Effect of decompression range on decompression limit of cervical laminoplasty

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Abstract

Backgrounds: Cervical posterior decompression surgery is used to relieve ventral compression indirectly by incorporating a backward shift of the spinal cord, and this indirect decompression is bound to be limited. This study aimed to determine the decompression limit of posterior surgery and the effect of the decompression range.

Methods: We retrospectively reviewed the data of 129 patients who underwent cervical open-door laminoplasty through 2008 to 2012 and were grouped as follows: C4–C7 ($n = 11$), C3–C6 ($n = 61$), C3–C7 ($n = 32$), and C2–C7 ($n = 25$). According to the relative location of spinal levels within a decompression range, the type of decompression at a given level was categorized as external decompression (ED; achieved at the levels located immediately external to the decompression range margin), internal decompression (ID; achieved at the levels located immediately internal to the decompression range margin), and central decompression (CD; achieved at the levels located in the center, far from the decompression range margin). The vertebral–cord distance (VCD) was used to evaluate the decompression limit. The C2–C7 angle and VCD on post-operative magnetic resonance images were analyzed and compared between groups. The relationship between VCD and decompression type was analyzed. Moreover, the relationship between the magnitude of the ventral compressive factor and the probability of post-operative residual compression at each level for different decompression ranges was studied.

Results: There was no significant kyphosis in cervical curvature ($> -5°$), and there was no significant difference among the groups ($F = 2.091$, $P = 0.105$). The VCD of a specific level depended on the decompression type of the level and followed this pattern: ED < ID < CD ($P < 0.05$). The decompression type of a level was sometimes affected by the decompression range. For a given magnitude of the ventral compressive factor, the probability of residual compression was lower for the group with the larger VCD at this level.

Conclusions: Our study suggests that the decompression range affected the decompression limit by changing the decompression type of a particular level. For a given cervical spinal level, the decompression limit significantly varied with decompression type as follows: ED < ID < CD. CD provided maximal decompression limit for a given level. A reasonable range of decompression could be determined based on the relationship between the magnitude of the ventral compressive factor and the decompression limits achieved by different decompression ranges.

Keywords: Cervical spondylosis; Ossification of posterior longitudinal ligament; Magnetic resonance imaging; Laminoplasty

Introduction

Posterior decompression surgeries such as laminoplasty, laminectomy, and laminectomy combined with arthrodesis are commonly performed for patients with multilevel cervical compressive myelopathy (CCM). All these procedures have a common mechanism of circumferential decompression, which is usually achieved directly by removing the dorsal compression and indirectly by the backward shift of the spinal cord to avoid ventral compression. Naturally, the extent to which the spinal cord moves backward is limited. The decompression limit of posterior surgeries can be defined as the maximum extent to which that the backward shift of the spinal cord can avoid the ventral compression after posterior surgery, which is the indirect decompression limit of the posterior surgery.

Some authors have attempted to quantify this capacity by measuring the change in the positions of specific sites in the spinal cord (*eg*, anterior margin, center, and posterior margin) on pre- and post-operative images.[1-5] However, conflicting results have been reported on the correlation of the backward shift of the spinal cord with clinical outcomes,[6] which is perhaps related to differences in the specific parameter being evaluated. Furthermore,

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another important and overlooked reason is that the backward shift of a specific spinal site may not always accurately reflect the indirect decompression limit of posterior surgery, as the backward shift measured on pre- and post-operative images is also affected by the severity of the ventral compression. Additionally, whether the decompression is sufficient for a given patient is more relevant to their prognosis than the precise shift of the spinal cord after decompression. Therefore, it is more meaningful to study the decompression limit and its influencing factors in posterior surgeries. Furthermore, we believe that the characteristics of the decompression at the levels located at the margins of the decompression range differ from the decompression characteristics at levels located far from the margins. A change in the decompression range may affect the decompression limit by changing the characteristics of decompression at a particular level. Hence, the purpose of this study was to evaluate the decompression limit of posterior surgeries and determine the effect of decompression range on this limit.

Methods

Ethical approval

This study was approved by the ethics committee of Peking University Third Hospital; Beijing Key Laboratory of Spinal Disease (No. IRB00006761-2012097). All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 *Declaration of Helsinki* and its later amendments or comparable ethical standards. Informed consent was obtained from all patients included in this study.

Patients selection

This retrospective study was conducted on CCM patients who met the following inclusion criteria through 2008 to 2012: (1) cervical open-door expansive laminoplasty (ELAP) as the sole surgical procedure performed, (2) cervical magnetic resonance imaging (MRI) performed 3 to 12 months after surgery, (3) C2–C7 angle on MRI greater than $-5°$ without significant kyphosis, and (4) cerebrospinal fluid filling between the compressive mass and the anterior edge of spinal cord on MRI, which indicated sufficient cervical spinal cord decompression. The patients were divided into four groups based on the range of decompression: the C4–C7, C3–C6, C3–C7, and C2–C7 groups.

Decompression surgery

Open-door ELAP was performed in all patients with unilateral preservation of the posterior muscular-ligament complex (PMLC)[7] or a hinge side anchoring procedure (HSAP).[8] Unilateral preservation of the PMLC was performed using a simplified Tani[9] procedure without the spacer on the opening side and by using titanium cables under tension instead of silk threads to achieve spinous process and laminar fixation. In our previous study, the spinal canal expansion was proven to be the same between the two forms of laminoplasty.[7]

Definition of decompression types at individual spinal levels

The decompression at individual spinal levels was categorized based on the location of the level in the decompression range and the corresponding decompression characteristics as follows: (1) External decompression (ED) refers to the decompression achieved at the levels located at immediately external to the decompression range margin. One of the two constituting laminae at these levels was decompressed and the other was not. For example, in the C3–C7 group, ED was achieved at the C2/3 and C7/T1 levels. (2) Internal decompression (ID) refers to the decompression achieved at the levels located immediately internal to the decompression range margin. Both the constituting laminae at these levels were decompressed, but only the adjacent upper or lower lamina was decompressed. For example, in the C3–C7 group, ID was achieved at the C3/4 and C6/7 levels. (3) Central decompression (CD) refers to the decompression achieved at the levels located at the center far from the decompression range margins. Both the constituting laminae at these levels as well as the adjacent upper and lower laminae were decompressed. For example, in the C3–C7 group, CD was achieved at the C4/5 and C5/6 level. Thus, for the C4–C7, C3–C6, C3–C7, and C2–C7 groups, the type of decompression achieved at the C3/4 level was ED, ID, ID, and CD, respectively [Figure 1].

MRI evaluation

We retrieved the post-operative MRI scans of the patients from our Picture Archiving and Communication System (GE Medical Systems, Milwaukee, WI, USA). All scans had been performed 3 to 12 months after surgery. T2-weighted images taken in the mid-sagittal plane in the neutral position were selected. On these images, we drew a line along the posterior margins of the vertebral bodies in the cervical spine [Figure 2]. On this line, we marked the midpoints of the C2/3, C3/4, C4/5, C5/6, and C6/7 intervertebral spaces. We drew five lines connecting each of these points to the anterior margin of the spinal cord along the direction of the intervertebral space. These lines represented the vertebral–cord distance (VCD).

The C2–C7 angle was measured on the same sagittal plane of MRI to represent the sagittal alignment of the cervical spine and was compared among the groups. We measured the VCDs at each individual level and compared them among the four study groups. For a given level, the decompression type may vary with the decompression range. Therefore, to reveal the influence of the decompression range on the decompression limit, we also analyzed the relationship between the VCD and the type of decompression.

Relationship between ventral magnitude of compressive factor (MCF) and probability of post-operative residual compression

Using the NORMDIST function (x, mean, standard deviation, cumulative) in Excel, the cumulative probability for a given VCD at each level for different decompression ranges was calculated, which is equal to the probability of

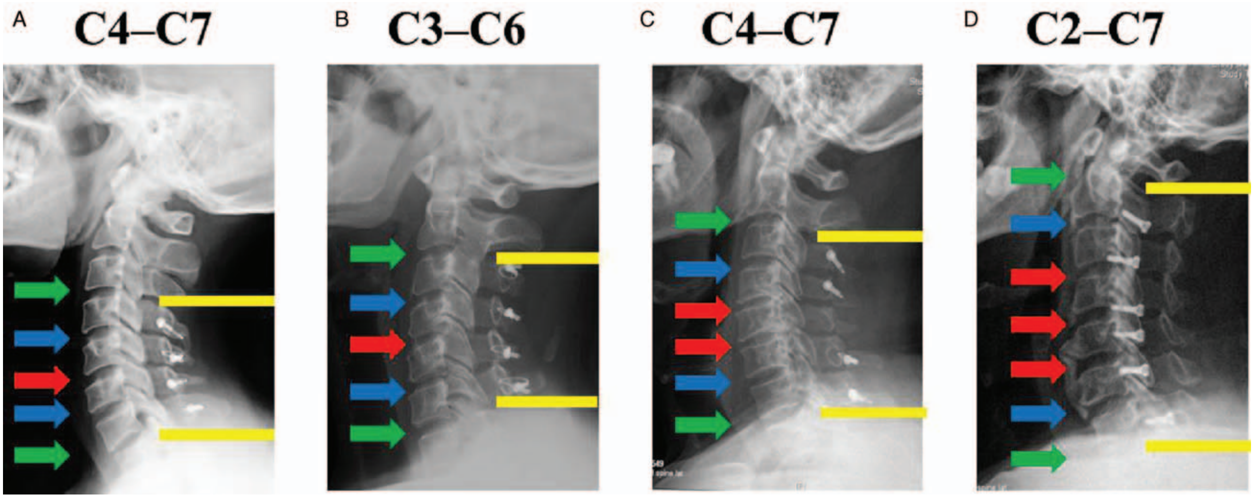

Figure 1: Decompression type at each cervical level for various decompression ranges (A–D). The decompression ranges are shown by the yellow lines. The green arrows show the levels with external decompression (ED). The blue arrows show the levels with internal decompression (ID). The red arrows show the levels with central decompression (CD).

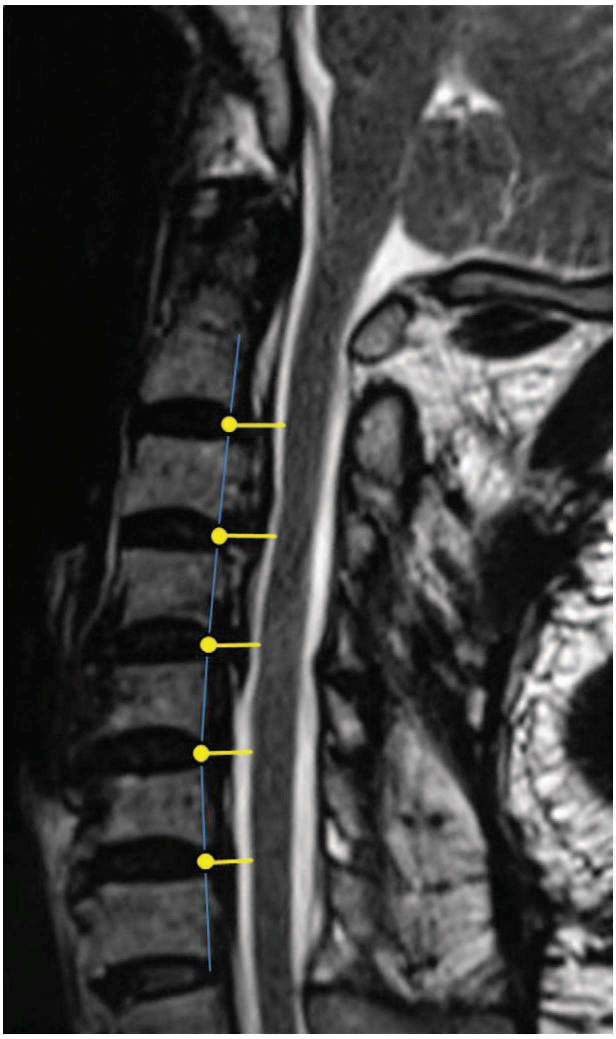

Figure 2: The midpoints of the intervertebral spaces (yellow points) are marked on a line drawn along the posterior margins of the vertebral bodies (blue line). The distance (yellow lines) between the midpoints and the anterior margin of the spinal cord is defined as the vertebral–cord distance (VCD).

post-operative residual compression when the ventral magnitude of compressive factor is the same as the given VCD (x = the given VCD = MCF; mean and standard deviation were set to those of the corresponding level and the decompression range; the cumulative was set to TRUE). The relationship between ventral MCF and the probability of post-operative residual compression at each level for different decompression ranges was studied.

Statistical analysis

The SPSS 15.0 (IBM, Armonk, NY, USA) was used for statistical analysis. The C2–C7 angles were compared among the four study groups by using one-way analysis of variance (ANOVA). When Levene test showed the variances were homogeneous, the ANOVA results were accepted. The VCDs at the same level were compared among the four study groups by *post hoc* multiple comparisons. The least significant difference test (LSD) was used when the variances were homogeneous. The Tamhane T2 test was used when the variances were not homogeneous. $P < 0.05$ was considered statistically significant.

Results

General characteristics, cervical alignment, and VCD

This study involved 129 CCM patients, including 95 men and 34 women [Table 1]. ANOVA results were accepted (Levene statistic = 2.394, $P = 0.072$) and showed that the C2–C7 angles did not significantly differ among the four groups (C4–C7 19.3° ± 6.0°, C3–C6 13.7° ± 11.4°, C3–C7 13.3° ± 7.5°, C2–C7 17.8° ± 9.3°; $F = 2.091$, $P = 0.105$). The post-operative VCDs and *post hoc* multiple comparisons between groups are shown in Table 2. At the level C2/3, the VCD significantly differed between the C2–C7 group and the other three groups. At the C3/4 level, the VCDs in groups C4–C7 and C2–C7 significantly differed from each other and differed from the VCDs of groups C3–C6 and C3–C7. At level C4/5, the VCDs in group C4–C7

Table 1: General characteristics of patients who underwent cervical open-door laminoplasty in the four groups.

Characteristics	C4–C7 ($n = 11$)	C3–C6 ($n = 61$)	C3–C7 ($n = 32$)	C2–C7 ($n = 25$)
Gender, n				
Male	5	46	25	19
Female	6	15	7	6
Age (years), median (range)	57.4 (30.0–73.0)	57.5 (22.0–83.0)	58.1 (33.0–78.0)	56.3 (40.0–71.0)
Diagnosis, n				
CSM	6	43	23	4
OPLL	5	18	9	21
Specific surgical procedure, n				
HSAP	5	25	18	20
PMLC	6	36	14	5

CSM: Cervical spondylotic myelopathy; HSAP: Hinge side anchoring procedure; OPLL: Ossification of posterior longitudinal ligament; PMLC: Unilateral preservation of the posterior muscular-ligament complex.

significantly differed from those in the other 3 groups. At levels C5/6 and C6/7, significant differences in VCD were found between group C3–C6 and the other three groups.

The results sometimes showed significant differences between 2 or more groups, which demonstrated that the decompression limit was sometimes affected by the decompression range. For example, the VCD for level C3/4 in both group C4–C7 and group C2–C7 significantly differed from those of the other three groups. For the same level, the VCD in groups C3–C6 and C3–C7 did not significantly differ from each other but significantly differed from those of the other 2 groups. In other words, the decompression limit at level C3/4 increased significantly when the decompression range changed from C3–C7 to C2–C7, while the decompression limit decreased significantly when the decompression range changed from C3–C7 to C4–C7. However, the limit did not change when the range changed from C3–C7 to C3–C6.

Relationship between decompression type at a given level and decompression range

The decompression type at each level in different decompression ranges is shown in Table 3. The decompression type of a level located close to the decompression margin would change from ED to ID and further to CD when the decompression range increased. For example, these changes occurred in the decompression type at C3/4 when the decompression range changed from C4–C7 to C3–C7 and then to C2–C7. Conversely, a reverse change occurred when the decompression range decreased. Thus, the decompression type of a particular level could be changed by adjusting the decompression range.

Relationship between decompression type and decompression limit

According to the above results, we found that the decompression range might affect the limit and type of decompression at a particular level. Combining Table 2 with Table 3, we further found that changes in decompression limit for a given cervical spinal level were synchronized with changes in decompression type [Table 4]. The decompression limits for different decompression types followed this pattern: ED < ID < CD (with significant differences between the three decompression types). For example, the decompression type at level C3/4 was categorized as ED in group C4–C7, ID in groups C3–C6 and C3–C7, and CD in group C2–C7. Thus, the decompression limit for level C3/4 significantly changed with changes in the decompression type, which could be adjusted by changing the decompression range. As the magnitude of the compressive factor at level C3/4 could be measured pre-operatively, the above relationship could be used to predict the decompression limit and select an appropriate range of decompression. For example, if a decompression range of C4–C7 is chosen, ED would be achieved at level C3/4, which was associated with the minimum decompression limit (average VCD, 4.90 ± 0.67 mm). If a range of C3–C7 is chosen, then ID would be achieved at level C3–C4, and the decompression limit would be significantly increased (average VCD, 6.60 ± 1.41 mm). Finally, if a range of C2–C7 is chosen, CD would be achieved at level C3/4, and the decompression limit would be maximized (average VCD, 8.74 ± 1.54 mm). Thus, by comparing the VCDs that would be obtained for the three decompression types at level C3/4 with the magnitude of the ventral compressive mass, a reasonable range of decompression could be selected to achieve sufficient decompression.

Another notable finding was that central decompression led to the maximum decompression limit for a given level, and no greater decompression could be achieved by further expanding the range of decompression. For example, if the decompression range is C3–C6, then CD would be achieved at level C4/5. If the decompression range is extended to C2–C7, the decompression type at level C4/5 remains CD, and the decompression limit is not significantly changed. Thus, for the decompression at level C4/5, expanding the decompression range would not be beneficial.

Relationship between ventral MCF and probability of post-operative residual compression

MCFs and the corresponding probabilities of post-operative residual compression at each level for different

Table 2: Comparison of VCD (mm) between the groups underwent laminoplasty with different decompression range (mm).

Range	C4–C7 ($n=11$)	C3–C6 ($n=61$)	C3–C7 ($n=32$)	C2–C7 ($n=25$)	I	J	Mean difference (I-J)	P
C2/3	5.49 ± 0.78	5.89 ± 1.31	6.13 ± 1.16	8.58 ± 1.52	C4–C7	C3–C6	0.39161	0.354
						C3–C7	−0.63761	0.158
						C2–C7	−3.08236	<0.001
					C3–C6	C4–C7	0.39161	0.354
						C3–C7	−0.24600	0.382
						C2–C7	−2.69075	<0.001
					C3–C7	C4–C7	0.63761	0.158
						C3–C6	0.24600	0.382
						C2–C7	−2.44475	<0.001
					C2–C7	C4–C7	3.08236	<0.001
						C3–C6	2.69075	<0.001
						C3–C7	2.44475	<0.001
C3/4	4.90 ± 0.67	6.58 ± 1.35	6.60 ± 1.41	8.74 ± 1.54	C4–C7	C3–C6	−1.68368	<0.001
						C3–C7	−1.70190	0.001
						C2–C7	−3.83869	<0.001
					C3–C6	C4–C7	1.68368	<0.001
						C3–C7	−0.01822	0.951
						C2–C7	−2.15501	<0.001
					C3–C7	C4–C7	1.70190	0.001
						C3–C6	0.01822	0.951
						C2–C7	−2.13679	<0.001
					C2–C7	C4–C7	3.83869	<0.001
						C3–C6	2.15501	<0.001
						C3–C7	2.13679	<0.001
C4/5	6.04 ± 0.79	7.47 ± 1.46	7.59 ± 1.55	8.42 ± 1.82	C4–C7	C3–C6	−1.42449	<0.001
						C3–C7	−1.54415	0.001
						C2–C7	−2.37367	<0.001
					C3–C6	C4–C7	1.42449	<0.001
						C3–C7	−0.11966	1.000
						C2–C7	−0.94919	0.145
					C3–C7	C4–C7	1.54415	0.001
						C3–C6	0.11966	1.000
						C2–C7	−0.82953	0.372
					C2–C7	C4–C7	2.37367	<0.001
						C3–C6	0.94919	0.145
						C3–C7	0.82953	0.372
C5/6	7.63 ± 1.63	5.89 ± 1.21	7.92 ± 1.94	8.18 ± 1.77	C4–C7	C3–C6	1.73893	0.033
						C3–C7	−0.28591	0.998
						C2–C7	−0.55451	0.938
					C3–C6	C4–C7	−1.73893	0.033
						C3–C7	−2.02484	<0.001
						C2–C7	−2.29344	<0.001
					C3–C7	C4–C7	0.28591	0.998
						C3–C6	2.02484	<0.001
						C2–C7	-0.26860	0.995
					C2–C7	C4–C7	0.55451	0.938
						C3–C6	2.29344	<0.001
						C3–C7	0.26860	0.995
C6/7	7.43 ± 1.49	5.08 ± 1.01	7.81 ± 1.65	7.35 ± 1.67	C4–C7	C3–C6	2.10659	0.002
						C3–C7	−0.37997	0.494
						C2–C7	0.08269	0.886
					C3–C6	C4–C7	−2.10659	0.002
						C3–C7	−2.48656	<0.001
						C2–C7	−2.02390	<0.001
					C3–C7	C4–C7	0.37997	0.494
						C3–C6	2.48656	<0.001
						C2–C7	0.46266	0.277
					C2–C7	C4–C7	−0.08269	0.886
						C3–C6	2.02390	<0.001
						C3–C7	−0.46266	0.277

Data were presented as mean ± standard deviation. VCD: Vertebral-cord distance.

decompression ranges are shown in Table 5. At a given level, the probability of post-operative residual compression increased with an increase in MCF for each decompression range. However, the rate of increase in residual compression probability was different between those groups in which the VCD was significantly different. For example, at level C3/4, when the MCF increased from 5 mm to 9 mm, the residual compression probability increased from 12.82% to 95.56% in group C3–C7, while it increased from 0.76% to 56.70% in group C2–C7. For a given MCF, the residual compression probability was lower in the group with a larger VCD at the same level. Thus, for level C3/4, group C2–C7 (which has a larger VCD) has a better indirect decompression limit than group C3–C7. For an objective decompression level in a given patient, the MCF at this level can be measured and compared with the predicted VCDs that can be achieved with various decompression ranges. Thus, the residual compression probabilities can be estimated by referring to Table 5, which would be helpful when choosing a reasonable decompression range.

Table 3: Relationship between decompression types at different levels and decompression ranges.

Level	C4–C7	C3–C6	C3–C7	C2–C7
C2/3	NA	ED	ED	ID
C3/4	ED	ID	ID	CD
C4/5	ID	CD	CD	CD
C5/6	CD	ID	CD	CD
C6/7	ID	ED	ID	ID

NA: not applicable; CD: central decompression; ED: external decompression; ID: internal decompression.

Table 4: Relationship between decompression types and decompression limits of the patients who underwent cervical open-door laminoplasty.

Groups	C4–C7 ($n=11$)	C3–C6 ($n=61$)	C3–C7 ($n=32$)	C2–C7 ($n=25$)
C2/3				
VCD (mm)	$5.49 \pm 0.78^{*}$	$5.89 \pm 1.31^{*}$	$6.13 \pm 1.16^{*}$	$8.58 \pm 1.52^{\dagger}$
Decompression type	NA	ED	ED	ID
C3/4				
VCD (mm)	$4.90 \pm 0.67^{\dagger}$	$6.58 \pm 1.35^{\ddagger}$	$6.60 \pm 1.41^{\ddagger}$	$8.74 \pm 1.54^{\dagger}$
Decompression type	ED	ID	ID	CD
C4/5				
VCD (mm)	$6.04 \pm 0.79^{\dagger}$	$7.47 \pm 1.46^{*}$	$7.59 \pm 1.55^{*}$	$8.42 \pm 1.82^{*}$
Decompression type	ID	CD	CD	CD
C5/6				
VCD (mm)	$7.63 \pm 1.63^{*}$	$5.89 \pm 1.21^{\dagger}$	$7.92 \pm 1.94^{*}$	$8.18 \pm 1.77^{*}$
Decompression type	CD	ID	CD	CD
C6/7				
VCD (mm)	$7.43 \pm 1.49^{*}$	$5.08 \pm 1.01^{\dagger}$	$7.81 \pm 1.65^{*}$	$7.35 \pm 1.67^{*}$
Decompression type	ID	ED	ID	ID

NA: Not applicable; CD: Central decompression; ED: External decompression; ID: Internal decompression; VCD: Vertebral-cord distance. * Significant differences between this group and one of the other groups ($P < 0.05$). † Significant differences between this group and the other three groups ($P < 0.05$). ‡ Significant differences between this group and two of the other groups ($P < 0.05$)

Table 5: Relationship between ventral magnitude of compressive factor and probability (%) of postoperative residual compression at each level for different decompression ranges.

MCF (mm)	C4–C7 (%)				C3–C6 (%)					C3–C7 (%)					C2–C7 (%)				
	C3/4	C4/5	C5/6	C6/7	C2/3	C3/4	C4/5	C5/6	C6/7	C2/3	C3/4	C4/5	C5/6	C6/7	C2/3	C3/4	C4/5	C5/6	C6/7
5.0	55.9	9.4	5.3	5.2	24.8	12.1	4.5	23.1	46.8	16.5	12.8	4.7	6.6	4.4	0.9	0.76	3.0	3.6	8.0
5.5	81.5	24.1	9.6	9.8	38.3	21.2	8.9	37.4	66.1	29.4	21.8	8.9	10.6	8.1	2.1	1.77	5.4	6.5	13.4
6.0	95.0	48.0	15.9	16.9	53.4	33.4	15.7	53.6	81.9	45.5	33.5	15.3	16.1	13.6	4.5	3.76	9.2	10.9	20.9
6.5	99.2	72.0	24.4	26.6	67.9	47.6	25.3	69.3	92.0	62.5	47.2	24.1	23.2	21.4	8.6	7.29	14.6	17.1	30.5
7.0	99.9	88.8	35.0	38.6	80.2	62.2	37.4	82.1	97.1	77.3	61.2	35.2	31.8	31.2	14.9	12.93	21.8	25.3	41.7
7.5	100.0	96.8	46.8	51.9	89.1	75.2	50.8	90.8	99.2	88.1	73.8	47.7	41.4	42.6	23.8	21.04	30.7	35.0	53.6
8.0	100.0	99.3	59.0	64.9	94.6	85.4	64.2	95.9	99.8	94.7	84.0	60.4	51.6	54.6	35.1	31.54	40.9	46.0	65.1
8.5	100.0	99.9	70.3	76.4	97.7	92.3	76.0	98.5	100.0	98.0	91.1	72.1	61.8	66.2	47.9	43.81	51.8	57.2	75.5
9.0	100.0	100.0	80.0	85.4	99.1	96.4	85.3	99.5	100.0	99.3	95.6	81.9	71.1	76.5	60.9	56.70	62.5	67.8	83.8
9.5	100.0	100.0	87.4	91.8	99.7	98.5	91.8	99.9	100.0	99.8	98.0	89.1	79.2	84.7	72.8	68.92	72.4	77.2	90.1
10.0	100.0	100.0	92.7	95.8	99.9	99.4	95.8	100.0	100.0	100.0	99.2	94.0	85.8	90.8	82.5	79.34	80.7	84.8	94.4
10.5	100.0	100.0	96.1	98.0	100.0	99.8	98.1	100.0	100.0	100.0	99.7	97.0	90.8	94.9	89.7	87.35	87.4	90.5	97.0
11.0	100.0	100.0	98.1	99.2	100.0	100.0	99.2	100.0	100.0	100.0	100.0	98.6	94.4	97.3	94.4	92.89	92.2	94.4	98.6
11.5	100.0	100.0	99.1	99.8	100.0	100.0	99.7	100.0	100.0	100.0	100.0	99.4	96.8	98.7	97.3	96.35	95.5	97.0	99.4
12.0	100.0	100.0	99.6	100.0	100.0	100.0	99.9	100.0	100.0	100.0	100.0	99.8	98.2	99.4	98.8	98.29	97.5	98.5	99.7

MCF: Magnitude of compressive factor.

Discussion

Backward shift of spinal cord is not an ideal parameter to evaluate indirect decompression limit of posterior surgeries

The backward shift of the spinal cord has been used to evaluate the indirect decompression limit. However, this shift does not always correlate with good clinical outcomes. Baba *et al*[1] found that patients with >50% neurological improvement had larger backward shifts, and Sodeyama *et al*[2] found that a mean shift of 3 mm was required to obtain good neurological improvement. However, other studies failed to corroborate this conclusion.[3-5] Denaro *et al*[6] systematically reviewed 12 articles related to the backward shift of the spinal cord after posterior multilevel decompression and concluded that consensus on the best way to measure the backshift of the spinal cord had not yet been established. We believe that the backward shift of the spinal cord does not truly represent the indirect decompression limit, which would explain its inconsistent association with clinical outcomes.

In patients without ventral spinal cord compression, the backward shift of the spinal cord after posterior surgery can be defined as the theoretical backward shift (TBS), which can represent the true indirect decompression limit of posterior surgery. In this hypothetical situation, the measured backward shift (MBS) is equal to the TBS [Figure 3A]. However, in patients with ventral spinal cord compression, which is the most common situation for patients undergoing surgery, the spinal cord has been pushed backward by the compressive lesion pre-operatively. If the TBS is large enough, a gap will appear between the spinal cord and the anterior compressive mass. This gap is the MBS on pre- and post-operative images, which is less than the TBS [Figure 3B].

Furthermore, the larger the ventral compressive mass, the greater the initial (pre-operative) passive backward movement of the spinal cord, and the smaller the gap that appears after posterior decompression, leading to underestimation of the indirect decompression limit. Some studies have used the center[1] or posterior margin[2] of the spinal cord to measure the backward shift; however, this does not completely eliminate the effect of the initial passive backward movement of the spinal cord due to the ventral compressive mass. The influence of the size of ventral compressive mass on the magnitude of the backward shift of the spinal was not assessed in previous studies, which might have affected their conclusions. A few patients with post-operative residual compression in the above studies had zero[2] or small[1] MBS (perhaps derived from the limited elastic expansion[10,11] of the spinal cord itself). Such patients with post-operative residual compression were included in the group with smaller values of backward shift, thereby lowering the clinical outcomes of the group and leading to the conclusion that a smaller shift of the spinal cord indicates a worse clinical recovery. However, in studies with no or few patients with post-operative residual compression, it was often concluded that the backward shift of the spinal cord was not correlated with an improvement in neurological function.[3-5] Thus, the MBS is not an ideal parameter to evaluate indirect decompression limit of posterior surgeries. Although the TBS can theoretically represent the indirect decompression limit, it cannot be actually achieved and used in clinical practice.

Clinical significance of the decompression limit for posterior surgery

Adequate decompression is the goal of decompression surgery. Although sufficient decompression does not guarantee satisfactory neurological recovery, inadequate decompression often leads to poor neurological recovery. Kong *et al*[12] divided 65 CCM patients into two groups who underwent C3–C7 or C2–C7 laminoplasty. The 2 groups were further divided into the contact and noncontact subgroups according to whether the decompression was adequate. A higher neurological recovery rate ($69\% \pm 20\%$ *vs*. $29\% \pm 11\%$; $P < 0.05$) was found in the noncontact group after surgery than in the contact group, with similar follow-up periods. Fujiyoshi *et al*[13] analyzed the correlation between the K-line-based classification and surgical outcomes in patients with cervical ossification of the posterior longitudinal ligament. The mean recovery rate was 66.1% in the K-line (+) group and 13.9% in the K-line (−) group. However, the K-line method essentially reflects the relationship between the adequacy of decompression with clinical outcomes. On intraoperative ultrasonography, the incidence of the contact type was significantly higher in the K-line (−) group ($P < 0.01$), while the incidence of the noncontact type was significantly higher in the K-line (+) group ($P < 0.05$).

Taniyama *et al*[14] used the modified K-line on MRI to predict the insufficient decompression after cervical laminoplasty. The patients were divided into group INTmin (minimum interval between the modified K-line and the ventral compression factor on a midsagittal image) < 4 mm and group INTmin ≥ 4 mm. The incidences of post-operative ventral compression of the spinal cord for these two groups were 50.0% and 9.4%, respectively. The neural function recovery rates for the same groups were 36.1% and 53.9%, respectively ($P < 0.05$).

These studies demonstrate that residual ventral compression affects clinical outcomes. Therefore, we reason that if we can predict the decompression limit pre-operatively and understand the factors that influence it, we may decrease the risk of residual post-operative compression.

Differences between our study and previous studies

We found that the range of decompression affected the decompression limit of a specific level by changing its decompression type. Adjusting the range of decompression as needed was sometimes helpful to obtain sufficient decompression. Although K-line is a parameter that synthesizes the two factors of cervical alignment and size of compressive mass, the 27 patients enrolled in that study[13] all underwent C3–C7 laminoplasty, so the effect of decompression range was not considered. Some studies have used the average spinal cord shift to represent the overall decompression limit.[2,15,16] However, a large average spinal cord shift does not necessarily mean that adequate decompression is achieved at each level.

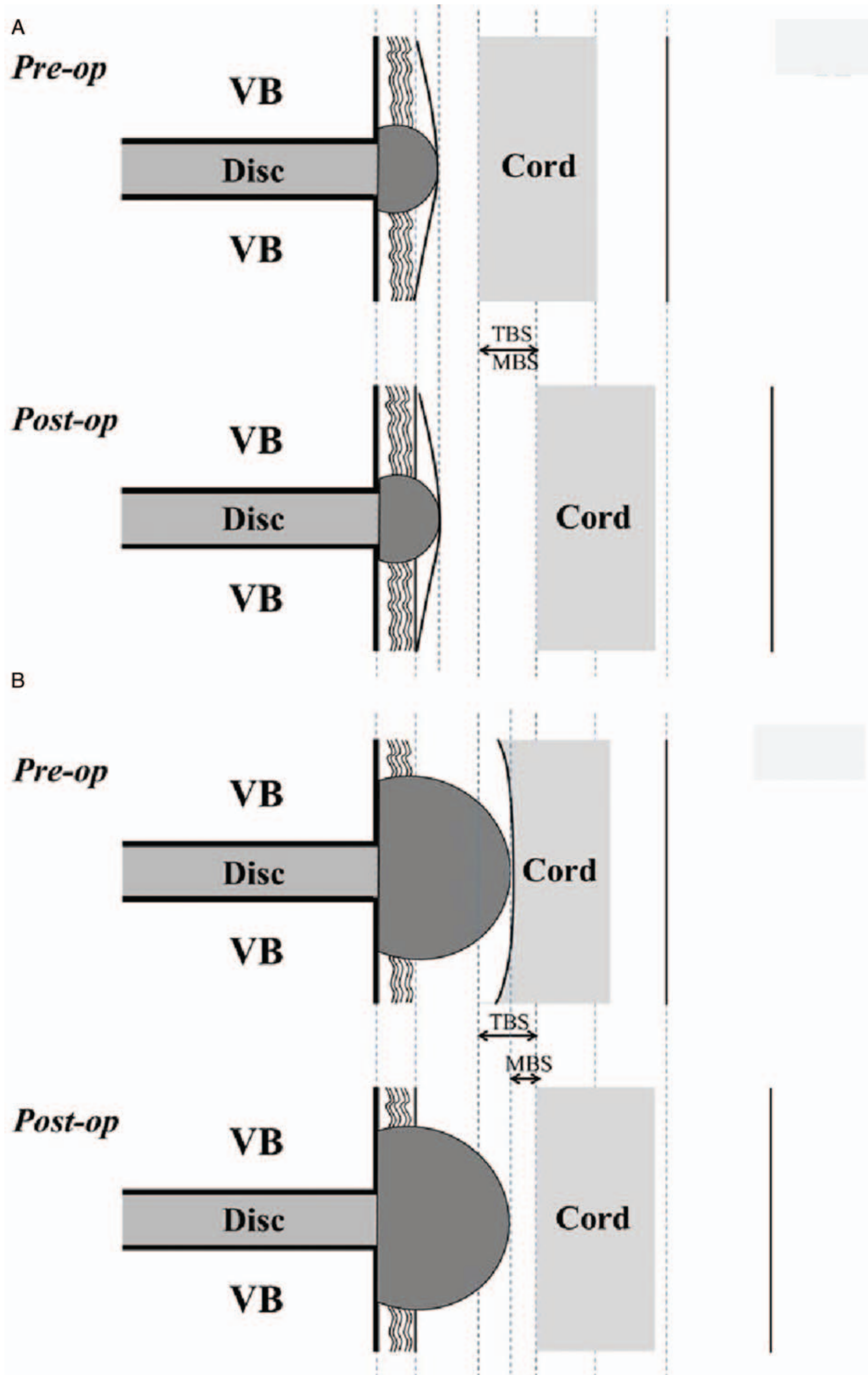

Figure 3: The MBS is affected by the ventral compressive factor. (A) When there is no pre-operative ventral spinal cord compression, the MBS is equal to the TBS. (B) In patients with pre-operative ventral spinal cord compression, the MBS is less than the TBS, leading to underestimation of the decompression limit of posterior surgery. MBS: The measured backward shift; TBS: The theoretical backward shift; VB: Vertebral body.

In contrast, our study quantitatively analyzed the decompression limits for each level from C2/3 to C6/7. The decompression limit for a particular level could be estimated for various decompression ranges and could be compared with the size of the ventral compressive mass. In this way, the probability of residual post-operative compression for different surgical strategies could be calculated, providing a basis for choosing a reasonable decompression range.

For example, as shown in Figure 4, the magnitude of the ventral compressive lesion at level C3/4 is 7.37 mm. The probabilities of residual compression at this level for the decompression ranges C4–C7, C3–C6, C3–C7, and C2–C7 can be estimated by referring to Table 5. Alternatively, the residual compression can be accurately predicted using the NORMDIST function in Excel ($x = 7.37$ mm, using the corresponding mean and standard deviation of VCDs at level C3/4 for each group; cumulative set to TRUE). These probabilities for the given decompression ranges were 99.99%, 72.08%, 70.75%, and 18.68%, respectively. Therefore, even if there is no obvious compression at the C2/3 level, the decompression range should be extended to C2 to obtain adequate decompression at the C3/4 level.

We found when the compressive factor was massive at a cervical level, adjusting the decompression range to achieve central decompression to maximize the decompression limit for that level could help to achieve sufficient decompression in some patients. However, if the maximum decompression limit has already been reached, the decompression range should not be expanded further. Comparing the VCDs obtained for different decompression ranges with the magnitude of the compressive factor could help to select a reasonable strategy to achieve adequate decompression and avoid unnecessary surgical trauma.

Study limitations

As the parameter to evaluate the decompression limit of posterior surgery in this study, VCD can be compared with the ventral MCF. In fact, VCD includes the TBS of the spinal cord and the inherent ventral reserve gap. Technically, the inherent ventral reserve gap varies among individuals, which reflects the inherent capacity of an individual to avoid ventral compression rather than the indirect decompression limit of posterior surgery. However, the magnitude of the inherent ventral reserve gap is not known for patients with CCM, and the distribution of the gaps in each group is balanced theoretically. Moreover, for a given patient, the effect of the decompression range on the decompression limit is not affected by this gap. We believe that the pattern of VCD changes in various decompression ranges is more significant than the absolute value of the VCD.

Conclusions

Our study showed that the VCD was an ideal parameter for evaluating the decompression limit (or indirect decompression limit) of posterior surgeries. In the absence of significant cervical kyphosis, the decompression limit of posterior surgery for a specific cervical level within the C2–C7 range was related to the decompression type at that level in the decompression range, which followed this pattern: ED < ID < CD with significant differences. Central decompression provided the maximum decompression for a given level, and no greater decompressive effect could be achieved by further

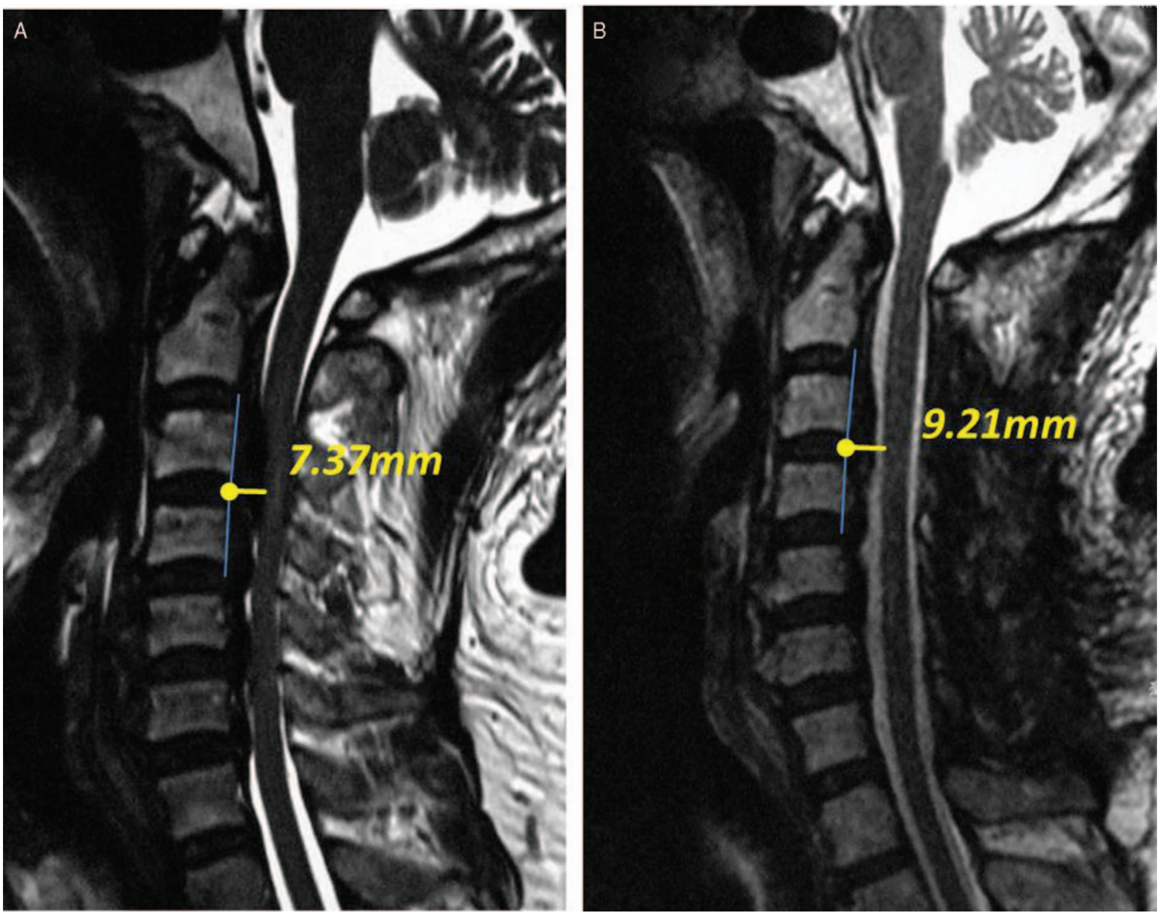

Figure 4: A 53-year-old man with OPLL underwent C2–C7 laminoplasty. (A) The magnitude of the ventral compression at the C3/4 level was 7.37 mm. The probability of residual postoperative compression at this level was predicted to 70.75% and 18.68% for decompression ranges of C3–C7 and C2–C7, respectively. (B) After C2–C7 decompression, the patient acquired sufficient decompression, with a VCD of 9.21 mm at level C3/4. OPLL: Ossification of posterior longitudinal ligament; VCD: Vertebral–cord distance.

expanding the decompression range. A reasonable range of decompression could thus be pre-operatively selected based on the relationship between the compressive mass and the estimated decompression limit.

Conflicts of interest

None.

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