**Original Article**

**Application of piezosurgery to treat thoracic myelopathy caused by ossification of the ligamentum flavum**

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**Abstract:** Objective: Piezosurgery is based on microvibrations generated by the piezoelectrical effect, which results in selective bone cutting with preservation of adjacent soft tissue. We aimed to study the applicability of piezosurgery in treating thoracic myelopathy caused by ossification of the ligamentum flavum (OLF). Methods: Between June 2011 and October 2015, thoracic myelopathy caused by OLF was diagnosed in 22 patients using plain radiography, CT, and MRI, and diagnoses were confirmed by postoperative pathological examination. Piezosurgery was supportively used to treat thoracic myelopathy in 22 patients with either OLF or dural ossification. After laminectomy, OLF or ossified dural mass was removed by piezosurgery to decompress the spinal canal. The modified Japanese Orthopedic Association (mJOA) scoring system was used to assess neurological status. The degree of postoperative expansion of the spinal cord was calculated on axial CT images. Results: In all 22 cases, Ossified mass, even those adhered onto dura or ossified dura could be safely removed by piezosurgery. No patient experienced any new neurological deficit after surgery. No serious complications ensured, only one patient suffered dura tear. Neurological status improved during follow-up (mean, 22.4 months) from a preoperative mean mJOA score of 5.05 ± 1.84 to 8.68 ± 1.52 points (t = 7.14, P < 0.05). Neurological-function recovery rate ranged from 33.3% to 100%. Conclusions: Piezosurgery could be a useful and safe technique for selective bone cutting in OLF decompression and removal, especially DO.

**Keywords:** Ossification of the ligamentum flavum, piezosurgery, thoracic myelopathy, bone cutting, dural ossification

**Introduction**

Ossification of the ligamentum flavum (OLF) is an important cause of thoracic spinal stenosis (TSS) in Asian populations, especially in Japan and China [1]. The disease has a predilection for the lower thoracic spine and frequently affects adults aged between 40 and 60 years. Dural-membrane involvement in ossification makes surgery more difficult and significantly increases the risks of spinal cord damage and complications, such as cerebrospinal fluid (CSF) leakage and meningitis. Under these circumstances, the choice of surgical techniques is important to avoid unnecessary complications, and surgical manipulation for removing the ossified mass must be performed very cautiously.

Laminectomy can decompress the spinal cord, and high-speed drills and rongeurs are often used to resect laminae and ossified ligaments. However, serious OLF results in severe spinal stenosis and maximum spinal cord compression, so any procedure using instruments inside the spinal canal can cause irreversible spinal cord injury and CSF leakage [2].

The relatively new piezosurgery technique is based on microvibrations, which are generated by the so-called piezoelectrical effect and has thus selective bone-cutting properties with preservation of adjacent soft-tissue structures [3, 4]. In this article, our piezosurgical devices manufactured by Surgybone (Silfradent SRL, Italy) with angled inserts was used supportively for the conventional rotating bur in 22 patients to remove ossified ligamentum flavum, especially ossified dura. In all cases, the applicability, advantages, and disadvantages of piezosurgery were evaluated for this indication.
Removal of OLF by piezosurgery

Materials and methods

Patient data

Twenty-two consecutively admitted patients with thoracic OLF underwent posterior decompression using the piezosurgery device between June 2011 and October 2015. Their mean age was 59.4 years (range, 48-71 years) at diagnosis. Follow-up duration was 22.4 months (range, 12-36 months). All patients were subjected to a neurological examination in which the clinical features, mode of onset, and inaugural symptoms of the illness were noted in a standardized manner. Magnetic resonance imaging (MRI) and three-dimensional CT were performed in every patient. The radiologic work-up provided the characteristics of OLF (i.e., location, number of affected segments, and unilateral or bilateral nature), possible spinal cord involvement, and accompanying narrowing of the cervical or lumbar canal. Decompression extent was evaluated by performing preoperative CT. Changes in signal intensity on the MRI of the vertebrae and spinal cord at the corresponding vertebral level were also observed for reference. The modified Japanese Orthopedic Association (JOA) scoring system was used by two experienced spinal surgeons to evaluate the neurological status of patients before and after surgical decompression [5, 6]. The maximum score of 11 indicates normal function. An improvement rate (IR) was calculated as follows: $IR = \frac{(\text{post-operative JOA score} - \text{preoperative JOA score})}{(11 - \text{preoperative JOA score})} \times 100\%$. IR was then used to define surgical outcome: excellent (IR ≥ 75%), good (75% > IR ≥ 50%), fair (50% > IR ≥ 25%) and poor (IR < 25%) [7].

Figure 1. Piezosurgical devices with handpiece, footswitch, and different inserts. The main unit contains a peristaltic pump for cooling with a jet of physiological saline solution and a control panel with digital display to select the different modes and power levels.
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**Piezosurgical device**

The piezosurgical device, manufactured by Surgybone (Silfradent SRL, Italy), was used to remove the laminae and ossified ligamentum flavum and decompress the spinal canal.

Our piezosurgery unit consisted of two piezo-electric handpieces and a footswitch connected to a main unit that supplied power and had holders for the handpieces and irrigation fluids. It contained a peristaltic pump for cooling with a jet of physiological solution (0.9% saline solu-

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**Figure 2.** Axial CT scan of the thoracic spine show narrowing of the central spinal canal due to ossification of the ligamentum flavum (OLF). The OLF may be either unilateral or bilateral. Axial CT image (A) show a V-shape of OLF. Axial CT scan indicate a typical tram track sign due to ossification of the ligamentum flavum (B).

**Figure 3.** Sagittal T2-weighted MRI of the thoracic spine (A) show hyperintense signal in the spinal cord due to compression. The ossification of the ligamentum flavum displays a hypointense signal. Axial T2-weighted MRI of the ossified ligamentum flavum (B) show a nodular low signal intensity mass.
Removal of OLF by piezosurgery

Table 1. Demographics and clinical outcomes of 22 patients surgically treated for thoracic ossification of the ligamentum flavum by piezosurgery

<table>
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<tr>
<th>Patient NO</th>
<th>Age</th>
<th>Sex</th>
<th>Symptom duration (months)</th>
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M = male, F = female, IR = improvement rate, JOA = Japanese Orthopedic Association, Preop. = preoperative, Postop. = postoperative.

Ultrasonic vibrations were generated by piezoelectricity with variable frequencies from 25 kHz to 35 kHz, which resulted in variations in cutting energy. The amplitude of the working tip ranged from 40 µm to 200 µm. The piezosurgical device was endowed with various inserts having different tips, angles, and diameters (Figure 1).

Surgical technique

Under general anesthesia, the patient was placed in the prone position and the abdomen was decompressed to avoid excessive epidural bleeding. The appropriate surgical level was confirmed by intraoperative radiography, and a standard posterior approach was taken. After the necessary dissection, the spinous processes and the superficial part of the laminæ were removed using rongeurs. High-speed drills were used to treat the deeper parts of the laminæ. Afterwards, the ossified ligamentum flavum was first subjected to piezosurgery using the SB P0700 insert with caution to cut through ossified ligamentum flavum. In this procedure, particular attention was paid to ensure that the ossified mass was excised without any violence because the ossified lesions differed in size, and the ossified ligamentum flavum varied between the laminæ and the ossified lesion in front of the facet joint. Moreover, excessive mechanical force can make the sawtooth puncture the dura and lead to CSF leakage. When the ossified ligamentum flavum had been excised away to be thin, we used SB P0100 inserts to carefully excise the ossified ligamentum flavum on the dura surface. During this procedure, a sharp dissector was used to peel off...
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the underlying dura. However, if ossification of the dura mater or a severe adhesion existed between the dura mater and OLF, we excised the ossified ligamentum flavum together with the adherent or ossified dura mater, leaving the arachnoid intact. An artificial membrane was not used to repair the dural defect. The laminectomy included the medial half of the width of the facet joint. We always placed a subfacial drain for posterior wounds, and drains were removed on the second postoperative day. All patients commenced a back extensor exercise program after hospital discharge.

Statistical analysis

Statistical analyses were performed using SPSS 16.0 statistics software. A paired t-test was used to assess the difference between mJOA scores before and after the operation. Continuous data are presented as mean standard deviation (SD), and categorical variables are presented as numbers. All statistical assessments were two sided, and evaluated at the 0.05 level of significance.

Result

Radiographs, CT scans, and MRI were used to confirm diagnosis in each patient [8]. We evaluated the extent of the ossified thoracic ligamentum flavum using three-dimensional CT scan [9]. CT scanning revealed that OLF appeared as radiodense bars along the line of the laminae, radiating inward from the facet joint capsules toward the midline, either unilaterally or bilaterally (Figure 2). Sagittal MRI demonstrated medullary compression because of a V-shaped or sawtooth-shaped lesion in the posterior margin of the canal. These lesions were hypointense on T1- and T2-weighted MRI, as shown in Figure 3.

A previous report has indicated that the best method of diagnosing TSS associated with OLF is MRI combined with CT scan [10]. A clear diagnosis can be obtained with a combination of medical history and thoracic radiography, CT scan, and MRI. For 22 patients, the MRI signal of the spinal cord was abnormal at the stenosis level. Demographics and clinical outcomes of
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22 patients surgically treated for thoracic ossification of the ligamentum flavum are shown in Table 1.

All patients were clearly diagnosed with TSS associated with OLF, one patient had an accompanying cervical-canal narrowing, and another had an accompanying lumbar-canal narrowing. All patients underwent posterior decompression with laminectomy, and an ossified mass was excised. The decompression extent was three to five laminae. Every patient underwent laminectomy without internal fixation to restore stability, and no thoracic kyphosis was observed after follow-up.

No serious complications were noted with this procedure. One dura tear occurred and repaired was by suture because we accidentally pricked the dura with a ragged tip. Then, we improved and used the nontraumatic tips to cut the ossified ligamentum flavum, and no dura tear occurred. For one patient who had dural ossification (DO), we carefully cut the ossified mass by piezosurgery bone; when we removed the ossified mass, we found a small area of dural defect and no CSF leakage because of the arachnoid membrane was intact. No subarachnoid space formed, and no postoperative wound infection occurred. No patient experienced thoracic myelopathy because of OLF regrowth or compression fractures in the involved vertebrae.

The diameter of the compressed spinal cord returned to normal postoperatively, as shown in the pre- and postoperative CT scans (Figure 4). Generally, neurological status improved at follow-up from a preoperative mean JOA score of 5.05 ± 1.84 (range, 2-9) points to 8.68 ± 1.52 (range, 5-11) points (t = 7.14, P < 0.05). These results were considered significant, and the surgery for OLF was considered effective. The IR of neurological function ranged from 33.3% to 100% (mean ± SD, 64.04% ± 18.23%). Surgical outcome was excellent in six (27.3%) patients, good in thirteen (59.1%) patients, and fair in three (13.6%) patients (Table 1). No patient had worsened neurological symptoms.

In all 22 cases, the piezosurgical instruments selectively cut bone with no damage to the dura, spinal nerves, and spinal cord. The handling of the instrument was generally easy, and the cutting process was extremely safe. The cut appeared to be precise and selective because the effect of bone drilling was due to microvibrations instead of rotating power, and bone can thus be removed using shaping movements as with a curette. Ossified mass, even those adhered onto dura or ossified dura, could be safely removed. Supportive use of decompression on the dura surface was also easily achieved without any complication. The integrated irrigation provides cooling and renders additional irrigation dispensable.

The handpieces cannot be used with mechanical force because the tips are not very strong; thus, the tip may break if the mechanical force outweighs its support. This phenomenon occurred at the beginning of our use. Another reason was the tips could prick the dura with mechanical force, especially ragged tips, so we must softly cut the bone and ossified mass with piezosurgery device. Therefore, the bone removal rate of the piezosurgery device was limited, resulting in prolonged operation time.

Discussion

Ossification of the ligamentum flavum in the thoracic spine is being increasingly recognized as a cause of thoracic myelopathy in Asian populations [11]. This condition commonly affects the lower thoracic spine, especially T9-L1 [12, 13].

Posterior decompression with laminectomy is commonly used to treat thoracic OLF. Traditional laminectomy (pedicle-to-pedicle en bloc laminectomy) includes removal of laminae, ossified ligamentum flavum, and medial half of the facet joint [14, 15]. Previous studies have suggested various surgical techniques depending on the radiological type of OLF [16, 17]. All of our patients underwent en bloc resection by cutting the bony junction between the pedicle and upper facet through piezosurgery.

Performing en bloc laminectomy in the presence of DO is not recommended because of the high probability of extensive dural lacerations. Wang and Chen [18] suggest leaving a floating fragment adherent onto the dura mater to avoid this complication, but this may not provide acceptable decompression. In our study of patients who were found to have an association between OLF and DO intraoperatively, we cannot resect the OLF from the ossified portion.
of the dura mater, and both DO and OLF were resected by piezosurgery. Arachnoid membrane was intact, and no CSF leakage was observed. The dural defect was not repaired, and meticulous closure of the paraspinous muscles, deep fascia, and skin was performed with application of continuous pressure to the wound. The IR of neurological function ranged from 33.3% to 100% (mean ± SD, 64.04% ± 18.23%). Surgical outcome was excellent in six (27.3%) patients, good in thirteen (59.1%) patients, and fair in three (13.6%) patients (Table 1). No patient had worsened neurological symptoms. Therefore, this method was effective.

In a retrospective study of 81 patients by Gu [19], 843 patients underwent decompression without instrumentation, and surgery was supplemented with posterior transpedicular screw fixation in 38 patients. These patients did not show a significant benefit compared with those who underwent nonfixation procedures with respect to the fact that all showed excellent to good outcomes. In a study of Jia [14], more than four laminae were successively removed without fixation in 13 patients, and no thoracic kyphosis was observed after a follow-up of more than 2 years. These studies show that posterior surgical methods do not affect thoracic-spine stability in patients with OLF and that no additional internal fixation or bone grafting is needed, thereby avoiding the economic burden caused by the need for internal fixation. In our study, all patients who underwent posterior decompression did so without screw fixation to restore the stability of the involved segments. Results of pre- and postoperative kyphosis of the involved vertebrae indicated that all patients who underwent posterior decompression without screw fixation maintained spinal stability postoperatively.

Piezosurgery is a relatively new technique that allows the soft tissue to rest and has a tendency for less bleeding by transmitting a special modular ultrasonic vibration frequency on the scalpel. This technique is clinically effective, and histological and histomorphometric evidence of wound healing and bone formation in experimental animal models show that tissue response is more favorable in piezosurgery than in conventional bone-cutting techniques, such as with diamond or carbide rotary instruments [20]. Voltage applied to a polarized piezoceramic causes it to expand in the direction of and contract perpendicular to polarity. A frequency of 25-35 kHz is used because the micromovements that are created within this frequency (40-200 μm) cut only mineralized tissue; neurovascular and other soft tissues are cut at frequencies exceeding 50 kHz [21]. These properties result in selective cutting of mineralized bone without or with minimal damage to soft tissue [22]. Its physical and mechanical properties have several clinical advantages: precise cutting, sparing of vital neurovascular bundles, and better visualization of the surgical field. Piezoelectric bone surgery seems to be more efficient in the first phases of bony healing; it induces an earlier increase in bone morphogenetic proteins, controls the inflammatory process well, and stimulates remodeling of bone as early as 56 days after treatment [23].

Piezosurgery was first used in the field of dental and oral implant surgery [24]. Later, the technique was also used for some indications in maxillofacial and otological surgery [4, 25, 26] and some have even used the device in neurosurgery or hand surgery [27]. Thus far, only Grauvogel J [28] reported the use of piezosurgery in spinal surgery. They believed piezosurgery is a useful and safe technique for selective bone cutting in neuroforamina decompression and osteophyte removal with preservation of neuronal and soft tissues in ACDF. Moreover, different-angled tips appear to be effective in cutting bone spurs behind adjacent vertebrae. No data exists on the use of piezosurgery in OLF and DO. However, the supportive use of an ultrasonic bone curette (Sonopet), which works on a similar physical basis, has been described for different spinal procedures [29, 30]. These studies do not specify the spinal procedures the device is used for, and they only provide some case illustrations in their papers. Kim [30] reported injuries of the dura and the spinal cord because of vibrations of the Sonopet device.

Almost all studies using the technique of piezosurgery, regardless of the operative discipline, reported a safe, precise, and selective bone cut without any injury of adjacent soft tissue [4, 22, 27]. The present study also confirmed that the cut was selective to bony osteophytes and did not injure spinal nerves, spinal cord, and dura, even if it was placed on the dura surface without mechanical strain. Mist airflow produced by
ultrasonic vibration also lowered the local temperature, avoiding thermal damage to spinal cord and dura using high-speed drills. It could make the cutting line clear as well, thereby ensuring cutting accuracy. Therefore, the procedure was safe and the device was generally easy to handle because it worked with microvibrations instead of rotating power and bone can be easily removed by shaping movements as with using a curette.

In this study, operating room time was prolonged because the device was used for the first time for this indication. Documentation of the intraoperative use for scientific reasons was also time consuming. Prolonged operation time was in accordance with the results of most studies using piezosurgery [25, 27].

Conclusions

Surgery for patients suffering from TSS because of OLF and DO is problematic. Resection of both OLF and DO is preferred because any attempt to preserve the dura mater introduces an unnecessary risk. Piezosurgery proved to be a useful and particularly safe technique for selective bone cutting in decompressing and removing OLF, especially DO. Thus, surgical techniques for OLF associated with DO in the thoracic spine with piezosurgery were effective.

Acknowledgements

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Disclosure of conflict of interest

None.

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