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Global Spine Journal Original Article

Age-Related Surgical Outcomes of Laminoplasty for Cervical Spondylotic Myelopathy

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Abstract

Study Design Retrospective clinical study.
Objective To investigate the age-related surgical outcomes of laminoplasty.
Methods One hundred patients who underwent an en bloc laminoplasty for cervical spondylotic myelopathy from 2004 to 2008 and were followed for at least 1 year were included in this study. The clinical outcomes were assessed with the Japanese Orthopaedic Association (JOA) score. Acquired points (postoperative JOA score minus preoperative JOA score) were also calculated. To investigate the age-related effect for laminoplasty, two analyses were conducted: (1) the correlation between age and clinical outcome; and (2) the clinical outcomes by decade. Patients were divided into four groups according to their age at the time of operation as follows: group 50s, 50 to 59 years old; group 60s, 60 to 69 years; group 70s, 70 to 79 years; and group 80s, 80 to 89 years. The pre- and postoperative JOA scores, acquired points, preoperative comorbidities, and postoperative complications were then compared among the groups.
Results Significant correlations were detected between age and JOA scores at the preoperative ($p = 0.03$), postoperative maximum ($p < 0.0001$), and final assessments ($p < 0.0001$). An age-related decline of JOA scores was observed over all periods. The analysis by decades showed the same results. On the other hand, the significant differences were not found for acquired points over all periods by either method. The preoperative comorbidities of hypertension and diabetes mellitus increased with age. Delirium was more common postoperatively in elderly patients.
Conclusions Although an age-related decline of JOA scores was found over all periods, there were no severe sequelae and no differences in the acquired points that were age-related.

Keywords
- cervical spondylotic myelopathy
- elderly patient
- laminoplasty
- age-related

Introduction

Cervical laminoplasty is a surgical option for patients with compression myelopathy, such as cervical spondylotic myelopathy (CSM), ossification of the posterior longitudinal ligament (OPLL), and cervical disk herniation (CDH).[1–14] As the number of elderly individuals in the population is increasing, surgical treatment for cervical myelopathy in elderly patients is becoming a great concern. Although many authors have reported age-related surgical outcomes for myelopathy due to

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cervical lesions, there were some limitations in terms of the surgical methods, such as anterior fixation, laminectomy, and laminoplasty,[15–19] and different pathologies, such as CSM, OPLL, and CDH.[16,17,19,20] Furthermore, some publications have reported the surgical outcomes of cervical laminoplasty for CSM in elderly patients, but their definitions of *elderly* varied.[7,14,21–26] No standard definitions of *elderly* might lead to paradoxical conclusions. In fact, some authors have reported poorer outcomes in elderly patients than in younger patients,[26] whereas others found no differences among the age groups.[21,23,25] To investigate the age-related surgical outcomes of laminoplasty, analyzing the correlation between age and the clinical outcomes appeared reasonable. Therefore, the purpose of this study was to investigate the age-related surgical outcomes of laminoplasty using two types of analysis without defining *elderly*.

Materials and Methods

Patient Population

From 2004 to 2008, 124 consecutive laminoplasties for CSM were performed at our institution. One hundred patients (50 to 86 years old) who were followed for at least 1 year were included in this study. The follow-up rate was 81%. Patients with rheumatoid arthritis, hemodialysis, OPLL, psychosis, and other neurogenic diseases were excluded. The patients were divided into four groups according to their age at the time of operation: group 50s, 50 to 59 years old (21 patients); group 60s, 60 to 69 years (32 patients); group 70s, 70 to 79 years (37 patients); and group 80s, 80 to 89 years (10 patients). Patients who were under 50 years old (4 cases) and above 89 years old (2 cases) were excluded. The average age of each group was 56, 64.1, 73.3, and 82.9 years, respectively. The symptom duration was investigated by reviewing the clinical records. The average symptom durations were 3.1, 2.7, 3.9, and 2.1 years, respectively. The average follow-up durations were 4.0, 4.4, 3.8, and 4.5 years, respectively (►**Table 1**). There were no significant differences among these groups in symptom duration and follow-up period.

Surgical Technique

In this study, all patients underwent an en bloc laminoplasty that was introduced by Itoh and Tsuji.[8] The surgical sites were: C3–C5 in 1 case, C3–C6 in 13 cases, C3–C7 in 6 cases, and C4–C7 in 1 case in group 50s; C3–C6 in 24 cases, C3–C7 in 7 cases, and C4–C6 in 1 case in group 60s; C3–C6 in 20 cases, C3–C7 in 12 cases, C3–T1 in 1 case, C4–C7 in 2 cases, C5–C6 in 1 case, and C5–C7 in 1 case in group 70s; and C3–C6 in 9 cases and C3–C7 in 1 case in group 80s. After surgery, the patients wore a soft cervical collar, which they were allowed to remove within a week. The mean operation time was 119 minutes (group 50s, 128 minutes; group 60s, 118 minutes; group 70s, 116 minutes; and group 80s, 115 minutes), and the mean estimated blood loss during the laminoplasty was 153 mL (group 50s, 108 mL; group 60s, 164 mL; group 70s, 164 mL; and group 80s, 173 mL). There were no significant differences among these groups in the operation time and blood loss (data not shown).

Clinical Assessment

The clinical outcomes were assessed using the scoring system proposed by the Japanese Orthopaedic Association (JOA). Briefly, the JOA score consists of upper extremity function (4 points), lower extremity function (4 points), sensory (6 points), and urinary bladder function (3 points). A normal JOA score was 17 points.

The clinical assessments were performed for all patients before surgery; at 1, 6, and 12 months after surgery; and then annually thereafter. The acquired points were also calculated in each period. Furthermore, the preoperative comorbidities and postoperative complications were investigated.

Statistical Analysis

To investigate the correlations between age and the clinical outcomes, the Spearman rank correlation coefficient was used for each factor. Values of $p < 0.05$ indicated significance. The Bonferroni test was performed for analyzing the differences among the four groups. Values of $p < 0.005/6 = 0.0083$ indicated significance for this analysis.

Results

Age and JOA Scores

Significant negative correlations were detected between age and the total JOA scores at the preoperative ($p = 0.03$), postoperative maximum ($p < 0.0001$), and final assessments

Table 1 Patient demographic data

	Group 50s	Group 60s	Group 70s	Group 80s
Number	21	32	37	10
Age	56	64.1	73.3	82.9
Male/female	14/7	25/7	24/13	6/4
Symptom duration (y)	3.1	2.7	3.9	2.1
F/U (y)	4.0	4.4	3.8	4.5
HT (%)	5 (24)	11 (34)	20 (54)	8 (80)
DM (%)	3 (14)	7 (22)	12 (32)	5 (50)

Abbreviations: DM, diabetes mellitus; HT, hypertension; F/U, follow-up.

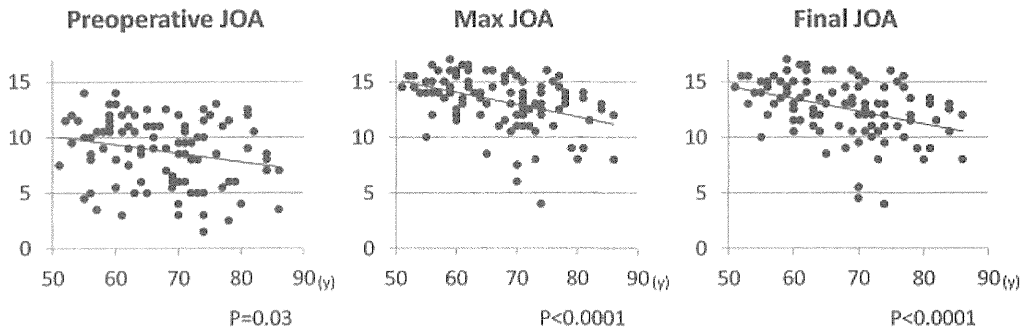

Fig. 1 Spearman rank correlation coefficient between age and Japanese Orthopaedic Association (JOA) score.

($p < 0.0001$; ►**Fig. 1**). For the upper extremity function, significant negative correlations were also detected between age and the JOA scores at the preoperative ($p = 0.0028$), postoperative maximum ($p < 0.0001$), and final assessments ($p = 0.0002$; data not shown). Similarly, with regard to the lower extremity function, significant negative correlations were detected between age and the JOA scores of the lower extremities at the preoperative ($p = 0.0037$), postoperative maximum ($p = 0.0003$), and final assessments ($p = 0.0004$; data not shown). In terms of the analysis by decade, the average total JOA scores at the preoperative, postoperative maximum, and final assessments were 9.7, 14.5, and 14.1 points in group 50s; 9.1, 13.8, and 13.1 points in group 60s; 7.9, 12.3, and 11.6 points in group 70s; and 8.2, 11.5, and 11.1 points in group 80s, respectively (►**Fig. 2**). Although no significant differences were detected in the preoperative JOA scores between the groups, those at the postoperative maximum and final assessments of groups 70s and 80s were significantly lower than those of groups 50s and 60s. Regarding the upper extremity function, the average JOA scores at the preoperative, postoperative maximum, and final assessments were 2.5, 3.6, and 3.5 points in group 50s; 2.0, 3.3, and 3.1 points in group 60s; 1.7, 3.0, and 2.8 points in group 70s; and 1.5, 2.8, and 2.7 points in group 80s, respectively (►**Fig. 2**). The average JOA scores of the upper extremities at the preoperative, postoperative maximum, and final assessments were significantly lower for group 70s and 80s than for group 50s. With regard to lower extremity function, the average JOA scores at the preoperative, postoperative maximum, and final assessments were 1.8, 2.9, and 2.8 points in group 50s; 1.7, 3.0, and 2.6 points in group 60s; 1.3, 2.3, and 2.1 points in group 70s; and 1.1, 1.9, and 1.8 points in group 80s, respectively (►**Fig. 2**). Although no significant differences were detected in the preoperative JOA scores between the groups, those at the postoperative maximum were significantly lower for groups 70s and 80s than for groups 50s and 60s, and those at the final assessments were significantly lower for groups 70s and 80s than for group 50s.

Age and Acquired Points

No correlations were detected between age and the acquired points in each category through all periods (data not shown). In terms of the analysis by decade, the average total acquired points at the postoperative maximum and final assessments were 4.8 and 4.5 in group 50s, 4.8 and 4.0 in group 60s, 4.4 and 3.6 in group 70s, and 3.1 and 2.9 in group 80s, respectively (►**Fig. 3**). Regarding the upper extremity function, the average acquired points at the postoperative maximum and final assessments were 1.0 and 1.0 in group 50s, 1.4 and 1.1 in group 60s, 1.3 and 1.1 in group 70s, and 1.3 and 1.2 in group 80s, respectively. With regard to the lower extremity function, the average acquired points at the postoperative

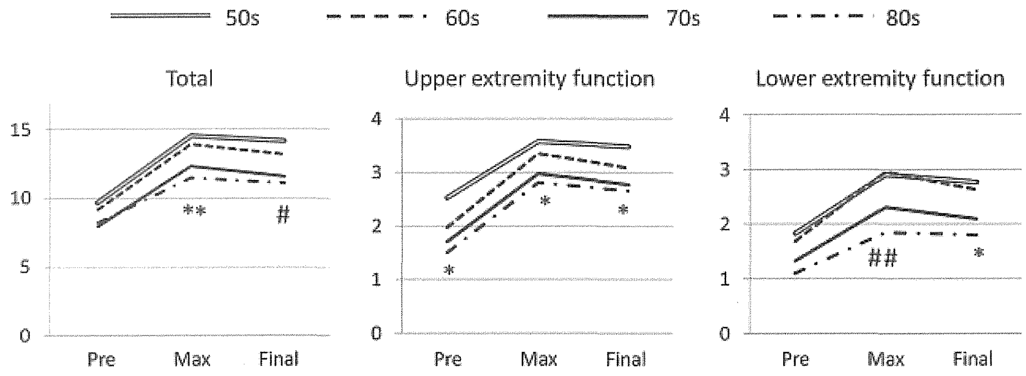

Fig. 2 Japanese Orthopaedic Association score. *Group 50s versus group 70s, group 50s versus group 80s: $p < 0.0083$. **Group 50s versus group 70s, group 50s versus group 80s, group 60s versus group 70s, group 60s versus group 80s: $p < 0.0083$. #Group 50s versus group 70s, group 50s versus group 80s, group 60s versus group 70s: $p < 0.0083$. ##Group 50s versus group 80s, group 60s versus group 70s, group 60s versus group 80s: $p < 0.0083$.

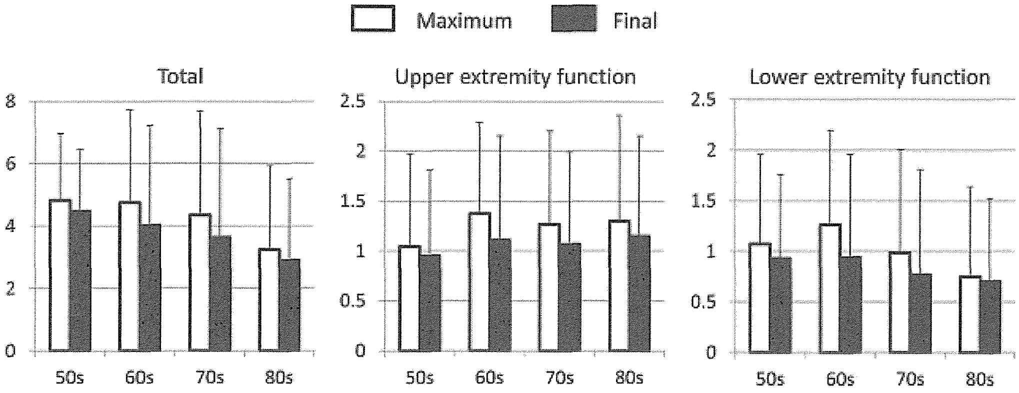

Fig. 3 Acquired points (p = not significant).

maximum and final assessments were 1.1 and 0.9 in group 50s, 1.3 and 0.9 in group 60s, 1.0 and 0.8 in group 70s, and 0.8 and 0.7 in group 80s, respectively (►**Fig. 3**). Although there were no significant differences in acquired points between the groups in each category through all the periods, the acquired points of the lower extremities tended to be low in groups 70s and 80s.

Preoperative Comorbidities and Postoperative Complications

In terms of the preoperative comorbidities, hypertension was observed in 5 patients (24%) in group 50s, 11 (34%) in group 60s, 20 (54%) in group 70s, and 8 (80%) in group 80s, and diabetes mellitus was detected in 3 patients (14%) in group 50s, 7 (22%) in group 60s, 12 (32%) in group 70s, and 5 (50%) in group 80s (►**Table 1**). In the patients with hypertension (HT +), the average JOA scores at the preoperative, postoperative maximum, and final assessments were 7.9, 12.5, and 11.8 points, respectively. And in the patients without hypertension (HT−), they were 9.3, 13.7, and 13.1 points, respectively. The average acquired points at the postoperative maximum and final assessments were 4.6 and 4.0 in HT+ patients and 4.3 and 3.7 in HT− patients, respectively. Although the average JOA scores at the preoperative, postoperative maximum, and final assessments were significantly lower for HT+ patients than for HT− patients, no significant difference was detected in the average acquired points at the postoperative maximum and final assessments. In the patients with diabetes mellitus (DM +), the average JOA scores at the preoperative, postoperative maximum, and final assessments were 7.9, 11.7, and 11 points, respectively. And in the patients without diabetes mellitus (DM −), they were 9.0, 13.1, and 13.7 points, respectively. The average acquired points at the postoperative maximum and final assessments were 3.8 and 3.1 in DM+ patients and 4.7 and 4.1 in DM− patients, respectively. Although the average JOA scores at the postoperative maximum and final assessments were significantly lower for DM+ patients than for DM− patients, no significant differences were detected in the average preoperative JOA score or average acquired points at the postoperative maximum and final assessments.

Regarding the postoperative complications, C5 nerve palsy was observed in 1 patient each in groups 50s (4.8%), 70s (2.7%), and 80s (10%) and 2 in group 60s (6.3%). Delirium was observed 3 (8%) in group 70s and 2 (20%) in group 80s. One patient in group 60s had a cerebral infarction (3.1%). There were no surgical site infections in this series (►**Table 2**).

Discussion

Cervical laminoplasty is a well-reported surgical treatment for cervical myelopathy with CSM, OPLL, and CDH. The long-term clinical and radiologic results of laminoplasty have been investigated, and the risk factors for poor outcomes (age at the time of operation, symptom duration, signal changes in the spinal cord on magnetic resonance imaging, transverse area of the spinal cord at the site of maximum compression, and kyphotic alignment) have been identified.[19–21,25]

In terms of age-related effects on laminoplasty, many authors have reported comparative studies of the surgical outcomes in elderly patients, but their conclusions were controversial because their definitions of *elderly* varied from 65 to 80 years.[7,14,21–26] Therefore, in the present study, the surgical outcomes of laminoplasty were examined in two

Table 2 Postoperative complications

	Group 50s	Group 60s	Group 70s	Group 80s
C5 palsy (%)	1 (4.8)	2 (6.3)	1 (2.7)	1 (10)
Delirium (%)	0	0	3 (8.1)	2 (20)
Cerebral infarction (%)	0	1 (3.1)	0	0
SSI	0	0	0	0

Abbreviation: SSI, surgical site infection.

ways: (1) the Spearman rank correlation coefficient between age and clinical outcome; and (2) the surgical outcomes by decade without a definition of *elderly*.

In the present study, a negative correlation was detected between age and preoperative JOA scores, but the decade classification did not show a significant difference. Furthermore, the postoperative JOA scores decreased significantly with aging. Symptom duration has often been discussed as one of the causes of the poor preoperative condition in elderly patients. Several authors have reported that long symptom duration contributed to the poor surgical outcomes of laminoplasty, especially in elderly patients.[19,21,25] Generally, surgeons hesitate to operate on elderly patients due to their comorbidities; however, in the acquired points, there were no significant difference between the patients with or without comorbidities in the present study. Delaying surgical treatment for elderly patients causes prolonged symptom duration, and severe myelopathy may develop. Nagata et al recommended that the surgical treatment be done as soon as possible after onset of progressive myelopathy in elderly patients.[19] Moreover, Matsunaga et al reported that the neurologic function deteriorated with increasing age in healthy volunteers.[27] The age-related degeneration of the spinal cord, such as a decrease in the number of anterior horn cells and myelinated fibers in the corticospinal tracts and posterior funiculus, might contribute to the preoperative and postoperative status.[28–30] For these reasons, we chose to operate on elderly patients as soon as possible, and there were no significant differences in symptom duration among the decades in the present series.

On the other hand, no correlation was seen between age and acquired points in each category through all periods. Similarly, the analysis by decade showed the same results. In the present study, the acquired points of the lower extremity tended to be low in groups 70s and 80s, and those of the upper extremity did not show any difference among the decades.

Machino et al pointed out one limitation of the recovery rate of the JOA score: the actual surgical outcomes in patients with the same recovery rate might differ according to the preoperative JOA score.[24] Patients with low preoperative JOA scores had poorer surgical outcomes than patients with high preoperative JOA scores, though both of them achieved the same JOA score. They recommended that acquired points should be used for evaluation of elderly patients rather than the recovery rate. Therefore, in the present study, the recovery rate was not calculated, and acquired points were considered for evaluation of surgical outcomes.

One limitation of this study was that the radiologic examinations were not evaluated. Further studies will be necessary to clarify the relationship between the age-related radiologic features and the clinical outcomes. However, to the best of our knowledge, this is the first report of an age-related decline of pre- and postoperative clinical status without defining *elderly*.

In conclusion, although an age-related decline of JOA scores was detected in all periods, there were no severe sequelae and no differences in the acquired points related to age. These results suggest that laminoplasty for cervical myelopathy is useful in elderly patients.

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Motor conduction measurement in myelopathy hand

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Summary

We studied the relationship between intramedullary high signal intensity (IMHSI) on T2-weighted magnetic resonance images and motor conduction in the spinal cords of cervical spondylotic myelopathy (CSM) patients.

There was no significant difference between the biceps or triceps central motor conduction times (CMCTs) of the patients who did and did not exhibit IMHSI, whereas the abductor pollicis brevis CMCT was significantly longer in the patients who exhibited IMHSI ($p<0.05$) than in those who did not. The CMCT of the abductor pollicis brevis is sensitive to the degree of damage in the cervical spinal cord. Hand dysfunction is a characteristic of CSM regardless of the cervical level affected by the condition.

The motor fibers innervating the intrinsic muscles of the hand in the long tract of the cervical spinal cord are more sensitive than other motor fibers. For this reason, we consider that myelopathy hand is a characteristic impairment of CSM. Transcranial magnetic stimulation of the hand motor cortex is useful for the evaluation of cervical myelopathy.

KEY WORDS: cervical spondylotic myelopathy, central motor conduction time, intramedullary high signal intensity, magnetic resonance imaging, myelopathy hand

Introduction

Some authors have described hand dysfunction that does not always involve paresis of the lower extremities as a characteristic feature of cervical spondylotic myelopathy (CSM) (Good et al., 1984; Nakajima and Hirayama, 1995; Sonstein et al., 1996). Ono et al. (1987) coined the term myelopathy hand to refer to abnormalities such as reduced manual dexterity and/or wasting of the hands, which they found to be characteristic features in patients with CSM. However, they found no correlation between myelopathy hand and cervical cord involvement at any particular level. Although myelopathy hand is the most frequently recognized symptom of CSM, regardless of the cervical level involved, evaluations of motor function alone do not contribute to determining which cervical level has been affected by the condition.

Matsumoto et al. (2005) reported a 66% rate of agreement between neurological and neuroimaging tests performed to determine the cervical level affected by CSM, whereas the rate of agreement between manual muscle and neuroimaging tests was 19%. However, few articles have studied the cause such discrepancies (Matsumoto et al., 2005).

We retrospectively studied the medical records of patients with chronic compression myelopathy and evaluated the relationship between intramedullary high signal intensity (IMHSI) on T2-weighted magnetic resonance imaging (MRI) scans and conduction disturbances in the motor tract.

In order to compare IMHSI sites with vertebral levels exhibiting electrophysiological changes, we investigated the conduction of the motor fibers in the middle and lower cervical spinal segments that innervate the upper extremity muscles. Furthermore, we assessed the utility of measuring motor evoked potentials (MEPs) to evaluate the severity of myelopathy.

Materials and methods

Patients

From July 1998 to June 2003, 51 consecutive patients with cervical myelopathy [46 CSM patients and five cervical disc herniation (CDH) patients] were assessed. After obtaining institutional review board approval, we conducted a retrospective case-control study.

We retrospectively reviewed the patients' medical records, electrophysiological measurement data, and MRI scans. Diagnoses of CSM and CDH were made on the basis of the results of neurological examinations and diagnostic imaging using various techniques including plain roentgenography and MRI. In all the patients, the cervical cord was compressed at some point between the C3/4 level and the C5/6 level. The mean age of the patients was 56 years (range: 41-78). Measurements were taken for all 102 hands of the 51 patients.

Motor evoked potentials

The patients were seated with their upper arms relaxed and the cathodes were placed on the motor points of the biceps brachii, triceps brachii and abductor pollicis brevis muscles. Reference electrodes were also placed on these muscles.

i) Following percutaneous electrical stimulation (amplitude: 30 mA, duration: 0.1 ms, rectangular wave) of the median nerve at the wrist, M- and F-waves were recorded from the abductor pollicis brevis at a bandwidth of between 5 Hz and 10 kHz using an electromyograph (Neuropack Four, MEM-4104, Nihon Kohden, Japan). The peripheral latency (PL) was calculated according to the formula devised by Kimura (1983):

PL = (the onset latency of M-waves + the onset latency of F-waves - 1)/2.

ii) The onset latency of the tendon reflex was measured in the biceps and the triceps tendon. A hammer (TA-420, Nihon Kohden, Japan) with a switch at the tip was then used to manually tap the biceps tendon, and 100 responses were averaged at a bandwidth of between 20 Hz and 10 kHz using a Neuropack Four (MEM-4104, Nihon Kohden, Japan). The PL was obtained in the manner described above and also described in detail by Tani et al. (1991).

PL = (the onset latency of the tendon reflex)/2

iii) MEPs elicited following transcranial (MEPcr) and cervical magnetic stimulation were recorded via the same electrodes using a magnetic stimulator (STM-1200, Nihon Kohden, Japan). We used a 14 cm (inner diameter) round 1.5 Tesla coil (YM-101) for the transcranial stimulation, as described in detail by Barker et al. (1985). To stimulate the motor roots, we used a 7 cm (inner diameter) round coil (YM-102).

The central motor conduction time (CMCT) was obtained by subtracting the PL from the latency of the MEPcr.

Evaluation of MRI

MRI examinations were performed using a clinical 1.5-T whole-body MRI system (VISART TM/EX, Toshiba, Tokyo, Japan). Images were acquired in the sagittal plane using a turbo spin echo T2-weighted (TR4000 ms/TE100 ms) sequence with a 3 mm section thickness and a 0.3 mm gap. The change in intramedullary signal intensity was evaluated on sagittal T2-weighted MRI scans of the cervical spine.

The patients were divided into five groups according to the location of any IMHSI.

1) Focal C3/4 group: focal IMHSI was seen at the C3/4 level on T2-weighted sagittal images (n = 22 hands of 11 patients)

2) Focal C4/5 group: focal IMHSI was observed at the C4/5 level on T2-weighted sagittal images (n = 12 hands of 6 patients)

3) Focal C5/6 group: focal IMHSI was noted at the C5/6 level on T2-weighted sagittal images (n = 32 hands of 16 patients)

4) Multi-segmental group: diffuse IMHSI was demonstrated at multiple levels on T2-weighted sagittal images (n = 16 hands of 8 patients)

5) No IMHSI group: No IMHSI was observed in the sagittal plane (n = 20 hands of 10 patients).

In the 33 patients in the focal C3/4, C4/5 and C5/6 groups, the vertebral level of the site of the most intense signal intensity was defined as the IMHSI site. None of the patients exhibited IMHSI at the C6/7 vertebral level.

Clinical assessment

The severity of myelopathy was evaluated using the score proposed by the Japanese Orthopedic Association (JOA score), and myelopathy hands were functionally evaluated using the grip-release test as follows: the patient was asked to form a tight grip and then release it as rapidly as possible whilst their forearm was in pronation. The number of complete grip-release cycles performed within 10 seconds was counted as described by Ono et al. (1987).

Statistics

Statistical software (Stadview 4.5J, SAS, Cary, NC) was used for data analysis. All values were presented as means ± standard deviation. The Mann-Whitney U-test (Statview 4.5J) was used to evaluate the significance between the values and the simple regression model (Stadview 4.5J) was used to analyze to the correlation between the measured values. All p values less than 0.05 were considered to indicate statistical significance.

Results

JOA scores

The JOA scores of the focal C3/4, focal C4/5, focal C5/6, multi-segmental, and no IMHSI groups were 10.2±2.6 points, 11.3±2.2 points, 10.6±2.9 points, 9.1±2.2 points, and 12.8±1.6 points, respectively. Only the JOA score of the no IMHSI group was significantly ($p<0.05$) higher than those of the other groups. There was no significant difference between the JOA scores of the IMHSI-positive groups (Fig. 1).

CMCTs of the biceps, triceps and abductor pollicis brevis muscles

THE CMCTs OF THE BICEPS BRACHII MUSCLE

The CMCTs of the biceps brachii muscle in the focal C3/4, focal C4/5, focal C5/6, multi-segmental, and no IMHSI groups were 6.0±2.1 ms, 6.2±0.9 ms, 5.6±1.2 ms, 5.8±1.3 ms, and 5.3±1.1 ms, respectively. There was no significant difference in the CMCT of the biceps brachii muscle between any of the groups (Fig. 2).

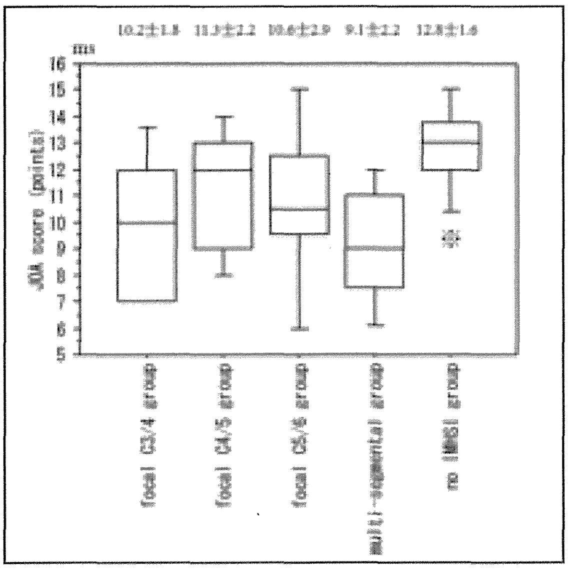

Figure 1 - The JOA scores of each group.
Only the JOA score of the no IMHSI group was significantly ($p<0.05$) shorter than those of the other groups. There was no significant difference between the JOA scores of the IMHSI-positive groups.

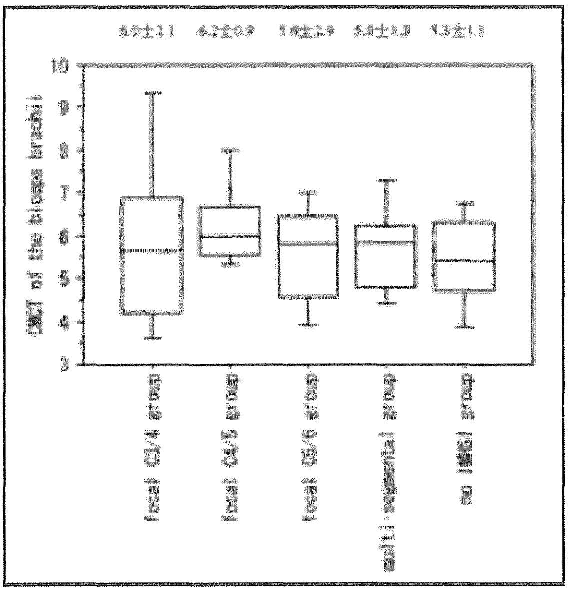

Figure 2 - The CMCT of the biceps brachii muscle in each group.
There was no significant difference between the biceps brachii muscle CMCT of the focal C3/4, focal C4/5, focal C5/6, multi-segmental, and no IMHSI groups.

THE CMCTs OF THE TRICEPS MUSCLE

The CMCTs of the triceps brachii muscle in the focal C3/4, focal C4/5, focal C5/6, multi-segmental, and no IMHSI groups were 7.7±1.8 ms, 7.9±1.4 ms, 7.5±1.8 ms, 7.5±1.4 ms and 6.6±0.9 ms, respectively. No significant difference in the CMCT of the triceps brachii muscle was detected between any of the groups (Fig. 3).

THE CMCTs OF THE ABDUCTOR POLLICIS BREVIS MUSCLE

The CMCTs of the abductor pollicis brevis muscle in the focal C3/4, focal C4/5, focal C5/6, multi-segmental, and no IMHSI groups were 12.7±3.7 ms, 13.2±3.3 ms, 12.6±3.9 ms, 14.3±3.9 ms and 8.1±1.4 ms, respectively. Only the CMCT of the no IMHSI group was significantly shorter than those of the other groups. However, there was no significant difference between the CMCTs recorded in the remaining groups (Fig. 4).

Grip-release test

Although the biceps brachii and triceps brachii muscle CMCTs did not exhibit any relationship with the JOA score, the CMCT of the abductor pollicis brevis muscle displayed a strong relationship with the JOA score ($r=-0.70$, $p<0.0001$, Fig. 5).

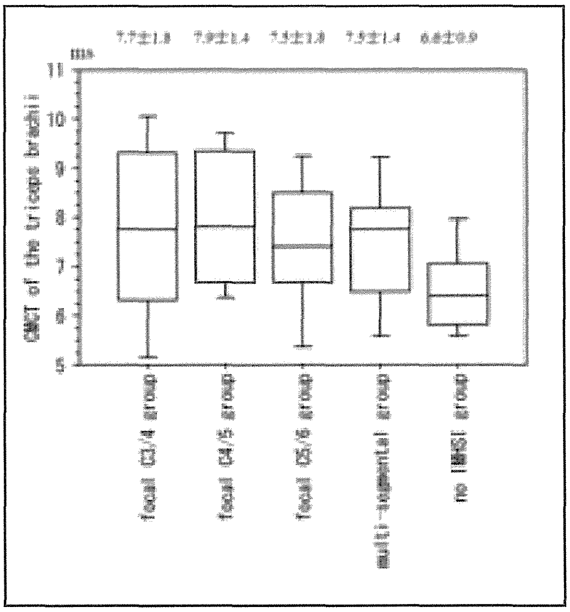

Figure 3 - The CMCT of the triceps brachii muscle in each group.
There was no significant difference between the triceps brachii muscle CMCT of the focal C3/4, focal C4/5, focal C5/6, multi-segmental, and no IMHSI groups.

Discussion

Transcranial magnetic stimulation (TMS) is a non-invasive technique that can be used to study conduction in the descending corticospinal tract (Barker et al., 1985; Hess et al., 1986). Lo et al. (2004) detected a strong correlation between TMS and MRI findings and stated that "TMS can be recommended as a non-invasive, less costly, and less time-consuming technique for screening and serial evaluation of cervical spondylotic myelopathy." We also consider it useful for detecting cervical disorders.

In some clinical reports, IMHSI was not found to be associated with the severity of myelopathy (Wada et al., 1999; Yone et al., 1992). However, in other reports the patients who displayed IMHSI were in a worse clinical condition (Matsuda et al., 1991). Takahashi et al. (1987) observed localized areas of high signal intensity within the spinal cord on T2-weighted images in cases of compression of the spinal cord and reported that high signal intensity was seen more frequently in cases involving severe degrees of spinal cord compression and in severely clinically impaired patients. In the current study, the no IMHSI group displayed significantly shorter abductor pollicis brevis muscle CMCTs than the IMHSI-positive groups, and the JOA score of the no IMHSI group was higher than those of the other groups. This suggests that IMHSI indicates the presence of damage involving the corticospinal tract.

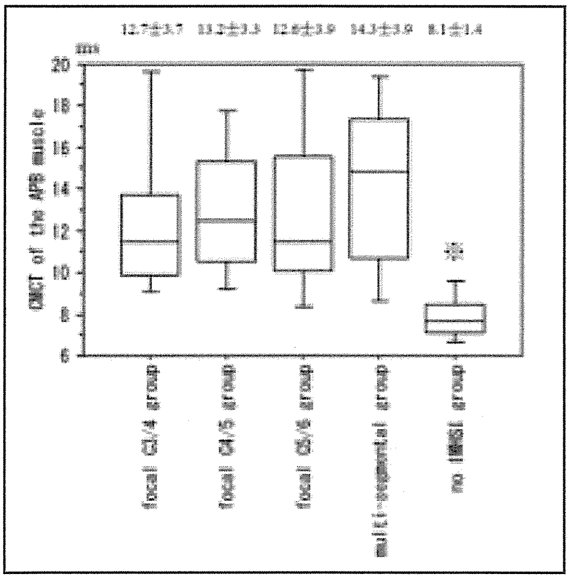

Figure 4 - The CMCT of the APB muscle in each group.
The abductor pollicis brevis (APB) muscle CMCT of the no IMHSI group was significantly shorter than those of the focal C3/4, C4/5, C5/6, and multi-segmental groups. There was no significant difference in the APB CMCT between the focal C3/4, C4/5, C5/6, and multi-segmental groups.

Ono et al. (1987) used the term myelopathy hand to describe hand disability combined with CSM. In addition, in order to evaluate the severity of the damage to the pyramidal tract, they counted the number of grip-release cycles that patients with the condition could perform within ten seconds (Ono et al., 1987). Recently, many physicians have employed this ten-second test. Doita et al. (2006) performed several hand function tests in cervical myelopathy patients and healthy controls and reported that hand function showed a good relationship with extent of cervical myelopathy.

As regards the electrophysiological diagnosis, Lyu et al. (2004) reported that the CMCT of the abductor pollicis brevis muscle was more sensitive than that of the tibialis anterior for diagnosing CSM. Previous reports demonstrated that the CMCT of the biceps brachii was longer in patients who had suffered damage at a cervical level above C4/5 than in those who had suffered damage below C5/6 (Di Lazzaro et al., 1992; Tavy et al., 1994). However, in the current study the biceps brachii muscle CMCTs of the focal C3/4 and focal C4/5 groups were not found to be significantly different from those of the focal C5/6, multi-segmental, and no IMHSI groups. On the contrary, the CMCT of the abductor pollicis brevis was longer in the patients who exhibited strong IMHSI than in the patients who did not display IMHSI. Hence, the corticospinal tract for the abductor pollicis brevis is considered to be more susceptible to causative lesions of IMHSI than the corticospinal tract for the biceps brachii and triceps

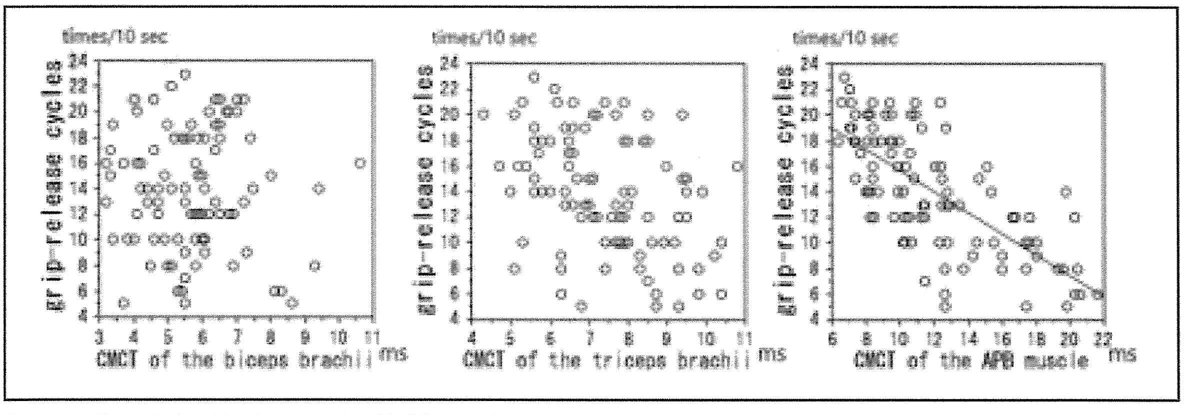

Figure 5 - The relationships between the CMCTs and the number of grip-release cycles performed within 10 seconds.
The CMCT of the biceps brachii muscle and triceps brachii muscle did not exhibit any relationship with the JOA score, whereas that of the abductor pollicis brevis muscle displayed a strong relationship with the JOA score (r=-0.70, p<0.0001).

brachii muscles. This suggests that the corticospinal tract is damaged inhomogeneously at IMHSI sites. Therefore, it is difficult to diagnose the most affected level on the basis of motor dysfunction.

Studies performed in 1929 and 1937 reported that spinal cord compression involving the upper cervical spine or the foramen magnum results in more severe functional disturbances in the upper extremities than in the lower extremities (Elsberg, 1929; Symonds and Meadows, 1937). Furthermore, Good et al. (1984) and Nakajima and Hirayama (1995) described the typical symptoms of CSM as numbness and reduced manual dexterity without functional disturbance of the lower extremities. Sonstein et al. (1996) observed atrophy of the intrinsic muscles of the hand in 13/25 patients with meningioma involving the foramen magnum. In addition, an experimental laceration of the pyramidal tract induced dysfunctions of the upper extremities, especially of the hand (Lawrence and Kuypers, 1968).

Central cord injuries were also found to demonstrate similar characteristic symptoms, i.e. the upper extremities were predominantly affected (Schneider et al., 1954).

As regards the question of why the corticospinal tract for the upper extremities is more vulnerable than that for the lower extremities, the somatotopic organization hypothesis states that the corticospinal tract for the hand muscles is nearer to the center of the spinal cord than the portions of the corticospinal tract for other muscles. However, Levi et al. (1996) pointed out that there is little anatomical evidence to support this hypothesis. The descending fibers for the innervation of the hand and arm are considered to be relatively common in the corticospinal tract, and a high proportion of the large fibers in the corticospinal tract are considered to innervate the anterior horn cells responsible for the hand muscles (Bortoff and Strick, 1993; Davidoff, 1990; Courtine et al., 2007). The electrophysiological measurements obtained in the current study support these findings, which explain why hand function might be valuable in indicating the severity of myelopathy. TMS of the hand motor cortex is useful for the evaluation of cervical myelopathy.

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In vivo 3D kinematics of the upper cervical spine during head rotation in rheumatoid arthritis

Clinical article

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Object. The upper cervical spine is commonly involved in persons with rheumatoid arthritis (RA). Although 2D measurements have long been used in the evaluation of cervical lesions caused by RA, 2D measurements are limited in their effectiveness for detecting subtle and complex morphological and kinematic changes. The purpose of this study was to elucidate the 3D kinematics of the upper cervical spine in RA and the relationship between 3D morphological changes and decreased segmental rotational motion.

Methods. Twenty-five consecutive patients (2 men and 23 women, mean age 63.5 years, range 42–77 years) with RA (the RA group) and 10 patients (5 men and 5 women, mean age 69.9 years, range 57–82 years) with cervical spondylosis and no involvement of the upper cervical spine (the control group) underwent 3D CT of the cervical spine in 3 positions (neutral, 45° head rotation to the left, and 45° head rotation to the right). The segmental rotation angle from the occiput (Oc) to C-2 was calculated for each participant using a voxel-based registration method, and the 3D destruction of articular facets was quantified using the authors' own parameter, the articular facet index.

Results. The segmental rotation angle was significantly smaller at C1–2 and larger at Oc–C1 in the RA group compared with the control group. The degree of the destruction of the articular facet at C-1 and C-2 correlated with the segmental rotation angle.

Conclusions. In vivo 3D kinematics of the upper cervical spine during head rotation in patients with RA were accurately measured, allowing quantification of the degree of joint destruction for the first time. Joint destruction may play an important role in decreasing segmental motion of the upper cervical spine in RA.
(http://thejns.org/doi/abs/10.3171/2014.1.SPINE13252)

KEY WORDS • **rheumatoid arthritis** • **upper cervical spine** • **3D** • **voxel-based registration** • **head rotation** • **articular facet**

THE upper cervical spine is commonly involved in persons with rheumatoid arthritis (RA),[10,16,18,23,24] and the cervical involvements are well known to follow a specific deformation pattern typified as atlantoaxial subluxation (AAS). However, these patterns have been assessed only two-dimensionally, mainly with lateral radiography, even though the deformities occur three-dimensionally with a wider range of variation than was previously thought. Although 2D measurements such as radiography, conventional CT, and conventional MRI[4,8,9,22,25,26] have long been used in the evaluation of cervical lesions caused by RA, 2D measurements are limited in their effectiveness for detecting subtle and complex morphological and kinematic changes in RA cervical lesions. Because of methodological difficulty, there have been few reports[7,20,21] on 3D morphology and kinematics of RA cervical lesions. In addition, there are no published quantitative evaluations of 3D morphological changes or explanations of how those changes affect joint kinematics.

In previous studies, we documented morphological and kinematic changes in the wrist and foot caused by RA, using our own 3D motion analysis method.[1,2,14] By comparing persons with RA and persons without RA, we showed that the morphological changes associated with RA could cause abnormal joint kinematics. It is thought

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Abbreviations used in this paper: AAS = atlantoaxial subluxation; ADI = anterior atlantodental interval; AFI = articular facet index; ICC = intraclass correlation coefficient; Oc = occiput; RA = rheumatoid arthritis; RMSE = root mean square error.

to be very important for spinal surgeons to have an accurate understanding of the morphological and kinematic changes in the cervical spine in RA, especially when making surgical plans and evaluating patients' postoperative condition. In the study we report here, we quantified the degree of 3D morphological change in RA cervical lesions for the first time using our own method. The purposes of our study were 1) to quantitatively measure 3D morphological and kinematic changes in the upper cervical spine in persons with RA by comparing their spines with those of persons without RA, and 2) to elucidate the relationship between those morphological and kinematic changes.

Methods

We included in our study 25 consecutive patients (2 men and 23 women, mean age 63.5 years, range 42–77 years) with cervical lesions caused by RA (the RA group), and 10 patients (5 men and 5 women, mean age 69.9 years, range 57–82 years) with cervical spondylosis who had no involvement of the upper cervical spine as an age-matched control group (the control group). There was no significant difference in age between the groups ($p = 0.09$). All study protocols were approved by our institution's review board.

Flexion-extension lateral radiographs, obtained with the patient upright, were used for measurement. The anterior atlantodental interval (ADI), the Ranawat value, and the Redlund-Johnell value were measured.[3,17,19] AAS was defined as an ADI > 3 mm on flexion lateral radiographs, and AAS was further classified as reducible or irreducible according to whether the ADI was reduced to < 3 mm during extension. Vertical subluxation for female study participants was defined as the presence of a Ranawat value of < 13 mm or a Redlund-Johnell value of < 32 mm. For male participants, it was defined as Ranawat value of < 13 mm or a Redlund-Johnell value of < 37 mm. Subaxial subluxation was defined as the distance between the posterior borders of adjacent vertebral bodies of > 3 mm. Radiographic classification identified 11 cases of reducible AAS, 13 cases of irreducible AAS, 17 cases of vertical subluxation, and 9 cases of subaxial subluxation (Table 1).

Acquisition of 3D CT

We obtained 3D CT scans for 3 positions for each study participant using a commercial CT system (LightSpeed VCT, GE Healthcare) with the following parameters: slice thickness 0.625 mm, pixel size 0.352 mm, tube rotation speed 0.5 seconds, beam collimation 40 mm, beam pitch 0.9, tube current 50 mA, and voltage 120 kV. Participants were placed in a neutral position supine on the CT table, and also with their head rotated 45° to the left and then 45° to the right. Those who could not rotate their head to 45° were excluded from the study. A support device was used to keep the head at the correct rotation point (Fig. 1). To reduce radiation exposure, scans done in positions other than neutral were performed with a lower tube current (15 mA). Total exposure was 60 dose-length products, which is less than that specified for routine CT by our hospital. CT data were transferred via a digital imaging and communications in medicine network into a computer workstation, where image processing was performed using Virtual Place software (M series, Medical Imaging Laboratory).

Motion Analysis

We conducted motion analysis as described in our previous reports.[11–13,15] First, each vertebra was semiautomatically extracted using intensity threshold techniques. Second, segmented images of the vertebrae in the neutral position were superimposed over images of other positions using voxel-based registration. As a result of the registration, the spatial migration of each vertebra was expressed by a matrix. Third, segmental motions at occiput (Oc)–C1 and C1–2 were calculated by converting the matrix obtained by the registration into a matrix representing relative motion with respect to the inferior adjacent vertebra. The results were expressed in 6 degrees of freedom by Euler angles, with the sequence of pitch (X), yaw (Y), roll (Z), and translations, using a previously defined coordinate system.[11–13] The rotation angle was calculated as the sum of the right (–RY) and left (+RY) rotation angles. The accuracy of the method described here was 0.13° in axial rotation, as previously described in detail.[6]

Evaluation of 3D Morphology

In our study, we defined the articular facet index (AFI) for the first time to assess the severity of joint destruction objectively. First, we chose 3 points free of RA invasion in each 3D bone model, from the occiput to C-2. At C-1 and C-2, the points were the volume centroids of the bilateral transverse processes and a posterior arch. At the occiput, the points consisted of the bilateral posterior border of the base of the occipital condyle and the center of the anterior arch of the foramen magnum. Then we created planes passing through these 3 points. Second, we chose 200 points on each right and left articular facet and measured the minimum distance (in mm) between these points and the plane. The mean value of these distances was calculated as the height of the articular facet. However, the mean value had to be corrected by the size of each vertebra for valid comparisons. Finally, the AFI was

TABLE 1: Radiographic classification of study participants with rheumatoid arthritis*

Classification	No. of Participants
reducible AAS	5
reducible AAS + VS	3
reducible AAS + VS + SS	3
irreducible AAS	2
irreducible AAS + VS	6
irreducible AAS + VS + SS	5
SS	1

* AAS = atlantoaxial subluxation; SS = subaxial subluxation; VS = vertical subluxation.

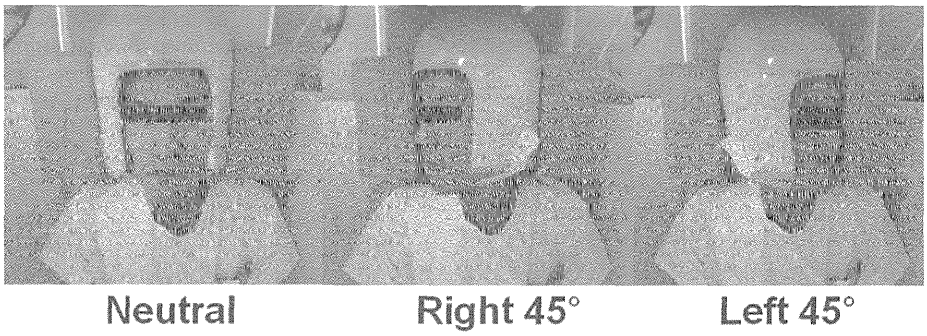

Fig. 1. Computed tomography scans were performed in 3 positions. A support device was used to ensure that head position was maintained during scanning.

calculated by dividing the height of the articular facet by the square root of the cross-section area (in mm^2) of each vertebra at the planes already described (S)[1] (Fig. 2): AFI = height of articular facet/$\sqrt{S}$.

A low AFI means a decrease in the thickness of the lateral mass; thus, the AFI is thought to reflect the severity of joint destruction.

Reproducibility of the AFI

To assess the reproducibility of measurement of the AFI, two authors (T.S. and Y.N.) independently calculated the AFI for 10 patients in the control group for the caudal side of the articular facet of C-1 twice, with 1 week elapsing between the measurements. Intraobserver and interobserver intraclass correlation coefficient (ICC) and root mean square error (RMSE) were assessed. For intraobserver reproducibility of measurement of the AFI, the mean ICC and RMSE were 0.926 and 0.01, respectively. For interobserver reproducibility, the mean ICC and RMSE were 0.845 and 0.02, respectively.

Statistical Analysis

Statistical analyses were performed with Microsoft Excel 2007 for Windows with the add-in program Statcel 2 (OMS Ltd.). The data were analyzed using the nonparametric Mann-Whitney U-test. A $p < 0.05$ was considered to indicate statistical significance. Correlation analyses were performed using the Spearman rank-correlation coefficient. ICC was calculated using SPSS for Windows (version 21.0, IBM). Mean values are presented with SDs.

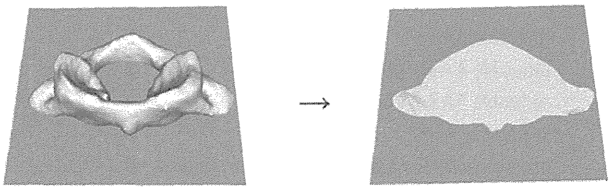

Fig. 2. S is the cross-section of each vertebra at a plane passing through 3 points free of RA invasion (see the main text for details). The articular facet index (AFI) was calculated by dividing the height of the articular facet by the square root of the cross-section of each vertebra at this plane (AFI = height of articular facet/$\sqrt{S}$).

Results

Morphological Analysis: Value of AFI

The mean AFI at the occipital articular facet was 0.14 ± 0.02 (0.13 ± 0.02 in men, 0.15 ± 0.02 in women) in the control group and 0.13 ± 0.02 (0.15 ± 0.02 in men, 0.12 ± 0.02 in women) in the RA group. The mean AFI on the cranial side of the C-1 articular facet was 0.18 ± 0.03 (0.20 ± 0.03 in men, 0.17 ± 0.03 in women) in the control group and 0.18 ± 0.03 (0.17 ± 0.02 in men, 0.18 ± 0.04 in women) in the RA group. The mean AFI on the caudal side of the C-1 articular facet was 0.15 ± 0.03 (0.15 ± 0.03 in men, 0.15 ± 0.04 in women) in the control group and 0.09 ± 0.04 (0.08 ± 0 in men, 0.09 ± 0.04 in women) in the RA group. The mean AFI on the cranial side of the C-2 articular facet was 0.27 ± 0.02 (0.27 ± 0.02 in men, 0.27 ± 0.03 in women) in the control group and 0.22 ± 0.05 (0.22 ± 0.01 in men, 0.22 ± 0.05 in women) in the RA group. There was no significant difference at the occipital articular facet or on the cranial side of the C-1 articular facet, but there were significant differences on the caudal side of the C-1 articular facet and the cranial side of the C-2 articular facet (Table 2). With respect to comparison of findings in women in both groups, there was a significant difference at the occipital articular facet ($p = 0.04$), but the same tendency was seen in other articular facets compared with overall analysis of data for men and women.

Kinematic Analysis

Head Rotation. The mean angle of axial rotation of the head was 89.4° ± 3.3° in the control group and 87.2° ± 8.5° in the RA group (not a significant difference, $p = 0.69$).

TABLE 2: Articular facet index

Measurement	Control Group (n = 10, 20 joints)	RA Group (n = 25, 50 joints)
lateral mass of Oc	0.14 ± 0.02	0.13 ± 0.02
articular facet of C-1 (cranial side)	0.18 ± 0.03	0.18 ± 0.03
articular facet of C-1 (caudal side)	0.15 ± 0.03*	0.09 ± 0.04*
articular facet of C-2 (cranial side)	0.27 ± 0.02*	0.22 ± 0.05*

* $p < 0.01$.

Segmental Rotation Angle at Upper Cervical Spine During Head Rotation. The mean segmental rotation angle at Oc–C1 was 3.3° ± 1.6° (3.3° ± 1.8° in men, 3.3° ± 1.6° in women) in the control group and 4.8° ± 4.2° (1.9° ± 2.5° in men, 5.1° ± 4.3° in women) in the RA group (not a significant difference). However, the segmental rotation angle at C1–2 was 54.5° ± 5.4° (56.8° ± 5.0° in men, 52.1° ± 5.1° in women) in the control group and 29.1° ± 18.0° (29.7° ± 7.5° in men, 29.4° ± 18.2° in women) in the RA group (a significant difference, $p < 0.01$, Fig. 3 left). In patients with RA, there was a weak inverse correlation between the rotation angle at Oc–C1 and the angle at C1–2 (rs = –0.21) (Fig. 3 right). With respect to comparison of women in both groups, the same tendency was seen compared with overall analysis of men and women.

Correlation Between Articular Facet Destruction and 3D Kinematics in the Upper Cervical Spine. At the occipital articular facet, the AFI did not correlate with the segmental rotation angle (rs = –0.13). Yet the AFI did correlate with the segmental rotation angle on the cranial and caudal sides of the C-1 articular facet (rs = 0.58 and 0.59, respectively) and with the cranial side of the C-2 articular facet (rs = 0.74) (Figs. 4 and 5).

Discussion

Regarding the morphological changes of RA in the cervical spine, there have been several previous reports based on cadavers or 2D images from data obtained by radiography, CT, and MRI.[4,8,9,22,25,26] Eulderink and Meijers performed pathological analysis using the cervical spines of cadavers with RA and reported that bony ankylosis of the articular facet was demonstrated in 15% of spines at Oc–C1 and in 10% at C1–2.[5] Iizuka et al. reported that joint destruction was demonstrated in 17% of patients at Oc–C1, 4% of patients at C1–2, and 4% of patients at both Oc–C1 and C1–2 in sagittal and coronal views on CT.[8] In those studies, the authors reported on the occurrence of joint destruction in the upper cervical spine in patients with RA, but minute morphological evaluation was not done. In addition, joint destruction was determined only by visual assessment. It is generally thought that in persons with RA, the more severe joint destruction is, the more severe the depression of the articular facet. For more objective evaluation, we developed a method for quantifying the severity of joint destruction: the AFI, which is an indicator of the extent of depression of the articular facet. We observed a significant decrease in the AFI in the RA group at C1–2, but no significant difference at Oc–C1. These results suggest that joint destruction is milder at Oc–C1 than at C1–2. From a mechanical viewpoint, this is a reasonable conclusion, considering the fact that the segmental motion of Oc–C1 is much smaller than that of C1–2. The AFI was calculated from the mean value of the minimum distance between 200 points on the articular facet and the plane passing through 3 points free of RA invasion. This index is the only method that can express the severity of joint destruction three-dimensionally as a single value with good reproducibility. The joint destruc-

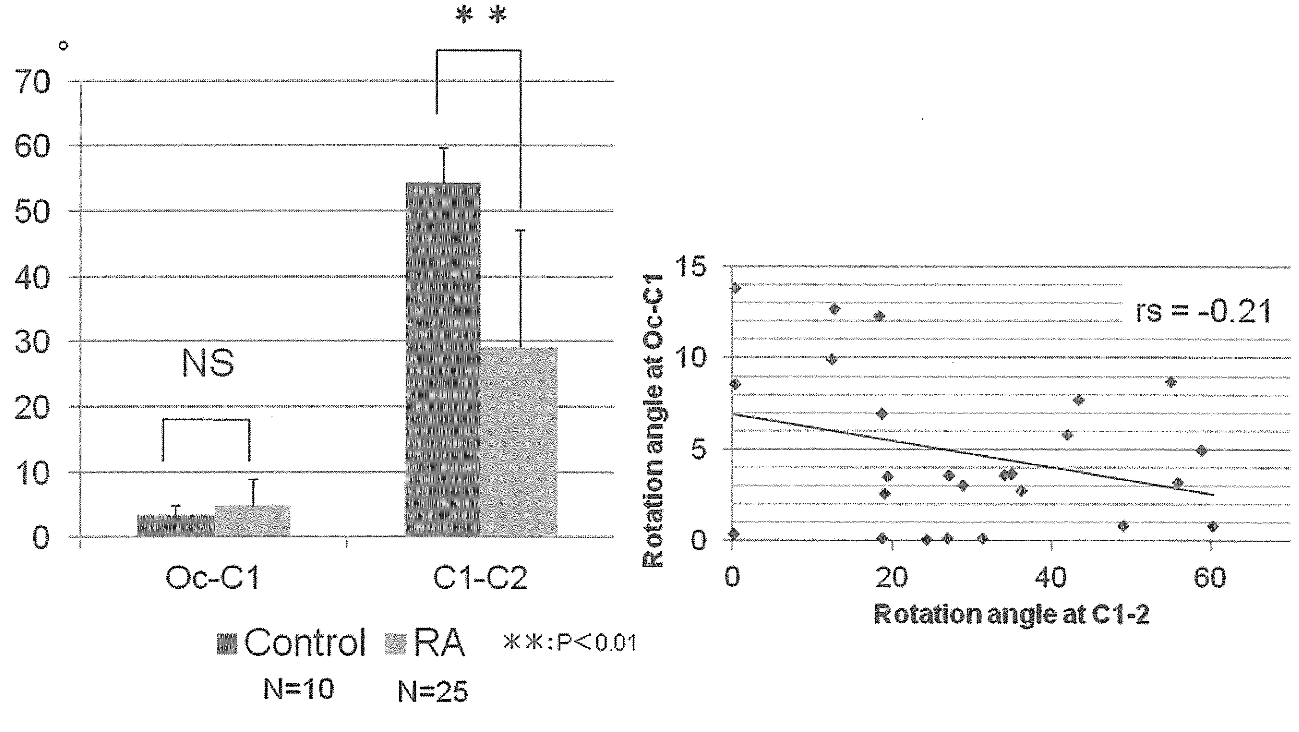

Fig. 3. Left: The mean segmental rotation angle at Oc–C1 was greater in the RA group than in the control group but the difference was not significant (NS). However, the mean angle at C1–2 was significantly smaller in the RA group than in the control group. *Error bars* represent 1 SD. **p < 0.01. **Right:** There was a weak inverse correlation between the segmental rotation angle at Oc–C1 and the angle at C1–2 in patients with RA (rs = –0.21).

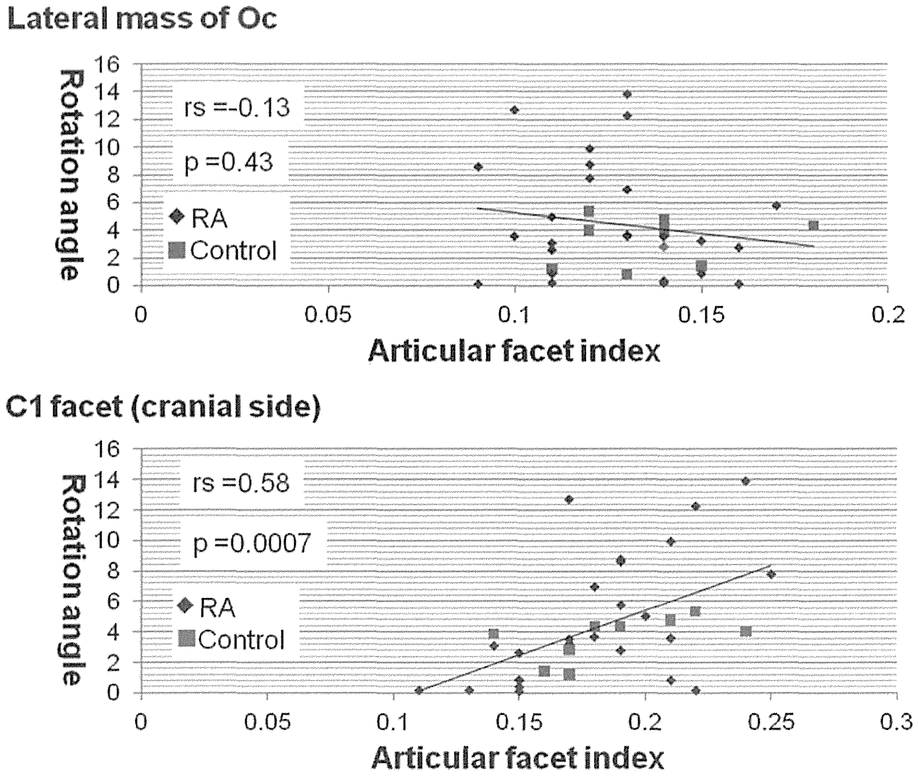

Fig. 4. Correlation between the segmental rotation angle and the AFI at Oc–C1. The AFI correlated with the segmental rotation angle at the cranial side of the articular facet of C-1 (rs = 0.58).

tion best detected by the AFI is that associated with homogeneous decrease of the lateral mass. However, the AFI cannot detect morphological changes such as localized depression of the articular surface or an indented articular surface. In our study, most joint destruction involved homogeneous depression of the lateral mass. Given these morphological findings, the AFI could be a useful indicator for assessing the severity of joint destruction of the cervical spine in RA. However, there is not yet an equivalent index for use in 2D image analysis. It is anticipated that the newly emerging technique of 3D image analysis will make measuring the AFI easy and quick.

There have been few studies of the kinematic changes in the cervical spine in RA.[7,20,21] Iai et al. measured 3D segmental motion of the upper cervical spine in RA, including rotation, by tracking the bony landmarks of each vertebra on biplanar roentgenograms, and they reported that the segmental rotation angle of persons with RA involving the upper cervical spine was larger at Oc–C1 and smaller at C1–2 compared with the angle in healthy persons.[7] However, their method presented major difficulties in precisely identifying the same reference points on sequential separate views of the same vertebra. Recently, Takatori et al. assessed the relationship between morphological change and kinematics during head flexion using dynamic CT, and they reported that movement of the upper cervical spine increased with C-2 unilateral mass collapse and decreased with a continuous bony lesion between the atlas and the odontoid process.[20] Although the accuracy of their measurements was much greater than any researchers had ever obtained before, their kinematic study was performed only during head flexion and their morphological study was performed using only visual assessment. Because the upper cervical spine has the largest segmental motion during head rotation, we hypothesized that the pathological changes of RA could be best detected during this motion. In our study, the segmental rotation angle in the RA group was greater than that in the control group at Oc–C1, but the difference was not significant. However, the segmental rotation angle was significantly smaller in the RA group than in the control group at C1–2. These results are similar to those of Iai et al. Furthermore, our study showed a weak inverse correlation between the segmental rotation angle at Oc–C1 and the angle at C1–2. This finding caused us to speculate that the segmental rotation angle might decrease at C1–2 and increase in compensation at Oc–C1 in persons with RA. We also quantitatively elucidated the relationship between morphological and kinematic changes for the first time. The AFI both at C-1 and at C-2 correlated with the segmental rotation angle. Because of that finding, we speculated that destruction of the articular facet might play an important role in the decrease of the segmental rotational motion of the upper cervical spine in RA.

Piecing together all of our findings, we speculated that the rotational motion at C1–2 might initially be reduced by destruction of the articular facet and that joint contracture at C1–2 might promote a compensatory increase in rotational motion at Oc–C1 with the progression of RA.

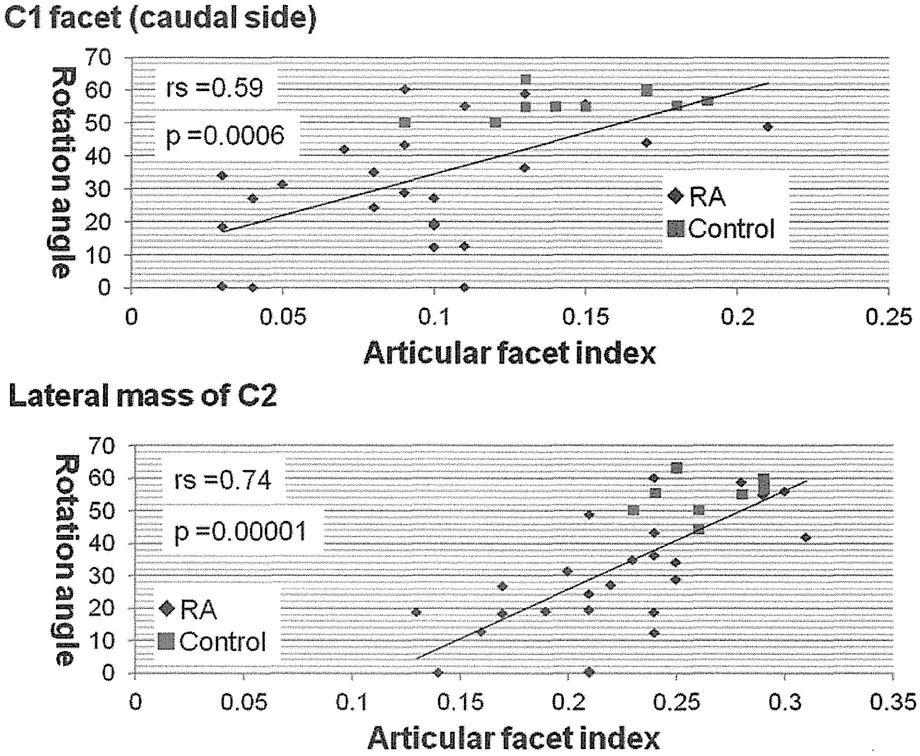

FIG. 5. Correlation between the segmental rotation angle and the AFI at C1–2. The AFI correlated with the segmental rotation angle on the caudal side of the articular facet of C-1 and the lateral mass of C-2 (rs = 0.59 and 0.74, respectively).

Our study had some limitations. First, data were not obtained from true real-time imaging in the upright position. Second, increased segmental motion caused by ligament laxity and ligament rupture could not be detected because our study was performed with the head fixed only at 45° of rotation. Third, the selection of study participants with RA was somewhat biased toward those with more severe disease. Fourth, there was a difference in the male-to-female ratios for the control group versus the RA group. Although there was a significant between-groups difference in the AFI at the occipital articular facet in women, the segmental rotation angle and the AFI at other articular facets showed the same tendency compared with overall analysis when analyzed for women alone. In addition, the AFI is contingent on the size of each vertebra, and it was thought not to be affected by the difference in size of vertebrae between men and women. Therefore, we think that the difference in male-to-female ratios had little effect on our study results. Despite all of these limitations, no other approaches have provided the kind of information provided by our study, and our findings thus represent a step toward a better understanding of the effects of RA on the cervical spine.

Conclusions

We accurately measured in vivo 3D kinematics of the upper cervical spine in RA during head rotation, quantified the degree of destruction of the articular facet for the first time using our own parameter, termed the AFI, and elucidated the relationship between the destruction of the articular facet and segmental rotational motion. The segmental rotation angle was significantly smaller at C1–2 in the RA group than in the control group. The AFI at C1–2 was significantly smaller in the RA group than in the control group and correlated with the segmental rotation angle at C-1 and C-2. In persons with RA, the destruction of the articular facet may play an important role in decreasing segmental rotational motion in the upper cervical spine.

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Disclosure

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Author contributions to the study and manuscript preparation include the following. Conception and design: Sugiura, Nagamoto. Acquisition of data: Sugiura, Nagamoto. Analysis and interpretation of data: Sugiura, Nagamoto. Drafting the article: Sugiura. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manu-

script on behalf of all authors: Sugiura. Statistical analysis: Sugiura. Administrative/technical/material support: Iwasaki, Murase, Tomita, Yoshikawa, Sugamoto. Study supervision: Nagamoto, Iwasaki, Yoshikawa, Sugamoto.

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