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Clinical and Radiological Outcomes of Two Modified Open-door Laminoplasties Based on a Novel Paraspinal Approach for Treatment of Multilevel Cervical Spondylotic Myelopathy

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Study Design. A case–control study.

Objectives. The aim of this study was to evaluate the outcomes of two modified laminoplasties (LPs) based on a novel paraspinal approach for treating multilevel cervical spondylotic myelopathy.

Summary of Background Data. No laminoplasty through a natural intermuscular plane mimicking Wiltse approach to minimize intraoperative injury to extensor muscles has ever been developed and studied.

Methods. Ninety-two patients were enrolled, including patients treated with either modified LP and patients treated with concurrent conventional LP. Operation time, blood loss, and complications were recorded. Clinical outcomes were evaluated by VAS, JOA scores, and recovery rate. Cervical sagittal alignment was measured on cervical radiographs. Spinal canal expansion was assessed on CT scans. Cross-sectional area (CSA) and atrophy rate (AR) of cervical deep extensors were evaluated on MRI.

Results. The average follow-up duration was 33.05, 31.55, 33.02, and 32.52 months, respectively in each group. Compared to concurrent conventional procedure, unilateral muscle-preserv-

ing procedure displayed similar, whereas bilateral muscle-preserving procedure showed significantly increased operation time and blood loss; each modified procedure resulted in comparable and satisfied perioperative clinical scores, spinal canal expansion while achieving significantly lower axial pain incidence, better cervical lordosis maintenance, and better deep extensor preservation. AR of deep extensors on the open side was significantly lower than that on the hinge side. Bilateral paraspinal approach demonstrated significantly better muscle-preservation on the open side and increased operation duration, with similar clinical scores, axial pain incidence, cervical lordosis maintenance, and spinal canal expansion compared to unilateral paraspinal approach. Loss of cervical lordosis was strongly correlated with AR of deep extensors.

Conclusion. Paraspinal approach is a good manner to protect deep extensor muscles; the two modified LPs have similar effects on clinical outcomes.

Key words: axial pain, cervical sagittal alignment, clinical outcome evaluation, deep extensor muscles, intermuscular plane, muscle atrophy, open-door laminoplasty, paraspinal approach, radiological outcome evaluation, semispinalis cervicis.

Level of Evidence: 3

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Middle- to long-term follow-ups demonstrated advantages of expansive open-door laminoplasty (LP) over cervical laminectomy for treatment of multilevel cervical spondylotic myelopathy (MCSM).^{1,2} However, unresolved complications still remain. In particular, axial pain, which can cause dissatisfaction and even has a negative impact on health-related quality of life, is frequently encountered with an incidence ranged from 7 to 58% after cervical LP.^{3,4} Researches investigating the causes of post-LP axial neck pain placed great emphasis on intraoperative damage to posterior elements especially extensor muscles, recognizing it as a possible etiology.^{5,6}

Inspired by Wiltse approach to lumbar spine,⁷ we developed a paraspinal intermuscular approach to cervical spine

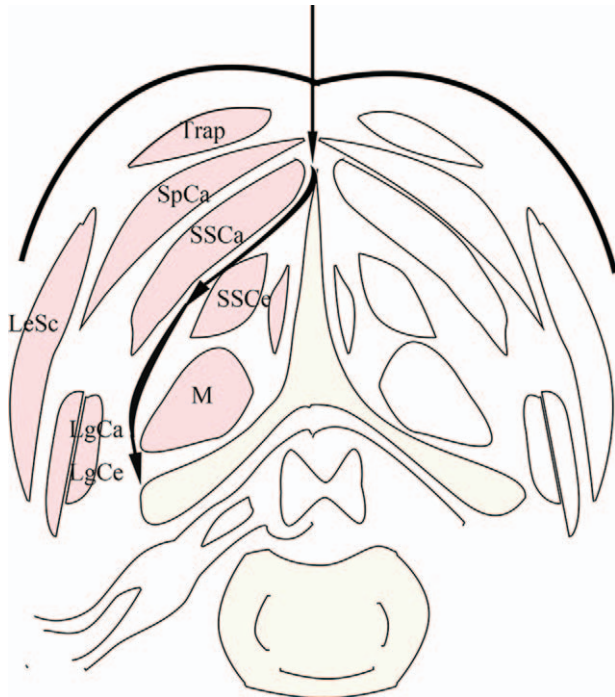


Figure 1. A diagram of our paraspinal approach. LeSc indicates levator scapulae; LgCa, longissimus capitis; LgCe, longissimus cervicis; M, multifidus; SpCa, splenius capitis; SSCa, semispinalis capitis; SSCe, semispinalis cervicis; Trap, trapezius.

and began to perform modified LP through bilateral paraspinal approach in 2010. Since this approach was based on natural plane between the lateral border of semispinalis cervicis (SSCe) and multifidus (M) and the medial border of semispinalis capitis (SSCa) (Figure 1), muscle attachment dissection would be minimized. As we detected a significant difference of postoperative variations in cross-sectional area of deep extensor muscles between open side and hinge side after following up a first few cases, we thought that preservation might benefit much more on the hinge side than on the open side so that performing unilateral intermuscular approach on the hinge side might achieve similar outcomes to the former one with less surgical time and skill requirement. In this view, we started to perform another modified LP in 2015. The intraoperative images of lamina exposure procedure in the above two modified LPs were shown in Figure 2A and B. In this study, we aimed to find out if preserving extensors through this novel approach could prevent muscle atrophy and retrospectively analyzed and compared data of MCSM patients treated with either one of modified LPs or concurrent conventional LP.

MATERIALS AND METHODS

Patient Population, Inclusion and Exclusion Criteria

From July 2015 to May 2016, 46 consecutive patients diagnosed as MCSM in Tongji Hospital were randomly divided into two groups and underwent modified LP preserving deep extensors on the hinge side (group A) and conventional LP (group B) respectively. In addition, 5 years

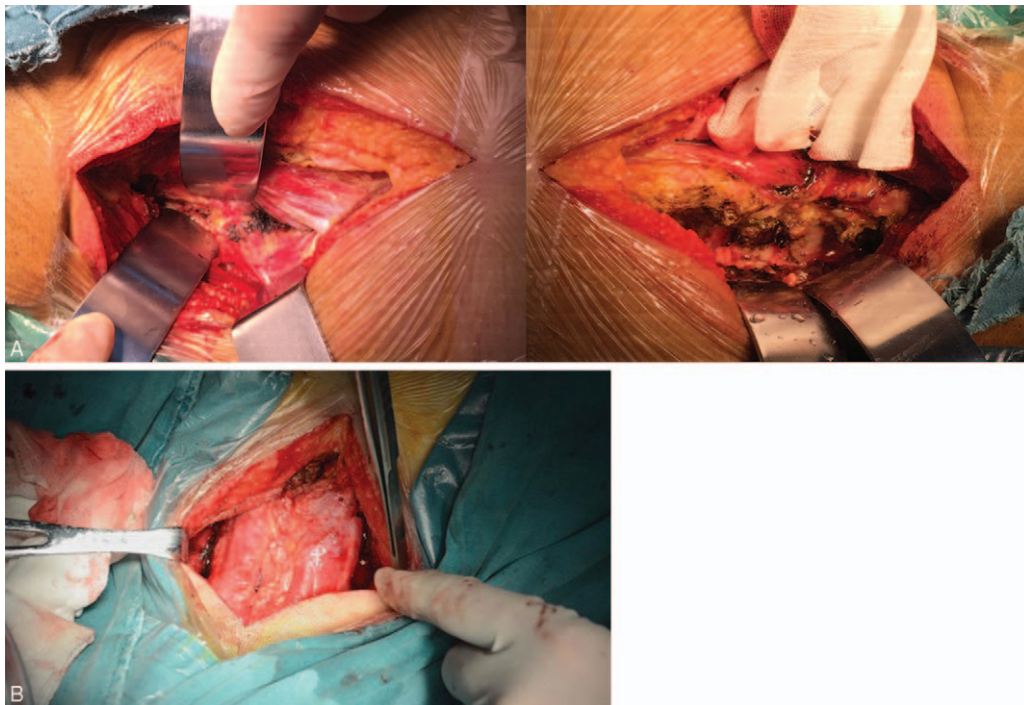


Figure 2. Intraoperative exposure of posterior elements by two modified procedures. (A) We performed exposure through paraspinal approach on the hinge side (left) and through midline approach on the open side (right) in the unilateral muscle-preserving laminoplasty. (B) We performed exposure through paraspinal approach bilaterally in the bilateral muscle-preserving laminoplasty.

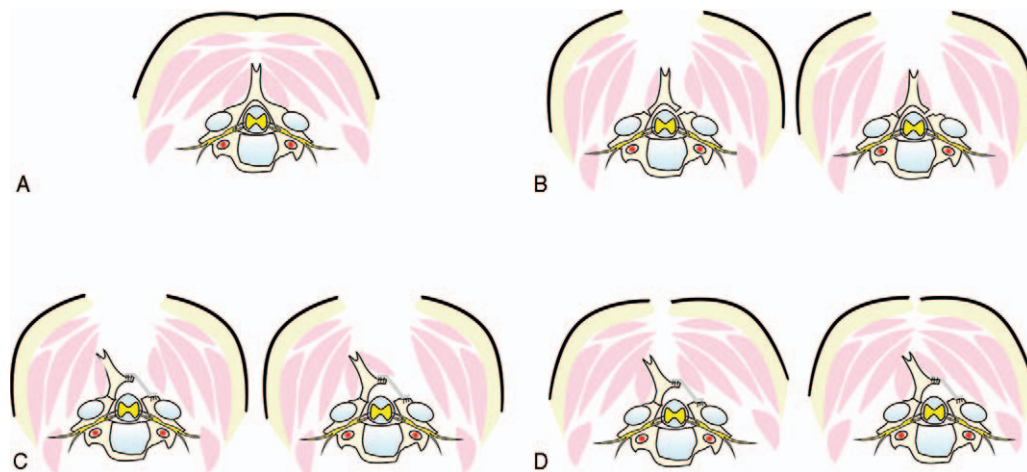


Figure 3. Surgical schematic diagram of our two modified laminoplasties. (A) Before exposure. (B) We performed two different approaches of exposure, where paraspinal approach on the hinge side and midline approach on the open side were used in group A (left) and bilateral paraspinal approach was used in group C (right). (C) Standard unilateral open-door procedure was performed without osteotomy for both modified laminoplasty preserving deep extensors on the hinge side (left) and modified laminoplasty preserving bilateral deep extensors (right). (D) The wound was closed for unilateral (left) and bilateral (right) muscle-preserving laminoplasties.

earlier, from November 2010 to November 2011, 46 consecutive MCSM patients were randomly grouped and underwent modified LP preserving bilateral deep extensors (group C) and conventional LP (group D) in Tongji Hospital. Group B (or D) was set as a concurrent control to group A (or C). The investigators and assessors were blind to the randomization process. All surgeries were performed by two experienced spine surgeons at the department of orthopedics, Tongji Hospital.

The patient inclusion criteria were: cervical myelopathy due to multilevel spinal cord compression requiring posterior decompression; positive modified K-line of cervical spine; complete follow-up for at least 2 years postoperatively. The exclusion criteria were: cervical instability; cervical kyphosis; traumatic spinal cord injury; history of anterior or posterior cervical fusion surgery.

Surgical Technique and Postoperative Management

After general anesthesia, the patient was placed in the prone position with the cervical spine in mild flexion and the head supported with a Mayfield headstock (Figure 3A). The paraspinal approach was used to expose the lamina in modified groups as follows: after midline incision was made, nuchal fascia and trapezius muscle were dissected; natural plane of the anatomic intermuscular space between SSCe and SSCa could be identified; laminae and facet joints were exposed after splitting and retracting these muscles laterally by blunt dissection. For the group with modified LP preserving bilateral deep extensors, muscles were dissected along this paraspinal approach on both the open side and the hinge side; for the group with modified LP preserving unilateral deep extensors, muscles on the hinge side were dissected and retracted using the paraspinal approach, and muscles on the open side were dissected subperiosteally using standard midline approach (Figure 3B). After

exposure of bony posterior elements, the C2–3 intersegmental ligamentum flavum was cut off on open side through standard midline approach; the same procedure was performed for C7–T1. A full-thickness gutter was drilled on the open side with a high-speed burr and a partial-thickness gutter was made at the junction of lateral mass and lamina on the hinge side. The door was opened and the posterior elements were elevated without the osteotomy of spinous processes; the expanded spinal canal was maintained using appropriate-sized titanium miniplates (ARCH fixation system, DePuy Synthes, Switzerland) which were secured with screws (Figure 3C). Finally, paravertebral muscles were sutured and the wound was closed, for the unilateral extensor-preserving group muscles on the open side should be sutured to spinous processes (Figure 3D). The control group underwent conventional procedure as described,⁸ also using the ARCH miniplates to maintain spinal canal enlargement without spinous process osteotomy. All surgeries were conducted by two experienced surgeons.

The patient was allowed to ambulate in the ward on the next day after surgery. Early cervical muscle exercises were required and a Philadelphia cervical collar was recommended to wear for 4 weeks as recommended.⁹ Patients returned for outpatient examinations 3, 6, 12, and 24 months after surgery.

Clinical and Radiological Outcome Evaluations

Neurological status of cervical spine was evaluated using Japanese Orthopedic Association (JOA) score and recovery rate.⁸ Axial neck pain defined as nuchal and/or scapular pain was assessed by visual analog scale (VAS) score. Operation time was recorded and assessed. Complications including infection, hardware failure, cerebrospinal fluid leakage, C5 nerve root palsy, and recurrence of symptoms were recorded till the final follow-up.

Plain radiographs, computed tomography (CT) scans, and magnetic resonance imaging (MRI) scans of patients were collected preoperatively, 1 week postoperatively and at the final follow-up. Parameters based on plain radiographs were measured by Surgimap (version 2.2.12.1; Nemaris Inc., New York, NY). Parameters based on CT and MRI scans were measured by mimics 17.0 (Materialise Inc., Leuven, Belgium). All measurements were taken three times by two assessors, and the mean value was used for analysis. Cervical lordosis was evaluated by C2-C7 Cobb angle and cervical curvature index (CCI) described by Ishihara¹⁰ on lateral radiographs (for patient whose shoulder blocked x-ray making C6-C7 invisible, C2-C6 Cobb angle was used as an alternative as recommended by Zhang *et al*¹¹ and CCI could be calculated from C2-C6 Cobb angle via the method provided by Takeshita *et al*).¹⁰ Spinal canal expansion was assessed by mean anteroposterior (AP) diameter, mean open angle and mean cross-sectional area of surgical spinal canal segments (mean spinal canal area) based on CT scans. Mean AP diameter and mean open angle were measured and calculated as described by Wang *et al*¹² in 2016 and mean spinal canal area was obtained as described by Wang *et al*¹³ in 2006. Satisfactory decompression was judged by presented high signal area around the spinal cord at the preoperative compressed levels on T2-weighted MRI. The volume of posterior deep extensors was quantified using magnetic resonance T2-weighted axial images from the C3/4 to C6/7 level; the cross-sectional area (CSA) of multifidus and semispinalis cervicis on each level was measured and added up as the total CSA of deep extensors. The atrophy rate (AR) of deep extensors was calculated using final and preoperative total CSA as follows: $AR(\%) = (1 - \text{final total CSA}/\text{preoperative total CSA}) \times 100\%$.

Statistical Analysis

We used SPSS software version 22.0 (SPSS Inc, Chicago, IL) to perform statistical analysis. Each radiological measurement was taken by two assessors independently for three times respectively and the average was recorded, inter- and intra-class correlation coefficients were used to evaluate the inter-examiner reliability and intra-examiner reproducibility. Data were presented as mean \pm standard deviation. For continuous

variable with a normal distribution, one-way analysis of variance (ANOVA) followed by Sidak multiple comparison test was performed for the comparison among multiple groups, and two-tailed Student *t* test was performed for the comparison between two groups. For continuous variable not complying with the normal distribution, Mann-Whitney *U* test was used. Categorical variables were assessed by χ^2 tests, continuity corrected χ^2 tests, and Fisher exact tests. Linear regression analysis and Pearson coefficients were used to evaluate correlations between variables. A *P* value ≤ 0.05 was considered to be statistically significant.

RESULTS

A total of 89 patients were followed-up for at least 24 months including 44 of 46 who underwent modified LP preserving deep extensors on the hinge side (group A) or conventional LP (group B), and 45 of 46 who underwent modified LP preserving bilateral deep extensors (group C) or conventional LP (group D). The average follow-up duration was similar among four groups: 33.05 months in group A (range, 28–38 months), 31.55 months in group B (range, 28–38 months), 33.02 months group C (range, 26–42 months), 32.52 months group D (range, 27–44 months). No significant difference existed in demographic and baseline characteristics either between each modified group and its concurrent control group or between two modified groups (Table 1). Representative images of patients were shown in Figure 4A–O. For radiographic parameter assessments, strong agreements were shown by the evaluation of reliability and reproducibility (overall inter- and intra-class correlation coefficients were 0.88 and 0.87, respectively).

Comparisons Between Each Modified Group and the Concurrent Control Group

The operation duration was not significantly different between group A and B, but was significantly increased in group C compared to group D ($P < 0.001$). For preoperative VAS and JOA scores, VAS and JOA scores at the final follow-up and recovery rate, no significant difference existed between each modified group and the concurrent control group. The VAS and JOA scores indicated significant improvement at the final follow-up compared to that

TABLE 1. Demographic and Baseline Data

	Group A (n = 22)	Group B (n = 22)	Group C (n = 21)	Group D (n = 24)	P1	P2	P3
Sex (male/female)	14/8	13/9	14/7	17/7	0.76	0.76	0.84
Age at surgery, y	52.41 \pm 9.20	51.05 \pm 8.32	54.92 \pm 10.66	57.03 \pm 11.21	0.66	0.91	0.41
Disease duration, mo	31.43 \pm 35.19	26.14 \pm 22.73	27.43 \pm 42.06	20.36 \pm 41.73	0.56	0.58	0.74
Follow-up duration, mo	33.05 \pm 3.03	31.55 \pm 4.22	33.02 \pm 4.27	32.52 \pm 3.81	0.25	0.61	0.98
Decompression segments							
C3–C7	6	7	4	8	0.94	0.53	0.81
C3–C6	12	11	13	13			
C4–C6	4	4	4	3			

LP indicates laminoplasty; p1, group A vs group B; p2, group C vs group D; p3, group A vs group C.

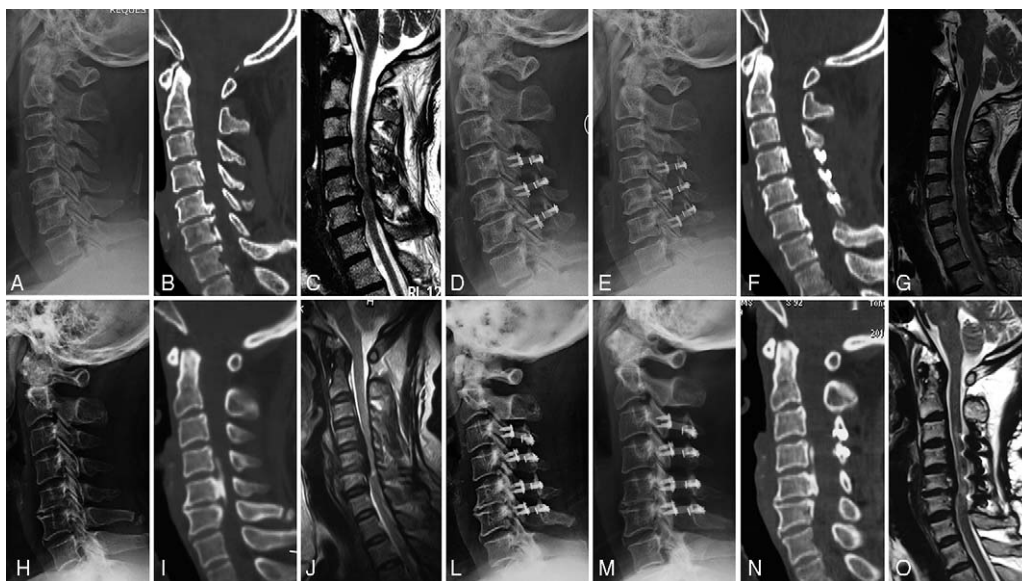


Figure 4. Representative images of two patients that underwent modified laminoplasties. Images of the patient that underwent modified laminoplasty preserving deep extensors on the hinge side: preoperative, 1-week postoperative and 34-month postoperative neutral radiographs (A, D, E), preoperative and 34-month postoperative computed tomography sagittal plane images (B, F), preoperative and 34-month postoperative magnetic resonance sagittal plane images (C, G); Images of the patient that underwent modified laminoplasty preserving bilateral deep extensors: preoperative, 1-week postoperative and 36-month postoperative neutral radiographs (H, L, M), preoperative and 36-month postoperative computed tomography sagittal plane images (I, N), preoperative and 36-month postoperative magnetic resonance sagittal plane images (J, O).

preoperatively in all four groups ($P < 0.001$ for each). The incidence of C5 palsy was not significantly different between each modified group and its control, but the incidence of new axial pain was significantly lower in each modified group compared to its control ($P = 0.02$ and $P = 0.04$ respectively). No dural tear, progression of myelopathy, new radiculopathy, infection, or hardware failure had been detected in all four groups during the follow-up. The details of data were shown in Table 2.

For radiological assessments, first, preoperative C2-C7 Cobb angle, C2-C7 Cobb angle at the final follow-up, and preoperative CCI all showed no significant difference between each modified group and its control, whereas CCI at the final follow-up indicated significant increase in each modified group compared to its control ($P < 0.05$ for each). Secondly, no significant difference in spinal canal expansion evaluated by mean AP diameter, mean spinal canal area and mean open angle was detected between each modified group and its control. All four groups achieved massive improvement of spinal canal size: mean AP diameter ($P < 0.001$ in each group) and mean spinal canal area ($P < 0.001$ in each group) were significantly increased at the final follow-up compared to that preoperatively; satisfied decompression of spinal cord was confirmed on MRI for every patient enrolled. Thirdly, no significant difference was found preoperatively between each modified group and its control in total CSA of bilateral posterior deep extensors and also in total CSA of posterior deep extensors on the hinge side and that on the open side respectively. However, at the final follow-up each modified group demonstrated

significant improvements in total CSA of bilateral deep extensors ($P < 0.01$ for each) and total CSA of posterior deep extensors on the hinge side ($P < 0.001$ for each) but showed no significant improvement in total CSA of posterior deep extensors on the open side compared to its control. Besides, each modified group showed significant decreases in both AR of bilateral deep extensors ($P < 0.001$ for each) and AR of deep extensors on the hinge side ($P < 0.001$ for each) compared to its control, but only bilateral preservation resulted in significantly decreased AR of deep extensors on the open side ($P < 0.001$). Moreover, AR on the open side was significantly increased compared to that on the hinge side in each group ($P < 0.001$ in group A, C and D, $P = 0.001$ in group B). The details of data were shown in Table 3. Representative images of spinal canal expansion and deep extensor atrophy for three LP techniques mentioned in this article were shown in Figure 5A–F and Figure 6A–F, respectively.

Comparisons Between Two Modified Groups

Group A (preserving unilateral deep extensors) showed significantly decreased operation duration compared to group C (preserving bilateral deep extensors) ($P < 0.001$). No significant difference was detected between two modified groups in preoperative VAS and JOA scores, VAS and JOA scores at the final follow-up, recovery rate, and complication incidences (Table 2).

For radiological assessments, no significant difference existed between two modified groups in preoperative C2-C7 Cobb angle and CCI, C2-C7 Cobb angle and CCI at the

TABLE 2. Operation Duration and Clinical Outcomes

	Group A (n = 22)	Group B (n = 22)	Group C (n = 21)	Group D (n = 24)	P1	P2	P3
Operation duration	172.00 ± 24.91	156.60 ± 29.37	196.00 ± 18.34	160.00 ± 20.36	0.07	<0.00-0.001*	<0.00-0.001*
Clinical outcomes							
VAS							
Pre-op	4.05 ± 2.04	3.96 ± 1.29	3.12 ± 2.41	3.43 ± 1.59	0.86	0.61	0.18
Final FU	0.55 ± 0.60	0.64 ± 0.73	0.31 ± 0.92	0.67 ± 1.09	0.66	0.24	0.31
P/test value (pre-op vs. final FU)	<0.001*/t = 7.72	<0.001*/t = 10.51	<0.001*/t = 4.99	<0.001*/t = 7.01			
JOA							
Pre-op	9.23 ± 2.27	9.73 ± 2.47	9.28 ± 1.24	9.43 ± 1.62	0.49	0.73	0.93
Final FU	15.18 ± 1.05	15.23 ± 1.54	15.71 ± 1.42	15.21 ± 1.39	0.57	0.24	0.17
P/test value (pre-op vs. final FU)	<0.001*/t = 10.78	<0.001*/t = 8.86	<0.001*/t = 15.63	<0.001*/t = 13.27			
Recovery rate at final FU (%)	76.93 ± 10.38	78.26 ± 17.91	82.57 ± 13.82	79.37 ± 11.21	0.45	0.40	0.14
Incidence of complications (%)							
C5 palsy	4.55	4.55	4.76	4.17	0.47	0.53	0.49
New axial pain	13.64	50.00	9.52	41.67	0.02*	0.04*	0.96
Dural tear	0.00	0.00	0.00	0.00	\	\	\
Progression of myelopathy	0.00	0.00	0.00	0.00	\	\	\
New radiculopathy	0.00	0.00	0.00	0.00	\	\	\
Infection	0.00	0.00	0.00	0.00	\	\	\
Hardware failure	0.00	0.00	0.00	0.00	\	\	\
<i>FU indicates follow-up; JOA, Japanese Orthopedic Association; p1, group A vs group B; p2, group C vs group D; p3, group A vs group C; Pre-op, preoperative; VAS, visual analog score.</i> <i>*Statistically significant.</i>							

final follow-up, and spinal canal expansion evaluated by mean AP diameter, mean spinal canal area, and mean open angle. Besides, no significant difference existed between two modified groups in total CSA of bilateral posterior deep extensors and total CSA of posterior deep extensors on the hinge side preoperatively and at the final follow-up, in preoperative total CSA of posterior deep extensors on the open side and also in AR of deep extensors on the hinge side. However, group C showed significantly improved total CSA of posterior deep extensors on the open side at the final follow-up compared to group A ($P < 0.01$). Moreover, group C demonstrated significant increases in both AR of bilateral deep extensors and AR of deep extensors on the open side compared to group A ($P < 0.001$ for each). The details of data were shown in Table 3.

Relationship Between Deep Extensor Atrophy and Sagittal Cervical Alignment

We calculated the loss of C2-C7 Cobb angle and the loss of CCI from values preoperatively and at the last follow-up. Results showed that both of these parameters were strongly correlated with AR of bilateral deep extensors for 89 patients enrolled in this study ($r = 0.49$, $P < 0.001$ and $r = 0.41$, $P < 0.001$ respectively), the details were shown in Figure 7A and B.

DISCUSSION

In conventional open-door LP, damages to posterior elements, including attached ligament cut-off and paraspinal extensor muscle detachment from spinous process and lamina, are often required and may cause axial symptoms and cervical malalignment.^{5,6} Deep extensor muscles especially multifidus and semispinalis contribute to curvature maintaining and motion function¹⁴; modified LP procedures preserving or reconstructing deep extensor muscle attachment acquired less axial pain and better outcomes than the conventional procedure.^{15,16} Among these procedures, preservation was thought to be better than reconstruction in consideration of less neck immobilization to ensure reunion required.¹⁶ Many muscle-preserving LP procedures were developed, some focused on preserving the spinous process with attachments at C2 and/or C7,^{17,18} some focused on skipping levels to minimize surgical damage,¹⁹ the other focused on preserving posterior muscle-ligament complex.²⁰ However, none of the above procedures achieved effective reduction in axial pain as expected, which would partially be explained by inevitable muscle attachment dissection when accessing the lamina.

To overcome the shortness of previous reported muscle-preserving LP procedures, we devised a new paraspinal approach based on the natural intermuscular plane

TABLE 3. Radiological Parameter Assessments

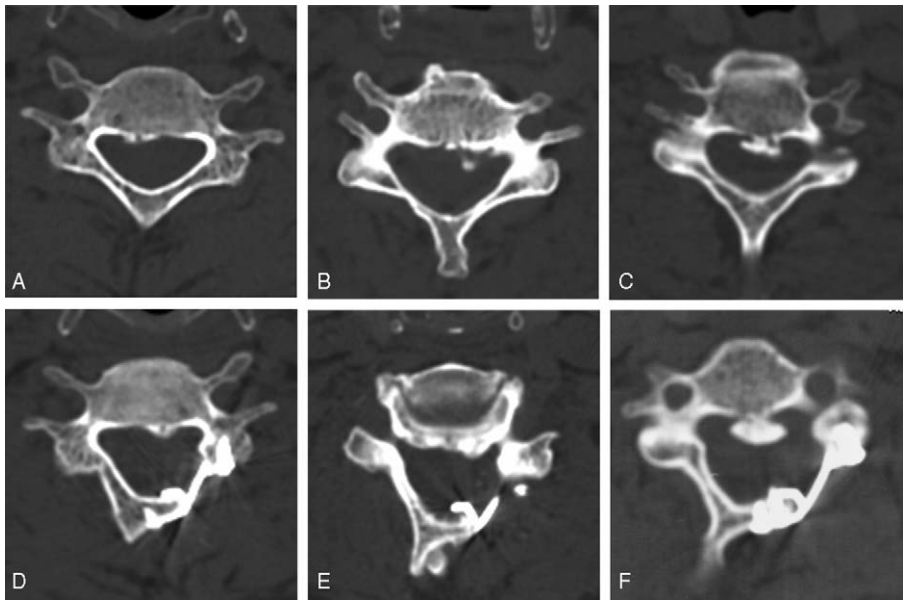
	Group A (n = 22)	Group B (n = 22)	Group C (n = 21)	Group D (n = 24)	P1	P2	P3
C2-C7 Cobb angle (°)							
Pre-op	14.55 ± 8.08	15.64 ± 7.80	14.31 ± 10.22	15.03 ± 11.12	0.65	0.82	0.93
Final FU	13.21 ± 7.35	11.77 ± 7.38	13.62 ± 10.41	11.82 ± 7.73	0.52	0.51	0.88
P/test value (pre-op vs. final FU)	0.57/t = 0.58	0.10/t = 1.69	0.83/t = 0.22	0.25/t = 1.16			
CCI (%)							
Pre-op	15.36 ± 8.58	14.02 ± 8.25	14.32 ± 7.34	12.61 ± 10.90	0.60/	0.55	0.67
Final FU	14.47 ± 7.97	9.79 ± 7.42	14.12 ± 8.70	8.42 ± 8.61	<0.05*	<0.05*	0.89
P/test value (pre-op vs. final FU)	0.72/t = 0.36	0.08/t = 1.79	0.94/t = 0.08	0.15/t = 1.48			
Mean AP diameter, mm							
Pre-op	11.18 ± 1.68	11.01 ± 1.34	11.15 ± 1.21	11.43 ± 1.31	0.71	0.46	0.95
Final FU	16.80 ± 1.71	16.68 ± 1.67	17.04 ± 1.61	16.94 ± 1.13	0.81	0.81	0.64
P/test value (pre-op vs. final FU)	<0.001*/t = 11.00	<0.001*/t = 12.42	<0.001*/t = 13.40	<0.001*/t = 15.60			
Mean open angle (°)							
Pre-op	27.79 ± 4.58	27.02 ± 3.06	28.68 ± 5.62	29.18 ± 6.23	0.52	0.78	0.58
Mean spinal canal area, mm ²							
Pre-op	213.39 ± 54.78	216.50 ± 37.86	219.89 ± 48.71	216.62 ± 36.13	0.83	0.80	0.68
Final FU	322.30 ± 45.37	325.47 ± 43.70	328.61 ± 47.03	305.39 ± 31.22	0.81	0.06	0.66
P/test value (pre-op vs. final FU)	<0.001*/t = 7.18	<0.001*/t = 8.84	<0.001*/t = 7.34	<0.001*/t = 9.11			
Total CSA of bilateral DE (OS and HS), mm ²							
Pre-op	690.90 ± 113.89	689.13 ± 134.58	678.44 ± 146.12	701.12 ± 95.60	0.96	0.54	0.76
Final FU	455.09 ± 74.29	374.28 ± 88.13	481.92 ± 95.22	409.62 ± 67.02	<0.01*	<0.01*	0.31
P/test value (pre-op vs. final FU)	<0.001*/t = 8.13	<0.001*/t = 9.18	<0.001*/t = 5.16	<0.001*/t = 12.23			
AR of bilateral DE (OS and HS, %)							
Pre-op	34.06 ± 3.72	45.77 ± 5.49	28.62 ± 4.37	41.01 ± 9.69	<0.001*	<0.001*	<0.001*
Total CSA of DE on the OS, mm ²							
Pre-op	343.42 ± 57.33	347.54 ± 65.17	336.43 ± 73.88	348.91 ± 48.13	0.82	0.50	0.73
Final FU	174.39 ± 26.89	176.90 ± 42.78	205.55 ± 48.91	183.02 ± 27.23	0.82	0.06	0.01*
P/test value (pre-op vs. final FU)	<0.001*/t = 12.23	<0.001*/t = 10.03	<0.001*/t = 6.77	<0.001*/t = 14.70			
AR of DE on the OS (%)							
Pre-op	48.93 ± 5.12	49.19 ± 6.23	39.03 ± 4.51	47.02 ± 8.43	0.88	<0.001*	<0.001*
Total CSA of DE on the HS, mm ²							
Pre-op	347.48 ± 56.68	341.59 ± 69.73	342.01 ± 72.38	352.21 ± 48.69	0.76	0.58	0.78
Final FU	280.70 ± 52.55	197.38 ± 45.77	276.37 ± 48.19	226.60 ± 43.02	<0.001*	<0.001*	0.78
P/test value (pre-op vs. final FU)	<0.001*/t = 3.96	<0.001*/t = 7.92	<0.001*/t = 3.46	<0.001*/t = 9.47			
AR of DE on the HS (%)							
Pre-op	19.35 ± 5.93	43.25 ± 4.98	18.42 ± 6.39	35.11 ± 11.72	<0.001*	<0.001*	0.62
P/test value (AR of DE on the HS vs. AR of DE on the OS)	<0.001*/t = 17.71	0.001*/t = 3.49	<0.001*/t = 12.08	<0.001*/t = 4.04			

AP diameter indicates anteroposterior diameter; AR, atrophy rate; CCI, cervical curvature index; DE, deep extensors; FU, follow-up; HS, hinge side; OS, open side; p1, group A vs group B; p2, group C vs group D; p3, group A vs group C; Pre-op, preoperative; TA, total area.
*statistically significant.

(Figure 1). Intermuscular approach described by Wiltse has been widely used in lumbar surgeries with satisfied outcomes due to its anatomic advantages over midline approach.²¹ However, to our knowledge, no such intermuscular approach has been developed except the one proposed

by Shiraishi *et al*,²² which required blunt splitting SSCe to spread space between adjacent upper and lower SSCe and interspinalis muscles. Differently, our intermuscular plane was between outer SSCa and inner SSCe and multifidus, which could be identified after superficial muscle dissection

Figure 5. Representative magnetic resonance cross-sectional plane images (cross-sectional MRI) of three patients who underwent two modified laminoplasties and conventional laminoplasty respectively. (A, D) preoperative and 31-month postoperative cross-sectional MRI of a patient that underwent conventional laminoplasty, the atrophy rate of deep extensors on the hinge side was 43.94%, that on the open side was 49.61%; (B, E) preoperative and 33-month postoperative cross-sectional MRI of a patient that underwent modified laminoplasty preserving deep extensors on the hinge side, the atrophy rate of deep extensors on the hinge side was 27.72%, that on the open side was 52.23%; (C, F) preoperative and 35-month postoperative cross-sectional MRI of a patient that underwent modified laminoplasty preserving bilateral deep extensors, the atrophy rate of deep extensors on the hinge side was 18.34%, that on the open side was 24.13%. The yellow curve marks the edge of deep extensors on the hinge side and the blue curve marks that on the open side.

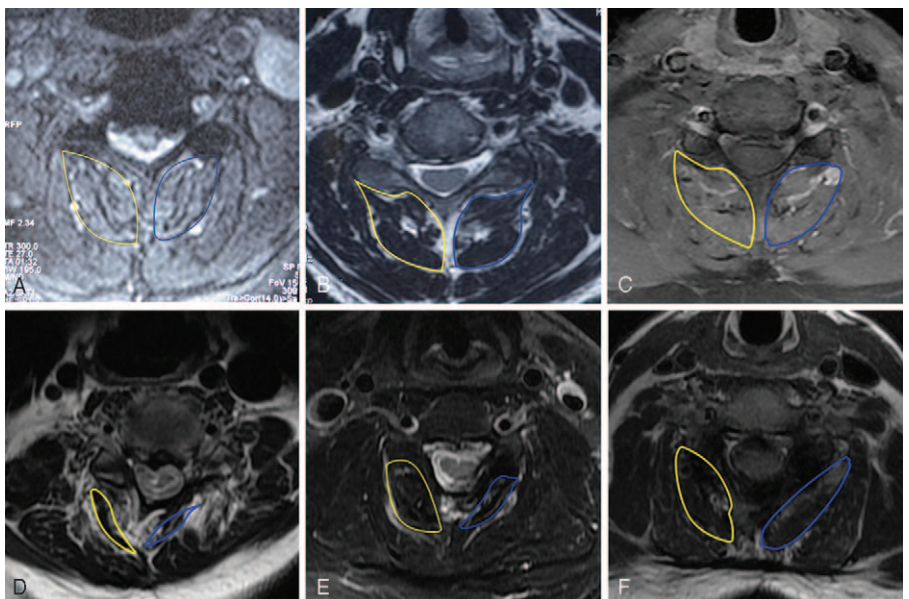


and spread to expose the posterior elements without intramuscular splitting and retraction. Similar to Wiltse approach, the muscle-spinous attachment and supraspinous and interspinous ligament were left intact, and muscle-lamina detachment was minimized when accessing the junction of lamina and lateral mass through our paraspinous approach for both the open and hinge sides, deep extensors including SSCe and multifidus were preserved.

We address some important details about this approach: first, since the key step is to identify the intermuscular plane, we suggest medial branches of the cervical dorsal rami as the anatomic marks of this plane because these branches are discernible and always run dorsomedially between SSCa and

SSCe²³; secondly, when performing the blunt splitting through this plane, we recommend that the muscular fascia on the medial border of SSCa should be protected because we observed that the integrity of it would help us identify nerve branches and venous plexus passing through the plane; thirdly, we think that the exposure of lamina should not exceed the medial border of lateral mass bilaterally so that the facet joint capsules can be preserved. The study curve for this approach is not steep; we popularized it nationwide during the last decade and found that for experienced spine surgeons five to 10 times of practicing our paraspinous approach on bodies would be enough to perform it perfectly.

Figure 6. Representative computed tomography cross-sectional plane images (cross-sectional CT) of three patients that underwent two modified laminoplasties and conventional laminoplasty respectively. (A, D) preoperative and 29-month postoperative cross-sectional CT of a patient that underwent conventional laminoplasty; (B, E) preoperative and 35-month postoperative cross-sectional CT of a patient that underwent modified laminoplasty preserving deep extensors on the hinge side; (C, F) preoperative and 37-month postoperative cross-sectional CT of a patient that underwent modified laminoplasty preserving bilateral deep extensors.



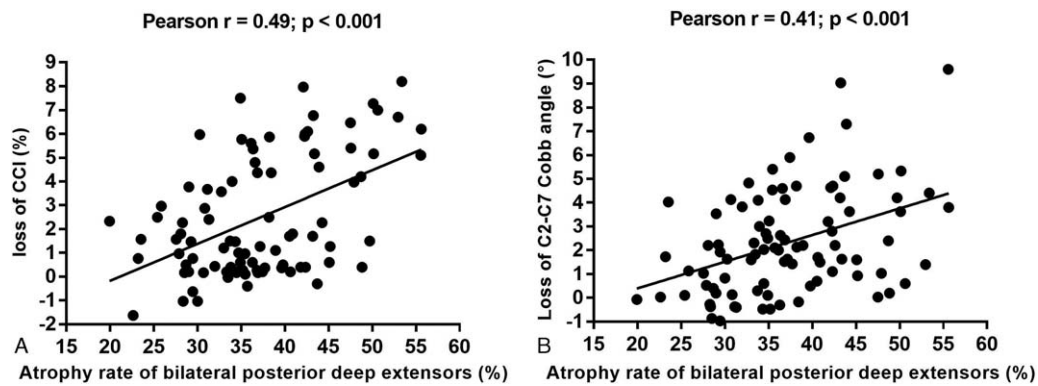


Figure 7. Relationship between deep extensor atrophy and sagittal cervical alignment. (A) Correlation between the loss of CCI and the atrophy rate of bilateral deep extensors; (B) Correlation between the loss of C2-C7 Cobb angle and the atrophy rate of bilateral deep extensors.

In this study, two modified LP procedures were performed based on this novel approach during two different time periods, patients were randomly grouped and had undergone either one of these modified LPs or concurrent conventional LP. No significant difference was found in sex, age at surgery, disease duration, follow-up duration and decompression segments either between each modified group and its control or between two modified groups. Results indicated that no significant decrease was detected in C2-C7 Cobb angle and CCI at the final follow-up compared to the preoperative values either in modified or in conventional groups but each modified procedure achieved significantly better cervical alignment maintenance accompanied with significantly decreased incidence of axial symptoms compared to its concurrent control procedure. Therefore, two modified procedures through this approach both had advantages in cervical lordosis maintenance and axial symptom prevention over conventional procedure. Besides, each modified procedure accomplished effective expansion of spinal canal and satisfied spinal cord decompression, attained significant improvement in VAS and JOA scores to its concurrent control. Previous studies had reported the positive effects of muscle-preserving LPs on postoperative axial symptoms and cervical sagittal alignment.^{17,24,25} Great emphasis was placed on the importance of deep extensor preservation or repair.^{6,24,26} Structure and strength of deep extensors were found to be related with axial neck pain.^{27,28} CSA of semispinalis cervicis was found to be directly correlated with postoperative loss of cervical lordosis in several researches.^{24,26} Our study demonstrated that compared to the conventional LP, each modified procedure achieved better preservation of total CSA of deep extensors that was strongly correlated to postoperative loss of cervical sagittal alignment, consistent with the previous studies. In addition, bilateral paraspinous approach resulted in better preservation of deep extensors on the open side compared to unilateral paraspinous approach. Other pre- and postoperative treatments including exercise recommendation and duration of external brace use were the same among groups, so we thought that this paraspinous approach benefited in

deep extensor preservation which might contribute to its advantages over conventional procedure.

Next, we compared the two modified procedures and found that unilateral preservation on the hinge side showed significantly less operation duration with similar clinical scores, axial pain incidence, cervical lordosis maintenance, and spinal canal expansion compared to bilateral preservation through this paraspinous approach. The idea of unilateral preservation has been established since 2005 when Hosono *et al* performed a modified en bloc LP with deep extensors undissected on the hinge side and had noticed a significant difference in the CSA of deep extensors between the hinge and open sides postoperatively.²⁹ Consistent with their results, our study showed that atrophy of deep extensors was significantly different between the hinge and open sides in patients with unilateral muscle-preserving procedures. But unexpectedly, we observed that both unilateral and bilateral muscle-preserving procedures yielded significantly more atrophy of deep extensors on the open side compared to that on the hinge side, which suggested that the paraspinous muscle-preserving approach had limited effect on the open side. We thought that the asymmetric retraction time, pressure and extent of exposure between the hinge and open sides would cause more evitable injuries to the deep extensors on the open side and thus partially account for the different post-LP deep extensor atrophy between the two sides in this study. Besides, many other factors different between these 2 sides might also be possible causes. Recently, a cadaveric study performed by Singhatanadgige *et al* found a significant difference in the muscle compartment pressures between the hinge and open sides after LP and linked increased pressures on the hinge side to postoperative axial pain rather than that on the open side.³⁰ Based on their conclusions, we speculated that our muscle-preserving approach might prevent axial pain by decreasing the postoperative swelling of paraspinous muscles and thus the significant increased pressures on the hinge side would be restrained, but unfortunately the open side demanded more time and pressure of extraction for lamina open and expanded which could not be solved by only paraspinous approach. Therefore, we inferred that the deep extensors on

the hinge side were more likely to be preserved after LP thus were more sensitive to the muscle-preserving approach and contributed much more to cervical alignment maintenance and post-LP axial neck pain than that on the open side.

Limitations existed in our study. First, the study was prospectively performed but the data was retrospectively reviewed. Secondly, the follow-up duration was short, the sample size was small, and it was not a multicenter study. Thirdly, the two modified procedures were not performed in the same period; we could only compare each one with its concurrent control procedure but the comparison between these two was not direct.

In conclusion, we designed a paraspinal intermuscular approach and performed two modified LPs based on it. Both modified procedures resulted in satisfied outcomes and had advantages in alignment maintenance and axial symptom prevention over the conventional procedure. Unilateral preservation of deep extensors on the hinge side resulted in similar clinical outcomes with decreased operation duration compared to bilateral preservation. Therefore, paraspinal approach is a good manner to protect deep extensor muscles from dissection, unilateral paraspinal approach on the hinge side may have similar effects on clinical outcomes to bilateral paraspinal approach.

➤ Key Points

- ❑ We developed a novel paraspinal intermuscular approach to minimize the muscle dissection during laminoplasty.
- ❑ Based on this novel approach, we performed two modified laminoplasties and found that both modified laminoplasties had satisfied outcomes and advantages over conventional laminoplasty.
- ❑ Moreover, unilateral muscle-preserving procedure demonstrated less operation time with similar outcomes compared to bilateral muscle-preserving procedure, the asymmetric atrophy of posterior deep extensors between the open and the hinge sides could play a role.

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