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Choice of open side affects clinical outcomes of unilateral open-door laminoplasty for inconsistent cervical ossification of the posterior longitudinal ligament

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Abstract

Background The best open side for unilateral open-door laminoplasty (UODL) to treat inconsistent cervical ossification of the posterior longitudinal ligament (OPLL) needs to be identified.

Methods Thirty-one individuals with inconsistent OPLL who underwent UODL between January 2016 and December 2018 were retrospectively divided into two groups: when the side of the open door was consistent with the side of the larger ossification occupancy area, patients were placed in the Consistent group; when the side of the open door was contralateral to the side of the larger ossification occupancy area, patients were placed in the Contralateral group. The following parameters were evaluated: neck disability index (NDI) score, Japanese Orthopaedic Association (JOA) score, visual analog scale (VAS) score, postoperative laminoplasty opening width and angle, and spinal cord diameter ratio. Spinal cord shifts were also evaluated to compare the clinical results between the two groups.

Results Patient demographics and major problems did not differ significantly between the groups. Transient pain in the deltoid region was more frequent in the Consistent treatment group. The spinal cord diameter ratio, VAS and NDI scores, opening width, and angle in postoperative laminoplasty did not differ significantly between the two groups. The JOA scores improved in the Consistent group. The spinal cord diameter ratio and spinal cord shift were more significantly improved in the Consistent group.

Conclusions For inconsistent cervical OPLL, the open-door side that was consistent with a larger ossification occupancy area was preferred in UODL.

Keywords Unilateral open-door laminoplasty (UODL), Ossification of the posterior longitudinal ligament (OPLL), Postoperative laminoplasty, Spinal cord ratio

Introduction

Ossification of the posterior longitudinal ligament (OPLL) is associated with various degrees of neurological impairment [1, 2]. Between 2 and 4% of individuals in Asian countries have OPLL [3–5]. Surgery is often necessary because conservative therapy is often unsuccessful. Posterior cervical unilateral open-door laminoplasty (UODL) is frequently performed in patients with cervical OPLL (ossification in three segments) [6, 7].

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Surgeons typically select the side with the most noticeable symptoms to treat patients with cervical OPLL and myelopathy. However, for inconsistent cervical OPLL, where the more serious symptoms and sign side are contralateral to the larger ossification occupancy area side, no research has been conducted to determine which side of the vertebral arch should be the open side.

In the present study, we attempted to identify the best open side in UODL for inconsistent cervical OPLL by retrospectively analyzing the CT, MRI, and radiography data of 31 patients with inconsistent cervical OPLL and the surgical results of various open sides.

Materials and methods

Case collection

The study included patients (1) with cervical OPLL who also had myelopathy; (2) whose side with more serious symptoms and signs was contralateral to the larger ossification occupancy area side; (3) who received only UODL therapy; and (4) who had been monitored for two years in a row.

The exclusion criteria were as follows: (1) symptoms and signs on both sides were similar; (2) the ossification occupancy area on both sides was similar; (3) history of infection, malignancy, or severe trauma; (4) presence of radiculopathy or neurological conditions, including Parkinson's disease, poliomyelitis, or myelitis; and (5) history of drug abuse.

When the side of the open door was consistent with the side of the larger ossification occupancy area, the patients were assigned to the Consistent group. When the side of the open door was contralateral to the side of the larger ossification occupancy area (consistent with more serious symptoms and signs), the patients were assigned to the Contralateral group.

Two doctors who were not involved in the study collected all the data. Another doctor, who was unaware of the data-gathering method, evaluated the data and translated them.

This trial was approved by the Medical Ethics Committee of the Tianjin Union Medical Center. Written informed consent was obtained from all patients and their families. The 1964 Declaration of Helsinki, its later revisions, and related ethical norms were considered in the design of this study.

Surgical procedures

Surgical decompression was performed from C3 to C7, according to the modified Hirabayashi method [8]. The cervical paravertebral muscles were separated to reveal the lamina and spinous processes from C2 to T1. The spinous processes were partially resected to a residual length of 5 mm in the surgical segment (C3–7). Magerl insertion holes for the lateral mass screws were also created on the hinge side. A 4-mm high-speed cutting burr produced an incomplete fracture hinge on the hinge side. Then, the lateral mass rivets (titanium alloy with nonabsorbable sutures, 2.8 × 11.7 mm; AR-1324HF; Arthrex, Inc., Naples, FL, USA) were placed into the previously made holes, enlarging them until the screw was covered. Drill holes in the spinous process were used to thread the nonabsorbable sutures with screws. A 5-mm high-speed cutting burr was used to thoroughly cut the trench between the lateral mass and lamina on the exposed side (a Kerrison punch was not used to prevent spinal cord damage). Prior sutures were knotted securely to avoid closure of the elevated lamina before the lamina door was gradually raised from C7 to C3. The same skilled spine surgeon completed all UODLs.

Clinical assessment

Sex, age, and body mass index (BMI) were considered as general information. The estimated surgical hemorrhage (mL) statistics were included in the intraoperative data. Duration of surgery (min). Symptoms and signs were evaluated by measuring the total strength of ten key muscle groups on each side [9].

The Japanese Orthopedic Association (JOA) score, visual analog scale (VAS) score for neck pain, neck disability index (NDI) score, and other metrics were used to assess surgical results and complication rates (including axial symptoms and C5 nerve root palsy) within a two-year follow-up period.

The radiographic measurement parameters were as follows: C2–7 Cobb angle (defined as the angle created by a line parallel to the inferior endplates of the C2 body and a line parallel to that of the C7 body) and the position of the K-line (which is a virtual straight line that connects the midpoints of the anteroposterior spinal canal diameter from C2 to C7). The condition in which the peak of the OPLL extends beyond the K-line is defined as K-line (-). The condition in which the peak of the OPLL does not exceed the K-line is defined as K-line (+), ossification length and postoperative progress of ossification (measured in CT center sagittal image), center sagittal canal and coronal canal diameters, Pavlov ratio, postoperative laminoplasty opening width and angle, preoperative ossification occupancy area of each side (defined as the left or right area of the OPLL divided by the median sagittal line at the thickest ossified part in the CT axial image), increased signal intensity (ISI) in T2-weighted imaging (T2WI) of the spinal cord, the ratio of the average cervical spinal cord diameter measured in the center sagittal plane of a T2WI center sagittal scan from C2/3 to C7/T1 (the ratio defined as the figures divided by the diameter on

C1), and cervical spinal cord shift (with the measurement of the average distance between the middle of the posterior margin of the vertebral body and anterior margin of the cervical spinal cord from C3 to C7 in the T2WI center sagittal image, where the difference value between the figures before and after the surgery represented spinal shift).

Statistical analyses

SPSS (version 25.0; SPSS Software Inc., Chicago, IL, USA) was used for the statistical analyses. The paired-sample t-test and Mann-Whitney U test were used to compare measurement differences across groups, which are expressed as the mean ± standard deviation. Chi-square tests were used to assess the enumeration data. Differences were considered statistically significant at $P < 0.05$.

Table 1 Patient demographics of the Consistent and Contralateral groups

	Consistent group ($n = 14$)	Contralateral group ($n = 17$)	*P* Value
Age, years	57.71 ± 8.07	59.82 ± 8.27	0.468
Sex, male: female	8:6	10:7	0.925
BMI, kg/m^2	26.37 ± 3.57	26.80 ± 4.32	0.769

Age and BMI data were analyzed using the Mann-Whitney U test, and sex data were analyzed using the chi-square test

BMI body mass index

Results

Patient demographics

Thirty-one patients with inconsistent cervical OPLL (Consistent group, ($n = 14$); Contralateral group, $n = 17$) were enrolled. Age, sex, and BMI were not significantly different between the two groups ($P > 0.05$) (Table 1). Each patient used a right hand.

Clinical outcomes

As shown in Table 2, the total strength on the side with more serious signs and symptoms was lower than that on the lower side in both groups ($P < 0.05$). There were no discernible variations in combined muscular strength between the two groups on either side ($P > 0.05$). There were no significant differences in the duration of surgery or volume of intraoperative blood loss between the two groups ($P > 0.05$). The VAS scores for neck pain, as well as the NDI and JOA scores, significantly improved after surgery in both groups ($P < 0.05$). There were no significant differences in the VAS and NDI scores between the two groups ($P > 0.05$). During the two-year follow-up period, the JOA scores in the Consistent group were higher than those in the Contralateral group ($P < 0.05$), indicating that the JOA scores improved significantly two years after surgery. There were no significant differences in the incidence

Table 2 Comparison of clinical outcomes in the Consistent and Contralateral groups

		Consistent group ($n = 14$)	Contralateral group ($n = 17$)	*P* Value
Total strength of muscle groups on the less serious symptom and sign side		38.86 ± 2.14	38.18 ± 2.53	0.444
Total strength of muscle groups on the more serious symptom and sign side		36.43 ± 2.13[#]	36.06 ± 2.46[#]	0.653
Duration of operation (min)		98.57 ± 11.67	99.41 ± 9.98	0.860
Intraoperative blood loss volume (ml)		116.79 ± 11.54	117.06 ± 8.11	0.625
VAS	Preoperative	3.00 ± 0.78	3.06 ± 0.83	0.526
	2-year follow-up	2.29 ± 0.61*	2.24 ± 0.66*	0.891
NDI	Preoperative	0.49 ± 0.08	0.49 ± 0.07	0.769
	2-year follow-up	0.27 ± 0.07*	0.28 ± 0.06*	0.681
JOA	Preoperative	9.36 ± 2.34	9.18 ± 2.21	0.769
	2-year follow-up	12.43 ± 1.65*	10.76 ± 1.92*	0.019
Transient pain in the deltoid region[a]		6	2	0.049($\chi^2 = 3.876$)
C5 nerve root palsy[a]		1	2	0.665($\chi^2 = 0.188$)
Axial symptoms[a]		8	9	0.815($\chi^2 = 0.550$)

[a] Analyzed using chi-square tests. The other data were compared using the Mann-Whitney U test

*Compared with preoperative values, analyzed using the paired-samples t-test, $P < 0.05$

[#] Compared with the less serious symptom and sign side, analyzed using the paired-samples t-test, $P < 0.05$

VAS visual analog scale, *NDI* neck disability index, *JOA* Japanese Orthopaedic Association of postoperative C5 nerve root palsy or axial symptoms between the two groups ($P > 0.05$). However, in the Consistent group, more transient pain occurred in the deltoid region, which is innervated by the C5 nerve root ($P < 0.05$). Transient pain nearly resolved within 48–72 h postoperatively after neurotrophic treatment.

Radiological assessment

As shown in Table 3, there were no appreciable variations in the preoperative location of the K-line, ISI of the spinal cord, center sagittal canal diameter, coronal canal diameter, Pavlov ratio, ossification occupancy area of each side, C2–7 Cobb angle, ossification length, or diameter of the spinal cord ratio between the two groups ($P > 0.05$).

Table 3 Comparison of radiological parameters in the Consistent and Contralateral groups

			Consistent group ($n = 14$)	**Contralateral group ($n = 17$)**	***P* Value**
K-line (+)[a]			6	10	0.376($\chi^2 = 0.784$)
ISI of spinal cord[a]			4	7	0.465($\chi^2 = 0.533$)
Coronal canal diameter		C3	22.94 ± 1.04	22.83 ± 1.00	0.799
		C4	25.24 ± 1.15	25.12 ± 1.14	0.739
		C5	26.14 ± 0.78	26.08 ± 0.82	0.891
		C6	25.98 ± 0.72	25.96 ± 0.74	0.922
		C7	25.69 ± 1.78	25.75 ± 1.81	0.953
Center sagittal canal diameter		C3	13.71 ± 0.52	13.81 ± 0.47	0.544
		C4	14.01 ± 0.94	14.06 ± 0.83	0.860
		C5	13.42 ± 0.70	13.52 ± 0.75	0.830
		C6	13.81 ± 0.64	13.93 ± 0.62	0.597
		C7	13.77 ± 1.21	13.92 ± 1.21	0.570
Pavlov ratio		C3	0.85 ± 0.03	0.85 ± 0.03	0.922
		C4	0.82 ± 0.50	0.82 ± 0.47	0.830
		C5	0.82 ± 0.04	0.81 ± 0.04	0.544
		C6	0.81 ± 0.04	0.82 ± 0.04	0.625
		C7	0.81 ± 0.04	0.81 ± 0.04	0.922
Ossification occupancy area (mm^2)	Less serious side		21.79 ± 8.59	20.94 ± 8.42	0.769
	More serious side		40.07 ± 11.83[#]	40.65 ± 9.56[#]	0.681
C2-7 Cobb angle	Preoperative		−2.50 ± 7.15	−1.94 ± 6.76	0.830
	2-year follow-up		−1.29 ± 10.46	−1.00 ± 9.65	0.922
Ossification length	Preoperative		68.77 ± 11.13	70.11 ± 9.92	0.681
	2-year follow-up		74.70 ± 11.22*	76.30 ± 9.38*	0.597
Laminoplasty opening angle		C3	46.86 ± 7.31	50.18 ± 10.77	0.316
		C4	49.36 ± 10.63	48.47 ± 11.63	0.860
		C5	48.57 ± 10.62	48.18 ± 11.34	0.922
		C6	45.36 ± 10.48	47.29 ± 11.06	0.681
		C7	41.93 ± 9.77	44.76 ± 10.40	0.493
Laminoplasty opening width		C3	13.89 ± 1.68	13.94 ± 1.58	0.953
		C4	14.41 ± 2.34	14.07 ± 1.93	0.769
		C5	14.69 ± 2.34	14.55 ± 2.40	0.769
		C6	14.68 ± 2.40	14.45 ± 2.36	0.681
		C7	14.83 ± 1.76	14.48 ± 1.76	0.544
Diameter of spinal cord ratio	preoperative		0.63 ± 0.03	0.62 ± 0.03	0.297
	2 years follow-up		0.90 ± 0.11*	0.77 ± 0.21*	0.000
Spinal cord shift			1.17 ± 0.33	0.80 ± 0.21	0.001

[a] analyzed using chi-square tests. The other data were compared using the Mann-Whitney U test

*Compared with preoperative values, analyzed using the paired-samples t-test, $P < 0.05$

[#] Compared with the less serious symptom and sign side, analyzed using the paired-samples t-test, $P < 0.05$

ISI increased signal intensity

However, the area occupied by ossification on the more severe side was significantly larger than that on the less severe side ($P < 0.05$). Although there was a small reduction in cervical lordosis in both groups at the two-year follow-up, there was no discernible difference between the groups or at the preoperative level ($P < 0.05$). At the two-year follow-up, the ossification lengths in both groups had considerably increased ($P < 0.05$); however, there was no discernible difference between the two groups ($P > 0.05$). The diameter and angle of the postoperative laminoplasty aperture did not change significantly ($P > 0.05$). We found that the spinal cord diameter ratio significantly improved at the two-year follow-up in both groups, and the improvement was greater in the Consistent group ($P < 0.05$) (Figs. 1 and 2). Similarly, spinal cord shift was greater in the Consistent group than in the Contralateral group during the two-year follow-up period ($P < 0.05$) (Figs. 1 and 2).

Discussion

UODL was first described in 1977 [8, 10]. Among the various methods of laminoplasty for cervical OPLL [11, 12], with the benefits of maintaining cervical mobility and the structure of the posterior neck muscle ligament, UODL remains an accepted technique [13–15].

The measurement of the ossification occupancy area in the OPLL was one of the key measurement techniques used in this study. We reduced the measurement error by taking multiple measurements independently and averaging them using two staff members. However, there is still the possibility of unavoidable errors. First, the "partial volume effect" of MRI may have affected the accuracy of the segment responsible for the cervical spinal cord compression. Second, owing to the difference in imaging principles, the positioning of the responsible segment on MR may not be completely consistent with that on the corresponding CT. Third, there were inevitable errors in judging the median sagittal line of the spinal canal on the axial CT images. Fourth, for the measurement of the left or right half of the ossified structure, we adopted image system recognition and manual assistance to calculate the occupied area; however, there were still inevitable measurement errors.

According to Hou et al., the pre- and postoperative JOA scores were 9.8 ± 1.9 and 12.4 ± 2.0, respectively, at three months following surgery [16]. Dhillon et al. observed that the JOA score significantly increased after UODL in patients with cervical OPLL (9.2 ± 1.1 13.7 ± 0.9) [17]. Cha et al. reported [18] that in patients with multilevel cervical myelopathy, the JOA score rose from 9.4 ± 3.3 preoperatively to 13.8 ± 2.2 after one year following UODL. In the current study, JOA scores increased in both groups after surgery (from 9.36 ± 2.34 to 12.43 ± 1.65 in the Consistent group and from 9.18 ± 2.21 to 10.76 ± 1.92 in the Contralateral group). This increase was more significant in the Consistent group.

Common factors affecting JOA score improvement include laminoplasty, K-line, door-opening angle, and width [19–22]. In addition, previous studies have shown that the occupancy ratio of OPLL ossification or the degree of spinal cord compression is significantly correlated with the severity of neurological signs and symptoms [23, 24]. This study observed better spinal cord dilation (higher diameter of the spinal cord ratio) and a higher JOA score at two years postoperative follow-up in the Consistent group. Therefore, we speculate that the reasons for the higher JOA score in this group might be better spinal cord dilation, more complete spinal cord morphological recovery, and more significant backward spinal drift [25]. Some studies have reported that larger spinal cord drift is correlated with higher JOA scores [26–28]. However, further biomechanical analyses and experimental assays are required in future research. Our research team has begun to conduct relevant basic experimental research to obtain direct evidence in the near future. However, unlike the study by Hua et al. [29], we observed lower JOA scores in the Contralateral group. We believe that the reasons for this result are twofold. First, we made a strict assessment of preoperative symptoms and signs, and the included cases were all non-consistent cervical OPLL patients, avoiding the bias caused by the inclusion of cervical OPLL patients with other manifestations. This is consistent with the findings of Kang et al. [30]. Second, during intraoperative operations, we tried our best to avoid iatrogenic injuries, including thermal and physical compression injuries that may occur during drill use [31], such as continuous water flushing and avoiding downward pressure during the drill operation. By reducing the negative effects of these iatrogenic injuries on clinical outcomes, the advantages of the Contralateral group will be greatly reduced, and the corresponding postoperative clinical outcome disadvantages will be more obvious, resulting in a lower postoperative JOA score.

According to Cha et al. [18], significant improvements in the VAS and NDI scores were generally observed in patients with multilevel cervical myelopathy one year after UODL (from 5.1 ± 2.2 preoperatively to 2.7 ± 0.9 at one year postoperatively, as measured by VAS). The mean NDI score decreased from 47.7 ± 5.2 to 32.2 ± 2.1. Wang et al. [32] observed the average NDI score was 20.1 ± 3.7 before surgery and 7.8 ± 2.5 at five years after UODL in patients with cervical compressive myelopathy. With mean pre- and postoperative VAS values of 2.7 ± 0.6 and 2.8 ± 0.4, respectively, Lee et al. [33] found contrasting results, showing that neck discomfort did

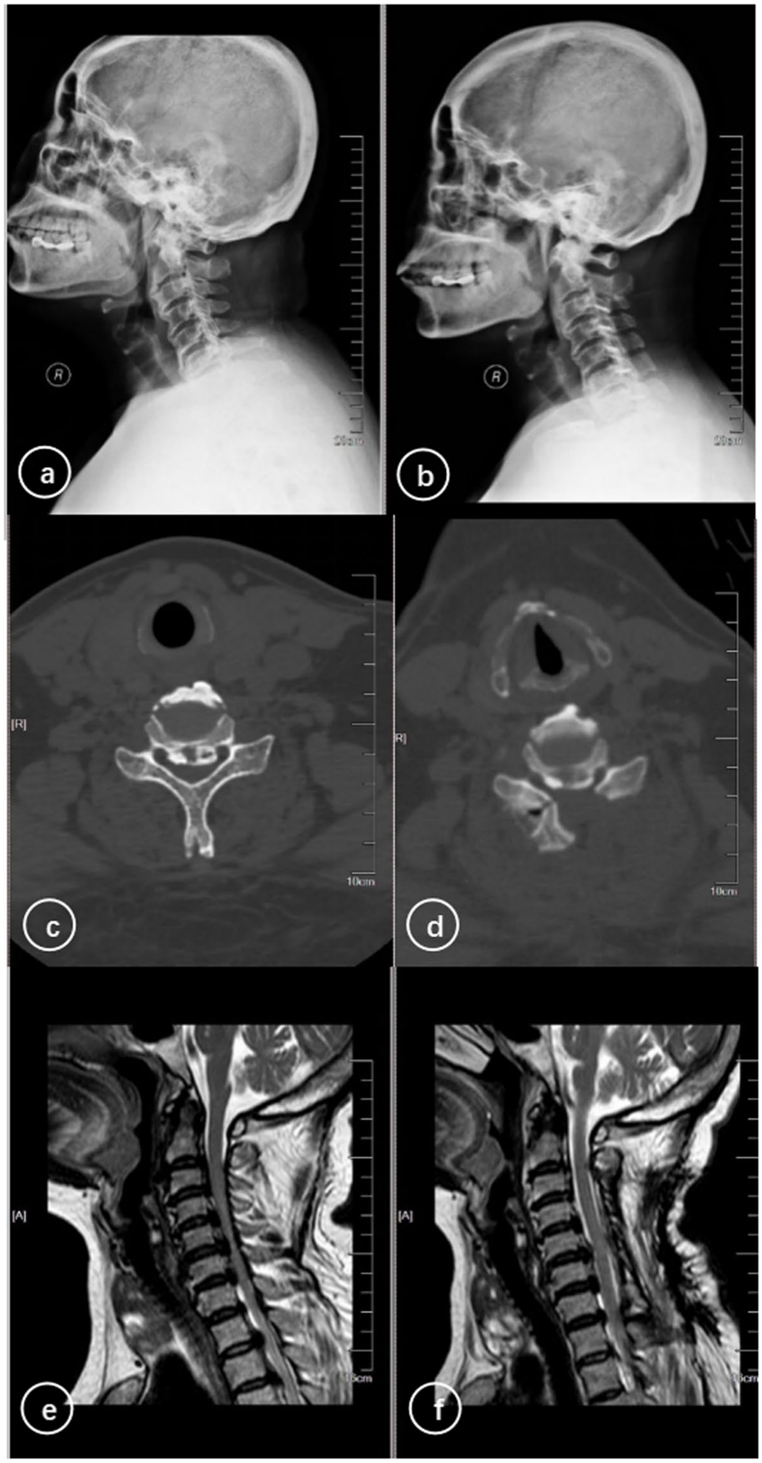

Fig. 1 Consistent group. A 60-year-old female patient who underwent unilateral open-door laminoplasty for inconsistent cervical ossification of the posterior longitudinal ligament (OPLL). **a**, **c**, **e** K-line (+), no increased signal intensity on T2-weighted imaging (T2WI). The left side had a larger ossification occupancy area (the ossification structure of the OPLL was divided into larger and smaller sides by the median sagittal line at the thickest ossified part in the CT axial image). **b** Radiograph at two years after surgery showing a decreased C2–7 Cobb angle. **d** The side of the open door was on the left side, consistent with the larger ossification occupancy area side. **f** T2WI at two years after surgery, showed that increased spinal cord diameter and spinal cord drift were more significant

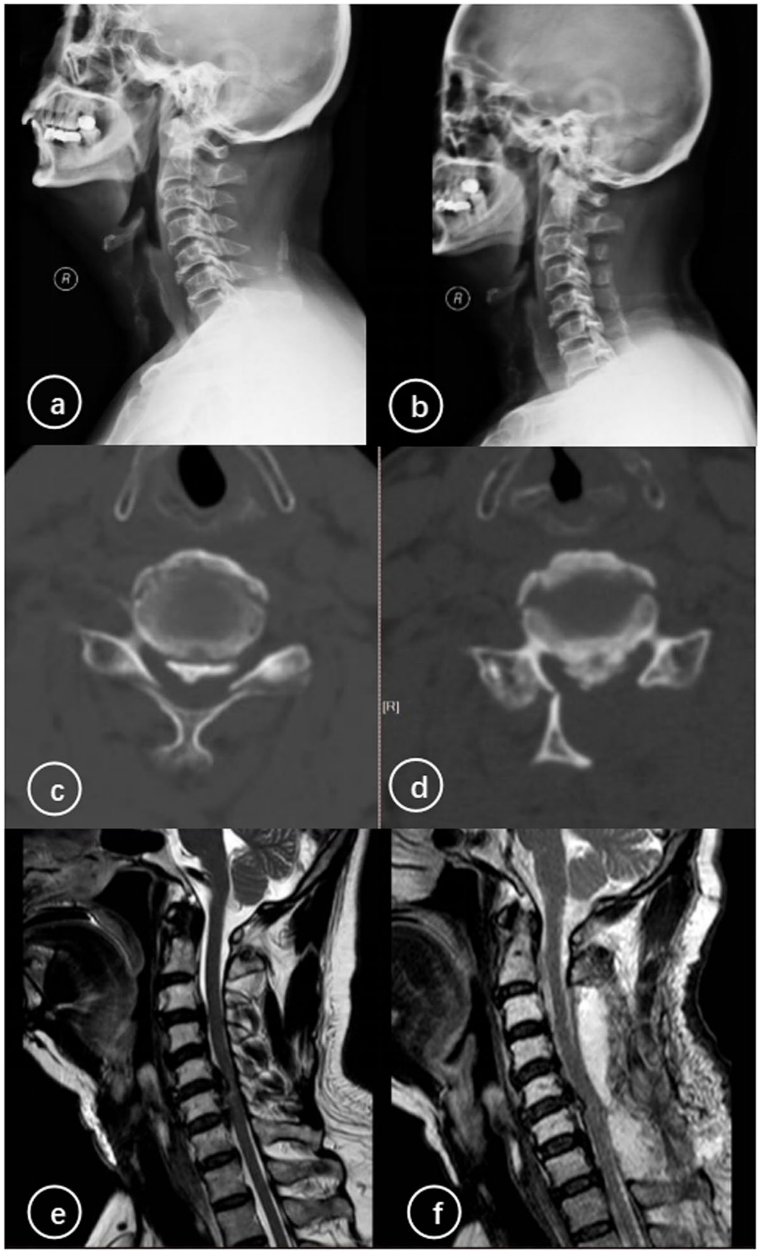

Fig. 2 Contralateral group. A 62-year-old male patient who underwent unilateral open-door laminoplasty for inconsistent cervical ossification of the posterior longitudinal ligament. **a**, **c**, **e** K-line (+), increased signal intensity on T2WI. The right side had a larger ossification occupancy area. **b** Radiograph two years after surgery, showing decreased C2–7 Cobb angle. **d** The side of the open door was on the left side, contralateral to the larger ossification occupancy area side. **f** T2WI at two years after surgery showed increased spinal cord diameter and spinal cord drift

not significantly improve after five years of assessment. Similar to previous studies, our results also found significant improvement in VAS and NDI scores after UODL in the two groups (VAS from 3.00 ± 0.78 to 2.29 ± 0.61 and 3.06 ± 0.83 to 2.24 ± 0.66; NDI from 0.49 ± 0.08 to 0.27 ± 0.07 and 0.49 ± 0.07 to 0.28 ± 0.06). Furthermore, there were no discernible differences between the two groups.

Tsuji et al. indicated that the optimal threshold between clinically satisfactory decompression and increased C5 palsy risk is a laminoplasty opening angle of 53.5° [34]. However, Lee et al. found that increasing the opening angle to 40° following laminoplasty could be a risk factor for nerve root palsy and did not diminish the incidence of restenosis [35]. In the present study, we found that the opening angle of C3–7 was $41.93 \pm 9.77°$ to $50.18 \pm 10.77°$, and the angle of C7 was the smallest. Furthermore, there were no discernible differences between the two groups at any level.

Gu et al. reported that the laminoplasty opening width was 18.36 ± 1.30, 18.51 ± 1.53, 18.64 ± 1.50, and 18.41 ± 1.16, 16.84 ± 1.07 at C3, C4, C5, C6, and C7, respectively, in 36 patients (27 patients with cervical spondylotic myelopathy [CSM] and nine patients with OPLL), who had undergone laminoplasty surgery [36]. Our results are consistent with those of the aforementioned studies. Additionally, there was no discernible difference between the two groups in terms of the laminoplasty opening diameter at C3–7.

When patients with CSM underwent posterior cervical expansive open-door laminoplasty, the C2–7 Cobb angle dropped from 13.9 ± 8.6° to 10.65 ± 10.7°, according to Pan et al. [37]. Li et al. also reported that the C2–7 Cobb angle decreased from 21.1 ± 5.8° to 18.5 ± 5.1° in a retrospective study involving 37 patients who underwent posterior open-door laminoplasty secured with anchors [38]. Our results also showed that the C2–7 Cobb angle decreased after surgery; however, there was no discernible difference between the two groups preoperatively and during the most recent follow-up visits, most likely because of the short follow-up duration.

Cha et al. reported that one year after surgery, the mean anteroposterior diameter had notably risen from 7.51 ± 1.79 mm before surgery to 13.98 ± 1.80 mm after surgery in 30 patients who underwent open-door laminoplasty using lateral mass anchoring screws [18]. However, there have been no investigations on the ratio of the center sagittal diameter of the cervical spinal cord, which could reduce system measurement errors. In our study, the spinal cord diameter increased in both groups after surgery. In addition, the increase was more significant in the Consistent group, indicating that the side of the open door was consistent with the side of the larger ossification occupancy area and was preferable.

Sun et al. found that after UODL [39], the spinal cord begins to wander rearward after UODL. In a comprehensive evaluation, Denaro et al. discovered that the average back displacement during cervical posterior decompression ranged from 0.6 mm to 4.1 mm. However, multiple methods have been used to quantify and report spinal cord back drift [40]. After surgery, spinal cord drift was observed in both groups and was more significant in the Consistent group, indicating that the side of the open door was consistent with the larger ossification occupancy area side was preferable also.

As shown in Fig. 3, the diameter and area of the spinal canal on the left and right sides of the cervical spine after single-door opening surgery were different. Because of the occlusion of the rear lamina of the door axis, the diameter of the spinal canal on the door-axis side a was much smaller than that on door-opening side b, and the area and volume of the spinal canal on the door-axis side were much smaller than those on the door-opening side. Therefore, compared with the door-axis side, the increase in spinal canal capacity on the door-opening side was more obvious. As shown in Fig. 4, the degree of cervical lordosis and the occupying effect of OPLL ossifying structures (red arrow) may be significant factors affecting backward spinal cord drift [25, 41–44]. Under the same degree of cervical lordosis, when the side with the door opening was contralateral to the side with the larger ossification structure of the OPLL, the space-occupying

Fig. 3 Examples of the diameter of the spinal canal on the left and right sides of the cervical spine after single-door opening surgery. The diameter of the spinal canal on the door axis side was "a." The diameter of the spinal canal on the door opening side is "b."

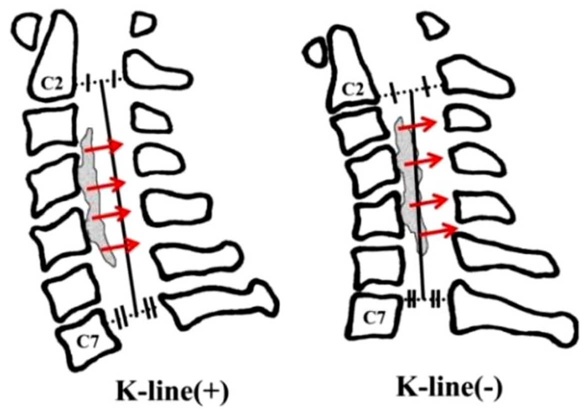

Fig. 4 Diagram showing the effect of the degree of cervical lordosis and the occupying effect of OPLL ossifying structures (red arrow) on spinal cord backward drift

effect of the ossification structure was smaller, and the backward compression effect on the spinal cord was less obvious, resulting in a lower significant backward drift of the spinal cord. However, this speculation lacks direct biomechanical evidence, which is a future research direction for our team. In addition, expansion of the spinal cord after laminoplasty depends on the contact area between the ossification and stress surface of the dura [45]. In the Contralateral group, a larger part of the ossified structure still had a larger contact area with the dural sac after surgery, which also reflected the poor backward drift of the spinal cord in this group.

Kaneyama et al. reported that the probability of C5 palsy may increase owing to asymmetric drift following UODL [46]. The frequency of postoperative C5 nerve root palsy and the rate of axial symptoms did not differ significantly between the two groups in our study. Nevertheless, transient pain in the deltoid region occurred more significantly in the Consistent group, which was innervated by the C5 nerve root. This may be attributed to the spinal cord drift being more significant in the Consistent group.

The progression of ossification after laminoplasty in patients with cervical OPLL has been observed in previous studies [7, 47]. In our study, the ossification length increased 5.93 ± 1.49 mm in a two-year follow-up in the Consistent group and 6.59 ± 1.59 mm in the Contralateral group. The two groups did not vary significantly from one another. In addition, the JOA score and spinal cord diameter increased, and spinal cord drift was more significant in the Consistent group, indicating that the side of the open door was consistent with the side of the larger ossification occupancy area and was preferable.

Conclusion

Inconsistent cervical OPLL may be treated safely and successfully with posterior cervical UODL, in which more serious symptoms and signs are contralateral to the larger ossification occupancy area. For inconsistent cervical OPLL, the side with an open door was consistent with a larger ossification occupancy area that may be preferred, resulting in an increased JOA score, spinal cord diameter, and spinal cord drift in our study. A prospective study with a larger sample size is required to confirm our findings.

This study has several limitations. First, the sample size was small. Therefore, caution should be exercised when generalizing these findings to larger populations. Second, this retrospective study included only a few patients from a single institution. Further research with larger multicenter cohorts is required. Third, we only selected patients treated by the same surgeon to control for the effect of the surgical method on the results. Selection bias may have resulted from these factors. Fourth, there were potential sources of error in the measurement of the ossification occupancy area. Finally, the follow-up period in this study was relatively short.

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Authors' contributions
PQ, WZ, TX, and RS performed the experiments; PQ and RT wrote the manuscript, RT reviewed and approved study; PQ and RT designed the study. All the authors have reviewed and approved the final manuscript.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
Approval to conduct the study was granted by Tianjin Union Medical Center medical ethics committee. Written informed consent was obtained from all patients and their families. The study was designed to conform to the 1964 Helsinki declaration and its later amendments and comparable ethical standards.

Competing interests
The authors declare no competing interests.

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References

1. Minagi H, Gronner AT. Calcification of the posterior longitudinal ligament: a cause of cervical myelopathy. Am J Roentgenol Radium TherNucl Med. 1969;105:365–9. https://doi.org/10.2214/ajr.105.2.365.
2. Tsuyama N. Ossification of the posterior longitudinal ligament of the spine. Clin Orthop. 1984;184:71–84. https://www.ncbi.nlm.nih.gov/pubmed/6423334.
3. Boody BS, Lendner M, Vaccaro AR. Ossification of the posterior longitudinal ligament in the cervical spine: a review. Int Orthop. 2019;43(4):797–805. https://doi.org/10.1007/s00264-018-4106-5.
4. Wu JC, Chen YC, Huang WC. Ossification of the posterior longitudinal ligament in cervical spine: prevalence, management, and prognosis. Neurospine. 2018;15(1):33–41. https://doi.org/10.14245/ns.1836084.042.
5. Cerecedo-Lopez CD, Tafel I, Lak AM, et al. Surgical management of ossification of the posterior longitudinal ligament in the cervical spine. J Clin Neurosci. 2020;72:191–7. https://doi.org/10.1016/j.jocn.2019.12.015.
6. Lee DH, Cho JH, Lee CS, et al. A novel anterior decompression technique (vertebral body sliding osteotomy) for ossification of posterior longitudinal ligament of the cervical spine. Spine J. 2018;18(6):1099–105. https://doi.org/10.1016/j.spinee.2018.02.022.
7. Kang MS, Kim KH, Park JY, et al. Progression of cervical ossification of posterior longitudinal ligament after laminoplasty or laminectomy with posterior fixation. Clin Spine Surg. 2019;32(9):363–8. https://doi.org/10.1097/BSD.0000000000000898.
8. Hirabayashi K, Watanabe K, Wakano K, et al. Expansive open-door laminoplasty for cervical spinal stenotic myelopathy. Spine (Phila Pa 1976). 1983;8:693–9. https://doi.org/10.1097/00007632-198310000-00003.
9. Beaty JH. Orthopaedic knowledge update, home study syllabus 6, Rosemont, IL, American Academy of Orthopaedic Surgeions, 1999:645.

10. Hirabayashi K, Miyakawa J, Satomi K, et al. Operative results and postoperative progression of ossification among patients with ossification of cervical posterior longitudinal ligament. Spine (Phila Pa 1976). 1981;6:354–64. https://doi.org/10.1097/00007632-198107000-00005.
11. Itoh T, Tsuji H. Technical improvements and results of laminoplasty for compressive myelopathy in the cervical spine. Spine. 1985;10:729–36. https://doi.org/10.1097/00007632-198510000-00007.
12. Yoshida M, Otani K, Shibasaki K, Ueda S. Expansive laminoplasty with reattachment of spinous process and extensor musculature for cervical myelopathy. Spine. 1992;17:491–7. https://doi.org/10.1097/00007632-199205000-00004.
13. Hirano Y, Ohara Y, Mizuno J, et al. History and evolution of laminoplasty. Neurosurg Clin N Am. 2018;29:107–13. https://doi.org/10.1016/j.nec.2017.09.019.
14. Guigui P, Benoist M, Deburge A. Spinal deformity and instability after multilevel cervical laminectomy for spondylotic myelopathy. Spine (Phila Pa 1976). 1998;23:440–7. https://doi.org/10.1097/00007632-199802150-00006.
15. Ratliff JK, Cooper PR. Cervical laminoplasty: a critical review. J Neurosurg. 2003;98:230–8. https://doi.org/10.3171/spi.2003.98.3.0230.
16. Hou Y, Liang L, Shi GD, et al. Comparing effects of cervical anterior approach andlaminoplasty in surgical management of cervical ossification of posterior longitudinal ligamentby a prospective nonrandomized controlled study. OrthopTraumatol Surg Res. 2017;103:733–40. https://doi.org/10.1016/j.otsr.2017.05.011.
17. Dhillon CS, Ega SR, Tantry R, et al. Outcome evaluation of modified uninstrumented open-door cervical laminoplasty for ossified posterior longitudinal ligament with cervical myelopathy. Indian J Orthop. 2019;53:510–7. https://doi.org/10.4103/ortho.IJOrtho_207_19.
18. Cha JR, Kim HW, Yang DG, et al. Open-Door laminoplasty using lateral mass anchoring screws andnonabsorbable sutures in patients with multilevel cervical myelopathy. Clin Orthop Surg. 2020;12:477–84. https://doi.org/10.4055/cios20013.
19. Yu C, Wu Y, Zhang Z, et al. Comparative effectiveness and functional outcome of C2 dome-like expansive versus C2 expansive open-door laminoplasty for upper cervical ossification of the posterior longitudinal ligament: a retrospective cohort study. Spine (Phila Pa 1976). 2022;47:E448–55.
20. Zhang Q, Guo R, Fang S, et al. The clinical efficacy of laminectomy fusion fixation and posterior single open-door laminoplasty in the treatment of multilevel cervical ossification of the posterior longitudinal ligament (OPLL): a retrospective study. BMC Surg. 2023;23:380.
21. Li N, Ma S, Duan F, et al. Are clinical outcomes affected by laminoplasty method and K-line in patients with cervical ossification of posterior longitudinal ligament? A multicenter study. J Orthop Surg Res. 2022;17:513.
22. Nori S, Nagoshi N, Suzuki S, et al. K-line (-) in the neck-flexed position negatively affects surgical outcome of expansive open-door laminoplasty for cervical spondylotic myelopathy. J Orthop Sci. 2022;27:551–7.
23. Nakashima H, Kanemura T, Kanbara S, et al. What are the important predictors of postoperative functional recovery in patients with cervical OPLL? Results of a multivariate analysis. Global Spine J. 2019;9:315–20.
24. Kim B, Yoon DH, Shin HC, et al. Surgical outcome and prognostic factors of anterior decompression and fusion for cervical compressive myelopathy due to ossification of the posterior longitudinal ligament. Spine J. 2015;15:875–84.
25. Denaro V, Longo UG, Berton A, et al. Favourable outcome of posterior decompression and stabilization in lordosis for cervical spondylotic myelopathy: the spinal cord back shift concept. Eur Spine J. 2015;24(Suppl 7):826–31.
26. Basu S, Gohil K. Comparing spinal cord drift, clinical outcomes and C5 palsy in degenerative cervical myelopathy: a study of cervical laminoplasty versus Laminectomy/Fusion. Global Spine J. 2024;22:21925682241235608.
27. Suk KS, Kim KT, Lee SH, et al. Significance of chin-brow vertical angle in correction of kyphotic deformity of ankylosing spondylitis patients. Spine (Phila Pa 1976). 2003;28:2001–5.
28. Sodeyama T, Goto S, Mochizuki M, et al. Effect of decompression enlargement laminoplasty for posterior shifting of the spinal cord. Spine. 1999;24:1527–31.
29. Hua Z, Li J, Li W, et al. Risk factors for poor neurological outcomes after unilateral open-door laminoplasty: an analysis of the characteristics of ectopic bone. J Orthop Surg Res. 2022;17:181.
30. Kang KC, Im SK, Lee JH, et al. Impact of lamina-open side on unilateral open door laminoplasty in patients with degenerative cervical myelopathy. Sci Rep. 2023;13:2062.
31. Li Y, Li J, Wang F, et al. Influence of K-line on intraoperative and hidden blood loss in patients with ossification of the posterior longitudinal ligament when undergoing unilateral open-door laminoplasty. J Orthop Surg Res. 2021;16:34.
32. Wang LN, Wang L, Song YM, et al. Clinical and radiographic outcome of unilateral open-door laminoplasty withalternative levels centerpiece mini-plate fixation for cervical compressive myelopathy: a five-year follow-up study. Int Orthop. 2016;40:1267–74. https://doi.org/10.1007/s00264-016-3194-3.
33. Lee DG, Lee SH, Park SJ, et al. Comparison of surgical outcomes after cervical laminoplasty: open-door technique versus French-door technique. J Spinal Disord Tech. 2013;26:E198–203. https://doi.org/10.1097/BSD.0b013e31828bb296.
34. Tsuji T, Matsumoto M, Nakamura M, et al. Factors associated with postoperative C5 palsy after expansive open-door laminoplasty: retrospective cohort study using multivariable analysis. Eur Spine. 2017;J26:2410–6. https://doi.org/10.1007/s00586-017-5223-3.
35. Lee DH, Park SA, Kim NH, et al. Laminar closure after classic Hirabayashi open-door laminoplasty. Spine. 2011;36:E1634-1640. https://doi.org/10.1097/BRS.0b013e318215552c.
36. Gu Z, Zhang A, Shen Y, et al. Relationship between the laminoplasty opening size andthe laminoplasty opening angle, increased sagittal canal diameter and the prediction of spinal canal expansion following open-door cervical laminoplasty. Eur Spine J. 2015;24:1613–20. https://doi.org/10.1007/s00586-015-3779-3.
37. Pan Y, Ma X, Feng H, et al. Effect of posterior cervical expansive open-door laminoplasty on cervical sagittal balance. Eur Spine J. 2020;29:2831–7. https://doi.org/10.1007/s00586-020-06563-9.
38. Li D, Hai Y, Meng X, et al. Posterior open-door laminoplasty secured with titanium miniplates vs anchors: a comparative study of clinical efficacy and cervical sagittal balance. J Orthop Surg Res. 2019;14:401. https://doi.org/10.1186/s13018-019-1454-9.
39. Sun K, Wang S, Sun J, et al. Surgical outcomes after anterior controllable antedisplacement and fusion compared with single open-door laminoplasty: preliminary analysis of postoperative changes of spinal cord displacements on T2-weighted magnetic resonance imaging. World Neurosurg. 2019;127:e288–98. https://doi.org/10.1016/j.wneu.2019.03.108.
40. Denaro V, Longo UG, Berton A, er al. Cervical spondylotic myelopathy: the relevance of the spinal cord back shift after posterior multilevel decompression. A systematic review. Eur Spine J. 2015;24:832–41. https://doi.org/10.1007/s00586-015-4299-x.
41. Kong Q, Zhang L, Liu L, et al. Effect of the decompressive extent on the magnitude of the spinal cord shift after expansive open-door laminoplasty. Spine (Phila Pa 1976). 2011;36:1030–6.
42. Diao YZ, Yu M, Zhang FS, et al. Effect of decompression range on decompression limit of cervical laminoplasty. Chin Med J (Engl). 2020;133:909–18.
43. Nishida N, Kanchiku T, Kato Y, et al. Cervical ossification of the posterior longitudinal ligament: factors affecting the effect of posterior decompression. J Spinal Cord Med. 2017;40:93–9.
44. Fujiyoshi T, Yamazaki M, Kawabe J, et al. A new concept for making decisions regarding the surgical approach for cervical ossification of the posterior longitudinal ligament: the K-line. Spine (Phila Pa 1976). 2008;33:E990-993.
45. Shao T, Gu J, Zhu Y, et al. Modified axial computed tomography classification of cervical ossification of the posterior longitudinal ligament: selecting the optimal operating procedure and enhancing the accuracy of prognosis. Quant Imaging Med Surg. 2021;11:1888–98.

46. Kaneyama S, Sumi M, Kanatani T, et al. Prospective study and multivariate analysis of the incidence of C5 palsy after cervical laminoplasty. Spine (Phila Pa 1976). 2010;35:E1553–8. https://doi.org/10.1097/BRS.0b013e3181ce873d.
47. Wang L, Jiang Y, Li M, et al. Postoperative progression of cervical ossification of posterior longitudinal ligament: a systematic review. World Neurosurg. 2019;126:593–600. https://doi.org/10.1016/j.wneu.2019.03.2.

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