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Original article

Computer-assisted minimally invasive spine surgery for resection of ossification of the ligamentum flavum in the thoracic spine

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Keywords: *computer-assisted minimally invasive spine surgery; ligamentum flavum, ossification; thoracic spinal canal stenosis; decompression*

Background Ossification of the ligamentum flavum (OLF) has been widely recognized as one of the main causes of thoracic spinal canal stenosis and thoracic myelopathy. Decompression is the only effective strategy for treating thoracic myelopathy caused by OLF. The purpose of this study was to describe the clinical outcomes of computer-assisted minimally invasive spine surgery (CAMISS) for posterior decompression in patients with thoracic myelopathy caused by OLF.

Methods In all cases, the surgical procedure was performed with the assistance of an intraoperative three-dimensional navigation system. Decompression of the spinal cord was performed with a high-speed drill; the supraspinal ligaments and spinous process were partially preserved. The outcomes were evaluated by a modified Japanese Orthopedic Association (JOA) scoring system and recovery rates.

Results The mean duration of follow-up for the 14 cases was 3.9 years. All patients experienced neurological recovery, the mean JOA score improving from 6.1 points preoperatively to 8.6 points at final follow-up and the mean rate of recovery being 52.7% (excellent in two cases, good in eight, fair in three, and unchanged in one).

Conclusion CAMISS is a safe and effective procedure for resection of the OLF in the thoracic spine.

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Ossification of the ligamentum flavum (OLF) was first described by Voss in 1972, this report being in the German language.[1] It has been widely recognized as one of the main causes for thoracic spinal canal stenosis and thoracic myelopathy, especially in east Asians.[2,3]

Thickening of the ligaments, resulting in narrowing of the spinal canal and compression of the spinal cord, causes the myelopathy that occurs in patients with OLF. Clinical observations suggest that compression greater than a threshold of 4 mm induces spinal cord symptoms or myelopathy.[4]

Hypertrophy and ossification of the ligamentum flavum are the main causes of spinal canal stenosis and myelopathy, which are induced by degeneration of fibroblasts in this ligament.[5] However, the precise pathogenesis of OLF is still unclear. This condition usually presents with progressive myelopathy. It can present acutely after minor trauma.[6]

Decompression is the only effective strategy for treating thoracic myelopathy caused by OLF. Several types of procedures are of proven effectiveness; these include *en bloc* dissection of lamina, laminectomy, and a microendoscopic technique.[6-8] There is a trend toward performing minimally invasive surgery, which is widely used in cervical,[9] lumbar,[10] and thoracic surgery,[11] to treat OLF, thus minimizing surgical trauma.[12]

During the last 25 years of spinal surgery, the development of smart technologies with the overall aim of reducing surgical trauma has resulted in various minimally invasive surgical techniques such as microsurgery, endoscopy, and various percutaneous techniques. Both these developments and improvements in implant materials have proven to be milestones in spinal surgery.[13]

Intraoperative navigation improves the accuracy of cervical pedicle screw placement by providing three-dimensional (3D) visual images that allow accurate guidance of the angle and depth.[14] Intraoperative 3D navigation systems, which offer the advantage of real-time observation in the axial, sagittal, and coronal planes, have been widely used in spine surgery.[9,11,15] Computer-assisted minimally invasive spine surgery (CAMISS) is a type of minimally invasive surgery that uses an intraoperative 3D navigation system to enable precise manipulation.[16]

METHODS

Patient data

This study included 14 consecutive patients with thoracic OLF (eight men and six women; mean age, 55.2 years) who underwent surgical treatment in our department from

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January 3, 2006 to June 9, 2012. The subjects provided written informed consent prior to inclusion in the study with the approval of our ethics committee. Relevant patient data are summarized in Table 1. Thoracic myelopathy was diagnosed and followed up by thorough neurological examinations and imaging studies, including plain radiography (Figure 1), computed tomography (CT) scans with or without myelography (Figures 2–4), and magnetic resonance imaging (MRI, Figure 2). Radiographic evaluation included identifying the location of the OLF and assessing spinal cord compression.

Table 1. Summary of operations on 14 patients with thoracic myelopathy due to OLF

Case No.	Sex	Age (years)	Segment (s)	Blood loss (ml)	Operation time (min)	JOA score (BP/6 m/final)
1	M	54	T9–11	500	180	6/8/9
2	M	73	T10/11	300	150	5/7/8
3	M	67	T9/10	500	220	8/9/10
4	M	42	T10/11	200	120	5/7/8
5	F	55	T2–4	150	115	6/8/9
6	M	45	T9/10	100	180	7/8/9
7	F	55	T12/L1	300	110	4/6/7
8	M	54	T10/11	500	105	4/6/7
9	F	64	T9/10	400	165	6/7/8
10	M	43	T10–12	450	220	7/9/10
11	F	57	T10/11	500	195	7/11/11
12	F	54	T11/12	200	120	7/8/9
13	F	51	T9–11	450	125	7/8/9
14	M	59	T11/12	100	100	7/7/7

BP: before operation; JOA: Japanese Orthopedic Association; OLF: ossification of the ligament flavum.

Surgical procedure

Spinal cord decompression levels were determined preoperatively based on the patient's neurological status and evaluation of radiological images, together with the findings on preoperative fluoroscopy with k-wires. Spinal cord activity was recorded using electrophysiological monitoring techniques. Decompression was performed mainly with a high-speed drill. The high-speed drill was registered by a tracker connected to the intraoperative 3D navigation system (Figure 5) and resection of the ossified ligamentum flavum was performed with the guidance of direct 3D views on the monitor (Figure 6). The borders of the OLF were clearly visible in these views. First, a dome was made in the spinous process to facilitate subsequent decompression with the high-speed drill. Next, the border of the OLF was drilled to a thin shell. With the aid of a curette or Kerrison laminectomy rongeur, the borders of the shell were severed and the OLF with/without associated ossified dura mater (ODM) gradually lifted off the arachnoid membrane/dura mater. Finally, the whole OLF plus ODM/OLF were removed to complete the decompression.

Intraoperative 3D image guidance was provided by the ARCADIS Orbic 3D system (Siemens Medical Solutions, Erlangen, Germany) together with navigation software (Stryker Spine Navigation System, MI, USA).

Neurological evaluation

Clinical results were assessed with the Japanese Orthopedic

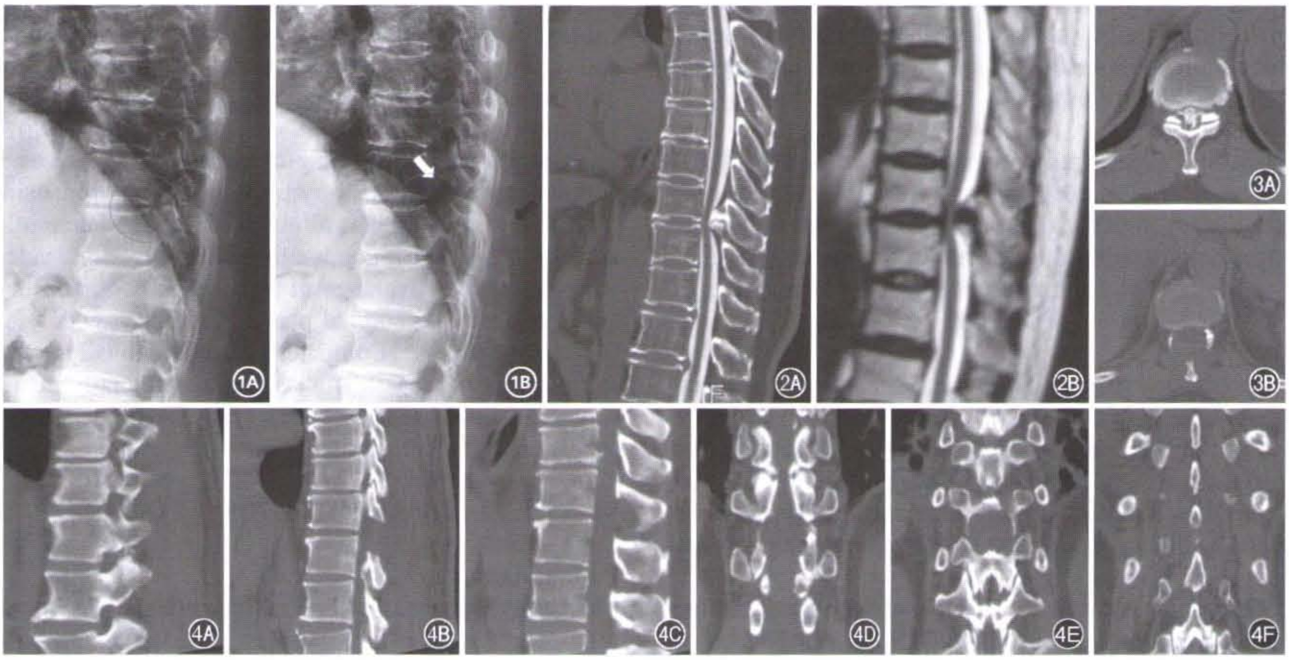

Figure 1. Preoperative and postoperative lateral X-ray films. The red circle indicates the segment to be operated on. **1A:** ossification of the ligament flavum (OLF) is visible. **1B:** the OLF has been resected (white arrow) and the spinous process has been preserved (black arrow).

Figure 2. Preoperative computed tomography myelography (CTM, **2A**) and magnetic resonance imaging (MRI, **2B**). The ossification of the ligament flavum (OLF) and compression of the spinal cord are clearly visible.

Figure 3. Preoperative and postoperative axial computed tomography myelography (CTM)/ computed tomography (CT) views. **3A:** ossification of the ligament flavum (OLF) is clearly visible as a compression. **3B:** the OLF has been resected and the spinous process and facet joint have both been partially preserved.

Figure 4. Postoperative coronal and sagittal computed tomography (CT) views of reconstruction. The spinous process and facet joint have both been partially preserved (**4A–4F**).

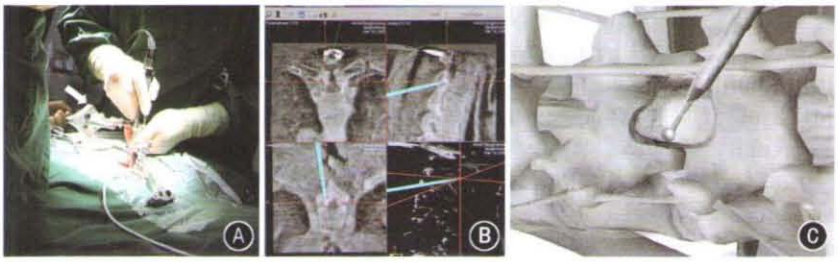

Figure 5. Decompression with the intraoperative guidance of a three-dimensional (3D) navigation system (**A**). The high-speed drill is registered by a tracker (white arrow), allowing the surgeon to directly view the decompression area on the monitor (**B**, **C**).

Association (JOA) scoring system for thoracic myelopathy (possible total of 11 points), which is derived from the JOA scoring system for cervical myelopathy (Table 2). JOA scoring was performed by a surgeon with 10 years' experience before surgery, 6 months after surgery, and at the final follow-up visit. The recovery rate was calculated as shown in Table 2. The Hirabayashi recovery rate (HRR) was calculated as excellent (100%–75%), good (74%–50%), fair (49%–25%), unchanged (24%–0%), and deteriorated (i.e., any decrease in score).[17,18] Statistical analysis was performed using the Wilcoxon rank test. A P value of less than 0.05 was considered statistically significant.

Table 2. JOA scoring system for thoracic myelopathy

Scores	Description
Lower extremity motor dysfunction	
0	Unable to walk
1	Able to walk on flat floor / walking aid
2	Able to walk upstairs &/or downstairs / handrail
3	Lack of stability & smooth reciprocation of gait
4	No dysfunction
Lower extremity sensory deficit	
0	Severe sensory loss or pain
1	Mild sensory loss
2	No deficit
Sensory deficit in trunk	
0	Severe sensory loss or pain
1	Mild sensory loss
2	No deficit
Sphincter dysfunction	
0	Unable to void
1	Marked difficulty in micturition
2	Minor difficulty in micturition
3	No dysfunction
Full score = 11 (normal)	

JOA: Japanese Orthopedic Association. The recovery rate was calculated according to the following formula: Recovery rate = (JOA score at follow-up–preoperative JOA score)/(11–preoperative JOA score)/100(%).

RESULTS

Surgical outcome

We assessed the location and number of involved surgical segments. In our study, four patients underwent surgery on two adjacent segments (two T9–11, one T2–4, and one T10–12). Ten patients underwent single level CAMISS; three T9/10, four T10/11, two T11/T12, and one T12/L1. Almost all surgical segments were in the lower thoracic spine. The mean operation time was 150.4 minutes (range 100–220 minutes). The mean intraoperative blood loss was 332.1 ml (range 100–500 ml). In two patients who underwent surgery on two adjacent segments, facet joint cancellous bone was also implanted.

Neurological outcome

The average JOA score of these patients improved from (6.1±1.2) points before surgery to (7.8±1.3) points at 6 months after surgery and (8.6±1.2) points at final follow-up (P <0.01). According to the JOA scoring system (Table 2), all patients achieved some degree of improvement in neurological status. The average HRR was 52.7% (excellent in two cases, good in eight, fair in three, and unchanged in one). No patient had postoperative deterioration in neurological status.

Complications

The only complication encountered was cerebrospinal fluid (CSF) leakage due to a dural tear during removal of adherent OLF with ODM (n=1). The CSF leakage was treated conservatively with intermittent drainage with a clip on the drain and local compression; intraoperative dural mater repair was not performed. By the last follow-up, no deterioration in neurological dysfunction, wound infection, kyphosis, or recurrence had occurred.

DISCUSSION

Fourteen consecutive patients with thoracic OLF were included in this study, with a mean age of 55.2 years. The prevalence of OLF increases with aging: it is reportedly highest in the 50–59 year age group, but may occur earlier. OLF occurs more frequently in the lower than in the upper and middle thoracic regions.[19] In our study, OLF occurred most frequently at the T10/T11 level, which is consistent

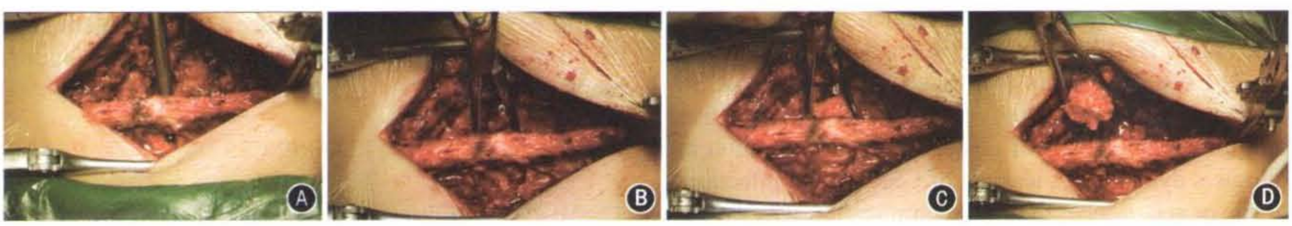

Figure 6. Resection of the ossification of the ligament flavum (OLF). A high-speed drill is used to resect the ossification and Kocher forceps to remove it (**A–D**).

with the report of Hirabayashi et al.[18]

The operative time for CAMISS for OLF and amount of blood loss vary. The learning curve for CAMISS may be partly responsible for this variation; the most recently performed procedure had the shortest operation time and least blood loss. The incidence of CSF leakage as a result of CAMISS was 7.1% (1/14). This low incidence may be attributable to having a direct 3D view of the OLF during the procedure. This view helped with separation of the OLF from the dural mater, minimizing tears in the dura mater. Even when ODM was present, the 3D view helped with separation of the ossified dural mater together with the OLF from the arachnoid membrane.

Decompressive surgery is indicated in patients in whom symptomatic thoracic spinal cord compression is caused by intruding OLF. Surgery should be performed as soon as possible, ideally before independent ambulatory function has been impaired.[20] CT with sagittal reconstructions and MRI are helpful for diagnosis and assessment of spinal cord involvement. When neurologic symptoms develop, decompressive laminectomy should be performed immediately. The surgical outcome is generally good provided hyperintense intramedullary signal changes in the spinal cord have not yet developed.[21]

Few clinical reports have focused on dural tears and CSF leakage after thoracic OLF surgery. Because dural adhesion and DO are common features of thoracic OLF, the incidence of CSF leakage in such patients is high and presents a significant clinical challenge.[22] In a case-control study, CSF leakage was the main complication, occurring predominantly in the patients with ODM. All leaks resolved in all patients after comprehensive treatment. However, DO had no effect on postoperative neurological recovery.[23]

In our study of CAMISS, the results were acceptable. According to JOA scores, all patients achieved varying degrees of improvement in neurological status; no patients deteriorated during follow-up. The average JOA score of these patients improved from (6.1 1.2) points before surgery to (8.6±1.2) points at the final follow-up (P <0.01). The average HRR was 52.7% and recovery was satisfactory in all patients.

En bloc resection without instrumented fusion is an alternative procedure for restoring the stability of the involved segments without repairing the dural defect. It is an effective treatment for OLF associated with DO in the thoracic spine. The mean increase in kyphosis is reportedly only 1.7±1.4 with 3 years follow-up.[24] In a study of 36 patients, *en bloc* resection proved to be safe and effective without the complications of postoperative deterioration in neurological dysfunction, leakage of CSF, wound infection, kyphosis, or recurrence; the only complication was a CSF cyst found in one patient 3 weeks postoperatively that had been absorbed spontaneously by 10 months after surgery.[25]

Laminectomy is both effective and safe for treating thoracic OLF; however, it must be performed with great care because of frequent dural adhesions to the OLF. The increase in kyphosis after laminectomy is minimal provided most of the facet joints are left intact and the patient engages in a back extensor exercise program postoperatively.[26]

Compared with the *en bloc* resection and laminectomy mentioned above, CAMISS for OLF preserves most of the structure of the posterior ligamentous complex and keeps most interspinous ligament(s) and the entire supraspinous ligament(s) intact. According to Denis's three-column theory, the surgical trauma of CAMISS only decreases the stability of the posterior column. In two patients who underwent surgery on two adjacent segments, the facet joints were implanted with autogenous cancellous bone graft to reduce the instability.

The microendoscopic technique offers an alternative decompression surgery for thoracic OLF. The procedure can provide sufficient decompression with minimal damage to the paraspinal muscles. However, because of its technical difficulties, the microendoscopic procedure is indicated only for selected patients with thoracic OLF, such as those with OLF without fusion in the middle of the spinal canal and OLF without DO.[8]

Because almost all the other strategies for decompression of OLF have limitations, CAMISS should be seriously considered. The current state of minimally invasive spine surgery is the result of a long period of development of consecutive smart technologies, along with stringent surgical training practices and improvements in instruments and techniques.[13] However, much effort in research and development is still mandatory to establish, maintain, and evolve minimally invasive spine surgery.[13]

According to our experience, when the procedure of CAMISS is performed, particular attention should be paid to the following points to ensure accuracy: (1) The navigation equipment should be placed in the appropriate position for receiving infrared signals. (2) The patient tracker should be firmly fixed during application of the navigation system. (3) The accuracy of the navigation should be checked by anatomical landmarks such as the spinous and articular processes. (4) Manipulations during the procedure should be performed in accordance with experience with the traditional approach. (5) Rough handling during the procedure may affect the accuracy by causing image drift. (6) Systematic training in the use of the navigation systems is needed to prevent failure or complications caused by incorrect or inaccurate manipulations.

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