Neurospine 2024;21(2):565-574.
https://doi.org/10.14245/ns.2347270.635

Neurospine
pISSN 2586-6583 eISSN 2586-6591

Original Article

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Received: November 22, 2023
Revised: January 31, 2024
Accepted: February 9, 2024

Clinical and Radiological Outcomes in C2 Recapping Laminoplasty for the Pathologies in the Upper Cervical Spine

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Objective: To evaluate C2 muscle preservation effect and the radiological and clinical outcomes after C2 recapping laminoplasty.
Methods: Fourteen consecutive patients who underwent C2 recapping laminoplasty around C1–2 level were enrolled. To evaluate muscle preservation effect, the authors conducted a morphological measurement of extensor muscles between the operated and nonoperated side. Two surgeons measured the cross-sectional area (CSA) of obliquus capitis inferior (OCI) and semispinalis cervicis (SSC) muscle before and after surgery to determine atrophy rates (ARs). Additionally, we examined range of motion (ROM), sagittal vertical axis (SVA), neck visual analogue scale (VAS), Neck Disability Index (NDI), and Japanese Orthopaedic Association (JOA) score to assess potential changes in alignment and consequent clinical outcomes following posterior cervical surgery.
Results: We measured the CSA of OCI and SSC before surgery, and at 6 and 12 months postoperatively. Based on these measurements, the AR of the nonoperated SSC was 0.1% ± 8.5%, the AR of the operated OCI was 2.0% ± 7.2%, and the AR of the nonoperated OCI was -0.7% ± 5.1% at the 12 months after surgery. However, the AR of the operated side's SSC was 11.2% ± 12.5%, which is a relatively higher value than other measurements. Despite the atrophic change of SSC on the operated side, there were no prominent changes observed in SVA, C0–2 ROM, and C2–7 ROM between preoperative and 12 months postoperative measurements, which were 11.8 ± 10.9 mm, 16.3° ± 5.9°, and 48.7° ± 7.7° preoperatively, and 14.1 ± 11.6 mm, 16.1° ± 7.2°, and 44.0° ± 10.3° at 12 months postoperative, respectively. Improvement was also noted in VAS, NDI, and JOA scores after surgery with JOA recovery rate of 77.3% ± 29.6%.
Conclusion: C2 recapping laminoplasty could be a useful tool for addressing pathologies around the upper cervical spine, potentially mitigating muscle atrophy and reducing postoperative neck pain, while maintaining sagittal alignment and ROM.

Keywords: Laminectomy, Laminoplasty, Postoperative complications, Spinal cord neoplasms, Cervical vertebrae, Muscular atrophy

INTRODUCTION

The surgery of craniovertebral junction (CVJ) could be complicated due to discreet relationships in the surrounding neurovascular structures, complex biomechanical issues, and intricate muscular structures.[1-10] The C2 spinous process gives attachment to obliquus capitis inferior (OCI), rectus capitis posterior major (RCPM), bulky portions of the semispinalis cervicis (SSC), spinalis cervicis, interspinalis and multifidus muscles. These C2 muscles form the long arms with the critical function of neck extension and rotation.[11-14] The detachment of C2 muscles not only hampers muscle function but also causes considerable postoperative pain and postoperative kyphosis.[15,16]

The preservation of C2 muscle attachments is essential to prevent postoperative cervical kyphosis.[17] Sparing C2 spinous process importantly preserves anchor points for extensor muscles and ligament structures and avoids the risk of cervical kyphosis after laminoplasty and spinal cord tumor surgery.[13] However, it is common practice to detach the C2 muscles in conventional upper cervical spine surgeries.

Recently, muscle-preserving technique was introduced for exposure of the posterior cervical spine.[15,18] However, the C2 recapping technique has been rare in the literature, and no study has investigated this new technique regarding long-term clinical and radiological outcomes.

Therefore, the purpose of this study is to quantitatively analyze muscle atrophy around the CVJ by measuring muscle volume before and after C2 recapping laminoplasty. Additionally, we will assess whether there is aggravation of neck pain or changes in radiologic parameters related to cervical alignment and clinical outcome indicators, thus confirming the clinically beneficial potential of this surgical methods.

MATERIALS AND METHODS

1. Study Design

This is a retrospective study of consecutive patients who had undergone C2 recapping laminoplasty surgeries around CVJ between January 2010 and January 2022. After obtaining approval from the Institutional Review Board (IRB) of Catholic Medical Center of The Catholic University of Korea (IRB No. PC23DASS0107), which waived the need for informed consent, patient data were retrospectively reviewed.

In this study, criteria for inclusion were patients who were older than 18 years old, had pre- or postoperative computed tomography (CT) images and C-spine x-rays including flexion and extension. And all patients also had patients-reported outcome measures such as neck visual analogue scale (VAS) score, Neck Disability Index (NDI) score, and Japanese Orthopaedic Association (JOA) score. Based on this data, C2 muscle atrophy of OCI and SSC muscles, change of cervical alignment, and postoperative complications were evaluated. In addition, we examined the volume of C2 muscles on CT scan, C2–7 SVA in neutral x-ray, C0–2 angle, and C2–7 angle in dynamic x-ray before and after surgery.

The patients were followed-up for at least one year following the surgery. The use of soft cervical collar was recommended for a month. Regular outpatient follow-up was conducted at 1, 3, 6, and 12 months after surgery to analyze the clinical and radiological evaluation.

To exclude factors that could potentially impact precise result analysis, the exclusion criteria were set as follows: cases with missing data in clinical and radiological evaluation within a year after surgery, cases where recapping laminoplasty was performed bilaterally, and cases with a history of previous cervical spine surgery.

2. Surgical Techniques (Figs. 1, 2; Supplementary video clip 1)

After general anesthesia, the patient was placed in the prone position, and the head was held in a slightly flexed position using a Mayfield head holder.

The surgical technique started with a midline skin incision from the inion to the C3 vertebra. The dissection continued through the subcutaneous tissues. The trapezius, splenius capitis, and the semispinalis capitis muscles were reflected from the midline and then the muscle plane of the suboccipital muscles was identified. The plane between the suboccipital and SSC muscles were developed deeply, and the semispinalis capitis muscles superficially.

C2 spinous process is split longitudinally with a threaded surgical wire or ultrasonic bone scalpel, leaving all muscular attachments (RCPM, OCI, and SSC muscles). The C2 lamina, pedicle, C1–2 joint, and C2–3 joints can be exposed by blunt dissection through the intermuscular plane between the SSC and the OCI muscle without damaging muscles. Next, a bone scalpel was used to make a lateral gutter on the lateral aspect of the C2 lamina.

If the tumor is skewed to one side, only one side C2 lamina can be opened and operated on. When wider exposure is needed because of the tumor size, the bilateral C2 lamina could be expanded. In this case, while the separation of the spinous process may pose a lack of physical support, it can still be beneficial in minimizing muscle injury.

Either C1 laminectomy or C1 laminoplasty could be possible to expand the surgical exposure. C1 laminectomy and C1 laminoplasty require resection of the RCPM muscle, of which function is trivial in humans.

The dura was suspended with tenting sutures and was cut along the midline for treatment of intradural tumors. Then the tumor or pathologic lesion was carefully separated from the

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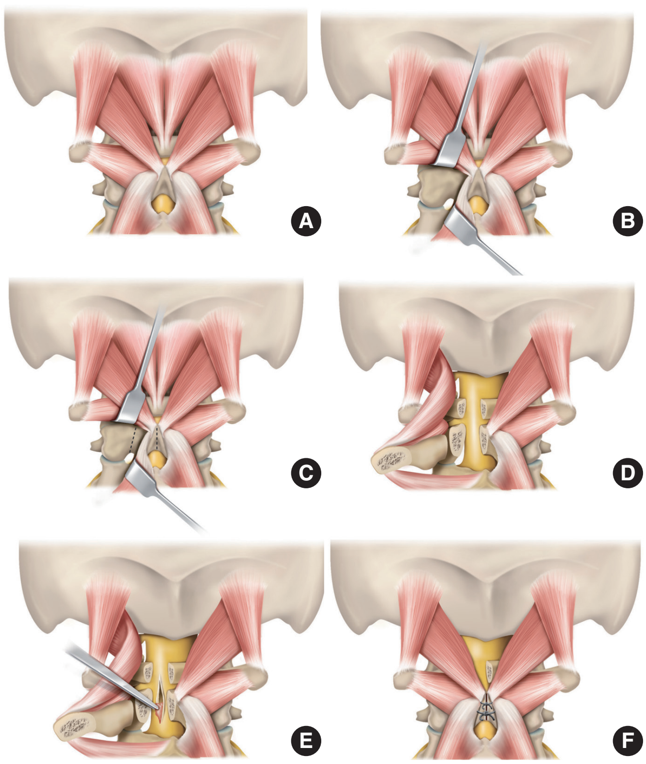

Fig. 1. Schematic representation of the C2 muscle preservation procedure. (A) The rectus capitis posterior major (RCPM), obliquus capitis inferior (OCI), and semispinalis cervicis (SSC) muscles are attached to C2 spinous process. The rectus capitis posterior minor is attached to C1 posterior arch. The OCI is the only suboccipital muscle that does not have an attachment to the cranium. (B) Division of the plane between the OCI muscle and the SSC muscles. (C) C2 spinous process is split longitudinally, and lateral gutter are made between the SSC muscles and the OCI muscles. Dotted line indicates the resection margin in the midline spinous process and lateral gutter. The bilateral SSC muscles and OCI muscles were completely preserved. (D) Unilateral C2 spinous process and lamina was retracted to expose spinal canal. While the C2 attachments of the SSC, OCI, and RCPM muscles are left intact, the C2 laminal flaps are elevated to swing open. Either C1 laminectomy or C1 laminoplasty could be possible to expand the surgical exposure. (E) Main surgical procedure and tumor removal can be performed after the opening of C2 lamina. (F) Reconstructing the C2 spinous process/lamina and the muscle attachments. Expanded half of the C2 spinous process then reattached to counterpart with stitch passed through drill-hole in each split half of spinous process.

nerve root and spinal cord. Finally, the blood supply to the lesion was blocked with coagulation and repeatedly washed with physiological saline; then, it was removed completely. To remove intramedullary tumors, the spinal cord was longitudinally cut from the most prominent and nearest area without blood

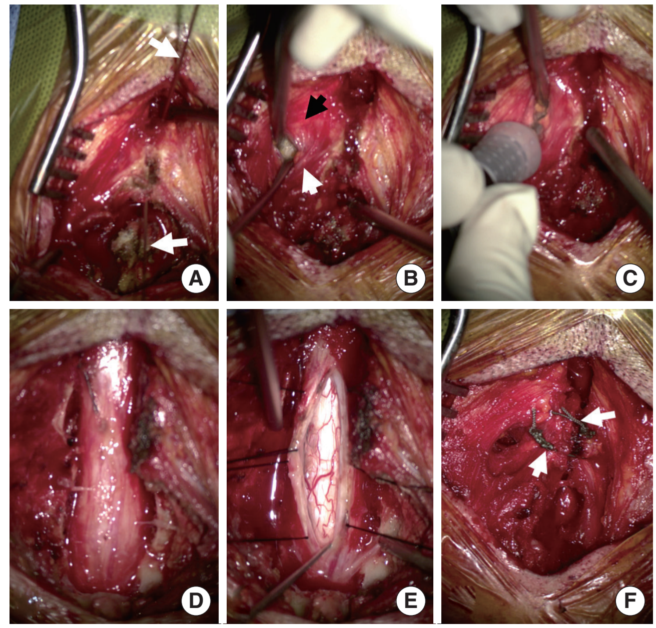

Fig. 2. Intraoperative photographs of C2 muscle preservation procedure. (A) C2 spinous process is split longitudinally with a surgical threaded wire (white arrows), leaving all muscular attachments (RCPM, OCI, and SSC muscles). (B) Dividing the plane between the OCI muscle (black arrow) and the SSC muscles (white arrow). A scalpel and bipolar forceps are used in the sharp dissection process to avoid heat damage to the muscles. (C) Making lateral gutter on the C2 lamina using bone scalpel for muscle-preserving C2 laminoplasty. (D) Unilateral C2 spinous process and lamina is retracted to expose spinal canal. While the attachments of the SSC, OCI, and RCPM muscles (at C2) are left intact, the C2 laminal flaps are elevated to swing open. (E) Spinal cord is exposed. Main surgical procedure and tumor removal can be performed after the opening of C2 lamina. (F) Reconstructing the C2 spinous process/lamina and the muscle attachments. Expanded half of the C2 spinous process then reattached to counterpart with stitch (white arrows) passed through drill-hole in each split half of spinous process. The bilateral SSC muscles and OCI muscles are completely preserved. RCPM, rectus capitis posterior major; OCI, obliquus capitis inferior; SSC, semispinalis cervicis.

vessels. The tumor was separated and removed along its border. When the tumor was separated, we only pulled the tumor, not the spinal cord. After tumor resection, the separated C2 laminae is brought back to its counterpart with stitches using non-absorbable suture composed of ethylene terephthalate, passed through drill holes in each split half of the C2 spinous process without damaging the C2 muscles. Finally, working layer by layer, the surgeon will close the incision using absorbable sutures.

3. Radiological Evaluation

We compared the radiological outcomes, such as C2 muscle atrophy, change of cervical alignment and segmental motion before and after the surgery. Standing lateral, flexion, and extension radiographs of the cervical spine were performed both preoperatively and postoperatively. Radiography and CT imaging examination were performed before surgery and at 6, 12 months after surgery. We examined the C2–7 sagittal vertical axis (SVA) in the neutral position, C0–2 angle, and C2–7 angle in extension and flexion before and after surgery. The angles were measured based on the following lines: McGregor line, the lines of lower endplates of C2, and the lines of the upper endplate of C7. The C2–7 SVA was defined as the horizontal offset of a plumb line dropped from the center of the C2 vertebral body to the posterosuperior corner of the C7 vertebra.

All enrolled patients underwent CT preoperatively, 6 months, and 1 year after the surgery. Axial CT images were aligned parallel to the inferior endplate of the vertebral body. Axial CT images were used to measure the cross-sectional area (CSA) of the muscles around the C2 spinous process (Fig. 3). We measured the CSA of the OCI muscle at the middle of the C2 spinous process and the CSA of the SSC at the C2–3 intervertebral disc level (Fig. 3). The muscle atrophy rate (AR) was measured as follows: muscle AR = [(preoperative CSA–postoperative CSA)/preoperative CSA] × 100. Two spine surgeons independently reviewed the imaging studies. All CSA measurements were performed twice by the same person to minimize the potential for error in constructing the polygons around the muscles' margins, and the average values were analyzed.

4. Clinical Evaluation

The clinical features of each patient, including age, sex, and diagnosis were recorded. Clinical outcome was assessed using JOA score for cervical myelopathy preoperatively and postoperatively. The recovery rate (RR) was calculated according to the following formula (Hirabayashi method): RR (%) = (postoperative JOA−preoperative JOA)/(17 [full score]−preoperative JOA) × 100.[19]

We used the VAS score to evaluate the neck pain and the NDI to assess the functional status of the patient's neck. Postoperative neck pain was assessed immediately after surgery, 1 month, 3 months, 6 months, and 1 year after the surgery.

We also evaluated the following postoperative wound complications: cerebrospinal fluid (CSF) leakage and postoperative infection.

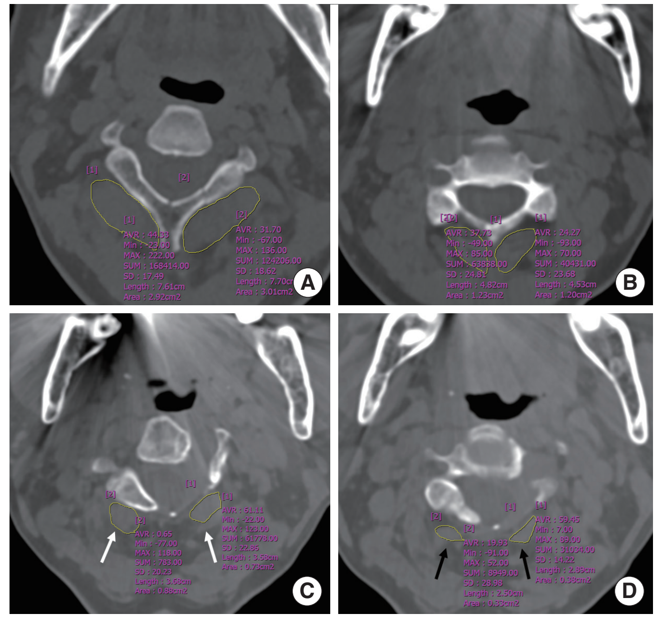

Fig. 3. (A) The postoperative axial computed tomography (CT) image demonstrating the measurement of cross-sectional area (CSA) for the OCI muscle at the middle of the C2 spinous process. (B) The postoperative axial CT image demonstrating the measurement of CSA for the SSC muscle at the C23 intervertebral disc level. (C) The postoperative axial CT image demonstrating atrophic change of the OCI muscle (white arrows) after C2 laminectomy for tumor removal. (D) The postoperative axial CT image demonstrating the bilateral atrophy of the SSC muscle at the C23 intervertebral disc level (black arrows) after C2 laminectomy. OCI, obliquus capitis inferior; SSC, semispinalis cervicis.

RESULTS

1. Patients Demographics

During the specified period, a total of 18 patients satisfying the inclusion criteria were identified. Two patients were not followed-up for a year and consequently excluded due to incomplete evaluation. And a patient who underwent bilateral laminoplasty and another patient who had history of previous cervical spine surgery were excluded.

A total of 14 patients were enrolled in this study in the end (Table 1). Overall, mean age of patients was 48.1 ± 15.9 years (range, 23–77 years), and 6 patients (42.3%) were male, and 8 patients (57.7%) were female.

The types of pathologies were schwannoma (n = 5, 35.7%), meningioma (n = 5, 35.7%), extradural ossified mass (n = 2, 14.2%), intramedullary tumor (n = 1, 7.1%), and syringomyelia (n = 1, 7.1%). The average follow-up period was 27.4 months (range, 12–74 months). There was 1 case of multiple schwan-

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nomas who needed extended cervical laminectomy in the subaxial cervical spine.

C1 laminectomy was required in 5 cases, accounting for 35.7% of the total surgeries. C1 laminoplasty was carried out in 5 cases (35.7%), while in 4 cases (28.6%), no additional procedures were performed.

2. Radiographic Evaluation

Inter- and intraobserver variability analyses showed intraclass correlation coefficient values were excellent (0.835–0.994) for measured cervical angles and that values measured by the 2 observers were well correlated.

The postoperative changes of each radiographical parameter are shown in Tables 2 and 3. The average postoperative AR of the OCI and the SSC muscles at 6 months were 0.8% ± 3.2% and 5.0% ± 8.8%, respectively, in the operated side. Meanwhile, the average postoperative AR of the OCI and SSC muscles at 6 months were -0.9% ± 2.8% and -0.9% ± 5.2%, respectively, in the nonoperated side. The trend persists at 12 months postoperatively, where the average postoperative AR of the OCI and the SSC muscles on the operated side were 2.0% ± 7.2% and 11.2% ± 12.5%, respectively. In contrast, on the nonoperated side, the values were -0.7% ± 5.1% and 0.1% ± 8.5%, respectively.

The preoperative C2–7 ROM was 48.7° ± 7.7°, and the postoperative C2–7 ROM at 6 months and 12 months were 44.9° ± 8.4° and 44.0° ± 10.3°. C02 ROM and SVA revealed no prominent change between preoperative and postoperative periods. (16.3 ± 5.9 vs. 16.3 ± 8.0 vs. 16.1 ± 7.2, 11.8 ± 10.9 vs. 12.8 ± 10.6 vs. 14.1 ± 11.6) (Table 2). And there was also no distinct change in sagittal alignment and ROM change after the surgery.

The bony fusion between the bisected C2 spinous process was completed in all patients. However, fusion was observed in the lateral gutter of the operated side in 11 out of the total 14 cases.

Table 1. Summary of patients' characteristics (n = 14)

Characteristic	Value
Age (yr)	48.1 ± 15.9
Sex	
Male	6 (42.3)
Female	8 (57.7)
Types of pathologies	
Meninigioma	5 (35.7)
Schwannoma	5 (35.7)
Extradural ossified mass	2 (14.2)
Intramedullary metastasis	1 (7.1)
Syringomyelia	1 (7.1)
Follow-up period (mo)	27.4 ± 23.1
Removal status of C1 lamina	
C1 laminectomy	5 (35.7)
C1 laminoplasty	5 (35.7)
Neither	4 (28.6)
Fusion rate of C2 spinous process	14 (100)
Fusion rate of lateral gutter on the lateral aspect of the C2 lamina	11 (78.6)

Values are presented as mean ± standard deviation or number (%).

Table 3. AR between operated and nonoperated sides

Variable	Nonoperated	Operated
OCI AR (%, 6 mo)	-0.9 ± 2.8	0.8 ± 3.2
OCI AR (%, 12 mo)	-0.7 ± 5.1	2.0 ± 7.2
SSC AR (%, 6 mo)	-0.9 ± 5.2	5.0 ± 8.8
SSC AR (%, 12 mo)	0.1 ± 8.5	11.2 ± 12.5

Values are presented as mean ± standard deviation.
OCI, oblique capitis inferior muscle; AR, atrophy rate; SSC, semispinalis cervicis muscle; SVA, sagittal vertical axis.

Table 2. Radiologic parameters between preoperative and postoperative period

Variable	Preoperative	Postoperative (6 mo)	Postoperative (12 mo)
OCI CSA (nonoperated) (mm²)	261.1 ± 119.3	262.9 ± 119.6	262.0 ± 120.0
OCI CSA (operated) (mm²)	241.1 ± 103.7	239.2 ± 105.1	238.7 ± 111.6
SCC CSA (nonoperated) (mm²)	119.1 ± 42.5	120.1 ± 43.3	119.4 ± 43.5
SCC CSA (operated) (mm²)	116.1 ± 41.2	109.4 ± 36.0	104.1 ± 37.5
SVA (mm)	11.8 ± 10.9	12.8 ± 10.6	14.1 ± 11.6
C02 ROM (°)	16.3 ± 5.9	16.3 ± 8.0	16.1 ± 7.2
C27 ROM (°)	48.7 ± 7.7	44.9 ± 8.4	44.0 ± 10.3

Values are presented as mean ± standard deviation.
OCI, oblique capitis inferior muscle; CSA, cross-sectional area; SSC, semispinalis cervicis muscle; SVA, sagittal vertical axis; ROM, range of motion.

3. Clinical Outcome Evaluation

In the 1-year follow-up period, the JOA score increased from 11.9±3.6 preoperatively to 15.0±3.5 postoperatively. The RR of the JOA score was 77.3%±29.6% while the VAS and NDI scores were improved after surgery (Table 4).

4. Postoperative Complication

Regarding complications, no severe intraoperative complications occurred after the surgery. There was no postoperative CSF leakage or wound infection after C2 recapping laminoplasty.

Table 4. Postoperative clinical outcome

Variable	Preoperative	Postoperative (6 mo)	Postoperative (12 mo)
VAS neck	5.2±1.9	1.3±1.3	0.9±1.1
NDI	28.1±8.1	9.0±4.4	6.9±5.5
JOA score	11.9±3.6	14.6±3.8	15.0±3.5
JOA score RR (%, 6 mo)		71.2±35.5	
JOA score RR (%, 12 mo)		77.3±29.6	

Values are presented as mean±standard deviation.
VAS, visual analogue scale; NDI, Neck Disability Index; JOA, Japanese Orthopaedic Association; RR, recovery rate.

5. Illustrative Cases

1) Case 1

A 30-year-old male patient presented with neck pain, headache and progressive quadriparesis. The preoperative magnetic resonance imaging (MRI) demonstrated intradural mass eccentric to the right side at the C2 level (Fig. 4). C2 recapping laminoplasty was performed and tumor removal was completed without any notable events. A durotomy was created that identified a tumor mass that was causing compression on the spinal cord from right to left. The mass was completely excised, and the dura was closed in a watertight manner. The patient's headache resolved immediately after surgery. The pathology result was schwannoma. His weakness recovered completely by the third postoperative month. Postoperative MRI demonstrated complete decompression of the spinal cord.

Postoperative CT showed complete fusion of the bisected spinous process and preserved volume of C2 muscles one year after surgery.

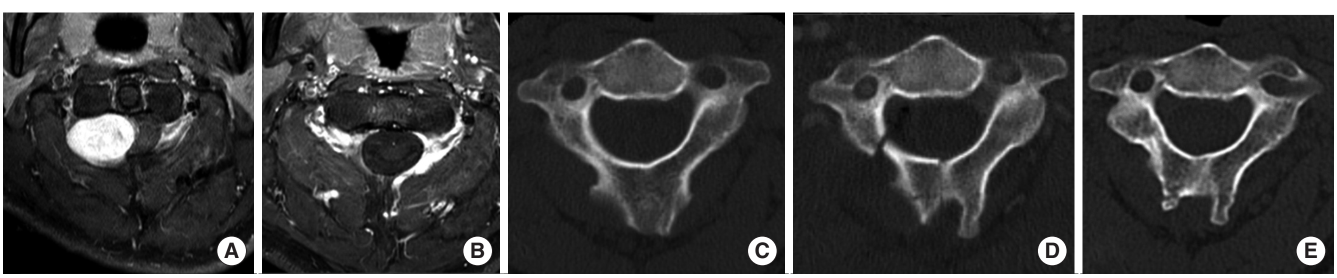

Fig. 4. Case 1. (A) Preoperative axial magnetic resonance image are showing that homogenously enhanced intradural mass compressed spinal cord at the C2 level. (B) Postoperative magnetic resonance imaging is showing that there is no enhanced mass or cord compression after the surgery. (C–E) Axial computed tomography images show the change of C2 spinous process and attached muscles before, 3 months after, and 1 year after surgery.

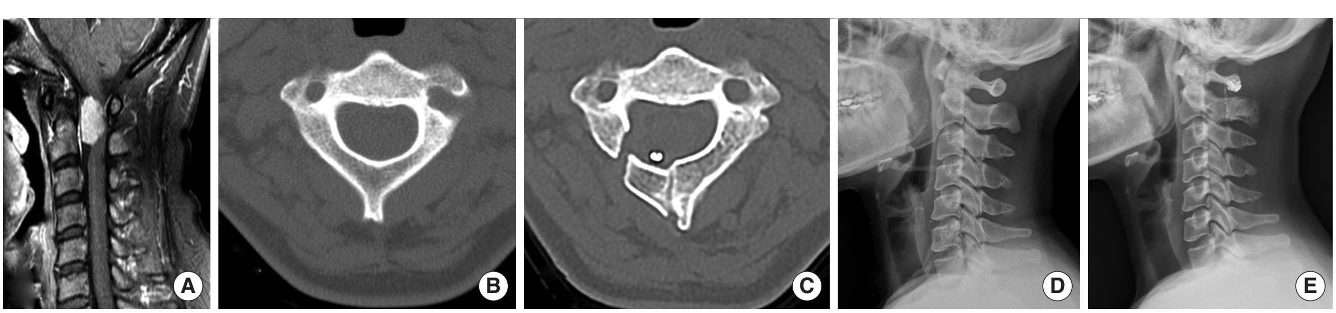

Fig. 5. (A) Preoperative enhanced magnetic resonance image showing that homogenously enhanced ventral intradural mass compressed spinal cord at the C1–2 level. The axial computed tomography images demonstrating C2 spinous process and the bilateral OCI muscles (CSA) at the C2 level before (B) and after surgery (C). The lateral radiographs demonstrating cervical alignment before (D) and after surgery (E). OCI, obliquus capitis inferior; CSA, cross-sectional area.

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2) Case 2

A 47-year-old male patient presented with neck pain and both hand clumsiness. The preoperative MRI demonstrated homogenously enhanced intradural mass to the right side at the C1 and C2 levels. C2 recapping laminoplasty and C1 laminoplasty was performed for tumor removal. The mass was completely excised, and the pathology result was meningioma. Postoperative CT showed that the volume of C2 muscles preserved one year after surgery. The lateral radiographs demonstrated that there was no prominent change in cervical alignment before and after surgery (Fig. 5).

DISCUSSION

The cervical extensor muscles play an essential role in cervical alignment.[13,18,20-23] Panjabi et al.[24] reported that the neck muscles provide nearly 80% of the needed mechanical stability of the cervical spine, while osteo-ligamentous structures contribute about only 20%. Previous reports have emphasized preserving muscles that attach to the C2 spinous process to prevent cervical lordosis loss after laminoplasty.[17,23,25-27]

Moreover, C2 spinous process is one of the key structures for the extensor muscles because the height of this spinous process increases the moment arm of the functioning muscles complex.[28]

The OCI muscle is a fleshy, thick muscle located in the neck. The OCI is the largest muscle of the 4 suboccipital muscles and the only suboccipital muscle that does not attach to the cranium. It instead inserts into the transverse process of the atlas on the infero-posterior part. Its origin is at the C2 spinous process. Bilateral contraction of this muscle causes head extension and unilateral contraction performs the critical role of providing rotation of the head towards the ipsilateral side.[29-31]

The SSC muscles originate from the transverse processes from T1 to T6 and insert to the spinous processes from C2 to C5. These muscles act as a stabilizer and one of the main extensors of the cervical spine, which are related to the cervical motion and alignment.[15,16,32]

The SSC inserting to C2 spinous process is the most developed among this muscle group. Preservation of the SSC insertion to C2 could prevent both the postoperative axial pain and the loss of cervical lordosis that can affect long-term outcomes after laminoplasty. There have been lots of studies about the significance of the C2 muscles so far. However, most of them are about the lower cervical spine surgeries, and studies on C2 muscle detachment for CVJ pathologies are rare.

So, the purpose of this study was to quantitatively measure volume of OCI and SSC muscle and evaluate clinical outcomes to determine the potential clinical usefulness of C2 recapping laminoplasty.

Conventional C2 laminectomy damaged the posterior muscle structures attached to the C2 spinous process and caused muscle atrophy after surgery (Fig. 3).

This study provided some interesting findings regarding the effect of C2 recapping laminoplasty.

First, when calculating the AR of each muscle, it is found that, except for the operated SSC, there was muscle atrophic change of less than 2%. Second, it seems that there were similar flexion/extension ROM both in the upper and subaxial cervical spine before and after surgery. Although atrophy of the SSC muscle on the operated side was confirmed, it did not appear to induce ROM change before and after surgery. This finding suggests that despite the loss of CSA of the ipsilateral SSC muscle, functional outcomes may not have been affected due to preserving contralateral SSC muscle and other extensor muscles may have prevented a ROM decrease after surgery. Third, it appears that the C2 recapping technique does not result in postoperative cervical malalignment. Finally, the C2 muscle preservation technique allows enough space for complete tumor excision and minimizing the amount of dead space while avoiding muscle damage encountered after conventional laminectomy. Undamaged C2 muscles with a rich blood supply could minimize the amount of dead space created and diminishes the incidence of deep wound infection and persistent CSF leakage. Moreover, the free muscle-bone fragment receives a rich blood supply through the preserved muscular attachments to the spinous process, facilitating bone fusion in the bisected spinous process.

Subaxial alignment change is not uncommon after upper cervical spine surgery.[28,33] Although the little study has sought to identify the risk factors of postoperative cervical malalignment following upper cervical spine surgery, we recently reported lower cervical spine alignment might change during the first year after CVJ posterior fixation, and lower cervical alignment is related to upper cervical angle after CVJ fixation.[28,34] Besides, the risk of subaxial kyphotic change increased after CVJ fixation when combined with lower cervical laminoplasty and comprehensive dissection of deep extensor muscle.[28]

These data showed that the C2 muscle detachment itself was not a risk factor of malalignment or postoperative neck pain. The risk of cervical malalignment and related neck disability increased only when combined dissection of deep extensor muscle down to the lower cervical spine.

In the patients with lower cervical kyphosis and sagittal malalignment, lateral radiographs show hyperlordotic angle in the upper cervical spine.[1,28,35-39] It is because when patients have sagittal malalignment in the lower cervical spine, the C0–2 segment's hyperextension holds up the head to compensate for distal kyphosis, sagittal imbalance, and maintaining horizontal gaze.[1,33,36]

These findings suggest that reciprocal interaction may likely affect not only global balance but also regional balance. We believe that the proposed technique may minimize the extent of soft tissue dissection, muscle splitting, and postoperative dead space. Additionally, minimizing the risk of soft tissue devascularization, denervation, and biomechanical change could decrease postoperative wound complication and adjacent level disease as previously reported. Furthermore, this could diminish postoperative pain and expedite postoperative recovery.

This study has several limitations that warrant consideration. First, it is limited by its retrospective, single-surgeon design, which may have caused selection bias. Second, the sample size could be relatively small, and the case etiologies were heterogeneous to draw meaningful conclusions. Finally, we did not evaluate axial plane movement and the rotation capacity of the OCI muscles. Although this study did not include all the C2 muscles and the whole direction of cervical motion, analyzing the 2 largest C2 muscles could reflect the pattern of postoperative changes.

Nevertheless, we believe our study might have a sufficient clinical impact. We have shown the results of a relatively long-term follow-up and time-dependent change in cervical alignment and related neck disability score following new techniques handling the C2 spinous process and its attached muscles. This study included the largest number of cases that have used the C2 recapping laminoplasty technique for CVJ pathologies to date to the best of the authors' knowledge.

However, we suggest multicenter, multiple neck movements, and larger-scale comparative studies to obtain more accurate information on the value of this C2 muscle preservation technique in the future.

CONCLUSION

C2 recapping laminoplasty might be effective for CVJ pathologies to preserve C2 muscle structures. Keeping the C2 musculature could help with pathologies around the upper cervical spine. It would help prevent the C2 muscles atrophy, maintain cervical ROM, and reduce postoperative neck pain and malalignment in the postoperative period.

However, it is necessary to conduct a comparative analysis with a larger sample size using statistical methods, including patients who have undergone conventional laminectomy to validate these findings.

NOTES

Supplementary Material: Supplementary video clip 1 can be found via https://doi.org/10.14245/ns.2347270.635.

Conflict of Interest: The authors have nothing to disclose.

Funding/Support: This study received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Author Contribution: Conceptualization: DHK, JTH, JWH, ISK, HJL, JBL; Formal analysis: DHK, JTH; Investigation: DHK, JTH, JWH, ISK, HJL, JBL; Methodology: DHK, JTH, HJL, JBL; Project administration: JTH, ISK, HJL, JBL; Writing – original draft: DHK, JTH; Writing – review & editing: DHK, JTH.

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https://doi.org/10.14245/ns.2347270.635