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A Modified Laminoplasty Technique to Treat Cervical Myelopathy Secondary to Ossification of the Posterior Longitudinal Ligament (OPLL)

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Background: This study aimed to evaluate the validity of modified laminoplasty in treating close-base OPLL with an occupying ratio of more than 60%.





Material/Methods: Forty-seven close-base OPLL patients with an occupying ratio of more than 60% were treated through modified laminoplasty (N=22) and combined anterior-posterior approach (N=25) in the study, including 17 females and 30 males, with a mean age of 60.59±6.76 years (ranging from 46 to 75 years). The patients' characteristics, the recovery rate of neurological function, length of the operation, intraoperative blood loss, hospital costs, and complications were recorded and compared between the 2 groups.

Results: The recovery rate of neurological function did not demonstrate a significant difference between the 2 groups ($P=0.886$). However, length of the operation and intraoperative blood loss in the modified laminoplasty group were shorter than those in the combined anterior-posterior approach group ($P=0.001$ and $P=0.023$). Moreover, the mean hospital costs in the modified laminoplasty group (5166.61±123.27 USD) decreased by 33.6% compared with the combined anterior-posterior approach group (7780.12±256.73 USD). Additionally, the complications of the modified laminoplasty group were lower than in the combined anterior-posterior approach group.

Conclusions: Modified laminoplasty may be considered a safe and effective strategy for patients that have demonstrated close-base OPLL with an occupying ratio of more than 60% and who cannot endure the trauma caused by the combined anterior-posterior approach due to medical disease.

MeSH Keywords: Cervical Vertebrae • Ossification of Posterior Longitudinal Ligament • Treatment Outcome

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Background

Ossification of the posterior longitudinal ligament (OPLL) has recently been recognized as one of the most common causes of severe cervical myelopathy. The prevalence of cervical OPLL was 0.4% to 3.0% in Asian countries and 2.2% in the United States, and it is higher in Asian Americans than in white Americans [1,2]. Because conservative treatment often cannot prevent the aggravation and improve the neurologic deficit, surgery is necessary in most cases [2]. The surgical strategy of OPLL includes anterior, posterior, and combined anterior-posterior approach on the basis of the CT and MRI imaging characteristics.

OPLL with an occupying ratio of 60% or more has been technically challenging for spinal surgery [3]. Although the posterior approach, such as laminoplasty, was relatively safe strategy in those patients with an occupying ratio of 60% or more, the posterior cord shift was limited. As a result, less recovery of neurological deficits has been reported compared with anterior approach [3–5]. Given absolute decompression and satisfactory outcome on long-term follow-up, most surgeons currently prefer the anterior approach, even if OPLL with an occupying ratio greater than 60% [3–5]. However, iatrogenic complications on the anterior approach, such as spinal cord and nerve root injury, cerebrospinal fluid leakage, hoarseness, graft-bone migration, dysphagia, and esophageal fistula, have also been widely reported in the published literature [6–10]. Although some of these surgical complications are transient, others may be permanent. Serious iatrogenic spinal injury and infection are rare, but the consequence is ruinous.

With the purpose of decreasing iatrogenic complications, Wang et al. described a new technology for treating massive open-base OPLL with an occupying ratio (OR) exceeding 50% through the anterior approach in 2012 [11]. They defined the open-base as when both lateral margins of the ossified foci were within the posterior cortex of the vertebral body and did not reach the pedicle. A satisfactory outcome was observed at final follow-up. However, Wang's strategy [11] was not a good choice for close-base OPLL with an occupying ratio (OR) exceeding 60%. Combined anterior-posterior is usually considered as a safe and effective strategy. Unfortunately, it was not suitable for all patients because of serious trauma from the operation and the expensive medical fees.

Herein, we present a new strategy of modified laminoplasty for treating OPLL with an occupying ratio greater than 60%. Firstly, the enlarged laminoplasty was performed from pedicle to medial margin of the zygapophysis. As a result, a relatively safe space in which to perform the operation was immediately formed. Then, the mass ossification was directly removed using burrs through the posterior approach alone. The operation is referred to as modified laminoplasty. In the present study,

we compared the curative effect between the modified laminoplasty and combined anterior-posterior approach (laminoplasty combined with anterior cervical corpectomy with fusion). Better outcomes were demonstrated in the modified laminoplasty group. We believe this is the first such report in the literature.

Material and Methods

Patient characteristics, preoperative image characteristics of the OPLL (occupying ratio of mass ossification), surgical data (length of the operation and intraoperative blood loss), recovery rate of neurological function, hospital costs, and complications were retrospectively evaluated on the basis of the HIS SYSTEM, which consists of the electronic medical record and the system of image storage, from 2010 to 2015. The recovery of neurological function (Japanese Orthopaedic Association Scores, JOA) was evaluated through a double-blind strategy. The occupying ratio of mass ossification was assessed through a single-blind strategy. Other data were collected on the basis of electronic medical records. This research was approved by the Medical Ethics Committee of our hospital, and informed consent was obtained from the patients.

Inclusion criteria were: 1) equaling or exceeding an occupying ratio of 60%; and 2) close-base appearance on axial CT image, with close-base defined as a massive ossification fused with the pedicle of the vertebral arch, and the spinal cord pushed to the opposite side of the massive ossification (Figures 1, 2); 3) focal OPLL and involving no more than 2 vertebrae; and 4) the absence of fixed kyphotic deformities (Figures 1, 2). Unlike open-base OPLL, removing the close-base OPLL seems to be very difficult using Wang's strategy [11]. Finally, 47 of 158 patients were included in the present study from 2011 to 2015. Twenty-five patients with a mean age of 59.24 ± 7.45 years (ranging from 46 to 72 years) were treated through the combined anterior-posterior approach, and clinical data were retrospectively collected and reviewed (Table 1). Because 22 of the patients with medical disease could not endure the serious trauma from combined anterior-posterior approach, they were treated by modified laminoplasty (Table 2). These 22 patients had a mean age of 62.14 ± 5.67 years (ranging from 46 to 75 years). Combined morbidity included coronary heart disease in 6 cases, coronary heart disease with hypertension and diabetes mellitus in 8 cases, coronary heart disease with hypertension in 5 cases, and diabetes mellitus with hypertension in 3 cases (Table 2).

Operative technique of the modified laminoplasty

We determined the 3-dimensional space location of the massive OPLL, vertebral artery, and spinal cord using 3-dimensional CT and MRI, and measured the occupying ratio of the OPLL



Figure 1. Anterior-posterior film preoperative.

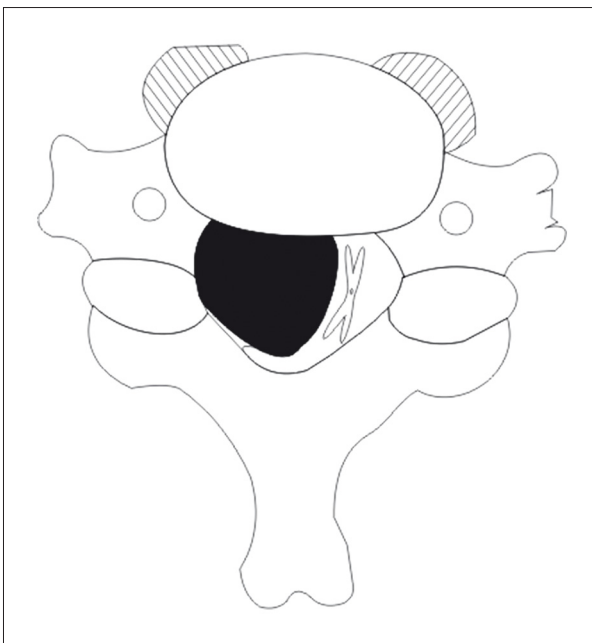


Figure 2. Mass ossification of the close-base was shown.

Then, a posterior midline incision was made, and the paravertebral muscles were retracted laterally. Because our cases presented close-base in which the mass ossification had fused with the pedicle of the vertebral arch, the modified laminectomy was performed from pedicle to medial margin of the zygapophysis. Transverse decompression width was larger than the

width of OPLL base in order to remove the mass ossification. The spinal cord was partially decompressed after the enlarged laminoplasty was performed from C3 to C6. Simultaneously, a relatively safe space of operation was immediately formed. Subsequently, the mass ossification was carefully resected using burrs. After the mass ossification was slowly hollowed out from inside, we used a nerve dissector to collapse the residuary ghost of the mass ossification (Figures 2–6). The flowchart of mimic surgical operation is shown in Figures 2–6.

Once the modified laminoplasty was performed, the spinal cord likely presented posterior shift. As a result, the nerve root would be further extended. Additionally, the cervical intervertebral foramen is sometimes narrow. Therefore, most patients needed to have the intervertebral foramen enlarged to decrease tension of the nerve foot. After foraminotomy was finished, nerve root direction could be determined. We first carefully removed the mass ossification of the ventral spinal cord using burrs according to the above-mentioned method. Then, the osteophyma around the nerve root was cautiously resected. A nerve dissector was used to protect the nerve root from iatrogenic injury while using burrs. Nerve root traction should be avoided during the operation. Bone grafts from dissected spinous processes were placed laterally on the door axis side of facet joints. Y-shape plates were used to prevent closure of the opened vertebral lamina. Bipolar electrocautery and absorbable gelatin sponge were used for hemostasis in the epidural space, and bone edges were waxed as necessary.

Table 1. The patients' characteristics, the preoperative image characteristics of the OPLL, and the surgical data were recorded in the group of the modified laminoplasty.

Cases	Sex	Age (years)	Combined morbidity	Follow-up period (months)	OPLL occupying (%)	length of operation (minutes)	Intraoperative blood loss (ml)	Pre-operative JOA	Post-operative JOA	Recovery rate (%)
1	M	62	CHD	19	66	96	320	8	15	78
2	F	60	CHD+H	36	62	100	360	7	14	70
3	F	75	CHD	32	74	128	450	7	15	80
4	M	59	CHD	38	79	144	420	8	14	63
5	M	63	CHD+H+D	16	70	147	340	7	15	80
6	M	46	CHD+H+D	18	74	133	420	9	14	63
7	M	69	CHD	28	68	98	450	9	13	50
8	M	58	CHD+H+D	34	82	95	290	8	15	78
9	F	62	CHD+H	35	68	105	340	10	14	57
10	M	65	CHD+H+D	28	64	147	360	7	15	80
11	M	64	CHD+H	22	76	126	470	7	15	80
12	F	57	CHD+H+D	16	64	121	290	8	14	63
13	M	68	H+D	20	68	105	250	11	15	67
14	F	65	CHD	30	72	132	450	9	13	50
15	M	63	CHD+H	36	73	100	430	8	15	78
16	M	65	CHD+H	38	79	98	310	8	15	78
17	F	61	CHD+H+D	26	72	96	330	7	14	70
18	M	59	CHD	22	80	137	260	7	13	60
19	M	58	H+D	29	81	89	250	7	13	60
20	M	62	CHD+H+D	32	67	95	300	8	15	78
21	M	68	H+D	34	78	92	250	7	11	40
22	F	58	CHD+H+D	12	82	89	310	7	14	70

CHD – coronary heart disease; CHD+H+D – coronary heart disease accompanying with hypertension and diabetes; CHD+H – coronary heart disease accompanying with hypertension; H+D – hypertension and diabetes.

Statistical analysis

Roentgenography, CT scan, and MRI were performed before and after the operation in each case. Ossification was measured and calculated based on the CT axial image. Preoperative age, follow-up period, and occupying ratio of mass ossification on the spinal canal were compared between the modified laminoplasty group and the combined anterior-posterior approach group using the independent *t* test.

Neurological function (Hirabayashi recovery rate), length of the operation, intraoperative blood loss, and hospital costs were

compared between the 2 groups using the independent *t* test. Neurological function was evaluated through the Hirabayashi recovery rate. The Hirabayashi recovery rate (%) was calculated using the following formula: (Postoperative JOA score - preoperative JOA score)/(17 - preoperative JOA score)×100.

Although the anterior approach can also achieve a satisfactory outcome in treating OPLL with an occupying ratio of more than 60%, in our experience, the complications (e.g., cerebrospinal fluid leakage, and nerve and spinal injuries) are relatively higher than in the combined anterior-posterior approach. In our study, most patients presented an occupying ratio of more

Table 2. The patients' characteristics, the preoperative image characteristics of the OPLL, and the surgical data were recorded in the group of combined anterior-posterior approach.

Cases	Sex	Age (years)	Combined morbidity	Follow-up period (months)	OPLL occupying (%)	length of operation (minutes)	Intraoperative blood loss (ml)	Pre-operative JOA	Post-operative JOA	Recovery rate (%)
1	M	58	No	38	62	176	420	9	15	75
2	M	55	No	32	60	158	440	8	13	55
3	M	59	No	24	64	144	370	7	14	70
4	M	62	No	34	66	188	550	8	15	78
5	M	72	No	26	68	182	460	7	14	70
6	F	55	H+D	18	66	210	300	10	15	71
7	M	64	No	22	58	155	480	7	14	70
8	F	72	No	36	64	150	380	10	14	57
9	M	66	No	12	72	168	510	8	15	78
10	M	58	No	60	75	177	420	9	13	50
11	F	54	H	34	68	226	550	9	15	75
12	F	59	No	14	77	200	410	7	15	80
13	M	61	No	17	65	182	380	10	15	71
14	F	72	H+D	19	58	166	350	8	14	67
15	F	63	No	58	62	174	430	7	14	70
16	M	66	No	35	59	195	310	9	15	75
17	F	55	No	30	79	198	338	9	15	75
18	M	50	No	22	74	176	260	8	14	67
19	F	48	No	19	72	174	390	7	14	70
20	M	70	No	15	64	184	360	8	13	56
21	F	55	No	56	57	196	380	7	14	70
22	F	54	D	32	63	182	340	8	14	67
23	M	46	H+D	16	71	196	410	10	15	71
24	M	52	H	18	70	224	360	9	14	63
25	M	55	No	24	60	166	350	9	13	56

than 60%. Therefore, we did not compare the curative effect between the modified laminoplasty and anterior approaches.

Results

The modified laminoplasty and combined anterior-posterior approach groups did not differ significantly in preoperative age and sex ($P=0.087$, and $P=0.549$). The mean follow-up period was 27.32 ± 7.99 months (ranging from 12 to 38 months) in the modified laminoplasty group, and was 28.44 ± 13.51 months

(ranging from 12 to 60 months) in the combined anterior-posterior approach group. No significant difference was observed in the follow-up period between the 2 groups ($P=0.054$).

The result of 3-dimensional CT at postoperative day 3 indicated that the mass ossification was completely removed and obtained a satisfactory decompression of the spinal cord in the 2 groups (Figures 1, 7–10). Neurological function also was obviously improved in the 2 groups. However, the recovery rate of neurological function was not significantly different between the 2 groups ($P=0.886$). It was notable that length of

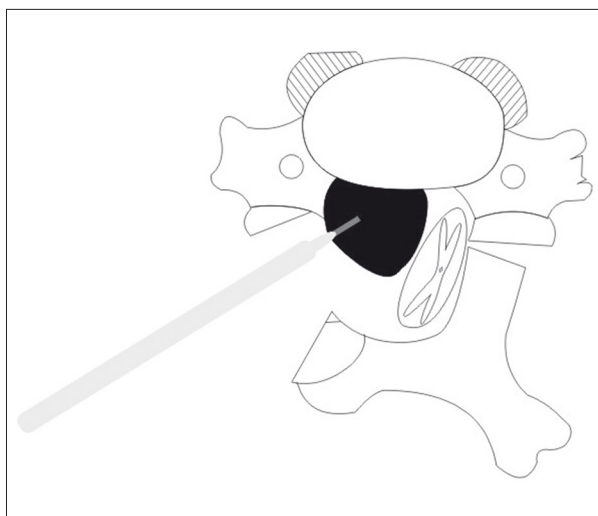


Figure 3. The modified laminectomy was performed from pedicle to medial margin of zygopophysis. Resecting the mass ossification was carefully performed by burrs.

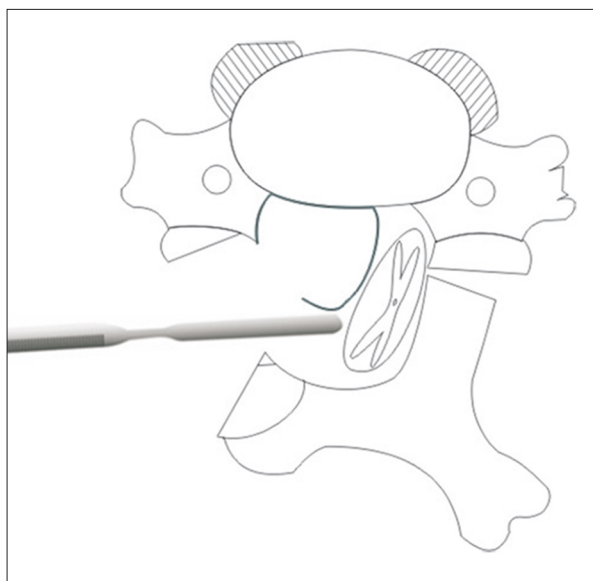


Figure 5. Nerve dissector collapsed the residuary ghost of the mass ossification from the ventral spinal cord.

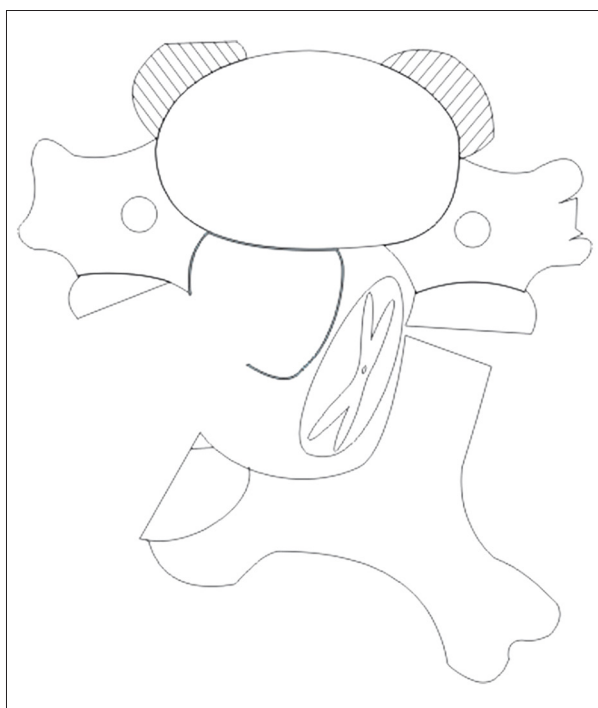


Figure 4. The mass ossification was slowly hollowed out from inside.

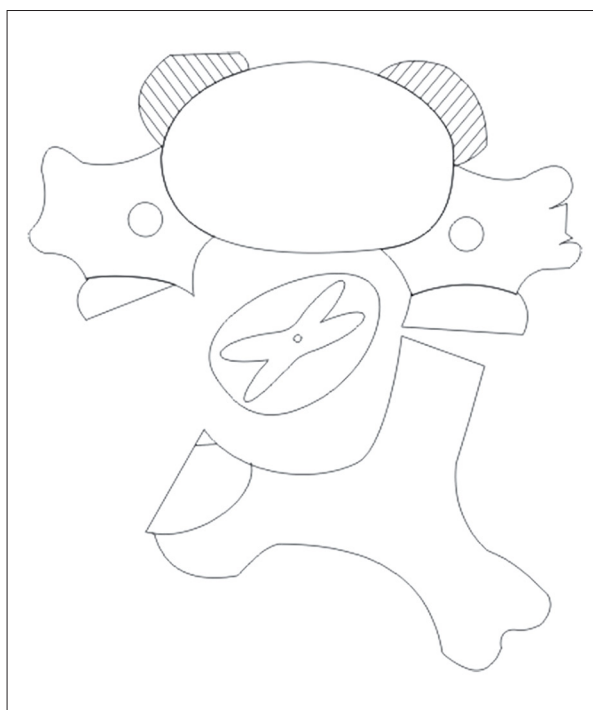


Figure 6. The mass ossification was removed.

the operation and intraoperative blood loss (112.41 ± 20.47 min and 347.73 ± 73.42 ml) in the modified laminoplasty group were shorter than those (181.88 ± 20.79 min and 397.92 ± 72.47 ml) in the combined anterior-posterior approach group ($P=0.001$ and $P=0.023$). Moreover, the mean of hospital costs in the modified laminoplasty group (5166.61 ± 123.27 USD) decreased by 33.6% compared to the combined anterior-posterior approach group (7780.12 ± 256.73 USD). Additionally, there were fewer

complications in the modified laminoplasty group than in the combined anterior-posterior approach group. In the combined anterior-posterior approach group, there were 6 cases (24%) of cerebrospinal fluid leakage (CSF). Dural suturing was performed in 1 patient due to a slight dural tear. Five patients presented dural defects. The dural defects were covered with dural patches and sealed with fibrin glue. Lumbar puncture-induced catheter drainage of CSF was not performed in these 5 patients.

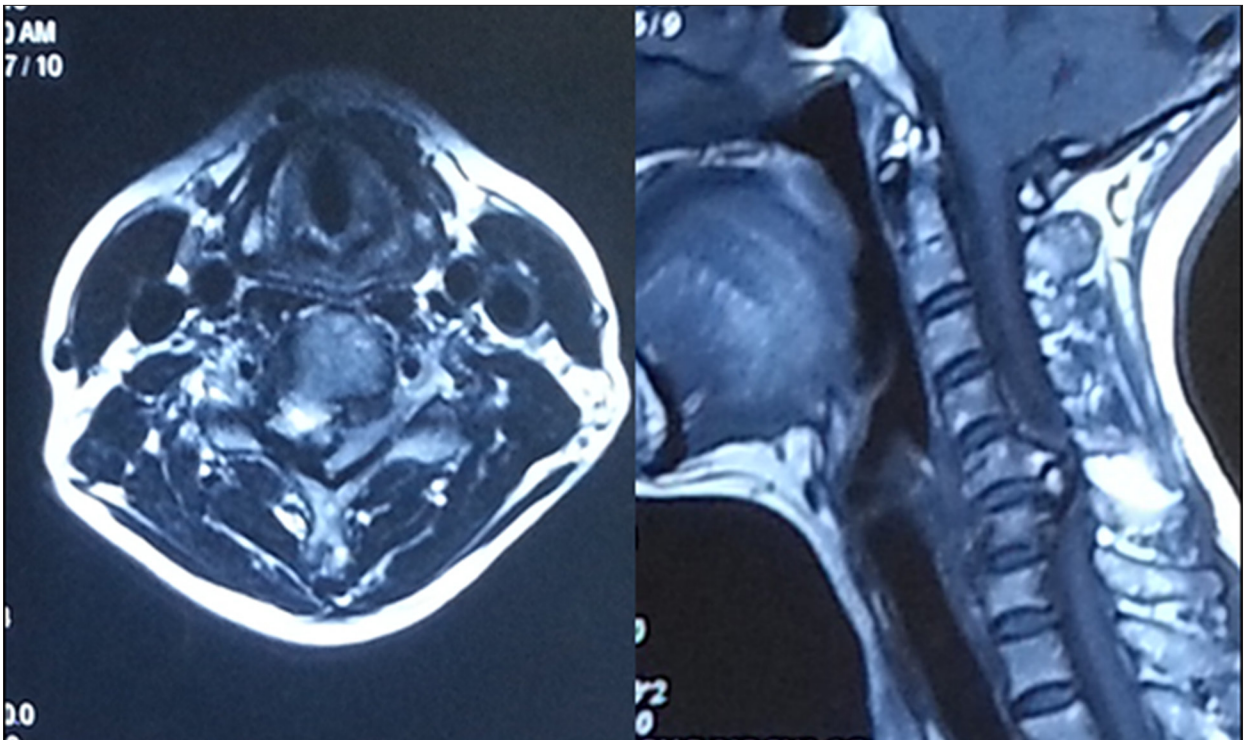


Figure 7. Transverse and sagittal MRI at preoperative observed that the spinal cord was compressed into a narrow space.

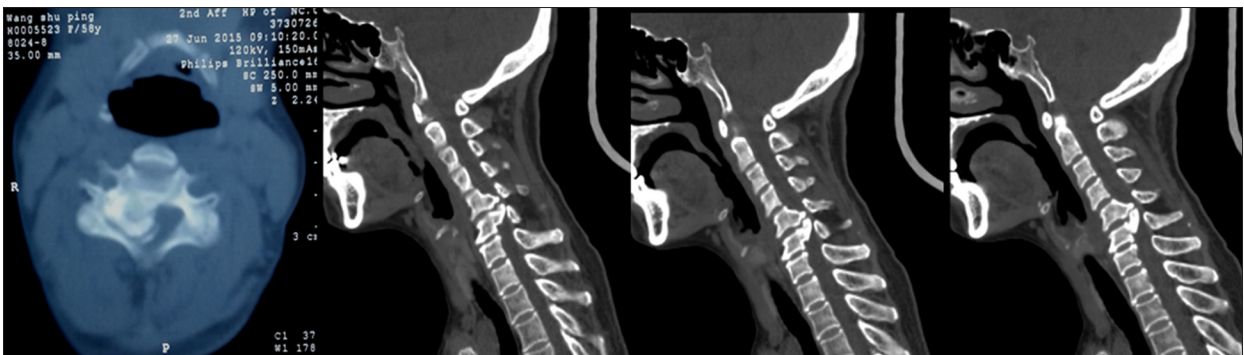


Figure 8. Preoperative transverse and sagittal CT reconstruction demonstrated a massive OP-LL with a spinal canal occupying of 82% at cervical 5 and 6.

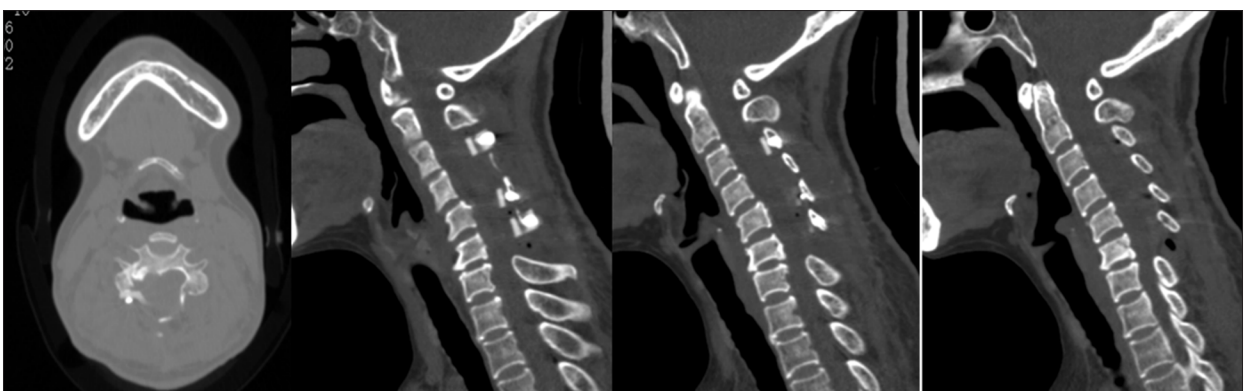


Figure 9. Postoperative transverse and sagittal CT reconstruction demonstrated that massive ossification was removed at cervical 5 and 6.

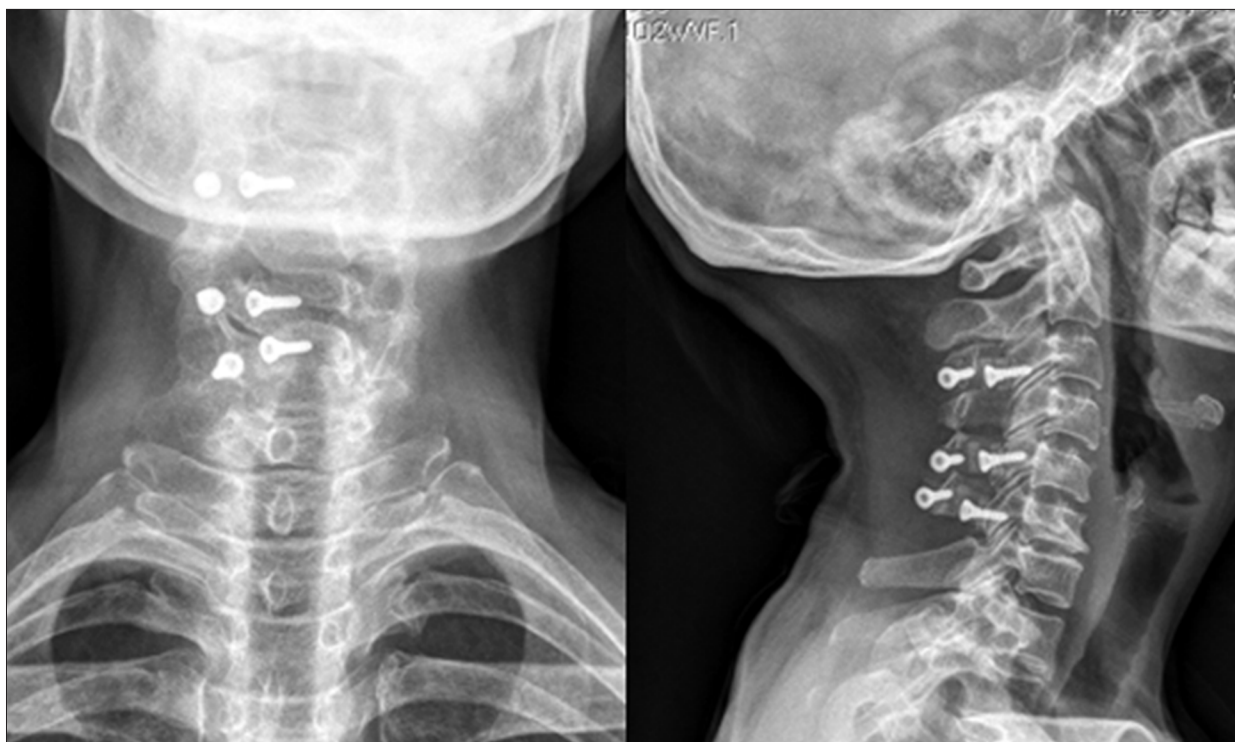


Figure 10. Anterior-posterior film at postoperative 12 months.

Table 3. The length of operation, intraoperative blood loss, recovery rate of neurological function, cerebrospinal fluid leakage (CFL), spinal cord injury (SCI), dysphagia, grafted bone extrusion subsidence (GBES), and C5 root palsy (C5RP) were recorded between the group of the modified laminoplasty and the group of combined anterior-posterior approach.

	Length of operation (minutes)	Intraoperative blood loss (ml)	Recovery rate (%)	Complication				
				CFL	SCI	Dysphagia	GBES	C5RP
ML	112.41±20.47	347.73±73.42	67.86±11.64	2 (9%)	0	0	0	0
CA	181.88±20.79	397.92±72.47	68.28±7.96	6 (24%)	1 (4%)	1 (4%)	1 (4%)	0

The group of the modified laminoplasty (ML); the group of combined anterior-posterior approach (CA).

Because the drainage volume was less than 30 mL per 24 h in 3 patients, cervical drainage tubes were removed at 3 days after the operation. Although the drainage volume of 2 patients was above 30 mL per 24 h (130 mL and 180 mL), cervical drainage tubes were also removed after wound healing. Given cervical progressive swelling within 2 days, elastic bandages were used for neck compression 2 days after the operation until the wound has completely healed and no cervical cyst was observed. Head elevation between 10 and 20 degrees, maintaining electrolyte balance, and antibiotics that can penetrate the blood-brain barrier were applied in all patients. Spinal cord injury was observed in 2 cases, dysphagia in 1 case, and grafted bone extrusion subsidence in 1 case (Table 3). In the modified laminoplasty group, there were 2 cases (9%) of slight CSF that resolved within 2 weeks without additional treatment. Spinal cord and never root injury were not observed in those cases (Table 3).

Discussion

Surgical management of OPLL mainly includes posterior, anterior, or combined anterior-posterior approaches. Although the posterior strategy is relatively simple and has a low complication rate, no satisfactory neurologic recovery rate in patients with severe kyphotic deformity and/or large OPLL and OPLL progression have been addressed in several studies due to the indirect neurologic decompression in this approach [3–5]. The surgeon can achieve good results by directly removing the OPLL and completely decompressing the spinal cord through the anterior approach, but this method has a higher incidence of surgery-related complications [6–10].

Iwasaki et al. retrospectively evaluated the surgical outcome in 66 patients who underwent laminoplasty for treatment of

cervical myelopathy due to OPLL [4,5]. The results indicated that surgical outcome of laminoplasty in patients with occupying ratio of 60% was significantly worse than those with occupying ratio <60%. They analyzed the effectiveness in 27 OPLL patients who underwent anterior decompression and fusion (ADF). Although the proportions of excellent or good result were similar between ADF and laminoplasty, poor outcome was more frequent in laminoplasty than in ADF. ADF yielded a better neurologic outcome at final follow-up than laminoplasty in patients with occupying ratio of 60%, although graft complications occurred in 15% and additional surgical intervention was required in 26%.

To compare the clinical outcome of the anterior approach (anterior decompression and fusion with floating method) and posterior approach (laminoplasty) in OPLL, Sakai et al. prospectively observed and assessed the clinical data of 42 patients [12]. Twenty patients were in the anterior group and 22 in the posterior group. At the 5-year follow-up, the mean JOA score for cervical myelopathy and the recovery rate in the anterior group were superior to those in the posterior group, especially for cases with 50% of the spinal canal compromised by OPLL or kyphotic alignment of the cervical spine, preoperatively. Postoperative progression of OPLL was observed in 5% of the ADF group and 50% of the laminoplasty group. Therefore, they recommended that ADF be considered especially suitable for cases with massive OPLL and preoperative kyphotic alignment of the cervical spine, although it leads to a higher incidence of surgery-related complications compared with laminoplasty.

Fujimori first reported the long-term outcome of anterior decompression and fusion versus laminoplasty in OPLL with an occupying ratio of 60% or more [3]. The anterior decompressions group had a significantly better recovery rate (53%) than the laminoplasty group (30%) at final evaluation. Anterior decompression was generally recommended for OPLL with an occupying ratio of 60% or more. A multi-institutional study assessed the complications of anterior approach of OPLL. The results indicated the incidences of deterioration in upper- and lower-extremity functions were 13.3% and 2.0%, respectively. Patients with a high occupying ratio of OPLL were at high risk of developing neurological deterioration.

Though accumulating evidence indicates that the anterior approach is superior to the posterior approach in OPLL with an occupying ratio $\geq 60\%$, the surgery-related complications, such as cerebrospinal fluid and spinal cord injury, was obvious higher than with the posterior approach. Although some of these surgical complications are transient, others may be permanent. Serious iatrogenic spinal injury happens rarely, but the consequence is ruinous. Yang et al. divided the spinal canal into 3 zones by 3 parallel lines – safety zone, intermediate zone,

and danger zone – based on axial CT imaging [10], and reported that 129 patients with OPLL were completely and safely resected in the safety zone and no cerebrospinal fluid leakage or spinal cord injury occurred. Although the most ossified material was resected when OPLL was within the danger zone (an OPLL occupying ratio $\geq 60\%$) in 21 patients, there were 2 cases of spinal cord injury and 7 cases of cerebrospinal fluid leakage.

With the purpose of decreasing iatrogenic complications, Wang et al. described a new technology for treating massive open-base OPLL with an occupying ratio (OR) exceeding 50% through the anterior approach in 2012 [11]. They defined the open-base as a lateral margin of ossified foci within the posterior cortex of the vertebral body that did not reach the pedicle. They described the technology as follows. Transverse decompression width was larger than the width of the OPLL base, while not offending the vertebral artery. The rongeur or burr was used to slightly thin the posterior vertebral wall and the ossified mass to facilitate further decompression. A special 90° angled micro-dissector was inserted through disc level to confirm the position of the lateral margin of OPLL. Then, a 1-mm Kerrison rongeur was used to divide the OPLL at the lateral margin joining with the posterior cortex of the cervical vertebrae. When dividing the OPLL at the other lateral margin, the micro-dissector was used to hold the partly floated ossified mass to prevent it from turning over, causing unintended spinal cord damage. In rare cases in which the ossified mass slightly adheres to the dura, the ossified foci can be lifted and removed as a whole after releasing it from the dura using the micro-dissector.

Their study indicated that no permanent neurological deterioration was observed in all 29 patients. Neurological improvement was observed in every patient, with an average improvement rate of $64 \pm 23\%$. However, it is notable that removing the ossified mass in our patients was almost impossible through the anterior approach because the ossified mass had fused with the pedicle of the vertebral arch (close-base OPLL). Although Wang's strategy [11] obtained a satisfactory outcome on the open-base OPLL, it was not suitable for the close-base OPLL. The spinal cord was compressed into a narrow space between the ossified mass and lamina of the vertebrae in those patients. Even if the surgeons use a 1-mm Kerrison rongeur or burrs, serious iatrogenic spinal injury seems to be inevitable using the anterior approach in those cases. The combined anterior-posterior approach is usually considered as a safe and effective strategy. Unfortunately, it is not suitable for all patients because of serious trauma from the operation and the expensive medical fees. For example, if patients with an OPLL simultaneously have coronary heart disease, hypertension, or diabetes mellitus, they could not tolerate the serious trauma from the combined anterior-posterior approach.

Our study indicated that modified laminoplasty obtained the same recovery rate of neurological function as with the combined anterior-posterior approach. Moreover, the length of operation, intraoperative blood loss, and iatrogenic complications were remarkably superior in the modified laminoplasty group versus the combined anterior-posterior approach group. Additionally, the medical fees of the modified laminoplasty were only 66.4% that of the combined anterior-posterior approach because it does not need fusion and fixation at anterior vertebrae. Modified laminoplasty is an attractive strategy for close-base cervical OPLL with an occupying ratio more than 60%. After the spinal canal was opened by laminoplasty, a safe buffer zone of operation was immediately presented. Because the safe buffer zone of operation existed, the incidence of iatrogenic spinal injury was significantly lower while the surgeon resected the mass ossification, which may explain the good clinical results and lack of iatrogenic spinal injury.

The limitations of this study should be noted. In particular, this was a retrospective study with a relatively small sample size (47 cases) and a short follow-up period. However, our aim was

to introduce another treatment option for the close-base cervical OPLL with an occupying ratio of more than 60%. In the present study, adjacent segment disease was not compared between the modified laminoplasty and combined anterior-posterior approaches due to a short follow-up period. Although the motion-sparing nature of laminoplasty may be protective against adjacent segment disease [13], the non-fusion strategy of anterior approach, such as artificial disc replacement and hybrid surgery, could also increase adjacent motion [14–16].

Conclusions

We found that the modified laminoplasty could be considered as an alternative strategy for patients that have demonstrated close-base OPLL with an occupying ratio of more than 60% and who cannot tolerate the serious trauma from the combined anterior-posterior approach due to medical disease.

Conflict of interest

The authors declare no conflict of interest.

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