ORIGINAL ARTICLE

Etiology of Cervical Myelopathy Induced by Ossification of the Posterior Longitudinal Ligament

Determining the Responsible Level of OPLL Myelopathy by Correlating Static Compression and Dynamic Factors

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Study Design: Retrospective study.

Objective: To determine the responsible level of cervical myelopathy induced by ossification of the posterior longitudinal ligament (OPLL). This was achieved by correlating the intervertebral range of motion (ROM) as the dynamic factor with the space available for spinal cord (SAC) as the static compression factor.

Summary of Background Data: The association between spinal canal stenosis and the occurrence of the myelopathy has previously been reported for OPLL patients, but not the detailed relationship between SAC, ROM, and myelopathy.

Methods: We investigated OPLL type, SAC, and ROM in relation to the responsible level of cervical OPLL myelopathy in 27 cases. SAC and ROM were measured at each vertebral and intervertebral levels. The responsible level was diagnosed using spinal cord-evoked potentials and classified as group A, whereas the nonresponsible level was classified as group B.

Results: Spinal cord-evoked potentials revealed 21 cases with a single responsible level and 6 cases with 2 responsible levels. The mean ROM of group A (8.9 degrees) was significantly higher ($P < 0.01$) than that of group B (5.7 degrees). The mean SAC of group A (8.2 mm) was significantly lower ($P < 0.01$) than that of group B (12.4 mm). Using discriminate analysis, significant differences for both SAC and ROM were observed between groups A and B [Box's M test: $\chi^2 = 3.31 < \chi^2_3$ (0.05)]. The discriminate formula for the borderline of symptomatic spinal compression can be described as: $Z = -0.21\text{ROM} + 0.47\text{SAC} - 2.76$.

Conclusions: Cervical OPLL myelopathy is induced by static factors, dynamic factors, or a combination of both. The discriminate formula for symptomatic cervical OPLL myelopathy contains both ROM and SAC.

Key Words: cervical spine, myelopathy, ossification of the posterior longitudinal ligament

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Ossification of the posterior longitudinal ligament (OPLL) is associated with a complicated spinal cord myelopathy. Spinal canal stenosis may occur at several vertebral levels, but all levels compressed by OPLL do not necessarily cause symptomatic spinal compression. Some patients with little ossification show myelopathy, whereas others with marked ossification do not. Static factors alone therefore cannot account for the pathogenesis of myelopathy induced by OPLL.

In this study, the space available for spinal cord (SAC, static compression factor) and the intervertebral range of motion (ROM, dynamic factor) were measured before surgery using lateral x-rays of the cervical spine.

SAC, ROM, and their relationship to the responsible level of spinal cord myelopathy induced by OPLL were evaluated. The responsible level of myelopathy was determined using spinal cord-evoked potentials (SCEPs).

CLINICAL MATERIALS AND METHODS

Twenty-seven patients (20 men and 7 women) who underwent cervical laminoplasty for cervical OPLL myelopathy were evaluated. The mean age of patients at the time of surgery was 62.4 years (range: 45 to 78 y). Informed consent was obtained from all patients.

SCEPs

Three types of SCEPs were measured: SCEPs after transcranial electrical stimulation (TCE-SCEPs), SCEPs after spinal cord stimulation (SC-SCEPs), and SCEPs after median nerve stimulation (MN-SCEPs).[1–3] For the recording of TCE-SCEPs, electrical stimulation was delivered with a duration of 0.2 ms and an intensity of 100 mA. The needle electrode was placed on the skull bilaterally at 7 cm lateral to the Cz position.

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Spinal cord stimulation was delivered by an epidural catheter electrode inserted caudally into the dorsal epidural space from the C7-T1 interlaminar space. The square wave pulse (0.2 ms duration, 3 Hz rate) was delivered at 1.5 times the SC-SCEPs threshold.

MN-SCEPs were recorded after median nerve stimulation at the wrist with a duration of 0.2 ms and an intensity of 20 to 30 mA.

All SCEPs were recorded intraoperatively using recording electrodes (13R25, Dantec, Denmark) inserted into the ligamentum flavum at each interlaminar space. As the reference, a needle electrode was inserted in subcutaneous tissue at the high thoracic level.

The bandwidth of the recording system was kept constant at 20 to 3000 Hz. All SCEPs were stored on hard disk using a standard-evoked potential/EMG machine (Nicolet Viking, Nicolet Biomedical). Averages were obtained for 100 to 200 MN-SCEPs, 20 to 30 TCE-SCEPs, and SC-SCEPs and the responses were superimposed.

TCE-SCEP abnormalities were diagnosed as attenuation of the D wave amplitude. The intervertebral disc level showing TCE-SCEPs with marked reduction in size of the negative peak (> 50%) was considered to present the upper level of the spinal cord lesion with respect to the corticospinal tract.[4] SC-SCEPs abnormalities were detected by marked reduction in size of the negative peak (> 50%). The intervertebral disc level showing the most abnormal SC-SCEPs was considered to represent the lower level of the spinal cord lesion with respect to the dorsal column. Abnormalities of MN-SCEPs were detected by attenuation of N13 amplitude compared with N13 amplitude at C6/7, as previously reported.[5]

Radiologic Evaluation

All patients were examined before surgery with radiographs of the cervical spine. These included lateral views in the flexion, neutral, and extension positions. The SAC in each vertebra was determined by the sagittal diameter of the spinal canal defined as the distance in millimeter between the posterior surface of OPLL and the nearest point on the corresponding anterior surface of the lamina. In addition, the angles between each vertebra were measured in flexion and extension using Scion Image (Scion Corp). ROM was defined as the difference between these 2 positions and was measured in degrees.

TABLE 1. Number With OPLL at Each Intervertebral Level

Number With OPLL				
C2/3	C3/4	C4/5	C5/6	C6/7
12	23	27	23	14

OPLL indicates ossification of the posterior longitudinal ligament.

Statistical Analysis

Responsible levels were defined as group A and nonresponsible levels as group B. The SAC and ROM of groups A and B were analyzed using unpaired t test. Box's M test was used in multivariate analysis to investigate the relationship between SAC and ROM and the responsible levels.

RESULTS

The OPLL was located at C2/3 in 12 cases, C3/4 in 23 cases, C4/5 in 27 cases, C5/6 in 23 cases, and C6/7 in 14 cases (Table 1). The mean SAC and mean ROM values for each intervertebral level are shown in Table 2, together with the range of values.

Results from the SCEP studies found that 21 cases had a single responsible level and 6 cases had 2 responsible levels. The responsible spinal compression levels were C3/4 in 8 cases, C4/5 in 15 cases, and C5/6 in 10 cases. The 6 cases with 2 responsible levels were all at C4/5 and C5/6. The responsible levels consisted of noncontinuous ossification levels in 10 cases, narrow spinal canal in 7 cases, edge of the OPLL in 4 cases, edge of the OPLL and noncontinuous ossification level in 3 cases, edge of the OPLL and the narrow spinal canal in 2 cases, and 2 noncontinuous ossification levels in 1 case (Table 3). In most cases, the responsible levels were diagnosed by MN-SCEP, with 1 case diagnosed by TCE-SCEP.

The mean SAC for group A (8.2 mm) was significantly lower ($P < 0.001$) than for group B (11.4 mm), whereas the mean ROM for group A (8.9 degrees) was significantly higher ($P < 0.001$) than for group B (5.7 degrees) (Table 4).

According to discriminate analysis [Box's M test: $\chi^2 = 3.31 < \chi^2_3\ (0.05)$] the combination of SAC and ROM were significantly different between groups A and B. The discriminate formula for the borderline of symptomatic spinal compression is shown in Figure 1 as: $Z = -0.21\text{ROM} + 0.47\text{SAC} - 2.76$.

TABLE 2. Mean and Range of SAC and ROM at Each Intervertebral Level

	Mean (Range)				
	C2/3	C3/4	C4/5	C5/6	C6/7
SAC (mm)	13.0 (8-18)	9.6 (6-14)	8.8 (5-13)	9.8 (5-18)	12.0 (5-16)
ROM (degrees)	3.4 (1.0-6.7)	7.1 (0-17.4)	7.9 (0-17.3)	7.4 (0-17.3)	7.3 (0-21.6)

ROM indicates range of motion; SAC, space available for spinal cord.

TABLE 3. Ossification Levels and the Responsible Levels for Each Case

Case	Ossification Levels	Responsible Levels
1	C2-C5/6	C4/5
2	C2-C5/6	C4/5
3	C2-C5/6	C5/6
4	C2-C4/5	C3/4
5	C2/3-C4/5	C3/4
6	C3/4-C6	C3/4
7	C3/4-C5/6	C4/5, C5/6
8	C4-C5/6	C4/5
9	C4/5-C6	C4/5, C5/6
10	C2, C3, C4, C5, C6	C5/6
11	C3, C4, C5, C6	C5/6
12	C4, C5, C6	C4/5, C5/6
13	C4, C5, C6	C4/5
14	C4, C5, C6	C4/5
15	C4, C5	C4/5, C5/6
16	C4	C4/5
17	C5, C6, C7	C4/5, C5/6
18	C2-C5/6, C5/6-C7	C3/4
19	C2-C4/5, C5, C6	C3/4
20	C2-C3/4, C4, C5, C6	C3/4
21	C2-C3/4, C4, C5, C6	C3/4
22	C2-C3/4, C4, C5	C4/5, C5/6
23	C2-C3/4, C4	C3/4
24	C4, C4/5-C6/7, C7	C4/5
25	C4, C4/5-C6/7	C4/5
26	C4, C4/5-C6/7	C5/6
27	C4/5-C5/6, C5/6-C6/7	C4/5

DISCUSSION

Matsunaga et al[6] reported that SAC values of < 6 mm induced myelopathy of the cervical spine. These workers suggested that pathologic compression might be the most significant causal factor for myelopathy beyond a certain critical point. Before that point, dynamic factors might be largely responsible for the development of myelopathy. Importantly, however, Matsunaga et al[6] used the ROM value for the entire cervical spine as the representative dynamic factor.

In this study, SAC and ROM were evaluated at each vertebral and intervertebral levels as contributing factors for OPLL myelopathy. The responsible level was determined using electro-physiologic methods, thus allowing the mechanism of cervical OPLL myelopathy to be examined in greater detail.

TABLE 4. Mean SAC and ROM of Groups A and B at Each Vertebral Level

	Mean SAC/Mean ROM					
	C2/3	C3/4	C4/5	C5/6	C6/7	Total
Group A	–/–	8.3/7.2	8.2/9.6	8.0/9.1	–/–	8.2/8.9*
Group B	12.7/3.4	10.2/6.9	9.6/5.7	10.9/6.4	12.5/7.3	11.4/5.7*

The mean SAC for group A was significantly lower ($P < 0.001$) than group B. The mean ROM for group A was significantly higher ($P < 0.001$) than for group B.
*$P < 0.001$.
ROM indicates range of motion; SAC, space available for spinal cord.

Holmes et al[7] measured the ROM of each vertebra using a method that involved tracing to paper. In this study, the ROM at each intervertebral level was evaluated using computer software (Scion Image), thus making it possible to measure intervertebral motion (ROM) using a more convenient and accurate method. In the study by Holmes et al,[7] the highest average ROM for normal patients (n = 50) was at C4/5 and the second highest was at C5/6. In the current series compromising OPLL cases only, the highest average ROM was at C6/7.

Shimoji et al[8] were the first to report a method for recording spinal potentials arising from peripheral nerve stimulation in humans. Others have subsequently reported on the usefulness of SCEPs for determining the responsible level of cervical OPLL myelopathy.[1–3,9] In this series, 3 types of SCEPs (TCE-SCEPs, MN-SCEPs, and SC-SCEPs) were used to determine the responsible level of myelopathy. Using these methods, we were able to precisely evaluate the relationship between SAC, ROM, and the responsible levels of myelopathy at each intervertebral level.

The borderline of symptomatic spinal compression can be described by a formula that includes SAC as the static factor and ROM as the dynamic factor. Some of the patients in our study showed symptomatic spinal compression at the noncontinuous part of the ossification or at the edge of the OPLL. In other cases, the symptomatic spinal compression levels were at the narrow part of the SAC. These findings suggest that myelopathy is caused not just by compression but also by intervertebral motion or a combination of both factors.

The mechanism of OPLL myelopathy is in some ways similar to the myelopathy observed in elderly patients. In these cases, the symptomatic spinal compression occurs at upper instability levels, even if compressions are apparent at several levels on magnetic resonance imaging. Tani et al[10,11] reported an association between degenerative spondylolisthesis of the cervical spine and conduction block at upper cervical levels. These workers found that degenerative spondylolisthesis cases accompanied by conduction block had significantly greater displacement with greater angular mobility than cases without conduction block. This implies that motion is a very important factor in the mechanism of spinal myelopathy.

There have been several reports on operative techniques for myelopathy caused by OPLL with most focused on decompression of the spinal cord. Anterior decompression by resection of the OPLL and anterior interbody fusion technique has been widely used as the operative method. However, Onari et al[12] reported that anterior interbody fusion without decompression was effective for cervical OPLL myelopathy. This again suggests that the intervertebral motion is involved with the cause of OPLL myelopathy. According to our study, anterior interbody fusion would be effective when SAC is < 5.15 mm.

In summary, our investigation of OPLL myelopathy focused not only on static compression using SAC but also on the precise evaluation of dynamic factors at each

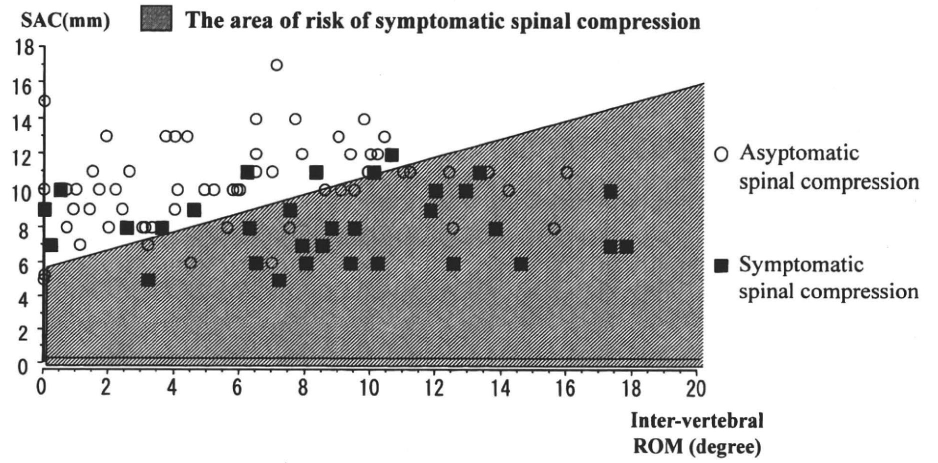

FIGURE 1. Borderline of symptomatic spinal compression of OPLL. The area under the line is the risk of responsible levels of OPLL myelopathy. The discriminate formula was: $Z = -0.21\text{ROM} + 0.47\text{SAC} - 2.76$. OPLL indicates ossification of the posterior longitudinal ligament. ROM, range of motion; SAC, space available for spinal cord.

intervertebral ROM. Our analysis revealed that even with a ROM value of 0 degrees, a case whose SAC was < 2.86 mm would still be at risk of developing myelopathy. Equally, a case whose SAC was 10.0 mm and ROM was > 9.78 degrees would also be at risk of developing myelopathy. Thus, cervical OPLL myelopathy can be induced by compression represented by SAC, by dynamic factors represented by ROM, or a combination of both. A discriminate formula for cervical OPLL myelopathy containing both the SAC and ROM variables was established.

CONCLUSIONS

The relationship of SAC as the compression factor and ROM as the dynamic factor to the relationship level of cervical OPLL myelopathy was investigated in 27 cases. To precisely evaluate each factor and the responsible level, SAC and ROM were measured at each vertebral and intervertebral level and the responsible level was determined by SCEPs. We concluded that cervical OPLL myelopathy is induced by compression factors, dynamic factors, or a combination of both. A discriminate formula containing SAC and ROM was developed for symptomatic cervical OPLL myelopathy.

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ORIGINAL ARTICLE

Clinical outcomes of microendoscopic decompression surgery for cervical myelopathy

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Abstract Retrospective study on the results of microendoscopic decompression surgery for the treatment of cervical myelopathy. The purpose of this study was to describe the microendoscopic laminoplasty (MEL) technique as the surgical method in the treatment of cervical myelopathy, and to document the clinical outcomes for MEL surgery. Endoscopic surgery poses several challenges for the aspiring endoscopic surgeons, the most critical of which is mastering hand–eye coordination. With training in live animal and cadaver surgery, the technical progress has reduced the problem of morbidity following surgery. The authors have performed microendoscopic decompression surgery on more than 2,000 patients for lumbar spinal canal stenosis. Fifty-one patients underwent the posterior decompression surgery using microendoscopy for cervical myelopathy at authors' institute. The average age was 62.9 years. The criteria for exclusion were cervical myelopathy with tumor, trauma, severe ossification of posterior longitudinal ligament, rheumatoid arthritis, pyogenic spondylitises, destructive spondylo-arthropathies, and other combined spinal lesions. The items evaluated were neurological evaluation, recovery rates; these were calculated following examination using the Hirabayashi's method with the criteria proposed by the Japanese Orthopaedic Association scoring system (JOA score). The mean follow-up period was 20.3 months. The average of JOA score was 10.1 points at the initial examination and 13.6 points at the final follow-up. The average recovery rate was 52.5%. The recovery rate according to surgical levels was, respectively, 56.5% in one level, 46.3% in two levels and 54.1% in more than three levels. The complications were as follows: one patient sustained a pin-hole-like dura mater injury inflicted by a high-speed air-drill during surgery, one patient developed an epidural hematoma 3 days after surgery, and two patients had the C5 nerve root palsy after surgery. The epidural hematoma was removed by the microendoscopy. All two C5 palsy improved with conservative therapy, such as a neck collar. These four patients on complications have returned to work at the final follow-up. This observation suggests that the clinical outcomes of microendoscopic surgery for cervical myelopathy were excellent or showed good results. This minimally invasive technique would be helpful in choosing a surgical method for cervical myelopathy.

Keywords Cervical spine · Clinical outcome · Endoscopic surgery · Laminoplasty · Myelopathy

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Introduction

Minimally invasive spinal procedures are currently being used effectively to treat a variety of commonly encountered degenerative conditions of the lumbar [7, 9, 13, 16], thoracic [10] and cervical spine [1, 4, 21]. These developments have led to surgical approaches to the spine that can result in less tissue trauma and reduce a patient's post-operative pain and discomfort, shorten hospital stays, and allow a quicker return to activities of daily living.

Endoscopic surgery poses several challenges for the aspiring endoscopic surgeons, the most critical of which is mastering hand–eye coordination. With training in live animal and cadaver surgery, the technical progress has reduced some problems of morbidity following surgery, such as dural tear, neural deficit, and so on [5]. Recently, microendoscopic decompressive techniques have been developed and applied to various spine pathologies including lumbar spinal stenosis and cervical radiculopathy and myelopathy [1, 4, 7, 9, 13, 16, 21]. Over 2,000 patients of lumbar spinal canal stenosis have undergone the microendoscopic decompression surgery in authors' institution. The authors have been applying microendoscopic laminoplasty (MEL) as a minimally invasive strategy to cervical posterior decompression surgery. The purpose of this study was to describe the MEL technique (used in 51 patients) as the surgical method in the treatment of cervical myelopathy, and to document the clinical outcomes for MEL surgery.

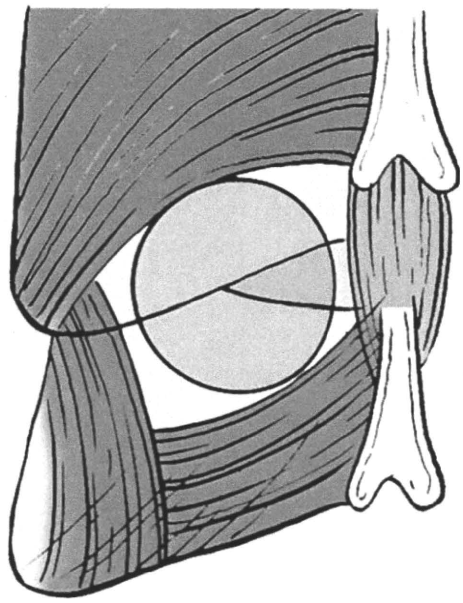

Fig. 1 The tubular retractor of microendoscopic system lies on the lamina and facet joint

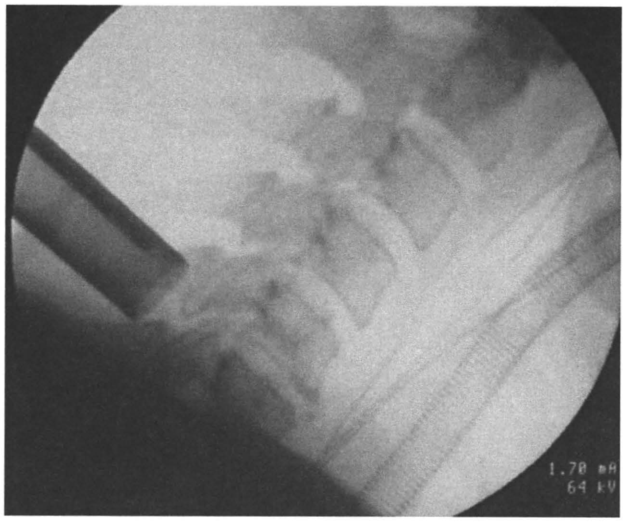

Fig. 2 The tubular retractor of microendoscopic system is tilted to the direction of the intervertebral disc. The setting position is confirmed by X-ray

Materials and methods

Surgical technique of cervical microendoscopic laminoplasty (C-MEL)

General endotracheal anesthesia was induced with adequate intravenous access and an intra-arterial monitoring catheter. The patient was secured in a Mayfield headholder, and was turned to the prone position. The neck was fixed in a neutral position. The fluoroscopic C-arm was brought into the surgical field so that real-time lateral fluoroscopic images could be obtained. The operator generally stood on the side of the approach and video monitors placed opposite to him. Under fluoroscopic guidance held laterally to the patient, the targeting level was marked on the side of the approach. A skin incision approximately 17 mm in length was made at the spinal level to be decompressed. The microendoscopic discectomy (MED) and instrumentation developed by Smith and Foley [16] for lumbar disc disease were used for this procedure. After splitting into paravertebral muscles, the set of serial dilators of the METRx endoscopic system (Medtronic Sofamor Danek, Memphis, TN, USA) was passed to gently dilate the cervical musculature. The 16-mm final working channel was then passed over the dilators and secured to the flexible-arm of the METRx retractor mounted to the table side rail. Final fluoroscopic confirmation of the working channel position was obtained, and the serial dilators were removed. The tubular retractor lay on the lamina and facet joints (Fig. 1), and was tilted parallel to the intervertebral disc (Fig. 2). The endoscope was then attached to the tubular retractor. Bipolar cautery was used to remove any residual muscular and soft tissues overlying the lamina and facet joint in the tubular retractor. With the bony edges well visualized, a small angled endoscopic curette was used to confirm the inter-lamina space and the medial edge of the fact complex. To begin the partial laminectomy (Fig. 3a), a high-speed drill with a long curved endoscopic bit (e.g., Midas-Rex) was used to thin the lamina near the attachment of ligamentum flavum. After adequate drilling, endoscopic Kerrison's rongeurs were used to continue the removal of the lamina. The superior attachment of ligamentum flavum was exposed, and the procedure was then continued to the superior portion of the inferior lamina. The inferior attachment of ligamentum flavum was

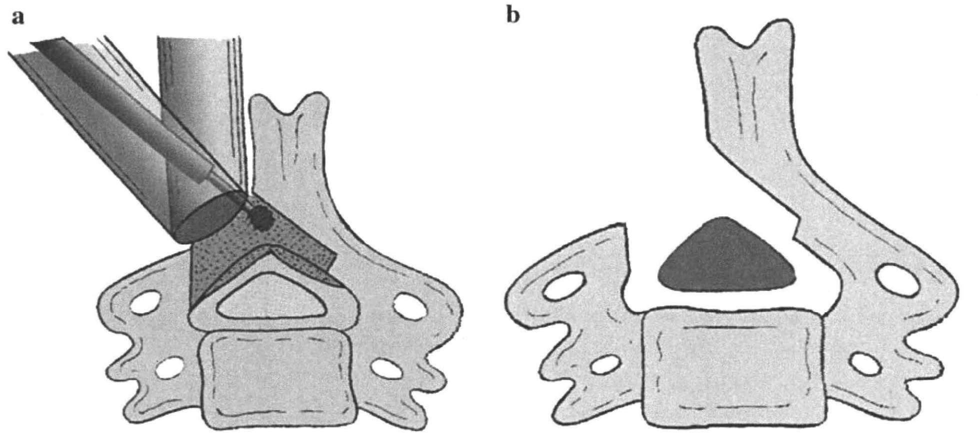

Fig. 3 The decompression surgery is preformed using a high-speed air-drill. **a** The hemilaminectomy is performed on the approaching side, and then the laminotomy on the contralateral side is done. **b** Finally, the laminoplasty is completed to enlarge the spinal canal

exposed. The endoscope was then swung medially and downward to obtain a contralateral view. After the basement of spinal process was drilled, the laminotomy was performed by a long curved high-speed drill with an endoscopic bit (Fig. 3b). The scope was rotated to a lateral position to make use of its 25° viewing angle. As a result of these maneuvers, an excellent viewing angle of nearly 60 to 75° was usually obtained with good contralateral visualization. It was important to continue the contralateral procedure without removing the ligamentum flavum to protect the spinal cord. When the spinal cord was completely decompressed, the floated ligamentum flavum was observed. Attention was directed to removing the ligamentum flavum. A small angled curette, nerve hook, or endoscopic Kerrison's rongeurs was used to gently dissect the ligament and to identify the plane between the ligamentum flavum and the underlying dura. When the ligamentum flavum was completely removed, the dural pulsation was observed. The C-MEL was completed (Fig. 3c). When the decompression surgery was needed for an adjacent level, the tubular retractor was inclined cranially or caudally. Then, the procedure as the above was added to the adjacent level. For more than three levels another skin incision was added. For example, in case of C3–C7 C-MEL, the skin incisions were made on C4 and C6 levels. A drain was placed at each level to prevent epidural hematoma after surgery. The tubular retractor and endoscope were removed, and the fascia and skin were closed using standard techniques. The drain was placed at the operative level(s) for 48 h to prevent the epidural hematoma after surgery.

Patient population

Between 2003 and 2008, a total of 51 patients with cervical myelopathy underwent this C-MEL at authors' institution. The criteria for exclusion were cervical myelopathy with tumor, trauma, severe ossification of posterior longitudinal ligament (OPLL), rheumatoid arthritis, pyogenic spondylitises, destructive spondylo-arthropathies, and other combined spinal lesion. There were 34 males and 17 females. The average age at the time of surgery was 62.9 years (range 24–85 years). All patients presented with symptoms of cervical myelopathy, such as clumsiness, numbness of upper and lower extremities, gait disturbance, and urinary disturbance. There were 44 patients with cervical spondylotic myelopathy (CSM), 4 patients with cervical myelopathy due to the calcification of ligamentum flavum (CLF), and 3 patients with cervical intervertebral disc herniation. The spinal cord compression was confirmed by magnetic resonance imaging (MRI), myelography and post-myelography computed tomography (CTM). The following items were assessed both pre- and postoperatively. A contributed lesion was reviewed by a symptom, neurological deficiency and imaging. As much as 26 patients suffered cervical myelopathy on one level, 17 patients on two levels, and 8 patients on more than three levels. These items evaluated were clinical outcomes including complications, neurological evaluation, and recovery rates, which were calculated following examination using Hirabayashi's method with the criteria proposed by the Japanese Orthopaedic Association scoring system (JOA score) [6, 22], blood loss during surgery, change of C reactive protein (CRP), visual analog scale (VAS) for assessment of treatment of axial pain, Short Form 36 (SF-36). The recovery rate was calculated as follows: recovery rate = 100 × (postoperative JOA score − preoperative JOA score)/(17 − preoperative JOA score).

Statistical analysis

All parameters were analyzed statistically. Either nonparametric Kruskal–Wallis test or Spearman's correlation coefficient by rank test was used to test differences in the recovery rate of JOA score between groups. The Mann–Whitney *U* test was used to test differences in the SF-36 subscales between preoperative and the final follow-up. A probability level of <0.05 was considered significant.

Results

The mean follow-up period was 20.3 months (6–56 months). The average of JOA score was 10.1 ± 2.7 points before surgery and 13.6 ± 2.3 points at the final follow-up. The average recovery rate was 52.5 ± 20.3% (Table 1). The duration of symptoms before surgery was an average of 20.1 months (range 1–78 months), and there was no correlation between the duration of symptoms and recovery rates (Spearman's correlation coefficient by rank test; $p = 0.6$). As for the contributed levels, the recovery rate was 56.5% on one level, 46.3% on two levels, and 54.1% on more than 3 levels. There were no significant differences between the contributed levels and recovery rates (Kruskal–Wallis test; $p = 0.065$). Four patients had some perioperative complications. One patient sustained a pin-hole-like dura mater injury inflicted by a high-speed air-drill during surgery. There was little leakage of the cerebrospinal fluid. So, fibrin paste was wound up on dura mater. In another patient who had undergone the C-MEL on one level, although the postoperative drain was retained on the epidural space for 48 h, the spinal cord was compressed by the epidural hematoma 3 days after surgery. He had the progressive quadriplegia, and underwent the emergency surgery to remove the epidural hematoma using microendoscopy. His quadriplegia improved immediately after surgery. After the C-MEL surgery on two or three levels, there were two patients who had temporal C5 nerve root palsy. These two patients were not able to evaluate their upper extremity on the corresponded side to the opened lamina (hemilaminectomy). Their neurological symptoms improved with conservative treatment on a Philadelphia collar. Both patients were able to evaluate their upper extremity a few months later. One of the two patients improved to a full score in manual muscle testing (MMT) for both deltoid and biceps muscles.

The mean amount of blood loss in surgery was 35.4 ml on one level, 22.9 ml on two levels, and 44.4 ml on more than three levels. The surgical time was an average of 106 min on one level, 146.4 min on two levels, and 178.2 min on more than three levels. The mean value of CRP 3 days after surgery was 1.1 ± 1.4 mg/dl (normal: <0.3). All patients could get up after awakening from anesthesia immediately and participated in rehabilitation from an early postoperative period. The average period of hospital stay was 8.6 days (range 4–21 days). There was no correlation between the JOA score before surgery and hospital stay (Spearman's correlation coefficient by rank test; $p = 0.28$). The VAS of axial symptoms was 46 ± 45 mm before surgery and 15 ± 22 mm at the final follow-up. There was none of the patients whose axial symptoms worsened postoperatively. As for the SF-36, all subscales at the final follow-up have been improved. The scores of role physical, bodily pain, social functioning, and role emotional subscales at the final follow-up were significantly higher than that before surgery (Mann–Whitney *U* test; $p < 0.05$, Fig. 4). On the alignment of cervical spine after surgery, no patient changed to kyphosis postoperatively. The lordotic angle of cervical spine (C2–C7) was 13.1 ± 14.0° before surgery and 13.5 ± 14.9° at the final follow-up (Table 1). The local angle of the surgical level was 6.7 ± 10.4° before surgery and 6.7 ± 9.1° at the final follow-up.

Table 1 JOA score and cervical alignment after C-MEL surgery

	Pre-operation	Final follow-up
JOA score (points)	10.1 ± 2.7	13.6 ± 2.3
Recovery rate (%) (JOA score)		52.5 ± 20.3
Lordotic angle (degree) (C2–C7)	13.1 ± 14.0	13.5 ± 14.9

Case presentation

Case 1

A 59-year-old woman noticed clumsiness in her finger motions and numbness in both her hands. She attended the authors' clinic, where she presented in a wheelchair and revealed urinary disturbance. An MRI and CTM showed severe spinal compression caused by the calcification of

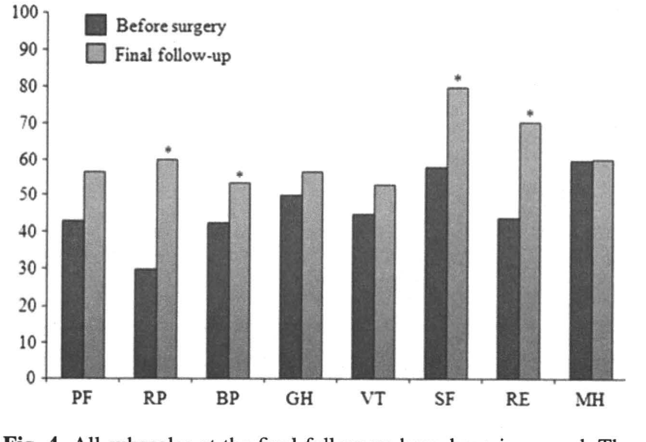

Fig. 4 All subscales at the final follow-up have been improved. The scores of RP, BP, SF, and RE subscales at the final follow-up were significantly higher than that before surgery. (*PF* physical functioning, *RP* role physical, *BP* bodily pain, *SF* social functioning, *GH* general health perceptions, *VT* vitality, *RE* role emotional, *MH* mental health) Significantly different from before surgery (Mann–Whitney *U* test, $^*p < 0.05$)

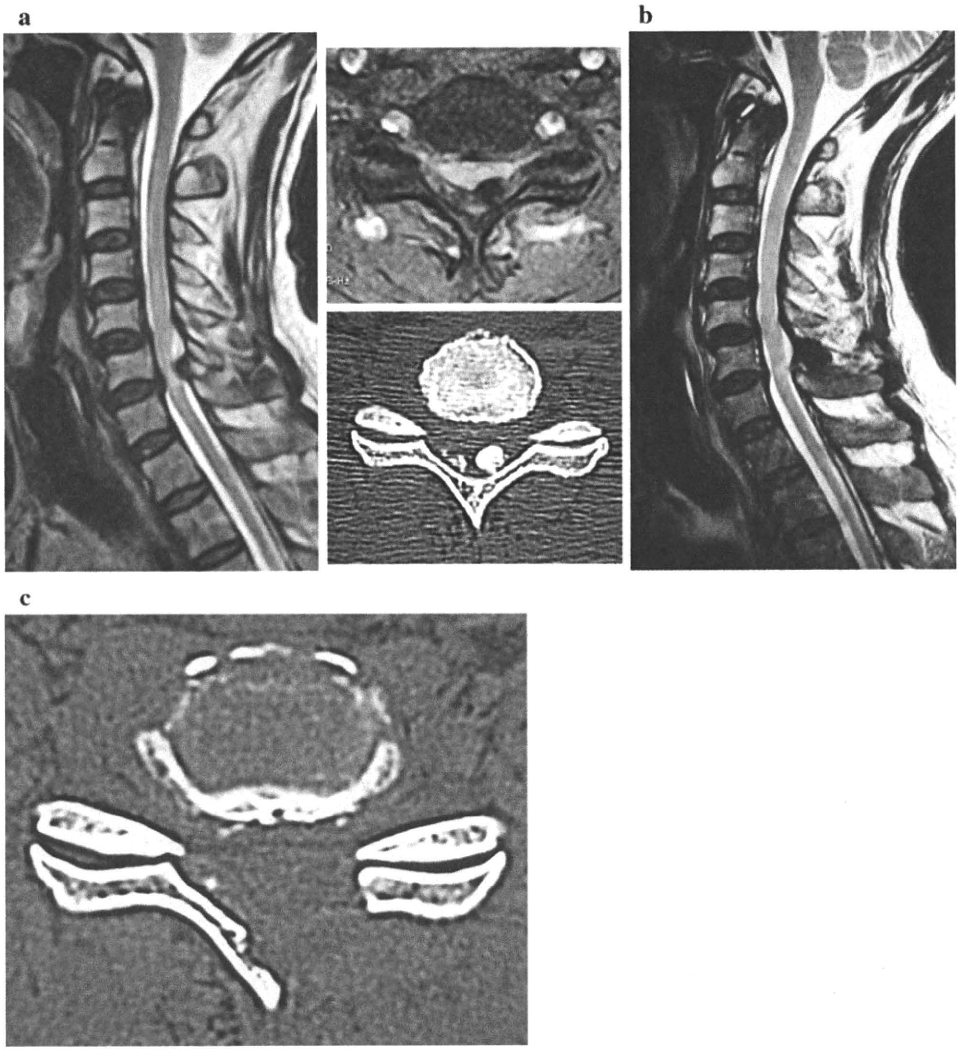

Fig. 5 **a** The 67-year-old patient had cervical myelopathy due to the calcification of ligamentum flavum at C6–C7. The JOA score was 8 points at the initial examination. **b, c** He underwent the microendoscopic laminoplasty at C6–C7, and the spinal cord was decompressed. The JOA score was improving to 14 points at the final follow-up

ligamentum flavum (CLF) at C6–C7. She underwent the C-MEL surgery at C6–C7, and the spinal cord was decompressed. Three years after surgery, her preoperative JOA score improved from 8 to 14 points. The recovery rate of JOA score was 66.7%. This case is presented in Fig. 5.

Case 2

A 64-year-old woman had noticed numbness in both her arms and hands. Gait and urinary disturbance developed gradually, and she visited the authors' outpatient clinic. The patient presented with spastic quadriparesis, and an MRI showed severe multilevel spinal cord compression by cervical spondylotic myelopathy. She underwent the C-MEL surgery from C4 to C7. Although the spinal cord showed the presence of T2 high signal intensity on MR imaging, the posterior spinal decompression was successful as revealed on MRI after surgery. Two years after surgery, her preoperative JOA score of 9 points improved to 13 points. The recovery rate of JOA score was 50%. This case is presented in Fig. 6.

Discussion

Numerous studies in endoscopic surgical visualization have been made for the past decade [1, 4, 7, 9, 10, 13, 16, 21]. Endoscopic assisted procedures have become increasingly popular for the treatment of a wide range of pathologic conditions of the spine, including hyperhydrosis, herniated discs, and fractures. Microendoscopic-assisted decompressive surgeries have been developed in herniated discs and spinal canal stenosis in the lumbar spine [7, 9, 13, 16]. This procedure is attractive because of its small skin incision, gentle tissue dissection, excellent visualization, and ability to achieve results equivalent to those of the open techniques. Visualization of the canal, ligamentum flavum, and existing nerve root interface is facilitated by the

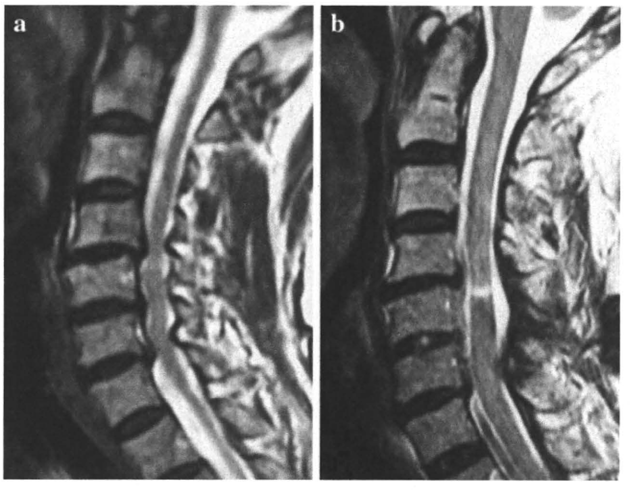

Fig. 6 **a** A 64-year-old patient had cervical spondylotic myelopathy at the multiple levels. The JOA score was 9 points at the initial examination. **b** She underwent the microendoscopic laminoplasty from C4 to C7. Although the spinal cord was the presence of T2 high signal intensity on MR imaging, the posterior spinal decompression was successful. The JOA score was improving to 13 points at 24 months after surgery

endoscope's 25° viewing angle. Successive angulations of the working channel into a more lateral and horizontal positions allow access to the contralateral dorsal spinal canal because of the endoscope's 25° angle. This visualization is superior to that of the unilateral open technique, wherein such an extreme contralateral angle of visualization is impossible to obtain with the operating microscope. The endoscopy provides wide visualization through the oblique lens, and the microendoscopic-assisted procedure also allows bilateral decompression via a unilateral approach, the so-called ''unilateral approach and bilateral decompression'' [11, 15, 19, 20]. In this study, the microendoscopic procedure is the hemilaminectomy on the approaching side and the laminotomy on the contralateral side. Finally, the laminoplasty is completed to enlarge the spinal canal. Exposure of the contralateral attachment of ligamentum flavum is critical to ensuring adequate bilateral decompression. Repositioning the working channel enables the base of the spinous process to be drilled away. This can then be extended to the ventral surface of the contralateral lamina. It is important to keep the surgical procedure, such as drilling without removing the ligamentum flavum to protect the spinal cord. After removal of the ligamentum flavum, the operation is deemed complete when both the posterior protrusion and beat of dural sac are visualized.

This study demonstrates the feasibility of decompressing the spinal canal using a unilateral endoscopic technique [11, 15, 19, 20]. Considerable experience is required to decompress the neural structures adequately. Microendoscopic techniques do involve a very steep learning curve that must be diligently overcome [7, 14]. The field of view through the endoscope is limited, making it difficult to appreciate the amount of bony work that has been performed. The two-dimensional view and hand–eye spatial separation of the endoscopic view can also be extremely disorienting. Ensuring a satisfactory canal decompression, while respecting the integrity of neural elements clearly, requires training and experience. Although the adjustment is being expanded from lumbar spine to cervical spine, authors' institution makes a standard in the case of the expansion. The standard is that each surgeon needs cadaver training and much experience for lumbar spine diseases, such as herniated intervertebral disc and spinal canal stenosis.

The clinical outcomes of this microendoscopic decompression surgery for cervical myelopathy were excellent or showed good results equal to the reported conventional cervical expansive laminoplasty [2, 6, 8, 23]. The privilege of this surgical procedure was less invasive in comparison with the reported conventional cervical laminoplasty. In this study, the bleeding loss, CRP after surgery, VAS of axial pain, and hospital stay were less than those of conventional techniques in authors' institution as follows (unpublished data): 30 patients underwent the conventional cervical expansive laminoplasty from 2004 to 2006, (1) the recovery rate was 51.5 ± 24.5%, (2) the mean bleeding loss was 178 ± 198 ml, (3) the mean value of CRP 3 days after surgery was 2.8 ± 1.7 mg/dl, (4) the VAS of axial pain at the final follow-up was 32 ± 32 mm, and (5) the mean hospital stay was 16 ± 3.9 days. As for the perioperative complication of this study, the incidence of C5 nerve root palsy was 2/51 patients (3.9%), and was similar to that of the conventional cervical laminoplasty, which has been reported to average 4.7% (range 0–30%) [17]. The developmental nerve root palsy appeared several days following surgery. The tethering effect on the nerve root induced by excessive posterior shift of the spinal cord after decompression is another hypothesized cause supported by a number of investigators [3, 12, 17, 18], but whether it is the main cause is still controversial.

The indication of this procedure was focused on a cervical myelopathy at one or two levels based on posterior factors, such as calcification or ossification of ligamentum flavum, and spondylotic pincers mechanism. In the multiple levels, the indication was limited on the spondylotic myelopathy excluded the developmental canal stenosis and OPLL. The enlarged space of spinal canal of this procedure was limited in comparison with that of the conventional laminoplasty because of laminotomy technique. For the developmental canal stenosis and continuous or mixed type OPLL, other cervical decompressive surgeries, such as the conventional expansive laminoplasty or anterior corpectomy would be alternative.

Conclusion

This observation suggests that the clinical outcomes of microendoscopic decompression surgery for cervical myelopathy were excellent or showed good results although the number of cases was limited. This minimally invasive technique would be helpful in choosing a surgical method for cervical myelopathy. In future, the minimally invasive spinal surgery will have developed to do it more safely with transducing navigation system and high vision imaging system.

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Risk Factors for Early Reconstruction Failure of Multilevel Cervical Corpectomy With Dynamic Plate Fixation

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Study Design. Retrospective case series.

Objective. To investigate risk factors for early reconstruction failure of multilevel cervical corpectomy with dynamic plate fixation.

Summary of Background Data. For anterior cervical decompression and fusion, reinforcement by plate fixation was performed to decrease early reconstruction failure and to increase the fusion rate. However, a relatively high complication rate such as graft dislodgement, has been reported in patients undergoing multilevel corpectomy and reconstruction. Risk factors associated with early reconstruction failure have not been explicitly described.

Methods. In 30 instrumented multilevel corpectomy and reconstruction, medical records and radiographic studies were reviewed to investigate risk factors with regard to sagittal alignment of the cervical spine, graft subsidence, screws used in fixation, endplate preparation, and intermediate screw for fibular graft.

Results. Reconstruction failures included anterior slipping at the bottom of the graft in 2 cases, fracture of the C7 vertebral body in 2 cases, and pullout of a screw in 2 cases. Four patients were found to have nonunion of the graft at the final follow-up, but none had experienced early reconstruction failure.

On radiologic measurement, the fusion area lordotic angle after surgery in the patients with reconstruction failures was significantly larger than that of the patients with no complications. The postoperative C2–C7 lordotic angles of the patients with reconstruction failure were also larger, but this trend was not statistically significant. No other factor, such as age and gender, type of screw used, intermediate screw or preservation of the endplates was related to reconstruction failures in this study.

Conclusion. Postoperative cervical hyperlordosis may adversely affect graft stability in the early postoperative period of the surgery of corpectomy and reconstruction with dynamic plate fixation.

Key words: anterior cervical fusion, anterior cervical plate, complication, cervical myelopathy, ossification of longitudinal ligament. **Spine 2010;XX:000–000**

Corpectomy and reconstruction are the treatment of choice in patients with ossification of the posterior longitudinal ligament (OPLL) or spondylotic myelopathy with a kyphotic alignment of the cervical spine. We have previously reported that the anterior floating method appears to yield adequate long-term outcomes when used to treat OPLL.[1] However, a relatively high complication rate, which includes complications such as respiratory distress and graft dislodgement, has been reported in patients undergoing multilevel corpectomy and reconstruction. Previous studies have found that graft reinforcement with anterior plate fixation is expected to decrease early reconstruction failure and to increase the fusion rate in patients undergoing multilevel corpectomy.[2,3]

However, Sasso *et al* reported a 71% failure rate after 3-level fixed plated reconstruction.[4] Daubs also reported an extremely high early failure rate (75%) with the use of a titanium mesh cage and a fixed anterior plate for reconstruction in patients undergoing multilevel corpectomies.[5] Interestingly, in a biomechanical experiment, Brodke *et al* found that a static plate loses its load-sharing capacity after 10% subsidence has occurred.[6] In contrast, with regard to the choice of the type of fixation that is used (*i.e.*, a constrained *vs.* a semiconstrained plate), most recent studies have reported that dynamic plate designs provide a faster fusion of the cervical spine in comparison to rigid plate designs.[7–10] In these reports, however, the authors did not include a detailed discussion of the complications associated with early reconstruction failure in multilevel corpectomy.[11]

This article details the results of a retrospective study of the factors associated with early reconstruction failure in patients undergoing multilevel corpectomy with dynamic plate fixation. Specifically, we review the preoperative and postoperative sagittal alignment of the cervical spine, the screws used in fixation, the use (or lack of use) of an intermediate screw for fibula grafts, the methods that were used for endplate preparation, and the characteristics of patients who required repeat surgery in the early postoperative period.

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Table 1. Characteristics of 30 Patients

Median age (range)	59 (44–79)
Gender (male:female)	27:3
Segments fused (cases)	
3	14
4	13
5	3
Type of fusion (fibula: hydroxyapatite)	
Long (LF)	25
Hybrid (HF)	5

LF indicates multilevel corpectomy and fusion; HF, a combination of segmental fusion and multilevel corpectomy with fusion.

Table 2. Complication

Neurological deterioration	
C5 palsy	2
Myelopathy	1
Reconstruction failure	
Graft migration	2*
C7 body fracture	2*
Screw pullout	2 (4)†

*One of the patients with graft migration and one of the patients with a C7 fracture had screws that had dislodged.
†Two patients showed only dislodged screws; this event coincided with graft migration and C7 fracture in other 2 patients.

Materials and Methods

Materials

Between 2000 and 2008, 31 patients with myelopathy caused by multilevel cervical spondylosis (n = 7) or OPLL (n = 24) underwent multilevel corpectomy and reconstruction with autologous fibula and anterior cervical plate placement. One patient with spondylotic amyotrophy was included in the group of patients with cervical spondylosis. Our patients were divided into 2 groups based on the operative methods we used: long fusion (LF) was defined as multilevel corpectomy and reconstruction without segmental fusion, and a hybrid group (HF) was defined as a combination of segmental fusion and multilevel corpectomy and reconstruction (Table 1). One patient treated with LF was lost to follow-up after within 1 year of surgery. Therefore, a total of 30 patients (3 female, 27 male) were observed for a minimum of 1 year after surgery. The average follow-up period was 3.5 years in this patient population. When we define a disc-level as "1 segment," we performed 3-segment (n = 14), 4-segment (n = 13), and 5-segement fusion (n = 3). In the LF group, there were 14 cases of 2-level corpectomy and reconstruction, 10 cases of 3-level corpectomy and reconstruction, and 1 case of 4-level corpectomy and reconstruction. In the HF group, there were 3 cases of 4-segment fusion (a discectomy and 2-level corpectomy), and 2 cases of 5-segment fusion (1- or 2-level discectomy and 3- or 2-level corpectomy, respectively).

Clinical results were evaluated using the Japanese Orthopedic Association (JOA) scoring system for cervical myelopathy, and the JOA score recovery rate was calculated using Hirabayashi 's method.[1]

The surgical procedure we used consisted of a standard anterior approach to the cervical spine with intraoperative spinal cord monitoring using motor-evoked potentials while the patient was under general anesthesia. No traction was used during the procedure. Lordosis of the cervical spine was maintained with a contoured foam pillow that was placed beneath the neck during the operation. Osteophytes that were compressing the spinal cord were removed using the microscope, and ossification of the posterior ligament was treated using an air drill such that the ligament was thinned and was allowed to migrate anteriorly (this is known as the "floating" method).[1,12] The endplates of the adjacent vertebral bodies were retained whenever possible but were sometimes removed to decompress areas of ossification behind the vertebral body or to better fit the vertebral column to the shape of the graft.

For reconstruction, a fibular bone graft reinforced by a rotationally dynamic plate was typically used. We used a fixed-type screw for the bottom and a variable-type screw for the top of the graft. This configuration allows the screws to pivot while preventing screw pullout.[7] A fibular bone graft reinforced by an anterior plate was used in 30 cases, and in 18 of these cases intermediate screws were added. The length and shape of the grafts were chosen such that the decompressed cervical column was extended slightly by mild manual distraction or with a Casper distractor.

The average operation time was 6 hours 3 minutes and ranged from 3 hours 25 minutes to 9 hours 15 minutes. The mean estimated blood loss during the operation was 440 mL (range: 70–2885 mL). Patients were permitted to walk 2 to 5 days after surgery and were placed in Philadelphia-type collars for 3 months. The length of admission ranged from 15 to 79 days (mean: 29 days). Patients' JOA scores before the operation ranged from 6 to 14.5 points with a mean of 11.0 ± 2.6 points. The JOA scores at the final follow-up appointment were 14.7 ± 2.3 points in the LF group and 14.9 ± 1.7 points in the HF group. The recovery rates of the JOA scores were 64.8% ± 27.9% in the LF group and 58.5% ± 50.5% in the HF group. Clinical outcomes did not differ significantly between the groups. Three patients experienced neurologic complications; 2 developed C5 palsy and 1 developed myelopathy (Table 2). One of the patients with C5 palsy also showed evidence of graft migration and screw pullout. All of the patients with neurologic complications had repeat surgery within 1 week after the initial surgery and had regained normal function by their 1-year follow-up appointment. Two of these patients displayed evidence of nonunion of the graft at their final follow-up appointment, which was most likely due to the fact that the graft was shortened somewhat during the second operation for neurologic complication. An additional 2 patients who had no particular risk factors also displayed evidence of nonunion at their 1-year follow-up appointments.

The clinical outcomes of these patients were not statistically significantly inferior to those of the patients who did not experience nonunion, but none of these 4 patients did exhibit early reconstruction failure.

Methods

This study is a case series of 30 patients who underwent multilevel corpectomy and reconstruction. Their medical records and radiographic studies were reviewed to investigate their individual risk factors for reconstruction failure.

We defined early reconstruction failure as graft migration, vertebral body fracture, or screw extrusion within 1 month of the index surgery regardless of whether it required repeat surgery. We examined the patients' surgical records to collect data regarding the type of screws that were used as well as whether the endplates were preserved. A series of lateral plain radiographs of the cervical spine were obtained to identify the presence of any implant or graft movement as well as to evaluate fusion status. Postoperative radiologic evaluation was performed on the radiographs that were taken within 1 week of surgery on the first day that patients were allowed to ambulate. Graft subsidence was defined as a >2 mm graft sinkage and was assessed by comparing lateral radiographs taken at 1 week and 1 month after the surgery. When either abnormal graft movement or screw pullout was suspected, a computer-assisted tomography (CT) scan was performed. This approach allowed us to detect fine fracture lines and anterior slippage at the bottom of the graft. Reformatted CT views that were obtained just after the surgery were also used for radiologic measurements when the borders of the C7 vertebral body were not clearly visible.

Sagittal alignment of the cervical spine was evaluated by measuring the C2–C7 angle between the tangential lines drawn from the posterior border of the C2 and C7 vertebral bodies. The lordotic angle of the fusion area was determined in a similar manner. The C7 horizontal angle was defined as the upper endplate angle of the C7 vertebral body viewed from the horizontal plane of the neutral lateral view. This angle was assessed with a radiograph that was taken with the patient in a sitting position. The graft was determined to have fused if there was absence of motion of the adjacent vertebral bodies and spinous processes in flexion-extension radiographs. We used the χ^2 test and Student's unpaired t test for our statistical analyses. All $P <$ 0.05 were considered to be statistically significant.

Results

The causes of reconstruction failures for which the patients underwent secondary operations included graft migration (n = 2), fracture of the C7 vertebral body (n = 2), and screw pullout (n = 2) (Table 2). Because one of the patients who experienced graft migration and one of the patients who experienced a C7 fracture also presented with screw pullout, a total of 4 patients had screws that had protruded. Four patients who had experienced graft migration or C7 fracture were treated by posterior spinous process wiring. Two patients with screw pullout had their implants removed after fusion was completed.

Reconstruction failures were observed in 5 patients in the LF group and in 1 patient in the HF group. A total of 1 of 14 patients who underwent 3-segment fusion, 3 of 13 patients who underwent 4-segment fusion, and 2 of 3 patients who underwent 5-segment fusion eventually presented with reconstruction failures. The number of segments that were fused was found to be statistically significantly related to the risk of reconstruction failures ($P < 0.05$). The following factors were not associated with reconstruction failure; nor with age, gender, the preservation of the vertebral endplates, screw type, the occurrence of postoperative graft subsidence within 1 month of surgery, and the use of intermediate screws for fibular grafting (Table 3).

With regard to radiologic measurements, the mean preoperative C2–C7 lordotic angle of patients who experienced reconstruction failure was 13.5° ± 10.9°, and that of the patients who did not experience any complications was 13.5° ± 17.1°. The fusion area lordotic angle of the patients who experienced reconstruction failure was 9.6° ± 13.1°, and that of the patients who did not experience complications was 7.4° ± 9.1°. There were no significant differences observed between the preoperative C2–C7 lordotic angles or the fusion area lordotic angles of these 2 groups.

Table 3. Factors Related to Reconstruction Failures

	Reconstruction Failures (6)	No Complication (24)	P
Average number of fused segments	4.2	3.5	$P < 0.05$
Removal of the top endplate of the fused area	4	6	$P < 0.1$
Removal of the bottom endplate of the fused area	4	13	n.s.
Fixed screw used at both ends	1	4*	n.s.
Intermediate screw	3/6	15/24†	n.s.
Subsidence	3	12	n.s

*No documentation about the screw in the 2 operative records.
†Excluding HA graft.

The postoperative C2–C7 lordotic angle of the patients who experienced reconstruction failures tended to be larger than those of patients who did not experience reconstruction failure, but this trend was not significant. The fusion area lordotic angle of the patients who experienced reconstruction failure was 15.6° ± 8.4°, which was significantly ($P < 0.05$) larger than that of the patients who did not experience reconstruction failure (8.6° ± 6.4°) (Figure 1). The C7 horizontal angle did not differ between these 2 groups. We did not observe any statistically significant differences between the groups with regard to changes in the C2–C7 lordotic angle or the fusion area lordotic angle (Table 4).

Discussion

Anterior cervical decompression and fusion is a valuable method for treating patients with cervical myelopathy caused by spondylosis or OPLL. However, among this procedure, a multilevel corpectomy and reconstruction are frequently accompanied by complications like plate

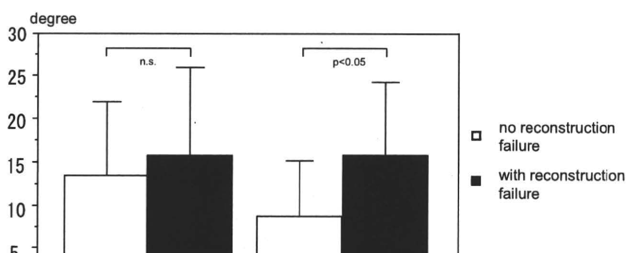

Figure 1. The postoperative C2–C7 lordotic angles and fusion area lordotic angles tended to be larger in patients who experienced reconstruction failure than they were in patients who did not experience reconstruction failure. The postoperative fusion area lordotic angles were statistically significant ($P < 0.05$).

Table 4. Radiological Measurements (Degrees)

	Reconstruction Failures (6)	No Complication (24)	*P*
C2–C7 lordotic angle	13.5 ± 17.1	13.5 ± 10.9	n.s
Fused area lordotic angle	9.6 ± 13.1	7.4 ± 9.1	n.s
PO C2–C7 lordotic angle	15.6 ± 10.2	13.3 ± 8.5	n.s
PO fused area lordotic angle	15.6 ± 8.4	8.6 ± 6.4	$P < 0.05$
C7 horizontal angle	22.7 ± 7.0	22.0 ± 6.8	n.s.
Change in C2–C7 lordotic angle	2.1 ± 11.8	−0.23 ± 7.4	n.s.
Change in fused area lordotic angle	3.1 ± 9.0	0.9 ± 8.9	n.s.

dislodgement and graft migration.[5,6,13] Figure 2 shows a typical case of graft subsidence and migration with screw pullout that occurred in the early postoperative period. Figure 3 shows images from another patient who also experienced early reconstruction failure. The original cervical curve of this patient was slightly lordotic, and we tried to change the alignment of the cervical spine more lordotic to decompress the spinal cord. However, screw pullout and fracture of C7 vertebra occurred during the early postoperative period. Reformatted CT views showed that the C2–C7 lordotic angle had increased after surgery and that C7 fracture had occurred.

In this study, 6 of 30 (20%) patients who underwent mutlilevel corpectomy and reconstruction without the use of a halo brace experienced reconstruction failures. The postoperative fusion area lordotic angle of the patients who experienced reconstruction failure was significantly larger than that of the patients who did not experience reconstruction failure (Figure 1). As seen in the scatter graph (Figure 4), 3 of the 6 patients who experienced early reconstruction failure exhibited postoperative fusion area lordotic angles of >15°. Although it is not easy to determine a cut-off with regard to the fusion area lordotic angle at which it is no longer advisable to perform this procedure, the risk of reconstruction failure may increase in patients with postoperative fusion area lordotic angles of >15°. In our study, this value (15°) was equal to the mean postoperative fusion area lordotic angle of the patients who did not experience reconstruction failure plus 1 standard deviation. Hyperlordosis of the cervical spine yields to high shear stress at the bottom of the fused segment, which can lead to anterior slippage of the construct. Herrmann and Geisler has pointed out that both device failure and pseudarthrosis have been observed with greater frequency at the inferior end of long-segment constructs than the top of the fused segment.[13,14] They speculated that the long lever arm of the anterior plate transmitted unacceptably high forces to the inferior level of the fusion area. They observed that shear stress increased at the bottom of the fusion area, especially in patients with a hyperlordotic alignment and continuing micromotion of their cervical spines, both of which can lead to reconstruction failure. These findings were similar to our results.

Additional factors that affected the 3 patients who experienced early reconstruction failure but did not have excessive lordosis of their cervical spines were not elicited in this study. We postulate that overdistraction during grafting could have been one of the causes of recon-

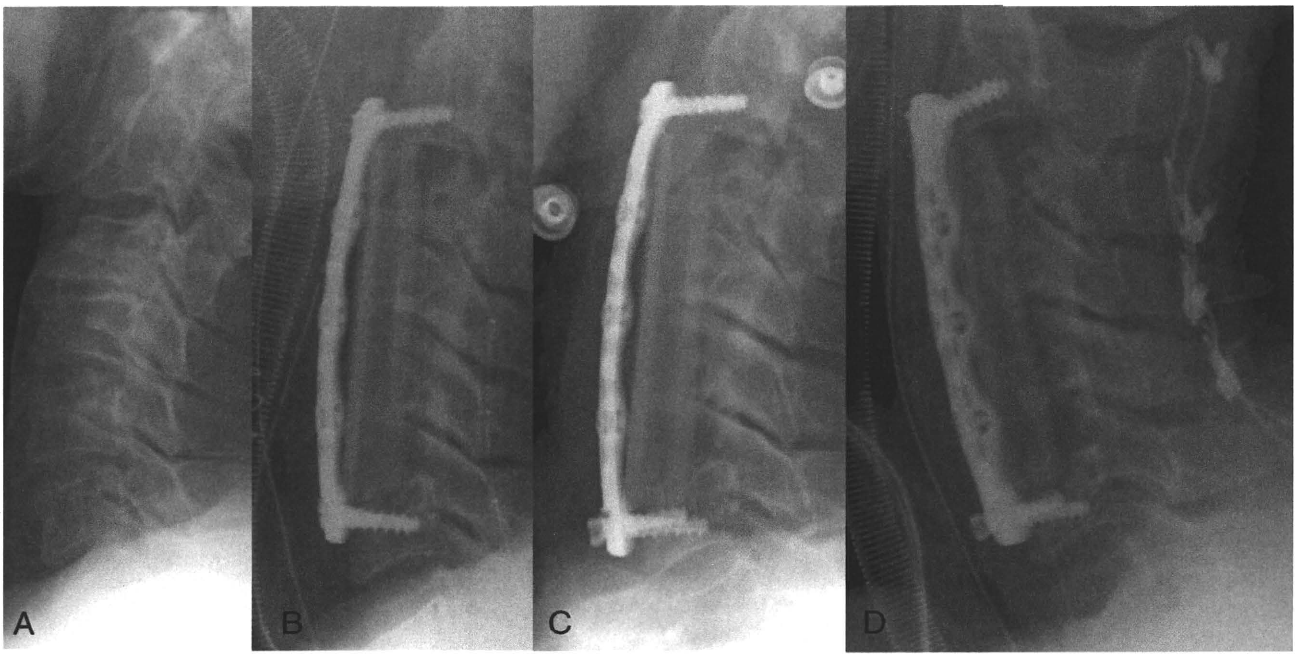

Figure 2. Preoperative radiograph of a 61-year-old man shows mixed-type OPLL with a fusion area lordotic angle of 25.8° (**A**). C2–C6 fusion was performed using an autologous fibular graft and a rotationally dynamic plate. Note the retention of the C6 endplate just after the operation (**B**). Graft subsidence and migration with screw pullout occurred 3 weeks after surgery (**C**). After in situ spinous process wiring, the degree of the patient's cervical lordosis decreased. However, solid fusion was observed (**D**).

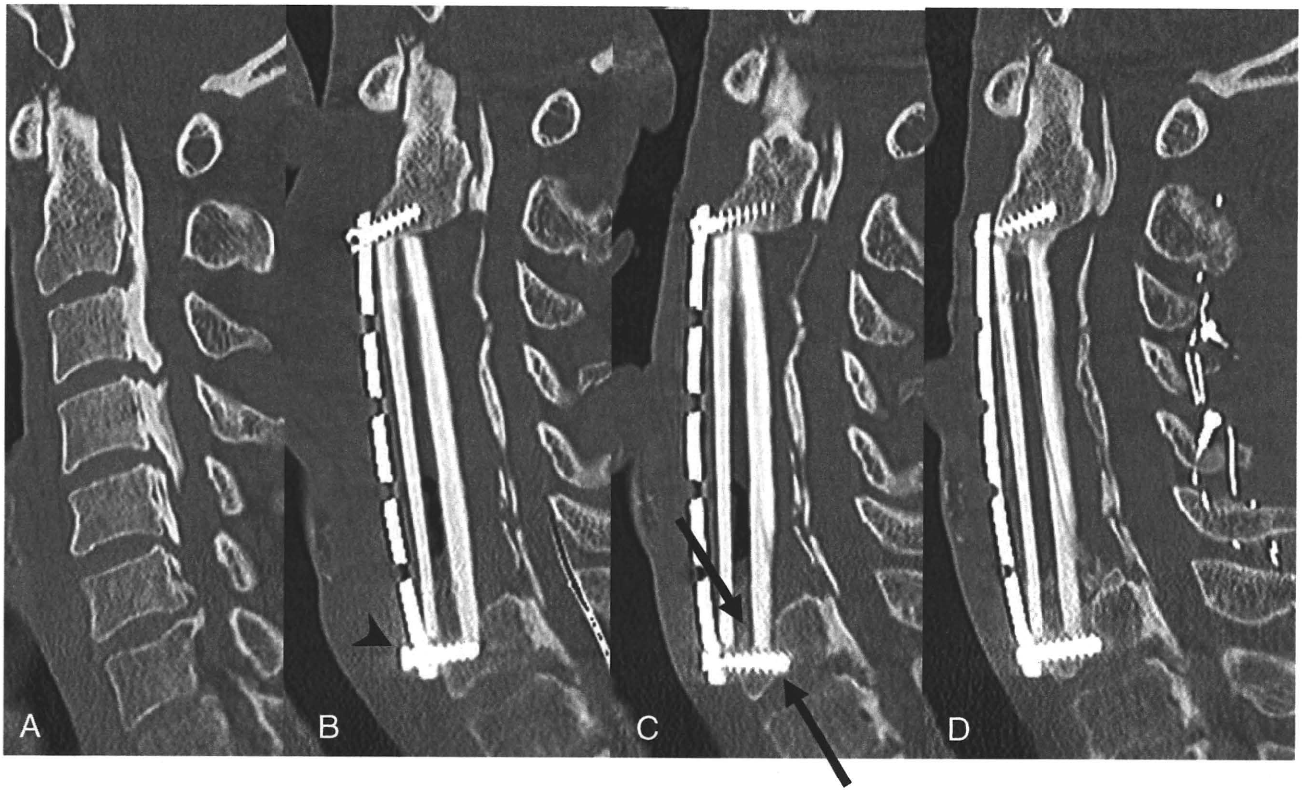

Figure 3. Preoperative radiograph of a 51-year-old man shows mixed-type OPLL with a slight lordosis (**A**). Postoperative scan taken 3 weeks after the surgery revealed screw pullout (arrow head) (**B**). Note cervical lordosis seemed to increase after the surgery. The screw was retightened, but graft subsidence and C7 fracture occurred (arrows) (**C**). After *in situ* spinous process wiring, the degree of the patient's cervical lordosis decreased. However, solid fusion was observed (**D**).

struction failure in these patients. We distracted the neck carefully while the graft was being inserted, but the distraction force was not controlled precisely.

The following factors were not associated with reconstruction failure: age, gender, preservation of the vertebral endplate, screw type, the occurrence of postoperative graft subsidence within 1 week of surgery, and the use of intermediate screws for fibular grafting. However, preservation of the vertebral endplate is thought to be important in patients with osteoporosis. In a biomechanical study, Lim *et al* confirmed that load to failure tended to decrease with incremental removal of the endplate and the risk of failure tended to increase.[15]

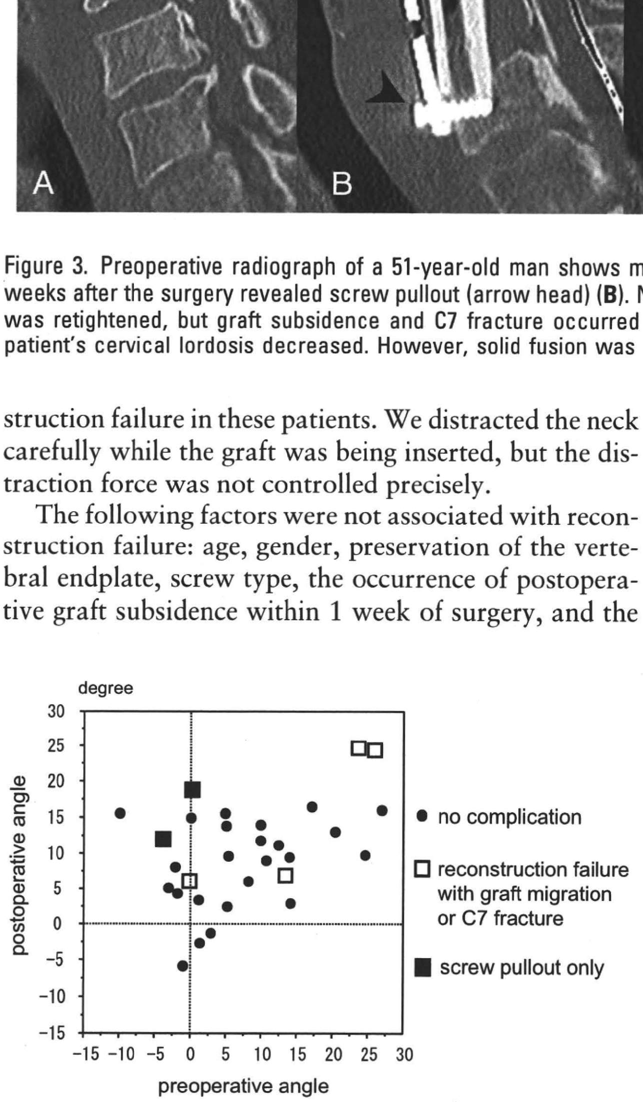

Figure 4. The preoperative and postoperative fusion area lordotic angles of the included patients have been plotted. Of the 6 patients, the 4 who experienced early reconstruction failure exhibited postoperative fusion area lordotic angles of >10°. Additional factors that affected the remaining 2 patients without excessive lordosis of their cervical spines were not elicited in the current study.

When the alignment of the cervical spine is lordotic, laminoplasty is normally performed. However, the clinical outcomes of patients with massive OPLL or with a kyphotic cervical alignment treated by anterior cervical decompression and fusion have been previously shown to be better than those of patients treated with posterior decompression.[16] Thus, some patients with cervical myelopathy respond well to multilevel corpectomy and reconstruction.[17] Cervical lordosis is also normally thought to be important for preventing long-term fusion-related problems such as adjacent segment degeneration. However, we hypothesized that postoperative cervical hyperlordosis may adversely affect graft stability in the early postoperative period.

When graft migration is discovered, posterior wiring can provide solid union. When the graft dislodges completely, reinforcement by screw fixation is needed. Because some authors recommend simultaneous anterior and posterior fixation for patients with hyperlordotic cervical spine alignments,[18,19] a combined surgical plan should be used to decrease the rate of early reconstruction failure in the limited number of patients this type of alignment.

The limitations of this study include its retrospective nature and the fact that only a small number of cases are included. A prospective study is, therefore, needed to further examine this paradoxical hypothesis that we generated based on the results of our study.

■ Key Points

- A retrospective study was conducted to investigate risk factors for early reconstruction failure of multilevel cervical corpectomy and reconstruction with dynamic plate fixation.
- Six of 30 cases experienced reconstruction failures, including graft migration at the bottom of the graft in 2 cases, fracture of the C7 vertebral body in 2 cases, and pullout of a screw in 2 cases.
- On radiologic measurement, the fusion area lordotic angle after surgery in patients with reconstruction failures was significantly larger than that of the patients with no complication.

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ORIGINAL ARTICLE

Impact of knee and low back pain on health-related quality of life in Japanese women: the Research on Osteoarthritis Against Disability (ROAD)

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Abstract Although knee and low back pain are major public health issues, little information is available on their impact on the quality of life (QOL). We have investigated the impact of knee and low back pain on the QOL in Japanese women by assessing the associations between knee pain and low back pain and various QOL domains using measures such as the Medical Outcomes Study Short Form-8, EuroQOL, and the Western Ontario and McMaster Universities Osteoarthritis Index. From the 3,040 Japanese women participating in the Research on Osteoarthritis Against Disability (ROAD) study, we analyzed data on 1,369 women >40 years old (mean age 68.4 years). We further examined the associations of Kellgren–Lawrence (KL) grade at the knee and lumbar spine and the presence of vertebral fracture (VFx) with the magnitude of QOL loss in women with knee pain and low back pain, respectively. Knee pain and low back pain were found to be significantly associated with lower QOL scores among the women comprising the study cohort. In women with knee pain KL = 4, knee osteoarthritis was strongly associated with the magnitude of QOL loss. For women with low back pain, no significant associations were found between KL grade and magnitude of QOL loss, while there was a moderate association between the latter and VFx.

Keywords Epidemiology · Knee · Pain · Osteoarthritis · Quality of life

Introduction

Knee pain and low back pain are major public health issues and important causes of physical impairment among the elderly populations of most developed countries [1–3]. The prevalence of knee pain and low back pain is quite high among elderly women in Japan [1, 3]. However, although it is important to determine the impact of knee pain and low back pain on the quality of life (QOL), few studies have assessed the association between knee pain and QOL [4]. Several studies have focused on the association between low back pain and QOL in Caucasian populations [5–8], but the results of a subsequent population survey suggested that disease patterns differ according to ethnicity [9]. Therefore, clarification of the impact of knee pain and low back pain on the QOL of the Japanese elderly would be of interest. Furthermore, although the association of knee pain and low back pain with QOL may not be independent, to date, no population-based studies have examined the impact of knee pain and low back pain on QOL in the same population using the same QOL assessment tools.

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A significant causal factor of knee pain is knee osteoarthritis (OA) [10, 11], and the prevalence of knee pain also increases with increasing severity of knee OA [3]. The impact of knee pain on QOL may thus differ according to the severity of knee OA, but there is a lack of population-based studies on possible associations between knee pain and QOL according to the severity of knee OA. Among the elderly, one of the main causes of low back pain is vertebral fracture (VFx), leading to impaired physical functioning, immobility, loss of self-esteem, and depression [12]. Low back pain is also believed to be a principal clinical symptom of lumbar spondylosis, but there has as yet been no population-based studies that have examined the associations between low back pain and QOL according to the presence of VFx or lumbar spondylosis.

Gender differences have also been observed in knee pain and low back pain, with the prevalence of both conditions being higher in women than in men [1, 3]. The associations of these kinds of pain with lumbar spondylosis and knee OA also differ between genders [1, 3]. Consequently, the impact of these diseases on QOL may also differ between genders. Although a number of studies have examined the association of knee pain [4] or low back pain [5–8] with QOL, men and women were not assessed separately in most of these studies [4–6], and only two large-scale population-based studies have examined these kinds of pain specifically in women [7, 8].

In the study reported here, we first investigated the impact of knee pain and low back pain on QOL among 1,369 women who were participating in the Research on Osteoarthritis Against Disability (ROAD) study, a nationwide prospective study on bone and joint diseases involving population-based cohorts from several communities in Japan. Secondly, we investigated the impact of pain on QOL in women according to the presence and severity of various diseases, such as VFx, lumbar spondylosis, and knee OA.

Materials and methods

Materials

Recruitment for the ROAD study has been described in detail elsewhere [13, 14]. To date, we have completed the creation of a baseline database that includes clinical and genetic information on 3,040 Japanese inhabitants (1,061 men, 1,979 women) in the age range of 23–95 years (mean 70.6 years), who were recruited from listings of resident registration in three communities. All participants provided written informed consent, and the study was conducted with the approval of the ethics committees of the University of Tokyo and the Tokyo Metropolitan Institute of Gerontology. Participants completed an interviewer-administered questionnaire consisting of 400 items, which included questions on lifestyle, such as smoking habits, alcohol consumption, family history, past history, physical activity, reproductive variables, and health-related QOL. Anthropometric measurements included height, weight, bilateral grip strength, and body mass index (BMI), which was calculated as weight in kilograms divided by the square of height in meters. All subjects were interviewed by well-experienced orthopedists on aspects related to knee pain and low back pain, who asked, "In the past month, have you experienced knee pain on most days?" and "In the past month, have you experienced low back pain on most days?", respectively. Those respondents who answered "yes" were defined as having pain. From the baseline data compiled on all ROAD participants, we extracted data on 1,369 Japanese women $\geq$40 years old who had completed the questionnaire comprising the Medical Outcomes Study Short Form-8 (SF-8) health survey [15], the EuroQOL (EQ-5D) [16], and the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) [17, 18].

Radiographic assessment

All participants underwent radiographic examination of both knees, both anteroposterior and lateral views, with weight-bearing and foot-map positioning, and of the lumbar spine, including intervertebral levels from L1/2 to L5/S, both anteroposterior and lateral views. Knee and lumbar spine radiographs by a single well-experienced orthopedist (S.M.) blinded to the participant's clinical status. VFx was assessed by lateral radiography of the lumbar spine (L1–L5) using a semiquantitative method [19]. Lumbar spondylosis and knee OA were assessed using the Kellgren–Lawrence (KL) radiographic atlas, and severity was determined by KL grading [20] (Fig. 1). For this study, we defined lumbar spondylosis and knee OA as KL $\geq$ 2 in at least one knee and one intervertebral level, respectively.

Assessment instruments

To carry out the QOL assessment, we used the SF-8, a new generic eight-item assessment that generates a health profile consisting of eight scales and two summary measures describing health-related QOL. The SF-8 is an alternate form to the SF-36 health survey (SF-36) [21], which is worldwide the most intensively used patient-based health status survey. The SF-8 uses one question to measure each of the eight SF-36 domains. Japanese versions of the SF-8 have been well-validated [15]. In the SF-8, each of the eight items assesses a different dimension of health: general health (GH); physical functioning (PF); role physical

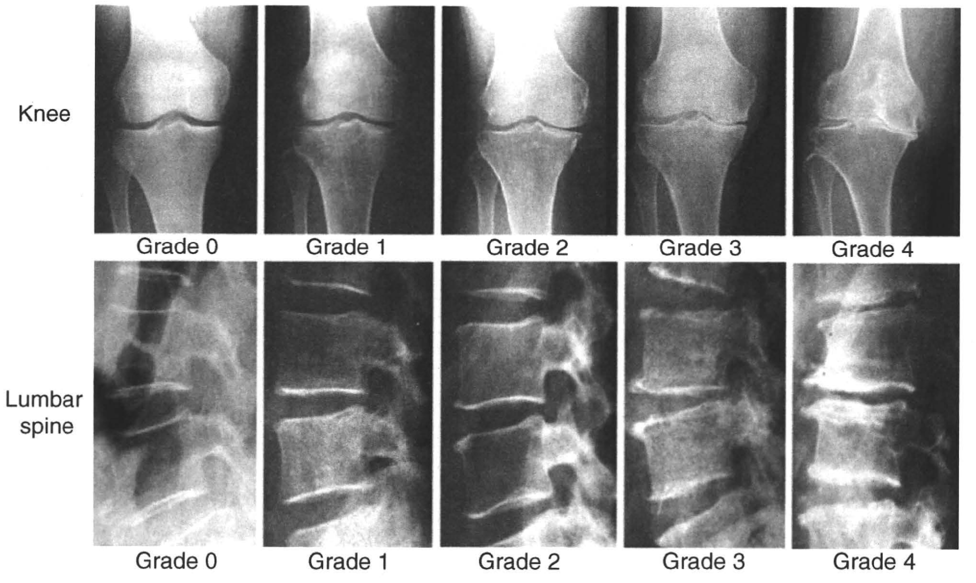

Fig. 1 Kellgren–Lawrence (KL) grade at knee and lumbar spine. *Knee*: *Grade 1* Doubtful narrowing of the joint space and possible osteophytic lipping, *Grade 2* definite osteophytes and possible narrowing of the joint space, *Grade 3* multiple moderate osteophytes, definite narrowing of the joint space, some sclerosis, and possible deformity of bone ends, *Grade 4* large osteophytes, marked narrowing of the joint space, severe sclerosis, and definite deformity of bone ends. *Lumbar spine*: *Grade 1* Minimal osteophytosis only, *Grade 2* definite osteophytosis with some sclerosis of the anterior part of the vertebral plates, *Grade 3* marked osteophytosis and sclerosis of the vertebral plates with slight narrowing of the disk space, *Grade 4* large osteophytes, marked sclerosis of the vertebral plates, and marked narrowing of the disk space

(RP); bodily pain (BP); vitality (VT); social functioning (SF); mental health (MH); role emotional (RE). The SF-8 provides two summary scores for physical and mental health [physical component summary (PCS) and mental component summary (MCS)]. The EQ-5D questionnaire [16] translated into Japanese was also used [22]. This five-dimensional healthcare classification includes questions on the status of morbidity, self-care, usual activities, pain/discomfort, and anxiety/depression. Participants were asked to indicate current health status by checking off the most appropriate of three statements on each of five QOL dimensions. Each statement represents an increasing degree of severity. These results were coded and converted to a score of utility using the tables of values. For disease-specific scales, the WOMAC (version LK 3.0) [17, 18], a 24-item OA-specific index, was utilized. The WOMAC consists of three domains: pain; stiffness; physical function. Domain scores range from 0 to 20 for pain, 0 to 8 for stiffness, and 0 to 68 for physical function. Japanese versions of the WOMAC have been validated [23].

Statistical analysis

We performed a non-paired Student's *t* test to examine differences between subjects with and without knee pain and low back pain. The impact of knee pain and low back pain on QOL was analyzed by multiple regression analysis after adjusting for age and BMI. We also examined the association of KL grade at the knee with the magnitude of QOL loss in subjects with knee pain using the Tukey honestly significant difference (HSD) test. If a subject showed pain in both knees, the more severe KL grade was designated as that of the subject. The Tukey HSD test was also used to examine the association of the presence of VFx and lumbar spondylosis with the magnitude of QOL loss in subjects with low back pain. For the lumbar spine, the most severe KL grade among all intervertebral spaces was designated as that of the subject. Data analyses were performed using SAS ver. 9.0 software (SAS Institute, Cary, NC).

Results

Characteristics of the 1,369 women $\geq$40 years old enrolled in the ROAD study are shown in Table 1. The prevalence of knee pain was higher than that of low back pain, while the prevalence of knee OA and lumbar spondylosis was similar and substantially higher than that of VFx.

Table 2 shows the mean scores for all QOL domains in the SF-8 and EQ-5D utility score according to the presence of knee pain and low back pain. We further examined the independent association of knee pain and low back pain with QOL using multiple regression analysis after