Comparable clinical and radiological outcomes between skipped-level and all-level plating for open-door laminoplasty

Abstract

Purpose: To compare the clinical and radiological outcomes between skipped-level and all-level plating for cervical laminoplasty.

Methods: Patients with CSM treated by open-door laminoplasty with minimum 2-year postoperative follow-up were included. All patients had opening from C3-6 or C3-7 and were divided into skipped-level or all-level plating groups. Japanese Orthopaedic Association (JOA) scores and canal measurements were obtained preoperatively, immediate (within 1 week) postoperatively, and at 2 weeks, 6 weeks, 3, 6 and 12 months postoperatively. Paired t-test was used for comparative analysis. Receiver operating characteristic analysis was used to determine the canal expansion cut-off for spring-back closure.

Results: A total of 74 subjects were included with mean age of 66.1±11.3 years at surgery. Of these, 32 underwent skipped-level plating and 42 underwent all-level plating. No significant differences were noted between the two groups at baseline and follow-up. Spring-back closure was observed in up to 50% of the non-plated levels within 3 months postoperatively. The cut-off for developing spring-back closure was 7mm canal expansion for C3-6. No differences were observed in JOA scores and recovery rates between the two groups. None of the patients with spring-back required reoperation.

Conclusions: There were no significant differences between skipped-level and all-level plating in terms of JOA or recovery rate, and canal diameter differences. This has tremendous impact on saving costs in CSM management as up to two plates per patient undergoing a standard C3-6 laminoplasty may be omitted instead of four plates to every level to achieve similar clinical and radiological outcomes.

Key Words: cervical spondylotic myelopathy; plates; spring-back; skipped-level; laminoplasty

Level of Evidence: III

Introduction

Cervical spondylotic myelopathy (CSM) is the leading cause of spinal cord dysfunction worldwide and is caused by narrowing of the cervical spinal canal leading to symptomatic cord compression.[1] The prevalence in the Japanese population has been reported to be 1.9-4.3%.[2] Furthermore, an increasing number of surgeons are performing prophylactic or early decompression in cases of asymptomatic or "silent" myelopathy to avoid catastrophic spinal cord injuries.[3] Posterior surgical approaches allow for indirect decompression without destabilizing intervertebral discs and in general carries less risk of postoperative instability and adjacent level degeneration as compared with anterior discectomy and fusion.[4]

Expansive open-door laminoplasty, first reported by Hirabayashi *et al*[5,6] in 1983, is a commonly adopted technique to manage CSM and avoids problems related to laminectomy such as instability, kyphosis and perineural adhesions. Traditionally, stay sutures have been used to anchor the spinous process to the facet joint capsule to maintain the hinge opening.[5-7] However, increased laminar closure or spring-back has been reported with this technique.[8,9] Spring-back phenomenon or closure, has a reported rate of 10%[9] depending on its definition, and is a major concern in laminoplasty as closure of the laminae opening can lead to re-narrowing of the spinal canal and recurrence of symptoms. Since then, mini-plates have been used as a more rigid fixation alternative to maintain the laminae opening.[10,11] Despite apparent clinical benefits[8], mini-plates are costlier. As healthcare providers, this increased cost is a factor that should be considered when designing a management strategy.

As such, the main aim of this study is to determine any clinical and radiological differences between skipped-level and all-level plating laminoplasty for CSM. It is also important to determine whether the specific level omitted is important and the timing of spring-

back if it occurs. An additional objective is to determine whether the degree of canal expansion has bearing on the risk of spring-back development.

Methods

Patients with multi-level CSM treated by open-door laminoplasty during the period of November 2010 to June 2014, with minimal follow-up of 2 years, were included in this retrospective study. Ethics was approved by the institutional review board. All patients with expansive open-door laminoplasty from C3-6 or C3-7 were included (**Fig. 1**). C7 was included if C6/7 compression was significant. All patients with ossification of posterior longitudinal ligament, laminoplasties anchored by stay sutures or by a hybrid of plate and sutures were excluded.

During surgery, the C2 paraspinal muscles were preserved as much as possible. The interspinous ligaments must be preserved during dissection. Laminotomies were performed down to dura at C2/3 and C6/7 or C7/T1. The ligamentum flavum at these levels were cut only on the open side up to 50% of the midline. The open side was determined preoperatively based on the more severe side clinically. A high-speed spherical burr was used, under cool saline irrigation, to open the lateral margin of the lamina on the open side first before the hinge side gutters were made. Only the lateral cortex and cancellous bone were removed on the hinge side by the burr prior to opening by gentle force to prevent hinge fracture. The intersegmental ligamentum flavum was cut on the open side to allow opening of the lamina to at least 50% of the midline. Appropriate sized plates were selected with two laminar and two lateral mass screws inserted per plate. Intraoperative radiographs were used to confirm no penetration into the facet joints. Rigid cervical neck collars were used for 3 weeks postoperatively in all patients.

Patients were separated into two groups: those with skipped-level (one or more levels not plated) and all-level plating laminoplasty. Of the 74 subjects, 32 underwent skipped-level plating and 42 underwent all-level plating. Out of the skipped-level plating, C4 (n=29) was the most common level skipped followed by C5 (n=5), C6 (n=10) and C3 (n=2). All patients with C3-7 laminoplasty had C7 plated and all patients with C3-6 had C6 plated. For the 32 skipped-level plating, 10 patients received C3-7 laminoplasty while the remaining 22 patients received C3-6 laminoplasty. Nine of the patients had two levels not plated for C3-6 laminoplasty. The other 23 patients had single level non-plated laminae, of which 10 had C3-7 laminoplasty. Decision for which laminae to skip was based on the surgeon's intraoperative assessment of stability. In essence, end-levels were generally plated and intervening levels were skipped.

Clinical symptomatology and signs were compared at baseline and at postoperative 1 year. The improvements with surgery was also compared between the two groups. Japanese Orthopaedic Association (JOA) scores were obtained preoperatively, immediate (within 1 week) postoperatively, and at 2 weeks, 6 weeks, 3, 6, 12 months postoperatively, and at final follow-up. Recovery rate was calculated using the Hirabayashi formula: recovery rate (%) = (postoperative JOA - preoperative JOA) / (17 [full score] - preoperative JOA) x 100. Similarly lateral cervical spine radiographs were obtained at each follow-up time-point for the anteroposterior canal diameter measurements. All lateral radiographs were obtained with the patient erect, standing against a board with set shoulder position. Patients were advised to have a horizontal gaze during the imaging. The focus film distance was set as 180cm while centering at the angle of mandible. The exposure was 62-peak kilovoltage and 8-10 milliamperage-seconds of x-ray energy. All canal diameter measurements were collected on these radiographs using the DICOM based Radworks 5.1 (Applicare Medical Imaging BV, Zeist, The Netherlands) computer software

program. The anteroposterior canal diameter were measured using Wolf's method[9,12,13], from the middle of the posterior border of the vertebral body to the anterior border of the lamina. Any spring-back closure was defined as >1mm loss of initial expansion.[12] This criterion was adopted for its strict definition.

Three independent readers performed all measurements of cervical spine radiographs. Assessment of inter-rater and intra-rater reliability was assessed using intraclass correlation coefficient (ICC). Inter-rater or intra-rater reliability was determined as good with ICC between 0.75 to 0.9, moderate if 0.5-0.75 and poor if less than 0.5. The clinical symptomatology and signs are dichotomous dependent variables, thus McNemar test was used to determine differences between the two groups and from baseline to postoperative 1 year. Paired t-test was used for analysis of difference between outcomes, in terms of post-operative expansion of spinal canal, improvement in JOA score and recovery rate. Receiver operating characteristic (ROC) analysis was utilized to determine the cut-off values of canal expansion with which spring-back occurred. The 95% confidence intervals (CIs) were listed when appropriate and a p-value of <0.05 was considered significant.

Results

A total of 74 subjects (18 females) were included in the study with mean age of 66.1±11.3 years at the time of surgery (**Table 1**). Mean JOA score preoperatively was 9.4±3.5 (range 1.5-14.5). The follow-up period ranged from 4 years 10 months to 5 years 11 months. Good intra-rater reliability was shown in both pre-operative and post-operative measurements of canal diameter at both plated and non-plated vertebral levels. For preoperative measurements, ICC ranged from 0.826 to 0.915, with $p<0.05$. As for the postoperative measurements, ICC

ranged from 0.878 to 0.936 and 0.855 to 0.884 with p<0.001 at plated and non-plated vertebral levels respectively. Similarly, good inter-rater reliability was achieved.

At baseline, most patients were significantly myelopathic with involvement of upper and lower limb numbness, clumsiness, and gait disturbances (**table 2**). Most patients had improvements in symptoms showed by the reduction of patients with these myelopathic symptoms at postoperative 1 year. When comparing between skipped-level and all-level groups (**table 3**), significant improvements were observed between upper and lower limb numbness, upper limb clumsiness and gait disturbance. Limited improvements were observed for Hoffman's sign and Romberg test at postoperative 1 year.

No significant differences in canal expansion were noted between the two groups at baseline and at follow-up (**Fig. 2**). Looking specifically at the non-plated levels within the skipped plating group however, reductions were observed for C4 at postoperative 6 weeks (6.2±1.2 to 5.6±1.2; p-value 0.087), C5 at postoperative 2 weeks (6.5±2.4 to 5.4±2.7; p=0.249), and C6 at postoperative 6 weeks (3.7±1.7 to 2.6±1.8; p=0.061). Hence, the reductions occurred early within 6 weeks postoperatively.

In general, spring-back closure was observed in 26.8% of non-plated vertebral levels at 2 weeks postoperatively, with more than 50% closure at 3 months postoperatively. There was an incidence of 67.9% (n=19), 50% (n=2) and 100% (n=9) of closure at levels C4, C5 and C6 respectively at the 12-month postoperative time-point for these non-plated levels. The cut-offs at which spring-back occurred were generated via ROC analysis and listed in **table 4**. C7 was not analysed since all patients had plating. In general, an expansion of more than 7mm was required to have reduced risk of any spring-back.

No difference in JOA scores (p=0.294-0.850) nor recovery rate (p=0.189-0.864) was observed between the two groups at all postoperative time points. Comparable improvements (**Fig. 3**) in JOA scores and recovery rate were observed in both groups at all follow-up time-points. No patients required reoperation. No complications of immediate postoperative drop in JOA scores, screw pullout or iatrogenic destabilization with postoperative spondylolisthesis were observed.

Discussion

Laminoplasty is the gold standard posterior surgical approach due to complications of segmental instability, kyphotic deformity, worse neck range of motion, perineural adhesion and late neurological deterioration in laminectomy.[14] It is ideally suited for multilevel disease due to its extensile approach. However, due to similar effectiveness and safety as compared to multiple anterior cervical discectomies and fusion, some surgeons prefer anterior surgery as compared to laminoplasty.[15] The popularized expansive “open-door” technique has been shown to achieve good clinical outcomes.[16] The traditional method for keeping the lamina opening is by sutures but there is risk of spring-back phenomenon where recurrence of symptoms may occur.[9] This complication has been reported in up to 40% of subjects[17], and hence recent trends have adopted more rigid devices like mini-plates for fixation to help prevent complications such as loss of fixation, hinge fracture and spring-back closure.[18-22] Titanium plates for fixation have long lasting patency with biological healing of the laminar arch without much complications.[22] We have an average of 5 year follow-up in our study which proves the satisfactory results of both techniques utilizing these mini-plates. This mirrors the results from a 5-year follow-up report of plated laminoplasty.[23]

The main aim of study is to determine whether a less expensive fixation approach with skipped-level plating can achieve similar clinical and radiological outcomes as all-level plating. Our results suggest that there are no significant differences in canal expansion between the two groups and at all levels from C3-7. By comparison, Yang *et al*[24] who studied plate fixation in an alternating (C4 and C6 not plated only) fashion observed reduced openings at the non-plated segments. Reduced opening is a concern for the effectiveness of decompression as there is less space to accommodate movement of the cord in flexion-extension. A possible rationale for why we did not observe this difference is our strict adherence to preserving the interspinous ligaments and half of the ligamentum flavum intact. These soft tissue stabilizers are important to the stability of the posterior column and as such less intersegmental motion is observed.[25,26] With improved stability of the opened laminae as a unit, the plated segments provide adequate support to uphold the non-plated segments. This was possible even in 2 non-plated levels out of 4 levels total for C3-6 laminoplasty.

Besides the initial canal expansion, the changes that occur postoperatively prior to hinge healing is important. Any reduction (1mm) in the canal diameter is considered as spring-back which may lead to restenosis of the cervical canal with compromise of the decompressed spinal cord.[12] With our length of follow-up, we can determine in the early and late follow-up whether spring-back occurs. Results suggest that reductions in the canal diameter may occur in the early phase at non-plated levels. This was only observed during the early follow-up at postoperative 6 weeks for C4 and C6, and postoperative 2 weeks for C5. The early findings may be related to the increased mobilization exercise allowed by the patient after the wound pain and stiffness related to the surgery has resolved. Given the absolute expansion, this is an insignificant amount of

reduction. Nevertheless, spring-back closure based on our criteria was common and occurred most often at C6 or the junctional level.

It is possible through the tethering by the ligamentum flavum after opening the laminae to a certain degree that the non-plated levels under tension do not experience spring-back.[25,26] Hence, we specifically analyzed whether there is a cut-off for laminae opening that is associated with less risk of spring-back. Our ROC analysis showed that in the non-plated levels from C3-6, there is a high sensitivity and specificity for a canal expansion of approximately 7mm to not result in spring-back closure. It is possible that with this 7mm opening that there is a threshold of ligamentum flavum tension with which the non-plated levels are kept opened by the plated levels. This postulation requires further study to verify.

Based on a non-inferiority principle, our technique with skipped-level plating provides equal canal expansion as the all-level plating patients. This provides us with a less costly option that will result in the same radiological outcomes. For the clinical outcomes, we used the JOA score and recovery rate data to compare between groups. The rate of JOA and recovery rate changes are consistent with what has been seen for alternate plating.[24,27] A comparable difference from these studies is our use of multiple skipped levels in C3-6 laminoplasty. Our results verify that any intervening levels from C3-6 or C3-7 without plating can still result in good symptomatic recovery and none of the patients with spring-back required reoperation. This is in line with the importance of maintaining interspinous ligament and ligamentum flavum integrity. Of note is the omission of C7 as a possible non-plated level in this study, and as such, whether or not C7 can also avoid plating needs to be addressed in future study. However, due to the increased segmental motion at the cervicothoracic junction, the authors hypothesize that further reductions in canal expansion would be observed. Due to laminotomies at C3/4 and C6/7

or C7/T1, plating is advised at the end segments. Hence surgeons should only consider skipping C4-C5 for C3-6 laminoplasty and C4-6 for C3-7 laminoplasty. This can reduce implant costs by 50% for a C3-6 laminoplasty and 60% for a C3-7 laminoplasty. Cost concerns are valid considering the cost-effectiveness benefits of routinely using plates in laminoplasty is still debatable.[28]

Several limitations exist for this study. We were unable to generate a standardized surgical procedure to compare between groups due to the study's retrospective nature. Having standard skipped-level plating patients may allow a more even comparison for non-plated levels. There is a wide spectrum of possible presentations for CSM. Although the JOA is a commonly used method for assessment of clinical outcomes, it only focuses on the physical signs without accounting for patient-perceived health-related quality of life. Future assessment using the Japanese Orthopaedic Association Cervical Myelopathy Evaluation Questionnaire (JOACMEQ) is more useful to not only cover the domains of the original JOA score but also patient-perceived health status.[29-31] Furthermore, we do not have postoperative MRIs to assess any spinal cord signal changes which may be useful to correlate the effects of our decompression surgery.[32] Our use of lateral radiographs to define springback was to avoid radiation exposure with computed tomography (CT). However, axial CT scans are most appropriate to study springback phenomenon.

This is a novel study that presents compelling data that highlights the non-inferiority of patients undergoing different combinations of skipped-level plating as compared with all-level plating for laminoplasty. No significant differences between groups were observed for spring-back closure at all levels without plating. Despite having some cases with early re-narrowing of

the canal, there was no effect on the JOA score or recovery rate. In addition, we proposed a threshold of at least 7mm canal expansion to avoid spring-back closure.

Conclusions

In this modern age with an increasingly conscious society to health economics, any management must also be balanced in terms of healthcare cost. It is our duty to select the best and most cost-effective treatment option for patients. As evidenced in this study, skipped-level and all-level plating for open-door laminoplasty yields similar clinical and radiological outcomes. With no perceivable superiority with every level plating, the implications of cost reduction with less plates used become more impactful and should be considered during management planning.

References

1. Kalsi-Ryan S, Karadimas SK, Fehlings MG (2013) Cervical spondylotic myelopathy: the clinical phenomenon and the current pathobiology of an increasingly prevalent and devastating disorder. The Neuroscientist : a review journal bringing neurobiology, neurology and psychiatry 19:409-421.
2. Smith ZA, Buchanan CC, Raphael D, Khoo LT (2011) Ossification of the posterior longitudinal ligament: pathogenesis, management, and current surgical approaches. A review. Neurosurg Focus 30:E10.
3. Shigematsu H, Cheung JP, Mak KC, Bruzzone M, Luk KD (2017) Cervical spinal canal stenosis first presenting after spinal cord injury due to minor trauma: An insight into the value of preventive decompression. J Orthop Sci 22:22-26.
4. Wang SJ, Jiang SD, Jiang LS, Dai LY (2011) Axial pain after posterior cervical spine surgery: a systematic review. Eur Spine J 20:185-194.
5. Hirabayashi K, Satomi K (1988) Operative procedure and results of expansive open-door laminoplasty. Spine (Phila Pa 1976) 13:870-876.
6. Hirabayashi K, Watanabe K, Wakano K, Suzuki N, Satomi K, Ishii Y (1983) Expansive open-door laminoplasty for cervical spinal stenotic myelopathy. Spine (Phila Pa 1976) 8:693-699.
7. Hirabayashi K, Miyakawa J, Satomi K, Maruyama T, Wakano K (1981) Operative results and postoperative progression of ossification among patients with ossification of cervical posterior longitudinal ligament. Spine (Phila Pa 1976) 6:354-364.

8. Liu FY, Ma L, Huo LS, Cao YX, Yang DL, Wang H, Yang SD, Ding WY (2017) Mini-plate fixation versus suture suspensory fixation in cervical laminoplasty: A meta-analysis. Medicine (Baltimore) 96:e6026.

9. Wang HQ, Mak KC, Samartzis D, El-Fiky T, Wong YW, Luo ZJ, Kang X, Cheung WY, Luk KD, Cheung KM (2011) "Spring-back" closure associated with open-door cervical laminoplasty. The spine journal : official journal of the North American Spine Society 11:832-838.

10. Chen G, Luo Z, Nalajala B, Liu T, Yang H (2012) Expansive open-door laminoplasty with titanium miniplate versus sutures. Orthopedics 35:e543-548.

11. O'Brien MF, Peterson D, Casey AT, Crockard HA (1996) A novel technique for laminoplasty augmentation of spinal canal area using titanium miniplate stabilization. A computerized morphometric analysis. Spine (Phila Pa 1976) 21:474-483; discussion 484.

12. Tung KL, Cheung P, Kwok TK, Wong KK, Mak KH, Wong WC (2015) Single-door cervical laminoplasty using titanium miniplates alone. J Orthop Surg (Hong Kong) 23:174-179.

13. Wolf BS, Khilnani M, Malis L (1956) The sagittal diameter of the bony cervical spinal canal and its significance in cervical spondylosis. J Mt Sinai Hosp N Y 23:283-292.

14. Heller JG, Edwards CC, 2nd, Murakami H, Rodts GE (2001) Laminoplasty versus laminectomy and fusion for multilevel cervical myelopathy: an independent matched cohort analysis. Spine (Phila Pa 1976) 26:1330-1336.

15. Jiang YQ, Li XL, Zhou XG, Bian C, Wang HM, Huang JM, Dong J (2017) A prospective randomized trial comparing anterior cervical discectomy and fusion versus plate-only

open-door laminoplasty for the treatment of spinal stenosis in degenerative diseases. Eur Spine J 26:1162-1172.

16. Chen H, Deng Y, Li T, Gong Q, Song Y, Liu H (2015) Clinical and radiography results of mini-plate fixation compared to suture suspensory fixation in cervical laminoplasty: A five-year follow-up study. Clin Neurol Neurosurg 138:188-195.

17. Mochida J, Nomura T, Chiba M, Nishimura K, Toh E (1999) Modified expansive open-door laminoplasty in cervical myelopathy. Journal of spinal disorders 12:386-391.

18. Deutsch H, Mummaneni PV, Rodts GE, Haid RW (2004) Posterior cervical laminoplasty using a new plating system: technical note. Journal of spinal disorders & techniques 17:317-320.

19. Gandhoke G, Wu JC, Rowland NC, Meyer SA, Gupta C, Mummaneni PV (2011) Anterior corpectomy versus posterior laminoplasty: is the risk of postoperative C-5 palsy different? Neurosurg Focus 31:E12.

20. Meyer SA, Wu JC, Mummaneni PV (2011) Laminoplasty outcomes: is there a difference between patients with degenerative stenosis and those with ossification of the posterior longitudinal ligament? Neurosurg Focus 30:E9.

21. Park AE, Heller JG (2004) Cervical laminoplasty: use of a novel titanium plate to maintain canal expansion--surgical technique. Journal of spinal disorders & techniques 17:265-271.

22. Rhee JM, Register B, Hamasaki T, Franklin B (2011) Plate-only open door laminoplasty maintains stable spinal canal expansion with high rates of hinge union and no plate failures. Spine (Phila Pa 1976) 36:9-14.

23. Wang LN, Wang L, Song YM, Yang X, Liu LM, Li T (2016) Clinical and radiographic outcome of unilateral open-door laminoplasty with alternative levels centerpiece mini-plate fixation for cervical compressive myelopathy: a five-year follow-up study. Int Orthop 40:1267-1274.

24. Yang HL, Chen GD, Zhang HT, Wang L, Luo ZP (2013) Open-door laminoplasty with plate fixation at alternating levels for treatment of multilevel degenerative cervical disease. J Spinal Disord Tech 26:E13-18.

25. Abdullah KG, Yamashita T, Steinmetz MP, Lubelski D, Wang JC, Benzel EC, Mroz TE (2012) Open-door cervical laminoplasty with preservation of posterior structures. Global Spine J 2:15-20.

26. Hartman RA, Tisherman RE, Wang C, Bell KM, Lee JY, Sowa GA, Kang JD (2016) Mechanical role of the posterior column components in the cervical spine. Eur Spine J 25:2129-2138.

27. Wang ZF, Chen GD, Xue F, Sheng XW, Yang HL, Qian J (2014) All levels versus alternate levels plate fixation in expansive open door cervical laminoplasty. Indian J Orthop 48:582-586.

28. Humadi A, Chao T, Dawood S, Tacey M, Barmare A, Freeman B (2017) A Meta-Analysis of Cervical Laminoplasty Techniques: Are Mini-Plates Superior? Global Spine J 7:373-381.

29. Cheung PWH, Wong CKH, Lau ST, Cheung JPY (2017) Psychometric Validation of the Adapted Traditional Chinese (Hong Kong) Version of the Japanese Orthopaedic Association Cervical Myelopathy Evaluation Questionnaire (JOACMEQ). Spine (Phila Pa 1976).

30. Fukui M, Chiba K, Kawakami M, Kikuchi S, Konno S, Miyamoto M, Seichi A, Shimamura T, Shirado O, Taguchi T, Takahashi K, Takeshita K, Tani T, Toyama Y, Wada E, Yonenobu K, Tanaka T, Hirota Y, Subcommittee on Low Back P, Cervical Myelopathy Evaluation of the Clinical Outcome Committee of the Japanese Orthopaedic A (2007) An outcome measure for patients with cervical myelopathy: Japanese Orthopaedic Association Cervical Myelopathy Evaluation Questionnaire (JOACMEQ): Part 1. J Orthop Sci 12:227-240.

31. Tanaka N, Konno S, Takeshita K, Fukui M, Takahashi K, Chiba K, Miyamoto M, Matsumoto M, Kasai Y, Kanamori M, Matsunaga S, Hosono N, Kanchiku T, Taneichi H, Hashizume H, Kanayama M, Shimizu T, Kawakami M (2014) An outcome measure for patients with cervical myelopathy: the Japanese Orthopaedic Association Cervical Myelopathy Evaluation Questionnaire (JOACMEQ): an average score of healthy volunteers. J Orthop Sci 19:33-48.

32. Ikegami S, Takahashi J, Misawa H, Tsutsumimoto T, Yui M, Kuraishi S, Futatsugi T, Uehara M, Oba H, Kato H (2017) Spinal cord MRI signal changes at 1 year after cervical decompression surgery is useful for predicting midterm clinical outcome: an observational study using propensity scores. The spine journal : official journal of the North American Spine Society.

Figure Legends

Fig. 1: (a) Skipped-level plating at C4 and C6 for C3-7 laminoplasty; (b) Skipped-level plating at C5 for C3-6 laminoplasty.

Fig. 2: Comparable canal diameter expansion is observed for (a) C3, (b) C4, (c) C5, and (d) C6 between skipped-level and all-level plating. Data are expressed in means with standard deviation bars.

Fig. 3: Similar improvements in (a) Japanese Orthopaedic Association (JOA) scores and (b) recovery rate were observed between skipped-level and all-level plating. Data are expressed in means with standard deviation bars.