artifacts in the cervical spinal cord.[13-17] Therefore, rFOV DTI is a novel modality that can indicate the degree of spinal cord damage in a tract specific manner.

We sought to quantify spinal cord damage at the tract level in patients with CCM using rFOV DTI.

Materials and Methods

Participants

All subjects provided written, informed consent prior to taking part in the research, which was approved by institutional review board. We enrolled 10 healthy volunteers and 20 patients with CCM in this study. Potential participants with a history of neurologic injury, spinal surgery or neurodegenerative diseases causing any spinal cord disorder were excluded. Healthy volunteers included 7 men and 3 women with a mean age of 42.9 ± 9.2 years. In the group of patients with CCM, there were 11 men and 9 women with a mean age of 67.6 ± 11.3 years. The clinical diagnoses included 11 patients with cervical spondylotic myelopathy, 6 with ossification of the posterior longitudinal ligament, 2 with cervical disc herniation, and 1 with atlantoaxial dislocation because of rheumatoid arthritis. Those who had a history of neurologic injury, spinal surgery or neurodegenerative diseases causing spinal cord disorder were excluded.

Clinical Evaluation

We evaluated clinical symptoms using Japanese Orthopaedic Association (JOA) scores. JOA scores are a widely used physician-based functional assessment scale for cervical spine myelopathy.[18-19] (Table 1) We also recorded JOA subscores for motor dysfunction of the lower extremities (LE) and upper extremities (UE). Total score and each domain constituting the JOA

score were assessed by 3 experienced spinal surgeons. If there was a discrepancy of JOA score between the surgeons, the score was determined by majority consensus.

Conventional MRI

The patients were studied using a 3.0 T MR system (Discovery MR 750, GE Healthcare, Waukesha, WI). An 8-ch head neck spine receiver coil was used. Conventional MRI scans consisted of T1-weighted (T1W) and T2-weighted (T2W) sagittal images, and T2-weighted axial images were also obtained. For sagittal imaging, the acquisition settings were as follows: FOV = 24 × 1.0 cm^2, slice thickness = 3 mm echo time (TE)/time of repetition (TR) = 8.4/500 ms (T1W) and TE/TR = 105/2710 ms (T2W). For axial imaging, the acquisition settings were as follows: FOV = 16 × 1.0 mm^2, slice thickness = 4 mm, TE/TR = 105/4000 ms.

Diffusion Tensor Imaging

For DTI acquisitions, diffusion-weighted spin-echo rFOV single-shot echo-planar imaging was used, with diffusion gradients applied in 6 noncollinear spatial directions and 1 baseline image with b = 700 s/mm^2. The thickness of each slice was 5 mm and the sequence parameters for DWI were: TE = 74.9 ms, TR = 3000 ms, FOV = 14 × 0.3 cm^2, NEX = 16 and the acquisition data matrix = 176 × 44. Transverse images covering the cervical spinal cord from C1 to T1 were acquired, each of which was placed at the center of either a vertebrae or intervertebral disc.

Image Analysis

We quantified diffusion tensor parameters using DTIStudio software (Johns Hopkins Medical Institute, Johns Hopkins University). Regions-of-interest (ROI) for the lateral column (LC) and

posterior column (PC) tracts were determined based on the geometry of the cord on the axial image of the FA map at one slice cephalic to the maximum compression level, and FA values were measured (Fig. 1). We analyzed the correlation between FA values and JOA score (total score and subscore for motor dysfunction of upper and lower extremities). We recorded increased signal intensity (ISI) of the spinal cord based on sagittal T2W images. The morphometry of the spinal cord was analyzed using the anteroposterior diameter at the level of highest compression in axial T2W images.

Reliability of ROI Measurement for DTI Analysis

ROI measurements were made by 2 experienced spinal surgeons 2 times at 2-week intervals. Intraclass correlation coefficients (ICC) were used to determine the interobserver and intraobserver reliabilities. We provide 95% prediction limits for the errors in measurements.

Statistical Analysis

A Mann–Whitney U test was used to compare FA values between patients with CCM and healthy controls, and was also used to compare JOA scores between patients with and without ISI. Correlation between anteroposterior diameters and JOA scores, and correlation between FA and JOA scores were determined using Spearman's correlation coefficient. The ICC values were classified as poor (less than 0.40), fair (0.40–0.59), good (0.60–0.74), and excellent (0.75–1.00).[20] $P < 0.05$ was considered significant. All the analyses were conducted using JMP version 10.0.2 (SAS Institute, Cary, NC).

Results

Clinical Symptoms

Seventeen of 20 patients with CCM presented gait disturbance and 15 of 20 patients presented hand clumsiness. The mean total JOA scores and subscores for motor dysfunction of upper and lower extremities in this cohort were 10.7 (range 5.5–17), 2.9 (range 1.0–4.0), and 2.2 (range 1.0–4.0) respectively.

FA Values

Tract-specific analyses revealed that the FA values in patients with CCM were significantly lower than those in healthy volunteers in both LC and PC tracts. The mean FA values in LC tracts in patients with CCM and healthy volunteers were 0.59 (range 0.40–0.76) and 0.71 (range 0.66–0.75) respectively ($P = 0.01$). The mean FA values in PC tracts in patients with CCM and healthy volunteers were 0.58 (range 0.40–0.82) and 0.72 (range 0.68–0.76) respectively ($P < 0.01$; Table. 2).

Correlation between JOA Score and FA Values

In patients with CCM, total JOA score moderately correlated with FA values in LC ($\rho = 0.48$, $P = 0.03$) and PC tracts ($\rho = 0.48$, $P = 0.03$). JOA subscores for motor dysfunction of the UE weakly correlated with FA value in PC tracts ($\rho = 0.23$, $P = 0.32$), whereas JOA subscores for motor dysfunction of the UE did not correlate with FA value in LC tracts ($\rho = 0.16$, $P = 0.50$). JOA subscores for motor dysfunction of the LE showed a strong correlation with FA value in LC ($\rho = 0.76$, $P < 0.01$) and PC tracts ($\rho = 0.74$, $P < 0.01$; Fig. 2).

Reliability of ROI Measurement for DTI Analysis

The ICC value for interobserver reliability of ROI measurements was 0.80 in LC and 0.72 in PC

tracts. The ICC value for intraobserver reliability of ROI measurements was 0.92 in LC and 0.90 in PC tracts. The inter- and intraobserver reliability of tract specific ROI measurements were found to be reliable for analyzing the FA maps of patients with CCM.

Conventional MRI Parameters

The mean anteroposterior diameter of the spinal cord in patients with CCM was 4.4 ± 1.5 mm at the most apparent cord compression level. The spinal cord diameter weakly correlated with total JOA score ($\rho = 0.21$, $P = 0.36$) and subscores for LE motor dysfunction ($\rho = 0.35$ $P = 0.13$), whereas there was no significant correlation between the spinal cord diameter and subscores for UE motor dysfunction ($\rho = -0.05$, $P = 0.82$; Fig. 3).

Fifteen of 20 patients (75%) showed ISI. The mean total JOA scores in patients with and without ISI were 9.8 (range 5.5–17) and 13.4 (range 12–16) respectively ($P = 0.013$). The mean subscores for motor dysfunction of UE in patients with and without ISI were 2.8 (range 1.0–4.0) and 3.0 (range 2.0–4.0) respectively ($P = 0.81$). The mean subscores for motor dysfunction of the LE in patients with and without ISI were 2.0 (range 1.0–4.0) and 2.9 (range 2.0–4.0) respectively ($P = 0.051$; Fig. 4). There was a significant difference between total JOA scores in patients with ISI and without ISI. Although there was a trend toward lower subscores for LE motor dysfunction in patients with ISI than in those without ISI, this difference was not significant.

DISCUSSION

The present study showed that it was feasible to evaluate specific tracts of the cervical spinal cord of patients with CCM using rFOV DTI. FA values in LC and PC tracts measured using rFOV DTI correlated strongly with severity of gait disturbance. In other words, rFOV DTI can

indicate the degree of damage in the long tracts of the spinal cord. To our knowledge, this is the first report showing correlations between FA of specific spinal cord tracts and severity of myelopathy in patients with CCM.

rFOV DTI of the spinal cord enables the acquisition of high resolution images with which to evaluate specific spinal cord tracts and distinguish white matter from gray matter.[16,21] DTI analyses of the spinal cord have been applied not only to CCM, but also to demyelinating disease. Naismith et al. evaluated patients with multiple sclerosis and neuromyelitis using DTI. They found correlations with spinal cord tract DTI parameters and specific clinical functions carried by those tracts.[22] Spinal cord morphology is preserved in patients with demyelinating disease, therefore it is easier to evaluate spinal cord at the tract level in patients with demyelinating disease than it is in patients with CCM and compression-induced spinal cord deformity. There have been several reports describing DTI analyses in patients with CCM. Recently, DTI was used to evaluate somatosensory tracts in patients with cervical spondylotic myelopathy (CSM).[10] Patients with abnormal somatosensory-evoked potentials had decreased FA in the dorsal column. However, no investigation of the correlation between DTI parameters and motor/sensory function of the patients was reported. In another recent study, Cui et al. used diffusion tensor tractography to evaluate specific columns in the spinal cord of patients with CSM. They reported FA is significantly lower in the LC and PC, while mean diffusivity, axial diffusivity, and radial diffusivity in the LC and PC are higher in patients with CSM compared with healthy subjects.[11] However, they did not find any correlation between DTI parameters and clinical symptoms. By contrast with earlier reports of DTI of patients with CCM, we report the evaluation of DTI parameters relevant to clinical symptoms in the present study.

Compared with conventional MRI findings such as ISI of the spinal cord and diameter of the

spinal canal, DTI measures FA, which indicates the severity of myelopathy. We found that conventional MRI parameters, including ISI of spinal cord on T2-weighted images and diameter of the spinal canal, had only weak correlations with the severity of myelopathy. ISI on T2W images reflects a variety of pathological changes induced by spinal cord compression including edema, ischemia, necrosis, myelomalacia, and cavitation.[23,24] Association between the presence of ISI and clinical symptoms remains controversial. Some investigators reported that the increased severity of neurological deficits are concomitant with ISI, whereas others noted no correlation between ISI and clinical presentation.[23–27] In the present study, patients with ISI presented lower JOA scores than patients without ISI. However, the presence of ISI is only a qualitative assessment and cannot quantify the severity of myelopathy.

It is well known that a discrepancy exists between the degree of spinal cord compression and the clinical symptoms.[28,29] Although in population studies there is correlation between narrow spinal canal diameter and cervical myelopathy, there is a considerable degree of overlap between the frequency histograms for minimum anteroposterior diameter of the asymptomatic population and those with CSM.[30] The present study also showed only weak correlations between anteroposterior diameter and JOA score. Therefore, spinal cord morphology evaluated by conventional MRI does not necessarily reflect pathology of spinal cord.

Consistent with previous DTI studies of patients with CSM, in the present study we found a decrease in FA at the compression site.[4,6–12] DTI has shown theoretical promise for assessing the integrity of white matter tracts, and decrease in FA is considered to reflect demyelination and axon damage in the spinal cord.[31–33] The lateral corticospinal tract, which is located in the LC, is the principal descending motor fiber tract conducting voluntary movement in the human spinal cord. PC mainly conducts deep sensation including position and proprioception, both of which

are important to coordinate voluntary movement.[34] Therefore, damage to LC and PC tracts, which can be detected by DTI as a reduction of FA, leads to gait disturbance. Reduction of FA at compressed levels showed weak correlation with total JOA scores compared with JOA subscores for LE motor dysfunction. In the JOA score of 17 points, 6 points reflect sensory disturbance assessed by a pinprick test and 3 points reflect bladder function. Because LC and PC tracts do not contribute to sensory disturbance of bladder function, it is reasonable that FA of these tracts is less strongly correlated with total JOA scores. Hand myelopathy reflects not only long tract symptoms, but also segmental and/or radicular symptoms at the lower cervical spine in patients with CCM. Considering a decrease in FA reflects dysfunction, particularly in the white matter, it is reasonable that a reduction of FA in the LC and PC tracts did not significantly correlate with finger disability.

By contrast with conventional MRI findings, DTI successfully revealed a neurological deficit in patients with CCM in the present study. The present results suggest that DTI may become an indispensable diagnostic modality for patients with CCM. A study is currently underway to determine the association between FA and functional outcomes after decompression surgery. This might suggest DTI as a predictor of surgical outcomes, to assist decision making for surgical intervention in patients with CCM.

A major limitation of the present study is the significant difference in age between the healthy volunteers and patients with CCM ($P < 0.01$). FA in the cervical spinal cord decreases with age.[35, 36] This may contribute to the significantly higher FA of the spinal cord of healthy volunteers. Therefore, age should be matched in future studies. Another limitation of the present study is the difficulty of defining the ROI in patients with severely compressed spinal cords. Deformity of the spinal cord leads to deviation of specific tracts, possibly reducing the

reproducibility of ROI determination. To reduce this problem, we placed the ROI at one slice cephalic to the level of maximum compression. In patients with CCM having prolonged latency of somatosensory-evoked potentials, FA decreases not only in the compression lesion, but also at the level cephalic to the lesion.[10] We showed high reliability and reproducibility using these strategies.

Conclusions

Using rFOV DTI, it is feasible to evaluate the cervical spinal cord at the tract level. Reduction of FA in LC and PC tracts strongly correlated with the JOA subscore for motor dysfunction of the LE. These findings suggest that FA indicates white matter damage in patients with CCM and is a candidate imaging biomarker for spinal cord impairment.

Acknowledgments

References

1. Young WF. Cervical spondylotic myelopathy: a common cause of spinal cord dysfunction in older persons. *Am Fam Physician*. 2000;62:1064–70, 1073.

2. Tracy JA, Bartleson JD. Cervical spondylotic myelopathy. *Neurologist*. 2010;16:176–87.

3. Baron EM, Young WF. Cervical spondylotic myelopathy: a brief review of its pathophysiology, clinical course, and diagnosis. *Neurosurgery*. 2007;60:S35–41.

4. Yoo WK, Kim TH, Hai DM, et al. Correlation of magnetic resonance diffusion tensor imaging

and clinical findings of cervical myelopathy. *Spine J.* 2013;13:867–76.

5. Nakamura M, Fujiyoshi K, Tsuji O, et al. Clinical significance of diffusion tensor tractography as a predictor of functional recovery after laminoplasty in patients with cervical compressive myelopathy. *J Neurosurg Spine.* 2012;17:147–52.

6. Gao SJ, Yuan X, Jiang XY, et al. Correlation study of 3T-MR-DTI measurements and clinical symptoms of cervical spondylotic myelopathy. *Eur J Radiol.* 2013;82:1940–5.

7. Jones JG, Chen SY, Lebel RM, et al. Diffusion Tensor Imaging Correlates with the Clinical Assessment of Disease Severity in Cervical Spondylotic Myelopathy and Predicts Outcome following Surgery. *AJNR Am J Neuroradiol.* 2013;34:471–8.

8. Uda T, Takami T, Tsuyuguchi N, et al. Assessment of cervical spondylotic myelopathy using diffusion tensor magnetic resonance imaging parameter at 3.0 tesla. *Spine (Phila Pa 1976).* 2013;38:407–14.

9. Wen CY, Cui JL, Liu HS, et al. Is diffusion anisotropy a biomarker for disease severity and surgical prognosis of cervical spondylotic myelopathy? *Radiology.* 2014;270:197–204.

10. Wen CY, Cui JL, Mak KC, et al. Diffusion tensor imaging of somatosensory tract in cervical spondylotic myelopathy and its link with electrophysiological evaluation. *Spine J.* 2014;14:1493–500.

11. Cui JL, Li X, Chan TY, et al. Quantitative assessment of column-specific degeneration in cervical spondylotic myelopathy based on diffusion tensor tractography. *Eur Spine J.* 2014;24(1)41-7

12. Ellingson BM, Salamon N, Grinstead JW, et al. Diffusion tensor imaging (DTI) predicts functional impairment in mild to moderate cervical spondylotic myelopathy. *Spine J.* 2014;

13. Wilm BJ, Gamper U, Henning A, et al. Diffusion-weighted imaging of the entire spinal cord.

NMR Biomed. 2009;22:174–81.

14. Saritas EU, Cunningham CH, Lee JH, et al. DWI of the spinal cord with reduced FOV single-shot EPI. *Magn Reson Med.* 2008;60:468–73.

15. Saritas EU, Lee D, Çukur T, et al. Hadamard slice encoding for reduced-FOV diffusion-weighted imaging. *Magn Reson Med.* 2014;72:1277 –90.

16. Xu J, Shimony JS, Klawiter EC, et al. Improved in vivo diffusion tensor imaging of human cervical spinal cord. *Neuroimage.* 2013;67:64–76.

17. Zaharchuk G, Saritas EU, Andre JB, et al. Reduced field-of-view diffusion imaging of the human spinal cord: comparison with conventional single-shot echo-planar imaging. *AJNR Am J Neuroradiol.* 2011;32:813–20.

18. Yonenobu K, Abumi K, Nagata K, et al. Interobserver and intraobserver reliability of the japanese orthopaedic association scoring system for evaluation of cervical compression myelopathy. *Spine (Phila Pa 1976).* 2001;26:1890–4; discussion 1895.

19. Ono K, Ebara S, Fuji T, et al. Myelopathy hand. New clinical signs of cervical cord damage. *J Bone Joint Surg Br.* 1987;69:215–9.

20. Lachin JM. The role of measurement reliability in clinical trials. *Clin Trials.* 2004;1:553–66.

21. Tang L, Wen Y, Zhou Z, et al. Reduced field-of-view DTI segmentation of cervical spine tissue. *Magn Reson Imaging.* 2013;31:1507–14.

22. Naismith RT, Xu J, Klawiter EC, et al. Spinal cord tract diffusion tensor imaging reveals Disability substrate in demyelinating disease. *Neurology.* 2013;80:2201–9.

23. Morio Y, Yamamoto K, Kuranobu K, et al. Does increased signal intensity of the spinal cord on MR images due to cervical myelopathy predict prognosis? *Arch Orthop Trauma Surg.* 1994;113:254–9.

24. Wada E, Ohmura M, Yonenobu K. et al. Intramedullary changes of the spinal cord in cervical spondylotic myelopathy. *Spine (Phila Pa 1976)*. 1995;20:2226–32.

25. Takahashi M, Yamashita Y, Sakamoto Y, et al. Chronic cervical cord compression: clinical significance of increased signal intensity on MR images. *Radiology*. 1989;173:219–24.

26. Nakamura M, Fujimura Y. Magnetic resonance imaging of the spinal cord in cervical ossification of the posterior longitudinal ligament. Can it predict surgical outcome? *Spine (Phila Pa 1976)*. 1998;23:38–40.

27. Ratliff J, Voorhies R. Increased MRI signal intensity in association with myelopathy and cervical instability: Case report and review of the literature. *Surg Neurol*. 2000;53:8–13.

28. Fujiwara K, Yonenobu K, Hiroshima K, et al. Morphometry of the cervical spinal cord and its relation to pathology in cases with compression myelopathy. *Spine (Phila Pa 1976)*. 1988;13:1212–6.

29. Gooding MR, Wilson CB, Hoff JT. Experimental cervical myelopathy. Effects of ischemia and compression of the canine cervical spinal cord. *J Neurosurg*. 1975;43:9–17.

30. Nurick S. The pathogenesis of the spinal cord disorder associated with cervical spondylosis. *Brain*. 1972;95(1):87–100

31. Ito R, Mori S, Melhem ER. Diffusion tensor brain imaging and tractography. *Neuroimaging Clin N Am*. 2002;12:1–19..

32. Bot JCJ, Blezer ELA, Kamphorst W, et al. The spinal cord in multiple sclerosis: relationship of high-spatial-resolution quantitative MR imaging findings to histopathologic results. *Radiology*. 2004;233:531–40.

33. Facon D, Ozanne A, Fillard P, et al. MR diffusion tensor imaging and fiber tracking in spinal cord compression. *AJNR Am J Neuroradiol*. 2005;26:1587–94.

34. Snell RS. *Clinical Neuroanatomy, 7th edition*. Philadelphia: Lippincott Williams & Wilkins; 2010.

35. Agosta F, Laganà M, Valsasina P, et al. Evidence for cervical cord tissue disorganisation with aging by diffusion tensor MRI. *Neuroimage*. 2007;36:728–35.

36. Vedantam A, Jirjis MB, Schmit BD, et al. Characterization and limitations of diffusion tensor imaging metrics in the cervical spinal cord in neurologically intact subjects. *J Magn Reson Imaging*. 2013;38:861–7.
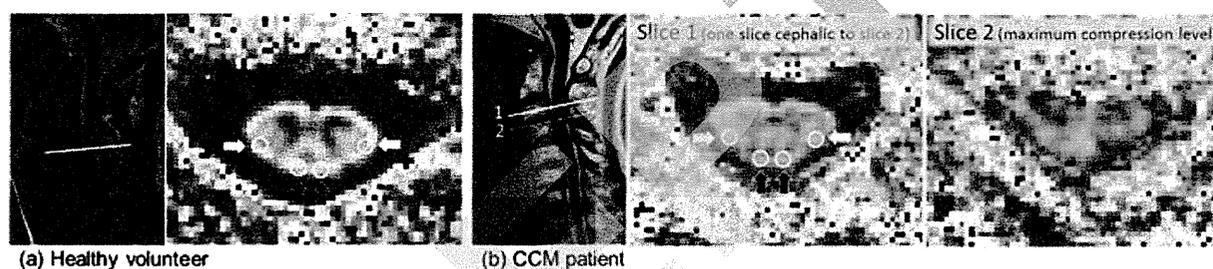
(a) Healthy volunteer (b) CCM patient

Figure 1. FA maps of (a) a healthy volunteer and (b) a patient with CCM. In the patients with CCM, ROIs were defined on axial images of the FA map at one slice cephalic to the level of maximum compression. ROIs were placed in the lateral columns (the white arrows) and posterior columns (the black arrows).
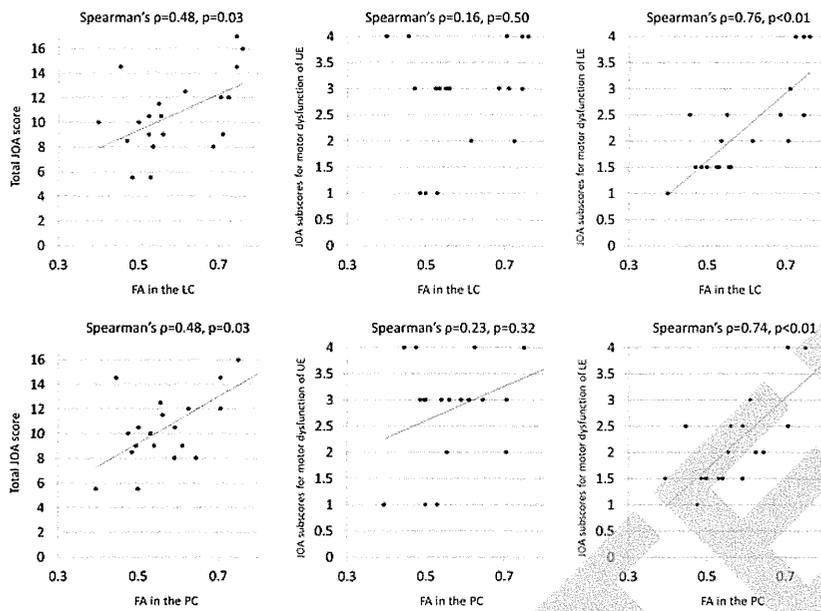
Figure 2. Sum of JOA score (left column), JOA subscore of motor dysfunction of UE (middle column) and JOA subscore of motor dysfunction of LE (right column). FA in the LC is shown in the upper row and FA in the PC is shown in the lower row.

FA: fractional anisotropy, LC: lateral column, PC: posterior column, UE: upper extremity, LE: lower extremity
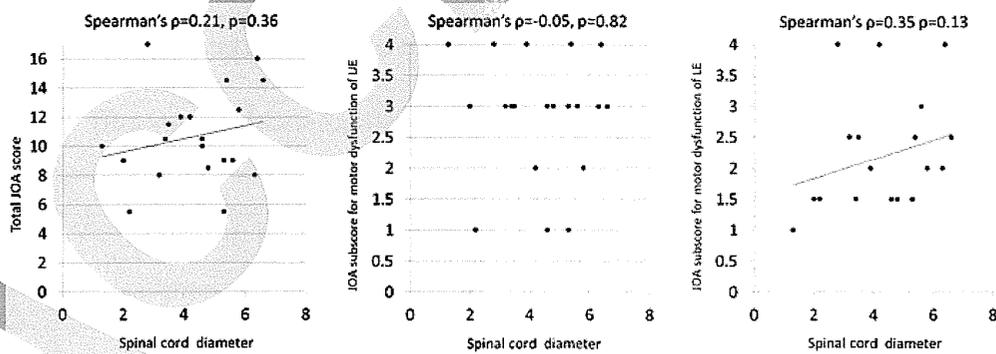

Figure 3. Spearman's correlation between JOA score and spinal cord diameter. The spinal cord diameter correlated only weakly with total JOA score and subscores for motor dysfunction of LE and did not correlate with subscores for motor dysfunction of UE.
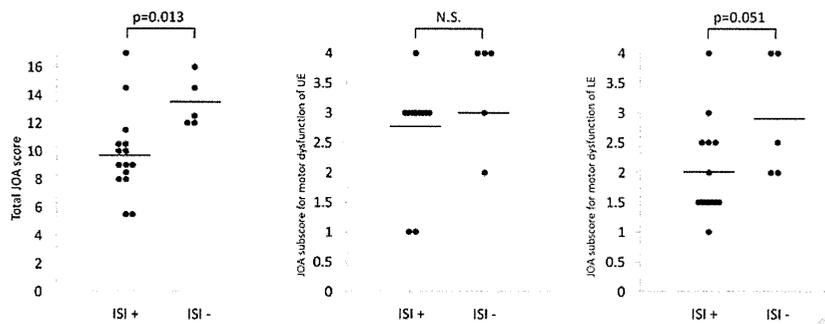
Figure 4. Comparison of JOA scores between patients with and without ISI. There was significant difference in total JOA scores and subscores for motor dysfunction of LE between patients with ISI and without ISI.

ISI: increased signal intensity, N.S.: not significant, UE: upper extremities, LE: lower extremities

Table 1. Japanese Orthopaedic Association Scoring System for Cervical Myelopathy

Function	Grade
Motor function	
Fingers	
Unable to feed oneself with any tableware including chopsticks, spoon, or fork, and/or unable to fasten buttons of any size	0
Can manage to feed oneself with a spoon, and/or fork but not with chopsticks	1
Either chopstick-feeding or writing is possible but not practical, and/or large buttons can be fastened	2
Either chopstick-feeding or writing is clumsy but practical, and/or cuff buttons can be fastened	3
Normal	4
Shoulder and elbow (evaluated by MMT score of the deltoid or biceps muscles, whichever is weaker)	
MMT 2 or less	-2
MMT 3	-1
MMT 4	-0.5
MMT 5	0
Lower extremity	
Unable to stand up and walk by any means	0
Able to stand up but unable to walk	0.5
Needs cane or aid on flat ground	1
Able to walk without support but with a clumsy gait	1.5
Walks independently on flat ground but needs support on stairs	2

Able to walk independently when going upstairs, but needs support when going downstairs	2.5
Capable of fast but clumsy walking	3
Normal	4
Sensory function	
Upper extremity	
Complete loss or touch and pain sensation	0
50% or less normal sensation and/or severe pain or numbness	0.5
More than 60% normal sensation and/or moderate pain or numbness	1
Subjective numbness of slight degree without any objective sensory deficit	1.5
Normal	2
Lower extremity	
Complete loss or touch and pain sensation	0
50% or less normal sensation and/or severe pain or numbness	0.5
More than 60% normal sensation and/or moderate pain or numbness	1
Subjective numbness of slight degree without any objective sensory deficit	1.5
Normal	2
Trunk	
Complete loss or touch and pain sensation	0
50% or less normal sensation and/or severe pain or numbness	0.5
More than 60% normal sensation and/or moderate pain or numbness	1
Subjective numbness of slight degree without any objective sensory deficit	1.5
Normal	2
Bladder function	
Complete retention	0
Severe disturbance (sense of retention, dribbling, incomplete continence)	1
Mild disturbance (urinary frequency, urinary hesitency)	2
Normal	3

MMT: Manual muscle test.

Table 2. Mean FA values in CCM patients and healthy volunteer

FA value	Controls	CCM patients	p
Lateral column	0.71 (range 0.66–0.75)	0.59 (range 0.40–0.76)	0.01
Posterior column	0.72 (range 0.68–0.76)	0.58 (range 0.40–0.82)	<0.01

FA values in CCM patients were significantly lower than that in healthy volunteers in both LC and PC

CERVICAL SPINE

Impact of Axial Neck Pain on Quality of Life After Laminoplasty

Atsushi Kimura, MD, PhD,* Teruaki Endo, MD, PhD,* Hirokazu Inoue, MD, PhD,* Atsushi Seichi, MD, PhD,†
and Katsushi Takeshita, MD, PhD*

Study Design. A prospective study.
Objective. The aim of this study was to elucidate the impact of axial pain following cervical laminoplasty on health-related quality of life (HRQOL).
Summary of Background Data. Axial neck pain is a frequently encountered complication after laminoplasty. However, limited information is available regarding the time-dependent changes in axial pain and the impact of this pain on clinical outcomes, including HRQOL.
Methods. One hundred sixty-two consecutive patients with cervical myelopathy underwent double-door laminoplasty using hydroxyapatite spacers from 2008 to 2012. The outcome measures included the Japanese Orthopaedic Association score (JOA score), the EuroQol 5 Dimension Questionnaire (EQ-5D), and the Short Form-36 survey (SF-36). The intensity of axial pain was assessed using an 11-point numerical rating scale (NRS). These assessments were conducted preoperatively and at 6-month, 1-year, and 2-year follow-ups. Patient satisfaction with outcome was graded using a 7-point NRS at the 2-year follow-up.
Result. One hundred twenty-one patients completed the 2-year follow-up. The mean axial pain intensity decreased slightly over time; however, the decrease was not significant. The JOA score, EQ-5D score, and all SF-36 domains, excluding general health perceptions, improved significantly compared with baseline levels at the 6-month follow-up or later. Baseline axial pain intensity showed a significant negative correlation with baseline

HRQOL only in the SF-36 bodily pain domain. In contrast, axial pain intensity showed significant negative correlations with all HRQOL measures at the 6-month follow-up. At the 2-year follow-up, patients with an axial pain intensity ≥3 showed significantly worse outcomes than did patients with a pain intensity <3 in the EQ-5D score, SF-36 score, and patient satisfaction grades, but not in the JOA score.
Conclusion. Axial neck pain has a significant negative impact on clinical outcomes, including a wide range of HRQOL measures and patient satisfaction with outcome, in patients undergoing conventional double-door laminoplasty.
Key words: cervical laminoplasty, cervical spondylosis, myelopathy, neck pain, ossification of posterior longitudinal ligament, outcome measure, patient satisfaction, postoperative pain, quality of life, range of motion.
Level of Evidence: 3
Spine 2015;40:E1292–E1298

Cervical laminoplasty is a widely used procedure for the treatment of multilevel compressive myelopathy. It provides an advantage over laminectomy in preventing postoperative kyphosis, segmental instability, and postlaminectomy membrane formation.[1] However, cervical laminoplasty is still associated with unresolved complications, including axial neck pain, C5 palsy, and reduction in neck motion.[2] In particular, axial neck pain is a frequently encountered complication after laminoplasty. Persistent axial pain can be a major cause of dissatisfaction after surgery, even in patients with excellent neurological recovery.

There is a growing awareness that traditional outcome measures do not adequately represent patients' experience of disease or perceptions of treatment.[3] Patient-reported outcome measures provide the patients' perspective on the benefits of a medical intervention by assessing health-related quality of life (HRQOL), symptoms, and more recently, treatment satisfaction.[4] Because outcome measures for cervical spine surgery historically used objective disease-specific scales, such as the Nurick scale[5] and the Japanese Orthopaedic Association (JOA) score,[6] limited information is available regarding the patients' perspective on residual symptoms after surgery.

-314-

In the present study, we prospectively investigated the time-dependent changes in axial neck pain and their relationship with various clinical outcomes, including HRQOL measures, following cervical laminoplasty. The purpose of this study was to elucidate the impact of axial neck pain on HRQOL in patients undergoing cervical laminoplasty.

PATIENTS AND METHODS

Patients

One hundred sixty-two consecutive patients with cervical myelopathy who underwent double-door laminoplasty using hydroxyapatite spacers from 2008 to 2012 were included in this prospective study. The research protocol was approved by the Institutional Review Board of the authors' institute. The diagnosis of myelopathy was confirmed both by a thorough neurological examination and by imaging findings of spinal cord compression, which is generally associated with an intramedullary high-intensity area on T2-weighted magnetic resonance imaging (MRI). Twenty-three patients were excluded due to comorbidities that impaired physical function (e.g., cerebral infarction, traumatic spinal cord injury, and severe lumbar canal stenosis).

Surgical Procedures

The procedure for conventional double-door laminoplasty has been described in detail elsewhere.[7] The cervical laminae were exposed laterally to the medial aspect of the facet joints through a midline approach. For a C2 split, the semispinalis cervicis, rectus capitis posterior major, and obliquus capitis inferior muscles were detached transiently. Bilateral gutters were made using a high-speed burr at the transitional area between the facet joint and the laminae, and the spinous processes were then split sagittally with a high-speed burr. The spinal canal was enlarged by opening the split laminae bilaterally with a spreader. To maintain the expanded position, HA spacers (Apacerum®; Asahi Optical Co., Ltd., Tokyo, Japan) were placed between the split laminae and fixed with nonabsorbable sutures. In the case of C2 laminoplasty, detached muscles were repaired with nonabsorbable sutures. Patients wore a cervical orthosis for 2 weeks.

Radiological Evaluation

The sagittal alignment of the cervical spine was defined by the Cobb angle between C2 and C7 (C2–C7 angle) on a lateral radiograph in the neutral position. The C2 and C7 range of motion (ROM) was measured on flexion-extension lateral radiographs.

Outcome Measures

The objective functional outcome was assessed with the JOA score. HRQOL measures included the EuroQol 5-Dimension Questionnaire (EQ-5D) and the Short Form-36 survey v2.0 (SF-36). Patients rated the average intensity of axial neck pain in the last month using an 11-point numerical rating scale (NRS) (0: no pain; 10: worst pain imaginable). These assessments were conducted preoperatively and at 6-month, 1-year, and 2-year follow-ups. Patient satisfaction with outcome was graded using a 7-point NRS (1, "very dissatisfied"; 2, "dissatisfied"; 3, "slightly dissatisfied"; 4, "neutral"; 5, "slightly satisfied"; 6, "satisfied"; and 7, "very satisfied") at 2-year follow-up.

Statistical Analysis

To estimate the impact of axial pain on HRQOL, Spearman's rank correlation coefficients were calculated between the intensity of axial pain and the HRQOL measures at each time point. Time-dependent changes in various outcome measures were tested for statistical significance by 1-factor repeated-measure analysis of variance (ANOVA) followed by Tukey's posthoc test. Between-group comparisons were performed using the Mann-Whitney U test. All data was analyzed using statistical software (SPSS version 17; SPSS Inc., Chicago, IL).

RESULTS

Objective Outcomes

One hundred twenty-one patients completed the 2-year follow-up (follow-up rate: 87.1%). The patients' characteristics are summarized in Table 1. Cervical lordosis defined

TABLE 1. Patients' Characteristics

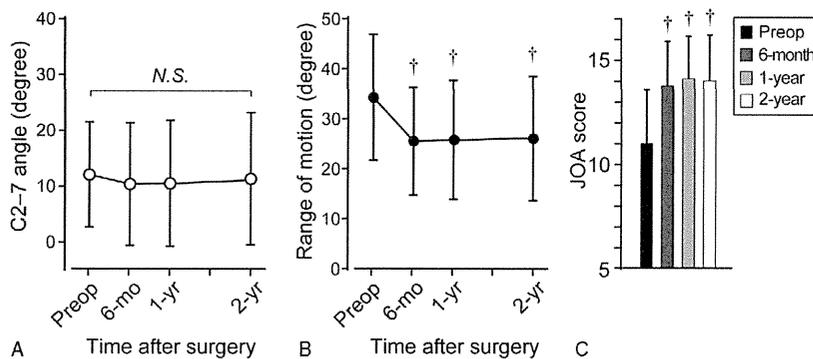| Characteristics		Total Number (N = 121)
Age (years)		63.6 ± 12.2
Sex (M/F)		81/40
Etiology	Spondylosis	78 (65%)
	OPLL	43 (35%)
Follow-up (month)		48.0 ± 14.1
Surgical levels	C3–C7	81 (67)
	C3–C6	28 (23)
	C2–C7	9 (8)
	C2–C6	3 (2)
Data are reported as numbers (%) or means ± SD. OPLL indicates ossification of the posterior longitudinal ligament.		

Figure 1. Objective outcomes. The JOA score improved significantly over baseline levels at the 6-month follow-up or later (A). Cervical lordosis was maintained at preoperative levels until the 2-year follow-up (B); however, cervical ROM decreased significantly by 23% at 6-month follow-up or later (C). *$P < 0.01$, one-way ANOVA followed by Tukey's test.

by the C2 and C7 angle was maintained at preoperative levels until 2-year follow-up; however, cervical ROM decreased significantly by 23% at the 6-month follow-up or later (Figure 1A, B). The JOA score improved significantly over baseline levels at the 6-month follow-up or later (Figure 1C).

Subjective Outcomes

The EQ-5D score improved significantly over baseline levels at the 6-month follow-up or later (Figure 2A). All SF-36 subscales excluding general health perceptions (GH) improved significantly compared with baseline levels at the 6-month follow-up or later (Figure 2B). Of all 121 patients, 97 (80.2%) reported a patient satisfaction grade ≥5 ("slightly satisfied" or more) at the 2-year follow-up.

Time-Dependent Changes in Axial Pain Intensity After Laminoplasty

Frequency distributions of axial pain intensity before surgery and at 2-year follow-up are shown in Figure 3A. Of the 121 patients, 59 (48.8%) and 54 (44.6%) reported axial pain ≥3 at baseline and at 2-year follow-up, respectively (Figure 3A). The mean axial pain intensity decreased slightly over time; however, the decrease was not significant (Figure 3B). Neither C2 nor C7 laminoplasty significantly increased postoperative axial pain; however, C2 laminoplasty significantly decreased cervical lordosis at 6-month

follow-up or later (Supplemental Tables 1 and 2, http://links.lww.com/BRS/B29).

Correlations Between Axial Pain Intensity and Objective Outcomes

Axial pain intensity showed no significant correlations with objective outcomes, including C2 and C7 angle, C2 and C7 ROM, and the JOA score, at any time point.

Correlations Between Axial Pain Intensity and Health-Related Quality of Life

Baseline axial pain intensity showed a significant negative correlation with baseline QOL measures only in the SF-36 bodily pain domain (Table 2). In contrast, axial pain intensity showed significant negative correlations with all QOL measures at the 6-month follow-up. The significant negative correlations between axial pain intensity and QOL measures were maintained until the 2-year follow-up, except for SF-36 physical function.

Impact of Axial Pain on Clinical Outcomes at the 2-Year Follow-Up

At the 2-year follow-up, patients with axial pain intensity ≥3 showed significantly worse outcomes than did patients with pain intensity <3 in the EQ-5D score (0.62 ± 0.18 vs. 0.75 ± 0.16; $P < 0.001$), as well as worse patient satisfaction grades (median, 5 vs. 6; $P < 0.001$), but no difference in the
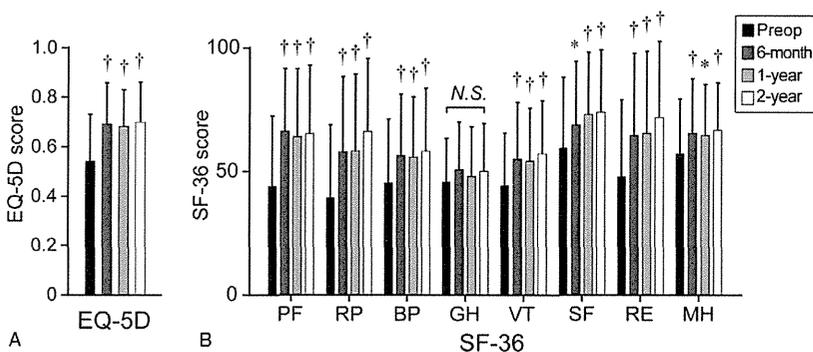

Figure 2. Subjective outcomes. EQ-5D improved significantly over baseline levels at 6-month follow-up or later (A). All SF-36 subscales excluding the general health perceptions (GH) improved significantly over baseline levels at 6-month follow-up or later (B). *$P < 0.05$, †$P < 0.01$, one-way ANOVA followed by Tukey's test.
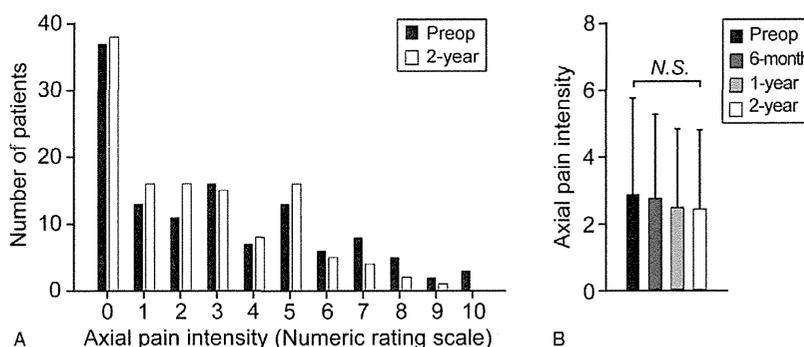
Figure 3. Time-dependent changes in axial pain intensity after laminoplasty. Of 121 patients, 59 (48.8%) and 54 (44.6%) reported axial pain intensity ≥ 3 at baseline and at 2-year follow-up, respectively (A). The axial pain intensity decreased slightly over time; however, the decrease was not significant (B).

JOA score $(13.7 \pm 2.3$ vs. 14.4 ± 2.4; $P = 0.073)$ (Figure 4A–C). Patients with axial pain intensity ≥ 3 also had lower mean SF-36 subscales compared with patients with pain intensity <3 (Figure 4D). The differences in SF-36 subscales were significant $(P = 0.014 - P < 0.001)$, except for the physical function and mental health domains $(P = 0.065$ and 0.198, respectively).

DISCUSSION

Axial neck pain has been recognized as one of the most important complications after posterior decompression surgery.[2] To the best of our knowledge, however, no study has investigated the detailed time-dependent changes in axial pain and the impact of this pain on HRQOL. The key finding of this study is that the axial pain intensity remained at preoperative levels following double-door laminoplasty and had a substantial negative impact on clinical outcomes, including a wide range of HRQOL measures and patient satisfaction with outcome at 2-year follow-up.

There are mixed results in the current literature regarding postoperative changes in axial pain after conventional

laminoplasty, with only a few prospective studies involving more than 100 patients that used a standardized pain-intensity scale. Consistent with our results, Ohashi et al[8] found no significant change in the visual analog scale (VAS) for neck pain at the 2-year follow-up in patients who underwent open-door cervical laminoplasty. Seng et al[9] reported a significant decrease in VAS neck pain after double-door laminoplasty; however, the mean postoperative change in the VAS score (1.4) was below the minimal clinically important difference of 2.5.[10] These results suggest that the conventional laminoplasty is not an effective treatment for reducing axial pain.

Although axial pain intensity decreased slightly after surgery, it showed a significant negative correlation with all HRQOL measures at 6-month follow-up, and the relationship seemed to be enhanced over time in some HRQOL measures. This finding suggests that the impact of axial pain becomes more prominent from the patients' perspective as their physical functions improve after surgery. This may be partly attributable to the striking difference between rapidly improving physical functions and

TABLE 2. Correlations Between Axial Pain Intensity and Health-Related Quality of Life Measures Before and After Surgery

Quality of Life Measure	Time After Surgery			
	Baseline	6-month	1-year	2-year
EQ-5D	−0.022	−0.329**	−0.319**	−0.404**
SF-36 Physical functioning	−0.084	−0.210*	−0.204*	−0.174
Role physical	−0.100	−0.322**	−0.316**	−0.401**
Bodily pain	−0.347**	−0.435**	−0.435**	−0.480**
General health perceptions	−0.173	−0.268**	−0.227**	−0.334**
Vitality	−0.075	−0.346**	−0.327**	−0.390**
Social functioning	−0.093	−0.230*	−0.203*	−0.229*
Role emotional	−0.053	−0.387**	−0.279**	−0.278**
Mental health	−0.123	−0.388**	−0.260**	−0.223*

Spearman's rank correlation coefficients. EQ-5D indicates EuroQOL 5 Dimensions questionnaire; SF-36, Short-Form 36-Item Health survey. *$P < 0.05$, **$P < 0.01$.*

-317-