Table 1 Characteristics of the participants

Clinical/demographic/QOL characteristics of study cohort	Values
n	1,369
Age (years)	68.4 ± 11.1
Height (cm)	150.0 ± 6.9
Weight (kg)	51.4 ± 9.0
BMI (kg/m^2)	22.8 ± 3.7
Knee pain (%)	27.9
Low back pain (%)	17.3
VFx (%)	7.7
Knee OA (%)	60.2
Lumbar spondylosis (%)	61.3
SF-8 score	
GH	49.5 ± 5.8
PF	49.5 ± 6.3
RP	49.8 ± 6.5
BP	49.1 ± 9.6
VT	49.3 ± 5.9
SF	51.9 ± 6.2
MH	53.3 ± 6.4
RE	51.4 ± 5.7
PCS	46.8 ± 7.0
MCS	52.5 ± 6.1
EQ-5D score	0.90 ± 0.15
WOMAC index	
Pain (0–20)	1.50 ± 2.57
Stiffness (0–8)	0.77 ± 1.33
Function (0–68)	4.49 ± 8.37

Unless indicated otherwise, values represent the mean ± standard deviation (SD)

QOL Quality of life,*BMI* body mass index, *VFx* vertebral fracture, *OA* osteoarthritis, *SF-8* Medical Outcomes Study Short Form-8 health survey, *GH* general health, *PF* physical function, *RP* role physical, *BP* bodily pain, *VT* vitality, *SF* social function, *MH* mental health, *RE* role emotional, *PCS* physical component summary, *MCS* mental component summary, *EQ-5D* EuroQOL questionnaire, *WOMAC* the Western Ontario and McMaster Universities Osteoarthritis Index

adjustment for age and BMI. Knee pain was significantly associated with lower QOL scores in all domains of the SF-8, with the exception of MH, RE, MCS, and also with lower EQ-5D utility scores. Low back pain was significantly associated with lower QOL scores in almost all domains of the SF-8, except for MCS, and with lower EQ-5D utility scores. The impact of low back pain was greater than that of knee pain in almost all QOL domains.

Scores of the SF-8, EQ-5D, and WOMAC by KL grade of knee in women with knee pain are shown in Table 3. The Tukey HSD test revealed that compared with women with KL = 0/1, PCS in the SF-8 and pain in the WOMAC were significantly lower in women with KL = 3 knee OA, while PF, RP, BP, and PCS in the SF-8 and all domains of the WOMAC were significantly lower in women with KL = 4 knee OA. After adjusting for age and BMI, PCS in the SF-8 and pain and physical function in the WOMAC were also significantly lower in women with KL = 4 knee OA compared with those with KL = 0/1.

Table 4 shows the association of KL grade for the lumbar spine and presence of VFx with QOL in subjects with low back pain. In women with low back pain, no associations were seen between KL grade and any of the domains of the SF-8 or EQ-5D utility scores, while PF, RP, RE, and PCS were significantly lower in subjects with VFx than in those without VFx.

To compare the magnitude of impact on PCS between knee pain graded as KL = 4 knee OA and low back pain with vertebral fracture, we then used multiple regression analysis after adjusting for age and BMI. The impact of knee pain graded as KL = 4 knee OA on PCS was larger than that of low back pain with VFx (beta: −0.11 and −0.09, $p < 0.0001$, respectively).

Discussion

Few previous studies have examined the associations of knee pain with QOL [4], and there have been no studies published to date on the impact of knee pain and low back pain on QOL in women. The results of our study reveal that among our study cohort of 1,369 Japanese women ≥40 years of age, knee pain and low back pain were significantly associated with lower QOL scores. The multiple regression analysis showed that the impact of knee pain on QOL was weaker than that of low back pain; however, knee pain with severe knee OA had a strong, negative impact on QOL that was greater than that of low back pain with VFx. In fact, the severity of knee OA was significantly associated with the magnitude of QOL loss in subjects with knee pain. In other words, the Tukey HSD test after adjustment for age and BMI showed that in subjects with KL = 4 knee OA, PCS in the SF-8 was significantly lower and pain and physical function in the WOMAC were both significantly higher, while QOL scores of subjects with KL = 2 knee OA were similar to those of subjects with KL = 0/1. These results indicate not only that the prevalence of knee pain is higher but also that the magnitude of knee pain may be more severe in subjects with severe knee OA, whereas the magnitude of knee pain may be similar in subjects with moderate knee OA and in those without knee OA. However, the two features of knee OA, joint space narrowing and osteophytosis, cannot be assessed separately using the KL grade, so we were unable to clarify the independent effects of these two features to the association

Table 2 Scores for QOL in participants with and without knee pain and low back pain and associations with knee and low back pain by multiple regression analysis after adjusting for age, BMI, knee pain, and low back pain

QOL assessment domain	Knee pain			Low back pain		
	No	Yes	Adjusted beta[a]	No	Yes	Adjusted beta[a]
SF-8						
GH	49.9 ± 5.8	48.8 ± 5.8[b]	−0.043[c]	50.1 ± 5.7	47.1 ± 5.5[b]	−0.152[c]
PF	50.1 ± 6.0	47.9 ± 6.8[b]	−0.064[c]	50.2 ± 5.9	46.0 ± 6.9[b]	−0.180[c]
RP	50.4 ± 6.3	48.4 ± 6.9[b]	−0.058[c]	50.6 ± 6.1	47.3 ± 7.5[b]	−0.182[c]
BP	50.4 ± 9.4	45.6 ± 9.2[b]	−0.163[c]	50.3 ± 9.5	43.3 ± 7.7[b]	−0.223[c]
VT	49.7 ± 5.9	48.4 ± 5.8[b]	−0.059[c]	49.7 ± 5.9	47.2 ± 5.0[b]	−0.134[c]
SF	52.4 ± 5.6	50.8 ± 7.3	−0.077[c]	52.4 ± 5.7	49.8 ± 8.0[b]	−0.111[c]
MH	53.6 ± 6.1	52.7 ± 6.8	−0.039	53.7 ± 6.2	51.4 ± 6.9[b]	−0.128[c]
RE	51.8 ± 5.4	50.8 ± 6.4	−0.038	51.9 ± 5.3	49.4 ± 7.1[b]	−0.131[c]
PCS	47.7 ± 6.9	44.5 ± 7.0[b]	−0.113[c]	47.8 ± 6.7	42.4 ± 7.0[b]	−0.218[c]
MCS	52.6 ± 5.9	52.6 ± 6.7	−0.004	52.7 ± 5.9	51.9 ± 7.3	−0.0052
EQ-5D	0.92 ± 0.14	0.85 ± 0.17[b]	−0.127[c]	0.91 ± 0.14	0.82 ± 0.17[b]	−0.150[c]

[a] Adjusted beta values are shown using multiple regression analysis after adjusting for age, BMI, knee pain and low back pain

[b] $p < 0.05$ vs. subjects without the corresponding pain by non-paired t test

[c] $p < 0.05$

Table 3 Scores for SF-8, EQ-5D, and WOMAC by Kellgren–Lawrence (KL) grade in participants with knee pain

Variables	KL 0/1	KL 2	KL 3	KL 4
Prevalence (%)	26.8	37.5	22.8	12.9
SF-8				
GH	49.3 ± 5.9	49.1 ± 5.7	48.5 ± 6.3	47.2 ± 5.3
PF	49.3 ± 6.8	48.3 ± 6.1	47.2 ± 7.6	45.0 ± 6.3[a]
RP	49.8 ± 6.4	48.4 ± 6.4	48.1 ± 7.8	46.1 ± 7.3[a]
BP	46.7 ± 8.9	46.9 ± 9.2	44.2 ± 9.2	42.0 ± 8.7[a]
VT	49.2 ± 6.0	49.0 ± 5.5	47.2 ± 6.2	46.8 ± 4.9
SF	51.6 ± 6.8	50.4 ± 7.2	50.5 ± 8.0	50.8 ± 7.3
MH	52.6 ± 7.6	52.5 ± 6.5	52.8 ± 6.8	53.6 ± 6.2
RE	51.4 ± 6.5	50.6 ± 5.9	50.6 ± 7.0	50.3 ± 6.7
PCS	46.1 ± 6.5	45.4 ± 6.4	43.5 ± 7.9[a]	40.6 ± 6.1[a,b]
MCS	52.5 ± 7.2	52.0 ± 6.1	52.7 ± 7.2	54.2 ± 6.3
EQ-5D	0.89 ± 0.15	0.84 ± 0.19	0.84 ± 0.16	0.81 ± 0.18[a]
WOMAC				
Pain	1.67 ± 2.72	2.33 ± 2.99	2.80 ± 2.76[a]	4.38 ± 3.29[a,b]
Stiffness	0.96 ± 1.59	1.14 ± 1.61	1.34 ± 1.50	1.88 ± 2.20[a]
Function	4.58 ± 9.38	6.95 ± 9.80	8.05 ± 9.56	14.94 ± 12.46[a,b]

Except where indicated otherwise, values represent the mean ± SD

[a] $p < 0.05$ vs. KL 0/1 in the corresponding group by the Tukey HSD test

[b] $p < 0.05$ vs. KL 0/1 in the corresponding group by the Tukey HSD test after adjustment for age and BMI

of knee pain with QOL. Furthermore, radiographic joint space narrowing represents not only joint cartilage destruction but also meniscal loss or extrusion. In addition, knee pain may arise from a variety of structures other than joint cartilage, including menisci, synovium, ligaments, bursae, bone, and bone marrow [24–28]. Comprehensive mechanistic studies of knee pain taking various tissues in and around the knee joint into consideration are thus needed to elucidate the relationships between radiographic OA and QOL.

The results of our previous study showed that lumbar spondylosis is weakly associated with low back pain. In the

Table 4 Scores for SF-8 and EQ-5D by KL grade and VFx in subjects with low back pain

Variables	Lumbar spondylosis				VFx	
	KL 0/1	KL 2	KL 3	KL 4	No	Yes
Prevalence (%)	28.3	12.9	26.6	32.2	10.7	89.3
SF-8						
GH	48.1 ± 5.6	47.1 ± 5.7	46.4 ± 5.7	46.9 ± 5.1	47.2 ± 5.5	46.1 ± 5.4
PF	46.8 ± 7.4	45.9 ± 6.7	44.7 ± 6.7	46.3 ± 6.6	46.2 ± 6.9	43.9 ± 6.3[a]
RP	47.2 ± 7.4	47.1 ± 6.9	44.7 ± 8.2	46.7 ± 7.2	46.7 ± 7.4	43.4 ± 7.6[a]
BP	43.8 ± 8.0	44.1 ± 8.3	43.4 ± 7.9	42.6 ± 7.2	43.6 ± 7.7	41.1 ± 7.4
VT	48.3 ± 5.3	45.6 ± 6.7	47.3 ± 5.5	46.9 ± 5.0	47.3 ± 5.6	46.3 ± 3.9
SF	51.4 ± 6.6	50.8 ± 6.5	47.8 ± 9.8	49.7 ± 7.9	50.0 ± 7.9	48.3 ± 8.7
MH	52.8 ± 6.0	52.0 ± 7.4	50.0 ± 7.5	51.2 ± 6.8	51.5 ± 6.9	49.8 ± 7.0
RE	50.7 ± 5.9	51.2 ± 5.2	47.8 ± 8.8	49.0 ± 6.7	49.7 ± 7.0	46.9 ± 7.1[a]
PCS	42.9 ± 7.7	42.3 ± 7.2	41.8 ± 7.0	42.4 ± 6.3	42.6 ± 7.0	40.2 ± 6.2[a]
MCS	53.5 ± 6.0	52.8 ± 6.7	50.3 ± 8.6	51.5 ± 7.1	52.0 ± 7.3	50.6 ± 6.8
EQ-5D	0.86 ± 0.15	0.87 ± 0.18	0.77 ± 0.18[a]	0.81 ± 0.17	0.83 ± 0.17	0.80 ± 0.21

Except where indicated otherwise, values represent the mean score ± SD

[a] $p < 0.05$ vs. KL 0/1 in the corresponding group by the Tukey HSD test

present study, we found that low back pain was strongly associated with lower QOL scores, while the severity of lumbar spondylosis was not significantly associated with the magnitude of QOL loss in women with low back pain. These results may be partly explained by the weak association between lumbar spondylosis and low back pain, as reported by us and other researchers [1, 29, 30]. KL grade encompasses assessments of both osteophytosis and disk space narrowing, but not of narrowing of the spinal canal, spondylolisthesis, or scoliosis, all of which are associated with low back pain. In addition, low back pain arises from a number of disorders other than disc space narrowing, such as nociceptive stimuli, inflammation, muscle weakness, and abnormal load on muscles, ligaments, or capsular tissues [31]. Indeed, disc degeneration was detected by magnetic resonance imaging (MRI) at at least one lumbar level in all but one asymptomatic volunteer in a 60- to 80-year-old age group [32]. Pain is also influenced by psychological status, such as depression, since significant associations between low back pain and depression have been confirmed in many longitudinal studies [33, 34]. In terms of VFx, previous studies have shown strong effects of clinical VFx on QOL in clinical studies [35, 36], and associations of subclinical vertebral deformity with QOL were found in women in a population-based study [37]. The results of our also show that VFx was significantly associated with the magnitude of QOL loss as measured by the PF, RP, RE, and PCS of the SF-8 in subjects with low back pain, indicating that low back pain with VFx has a strong impact on QOL in women.

Knee pain and low back pain were not significantly associated with lower scores for the MCS of the SF-8 in this study. MCS questions within the SF-8 include generic questions on energy levels, feelings of being "downhearted and blue", and interference with daily activities as a result of emotional problems. As such, this summary score is less sensitive to the presence of mental health issues than disease-specific scales such as the Kessler psychological distress scale [38]. In fact, although in one study psychological distress was significantly more frequent in individuals with pain than in those without [39], the MCS score did not differ significantly between these two groups [40]. Whether the MCS is not associated with knee pain and low back pain is thus unclear. A further complication is that previous research has shown that chronic pain patients who accept their diagnosis display lower levels of pain and affective distress than those who are uncertain [41, 42], which may be one reason why in our study MCS was not associated with pain. The ROAD study is a longitudinal survey, and analysis of its data over time may elucidate the association of QOL measured by MCS and pain.

This study has several limitations. First, it was a large-scaled population-based study, but the baseline data were cross-sectional, so causal relationships could not be determined. The ROAD study is a longitudinal survey that will eventually shed light on the causal relationships. Second, we only used a semi-quantitative method to assess VFx. In addition, the KL system was used for knee OA and lumbar spondylosis. The KL system is the most conventional grading system to detect the radiographic severity of knee OA, but joint space narrowing and osteophyte formation cannot be assessed separately in this categorical system. In addition, since the KL system emphasizes osteophytosis, the handling of data on lumbar spondylosis

with disc space narrowing but no osteophytosis is unclear. In addition, in terms of the lumbar spine, we did not include lumbar spinal canal stenosis (LSCS), scoliosis, spondylolisthesis, or narrowing of the nerve canal in our analysis, although these changes are also associated with QOL. To determine the associations of these changes of the lumbar spine and knee with QOL, we are currently developing a computer-aided diagnostic program to enable automatic measurement of the major features of VFx, disc space narrowing, osteophytosis, LSCS, scoliosis, spondylosis, and narrowing of the nerve canal in the lumbar spine, and of joint space narrowing and osteophytosis at the knee on plain radiographs [13]. Third, we did not include the onset of VFx in the analysis, although the severity of low back pain often appears to be associated with the interval from the onset of VFx. With respect to clinical fractures, we examined the history of fracture, including vertebral fracture, in the ROAD study by self-report, and no clinical vertebral fractures occurred within 1 month prior to baseline examination. However, we could not compare radiographs of the lumbar spine at baseline examination with those before the examination as the subjects had not undergone radiography of the lumbar spine prior to that examination. We were therefore unable to assess the incidence of subclinical fracture within the month prior to the baseline examination. Both clinical and subclinical vertebral fractures are associated with lower QOL in women [11], but the association between the severity of low back pain and the interval from onset of subclinical VFx may be weaker than that for clinical VFx; consequently, the absence of data on the incidence of subclinical VFx may not strongly affect the present results.

In conclusion, the results of our cross-sectional study using a large-scale population (1,369 Japanese women ≥40 years of age) from the ROAD study reveal that knee pain and low back pain were significantly associated with the QOL of these women. In women with knee pain, KL = 4 knee OA was strongly associated with QOL loss. In women with low back pain, no significant associations were seen between KL grade and QOL, while VFx may have some associations with QOL loss. The impact of knee pain with KL = 4 knee OA for PCS was larger than that of low back pain with VFx. Future studies, along with the continued longitudinal survey in the ROAD study, will elucidate the environmental and genetic backgrounds of knee pain and low back pain.

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Conflict of interest statement None.

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In Vivo Three-Dimensional Kinematics of the Cervical Spine During Head Rotation in Patients With Cervical Spondylosis

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Study Design. Kinematics of the cervical spine during head rotation was investigated using 3-dimensional (3D) magnetic resonance imaging (MRI) in patients with cervical spondylosis (CS).

Objective. To demonstrate *in vivo* 3D kinematics of the spondylotic cervical spine during head rotation.

Summary of Background Data. Several in vivo studies have identified kinematic differences between normal and spondylotic subjects, but only two-dimensional flexion/extension motion has been investigated. Differences of *in vivo* 3D cervical motion during head rotation between normal and spondylotic subjects have yet to be clarified.

Methods. Ten healthy volunteers (control group) and 15 patients with CS (CS group) underwent 3D MRI of the cervical spine with the head rotated to 5 positions (neutral, ±45° and ±maximal head rotation). Relative motions of the cervical spine were calculated by automatically superimposing a segmented 3D MRI of the vertebra in the neutral position over images for each position using volume registration. The 3D motions of adjacent vertebra were represented with 6 degrees of freedom by Euler angles and translations on the coordinate system.

Results. Compared with the control group, the CS group showed significantly decreased mean axial rotation and mean coupled lateral bending at C5–C6 and C6–C7 and significantly increased mean coupled lateral bending at C2–C3 and C3–C4, although both the groups showed the same pattern of coupled motions.

Conclusion. The in vivo 3D kinematics of the spondylotic cervical spine during head rotation was accurately depicted and compared with those of healthy cervical spines for the first time.

Key words: kinematics, coupled motion, cervical spondylosis, volume registration. **Spine 2010;XX:000–000**

The human cervical spine is composed of highly specific tissues and structures, which together provide the extensive range of motion and considerable load-carrying capacity required for physical activities of daily living (ADL). This is 1 reason why degenerative changes in the cervical spine start as early as middle age and affect more than 95% of patients older than 65 years.[1] Even though nerve root or cord compression develops in 10% to 15% of the population,[2] the pathophysiology of cervical spondylosis (CS) remains poorly understood.[3]

Achieving a better understanding of this pathophysiology requires clarification of the differences in kinematics between the normal and spondylotic cervical spine. Several kinematic studies associated with aging and/or degeneration of the cervical spine have been reported using simple extension and flexion radiography,[4–7] motion analysis,[8] cineradiography,[9] and magnetic resonance imaging (MRI).[10] However, most of these studies have investigated only 2-dimensional flexion/extension motion, and 3-dimensional (3D) analysis using a motion analyzer has been vague and indirect. No study comparing in vivo 3D cervical motion during head rotation between normal and spondylotic subjects has been conducted, despite the importance of these motions in ADL. This is because of the difficulty in measuring *in vivo* cervical segmental motion, particularly during head rotation and lateral bending, which involves complex 3D motions called "coupled motion." We have developed a 3D MRI system to evaluate the *in vivo* 3D kinematics of the spine[11–14] and have already reported accurate *in vivo* 3D kinematics of the normal cervical spine using this method.[11–13] The objectives of this study were to investigate *in vivo* 3D kinematics of the spondylotic cervical spine during head rotation and to compare those with kinematics of the healthy cervical spine.

■ Materials and Methods

Subjects in this study comprised 10 healthy volunteers (control group) and 15 patients with CS (CS group). The 10 healthy volunteers (5 men, 5 women; mean age, 25.1 years; range, 22–31 years) had neither neck pain nor any medical history of cervical spine disorders. As for the control group, all subjects were included in our previous publications[11–13] and retrospective analysis was performed. The 15 patients (7 men, 8 women; mean age, 60.2 years; range, 41–70 years) had been referred to our institution because of axial and/or neurologic symptoms and showed radiographic findings of CS as follows: loss of disc space height; spondylotic bars; foraminal osteophytes; and ky-

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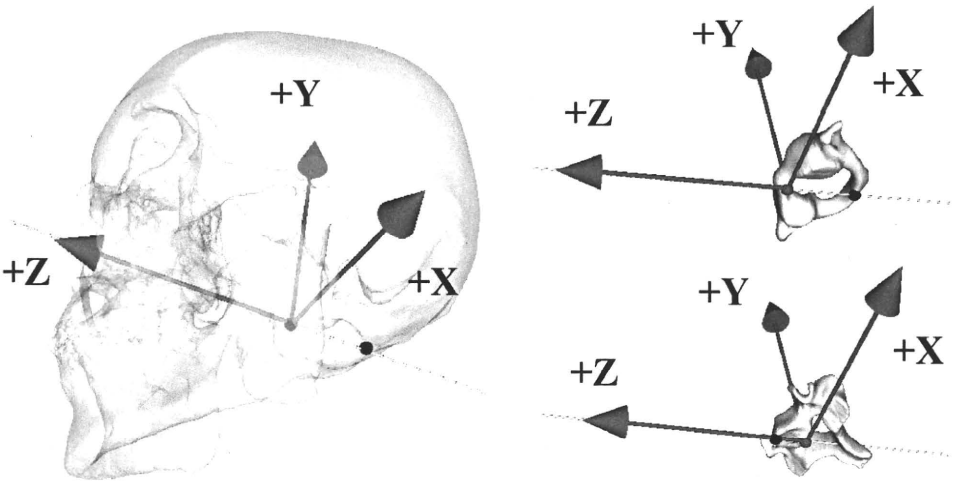

Figure 1. Anatomic orthogonal coordinate system for Oc, C1, and subaxial cervical vertebrae (C5). The methods have been fully described in previous studies.

phosis. Subjects with a history of cervical spine surgery, trauma, tumors, infection, rheumatoid arthritis, or ossification of the posterior longitudinal ligament were excluded. All study protocols were approved in advance by the institutional review board.

Each subject was placed supine on the MRI table and underwent 3D MRI in 5 positions with the head rotated 0° (neutral position), 45°, and maximally to the left and right. All subjects were instructed to rotate the head as perpendicular as possible to the axis of the body trunk, and the shoulders were fixed to the table with a band. In the control group, MRI was performed using a 1.0-T commercial magnetic resonance system (Signa LX; General Electric, Milwaukee, WI). A 3D fast-gradient recalled acquisition in the steady state sequence was used with the following settings: repetition time, 8.0 ms; echo time, 3.3 ms; slice thickness, 1.5 mm; no interslice gap; flip angle, 10°; field of view, 24 cm; and 256 × 224 in-plane acquisition matrix. In the CS group, MRI was performed using a 1.5-T commercial magnetic resonance system (MAGNETOM Espree; Siemens, Erlangen, German). A 3D multiecho data imaging combination sequence was used with the following settings: repetition time, 40.0 ms; echo time, 20.0 ms; slice thickness, 1.3 mm; no interslice gap; flip angle, 12°; field of view, 24 cm; and 256 × 226 in-plane acquisition matrix. All subjects provided informed consent to undergo 3D MRI for the kinematics study and those for whom MRI proved difficult to perform because of axial and/or neurologic symptoms were excluded. All examinations were performed by the first or second author.

MRI data were saved in Digital Imaging and Communications in Medicine format and transmitted to a computer workstation, where image processing was performed using software developed in our laboratory (Virtual Place M series; Medical Imaging Laboratory, Tokyo, Japan). The method used in this study has been fully described in previous reports[11–13] and is, therefore, only described briefly here. This method showed high accuracy as follows: 0.24° for flexion/extension, 0.31° for lateral bending, 0.43° for axial rotation, 0.52 mm for superoinferior translation, 0.51 mm for anteroposterior translation, and 0.41 mm for lateral translation[11]. As a result of image processing (volume registration method), 3D motions of each vertebra expressed as a matrix were obtained. For easier comprehension of complicated 3D motions, relative 3D cervical motions of all motion segments were calculated by converting the matrix obtained by image processing into a matrix representing relative motion with respect to the inferior adjacent vertebra, and these motions were expressed in 6 degrees of freedom by Euler angles with the sequence of yaw (X)-pitch (Y)-roll (Z) and translations using a previously defined coordinate system as follows: the z-axis of occipital bone (Oc) was parallel to the line connecting anterior and posterior borders of the foramen magnum, with anterior considered positive. The y-axis was defined as perpendicular to the z-axis, with superior being positive. The x-axis was positive to the left. The coordinate system of C1 was defined using 2 points: the posteroinferior border of the anterior arch and the anteroinferior border of the posterior arch. Origins were located at the anterior border of the foramen magnum on Oc and the posteroinferior border of the anterior arch on C1. The coordinate system of subaxial cervical vertebrae was defined as follows: the origin was located at the most inferior point on the posterior wall of the vertebral body in the midsagittal plane. The z-axis was defined as the line connecting anterior and posterior points in the inferior plane of the vertebral body, with anterior considered positive. The y-axis was defined as perpendicular to the z-axis, with superior being positive. The positive x-axis was directed to the left (Figure 1).[11–13] The coordinate system was always set with moving vertebrae (suprajacent vertebra of the functional spinal unit) in this study. Mean values and standard deviations for range of motion to 1 side were computed in each group. Segmental motions were calculated as the average of the sum between left and right motions for coupled extension flexion, coupled anteroposterior translation, and coupled superoinferior translation, using constant codes between left and right rotation, and also calculated as the average difference between left and light motions for main axial rotation, coupled lateral bending, and lateral translation, using differing codes between left and right rotation.

In addition, degree of head rotation was measured accurately on the absolute spatial coordinate system using volume registration of the occiput. A 3D animation of each subject was also constructed to facilitate an understanding of these complex motions using methods that have been fully described in previous studies.[11–13]

Comparisons of rotations and translations by spinal level between groups were performed using the nonparametric Mann-Whitney U test. Values of $P < 0.05$ were considered statistically significant.

■ Results

Mean (±standard deviation) maximal head rotation was 72.0 ± 5.3° in the control group and 63.4 ± 8.9° in the

Table 1. Rotations by Spinal Level for Control and CS Groups at 45° Head Rotation

	Oc–C1	C1–C2	C2–C3	C3–C4	C4–C5	C5–C6	C6–C7	C7–T1
AR								
Control(°)	0.4 ± 2.1	29.4 ± 3.2	0.5 ± 0.4	2.1 ± 0.5	2.4 ± 0.9	2.6 ± 0.7*	1.6 ± 0.7*	0.8 ± 0.6
CS(°)	0.2 ± 1.1	28.8 ± 3.7	0.9 ± 0.5	2.0 ± 0.7	2.0 ± 0.8	1.1 ± 0.7*	0.6 ± 0.3*	0.7 ± 0.3
Cp LB								
Control(°)	−4.0 ± 1.4*	−3.8 ± 1.8†	0.7 ± 1.2*	2.7 ± 0.7†	3.1 ± 0.8	2.8 ± 1.1*	2.5 ± 1.6†	0.5 ± 0.9
CS(°)	−2.3 ± 0.8*	−5.7 ± 1.6†	2.2 ± 1.0*	3.8 ± 1.2†	2.5 ± 1.3	1.3 ± 0.9*	1.3 ± 0.9†	0.6 ± 0.6
Cp F/E								
Control(°)	−5.4 ± 2.7†	−3.4 ± 2.0	−0.6 ± 1.0	0.8 ± 1.2	−1.1 ± 2.0	0.7 ± 1.5	1.0 ± 1.4†	0.8 ± 1.1
CS(°)	−7.7 ± 2.4†	−4.9 ± 2.8	−0.7 ± 0.4	−0.9 ± 0.7	−1.0 ± 1.1	−0.1 ± 0.7	0.5 ± 0.8†	1.3 ± 0.9

*$P < 0.01$.
†$P < 0.05$.
AR indicates axial rotation; Cp LB, coupled lateral bending; Cp F/E, coupled flexion/extension; CS, cervical spondylosis.

CS group. As a large range of mobility was identified between groups, only kinematics at 45° of head rotation was compared.

Main Axial Rotation at 45° Head Rotation

Significant decreases in axial rotation were observed at C5–C6 and C6–C7 in the CS group at both 45° (Table 1 and Figure 2).

Coupled Lateral Bending at 45° Head Rotation

In both groups, coupled lateral bending opposite to head rotation to 1 side was observed in the upper cervical spine, whereas the subaxial cervical spine displayed coupled lateral bending in the same direction as head rotation (Table 1 and Figure 3). Significant decreases in coupled lateral bending were observed at Oc-C1, C5–C6, and C6–C7, and significant increases were also observed at C1–C2, C2–C3, and C3–C4 in the CS group compared with the control group.

Coupled Flexion/Extension at 45° Head Rotation

In both groups, extension coupled with head rotation to 1 side occurred in the upper and middle cervical spine, whereas in the lower cervical spine, flexion was coupled with head rotation (Table 1 and Figure 4). Significant decreases in coupled flexion/extension were observed at C6–C7, and significant increases were observed at Oc–C1 in the CS group compared with the control group.

Coupled Translations at 45° Head Rotation

Although coupled translations were barely seen and most of these values were beyond the limit of accuracy and too small to analyze statistically, concerning lateral translation, the CS group showed a tendency toward larger motion in the middle cervical spine compared with the control group (Table 2 and Figure 5).

■ Discussion

Hypomobility at the Lower Cervical Segments in the Degenerative Cervical Spine

General agreement is seen in the literature that the most commonly involved level is at C5–C6, followed by C6–C7 with increasing age.[4,15,16] Degenerative changes are speculated to arise most frequently at these levels because maximum distribution of axial load occurs at the lower cervical levels representing the sites of lordotic inversion.[10,17,18] To the best of our knowledge, few studies have addressed the *in vivo* kinematic changes of cervical motion segments after degeneration, despite a number of 2-dimensional flexion/extension motion studies of the normal cervical spine. Dvorak *et al*[4] showed signifi-

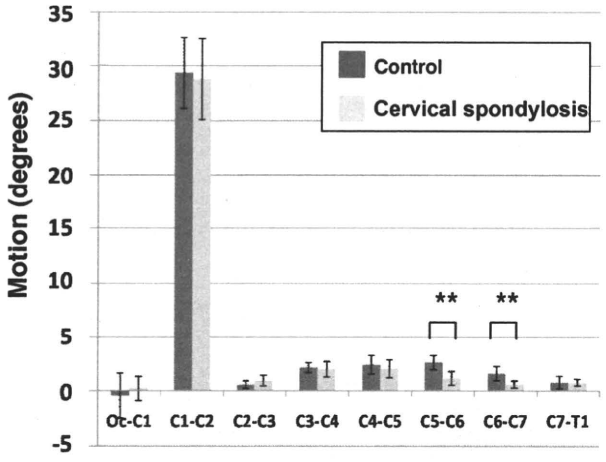

Figure 2. Main axial rotation by spinal level for the Control and CS groups at 45° head rotation. Data represent mean ± standard deviation. *$P < 0.05$ and **$P < 0.01$.

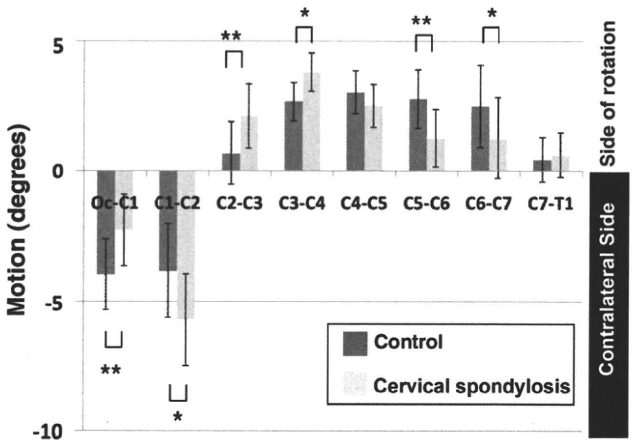

Figure 3. Coupled lateral bending by spinal level for the Control and CS groups at 45° head rotation. Data represent mean ± standard deviation. *$P < 0.05$ and **$P < 0.01$.

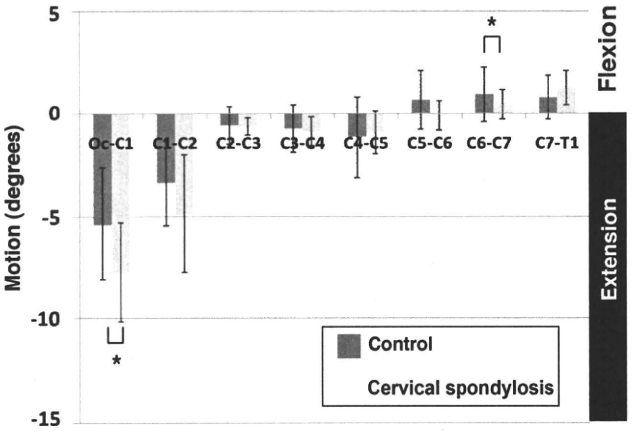

Figure 4. Coupled flexion/extension by spinal level for the Control and CS groups at 45° head rotation. Data represent mean ± standard deviation. $*P < 0.05$ and $**P < 0.01$.

cant hypomobility in sagittal rotation at C6–C7 in subjects with degenerative spine based on a functional flexion/extension radiographic study. Miyazaki *et al*[10] revealed that decreased segmental motion during extension-flexion starts at C4–C5 and C5–C6 with increasing age in a kinetic MRI study. No studies have clarified the kinematic changes occurring head rotation, because of the difficulties inherent in measuring such 3D motions *in vivo*. This study succeeded in detecting kinematics of the cervical spine during head rotation in patients with CS using a unique method. Comparison with healthy cervical spines yielded comparable results to previous cervical flexion/extension motion studies, showing significant decreases in main axial rotation and coupled lateral bending during head rotation at C5–C6 and C6–C7 segments in the CS group. These results indicate that in the lower cervical spine of the CS group, which is vulnerable to degeneration, motion segments might have already been in the stabilization phase put forward by Kirkaldy-Willis and Farfan[19] and hypomobility might have been present.

As for main axial motion, significant compensatory motions were barely seen at the suprajacent segments. However, the question arises as to where compensation occurs, because both groups were compared at 45° fixed head rotation. Total cervical motion at 45° fixed head rotation and the contribution ratio ([total cervical rotation {°}/head rotation {°}] × 100) was 38.9° (89%) in the control group and 36.4° (83%) in the CS group. Slight but significant decreases in motion were identified in the CS group ($P < 0.01$, nonparametric Mann-Whitney *U* test). Given the above findings, some compensation can safely be said to occur beyond the upper thoracic spine, but the precise location at which compensation occurred could not be identified.

Coupling Pattern of the Degenerative Cervical Spine

Although coupling patterns provide important clues for the detection of selected elements of spine pathology,[20] coupled motion is thought to be difficult to assess precisely because of the complex 3D motions and *in vivo* explorations have been rare. White and Panjabi[21] described abnormal coupled motion as 1 feature of abnormal spine kinematics. As we have already succeeded in accurately detecting 3D coupled motion of the cervical spine *in vivo*, we investigated coupled patterns of the spondylotic cervical spine during head rotation and compared the results with those of the healthy cervical spine. Although almost the same coupling patterns were identified in both groups, the spondylotic cervical spine showed significant hypomobility in axial and lateral directions at the lower cervical spine and significant lateral hypermobility, including coupled lateral bending at the middle cervical spine (Table 3). The fact that hypermobility in lateral directions was observed at the middle cervical spine in the CS group compared with the control group indicates that intervertebral mechanical stresses are increased in lateral directions at the middle cervical spine. As head axial rotation movements are reportedly half as frequent as flexion/extension movements and just as frequent as lateral bending movements,[22] head axial rotation movements are often repeated during ADL. Given these considerations, repetition of head rotation in ADL might have promoted degenerative changes of the middle cervical spine in the CS group.

This study has several limitations. First, the information was not obtained from true real-time imaging in the upright position. Second, the study was conducted using a small sample size. Third, patients were grouped together in the CS group despite a wide degree of variation in age, deformity, and symptoms. In this regard, further research focused more specifically on a particular subject group should be undertaken to elucidate details of the

Table 2. Coupled Translations by Spinal Level for Control and CS Groups at 45° Head Rotation

	C2–C3	C3–C4	C4–C5	C5–C6	C6–C7	C7–T1
Lateral translation						
Control (mm)	0.2 ± 0.0	−0.2 ± 0.0	−0.4 ± 0.1	−0.5 ± 0.0	−0.3 ± 0.1	−0.2 ± 0.0
CS (mm)	−0.2 ± 0.2	−0.6 ± 0.3	−0.5 ± 0.2	−0.5 ± 0.4	−0.3 ± 0.1	−0.2 ± 0.0
Superoinferior translation						
Control (mm)	−0.1 ± 0.1	−0.1 ± 0.2	−0.0 ± 0.3	0.1 ± 0.3	0.3 ± 0.3	0.2 ± 0.5
CS (mm)	−0.2 ± 0.1	−0.1 ± 0.2	−0.1 ± 0.1	−0.0 ± 0.1	0.1 ± 0.2	0.1 ± 0.2
Anteroposterior translation						
Control (mm)	−0.1 ± 0.2	−0.1 ± 0.2	−0.0 ± 0.3	0.2 ± 0.3	0.4 ± 0.4	0.3 ± 0.7
CS (mm)	−0.1 ± 0.1	−0.1 ± 0.2	−0.1 ± 0.2	0.1 ± 0.1	0.1 ± 0.1	0.2 ± 0.1

CS indicates cervical spondylosis.

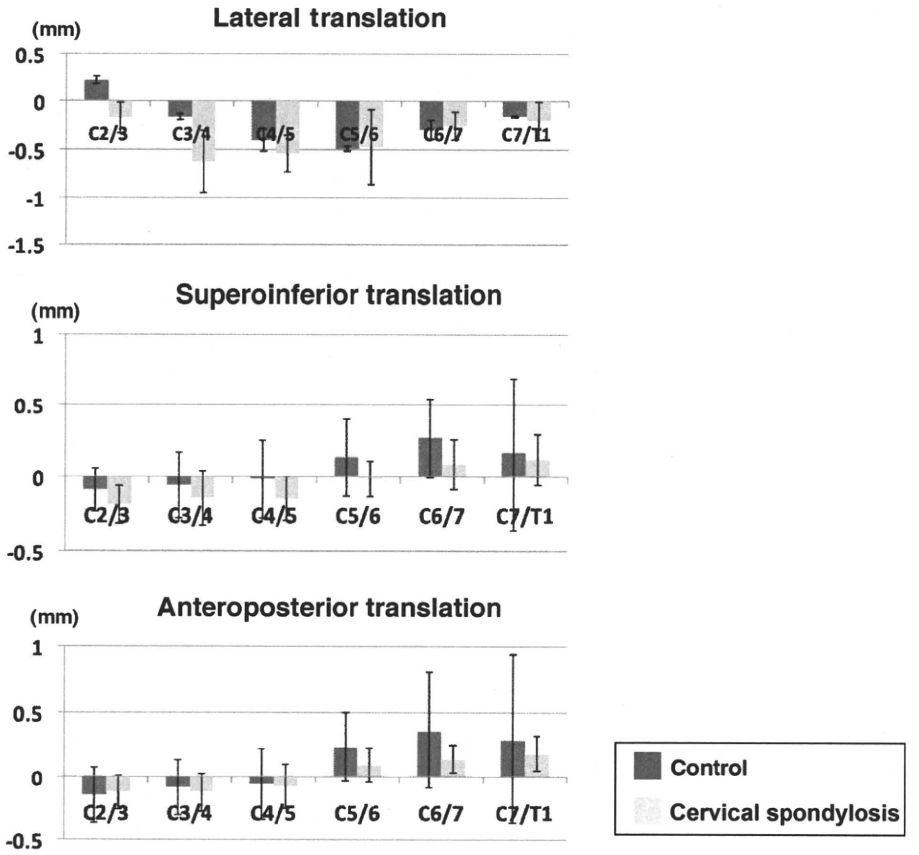

Figure 5. Coupled translations by spinal level for the Control and CS groups at 45°. Intervertebral motions are expressed in mm.

natural history of cervical spine motion after degeneration. Fourth, there might be some differences between the images obtained from the 2 different scanners in the 2 groups. Despite all these limitations, no other approaches to kinematic analysis have provided the kind of information given in this study, and these findings thus represent a step toward a better understanding of CS.

In conclusion, we accurately determined *in vivo* 3D kinematics of the spondylotic cervical spine during head rotation and compared the results with kinematics for the healthy cervical spine for the first time. Comparison with healthy cervical spine yielded comparable results with previous cervical flexion/extension motion studies, significant decreases in main axial rotation, and coupled lateral bending during head rotation at C5–C6 and C6–C7 segments in the spondylotic cervical spine. Although almost the same coupling patterns were observed in both groups, significant hypomobility in axial and lateral directions at the lower cervical spine and significant hypermobility in lateral directions at the middle cervical spine were apparent in the spondylotic cervical spine. Because hypermobility in lateral directions at the middle cervical spine in the CS group were thought to reflect increased intervertebral mechanical stresses, repeated head rotation in ADL might contribute to the progression of degenerative changes in the middle cervical vertebrae of the spondylotic cervical spine.

Table 3. Summary of Coupling Pattern for the CS Group Compared With the Control Group

	Main Motion	Coupled LB	Coupled F/E
Upper (Oc–C2)	N	N	N
Middle (C2–C5)	N	Increased	N
Lower (C5–T1)	Decreased	Decreased	N

LB indicates lateral bending; F/E, flexion/extension; N, no marked difference between groups; CS, cervical spondylosis.

■ Key Points

- *In vivo* 3D kinematics of the spondylotic cervical spine during head rotation was investigated for the first time.
- Almost the same coupling patterns were observed in both healthy and spondylotic cervical spine.
- Significant hypomobility at the lower cervical segments were observed in the spondylotic cervical spine; significant decreases in main axial rotation and coupled lateral bending at C5–C6 and in coupled flexion/extension as well as main axial rotation and coupled lateral bending at C6–C7.
- On the contrary, significant hypermobility in lateral directions were observed at the middle cervical segments in the spondylotic cervical spine; significant increases in coupled lateral bending at C2–C3 and C3–C4.

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Preservation of Muscles Attached to the C2 and C7 Spinous Processes Rather Than Subaxial Deep Extensors Reduces Adverse Effects After Cervical Laminoplasty

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Study Design. Prospective study.

Objective. To examine whether preservation of subaxial deep extensor muscles plays any significant role in reducing axial neck pain and unfavorable radiologic changes after cervical laminoplasty in patients with cervical spondylotic myelopathy and to confirm the benefits of preserving muscles attached to the C2 and C7 spinous processes.

Summary of Background Data. Axial neck pain and unfavorable radiologic changes after cervical laminoplasty have been reported to mostly result from detachment of cervical extensor muscles, particularly muscles attached to the C2 and C7 spinous processes. Other surgeons have reported that preservation of subaxial deep extensor muscles reduces these adverse effects after cervical laminoplasty.

Methods. Subjects comprised 36 patients with cervical spondylotic myelopathy who underwent C3–C6 open-door laminoplasty and were followed up for >24 months. Of these, 18 consecutive patients underwent our modified laminoplasty (muscles-preserved group) and the remaining 18 consecutive patients underwent the conventional procedure (muscles-disrupted group). Both procedures preserved all muscles attached to the C2 and C7 spinous processes. Subaxial deep extensor muscles on the hinged side were also preserved in the muscles-preserved group. Radiologic and clinical data were prospectively collected.

Results. Both groups achieved equal neurologic improvement. Frequencies of axial neck pain showed no significant differences between groups. This value did not vary according to the side of preservation of subaxial deep extensor muscles or the side of muscle disruption. Postoperative loss of lordosis and range of motion of the cervical spine also demonstrated no significant difference between groups.

Conclusion. These results indicate that preservation of subaxial deep extensor muscles plays no significant role in reducing axial neck pain and unfavorable radiologic changes after cervical laminoplasty, supporting the hypothesis that these adverse effects after laminoplasty largely result from detachment of muscles attached to the C2 and C7 spinous processes.

Key words: cervical spine/surgery, postoperative complication, neck extensor muscles. **Spine 2010;35:E782–E786**

Laminoplasty is a reliable procedure for multisegmental cervical compression myelopathy. However, some surgery-associated problems remain yet to be solved, including undesirable postoperative radiologic changes such as kyphotic deformity, restriction of range of motion (ROM), axial neck pain, and segmental motor paralysis.[1] Adverse radiologic changes and axial neck pain after cervical laminoplasty have been reported as mostly resulting from neck muscle disruption, particularly detachment of muscle insertions to the C2 and C7 spinous processes.[2–8] Other surgeons have reported that preservation of subaxial deep extensor muscles, including the semispinalis cervicis groups, reduces these adverse effects after cervical laminoplasty.[9] Between September 2002 and December 2004, modified C3–C6 open-door laminoplasty had been our standard procedure for almost all patients with cervical spondylotic myelopathy (CSM). Our modified procedure preserves deep extensor muscles attached to the subaxial spinous processes on the hinged side, as well as all bilateral muscles attached to the C2 and C7 spinous processes.[6,10] To examine whether preservation of subaxial deep extensor muscles plays any significant role in reducing adverse radiologic changes and axial neck pain after cervical laminoplasty, our standard procedure has been changed to conventional C3–C6 open-door laminoplasty since January 2005. In our conventional procedure, all bilateral muscles attached to the C2 and C7 spinous processes are preserved, but bilateral subaxial deep extensor muscles are disrupted during surgery. The purpose of this prospective study was to examine whether preservation of subaxial deep extensor muscles could prevent adverse effects after laminoplasty in patients with CSM and to confirm the benefits of preserving muscles attached to the C2 and C7 spinous processes.

■ Materials and Methods

Since September 2002, all patients with CSM have been treated in our institution using C3–C6 open-door laminoplasty except for those with moderate or severe cervical kyphosis, single level anterior lesion without narrow spinal canal, or spinal cord

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IRB of our institute approved this study.
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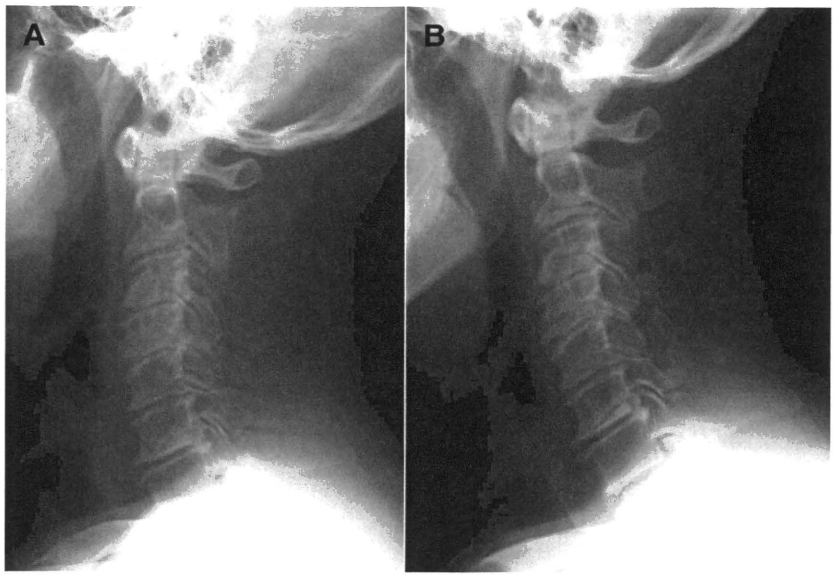

Figure 1. Lateral radiographs of the cervical spine in a 61-year-old man from the muscles-preserved group. **A,** Before surgery. **B,** 2 years after surgery. C3–C6 spinous processes and subaxial deep extensor muscles on the hinged side were preserved as well as all bilateral muscles attached to the C2 and C7 spinous processes.

compression at the C6–C7 and/or lower levels. On the basis of these criteria, 18 consecutive patients underwent our modified C3–C6 open-door laminoplasty between September 2002 and December 2004, and have been followed up for >24 months. In these 18 patients, deep extensor muscles attached to the subaxial spinous processes on the hinged side were preserved along with all bilateral muscles attached to the C2 and C7 spinous processes during laminoplasty (muscles-preserved group, Figure 1).[6] Conversely, 18 consecutive patients with CSM have undergone conventional C3–C6 open-door laminoplasty since January 2005, and have been followed up for >24 months. In these 18 patients, all bilateral muscles attached to the C2 and C7 spinous processes were preserved, but bilateral subaxial deep extensor muscles were disrupted during surgery (muscles-disrupted group, Figure 2). The muscles-preserved and muscles-disrupted cohorts were comparable with regard to gender ratio, age at time of surgery, and severity of myelopathic symptoms (Table 1). All 36 patients wore a soft collar for the first 2 weeks after surgery. All underwent follow-up examinations at regular intervals. Radiologic and clinical data were collected prospectively. Neurologic status was assessed using Japanese Orthopedic Association (JOA) score.[11] Axial neck pain was graded as severe (painkillers or local injection needed regularly), moderate (physiotherapy or compress needed regularly), or mild (no treatment needed), in accordance with a previous report.[6] Severe or moderate pain persisting >1 week during the first month after surgery was considered to constitute early axial pain. Severe or moderate pain persisting >1 month during the first year after surgery was considered to constitute late axial pain.[6] Laterality of axial neck pain was also recorded. Maximal flexion and neutral and maximal extension were examined on lateral radiographs of the cervical spine taken before surgery and at intervals thereafter. Sagittal alignment of the cervical spine was measured as the C2–C7 angle formed by 2 lines drawn parallel to the posterior margin of the vertebral body on a radiograph in the neutral position.

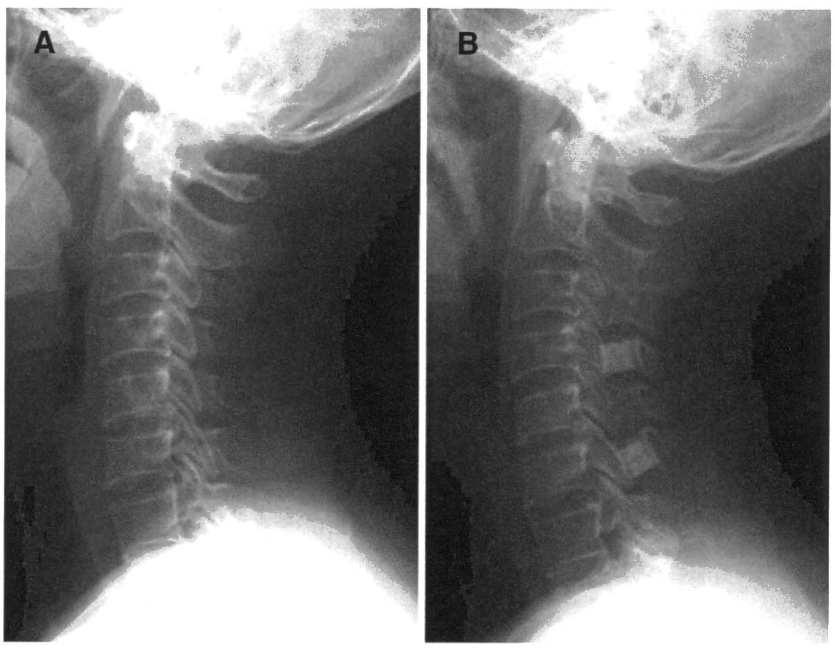

Figure 2. Lateral radiographs of the cervical spine in a 62-year-old woman from the muscles-disrupted group. **A,** Before surgery. **B,** 2 years after surgery. C3–C6 spinous processes were resected and all bilateral subaxial deep extensors were disrupted, but all bilateral muscles attached to the C2 and C7 spinous processes were preserved.

Table 1. Characteristics for All Patients in Muscles-Preserved and -Disrupted Cohorts

	Muscles-Preserved Group	Muscles-Disrupted Group	*P*
No. patients	18	18	NS
Male:female	14:4	13:5	NS
Age at the surgery (yr)	66.0 ± 11.0	62.5 ± 16.0	NS
JOA score before surgery (points)	10.2 ± 2.3	10.5 ± 3.3	

Mean ± standard deviation.
JOA indicates Japanese Orthopaedic Association; NS, not statistically significant.

Kyphosis and lordosis were defined as C2–C7 angle $\leq -10°$ and $\geq 10°$, respectively. All other spines were classified as straight. ROM of the cervical spine was calculated by subtracting maximal flexion angle from maximal extension angle.

The unpaired t test, Mann-Whitney *U* test, or Fisher exact probability test was applied for statistical analysis using JMP 5.0.1 software (SAS Institute, Cary, NC), as appropriate. Values of $P < 0.05$ were considered to indicate statistical significance.

■ Results

Neurologic Outcomes

Mean JOA score improved from 10.2 points before surgery to 14.7 points at the 2-year follow-up in the muscles-preserved group, and from 10.5 points to 14.3 points in the muscles-disrupted group. Mean recovery rate of JOA score at 2-year follow-up was 66.2% for the muscles-preserved group and 64.9% for the muscles-disrupted group. Neurologic gain after surgery showed no significant difference between groups (Table 2).

Axial Neck Pain

Early axial neck pain was identified in 3 patients (16.7%) from the muscles-preserved group and 4 patients (22.2%) from the muscles-disrupted group (Table 2). Two patients (11.1%) in each group experienced persistent late axial neck pain. Frequencies of early and late axial pain did not differ significantly between groups. This value did not vary between sides of preservation or disruption of subaxial deep extensor muscles (Tables 3, 4).

Table 2. Surgical Outcomes at 2-Year Follow-up for Each Group

	Muscles-Preserved Group	Muscles-Disrupted Group	*P*
JOA score at 2-yr follow-up (points)	14.7 ± 1.7	14.3 ± 2.6	NS
Recovery rate of JOA score at 2-yr follow-up (%)	66.2 ± 26.7	64.9 ± 21.4	NS
Early axial pain—-No. (%)	3/18 (16.7)	4/18 (22.2)	NS
Late axial pain—-No. (%)	2/18 (11.1)	2/18 (11.1)	NS

Mean ± standard deviation.
JOA indicates Japanese Orthopaedic Association; NS, not statistically significant.

Table 3. Incidence of Early Axial Neck Pain on Subaxial Deep Extensor Muscles-Preserved and -Disrupted Sides

	Muscles-Disrupted Side	Muscles-Preserved Side	*P*
Axial pain (+)	9	2	
Axial pain (−)	45	16	NS

NS indicates no significant difference, was found by Fisher exact probability test.

Sagittal Alignment of the Cervical Spine

Mean C2–C7 angle decreased from 17.6° before surgery to 14.1° at 2-year follow-up in the muscles-preserved group and from 17.5° to 14.5° in the muscles-disrupted group. Mean (± standard deviation) change in C2–C7 angle was −3.5° ± 10.1° in the muscles-preserved group and −2.9° ± 16.5° in the muscles-disrupted group. Postoperative loss of C2–C7 angle showed no significant difference between groups (Table 5). According to our classifications, 1 patient (5.6%) in each group developed postoperative kyphosis (Table 5).

ROM of the Cervical Spine

Mean residual C2–C7 ROM (%ROM = ROM at 2-year follow-up/ROM before surgery) was 74.0% in the muscles-preserved group and 75.7% in the muscles-disrupted group. Postoperative restriction of C2–C7 ROM did not show any significant difference between groups (Table 5).

■ Discussion

Ratliff and Cooper, in their review of cervical laminoplasty, identified some surgery-associated problems that have yet to be solved, including axial neck pain, undesirable postoperative radiologic changes such as deterioration of sagittal alignment, restriction of ROM, and segmental motor paralysis.[1] Regarding axial neck pain after cervical laminoplasty, we have previously reported in a prospective study that disruption of muscle insertions into the C7 spinous process is associated with a significantly increased frequency of persistent postoperative axial neck pain.[6] Intensity of axial neck pain increases in the sitting position and decreases in the supine position. Given this characteristic, downward displace-

Table 4. Incidence of Late Axial Neck Pain on Subaxial Deep Extensor Muscles-Preserved and -Disrupted Sides

	Muscles-Disrupted Side	Muscles-Preserved Side	*P*
Axial pain (+)	6	1	
Axial pain (−)	48	17	NS

NS indicates no significant difference, was found by Fisher exact probability test.

Table 5. Radiologic Outcomes at 2-Year Follow-up for Each Group

	Muscles-Preserved Group	Muscles-Disrupted Group	*P*
Loss of C2–C7 angle (°)	3.5 ± 10.1	2.9 ± 16.5	NS
Kyphotic deformity—No (%)	1/18 (5.6)	1/18 (5.6)	NS
Residual ROM (%)	74.0 ± 34.3	75.7 ± 36.2	NS

Mean ± standard deviation.
NS indicates not statistically significant; ROM, range of motion.

ment of the upper extremities seems to induce axial pain in the upright position. The C7 spinous process would play a critical role as a fulcrum for shoulder suspensory muscles, as the transverse portion of the trapezius muscle arises from the C7 and the first 5 thoracic spinous processes, and the rhomboid minor muscle attaches to the spinous processes of C7 and T1. Although the exact pathogenesis of postoperative axial neck pain remains unclear, we speculate that postoperative persistent axial neck pain might be caused by injury to these shoulder suspensory muscles after surgical exposure of the C7 spinous processes. Some surgeons have recently reported results supporting our speculation.[7,8,12] In the present study, all bilateral muscles attached to the C7 spinous processes were preserved in all patients, and only 2 patients in each group (11.1%) experienced persistent axial neck pain. These results indicate that preservation of muscle insertions to the C7 spinous process significantly lowers the incidence of axial neck pain after laminoplasty.

Focusing attention on postoperative deterioration of sagittal alignment, loss of C2–C7 angle reaches 6.2 to 11.7° after conventional C3–C7 laminoplasty.[13,14] These changes have been assumed to mostly result from disruption of neck muscles, particularly detachment of muscle insertions to the C2 spinous process. Biomechanical analysis by Nolan and Sherk demonstrated that the semispinalis cervicis and C2 lamina act as the main dynamic stabilizers of the cervical spine and that removal of the semispinalis attachment to the C2 spinous process leads to a loss of normal cervical sagittal alignment.[15] Steinbok *et al* also showed that laminectomy from C1 or C2 to the subaxial cervical spine often results in spinal deformity.[16] Some surgeons have recently reported that preservation of muscle insertions to the C2 spinous process reduces loss of lordosis after surgery compared with conventional laminoplasty.[2–4] Takeshita *et al* reported that a mean change in C2–C7 angle was only −1.5° after laminoplasty with preserved muscle insertion to the C2 spinous process.[3] In the present study, all bilateral muscles attached to the C2 spinous processes were preserved in all patients, and mean change in C2–C7 angle was only −3.5° in the muscles-preserved group and −2.9° in the muscles-disrupted group. These results support the concept that preservation of muscle insertions to the C2 spinous process may play a role in maintaining cervical lordosis after laminoplasty.

In contrast, some surgeons have reported that preservation of subaxial deep extensor muscles, including the semispinalis cervicis groups, plays a significant role in reducing adverse effects such as deterioration of sagittal alignment and axial neck pain after cervical laminoplasty.[9] However, in the present study, postoperative loss of C2–C7 angle showed no significant differences between muscles-preserved and muscles-disrupted groups. Similarly, no significant differences were seen in frequencies of early or late axial neck pain between these groups. This value did not vary on the side of either preservation or disruption of subaxial deep extensor muscles. These results indicate that irrespective of preservation of subaxial deep extensor muscles, adverse radiologic changes and axial neck pain after cervical laminoplasty are best reduced by preserving muscle insertions to the C2 and C7 spinous processes. Although this study relates to the likelihood of a type II error as a potential limitation, we concluded that preservation of subaxial deep extensor muscles, representing a technically demanding and time-consuming procedure, is not required to reduce these adverse effects after cervical laminoplasty.

■ Key Points

- Incidence of axial neck pain after C3–C6 laminoplasty showed no significant differences between groups with preservation or disruption of subaxial deep extensor muscles.
- Postoperative loss of lordosis and restriction of range of motion of the cervical spine demonstrated no significant differences between groups.
- These results indicate that preservation of subaxial deep extensor muscles plays no significant role in reducing adverse effects after cervical laminoplasty, supporting the idea that adverse effects after laminoplasty largely result from detachment of muscles attached to the C2 and C7 spinous processes.

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C5 palsy after cervical laminoplasty

A MULTICENTRE STUDY

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We have reviewed 1858 patients who had undergone a cervical laminoplasty and identified 43 (2.3%) who had developed a C5 palsy with a MMT (MRC) grade of 0 to 2 in the deltoid, with or without involvement of the biceps, but with no loss of muscular strength in any other muscles. The clinical features and radiological findings of patients with (group P; 43 patients) and without (group C; 100 patients) C5 palsy were compared. CT scanning of group P revealed a significant narrowing of the intervertebral foramen of C5 ($p < 0.005$) and a larger superior articular process ($p < 0.05$). On MRI, the posterior shift of the spinal cord at C4-5 was significantly greater in group P, than in group C ($p < 0.01$).

This study is the first to correlate impairment of the C5 nerve root with a C5 palsy. It may be that early foraminotomy in susceptible individuals and the avoidance of tethering of the cord by excessive laminoplasty may prevent a post-operative palsy of the C5 nerve root.

Cervical compression myelopathy is a common cause of serious morbidity in the middle-aged and elderly, and classically presents with progressive spastic quadriparesis, sensory loss at or below the neck, and urinary incontinence.[1,2] The accepted treatment for the underlying stenosis of the cervical canal is some form of surgical decompression or stabilisation.[3-7] The number of patients needing surgery has increased proportionately with the increasing age of the population. Cervical laminoplasty has been widely performed and has given good results, as it is easy, safe and effective, and there is now no need for external bracing.[8-12] However, post-operatively, a C5 palsy remains a serious complication.[13,14] Although its prevalence is low, affected patients suffer from muscle weakness, brachialgia and numbness, and are dissatisfied with their surgery. Various aspects of the surgical procedure, pathology of the spinal cord and impairment of the nerve root have been implicated as causes of a C5 palsy,[15-19] but owing to its low prevalence most studies have included only a few patients. This has prevented any clarification of the pathology and the resultant development of preventive methods.[20,21] In addition, many studies have also included cases of paralysis of other nerves (C6, C7 and C8) after laminoplasty,[15,17,19] which has complicated matters. The objectives of this study were to review the clinical and radiological findings in patients with a C5 palsy (manual muscle test (MMT) score < 3) after cervical laminoplasty and to look for any features on the pre-operative imaging that might help to predict its occurrence. The MMT score is very similar to the MRC grade,[22] and uses the same 0 to 5 grading system.

Patients and Methods

Between 1991 and 2005, 1858 patients underwent cervical laminoplasty for a chronic compression myelopathy at hospitals in the Nagoya Spine Group. There were 1096 men and 762 women, with a mean age of 62.5 years (36 to 93) at the time of surgery. There were 1570 patients with a cervical spondylotic myelopathy and 288 with ossification of the posterior longitudinal ligament. All patients were followed for at least two years after surgery.

A C5 palsy was defined as a paresis of deltoid (MMT score 1 or 2), with or without involvement of the biceps, but no loss of strength in other muscles. We excluded 159 patients with injuries, tumours, rheumatoid arthritis, a destructive spondyloarthritis caused by haemodialysis, previous cervical surgery, an MMT score of 3 to 5 or a C6 to C8 palsy.

Cervical laminoplasty was performed with the patient lying prone on a Hall frame under general anaesthesia. Most of the operations were performed without neurological monitoring. After operation, patients were kept in bed for two or three days. After removal of their drains they were allowed to mobilise in a soft cervical collar, which they wore for one to four weeks depending on the severity of their neck pain.

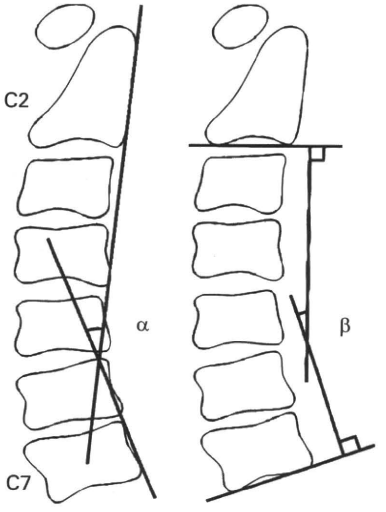

Fig. 1a Fig. 1b

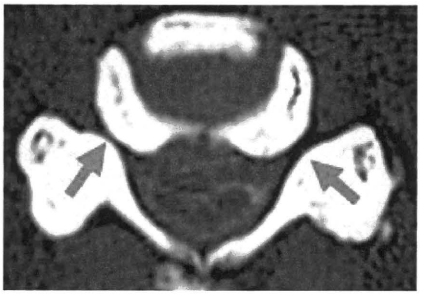

Fig. 1d

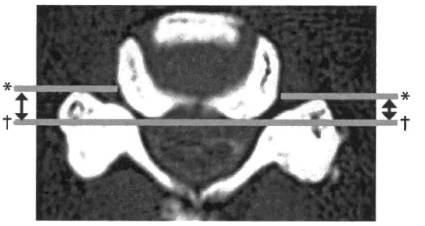

Fig. 1e

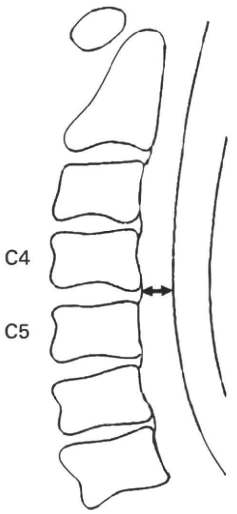

Fig. 1c

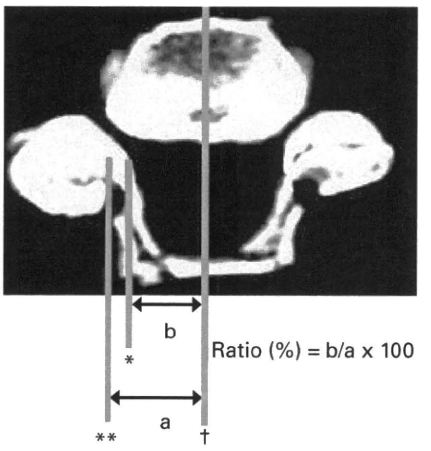

Fig. 1f

Diagrams of radiological assessment. a and b) cervical curvature (α) and Cobb angle (β) at C2 to C7 on a plain radiograph. c) posterior shift of the spinal cord at C4-5 on mid-sagittal MRI (double arrow). Radiological measurements by CT recorded bilaterally. d) The width of the C5 foramen was measured at the narrowest point (arrow). e) the anterior protrusion of the C5 superior articular process (SAP) (double arrow). † indicates the posterior line of the vertebral column. * indicates the line of the most prominent site of the C5 SAP parallel to the posterior line of the vertebral column. f) The ratio of the width of the bony gutter and the facet joint, reflecting the position of the bony gutter. † indicates the midline of the vertebral column, * indicates the medial point of the bony gutter, ** indicates the medial point of the facet joint. These lines are vertical to the posterior line of the vertebral column. The distances between † and ** (a), and between † and * (b) were measured. All these measurements were adjusted for the actual length.

The records of doctors, nurses and rehabilitation staff were reviewed by SI and were found to be complete. Any C5 palsy was diagnosed during the course of routine post-operative examination by a spine specialist with at least 15 years' experience (one of the authors).

The clinical features of each patient were recorded and any difference between those of patients with (43 patients) and without (1815 patients) a C5 palsy were noted. These features included age, gender, duration of symptoms, disease, operating time, estimated blood loss, type of surgical procedure, laterality and onset of paralysis, pre- and post-operative symptoms, treatment of C5 palsy, period of recovery, level of recovery of motor paralysis, pain and sensory disturbance, and recovery of neurological function calculated from the pre- and post-operative Japanese Orthopaedic Association scores.[23] This score is based on the rating of motor function (fingers, 0 to 4 points; shoulder and elbows, -2 to 0 points; and lower extremity, 0 to 4 points), sensory function (upper extremity, 0 to 2 points; lower extremity, 0 to 2 points; and trunk, 0 to 2 points) and urinary bladder function (0 to 3 points). A normal Japanese Orthopaedic Association score is 17 points. The recovery

Table I. Characteristics of patients who developed a C5 palsy among 1858 patients who underwent laminoplasty

	C5 palsy	No C5 palsy	Control group	p-value*
Number of patients (%)	43 (2.3)	1815	100	
Mean age in yrs (range)	63.3 (46 to 81)	62.5 (40 to 85)	61.3 (41 to 84)	NS
Gender				
Male	32	1064	75	
Female	11	751	25	NS
Mean duration of symptoms (mths)	27.8 (2 to 144)	29.5 (1 to 223)	29.1 (1 to 220)	NS
Disease				
Cervical spondylotic myelopathy	33	1537	75	
Ossification of the posterior longitudinal ligament	10	278	25	NS
Mean operating time in mins (range)	124 (62 to 216)	121 (45 to 190)	122 (81 to 180)	NS
Mean estimated blood loss in ml (range)	99.5 (10 to 450)	99.0 (5 to 425)	99.1 (10 to 400)	NS
Mean Japanese Orthopaedic Association scores				
(Pre-op)	10.5 (5 to 15)	10.1 (2 to 15)	10.2 (4 to 15)	NS
(2 years post-op)	13.1 (8 to 16.5)	13.5 (3 to 17)	13.7 (4 to 17)	NS
(% improvement)	41.4 (0 to 93)	47.5 (0 to 100)	48.7 (0 to 100)	NS

* the p-value for comparison of the groups with and without C5 palsy; NS, not significant

rate was calculated using Hirabayashi's method[9] based on the formula:

recovery rate (%) = [(post-operative score - pre-operative score) × 100]/17 - pre-operative score).

We also reviewed the radiological findings from plain radiographs, MRI and CT scans. The cervical lordotic angle (cervical curvature, α[24]; Cobb angle, β[25]) (Figs 1a, 1b), intervertebral angle (C4-5; positive value indicates lordotic angle), local kyphosis angle, and cervical alignment were assessed on a standard lateral radiograph in neutral, in instability (an intervertebral range of movement $\geq 5°$) and in the presence of listhesis ($\geq$ 2 mm) on flexion and extension views.

The cervical spine was classified as lordotic ($> 5°$), straight ($-5° \leq \alpha \leq 5°$), sigmoid, or kyphotic ($\alpha < -5°$).

MRI was used to assess the number of levels of compression, the most compressed level of the spinal cord, and the presence of a high-intensity area in the spinal cord on the T2-weighted images pre-operatively. The level and extent of the high-intensity area (classified as focal and linear) were also checked post-operatively, as was the post-operative posterior shift of the spinal cord (C4-5) in the mid-sagittal plane (Fig. 1c).[26]

CT was used to measure the width of the intervertebral foramen at C5 (Fig. 1d), the anterior protrusion of the superior articular process,[27] of C5 (Fig.1e), the presence of hinge dislodgement, and the position of the bony gutter (Fig. 1f). The CT images were acquired in the horizontal plane of the intervertebral disc. The width of the C5 intervertebral foramen was measured at its narrowest point, and the anterior protrusion of the superior articular process of C5 was measured at its most prominent. The gutter position was expressed as the ratio of the distance between the midline of the vertebral column at C5 and the medial point of the gutter relative to the distance between the midline of the vertebral column at C5 and the most medial part of the facet joint (Fig. 1f).

In order to compare the radiological findings of patients with a C5 palsy (group P) and those without (control group C), 100 patients were randomly selected from the 1815 patients without C5 palsy. A total of 43 patients with a C5 palsy were identified from eight different hospitals. Their controls were selected according to the ratio of patients with C5 palsy in each of the hospital populations. For instance, if an institute had three palsy cases (3 of 43: 7%), seven controls (7 of 100: 7%) were selected from the same hospital, and matched by year of operation, disease, age and gender (Table I). The control cases were selected by a secretary who was unaware of the imaging findings for the patients. If there was no control case with a complete match to a palsy case, the year of operation and disease were used preferentially. This resulted in a slightly higher percentage of women in the control group than in the C5 palsy group, but this difference was not significant.

The radiographic measurements (mm) of individual images were adjusted for the actual length. Each image was then independently evaluated twice by the same two spine specialists (SI, RT), who were unaware of the clinical and neurological status of the patient. The correlations between the first and second measurements of either examiner ranged from 0.904 to 0.958 ($p < 0.0001$) for all radio-

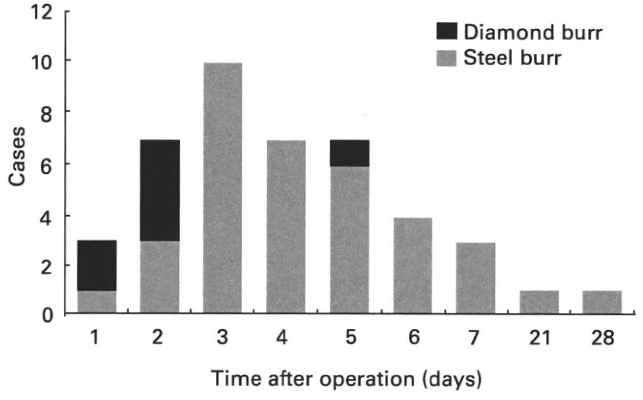

Fig. 2

Graph showing the onset of C5 palsy which occurred at a mean of 4.7 (1 to 28) days after surgery. The patients were allowed to sit and stand on post-operative days 2 or 3. The majority of patients (38) developed C5 palsy after sitting and standing, and 26 developed C5 palsy on the first or second day of standing.

logical measurements. The correlations between the examiner's measurements ranged from 0.913 to 0.943 ($p < 0.0001$). Means were calculated, and from these the standard error of the mean (SEM) was obtained.

An unpaired *t*-test, Mann-Whitney U test, Fisher's exact probability test or Pearson's correlation coefficient were used for statistical analysis, with $p < 0.05$ taken to indicate statistical significance.

Results

The characteristics of patients with and without a C5 palsy are shown in Table I. Of 1858 patients who underwent a cervical laminoplasty, 43 (2.3%, 95% confidence interval (CI) 0.017 to 0.031) developed a C5 palsy with an MMT score < 3 (group P). There were 32 men and 11 women with a mean age at the time of surgery of 63.3 years (46 to 81). The mean duration of symptoms was 27.8 months (2 to 144). In all, 33 and ten patients had cervical spondylotic myelopathy and ossification of the posterior longitudinal ligament, respectively. In group P, 28 patients underwent unilateral open-door laminoplasty and 15 a French-window laminoplasty. In group C, unilateral open-door laminoplasty was carried out in 63 patients, and French-window laminoplasty in 37. In group P, the mean operating time was 124 minutes (62 to 216) and the mean estimated blood loss was 99.5 ml (10 to 450). In group C the mean operating time was 122 minutes (81 to 180) and the mean estimated blood loss was 99.1 ml (10 to 400). The patient characteristics, disease process and the type of surgical procedure had no significant effect on the prevalence of C5 palsy.

No patient with a C5 palsy needed a further operation. All were treated conservatively with rest, rehabilitation of muscle strength and range of movement exercises in bed, intravenous corticosteroids for two or three days, and further physiotherapy once their pain subsided. The mean Japanese Orthopaedic Association score for the 43 patients with a C5 palsy improved from 10.5 (5.0 to 15.0) pre-operatively to 13.1 (8.0 to 16.5) at two years' follow-up, an improvement of 41%. There was no significant difference in the recovery rate between the two groups (Table I).

Surgical procedure. In group P, of the 28 patients who had a unilateral open-door laminoplasty, paralysis occurred on the open side in 13, the hinge side in 14, and on both sides in one. Of the 15 patients who had a French-window laminoplasty, 14 had paralysis on one side and one on both sides. There was no significant correlation between the surgical procedure and the side that was paralysed. A high-speed drill was used in each case, with a steel burr for 37 patients, a diamond burr for four, and both types for two patients. Patients who were operated on with a diamond burr developed a more severe motor paralysis in their deltoid muscle ($p = 0.048$), but there was no correlation between the type of drill used and the period or extent of recovery from paralysis.

Onset of C5 palsy. Paralysis was noted after a mean of 4.7 (1 to 28) days post-operatively (Fig. 2). There were five patients who developed a C5 paralysis in the first two post-operative days before they had been mobilised: three of the five had been operated on using a diamond burr. The other 38 patients (88%) became paralysed after mobilising: 18 (42%) on the first day of standing and eight (19%) on the second day.

Motor paralysis. The mean MMT score at the onset of paralysis was 1.6 (0 to 2) for deltoid and 2.8 (0 to 5) for biceps brachii. Conservative treatment resulted in complete recovery from motor paralysis in 29 patients (67%) and a residual motor paralysis with mean MMT scores of 3.2 (1 to 4) (deltoid) and 3.6 (2 to 5) (biceps) in 14. The mean time to complete recovery from paralysis was 4.1 months (3 days to 17 months), except for one patient who showed no recovery after five years. The mean MMT scores in patients who exhibited residual paralysis were 1.2 (0 to 2) (deltoid) and 2.0 (0 to 4) (biceps) at onset, compared to 1.8 (1 to 2) (deltoid) and 3.1 (1 to 5) (biceps) in patients who recovered completely, indicating that those with severe motor defects initially fail to recover completely ($p = 0.0090$).

Pre-operatively, of the group P patients, 36 (84%) had no muscle weakness in the upper limb, including the C5 area but seven (16%) had a motor deficit with muscle weakness and an MMT score of 3 or 4. This was on the side of the subsequent paralysis in five patients, on the opposite side in one, and on both in one patient. These seven cases took considerably longer to recover their pre-operative level ($p < 0.05$), but there was no correlation between pre-operative muscle weakness and degree of recovery from paralysis.

Brachialgia and numbness. Pain in the distribution of the C5 nerve root accompanied the C5 palsy in 34 patients (79%). This recovered completely with conservative treatment in 28 patients (82%), but three were left with mild pain and three had continuous pain at the final follow-up (6 of 34: 18%). Pre-operatively, 38 patients (88%) had some numb-