually the left) was deepened and finally the lamina was cut completely by using a Kerrison punch. Then, the operator pushed the spinous processes to the uncut side, making the lamina on the cut side wide enough for a hydroxyapatite spacer to be inserted. The spacers were

Table 2 Japanese Orthopaedic Association scoring system for cervical myelopathy

(a) Motor function—upper extremity: feeding oneself with chopsticks or a spoon
(0) Total disturbance: unable to feed oneself
(1) Severe disturbance: unable to use chopsticks, but able to use a spoon
(2) Moderate disturbance in the use of chopsticks
(3) Mild disturbance in the use of chopsticks
(4) Normal
(b) Motor function—lower extremity: gait
(0) Total disturbance: unable to walk
(1) Severe disturbance: needs aid on flat ground
(2) Moderate disturbance: needs aid on stairs
(3) Mild disturbance: needs no aid on stairs but unstable
(4) Normal
(c) Sensory function—Upper extremity, lower extremity, and trunk
(0) Complete or apparent sensory loss or severe paraesthesia
(1) Mild sensory loss or paraesthesia
(2) Normal
(d) Bladder function
(0) Total disturbance: complete retention or complete incontinence
(1) Severe disturbance: incomplete retention, incomplete incontinence, or straining
(2) Moderate disturbance: frequency or hesitation
(3) Normal
Maximum points = 17

Fig. 1 An integrated schema showing our evaluation method for the alignment of the cervical spinal column and spinal cord. On each roentgenogram, two lines were drawn through the posterior–superior and posterior–inferior body corners of C2 and C7. The angle formed by these two lines (C27Xp) was used to present the lordosis of the cervical spine. On each MRI, a line was drawn through the center points of the spinal cord at the foramen magnum and C2/C3 disc level, while another line was drawn through those at the C6/C7 and Th1/Th2 disc levels. The angle formed by these two lines (C27cord) was used for the evaluation of spinal cord alignment

then fixed to the lamina by nonabsorbable threads. During the surgical procedure, care was taken at the following steps: while detaching the PVMs from around the facet joints, not to injure the cervical dorsal rami [25]; after the laminae was opened, to remove the soft tissue between the dura and lining side of the laminae to avoid post-operative stretch injury of the spinal nerve roots [23] and for the insertion of spacers, incomplete fractures of laminae should be made at the uncut side of laminae. For the patients in group A, simultaneous C1 laminectomy was performed by removing the central part of the posterior arch at a width of 2–3 cm, which was wider than the diameter of the dural sleeve observed herein. Before closing the wound, the ends of muscles detached from the C2 spinous process were ligatured to the ligamentous complex at the C2 level in an X-shaped fashion, aiming to arrest the loss of cervical lordosis.

Neurological studies

The neurological outcomes of the patients were evaluated using the Japanese Orthopedic Association (JOA)

scoring system for cervical myelopathy (Table 2) pre-operatively (pre-JS), postoperatively (post-JS1, two months after the operation), and during their latest visit to our institute (post-JS2, 12–120 months after surgery).

Neuroradiological studies

Pre- and post-operative (4–12 months after surgery) cervical spine roentgenograms and MRIs were obtained. The lateral roentgenograms and the sagittal T2-weighted MRIs through the median plane of the spinal cord, with the neck in neutral position, were selected for further analysis using a personal computer and public-domain software (NIH Image, version 1.62).

On the roentgenograms, lines were drawn through the posterior–superior and posterior–inferior vertebral body corners of C2 and C7, like the Harrison Posterior Tangent Method [9]. The angle formed by these two lines, C27Xp, was used to present the lordosis of the cervical spine. On each MRI, lines were drawn through the center points of the spinal cord at the foramen magnum and C2/C3 disc level, with another line drawn

Fig. 2 Schematic illustration for the measurement of sagittal T2-weighted MRI. The perpendicular line (*broken line*) toward the dural sleeve was drawn at the middle point of the posterior edge of each vertebral body. At the C1 level, a perpendicular line was drawn from the center of the posterior arch to the dural sleeve. **a** anterior subarachnoid space (ASAS), **b** diameter of the spinal cord (CORD), **c** diameter of the dural sleeve (DURA)

through the center points of the spinal cord at the C6/C7 and Th1/T2 disc levels. The angle formed by these two lines, C27cord, was used for the evaluation of the spinal cord alignment (Fig. 1). The differences of these angles between pre- and post-operation, D-C27Xp and D-C27cord (calculated by subtracting the post-operative from the pre-operative values) were obtained for each patient.

Additionally, on each MRI, at the C2–C7 levels, from the middle point of the posterior edge of each vertebral body, perpendicular lines were drawn backward to the dural sleeve and the spinal cord. At the C1 level, a perpendicular line was drawn from the center of the posterior arch forward to the dural sleeve. The widths of the anterior subarachnoid space, the spinal cord and the dural sleeve were measured on these lines and designated as anterior subarachnoid spaces (ASAS), CORD, and DURA, respectively. CORD and DURA were regarded as the diameters of the spinal cord and the dural sleeve. The differences of these values between pre- and post-operation, D-ASAS, D-CORD, and D-DURA (calculated by subtracting the pre-operative from the

Fig. 3 Graphic data of the Japanese Orthopedic Association (JOA) scores of the three groups (values described in the text). Assessments were performed preoperatively (pre-JS), 2 months and 12–120 months postoperatively (post-JS1 and post-JS2), respectively. * $P < 0.05$ for intragroup comparison with the previous assessment

post-operative values) were also obtained. Furthermore, in order to express the indication of additional C1 laminectomy in special figures, the ratios of pre-operative CORD and DURA (CORD/DURA) at the C1–C2 levels of patients in groups A and B were calculated (Fig. 2). The ruler-like bar scales in the MRIs were used for distance measurements.

The neuroradiological measurements for all patients were performed alternately by two surgeons who had not attended any surgery.

Fig. 4 Graphic data show the loss of lordosis of the cervical spinal column (D-C27Xp) and spinal cord (D-C27cord) after surgery in the three groups (values described in the text). * $P < 0.05$ for intragroup comparison between pre- and post-operation; # $P < 0.05$, for intergroup comparison

Table 3 Statistical study of the differences in the anterior subarachnoid space (ASAS), the diameter of the cord (CORD), and the diameter of the dural sleeve (DURA) among groups A, B, and C ($P < 0.05$ and $*P < 0.01$)

Compared groups		Comparison of median values	Spinal levels showing significant difference		
			ASAS	CORD	DURA
Pre-operation	A and C	$C > A$	C4	C3, C4	C1, C2, C3, C4
	A and B	$B > A$	C2*, C3	C2	C1*, C2*
	B and C	$C > B$		C4	C3, C4
Post-operation	A and C	$A > C$	C1*, C2*	C1*, C2*, C3	C1*, C2*, C3
	A and B	$A > B$	C1, C4, C5	C5	C1*, C5*
	B and C	$B > C$	C2*	C1, C2*, C3*	C2, C3*

Statistical analysis

Since none of the data sets in the present study follows the normal distribution, Wilcoxon's rank test and Mann-Whitney U test were used for intragroup and intergroup comparisons, respectively. The values of the indices for each group were presented as median values (interquartile range) in the results.

Results

Neurological improvement

The pre-JSs, post-JS1, and post-JS2s of the patients were as follows: 12 (9.5–13), 13 (11–15), and 14 (13–16) in group A; 12 (9–13), 13.5 (12–15), and 14 (12–15) in group B and 11 (9–12), 13.5 (12–14.5), and 14 (12–15) in group C, yielding a total improvement of about two points in each group ($P < 0.01$). No significant differences in the pre-JS and post-JS2 among the three groups were found (Fig. 3).

Neuroradiological studies

In all patients, the pre-operative C27Xp was positive, i.e., they all had lordotic alignment of the spinal column. After surgery, despite changes in the degree of lordosis in some patients, the lordotic alignment of the spinal column was maintained in all patients. The D-C27Xp of groups A, B, and C were 1.9 (–4, 13)°, 3.9 (–5.3–8.9)°, and 0.6 (–5.3–7.9)°, respectively, showing neither a significant constant trend of change in any group nor significant differences among the three groups (Fig. 4).

The lordotic alignment of the spinal cord was decreased in each of the three groups, with a D-C27cord of 5.5 (2.0–11.0)° in group A ($P < 0.01$), 2.9 (–1.5–9.3)° in group B ($P < 0.01$), and 2.3 (–1.6–7.8)° in group C ($P < 0.05$). The D-C27cord in group A was larger than those of groups B and C ($P < 0.05$), whereas no significant differences were found between groups B and C.

The comparison of the results of ASAS, CORD, and DURA among groups A, B, and C is shown in Table 3. Generally, as compared to group C, most values of group B at the C2–C5 levels changed as follows: from a significantly smaller to an equal degree or from an equal degree to a significantly larger degree. This trend was the same in group A when comparing to groups B and C.

D-ASAS, D-CORD, and D-DURA are shown in Fig. 5. Briefly, after surgery, enlargements of ASAS were 1–2 mm at the C1–C6 levels in group A ($P < 0.01$), 0.5–1 mm at C2–C6 in group B ($P < 0.01$) and at C4–C6 in group C ($P < 0.01$) (Fig. 5a). The enlargements of CORD were 1–2 mm at C1–C6 in group A ($P < 0.01$), about 1 mm at C2–C6 in group B ($P < 0.01$) and at C4–C6 in group C ($P < 0.01$) (Fig. 5b). The enlargements of DURA were 2–4 mm at the C1–C6 in group A ($P < 0.01$), 2–3 mm at C3–C6 in group B ($P < 0.01$) and about 2 mm at C4–C6 in group C ($P < 0.01$) (Fig. 5c). Additionally, the enlargement of ASAS in group A was larger than that of group B at C1–C5 ($P < 0.05$), as were those of CORD and DURA at C1–C2 and C4–C5 ($P < 0.05$). The enlargement of ASAS in group A was larger than that of group C at C1–C4 ($P < 0.05$), as were those of CORD and DURA at C1–C5 ($P < 0.05$).

The pre-operative CORD/DURAs at the C1 level in group A [0.48 (0.45–0.53)] were larger than those of group B [0.47 (0.43–0.51)] ($P < 0.05$), with nearly 80% values in group A being bigger than 0.5 and most of that in group B smaller than 0.5. No significant differences in CORD/DURA at the C2 level were found between the two groups.

Discussion

Both CSM and OPLL are progressive illnesses, in which compression of the spinal cord proceeds in small steps and neurological outcomes are usually delayed to the imaging appearance. In CSM, the spinal cord tends to initially be compressed at the middle and lower cervical levels, for that the degenerative changes tend to occur at

Fig. 5 **a** Graphic illustrations show the enlargement of the anterior subarachnoid space (D-ASAS), **b** the diameter of the spinal cord (D-CORD), and **c** the diameter of the dural sleeve (D-DURA) of the three groups at C1–C7 (values described in the text). * $P < 0.05$ for comparison between the two groups; # $P < 0.05$ for comparisons among the three groups

these levels [16, 13]. The disc spaces become narrowed and disc herniation and bony spur protrude into the spinal canal. In relatively younger patients, the spinal cord at the lower cervical levels, such as C5 or C6 is most vulnerable. With progressive degenerative changes of the cervical column due to aging, the spinal cord at the upper cervical levels such as C2 or C3 become vulnerable, since the lower cervical columns become stable and, as a result, degenerative changes tend to occur at the upper cervical level [10, 2]. In OPLL, ossification gradually grows within the spinal canal not only in the lateral direction but also in the longitudinal direction [17]. These changes tend to particularly occur after posterior decompression surgery, probably because of decreased posterior stability. The posterior longitudinal ligament is located between the bottom of the clivus and the first sacral level. Therefore, even though the OPLL initially locates at the middle or lower cervical levels, it may extend toward the C1 level in future. Taken together, the strategy for the management of CSM or cervical myelopathy caused by OPLL should include consideration of relieving the spinal cord from the compressed condition and giving it flexibility to accommodate to the pathological process.

There are two main approaches for surgical decompression of cervical myelopathy. The anterior approach is generally performed when the myelopathy is caused by anterior compression at one or two levels and in patients with kyphosis, while the posterior approach, mostly laminoplasty, is recommended for more than three levels of decompression. Effectiveness through a posterior approach depends on dorsal shift of the spinal cord. To reach this objective, decompression should be performed at not only compressed but also the adjacent levels. However, to our knowledge, there is currently no report showing how different the effect will be if the surgical levels are varied and how to define the appropriate range of surgical spinal levels in expansive laminoplasty. To answer this question, we compared the effect of TBL performed at different spinal levels as a management for cervical myelopathy, such as, C3–C7 and C2–C7 TBL for the patients with spinal cord compressed at cervical levels up to C5 (in group C) and C4 (in group B), respectively, while C2–C7 TBL and simultaneous C1 laminectomy for the cases with C2–C3 levels also involved or narrow dural sleeves at C1 level (CORD/DURA > 0.5 , by our experience) (in group A). Surgical spinal levels were determined based on neuroradiological findings, since anatomical condition is the original cause of nerve injury and its modification is the goal of decompression surgery.

It was generally speculated that the posterior approach would reduce the cervical spine lordosis.

Fig. 6 Sagittal T2-weighted MRIs of 50-year-old males with CSM from group A (a1, a2), B (b1, b2), and C (c1, c2). The images of a1, b1 and c1 were obtained preoperatively, while a2, b2 and c2 at 2, 4 and 10 months after surgery, respectively. At C3–C7, the dural sleeve was enlarged in a2, b2, and c2. At C1–C2, the dural sleeve

was enlarged and the spinal cord shifted backward in a2 but not in b2 and c2. Additionally, the spinal cord was compressed at the C1 level in b2 and c2. The JOA scores of these patients were described in the text

However, in the present study, neither significant change of lordotic alignment of the spinal column (D-C27Xp) in any of the groups nor significant difference among the groups was found. And there was no complaint due to instability of the cervical spine occurred to any patients during the follow-up period. Our efforts in the surgical procedures, briefly, avoiding inadvertent injury of the median branches of the cervical dorsal rami [18], reserving the posterior ligamentous complex and reattaching the cervical semispinalis and rectus capitis to the nuchal ligament at the C2 level, were thought to contribute to arrest the loss of cervical spine lordosis.

Neuroradiologically, the widest expansion of the dural sleeve and the largest posterior shift of the spinal cord at the C1–C5 levels were obtained in group A. Additional decompression at C1–C2 allowed the wider expansion of the dural sleeve and a larger posterior shift of the spinal cord at not only C1–C2 but also C3–C5. Conversely, for some patients in group B, the dural sleeve was even narrowed at C1–C2, and so was that in group C at C1–C3. This was consistent with the change of the spinal cord alignment, that was, the lordotic alignment of the spinal cord became significantly smaller in group A than those of the patients in groups B and C. Checking references from the spinal and spinal cord alignment, we concluded that C2–C7 TBL with simultaneous C1 laminectomy (in group A) gave the spinal cord maximum backward movement at C5 or higher levels without changing spinal alignment. It must be emphasized here that what we compared were the neuroradiological changes brought to each group by different operations and that significant differences appeared at all of the C1–C5 levels, including those showing no significant neuroradiological difference among these groups preoperatively (Table 3).

Comparative study made among the three groups aimed to investigate the potential of each operation, but not in order to find which one is the best for all cases. The neurological results showed the three operations were all effective for the proper patients. However, they were performed for the patients with different anatomical conditions, thus the comparable neurological improvements did not mean they had identical effectiveness. As mentioned above, compression caused cervical myelopathy in small steps. This made existent practicable techniques difficult to figure out exactly what the nerve condition was. On the other hand, it is widely accepted that spinal cord is at higher risk of injury in a narrower canal, and the improvement of neurological function depends not only on effective decompression but also on pre-operative nerve condition. In this study, the pre-JSs were equal among all groups, yet the severity order of compression was group A > group B > group C, implying the deterioration speed at the same order. Accordingly, the comparable post-JS2s suggested that the effect order of the three operations in functional recovery and prevention of aggravation should be C2–C7 TBL with simultaneous C1 laminectomy > C2–C7 TBL > C3–C7 TBL.

The limitation of this study was that we could not show any data to indicate how the patients of each group would have fared if they underwent the procedures for the other two groups, because those operations were thought to be the most appropriate treatments for them. Alternatively, here we provided the MRIs of a typical patient in group A and those of two other patients with unsatisfactory results from groups B and C to emphasize the importance of manipulation at C2 and C1 levels for the patients with aforementioned indications. In Fig. 6, a1–2 are images of a typical patient from

group A; decompression was completed with the JOA score going up from 11 to 15 and keeping it to the latest neurological assessment. On the other hand, b1–2 and c1–2 are the images of patients from groups B and C, whose JOA scores were improved from 11 to 13 but declined to 11 during the long-term follow-up. This degradation of neurological function was considered to

result respectively from the new compression at C1, and C1–C2 levels immersed postoperatively.

In conclusion, C2–C7 TBL was proved to be an effective and safe treatment for cervical myelopathy in patients with compressed levels up to C4, and it can be expanded to include C1 laminectomy if the higher levels were also affected.

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