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ORIGINAL COMMUNICATION

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Lordotic alignment and posterior migration of the spinal cord following en bloc open-door laminoplasty for cervical myelopathy: a magnetic resonance imaging study

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Abstract We investigated lordotic alignment and posterior migration of the spinal cord following en bloc open-door laminoplasty for cervical myelopathy. Fifty-five patients (32 men and 23 women) were studied, with an average follow-up of 2.4 years. Radiological examination included evaluation of lordosis of the cervical spine and spinal cord, degree of enlargement of bony spinal canal, and the magnitude of posterior cord migration. We also correlated these changes with neurological improvement. Postoperatively, there was an average of 5% loss of cervical spine lordosis ($P > 0.01$) on radiographs and 12% reduction in the lordotic alignment of the spinal cord ($P > 0.05$) on magnetic resonance imaging. Postoperatively, the size of the bony spinal canal increased by 48%. Posterior cord migration showed a significant correlation with the preoperative cervical spine and spinal cord lordosis ($P < 0.05$). Thirty-seven (67%) patients with neurological improvement exceeding 50% showed significant posterior cord migration following laminoplasty compared with those demonstrating less than 50% improvement ($P = 0.01$). Our results suggest that a significant neurological improvement is associated with posterior cord migration after cervical laminoplasty.

Key words Magnetic resonance imaging · Cervical laminoplasty · Spinal cord · Lordosis

Introduction

En bloc open-door laminoplasty is one of the surgical options for cervical myelopathy. The operative procedure is safe and time-effective for multiple vertebral involvement at three or more levels. The neurological outcome is often equally good and sometimes even more favourable than that of anterior decompression [5, 10, 12, 13–16]. Postoperatively, it is thought that the cervical spinal cord migrates posteriorly, simultaneously enlarging the spinal canal and preserving the posterior bony and ligamentous structures [18, 26, 27]. In addition to the static compression of the cord anteriorly, cervical spondylosis with multiple-level subluxation and ossification of the posterior longitudinal ligament can cause abnormal sagittal alignment, such as lordosis and kyphosis, which may also affect neurological function. However, a few reports have quantitatively examined posterior cord migration following laminoplasty [29], or even extensive laminectomy [1, 8], in relation to the sagittal alignment of the cervical spine and spinal cord as well as the bony spinal canal enlargement. Furthermore, the contribution of the posterior cord migration, in relation to its sagittal alignment, particularly lordosis, to postoperative neurological improvement remains less well understood, despite a number of reports of spinal cord morphometry using different imaging techniques [9, 20, 21, 23, 29].

The present study was designed to investigate lordotic alignment and posterior migration of the spinal cord after cervical laminoplasty, and their relation to spinal canal enlargement as well as their effects on postoperative neurological improvement.

Table 1 The Japanese Orthopaedic Association scores for assessment of cervical myelopathy [17]. The neurologically normal condition is a total of the best scores: (I+II+III+IV) = 17 points. Rate of neurological improvement = (postoperative score – preoperative score), divided by (17 – preoperative score) multiplied by 100 (%)

Categories	Score
I. Motor function of the upper extremity	
Unable to eat with either chopsticks or a spoon	0 point
Able to eat with a spoon, but not with chopsticks	1
Able to eat with chopsticks, but inadequately	2
Able to eat with chopsticks, but awkwardly	3
Normal	4
II. Motor function of the lower extremity	
Unable to walk	0
Needs a cane or other walking aid on flat ground	1
Needs walking aid only on stairs	2
Able to walk unaided, but slowly	3
Normal	4
III. Sensory function	
(a) Upper extremity	
Apparent sensory disturbance	0
Minimal sensory disturbance	1
Normal	2
(b) Lower extremity	
Apparent sensory disturbance	0
Minimal sensory disturbance	1
Normal	2
(c) Trunk	
Apparent sensory disturbance	0
Minimal sensory disturbance	1
Normal	2
IV. Bladder function	
Urinary retention or incontinence	0
Severe dysuria (sense of retention)	1
Slight dysuria (pollakiuria, retardation)	2
Normal	3

Patients and methods

Patients and neurological assessment

Included in the present study were 55 consecutive patients (32 men and 23 women), who underwent en bloc open-door laminoplasty for multisegmental impingement of the cervical spinal cord. The age of the patients at operation averaged 63.9 years (range, 38–85), and the average neurological and radiological follow-up was 2.4 years (range, 1–4.2). Thirty-eight patients had cervical spondylosis, while 17 had ossification of the posterior longitudinal ligament. Patients presented with a wide spectrum of clinical features of myelopathy preoperatively. The neurological assessment was conducted in accordance with the Japanese Orthopaedic Association (JOA) scoring system (Table 1) [17]. According to this system, the rate of neurological improvement was calculated as:

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

Basically, the result denotes a favourable outcome when the improvement rate is ≥ 50%, and unfavourable when it is < 50%.

En bloc open-door laminoplasty

Our surgical technique has been described previously [3–7]. The patient is fixed with a three-point head rest, and a midline skin incision is made straight over the spinous process between C2 and T1 levels, followed by exposure of the laminae and bilateral facet joints from C3 to C7. Two longitudinal lateral troughs are made at sites just medial to the facet joints between C3 and C7. The inner cortices of the laminae on the neurologically advanced side are routinely excised with a high-speed diamond burr and a micro-Kerrison rongeur, whereas the contralateral hinged side of the laminae is thinly shaved. The laminae of C3 to C7 are carefully opened on the more affected side followed by spacer bone grafting between the facets and corresponding laminae, usually at C4 and C6, using the spinous processes harvested from C6 and C7, or T1. A spacer bone graft, about 8–10 mm in length, is essential for the laminae so as to be maintained in the "kept open" position postoperatively. However, the period for osseous union depends on the bone quality of the graft in each individual. Isometric neck extension exercises are encouraged from the 2nd week after surgery, and a soft neck collar fixation continued for approximately 3 months postoperatively. No patient in this series developed radiculopathy as a result of root(s) tethering or stretching following laminoplasty during the early postoperative period. Each patient was allowed to return to normal activity in due course.

Radiological examination

Serial lateral radiographs, including neutral and flexion-extension views, were taken every 3 months after surgery. These radiographs showed osseous union of the spacer bone graft between 4 and 10 months postoperatively in all patients. This was also confirmed by computed tomography (CT). Radiological examination included (1) lordotic alignment of the cervical spine on radiographs taken in the neutral position, designated as cervical spine lordosis; (2) increased size of the bony spinal canal, measured by CT, at each vertebral level; (3) lordotic alignment of the cervical spinal cord on magnetic resonance imaging (MRI; 1.5 T; Signa, General Electric, Milwaukee, Wis.) (Fig. 1a,b), termed spinal cord lordosis; and (4) posterior cord migration, expressed as posterior shift score, on MRI.

Cervical spine lordosis represented the percentage of d relative to D (points) in radiographs taken in the neutral position (Fig. 2a). The value d represented the maximum distance between a vertical line extending from the postero-inferior vertebral rim of C2 to the postero-superior edge of the T1 vertebra. On the other hand, D represented the distance between the above two vertebral corners. An increase in the size of the bony spinal canal was calculated by X′–X (Fig. 2b). The spinal canal expansion ratio was then given by:

$$\text{Ratio (\%)} = \sum \frac{X' - X}{X} \times 100$$

On T2-weighted images taken with the neck in the neutral position, spinal cord lordosis was scored as:

$$\text{Score (points)} = \sum \frac{Sn}{S\ (n = 1\text{–}5)} \times 100$$

(Fig. 2c), where S1 was measured at C3, and S represents the distance between the centres of the spinal cord at the postero-inferior and postero-superior vertebral corners of C2 and T1, respectively. At each spinal level, Sn represents the distance between the centre of the cord and the perpendicular line used for measuring the S value. In addition, on preoperative and postoperative T2-weighted MRI, the posterior shift score of the cord was calculated according to the following equation (Fig. 2d), where p_1 and $p_{1'}$ were measured at C3:

$$\text{Score (points)} = \sum \frac{p'n - pn}{pn\ (n = 1\text{–}5)} \times 100$$

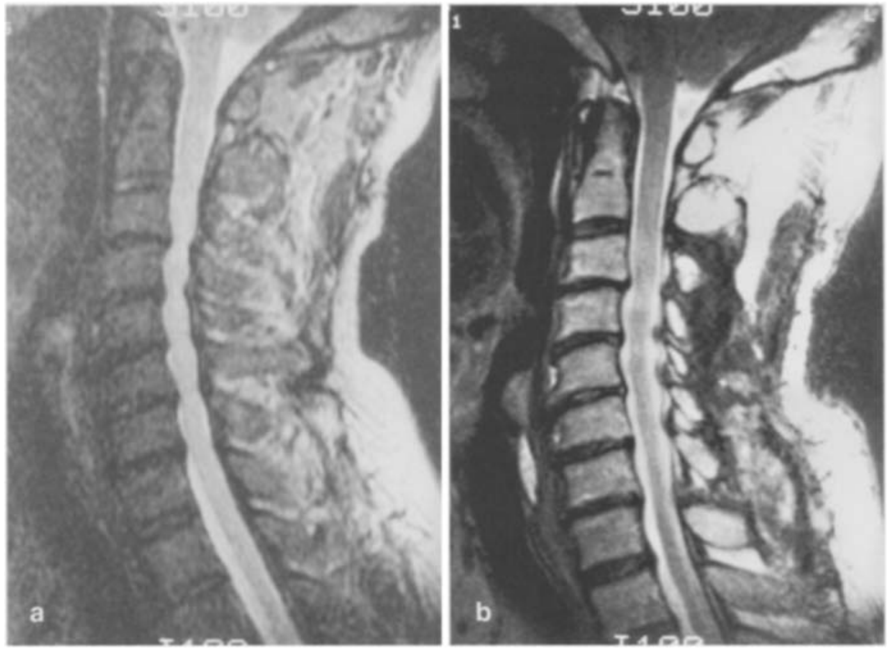


Fig. 1a, b Magnetic resonance imaging of a patient treated with a C3–C7 laminoplasty. **a** Before surgery (T2-weighted sequence; TR 2609 ms, TE 100 ms). **b** At follow-up (T2-weighted sequence; TR 5000 ms, TE 98 ms)

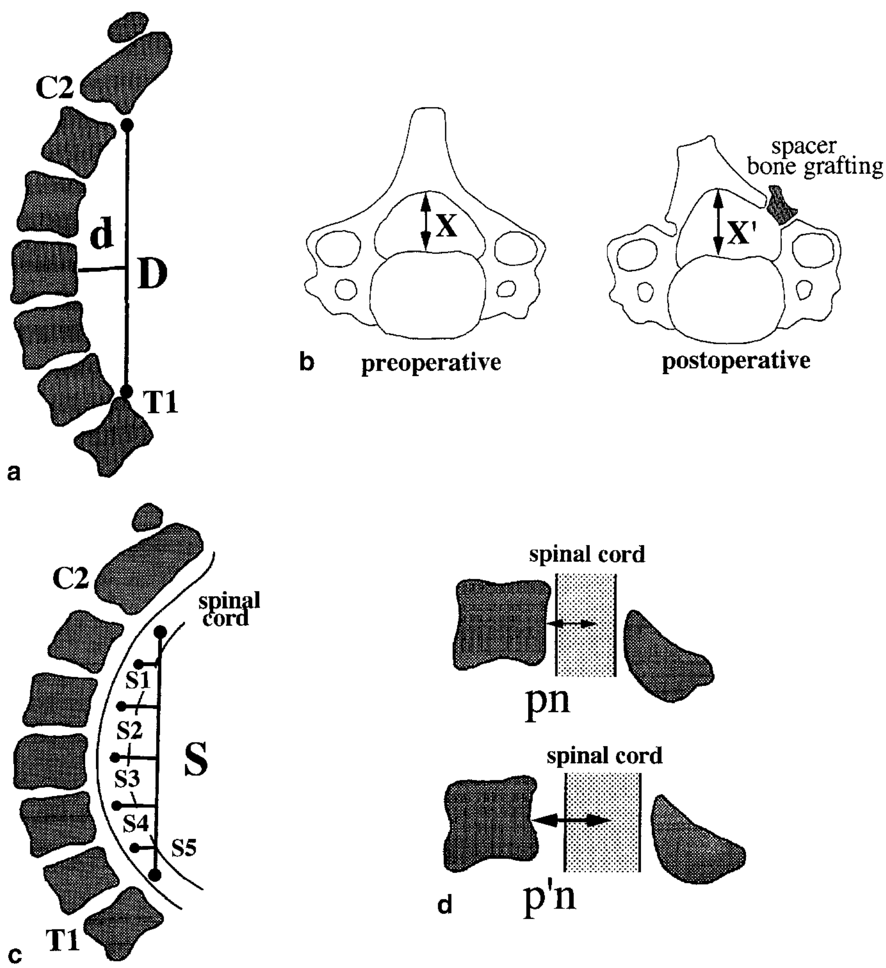
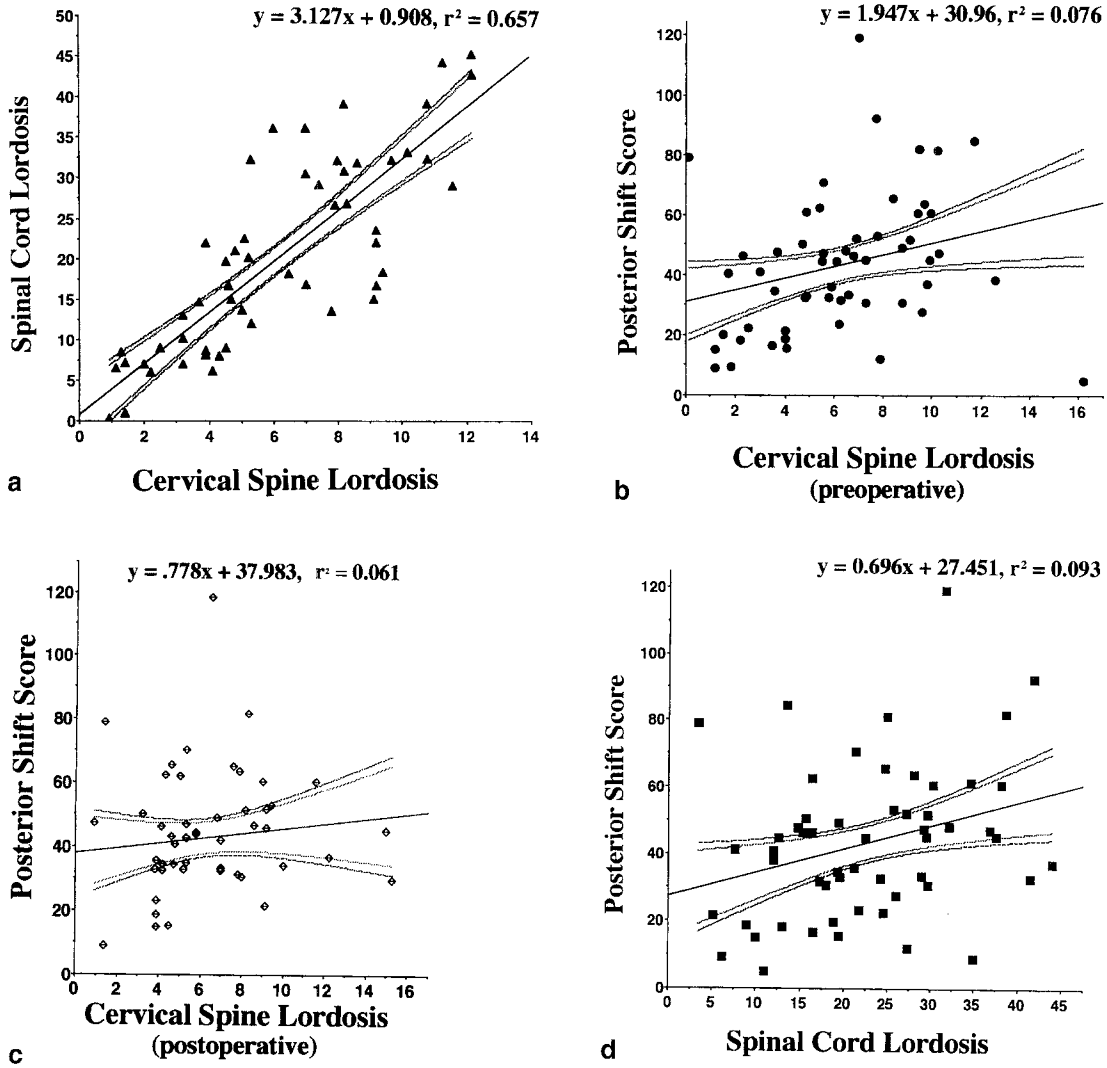


Fig. 2a–d Radiological measurements of the cervical spine and spinal cord. **a** Cervical spine lordosis is scored radiographically as a percentage of *d* relative to *D* (points). **b** The spinal canal expansion ratio (%) is represented by $[(X' - X) \times 100/X]$. **c** Spinal cord lordosis is scored as $\Sigma\, Sn/S$ (n = 1–5) $\times$ 100 on a T2-weighted image. **d** Posterior shift score is expressed as the value obtained by $\Sigma\, (p'n - Pn)/Pn$ (n = 1–5) $\times$ 100 on a T2-weighted sequence. *Top* Preoperative, *bottom* postoperative



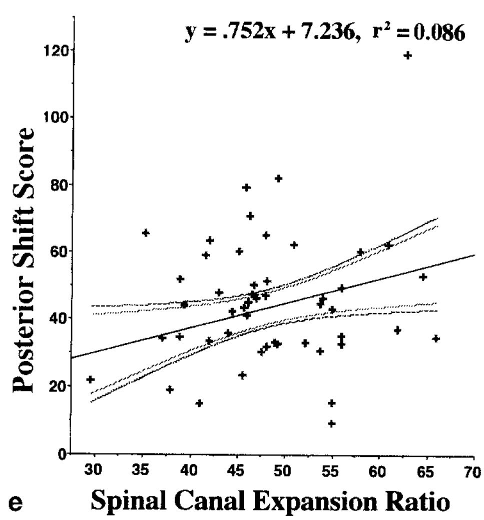


Fig. 3a–e The relationship between posterior cord migration and cervical spine as well as spinal cord lordosis. Postoperative spinal cord lordosis correlates significantly with cervical spine lordosis (**a**). Posterior cord migration correlates significantly with cervical spine lordosis preoperatively (**b**) and postoperatively (**c**). Posterior cord migration shows a significant correlation with spinal cord lordosis preoperatively (**d**). Posterior cord migration significantly correlated with the spinal canal expansion ratio (**e**)

All images were stored on a Macintosh Quadra 650 computer (Apple, Cupertino, Calif.) using the NIH image software (Ohlandorf Research, Ottawa) for detailed morphological measurements.

Data were expressed as mean, standard deviation. Statistical correlations were examined using Pearson's correlation analysis and the Student's t test as well as cumulative chi square test using the StatView II™ program (Abacus Concepts, Berkeley, CA). A P value of less than 0.05 was considered significant.

Results

Cervical spine and spinal cord lordosis

Cervical spine lordosis was scored as 6.5, SD 3.1 points preoperatively and 6.2, SD 2.9 points postoperatively. There was a 5% decrement in this value after surgery (Student's t-test, $P > 0.01$). Spinal cord lordosis, on the other hand, was scored as 22.8, SD 10.5 points and 20.1, SD 12.3 points preoperatively and at follow-up, respectively. This score showed a 12% decrease after surgery (Student's t-test, $P > 0.05$). Significant correlation was found between cervical spine lordosis and spinal cord lordosis after surgery (Fig. 3a, $r^2 = 0.657$, $P = 0.0001$).

Posterior cord migration

The mean postoperative posterior shift score was 43.3, SD 24.5 points. Posterior cord migration correlated significantly with preoperative cervical spine lordosis (Fig. 3b, $r^2 = 0.076$, $P = 0.039$) and with postoperative cervical spine lordosis (Fig. 3c, $r^2 = 0.061$, $P = 0.048$) The correlation between posterior cord migration and postoperative spinal cord lordosis was significant (Fig. 3d, $r^2 = 0.093$, $P = 0.024$). However, the degree of posterior cord migration did not correlate significantly with spinal cord or cervical spine lordosis.

The spinal canal expansion ratio was 49.4, SD 14.8% at C3, 54.2, SD 19.7% at C4, 49.1, SD 13.5% at C5, 40.5, SD 15.3% at C6, and 47.3, SD 12.8%. The ratio at each level was not significantly different from that of other levels. Posterior cord migration correlated significantly with the spinal canal expansion ratio (Fig. 3e, $r^2 = 0.086$, $P = 0.035$).

Neurological improvement and radiological parameters

The pre- and postoperative JOA scores were 7.4, SD 3.7 and 13.2, SD 2.8 points, respectively. The postoperative neurological improvement was thus determined to be 60.4%, and correlated significantly with the postoperative posterior cord migration (Fig. 4, $r^2 = 0.092$, $P = 0.033$).

The average posterior shift score was 55.3, SD 22.9 points (range, 37.4–79.3) in 37 (67%) patients who showed ≥ 50% neurological improvement (mean, 59.5, SD 13.7%). The other 18 patients with < 50% neurological improvement (mean, 27.7, SD 18.3%) had an average posterior shift score of 31.9, SD 14.4 points (range, 11.5–43.5). It was noted that patients with ≥ 50% improvement had a significantly larger posterior shift score (cumulative χ^2 test, $\chi^2 = 5.733$, $P = 0.014$).

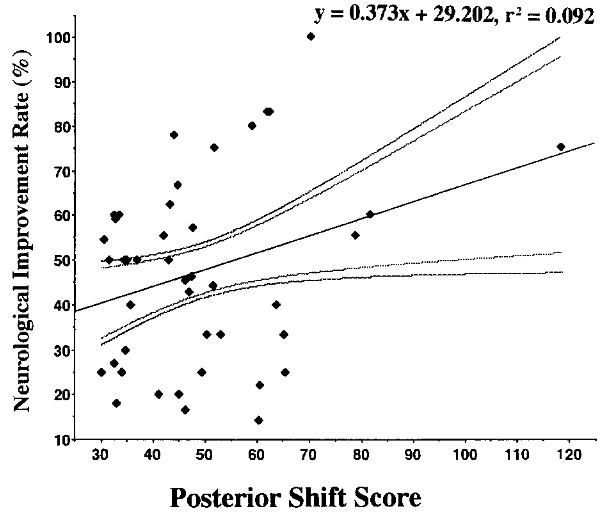


Fig. 4 Correlation between posterior cord migration and neurological improvement

Discussion

En bloc open-door laminoplasty is a surgical technique recommended for cervical myelopathy with multilevel spondylosis or ossification of the posterior longitudinal ligament [3–7, 20, 23, 29]. This surgery may allow posterior cord migration and is associated with a favourable neurological recovery. The surgical technique includes variable modification and restructuring of the posterior osseo-ligamentous complex covering the spinal cord posteriorly. Maintenance of the strength of neck-extension muscles as well as biomechanical stability posteriorly [14, 22, 24] is a fundamental component of the modification procedure. We have used an open-door type of C3–C7 laminoplasty since 1982 for patients with multiple cervical spine involvement of three or more vertebrae. Several investigators [16, 20], including our group [3–7], have reported satisfactory neurological improvement after cervical laminoplasty, and postulated that the results are probably due to posterior cord migration. The dorsal movement of the compromised cord is also highly possible following extensive laminectomy operations [1, 8, 9, 11, 25]. Levi et al. [19] observed significant dorsal migration of the cord in their patients with the central cord syndrome who underwent extensive cervical laminectomy. Regardless of the procedure selected (laminoplasty or laminectomy), the compromised cervical cord is likely to shift and extend posteriorly. We believe it is important to assess posterior cord migration by MRI and to relate these changes to neurological recovery.

Cervical laminoplasty is known to reduce lordosis of the spine although it ameliorates spinal cord decompression [6, 18]. This reduction may be an inevitable complication resulting from surgical trauma of the muscles involved in neck extension or ligaments and posterior bony elements of the cervical spine. Theoretically speaking, it is more convenient for the cervical spine to be physiologically lordotic and [2, 8, 28], therefore, the spinal cord to migrate posteriorly following laminoplasty or laminectomy. Batzdorf and Batzdorff [8] examined the cervical spine curvature in 28 surgical patients who were treated with extensive laminectomy, and emphasized the importance of normal and lordotic alignment of the cervical spine for obtaining good neurological improvement. Kyphosis can increase the longitudinal tension of the spinal cord and may enhance the effect of a spondylotic lesion or ossified posterior longitudinal ligament by allowing further impingement on the cord. In this regard, Kawai [18] described a certain reduction of lordotic alignment in approximately 30% of patients treated with laminoplasty, using a method slightly different from the one described in the present study. In a previous preliminary study we observed a loss of lordotic alignment in 12 (26%) of 47 patients treated with laminoplasty [6]. The present results demonstrated that cervical spine lordosis diminished by approximately 5% after surgery, while spinal cord lordosis after surgery was only 88% of the preoperative value, although both changes were statistically insignificant. The postoperative difference may be partly due to improved and facilitated neck rehabilitation, but more importantly, the results confirm that the operative technique influences the cervical spine as well as the spinal cord by reducing lordosis.

Interestingly, we found that patients with favourable neurological results (rate of improvement ≥ 50%) had significantly higher posterior shift scores for the spinal cord than those with unfavourable recovery (rate of improvement < 50%). There was also a significant correlation between posterior cord migration and postoperative neurological improvement. Obviously, recovery of spinal cord function is markedly influenced by the severity of neurological compromise before treatment. However, more importantly, based on our results, we suggest that posterior cord migration plays a significant role in recovery of spinal cord function. Postoperatively, the spinal cord certainly shows a trend towards reduced lordosis that is inconvenient for neurological recovery. Multivariate analysis of other factors may provide more definitive evidence supporting this suggestion. On the other hand, Yone et al. [29] observed anteroposterior enlargement of the cervical cord with a significant correlation with spinal canal expansion after laminoplasty, and similar ideas have been suggested by Matsuyama et al. [20]. These workers concluded that the surgical techniques used in their studies were effective for spinal cord decompression posteriorly, and suggested possible dorsal transposition of the cord. Since the surgical technique used in our study is similar to that described in the above reports, the MRI findings extend the findings of these early studies by providing firm evidence for the proposed likelihood of dorsal translocation of the spinal cord after surgery.

We have also demonstrated, in a different group of patients, an average increase of 40% in the size of anteroposterior bony canal after laminoplasty [3, 6]. Reports from other groups demonstrated a 30–70% increase in canal size, contributing to spinal cord decompression posteriorly [20, 23, 29]. In the present study, we found a > 40% (40.5–54.2%) increase in the size of the bony canal that significantly correlated with posterior cord migration. Thus, these results allow us to speculate that postoperative enlargement of the anteroposterior diameter of the spinal cord, together with bony canal expansion and posterior cord migration, are markedly responsible for the favourable neurological recovery from cervical compressive myelopathy. The statistical significance of each of these factors in contributing to neurological recovery requires further investigation using more detailed analysis, such as multivariate analysis.

We conclude that posterior cord migration occurs in patients treated with en bloc open-door laminoplasty for cervical myelopathy. Even when the vertebral column and the spinal cord do not show an increase of lordosis, posterior cord migration develops in patients with a significant neurological recovery. The operative technique allows posterior migration of the cervical cord, which promotes neurological recovery from compressive myelopathy.

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References

1. Aboulker J, Metzger J, David M, Engel P, Ballivet J (1965) Les myélopathies cervicales d'origine rachidienne. Neurochirurgie 11: 87–198
2. Adams CBT, Logue V (1971) Studies in cervical spondylotic myelopathy. II. The movement and contour of the spine in relation to the neural complications of cervical spondylosis. Brain 94: 569–586
3. Baba H, Furusawa N, Imura S, Kawahara N, Tsuchiya H, Tomita K (1993) Late radiographic findings after anterior cervical fusion for spondylotic myeloradiculopathy. Spine 18: 2167–2173

4. Baba H, Furusawa N, Chen Q, Imura S (1995) Cervical laminoplasty in patients with ossification of the posterior longitudinal ligaments. Paraplegia 33: 25–29
5. Baba H, Imura S, Kawahara N, Nagata S, Tomita K (1995) Osteoplastic laminoplasty for cervical myeloradiculopathy secondary to ossification of the posterior longitudinal ligament. Int Orthop 19: 40–45
6. Baba H, Maezawa Y, Furusawa N, Imura S, Tomita K (1995) Flexibility and alignment of the cervical spine after laminoplasty for spondylotic myelopathy: a radiographic study. Int Orthop 19: 116–121
7. Baba H, Chen Q, Uchida K, Imura S, Morikawa S, Tomita K (1996) Laminoplasty with foraminotomy for coexisting cervical myelopathy and unilateral radiculopathy: a preliminary report. Spine 21: 196–202
8. Batzdorf U, Batzdorff A (1988) Analysis of cervical spine curvature in patients with cervical spondylosis. Neurosurgery 22: 827–836
9. Batzdorf U, Flannigan BD (1991) Surgical decompressive procedures for cervical spondylotic myelopathy: a study using magnetic resonance imaging study. Spine 16: 123–127
10. Epstein N (1993) The surgical management of ossification of the posterior longitudinal ligament in 51 patients. J Spinal Disord 6: 432–455
11. Faccioli F, Buffatti P, Grosslercher JC, Bricolo A, Dalle-Ore G (1988) Laminotomie cervicale decompressive a "porte ouverte". Technique et premieres experiences. Neurochirurgie 33: 38–43
12. Frank E, Keenen TL (1994) A technique for cervical laminoplasty using mini plates. Br J Neurosurg 8: 197–199
13. Herkowitz HN (1988) A comparison of anterior cervical fusion, cervical laminectomy, and cervical laminoplasty for the surgical management of multiple level spondylotic radiculopathy. Spine 13: 774–780
14. Herkowitz HN (1988) Cervical laminaplasty: its role in the treatment of cervical radiculopathy. J Spinal Disord 1: 179–188
15. Herkowitz HN (1989) The surgical management of cervical spondylotic radiculopathy and myelopathy. Clin Orthop 239: 94–108
16. Hukuda S, Ogata M, Mochizuki T, Schchikawa K (1988) Laminectomy versus laminoplasty for cervical myelopathy: brief report. J Bone Joint Surg [Br] 70: 325–326
17. Japanese Orthopaedic Association (1976) Criteria for the evaluation of treatment of cervical myelopathy. J Jpn Orthop Assoc (Tokyo) 49: addendum no. 5
18. Kawai S (1991) Cervical laminoplasty. In: Bridwell KH, DeWald RH (eds) The textbook of spinal surgery, vol 2. Lippincott, Philadelphia, pp 805–812
19. Levi L, Wolf A, Mirvis S, Rigamonti D, Fianfaca MS, Monasky M (1995) The significance of dorsal migration of the cord after extensive cervical laminectomy for patients with traumatic central cord syndrome. J Spinal Disord 8: 289–295
20. Matsuyama Y, Kawakami N, Mimatsu K (1995) Spinal cord expansion after decompression in cervical myelopathy: investigation by computed tomography myelography and ultrasonography. Spine 20: 1657–1663
21. Mehalic TF, Pezzuti RT, Applebaum BI (1990) Magnetic resonance imaging and cervical spondylotic myelopathy. Neurosurgery 26: 217–227
22. Nowinski GP, Visarius H, Nolte LP, Herkowitz HN (1993) A biomechanical comparison of cervical laminaplasty and cervical laminectomy with progressive facetectomy. Spine 18: 1995–2004
23. Okada Y, Ikata T, Yamada H, Sakamoto R, Kato S (1993) Magnetic resonance imaging study on the results of surgery for cervical compression myelopathy. Spine 18: 2024–2029
24. Raynor RB, Moskovich R, Zidel P, Pugh J (1987) Alteration in primary and coupled neck motions after facetectomy. Neurosurgery 21: 681–687
25. Scoville WB (1961) Cervical spondylosis treatment by facetectomy and laminectomy. J Neurosurg 18: 423–428
26. Skowronski J, Bielecki M (1992) The results of laminectomy and laminoplasty in cervical myeloradiculopathy. Rocz Akad Med Bialymst 37: 71–73
27. Transfeldt EE (1991) Cervical spondylosis. In: Bridwell KH, DeWald RL (eds) The textbook of spinal surgery. Lippincott, Philadelphia, pp 771–804
28. White AA IIIrd, Panjabi MM (1988) Biomechanical considerations in the surgical management of cervical spondylotic myelopathy. Spine 13: 850–856
29. Yone K, Sakou T, Yanase M, Ijiri K (1992) Preoperative and postoperative magnetic resonance image evaluations of the spinal cord in cervical myelopathy. Spine 17: S388–S392