CLINICAL ARTICLE

Efficacy and Safety of Ultrasonic Bone Curette-assisted Dome-like Laminoplasty in the Treatment of Cervical Ossification of Longitudinal Ligament

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Objective: To assess the efficacy and safety of ultrasonic bone curette-assisted dome-like laminoplasty in the treatment of ossification of longitudinal ligament (OPLL) involving C2.

Methods: A total of 64 patients with OPLL involving C2 level were enrolled. Thirty-eight patients who underwent ultrasonic bone curette-assisted dome-like laminoplasty were defined as ultrasonic bone curette group (UBC), and 28 patients who underwent traditional high-speed drill-assisted dome-like laminoplasty were defined as high-speed drill group (HSD). Patient characteristics such as age, sex, body mass index (BMI), symptomatic duration, and other information like the type of OPLL, the time of surgery, blood loss, C2–C7 Cobb angle change and complications were all recorded and compared. The Japanese Orthopaedic Association (JOA) score, the nerve root functional improvement rate (IR), and the visual analogue scale (VAS) were used to assess neurological recovery and pain relief. The change of the distance between the apex of ossification and a continuous line connecting the anterior edges of the lamina was measured to assess the spinal expansion extent. The measured data were statistically processed and analyzed using SPSS 21.0 software, and the measurement data were expressed as mean ± SD.

Results: In ultrasonic bone curette (UBC) group and high-speed drill group (HSD) group, the average time for laminoplasty was 52.3 ± 18.2 min and 76.0 ± 21.8 min and the mean bleeding loss volume was 155.5 ± 41.3 mL and 177.4 ± 54.7 mL, respectively, with a statistically significant difference between the groups. Both groups demonstrated a significant improvement in neurological function. However, the VAS score in UBC group was lower than in HSD group at the 6-month follow-up ($P < 0.05$), but there was no significant difference at 1-year follow-up. We found that the loss of lordosis was 1.5° ± 1.0° in UBC group, which is significantly lower than that of HSD group at 1-year follow-up (3.8° ± 1.2°, $P < 0.05$). According to the change of canal dimension, we found that the expansion extent of the spinal canal in UBC group was similar to that of HSD group ($P > 0.05$). Only one patient in the UBC group and five patients in the HSD group displayed cerebrospinal fluid (CSF) leakage.

Conclusions: With the use of ultrasonic bone curette in OPLL dome-like decompression, the decompression surgery could be completed relatively safely and quickly. It effectively reduced the amount of intraoperative blood loss and complications, and had better initial recovery of neck pain.

Key words: Axis; Dome-like laminectomy; Laminoplasty; OPLL
Introduction

Ossification of the posterior longitudinal ligament (OPLL) is a disease that occurs due to ectopic ossification, which is a common cause of cervical compressive myelopathy and neurological injury. It was originally described from occurrences in the Japanese and East Asian populations. The prevalence of OPLL has been 1.9%–4.3% among individuals older than 30 years with cervical spine disorders. Recent research has demonstrated that the incidence of OPLL has reached 0.1%–1.7% among North Americans and Europeans in recent years. Normally, OPLL took place in the lower cervical spine, but in severe cases like the continuous type and mixed type of OPLL, the upper cervical spine is often involved. Since the narrowest space of the spinal cord is mostly located from region C2 to C4, there is a high risk that OPLL patients with their upper cervical spine involved will result in unsatisfied surgical outcomes after the operation due to inadequate decompression with traditional single open-door laminoplasty, which is most effective in dealing with C3–7 cervical stenosis. Recent techniques of dome-shape decompression at C2 level were reported to result in better clinical outcomes in laminoplasty-treated C2-level-involved severe OPLL patients. However, whether these techniques were all safe and effective to treat severe OPLL patients remains unknown.

Although the direct removal of the ossified mass can be achieved by anterior approach, the complex anatomic structures around the upper cervical spine caused it to be extremely challenging to attempt direct decompression in OPLL. Besides, it has been reported that posterior decompression can significantly lower the occurrence of complications like dysphagia and recurrent laryngeal nerve injury compared to anterior approach. Among all posterior approaches, single open-door laminoplasty is most widely used by achieving indirect decompression through shifting of the spinal cord posteriorly. Studies showed that the degree of the cervical spinal cord shifting after the decompression post laminoplasty directly affected the postoperative outcome. However, the decompression of C2 level is often inadequate due to the concern that C2 open-door laminoplasty would induce postoperative kyphosis and axial neck pain as a result of injury to the paraspinal muscle at C2 level. Thus, preservation of muscle attachments is an important technique for the laminoplasty to reduce axial neck pain and restriction of cervical range of motion (ROM). In 1989, Matsuzaki et al. first reported a dome-like laminoplasty technique to fully preserve the posterior structure of C2 instead of axis laminoplasty. Since then, many studies have reached the consensus that protection of muscle attachments positively contributed to the reduction of postoperative complications. However, the traditional procedure of high-speed drill-based dome-like laminectomy in C2 has a high risk of spinal cord and nerve injury, which requires careful handling and high technical demand.

More recently, ultrasonic bone curette has been adapted to perform not only endoscopic bone removal over the skull base, but also spine surgeries. Although it has been reported that decompression surgery could be completed more safely and quickly by using ultrasonic bone curette in thoracic surgery when compared with high-speed drills. However, the efficacy and safety of ultrasonic bone curette in dome-like laminoplasty have not been reported. Due to the safety concerns of high-speed drill-based dome-like C2 laminectomy and cervical single open-door laminoplasty, we hypothesized that using ultrasonic bone curette instead of high-speed drill in dome-like C2 laminectomy accompanied with single open-door laminoplasty would be safer and more effective. In order to prove this hypothesis, we: (i) specified the technical procedure of ultrasonic bone curette-assisted dome-like single open-door laminoplasty in the treatment of C2-cervical-spine-involved OPLL disease; (ii) compared the clinical outcomes and radiographical outcomes of high-speed drill-based or ultrasonic bone curette-assisted dome-like single open-door laminoplasty in treating severe OPLL patients; and lastly (iii) compared the incidence of perioperative complications of the patients in both groups. Through this study, we try to specify the efficacy and safety of ultrasonic bone curette-assisted dome-like single open-door laminoplasty in the treatment of upper-cervical-spine-involved OPLL disease.

Materials and Methods

Ethics Approval and Consent to Participate

This retrospective study was approved by the ethics committee of our hospital of our university. Written informed consent was obtained by all participants.

General Information

This study retrospectively reviewed 64 patients with C2-involved OPLL from January 2015 to January 2018. Thirty-eight patients (UBC group: 24 male, 14 female, 64.2 ± 6.6 years old) underwent ultrasonic curette-assisted C2 dome-like laminoplasty, and twenty-six patients (HSD group, 18 male, 8 female, 63.4 ± 5.4 years old) underwent traditional high-speed drill-assisted C2 dome-like laminoplasty. Inclusion criteria were as follows: (i) patients have typical cervical myelopathy symptoms, and presence of OPLL in C2 and downward cervical level was confirmed by imaging, with no significant disc herniation; (ii) diagnosed patients underwent cervical laminoplasty using either ultrasonic bone curette or high-speed drill-assisted dome-like C2 laminectomy accompanied with single open-door laminoplasty; (iii) surgical treated patients with more than 12 months follow-up. Exclusion criteria were: (i) patients with cervical kyphosis >13° before surgery or K-line negative; (ii) patients diagnosed with OPLL combined with trauma, tumor, infection, or other systematic diseases; (iii) patients had a mental disorder and other diseases that had an impact on VAS scores. Patient characteristics such as age, sex, BMI, and symptomatic duration were obtained before surgery.

Surgical Methods

The surgical procedure of dome-like laminoplasty involves two steps. First, general single open-door laminoplasty from...
C₃ downwards and second, C₂ dome-like laminectomy. In the ultrasonic bone curette group (UBC group), the ultrasonic curette is applied to achieve laminectomy of lower 1/3 of the posterior column of C₂ (axis) from caudal spinous process to the anterior and cranial C₂ lamina without dissecting the attached muscles (Fig. 1). The resection is performed bilaterally to ensure adequate decompression at C₂ level. Then Kerrison rongeur is used to remove the flavum ligament to ensure sufficient space for spinal cord to shift back after the procedure (Fig. 2).

In high-speed drill group (HSD group), the procedure is similar to that of UBC group. Firstly, the single open-door laminoplasty was performed from C₃ to lower vertebrae. The ligaments between C₂ to C₃ were severed by a rongeur, and, using high-speed drill bar, a dome-like groove is made on the caudal surface of the C₂, leaving up to 5 mm in the posterior wall of the spinal cord–lamina surface. Next, grooves were drilled posterior–anteriorly in a semicircular fashion until the surface of ligamentum flavum was exposed. Finally, a Kerrison rongeur was used to dissect the ligamentum flavum.

**Radiographic Analysis**

**General Measurement Methods**

Cervical spine anteroposterior, lateral, flexion, and extension X-ray radiographs and cervical spine high-resolution computed tomography (CT) scans were taken preoperatively and postoperatively. The type of OPLL was confirmed by preoperative CT scans and three-dimensional reconstruction images (Fig. 3). Measurements were performed by Centricity PACS 4.0 system (GE Healthcare, USA), and the contrast...
adjustment was made to visualize all cervical spine vertebrae. Two independent clinical research assistants, who were not involved with the study and blinded to all clinical information, performed radiological measurements, and the average values of both observers were used in the present study.

Cervical Lordosis
Cervical lordosis was assessed by the C2–C7 Cobb angle. The Cobb angle from C2 to C7 was used as a measurement of the cervical alignment, which was defined as the angle formed by the inferior end plates of C2 and C7 in lateral positioned radiographs.

Postoperative Cobb Angle Change
The change of the C2–C7 Cobb angle was calculated. Postoperative alignment change was assessed by comparing the preoperative and postoperative C2–C7 Cobb angle in standing lateral radiographs and was calculated with the following formula: alignment change (°) = (preoperative C2–C7 Cobb angle) – (postoperative C2–C7 Cobb angle).

Spinal Cord Expansion Distance
Spinal cord expansion distance was calculated by first drawing a continuous line connecting the anterior edges of lamina on axial CT scans and measured the change of the distance between this curve line and the apex of ossification to assess the expansion extent of the spinal cord.

Outcome Measurements
Surgical Information
The time of operation and intraoperative bleeding volume were calculated by two residents. In addition, intraoperative complication such as dural tear was recorded.

Neurological Function Assessment
The Japanese Orthopaedic Association (JOA) scoring system was adapted to evaluate the neurological function. We use nerve function improvement rate (IR) to assess the symptom improvement, which was calculated as IR = (6 months after surgery JOA scores-preoperative JOA scores) / (17-preoperative JOA scores) × 100%. Two independent clinical research assistants, who were not involved in the study and blinded to all clinical information, performed the assessments, and the average values of both observers were used in the present study.

Neck Pain Assessment
The neck pain was measured by the visual analogue scale (VAS) system. Two independent clinical research assistants, who were not involved in the study and blinded to all clinical information, performed the assessments, and the average values of both observers were used in the present study.

Complications
Postoperative cerebrospinal fluid (CSF) leakage, the event of axial neck pain, and C5 nerve root palsy were recorded in both groups.

Statistical Analysis
Data analyses were analyzed using SPSS version 20 for Windows (SPSS, Inc., Chicago, IL, USA). Data are presented as the number of subjects in each group or mean ± SD. Each independent variable, such as age, sex, symptom duration, follow-up period, JOA score, VAS score, C2–C7 Cobb angle, and C2–C7 ROM was compared between the two groups using the Mann–Whitney U test for continuous variables, and the χ² test or Fisher exact test for categorical variables. A statistically significant difference was set at P value <0.05.

Results
General Results
Thirty-eight patients who underwent ultrasonic curette-assisted C2 dome-like laminoplasty were defined as group UBC, and twenty-six patients who underwent a traditional single open-door laminoplasty using high-speed drills were
defined as group HSD. There was no significant difference among age, sex, BMI, symptomatic duration, and the type of OPLL between the two groups (Table 1, P > 0.05). All patients enrolled had a follow-up period of longer than 1 year.

**Surgical Outcomes**
The average time of operation was 52.3 ± 18.2 min in UBC group, which is significantly lower (P = 0.04) than that of HSD group (76.0 ± 21.8 min, Table 2). In addition, the mean bleeding loss volume was 155.5 ± 41.3 mL and 177.4 ± 54.7 mL, respectively, with no statistical significance between the groups (P = 0.21). Only one patient in the UBC group compared to four patients in the HSD group (P = 0.04) had CSF leakage. No other complications were found in both groups during the surgery.

**Radiographic Results**

**General Results**
All patients showed good neural decompression from postoperative radiographic analysis. The dome-shape laminectomy in C2 level resulted in an average of 3.62 ± 1.3 mm width in UBC group and 3.3 ± 1.2 mm in HSD group with no significant differences (P = 0.27). The postoperative change of spine canal mean width was 3.9 ± 1.1 mm in UBC group and 4.2 ± 1.2 mm in HSD group, which also showed no significant differences (P = 0.32, Table 2). The occupation rate (OR) of osteophytes in C2 level has changed from 42.3 ± 5.6 (%) before surgery to 17.5 ± 3.8 (%) after surgery in UBC group, and 45.6 ± 4.3 (%) to 18.2 ± 3.6 (%) in HSD group, no significant differences were found between the groups (P > 0.05).

**Postoperative Cobb Angle Change**
The loss of lordosis in the two groups also showed no significant differences (P = 0.06), with 1.5° ± 1.0° in UBC group and 2.8° ± 1.2° in HSD group, respectively (Table 3).

**Clinical Outcomes**

**Neurological Function Assessment**
Both groups demonstrated a significant improvement in neurological function, and there were no significant differences between the JOA score (14.2 ± 2.2 in UBC group and 13.9 ± 2.4 in HSD group respectively, Table 3, P = 0.49) and the IR (58.4% ± 9.2% in UBC group and 56.5% ± 8.9% in HSD group respectively, Table 3, P = 0.45) between the two groups.

**Complications**
After the surgery, two patients in UBC group and six patients in HSD group experienced sustained axial pain (P = 0.05), and all recovered within 1-year post-operation. One patient in UBC group and five patients in HSD group

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**TABLE 1 Comparison of patient demographics and characteristics**

| Characteristic                      | UBC Group | HSD Group | P value |
|-------------------------------------|-----------|-----------|---------|
| Age                                 | 64.2 ± 6  | 63.4 ± 5.4| 0.68    |
| Gender (Male: Female)               | 24:14     | 18:8      | 0.92    |
| BMI                                 | 26.1 ± 3.0| 25.5 ± 2.5| 0.40    |
| Type of OPLL                        |           |           | 0.56    |
| Local                               | 0         | 0         |         |
| Segmental                           | 1         | 2         |         |
| Continuous                          | 8         | 4         |         |
| Mixed                               | 29        | 22        |         |
| Symptom duration (Months)           | 10.8 ± 10.4| 12.6 ± 12.2| 0.63    |
| Follow-up period (Months)           | 18.2 ± 6.8| 17.8 ± 6.2| 0.38    |

**TABLE 2 Comparison of surgical information between ultrasonic bone curette and high-speed drill-assisted laminoplasty**

| Characteristic                      | UBC Group | HSD Group | P value |
|-------------------------------------|-----------|-----------|---------|
| Time of surgery (min)               | 52.3 ± 18.2| 76.0 ± 21.8| 0.04*   |
| Bleeding loss volume (mL)           | 155.5 ± 41.3| 177.4 ± 54.7| 0.21    |
| Spinal cord expansion (mm)          | 3.9 ± 1.1 | 4.2 ± 1.2  | 0.32    |
| CSF leakage                         | 1         | 4         | 0.04*   |

BMI, body mass index; HSD Group, traditional single open-door laminoplasty using high-speed drills treated patients; OPLL, ossification of posterior longitudinal ligament; UBC Group, ultrasonic curette-assisted C2 dome-like laminoplasty treated patients. Values are expressed as the mean ± standard deviation. * * represents values were not compared for differences.
TABLE 3 Postoperative clinical data comparison of the patients

|                      | UBC Group | HSD Group | P value |
|----------------------|-----------|-----------|---------|
| JOA score            |           |           |         |
| Before surgery       | 10.3 ± 2.5| 9.8 ± 2.7 | 0.52    |
| 6 months after surgery| 14.2 ± 2.2| 13.9 ± 2.4| 0.49    |
| IR (%)               | 58.4 ± 9.2| 56.5 ± 8.9| 0.45    |
| VAS                  |           |           |         |
| Before surgery       | 5.2 ± 1.5 | 5.4 ± 1.3 | 0.43    |
| 6 months after surgery| 2.8 ± 1.6 | 3.9 ± 1.7 | 0.03*   |
| The final follow-up  | 2.1 ± 1.5 | 2.9 ± 1.6 | 0.21    |
| C2-3 Cobb angle (degree) |         |           |         |
| Before surgery       | 12.2 ± 2.7| 11.9 ± 2.5| 0.52    |
| 6 months after surgery| 11.5 ± 2.8| 10.1 ± 2.7| 0.19    |
| The final follow-up  | 10.8 ± 2.3| 8.2 ± 2.2 | 0.09    |
| The loss of lordosis | 1.5 ± 1.0 | 2.8 ± 1.2 | 0.06    |
| Postoperative Complications (number of patients (percentage)) | | | |
| Axial neck pain      | 2 (5.3%)  | 6 (23.0%) | 0.05*   |
| C5 nerve root palsy  | 1 (2.6%)  | 4 (15.4%) | 0.15    |
| CSF leakage          | 1 (2.6%)  | 5 (19.2%) | 0.04*   |

Values are expressed as the mean ± standard deviation. CSF, cerebrospinal fluid; HSD, high-speed drill; IR, improvement rate; JOA, Japanese Orthopaedic Association; VAS, Visual Analog Scale; UBC, ultrasonic bone curette. * P < 0.05.

experienced cerebrospinal fluid (CSF) leakage during and after the surgery (P = 0.04). One patient in UBC group and four patients in HSD group experienced C5 palsy after the surgery (P = 0.15), but recovered within 4 months, and no significant differences were found between the two groups (Table 3). There was no nerve root injury, postoperative hematoma, or other complications that occurred after operation.

Discussion

Essentiality of Preserving C2 Muscle Attachments

Muscles and ligaments attached to the lamina and spinous process are recognized as the components of neck dynamic equilibrium. However, it is unavoidable to dissect paraspinous muscles in laminoplasty. A wide range of decompression results in excessive posterior structure destruction. For most patients, a C3–C7 laminoplasty can achieve satisfied indirect decompression due to a spinal cord shift. Nevertheless, in some cases, considering the C2 segment was severely compressed, or with a high-intensity signal on T2-weighted magnetic resonance imaging, C2 decompression was recommended, which can cause the sacrifice of cervical deep extensor. Some studies suggested that, due to the expansion of the decompression range, the backward shift distance of the spinal cord for C2–C7 surgery was indeed increased compared with that of C3–C7 surgery18, 19. But posterior cervical deep extensors, especially the semispinalis cervicis, play an important role in maintaining the lordosis and alignment of the cervical vertebrae. Besides, many researchers have attributed axial neck pain and loss of ROM to the destruction of C2 muscle attachments20, 21. On the other hand, A meta-analysis suggested that laminoplasty preserving the C2 posterior deep extensor muscle could decrease the atrophy rate and reduce the incidence of postoperative axial symptoms22. Thus, to address this problem, several modified surgical techniques of laminoplasty have been reported. The C2 canal space is wider at the cranial and narrower at the caudal end; thus, ventral decompression of C2 lamina may provide extra space for spinal cord shift. This theory was first proved by Matsuzaki et al. in 1989, as their dome-like decompression of C2 lamina was able to fully preserve the posterior deep extensor muscle. However, space for surgeons to perform this surgical technique using a high-speed drill is quite limited, which can result in a high risk of dural tear.

Safety of Ultrasonic Bone Curette in Dome-Like Laminoplasty

Although the ultrasonic aspirator was introduced for removal of dental plaque in 1947, the application of ultrasonic osteotome has turned out to be a versatile, safe, and efficient method for bone removal within spine surgery in recent years, especially in the thoracic spine and lumbar spine23, 24. The previous study has suggested that the ultrasonic bone curette had some technical advantages in cutting the laminae. For instance, the device is lightweight, requires the use of only one hand, features both irrigation and aspiration attachments, and allows for the placement of cotton buffers25. Because there was no rotational movement, the tip of the device was much more stable. Besides, ultrasonic bone curette produces less heat compared with a high-speed drill. While the curette is being used, the handpiece end is cooled by the automatic irrigation of saline water. There is less danger of causing thermal injury to the surrounding important neural and vascular structures. It also can reduce the bleeding and shorten the operation time during the process of cutting the lamina26. In this present study, we further proved that using ultrasonic bone curette could reduce blood loss and the time of operation in dome-like laminoplasty. There was only one case of CSF leakage in the ultrasonic bone curette-assisted laminoplasty group, which showed merit over the traditional high-speed drill in dealing with the dome cutting (five patients in this group were found to have CSF). Also, the incidence of other complications was much lower than that in the high-speed drill group. However, care must be taken to avoid iatrogenic dural tears. We suggested using covering cotton patties on the surface of dura to prevent intraoperative dural tear.

Clinical Outcomes of Ultrasonic Bone Curette-assisted Dome-like Laminoplasty

In this study, both groups showed significant improvement in neurological function. However, the VAS score in ultrasonic bone curette group was significantly lower than that in the high-speed drill group at 6-month follow-up. As the previous study demonstrated, the injury of the C2 spinous process could be a factor of axial neck pain. We considered that the reason of why VAS score was significantly higher in
high-speed drill group might be due to the substantial exposure of C2 laminae using a high-speed drill. Nevertheless, no significant difference was found at the final follow-up. Although kyphosis did not occur in both groups, we observed some loss of lordosis at the final follow-up in high-speed drill group, which may be caused by the over-exposure of the C2 laminae, which sacrificed more muscle attachments than ultrasonic bone curette group in order to maintain safe surgery.

It is the first time that we have presented a change of the distance between a continuous line connecting the anterior edges of the lamina and the apex of ossification to assess the expansion extent of the spinal cord on axial CT scans. As a result, the mean change of distance was 3.9 ± 1.1 mm post-operatively in UBC group, which is similar to high-speed drill group. The change of distance demonstrated that the distance of the spinal cord shift is approximately 4 mm after dome-like laminoplasty, which resembles to that of traditional single open-door laminoplasty from C2–C7.

**Limitation**

This is a retrospective study, meaning that inherent biases may exist that interfere with the results. The sample size in this study was relatively small and needs further comparison with large-scale cases. Hence, large sample size and long-term follow-up research is needed for further confirmation.

**Conclusion**

Our findings have shown that the ultrasonic curette-assisted dome-like decompression surgery could be completed relatively safely and quickly. It effectively reduced the amount of intraoperative blood loss and complications and had better initial recovery of neck pain.

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**Authors’ Contributions**

Study conception and design: BS, CX, YL; Acquisition, analysis and/or interpretation of data: BS, CX, YL, SW, YZ; Drafting/revision of the work for intellectual content and context: HW, MQ, XS, WY; Final approval and overall responsibility for the published work: YL, WY. All authors read and approved the final manuscript.

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