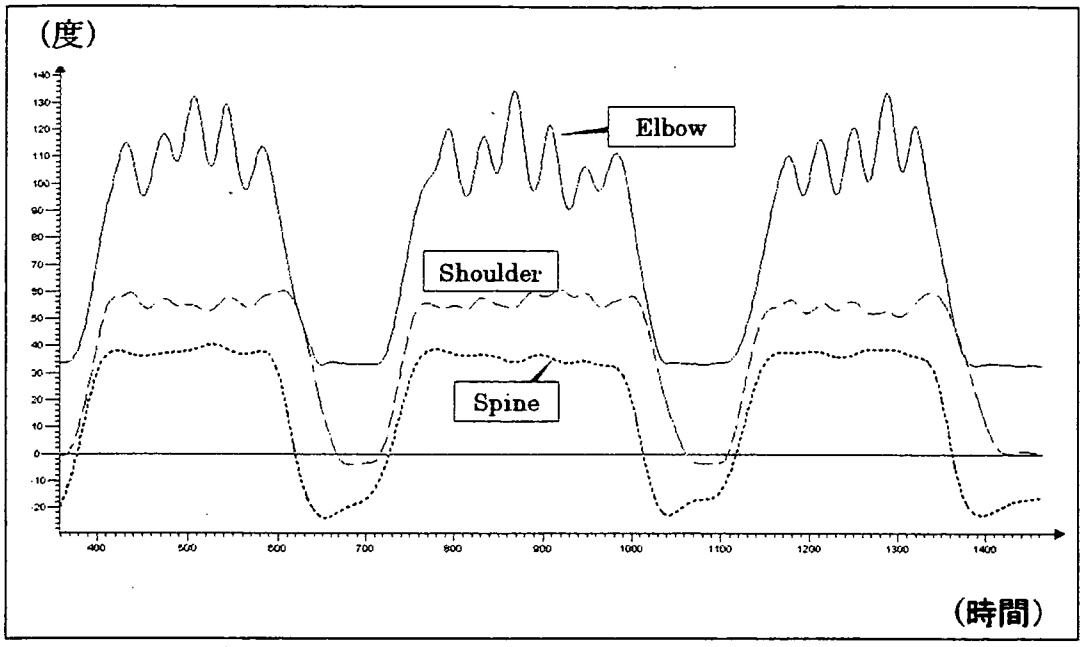

図１．洗髪動作における健常者の頚椎上肢の屈曲角度の時間的変化

度と大きく異なっていた。

次にRA拘縮肘患者の洗髪動作に於ける各関節の最大屈曲角度は、頚椎56度、肩関節67度、肘関節 109 度となっていた。健常者（case 1）の動きと比較すると、RAによる肘関節拘縮による屈曲角度が健常者の 135 度から 109 度と減少したのに対し、頚椎、肩関節の屈曲角度はそれぞれ39度が56度に、61度が67度に増加していた（表２）。

〔考察〕光学式三次元位置計測システムの上肢機能評価に於ける精度は、0.78～2.56度と３度以内の測定誤差におさまっており高い再現性を示した。また、万能角度計と VICON での測定値との相関係数は0.69以下のものはなく、本システムは万能角度計による可動域計測と高い相関があることがわかった。以上から、このシステムは再現性も高く、万能角度計とも高い相関があることから、頚椎と上肢の機能評価に有用と考えられた。

洗髪、洗顔、食事動作などの ADL に於いて、頚椎、肩関節、肘関節は協調して目的の動作を達成する。いずれの動作に於いても、肘関節、肩関節の最大屈曲角度は一定の値を示し、特に肘関節はほぼ最大屈曲角度を要していた。それに対し、頚椎の屈曲角度は各動作により大きく異なっており、各動作で必要とされる屈曲角度が異なることがわかった。各関節の屈曲角度が一定の傾向を示すことから各関節の屈曲角度の総和を total flexion angle とすると、洗髪 261 度、洗顔 207 度、食事動作 185 度と、被験者によるばらつきは少なく一定の値を示していた（表1）。一方、RA拘縮肘患者も健常者と同様、各動作に於いて肘関節は最大屈曲しており、頚椎の屈曲は各動作により大きく異なっていた。また健常者のcase 1 との比較では Total flexion angle はcase 1の 235 度に対し 231 度とほぼ同じであったが、肘関節の屈曲が減少したため、他の部位、特に頚椎の屈曲が代償性に増加しているのがわかった。つまり、洗髪、洗顔、食事などの ADL においては、頚椎、肩、肘関節の屈曲角度の総和は一定で、１つの関節の屈曲角度が減少した場合他関節（特に頚椎）の代償運動が起こることがわかった。以上のことから、関節リウマチのように多関節障害がある場合、障害されている動作を改善するために、どの関節の可動域をどの程度改善すれば良いかを、術前に予見可能である。また、手術で予想される獲得可動域がある程度わかっている場合、術後獲得出来る ADL を術前に予見することも可能である。

今後はデーターの蓄積により、各 ADL に於ける各関節の最大可動域のみならず、障害された関節がある場合の隣接関節の代償運動の特徴を明らかにする予定である。

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ORIGINAL ARTICLE

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Adrenocorticotropic hormone and dehydroepiandrosterone sulfate levels of rheumatoid arthritis patients treated with glucocorticoids

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Abstract To assess adrenal function with respect to the presence or absence of steroid therapy, we investigated differences in the blood levels of adrenocorticotropic hormone (ACTH) and dehydroepiandrosterone sulfate (DHEAS) in relation to steroid (prednisolone) administration in 123 patients with rheumatoid arthritis (RA). Levels of ACTH and DHEAS were significantly lower in the steroid-treated group than in the non-treated group (ACTH: 11.79 pg/ml vs 27.92 pg/ml) (DHEAS: 418.12 ng/ml vs 883.91 ng/ml) ($P < 0.0001$). We observed no steroid dose-related differences in ACTH levels. However, DHEAS levels showed a slight decrease at a prednisolone dose of 2.5 mg/day, with a significant decrease being observed at a dose of 5 mg/day when statistical adjustments were made for age and sex ($P < 0.0001$). At doses of 7.5 mg/day or greater, DHEAS levels were significantly lower than those for 5 mg/day ($P < 0.0006$). These results suggest that low-dose prednisolone reduces adrenal function in patients with RA. We recommend that doses of prednisolone should be limited to 5 mg/day or less in consideration of adrenal function when treating RA patients. The measurement of ACTH and DHEAS may be useful for evaluating adrenal function in patients with RA.

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Key words Adrenocorticotropic hormone (ACTH) · Dehydroepiandrosterone sulfate (DHEAS) · Rheumatoid arthritis (RA) · Steroid administration · Stress

Introduction

Dehydroepiandrosterone (DHEA) and dehydroepiandrosterone sulfate (DHEAS) are secreted by the adrenal cortex and are classified as sex hormones.[1] Dehydroepiandrosterone sulfate levels markedly increase during adolescence, and reach a peak at about 20 years of age, after which they decrease with age. As such, DHEAS may be used as a parameter of aging.[2,3] Previous studies have suggested that DHEAS prevents osteoporosis, cardiovascular disease and arteriosclerosis, and it is becoming increasingly recognized that DHEAS is important for maintaining a healthy state.[4,5] In patients with rheumatoid arthritis (RA), there have been reports of normal, increased, and decreased DHEAS values.[6–9] However, steroids are often administered to these patients, and may decrease the levels of adrenocorticotropic hormone (ACTH) and DHEAS via negative feedback mechanisms.[1] Furthermore, a previous study has reported that blood levels of DHEAS are constant for a long period,[8] but that mental or physical stress and inflammatory responses may influence DHEAS levels via ACTH.[1,10] In this study, we investigated differences in the blood levels of ACTH and DHEAS in subjects on and off of various doses of steroids. In addition, we examined changes in ACTH and DHEAS levels in 14 patients for whom these parameters were measured twice.

Patients and methods

Of 130 RA patients meeting the criteria established by the American College of Rheumatology,[11] for whom levels of ACTH and DHEAS were measured between February 2002 and September 2002, there were 123 patients (137

samples) for whom confirmation of the undertaking and dosages or non-undertaking of prednisolone therapy could be made (patients treated with betamethasone were excluded). In the 14 patients for whom these parameters were measured twice, the values at the second measurement were also evaluated. Subjects were 123 patients (26 males, 97 females) consisting of 19 inpatients and 104 outpatients, with a mean age of 57.24 years (±12.58) at the time of examination. Steroids had been administered to 78 of these patients, the daily prednisolone doses were 2.5mg in 16 patients, 5mg in 47 patients, 7.5mg in 9 patients, and 10mg in 6 patients (Table 1).

Adrenocorticotropic hormone levels were determined by a one-step IRMA (immunoradiometric assay) method using biotinylated antibodies, and, for B/F (bound/free) isolation, avidin-bound beads were used (Allegro HS-ACTH IRMA kit: Nichols Diagnostics, San Juan Capistrano, CA, USA). Serum DHEAS was determined after serum was allowed to react competitively with I-labeled DHEAS in a DHEAS antibody coated tube (DHEA-S kit: Coat-A Count DHEA-SO_4, Mitsubishi Kagaku Iatron, Tokyo, Japan). In addition, we investigated the correlations of ACTH and DHEAS values with age, erythrocyte sedimentation rate (ESR), matrix metalloproteinase (MMP_3), red blood cell count (RBC), and rheumatoid factor (RF). Blood samples were measured between 08:30 and 11:00h. Before the measurement of these values, informed consent was obtained from all patients.

Reproducibility of ACTH and DHEAS measurements

Using 3 samples of ACTH with different concentrations, Intra-day ACTH concentrations were evaluated 10 times on 1 day. The coefficients of variation (CV) were 3.8%, 2.4%, and 2.2%. Inter-day ACTH concentrations were evaluated daily over a period of 5 days. The CV were 1.3%, 5.1%, and 3.6%. Using 3 samples of DHEAS with different concentrations, intra-day DHEAS concentrations were evaluated 20 times on 1 day. The CV were 7.2%, 4.7%, and 3.4%. Inter-day DHEAS concentrations were evaluated daily over a period of 10 days. The CV were 10.6%, 4.9%, and 4.2%. These values confirmed the reproducibility of ACTH and DHEAS measurements.

Table 1. Characteristics of 123 rheumatoid arthritis (RA) patients treated with various doses of prednisolone

Steroid dose (mg)	No. of cases	Sex		Age (years)[a]
		Male	Female	
0	45	6	39	54.76 ± 12.37
2.5	26	1	15	61.13 ± 7.91
5	47	11	36	56.45 ± 14.65
7.5	9	5	4	60.33 ± 8.02
10	6	3	3	67.00 ± 3.03
Total	123	26	97	57.24 ± 12.58

[a] Mean ± SD

Statistical analysis

Differences between the ACTH and DHEAS levels of steroid-treated and non-treated RA patients were compared using a Wilcoxon rank sum test. In addition, the effects of steroids on ACTH and DHEAS levels were evaluated by analysis of variance with steroid dosage as a factor, and by analysis of covariance with steroid dosage as a factor and with age and sex as covariates. Prior to the comparison, it was confirmed that there were no correlations between ACTH or DHEAS levels and age, CRP, ESR, MMP_3, RBC, or RF through simple correlation coefficients and partial correlation coefficients. P values of less than 0.05 were considered to be significant.

Results

Differences in ACTH and DHEAS levels related to the steroid administration and dosage

In the steroid-treated group, ACTH and DHEAS levels were lower (Wilcoxon's test, $P < 0.0001$) (Table 2) than the non-treated group. There were no dose-related differences in ACTH levels (Table 3). However, DHEAS levels in the steroid-treated group were lower than in the non-treated group at a prednisolone dose of 2.5mg/day (Table 4), and significant decreases in DHEAS levels were observed at doses of 5mg/day ($P < 0.0002$) or greater after adjustments were made for age and sex (Table 4). In addition, at doses of 7.5mg/day or higher, DHEAS levels were significantly lower than at doses of 5mg/day ($P < 0.0006$).

Table 2. Adrenocorticotropic hormone (ACTH) and dehydroepiandrosterone sulfate (DHEAS) levels in RA patients on and off steroid treatments

Steroid administration	No. of cases	ACTH (pg/ml)	DHEAS (ng/ml)
No	45	27.92 ± 19.74	883.91 ± 655.23
Yes	78	11.79 ± 10.13	418.12 ± 442.83

Values are mean ± SD
$P < 0.0001$

Table 3. ACTH levels in RA patients according to prednisolone dose

Dose (mg)	No. of cases	Mean (pg/ml) ± SD	P^a
0	45	27.92 ± 19.74	
2.5	16	13.31 ± 8.50	0.0004*
5	47	11.51 ± 8.47	<0.0001*
7.5	9	7.67 ± 4.56	0.0003*
10	6	16.17 ± 24.70	0.0514

[a] Adjusted for age and sex
* Significant difference compared with 0mg dose

Table 4. DHEAS levels in RA patients according to prednisolone dose

Dose (mg)	No. of cases	Mean (ng/ml) ± SD	P^a
0	45	883.91 ± 655.23	
2.5	16	443.94 ± 369.54	0.1648
5	47	482.43 ± 503.51	0.0002*
7.5	9	196.11 ± 173.38	0.0002*
10	6	178.50 ± 176.39	0.0271*

[a] Adjusted for age and sex
* Significant difference compared with 0 mg dose

Changes in ACTH and DHEAS levels in 14 patients for whom these parameters were measured twice

In one of the 14 patients, a steroid-free treatment approach was switched to prednisolone therapy at a dose of 5 mg/day. In another patient, the daily steroid dose was increased from 5 to 7.5 mg. In both of these patients, DHEAS levels decreased (Fig. 1). Some of the remaining 12 patients showed changes in ACTH and DHEAS levels, despite the constant steroid dosage (Fig. 2).

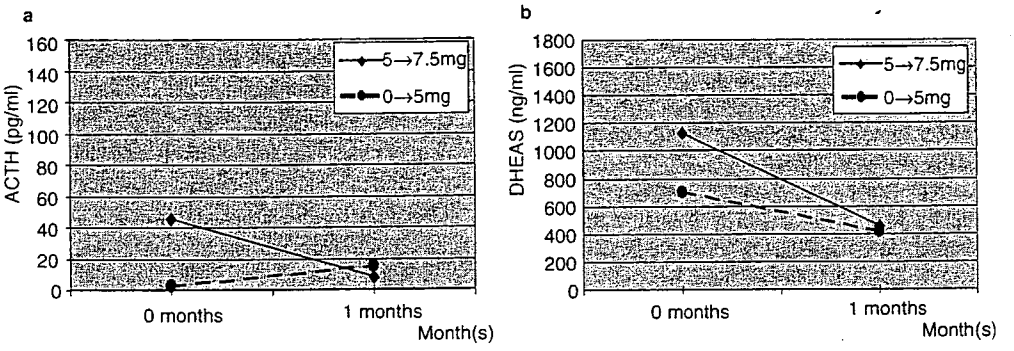

Fig. 1. Changes in adrenocorticotropic hormone (*ACTH*) and dehydroepiandrosterone sulfate (*DHEAS*) levels after increased doses of prednisolone in two patients

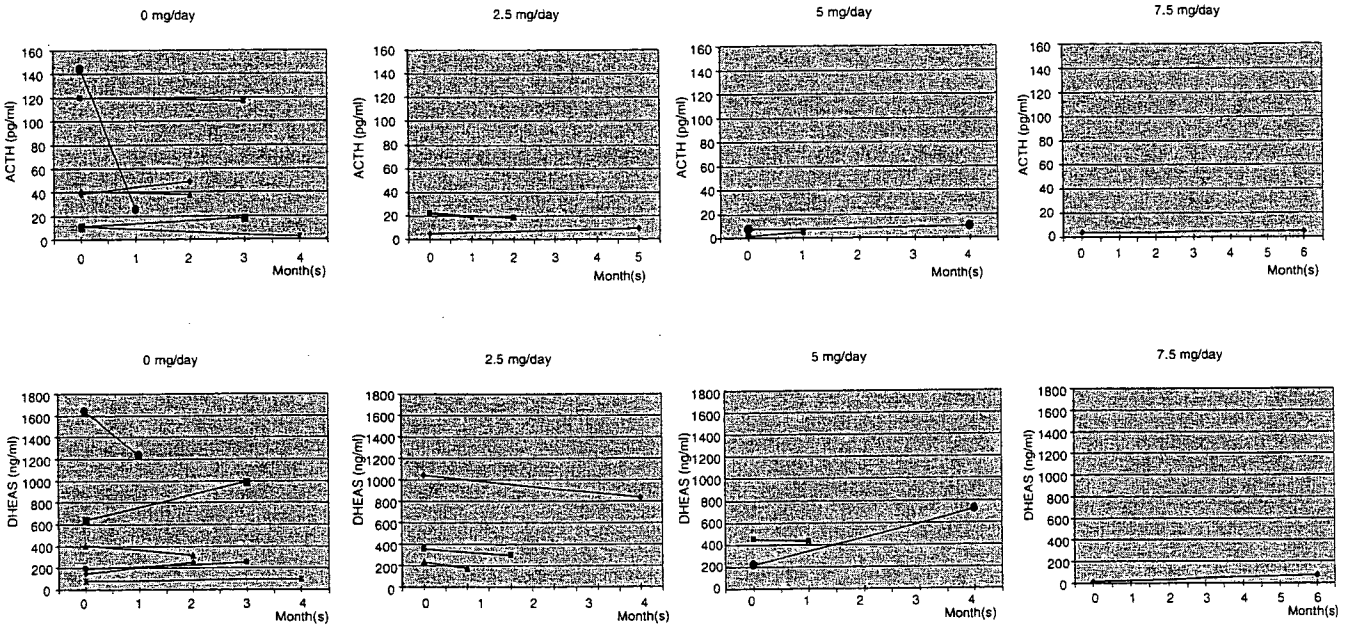

Fig. 2. Changes in adrenocorticotropic hormone (*ACTH*) and dehydroepiandrosterone sulfate (*DHEAS*) levels in patients on fixed doses of steroids

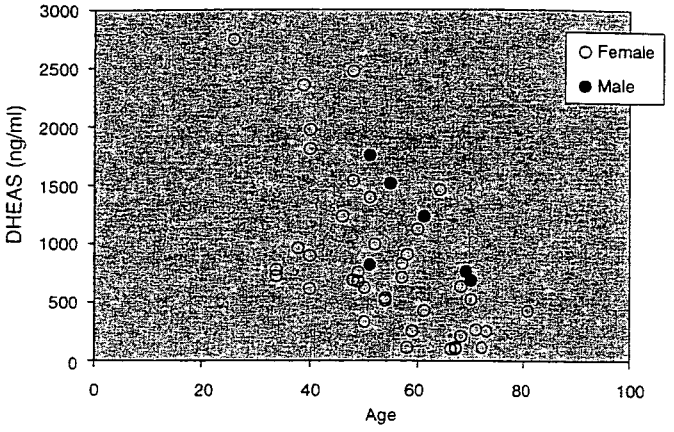

Fig. 3. Dehydroepiandrosterone sulfate (*DHEAS*) levels in rheumatoid arthritis patients without steroid treatment

Correlations of ACTH and DHEAS with age, ESR, CRP, MMP_3, and RBC values

We observed a correlation between ACTH and DHEAS (r = 0.37125). Dehydroepiandrosterone sulfate was negatively correlated with age (r = –0.43464). In addition, CRP values were correlated with ESR (r = 0.50421), RF (r = 0.46516), and MMP_3 (r = 0.39224) (r > 0.3000 or more was extracted).

Discussion

Dehydroepiandrosterone sulfate levels decrease with age,[2,3] and a high blood DHEAS level is related to a long life span.[12] It is also thought that DHEAS may exhibit anti-aging actions. In our patients, DHEAS was negatively correlated with age, supporting that supposition. Furthermore, cortisol and DHEAS are secreted by the adrenal cortex as a result of stimuli from ACTH secreted by the pituitary gland.[1] However, cortisol has a negative feedback mechanism, and blood levels of cortisol show a marked circadian variation.[1,13] In addition, steroids are administered to a high percentage of patients with RA. In comparison to cortisol, DHEAS does not have any negative feedback mechanism, and there may be less marked circadian variations,[1] meaning that the measurement of ACTH and DHEAS levels may be more useful for evaluating adrenal function.

Studies have reported that the blood levels of DHEAS in patients with RA are lower,[6–8] or similar[9] to those of normal controls; however, in the Hall et al.[7] study involving a large number of samples, it was reported that blood levels of DHEAS are lower in patients with RA, and that these levels are further reduced in patients receiving steroids or in those with a history of steroid use. We found that the levels of DHEAS and ACTH were decreased in the group receiving steroid therapy. There were no steroid dose-related differences in ACTH levels. However, DHEAS levels were reduced at a prednisolone dose of 2.5 mg/day, with levels significantly lower at a dose of 5 mg/day, and with further decreases at doses of 7.5 mg/day or higher. We consider a negative feedback mechanism to be involved in steroid therapy-related decreases in the levels of DHEAS and ACTH. While we observed significant differences in levels of DHEAS, there were no significant differences in ACTH levels related to steroid dose, possibly because there was circadian variation in ACTH[1] and because samples were not collected at a specific time point (samples were collected between 08:30 and 11:00 h). Another study has reported that steroid therapy reduces the responsiveness of ACTH to hypoglycemic stress stimuli, although the function of ACTH is maintained.[14] Many of our subjects visited our hospital as outpatients from distant areas by train or bus, which may have influenced ACTH levels as a result of physical activity.[15] In addition, mental stress and increases in interleukin-6 and tumor necrosis factor-α may influence the ACTH level.[1,10] These factors may have contributed to no steroid dose related differences being noted in the ACTH levels, which differed from our results for DHEAS levels.

A previous study has reported that blood DHEAS levels are constant during clinical courses.[8] However, in our study, some of our patients showed changes in ACTH and DHEAS levels, although the steroid dosage was not changed. This may be related to physical or mental stressors, including increased RA activity.[10,16–19] Concerning the relationship between stress and hormones, Nishikaze and colleagues hypothesized that urinary 17-hydroxycorticosteroid (17OHCS mg/g Cr.) and 17-ketosteroid sulfates (17KS-S mg/g Cr.), respectively, reflect the level of stress and recovery ability, and reported that the level of stress and the ability to cope with stress can be assessed by measuring these two urinary hormones.[20–22] Briefly, 17OHCS levels increase in the alarm reaction and resistance phases of Syle's general adaptation syndrome.[23] In the exhaustion phase, the 17OHCS and 17KS-S levels decrease. In the recovery phase, the 17KS-S level increases. We previously reported that the level of stress could be evaluated by measuring urinary levels of 17OHCS and 17KS-S in patients with RA.[24] Urinary 17OHCS is a metabolite of blood cortisol, and 17KS-S is a metabolite of blood DHEA(S).[20] In the presence of ACTH stimulation, cortisol is secreted by the adrenal cortex. We consider that the level of stress in patients with RA and their recovery ability can be evaluated by measuring ACTH and DHEAS levels, and urinary levels of 17OHCS and 17KS-S. Based on Syle's general adaptation syndrome, it is considered that the levels of ACTH and cortisol may increase in the alarm reaction and resistance phases. However, we speculate that when ACTH stimulation shifts to cortisol in these phases, there may be no change or a reduction in DHEAS levels.[9,25] In the exhaustion phase, the adrenal gland function appears to become inhibited, with cortisol and DHEA levels decreasing despite an increase in ACTH levels. In addition, when functional disorders of the hypothalamic-pituitary-adrenocortical (HPA) system occur, the levels of ACTH and DHEAS decrease.[26] Increases in ACTH and decreases in DHEAS were observed in cases of adrenal hypofunction.[1] In this study, as was reported by Hall et al.,[19] DHEAS was not

correlated with ESR or CRP. However, some studies have found correlations between DHEAS and these parameters.[27,28] We speculate that DHEAS levels are increased in patients with marked inflammatory responses, involving ESR and CRP, in the resistance phase described by Syle.[9,10] Thus, the measurement of ACTH and DHEAS may be useful for evaluating HPA system function and stress.

An association between blood levels of DHEAS and osteoporosis has also been suggested,[4,29,30] and it has been suggested that DHEA intake helps prevent osteoporosis.[31-33] On the other hand, it has been reported that prednisolone at doses of more than 5 mg/day may increase the risk of osteoporosis.[34,35] This was supported by the results of our study. In short, DHEAS levels in patients receiving prednisolone at 7.5 mg/day or higher are lower than in those who receive 5 mg/day, thus increasing the risk of osteoporosis.[36] We therefore consider DHEAS may be a possible blood marker of osteoporosis in patients with RA. Dehydroepiandrosterone sulfate levels in the 45 patients not on steroid therapy are presented in Fig. 3. There was a marked variation in DHEAS levels. In patients with decreases in DHEAS, adrenal function may have been reduced. In this group with decreases in the DHEAS levels, adrenal hypofunction may have been associated with the various factors described above. Prior to steroid therapy, adrenal function in patients with RA should be evaluated by measuring blood levels of ACTH and DHEAS.

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ORIGINAL ARTICLE

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A biomechanical study of activities of daily living using neck and upper limbs with an optical three-dimensional motion analysis system

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Abstract In activities of daily living such as eating meals, the neck and upper limbs move in coordination. However, no methods have been established to analytically and quantitatively capture motion of the neck and limbs during these activities. We used a Vicon 512 system to simultaneously measure ranges of motion (ROMs) for the cervical spine, shoulders, elbows, and forearms. Correlations between the motion analyzer and the universal goniometer were >0.76. Repeatability of measurements using this analyzer were ≤3° for all values. This system is thus highly accurate and can be useful for motion analysis of the neck and upper limbs. The sum of flexion angles for the cervical spine, shoulders and elbows were almost constant for each activity, at 261° for shampooing, 207° for washing the face, and 185° for eating a meal.

Key words Daily activity · Neck movement · Three-dimensional (3D) motion analysis · Upper limb movement · Vicon

Introduction

In activities of daily living that use the upper extremities, such as eating meals, washing the face, and shampooing, the neck and upper limbs move in coordination. Conversely, if part of this coordinated system is impaired, compensatory movement of the other components will be indispensable for accomplishing activities. However, disability of the upper limb and neck is evaluated by functional assessment, mainly by measuring range of motion (ROMs) for each joint and assessing typical activities of daily living using a questionnaire. Data obtained using these methods are therefore subjective, static and nonanalytical.

With recent rapid advances in computer technology, motion analysis using optical three-dimensional (3D) motion analyzers has become more sophisticated and has seen application in various fields including gait analysis, computer graphics, and computer game animation.[1–4] To the best of our knowledge, no previous reports have examined systems evaluating combined motion of the neck and upper limbs.[5–7] This kind of technology would seem applicable to quantitative analysis of motions of the neck and upper limbs. The purpose of the present study was thus to assess the reliability of using a motion analyzer and to analyze the neck and upper limb motion during activities of daily living in a healthy volunteer. Analysis of neck and upper limb motion during activity would help in the formation of reconstruction plans appropriate for the individual condition of patients with joint deterioration.

Material and methods

System overview

The Vicon 512 system (Vicon Peaks, CA, USA) was used as an optical 3D motion analyzer. This system was placed in the rehabilitation room of our institution. Markers comprising inflated light-reflective plastic balls (diameter, 25 mm) were attached to the skin of the subject. Marker motions were tracked and captured on charge-coupled device (CCD) cameras, and visualized on a computer display. Based on these data, each joint motion was calculated automatically on a Vicon 4.5 workstation.[8]

Individual markers were placed at 23 points as designated by the manufacturer (Fig. 1 and Table 1): head, 4

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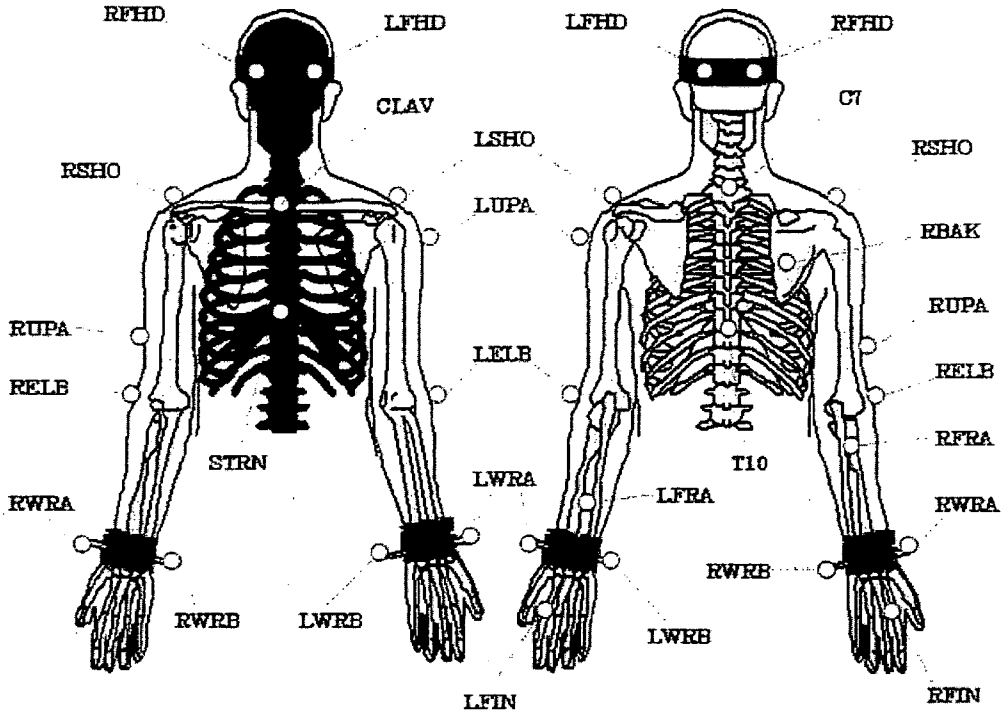

Fig. 1. Marker arrangement designated by Vicon. *Abbreviations*: see Table 1

Table 1. Marker configuration defined by Vicon

Marker name	Definition
LFHD	Left front head
RFHD	Right front head
LBHD	Left back head
RBHD	Right back head
C7	7th cervical vertebrae
T10	10th thoracic vertebrae
CLAV	Clavicle
STRN	Sternum
RBAK	Right back
LSHO	Left shoulder marker
LUPA	Left upper arm marker
LELB	Left elbow
LFRA	Left forearm marker
LWRA	Left wrist marker A
LWRB	Left wrist marker B
LFIN	Left fingers
RSHO	Right shoulder marker
RUPA	Right upper arm marker
RELB	Right elbow
RFRA	Right forearm marker
RWRA	Right wrist marker A
RWRB	Right wrist marker A
RFIN	Right fingers

markers; trunk, 5 markers; and each upper limb, 7 markers. As markers were light and did not require a power or light source such as a light-emitting diode, subjects were able to move naturally. Six CCD cameras were placed around each subject, with four cameras placed at a height of 3 m, and the remaining two cameras placed at a height of 1 m to capture the front of the thoracic region (Fig. 2). Sampling frequency of the cameras was 60 Hz.

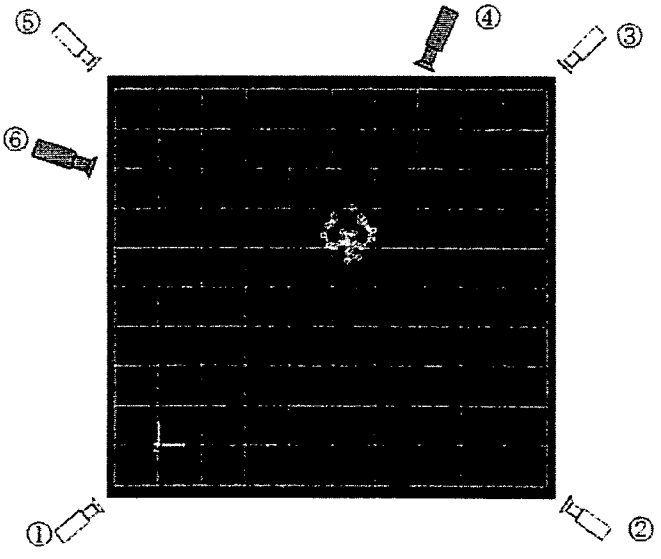

Fig. 2. Top view of set-up for this study

Evaluation of accuracy

Performance and accuracy of the Vicon 512 system has been confirmed previously.[9,10] However, in clinical trial, while moving skin markers during various motions a deterioration in the accuracy can occur. Therefore, the first part of the study assessed the accuracy of the motion analyzer on neck and upper limb motions in a clinical setting.

Subjects comprised five healthy volunteers (3 women, 2 men). Mean subject age was 23 years (range, 20–28 years). Ranges of motion examined were cervical spine flexion and

extension, shoulder flexion, elbow flexion and extension, and forearm pronation and supination. The following two examinations were performed. First, maximum ROMs were examined by comparing angles calculated using the analyzer with those measured using a conventional universal goniometer (Minato Medical Science, Osaka, Japan). In the analysis of differences between two methods the correlation coefficient was used and P values were adjusted with Pearson's correlation coefficient test. The level of significance was set at a P value of 0.05 or less. Next, the error of this system consisted of standard deviations of calculated maximum ROMs by repeating all measurements three times. Makers were reapplied between each measurement. Repeatability in measurements of ROMs were examined by comparing the error of the analyzer with those of the conventional universal goniometer.

Analysis of motions in activities of daily living

Three motions were studied using the same five volunteers participated in the evaluation of accuracy: eating a meal, washing the face, and shampooing. The motions were not actually performed, but were acted out. Points of maximum angle in cervical spine flexion, shoulder flexion, and elbow flexion were measured during these activities, and relationships between each maximum angle were then analyzed.

Results

Maximum angle of each joint measured by the motion analyzer and universal goniometer are summarized in Table 2. The correlation coefficient was >0.76 for all values (range, 0.76–0.94). Correlation between the motion analyzer and universal goniometer was very high for cervical flexion (0.90), shoulder flexion (0.94), and elbow flexion (0.91). P values with Pearson's correlation coefficient test were less than 0.05 at all angles.

Error of measurements using the analyzer was examined by looking at differences in three repeated measurements (Table 3). Standard deviations of values were ≤3° for all values (range, 0.78–2.56°). Repeatability was very high for shoulder flexion (0.78°) and elbow extension (0.89°).

The system was next used to analyze motions for shampooing, washing the face, and eating a meal. Figure 3 shows the motion analysis for shampooing in a healthy volunteer (Case 1). When shampooing, the neck and upper limbs move in coordination, not separately. In Case 1, shampooing required 39° of flexion for the cervical spine, 61° of flexion for the shoulder, and 135° of flexion for the elbow. Maximum angles of flexion measured during these activities for the cervical spine, shoulder, and elbow are shown in Table 4. Maximum angle of flexion for each joint was almost constant for the three activities. The elbow required maximum elbow flexion for all activities, at 151° for shampooing, 140° for washing the face, and 146° for eating a meal. Conversely, the angle of flexion for the cervical spine varied for different activities, at 46° for shampooing, 16° for washing the face, and −8° for eating a meal. As maximum flexion angle for each joint was almost constant for these three activities, the sum of cervical spine, shoulder, and elbow flexions was defined as the total flexion angle (Table 5). Total flexion angle was almost constant for the three activi-

Table 2. Correlation between maximum angle of each joint measured using the Vicon 512 system and the universal goniometer

	Motion analyzer	Goniometer	γ
Cervical			
Flexion	47	50	0.90
Extension	64	56	0.89
Shoulder			
Flexion	161	160	0.94
Elbow			
Flexion	175	161	0.91
Extension	6	6	0.83
Forearm			
Pronation	75	76	0.76
Supination	100	93	0.78

γ, correlation coefficient

Table 3. Mean and standard deviations of maximum ranges of motion using the motion analyzer for three repeated measurements

		Mean	SD
Cervical	Flexion	47	2.03
	Extension	64	2.56
Shoulder	Flexion	161	0.78
Elbow	Flexion	175	1.81
	Extension	6	0.89
Forearm	Pronation	75	2.35
	Supination	100	2.12

Table 4. Maximum flexion angle measured during shampooing, washing the face and eating a meal for the cervical spine, shoulder and elbow flexion

	Shampooing	Washing the face	Taking a meal
Cervical			
Flexion	46 ± 10	16 ± 7	−8 ± 13
Shoulder			
Flexion	64 ± 9	50 ± 7	43 ± 6
Elbow			
Flexion	151 ± 9	140 ± 5	146 ± 5

Numbers are shown in degrees

Table 5. Sum of cervical spine, shoulder and elbow flexion (defined as total flexion angle) for shampooing, washing the face and eating a meal

Case	Shampooing	Washing the face	Taking a meal
1	244	215	195
2	288	209	186
3	242	202	181
4	264	199	172
5	264	209	194
Total flexion angle	261 ± 18	207 ± 8	185 ± 10

Numbers are shown in degrees

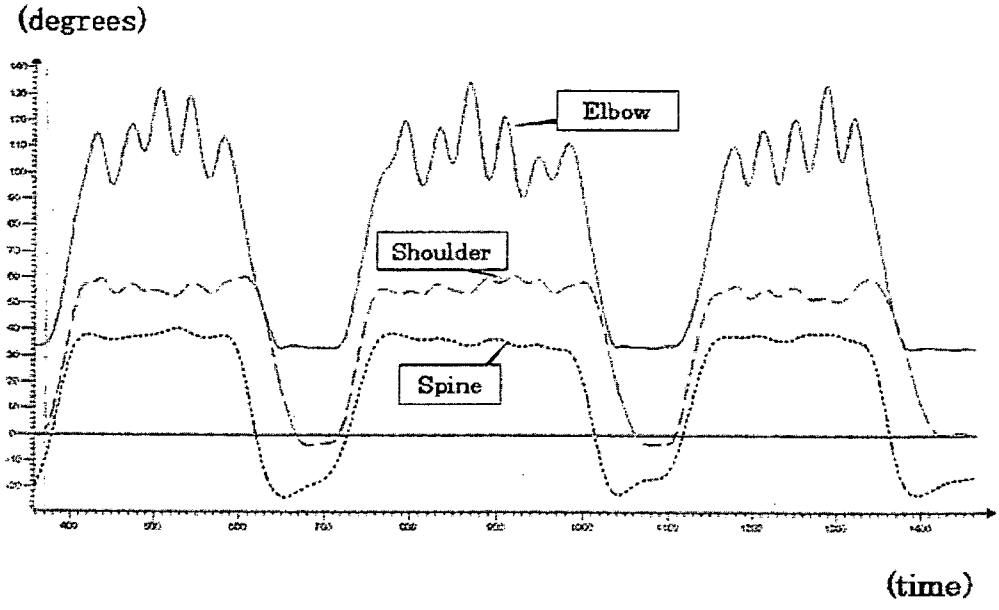

Fig. 3. Joint angles at cervical spine and upper limbs for shampooing in a healthy volunteer (Case 1)

ties, at 261° for shampooing, 207° for washing the face, and 185° for eating.

Discussion

Range of motion is typically evaluated using the universal goniometer. This method is simple, but large interexaminer differences can occur and simultaneous evaluation of multiple joints is not possible. While electrogoniometers are able to measure ROMs for multiple joints simultaneously, accuracy is considered low because of the bulkiness of the equipment.[11–13]

Electromagnetic motion analysis and optical 3D motion analysis systems are used for measurement of ROMs for multiple joints simultaneously. Both systems use markers for taking measurements and are highly accurate.[9,10] However, when markers are placed on the skin, accuracy may suffer because of skin motion.[2,5,14–20] In addition, the electromagnetic motion analysis system has a limited measuring area and metal can distort the magnetic field, while optical 3D motion analysis allows measurement of a wide area, but markers are sometimes measured incorrectly.

Accuracy of the Vicon 512 system has been evaluated using a gait analysis, revealing a high degree of accuracy.[9,10] As this system has not previously been used to evaluate movement of the neck and upper limbs, we assessed the accuracy of the system for movements of the neck and upper limbs. Error in measurements of ROMs for the neck and upper limbs using a universal goniometer have been reported in several studies.[21–26] A goniometric error at the elbow of 2.4°–3.4° was reported by Fish and Windgate.[21] In the present study, repeatability of the analyzer was examined by looking at differences over three repeated measurements. Standard deviation of the values was between 0.78° and 2.56°, almost equal to the standard deviation of measurements using a conventional goniometer. Next, maximum ROMs were examined by comparing angles calculated using this analyzer with those measured using a conventional goniometer. Correlation coefficient between the analyzer and goniometer was examined. Generally, a correlation coefficient >0.9 is very high, while <0.69 is considered low.[27] In this study, correlation coefficient between the analyzer and goniometer was >0.69 for all values. Maximum ROMs examined using this analyzer and the goniometer were closely correlated. The Vicon 3D motion analysis system thus appears useful for evaluating motion of the neck and upper limbs.

In activities of daily living that use the upper extremities, such as shampooing, washing the face, and eating, the neck and upper limbs move in a coordinated manner. Flexion angle for the shoulder and elbow in the three activities is almost constant, with the elbow requiring a maximum flexion angle for all activities. On the other hand, flexion angle for the cervical spine varies with different activities. The necessary angle of flexion for each activity varies for each joint. As the maximum angle of flexion for each joint was almost constant for each activity, the sum of the cervical spine, shoulder, and elbow flexion, defined as total flexion angle, was almost constant for the three activities, at 261° for shampooing, 207° for washing the face, and 185° for eating. The total flexion angle is suspected of having a minimum cumulative flexion angle to achieve the three activities. In this study shoulder abduction, rotation of forearm, and wrist flexion were not assessed, as the maximum angle varies over time. As these motions have a close relation to each activity, we intend to evaluate them in future.

For patients with multiple joint deterioration as in rheumatoid arthritis, surgical reconstruction is performed according to evaluation of each lesion, and this sometimes results in unsatisfactory improvements of disability. One reason for this is that the neck, shoulder, elbow, forearm, and wrist are not recognized as interrelated functional units. Analysis of impairments of neck and upper limb lesions in multiple arthropathies as changes in functional units

would enable us to determine appropriate multiple joint reconstruction plans to achieve maximum improvement in activities.

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Open-Door Laminoplasty for Cervical Myelopathy Resulting From Adjacent-Segment Disease in Patients With Previous Anterior Cervical Decompression and Fusion

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Study Design. This is a retrospective study of patients with cervical myelopathy resulting from adjacent-segment disease who were treated by open-door expansive laminoplasty.

Objectives. The purpose of this study was to evaluate the effectiveness of laminoplasty for cervical myelopathy resulting from adjacent-segment disease.

Summary of Background Data. Adjacent-segment disease is one of the problems associated with anterior cervical decompression and fusion. However, the optimal surgical management strategy is still controversial.

Methods. Thirty-one patients who underwent open-door expansive laminoplasty for cervical myelopathy resulting from adjacent-segment disease and age- and sex-matched 31 patients with myelopathy who underwent laminoplasty as the initial surgery were enrolled in the study. The pre- and postoperative Japanese Orthopedic Association scores (JOA scores) and the recovery rate were compared between the two groups.

Results. The average JOA scores in the patients with adjacent-segment disease and the controls were 9.2 ± 2.6 and 9.4 ± 2.3 before the expansive laminoplasty and 11.9 ± 2.8 and 13.3 ± 1.7 at the follow-up examination, respectively; the average recovery rates in the two groups were 37.1 ± 22.4% and 50.0 ± 21.3%, respectively ($P = 0.04$). The mean number of segments covered by the high-intensity lesions on the T2-weighted magnetic resonance images was 1.87 and 0.9, respectively ($P = 0.001$).

Conclusions. Moderate neurologic recovery was obtained after open-door laminoplasty in patients with cervical myelopathy resulting from adjacent-segment disc disease, although the results were not as satisfactory as those in the control group. This may be attributed to the irreversible damage of the spinal cord caused by persistent compression at the adjacent segments.

Key words: open-door expansive laminoplasty, adjacent-segment disease, cervical myelopathy, anterior cervical decompression and fusion. **Spine 2006;31:1332–1337**

Anterior cervical decompression and fusion (ACDF) is an effective and widely used surgical procedure for degenerative diseases or trauma of the cervical spine. The short-term surgical outcome of this procedure has been reported to be satisfactory in a majority of the patients. However, degeneration of the intervertebral discs adjacent to the fused segments could be accelerated after ACDF, causing symptoms such as neck pain, radiculopathy, and myelopathy.[1–6] Hilbrand *et al*[5] reported the results of a long-term follow-up study conducted on 374 consecutive patients who underwent anterior cervical arthrodesis for cervical spondylosis with radiculopathy, myelopathy, or both. They found that symptomatic adjacent-segment disease occurred at a relatively constant incidence of 2.9% per year during the 10 years after the operation, and that symptomatic adjacent-segment disease affected more than one fourth of all the patients within 10 years after anterior cervical arthrodesis. Ishihara *et al*[6] reported the development of symptomatic adjacent-segment disease in 19 of 112 patients (19%). Thus, much effort has been directed toward preventing adjacent-segment disease, including that which led to the recent development of artificial cervical discs.[7]

Among the various manifestations of adjacent-segment disease, cervical myelopathy is one of the most problematic, and the optimal management strategy for this complication remains controversial. Repeated fusion surgery may be effective but can result in further adjacent-segment lesions and, according to Hilibrand *et al*,[8] achieving fusion is more difficult when anterior cervical arthrodesis is performed for segments adjacent to a prior fusion. Moreover, scars in the anterior neck involving the esophagus and internal carotid artery and vein make a repeated anterior approach to the cervical spine hazardous and complicated.[9] Therefore, a posterior approach would seem to be more reasonable for dealing with cervical myelopathy resulting from adjacent-segment disease.

Open-door expansive laminoplasty (ELAP) developed by Hirabayashi *et al*[10] is believed to expand the whole cervical spinal canal and to spare but restrain intersegmental motion of the cervical spine. This surgical method has been widely used for the treatment of cervical compression myelopathy caused by spondylosis, soft disc herniation, and ossification of the posterior longitudinal ligament.[11–13] The advantages and disadvantages of the treatment of cervical compression myelopathy in patients without previous surgery have been frequently

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Table 1. Demographics of Patients

Group	Group A	Group B
Age (years) (range)	60 (39–83)	58 (42–77)
Gender		
Male	26	26
Female	5	5
Interval between ACDD and ELAP (range)	12 y 3 m (1 y 4 m to 36 y 11 m)	—
No. of fused levels		
Single	12	
Two	14	—
Three	5	

ACDF indicates anterior cervical decompression and fusion; ELAP, expansive laminoplasty.

discussed; however, reports of treatment in those who have undergone previous ACDF have been rather scarce. The purpose of this study was to elucidate the effectiveness of ELAP for cervical myelopathy resulting from adjacent-segment disease by a retrospective review of the surgical outcomes for this condition.

■ Materials and Methods

Thirty-one patients with a history of previous ACDF who underwent ELAP for cervical myelopathy resulting from adjacent-segment disease were enrolled in this study (group A) (Table 1). There were 26 males and five females with a mean age of 60 years (range: 39–83 years) and a mean follow-up duration after ELAP of 45 months (range: 25–60 months). The average interval between the ACDF and ELAP was 12 years 3 months (range: 1 year 4 months to 36 years 11 months). Fusion was conducted at a single level in 12 patients (C3–C4 in one, C4–C5 in four, C5–C6 in seven patients), over two levels in 14 patients (C3–C5 in two, C4–C6 in five, and C5–C7 in seven patients), and over three levels in five patients (C3–C6 in one and C4–C7 in four patients). Twenty-nine patients had undergone ACDF once, whereas two patients had undergone the surgical procedure twice as a result of a history of adjacent-segment disease. The ACDF had been performed at our hospital in 26 patients and at other hospitals in five patients. The indications for ACDF included disc herniation in 14 patients, spondylotic myelopathy in 15 patients, and spinal injury in two patients. The preoperative symptoms before ACDF were myelopathic symptoms in 24 patients, nonmyelopathic symptoms in five patients, and unknown in two patients. The adjacent lesions were spondylosis in 27 patients and disc herniation in four patients, and they occurred in the superior segment in 21 patients and in the inferior segment in 10 patients. Thirty-one age- and sex-matched patients with cervical spondylotic myelopathy who underwent ELAP during the same period, who gave no history of surgery on the cervical spine, were enrolled as controls (group B; 26 males, five females; mean age: 58 years). Matching was made by a third person who had no information on the patients, by choosing 31 of 108 patients who underwent ELAP, who were stratified by the age group and gender.

ELAP was performed from C3–C7 according to the method originally reported by Hirabayashi *et al*[10] with some modifications. Because two or three adjacent laminae showed osseous fusion at the levels of the ACDF, they were opened up en bloc after making a gutter on the hinge side and cutting the laminae on the open side. A single stay suture was placed on a block of laminae and also on the paravertebral muscles around the laminae, and the block of laminae was held open by tying the suture. Adhesions between the laminae and the dura matter did not compromise the decompression procedure in any of the patients. The open side was usually on the left side and the hinge side was on the right unless spinal cord compression was significantly more severe on the right side than on the left side.

The pre- and postoperative Japanese Orthopedic Association scores (JOA scores, Table 2)[14] and the recovery rates were compared between the two groups. The recovery rate was calculated as follows; (JOA score at follow up − preoperative JOA score)/(17 − preoperative JOA score) × 100 (%),[15] and the surgical outcomes were classified into four grades based on the calculated recovery rate; excellent: recovery rate 75% or higher, good: 50–75%, fair: 25–50%, and poor: lower than 25%. Evaluation was made on radiographic findings, including the range of motion and the jaw diameter (a measured line from the posteroinferior corner of the vertebral body to the anterior aspect of the subjacent lamina) at the adjacent levels in group A and the affected levels in group B and the spinal canal diameter at the C4 level in both groups. The C4 level was chosen for this measurement, because the spinal canal is usually narrowest at this level. On magnetic resonance imaging, the cross-sectional

Table 2. Evaluation System for Cervical Myelopathy (JOA scoring system)

Category	Score (points)
Motor function	
Upper extremity	
Unable to feed oneself with any tableware including chopsticks, spoon, or fork, and/or unable to fasten button of any size	0
Can manage to feed oneself with spoon and/or fork but not with chopsticks	1
Either chopsticks feeding or writing is possible but not practical, and/or large button can be fastened	2
Either chopsticks feeding or writing is clumsy but practical, and/or cuff button can be fastened	3
Normal	4
Lower extremity	
Unable to stand and walk by any means	0
Unable to walk without a cane or other support on a level	1
Walks independently on a level but needs support on stairs	2
Capable of fast but clumsy walking	3
Normal	4
Sensory function	
Upper extremity	
Apparent sensory disturbance	0
Minimal sensory disturbance	1
Normal	2
Lower extremity	
Apparent sensory disturbance	0
Minimal sensory disturbance	1
Normal	2
Trunk	
Apparent sensory disturbance	0
Minimal sensory disturbance	1
Normal	2
Bladder function	
Urinary retention and/or incontinence	0
Sense of retention and/or dribbling and/or thin stream and/or incomplete continence	1
Urinary retardation and/or pollakiuria	2
Normal	3

Table 3. Clinical Results

	JOA Scores			Outcome Classification			
	Preoperative	Postoperative	Recovery Rate	Excellent	Good	Fair	Poor
Group A (range)	9.2 ± 2.6 (4–14)	11.9 ± 2.8 (6–15)	37.1 ± 22.4 (0–81)*	1	11	11	8
Group B (range)	9.4 ± 2.3 (4–14)	13.3 ± 1.7 (10–16)	50.0 ± 21.3 (14–90)	4	15	7	5

*Statistically significant ($P = 0.04$).

area of the spinal cord was measured at the adjacent levels in group A and at the level at which compression of the spinal cord was maximal in group B. For the measurements, hard copies of magnetic resonance images were photographed using a high-resolution digital camera (Cybershot; Sony, Tokyo), and the cross-sectional area of the spinal cord was measured on a personal computer using the Scion software (Scion Inc., MD). The measurement was conducted twice, and the average of the two values was used for the analyses. The presence or absence of high-signal-intensity lesions on T2-weighted magnetic resonance images was also evaluated.

Statistical Methods. Statistical analyses were conducted using the SPSS software (SPSS Japan Inc., Tokyo). χ^2 test or Mann-Whitney U was used for categorical or ordinal data, and the t test and analysis of variance (ANOVA) were used for interval data with normal distribution.

In all tests, a P value of less than 0.05 was considered to denote statistical significance.

■ Results

Clinical Outcomes

The average JOA scores in group A and group B were 9.2 ± 2.6 and 9.4 ± 2.3 before the ELAP and 11.9 ± 2.8 and 13.3 ± 1.7 at the follow-up examination, respectively, and the average recovery rates in the two groups were 37.1 ± 22.4% and 50.0 ± 21.3%, respectively (Table 3). Thus, the recovery rate in group A was significantly lower than that in group B ($P = 0.04$; unpaired t test). Clinical results of group A and group B were classified into excellent in one patients (3.2%) and four patients (12.9%), good in 11 (35.5%) and 15 (48.4%), fair in 11 (35.5%) and seven (22.6%), and poor in eight (25.8%) and five (16.1%), respectively. In regard to stratification of the recovery rates according to diagnosis before ACDF in group A, the rate was 41.1 ± 21.5% in cases with soft disc herniation, 35.9 ± 23.0% in cases of spondylotic myelopathy, and 20.8 ± 29.4% in cases of spine injury ($P = 0.48$, ANOVA). A weak correlation was observed between the recovery rate and the interval between the initial ACDF and the ELAP (correlation coefficient, 0.33, $P = 0.062$).

Complications associated with ELAP included postoperative hematoma with the development of quadriplegia in one patient from group A, which was treated by emergency revision surgery, and C5 palsy in one patient from group B. Although neck pain was not a major problem in either group before the ELAP, one patient from group A and two patients from group B experienced intractable axial pain after ELAP, which necessitated the use of nonsteroidal antiinflammatory drugs.

Radiologic Findings

The mean preoperative anterior–posterior diameter at the C4 vertebral level was 12.7 ± 1.4 mm in group A and 13.7 ± 1.2 mm in group B ($P = 0.03$, unpaired t test) (Table 4). The mean angular motion at the adjacent levels in group A was 10.5 ± 5.6 degrees before the ELAP and decreased significantly to 7.0 ± 6.6 degrees at the follow-up evaluation ($P = 0.008$, paired t test). The preoperative angular motion *and* the jaw diameter at the adjacent levels in group A and at the affected levels in group B was not significantly different ($P = 0.66$ and 0.15, respectively, unpaired t test). On magnetic resonance imaging, the mean cross-sectional area of the spinal cord at the adjacent segments in group A was 30.9 ± 12.2 cm^2 and at the most compressed level in group B was 31.2 ± 9.0 cm ($P = 0.95$, unpaired t test). High-intensity lesions in the spinal cord were observed on the T2-weighted magnetic resonance images in 30 of the 31 patients (97%) in group A and in 27 of the 31 patients (87%) in group B ($P = 0.35$, χ^2 test). The mean number of segments covered by the high-intensity lesions on the T2-weighted magnetic resonance images was 1.87 (range: 0–5) in group A and 0.9 (range: 0–2) in group B ($P = 0.001$, Mann-Whitney U test).

Table 4. Radiologic Findings

	Spinal Canal Diameter (mm)	Jaw Diameter (mm)	Angular Motion of Affected Segment (degree)		Spinal Cord Area (mm^2)	T2 High-Intensity Lesion	
			Preoperative	Postoperative		No. of Patients	No of Levels (range)
Group A	12.7 ± 1.4*	12.7 ± 2.1	10.5 ± 5.6	7.0 ± 6.6	30.9 ± 12.2	30 (97%)	1.87 (0–5)†
Group B	13.7 ± 1.2	11.7 ± 2.7	9.8 ± 6.0	4.7 ± 5.1	31.2 ± 9.9	27 (87)	0.9 (0–2)

*$P = 0.03$.
†$P = 0.001$.

■ Discussion

There have been numerous studies regarding the choice of surgical methods for patients with cervical compressive myelopathy undergoing initial decompression surgery.[16–19] Some authors recommend ACDF, whereas others recommend ELAP or laminectomy with or without instrumentation. Yonenobu *et al*[19] and Wada *et al*[17] found no significant differences in the clinical results between patients treated by ACDF and those treated by ELAP. Edwards *et al*[18] compared the clinical results and complications of multilevel corpectomy and laminoplasty, and found that both the surgical methods reliably arrested the progression of myelopathy in cases with multilevel cervical myelopathy. However, because the patients treated by laminoplasty required less pain medication at follow up and experienced fewer complications, they believed that laminoplasty might be the preferred method of treatment for multilevel cervical myelopathy in the absence of preoperative kyphosis.

In contrast to the abundance of studies on the initial surgical treatment for cervical spondylotic myelopathy, those on cervical myelopathy developing at the adjacent segments after ACDF have been rather scarce, and no consensus has been evolved until now as to the optimal treatment method for this pathologic condition. Baba *et al*[20] reported 18 patients with myeloradiculopathy who had undergone expansive laminoplasty after ACDF; they found that the neurologic improvement was excellent in four patients, good in six cases, fair in four cases, and poor in four cases. Because more than half of their patients had a narrow spinal canal on radiograph, they recommended laminoplasty for revision surgery. Wang *et al*[21] reported 24 patients with failed ACDF who were treated by laminoplasty. They concluded that laminoplasty was the most straightforward and effective treatment strategy for failed ACDF. However, their study included not only patients with adjacent-segment disease, but also those with inadequate anterior decompression surgery; therefore, the effects of ELAP purely on patients with adjacent-segment disease could not be clearly demonstrated in that study.

On the other hand, Hilibrand *et al*[8] performed ACDF in 38 patients with adjacent-segment disc disease and found that firm arthrodesis was achieved in only 63% of the patients treated by discectomy with interbody grafting at one or more levels, whereas it was achieved in 100% of the patients treated by corpectomy with strut grafting. However, because the patients' symptoms were not clearly described in that report, it is unknown how many patients had myelopathy before revision surgery and to what extent postoperative improvement in myelopathy had been achieved. Ishihara *et al*[6] reported five cases with cervical myelopathy at an adjacent segment, of whom three were treated by ACDF and two by ELAP. In both groups, good to excellent surgical outcomes were obtained.

In the present study, moderate recovery could be achieved after ELAP in patients with cervical myelopathy resulting from adjacent-segment disc lesions. However, the recovery rate was not as satisfactory as that in the control group (37% versus 50%). This may be attributed to the irreversible damage of the spinal cord caused by persistent compression at the adjacent segment, which was suggested by the fact that the T2 high-intensity lesions of the spinal cord extended over a larger area in group A than in group B (Figure 1). Although not statistically significant, the interval between ADCF and ELAP was weakly correlated with the recovery rates. Therefore, patients undergoing ACDF should be followed up periodically, and at the first sign of neurologic deterioration, they should be promptly treated by decompression surgery.

ELAP may be one of the most suitable options for decompression surgery, because it can expand the cervi-

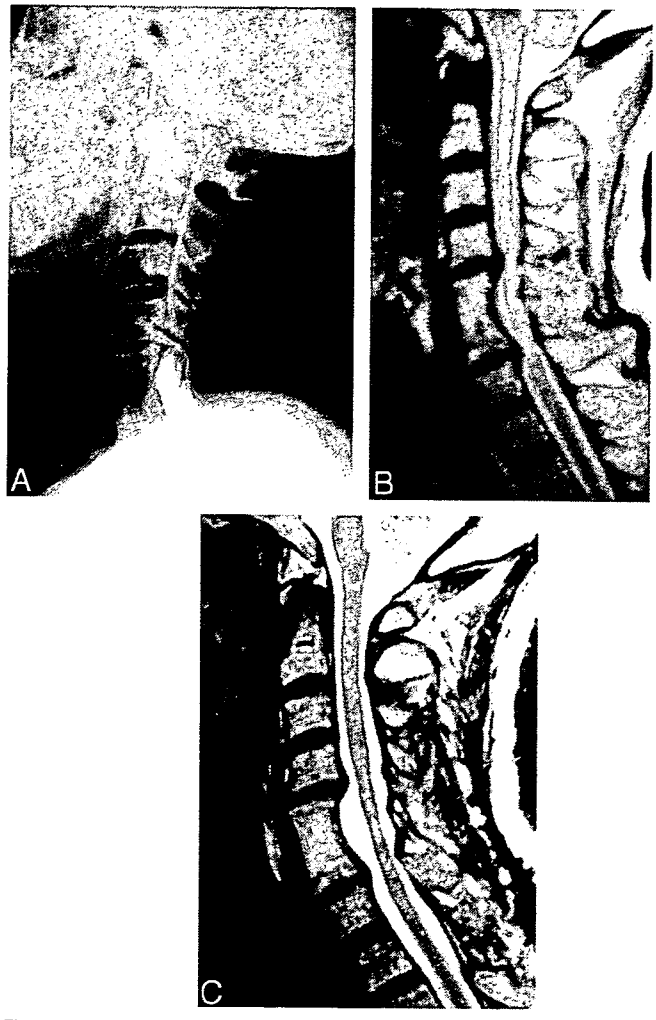

Figure 1. A 57-year-old man had undergone anterior cervical decompression and fusion (ACDF) at C5–C6 for cervical myelopathy resulting from soft disc herniation 17 years before. He had recurrence of cervical myelopathy and underwent expansive laminoplasty with improvement of his symptoms (clinical outcome; good). **(A)** Preoperative myelogram. **(B)** Preoperative magnetic resonance image (T2-weighted sagittal image). **(C)** Postoperative magnetic resonance image (T2-weighted sagittal image). Decompression of the spinal cord was good, whereas the T2 high-intensity area spread widely from the segment of ACDF to the upper and lower adjacent segments.

cal spinal canal and stabilize the motions of the adjacent segments and, thereby, allow further surgery to be avoided (Figure 2). In this study, the patients in group A had a significantly narrower spinal canal than those in group B. The angular motions at the adjacent segments were significantly decreased after ELAP in group A, indicating that ELAP effectively restrained the excessive motions of the adjacent segments.

There are, however, several limitations to this study. First, we did not compare the results of ELAP with those of ACDF for cervical myelopathy resulting from adjacent-segment disc disease. Therefore, we could not arrive at any definitive conclusion as to whether ELAP or ACDF would be the more favorable surgical option for this pathologic condition. This comparison remains to be conducted in the future, preferably in a prospective study. However, the present study was the first to be conducted on at least a moderate number of patients with myelopathy caused by adjacent-segment disease treated by ELAP and demonstrated the effectiveness and limitations of ELAP in these patients. Second, the interval between the initial ACDF and ELAP ranged widely between 1 year 4 months and 36 years 11 months. Adjacent-segment disease developing more than 30 years after ACDF may be debated as being the result of the normal aging process rather than actually representing adjacent-segment disease. Gore *et al*[22] comparatively reviewed the lateral cervical roentgenograms of 90 patients who had undergone ACDF with those of age- and sex-matched controls. The average interval from surgery to the review was 5 years. They found no difference in the incidence of degenerative changes between the operated and the control group at levels above and below the fusion with the exception of anterior entophyte formation in the ACDF group. Thus, a clear definition of adjacent-segment disease should be established, including a consideration of the appropriate interval after the ACDF and the severity of symptoms and radiologic findings.

In conclusion, ELAP, which expands the whole spinal canal and restrains the motions of the adjacent segments, is a moderately effective surgical option for cervical myelopathy developing in adjacent segments after ACDF.

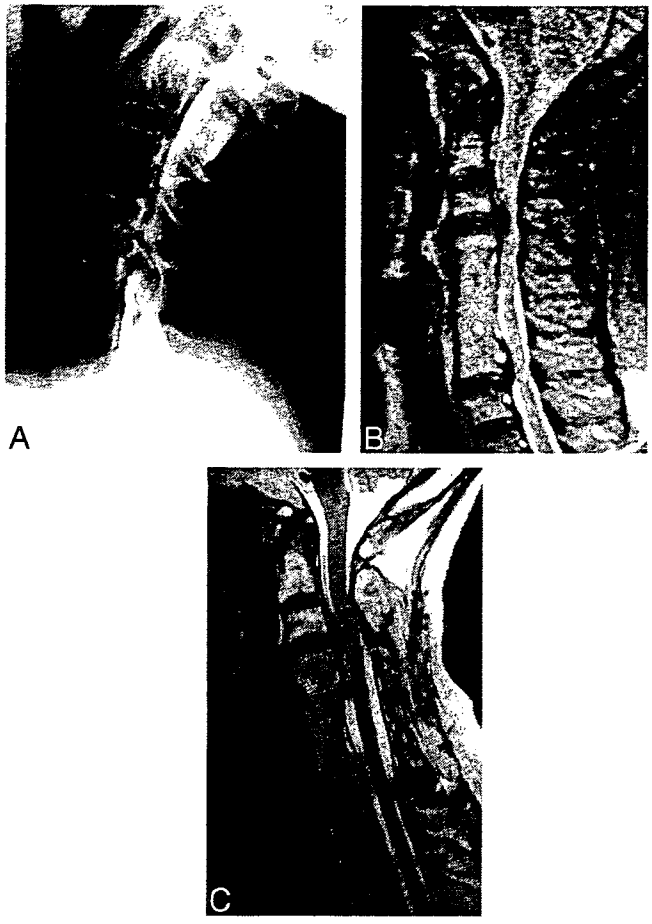

Figure 2. A female patient had undergone anterior cervical decompression and fusion (ACDF) from C5–C7 for cervical myelopathy resulting from soft disc herniation when she was 58 years old. She developed another disc herniation at C4–C5 2 years later and had ACDF again. At the age of 66 years, she developed cervical myelopathy again resulting from disc herniation at the adjacent segment (C3–C4), which was treated by expansive laminoplasty from C3–C7. She had moderate neurologic recovery after surgery (pre- and postoperative JOA scores 10 and 14, respectively). **(A)** Myelogram before the second surgery. **(B)** Magnetic resonance image before ELAP (T2-weighted sagittal image). **(C)** Magnetic resonance image at 9 years after ELAP (T2-weighted sagittal image). Although disc herniation at C3–C4 was still present, the spinal cord was nicely decompressed.

■ Key Points

- Moderate neurologic recovery was obtained after open-door laminoplasty in patients with cervical myelopathy resulting from adjacent-segment disease.
- The results were not as satisfactory as those in the patients without previous anterior cervical decompression and fusion.
- Open-door laminoplasty is considered to be one of the ideal surgical options to expand the cervical spinal canal and simultaneously stabilize the movements of the adjacent segments.

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新しい医療技術

環椎外側塊スクリュー

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要旨：環椎外側塊スクリューは環軸椎固定および環椎-中下位頚椎再建の固定アンカーとして有用である。椎骨動脈に対するリスクはMagerl法より低いと考えられる。また，Magerl法に勝る他の利点として，スクリュー刺入後でも環軸椎配列異常の矯正が可能であることが挙げられる。スクリューの刺入方法には後弓経由と後弓基部経由があり一長一短である。

はじめに

後方経環軸椎関節スクリュー固定であるMagerl法は1990年代に入ってから世界的に普及し，最も一般的環軸椎固定方法となった。その良好な固定性が他の環軸椎固定方法をしのぐことは生体力学実験でも証明されている[1)2)]。一方，環軸椎関節スクリュー刺入に伴う椎骨動脈に対するリスクは高く，同動脈損傷の報告は少なくない[3)4)]。他の環椎の後方固定アンカーとしては，Gallie法，Brooks法，環椎後弓フックやクランプなどあるが固定力は十分とはいえない。近年，環椎外側塊スクリュー（lateral mass screw of the atlas）を固定アンカーとする環軸椎固定や頚椎固定が広まってきている。椎骨動脈に対するリスクが小さいことのほか，Magerl法と異なりスクリュー刺入後でも環軸椎間の変形矯正が可能な点も環椎外側塊スクリューを使用する大きな利点である。本稿では，環椎外側塊スクリュー固定の歴史，頚椎後方再建手術におけるその位置づけ，関連した形態学，手術手技などにつき述べる。

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Lateral mass screw of the atlas

Key words：Lateral mass, Atlas, Screw fixation

Ⅰ．環椎外側塊スクリューの歴史と位置づけ

英文の文献を検索した限りでは，環椎外側塊を固定アンカーとした頚椎再建の最初の報告は，インドの脳神経外科医であるGoelによって1994年になされた。Goelはその論文で，環椎外側塊スクリューを使用した環軸椎固定を1988年に開始したと述べている[5)]。Goelは先天奇形および外傷の30例に外側塊スクリューとプレートを使用した再建手術を行っているが，うち5例は後頭環軸椎固定であり，軸椎の固定アンカーには軸椎椎弓根スクリューを使用し，プレートで連結した（図1）。前腕骨固定用プレートを使用したのでnon-constrained typeの固定であった。軸椎椎弓根スクリュー固定の最初の報告はLeconte[6)]により1964年になされている。これは軸椎のhangman骨折の骨折部骨接合術に使用したもので，Leconte自身は椎弓根スクリューという用語を使用していないが，軸椎椎体にまで刺入しているので椎弓根スクリューと称されてよいであろう。Goelの報告はあまり注目されず，その後，Harms[7)]はpolyaxial screwを使用した環軸椎固

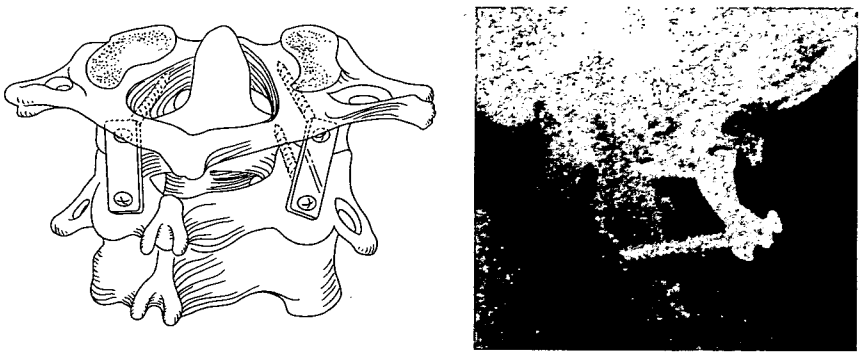

図 1　Goel による環椎外側塊スクリュー使用の環軸椎固定[1]
1994 年，Goel は環椎外側塊スクリューと軸椎椎弓根スクリューを前腕骨固定用プレートで連結する環軸椎固定法を最初に発表した。

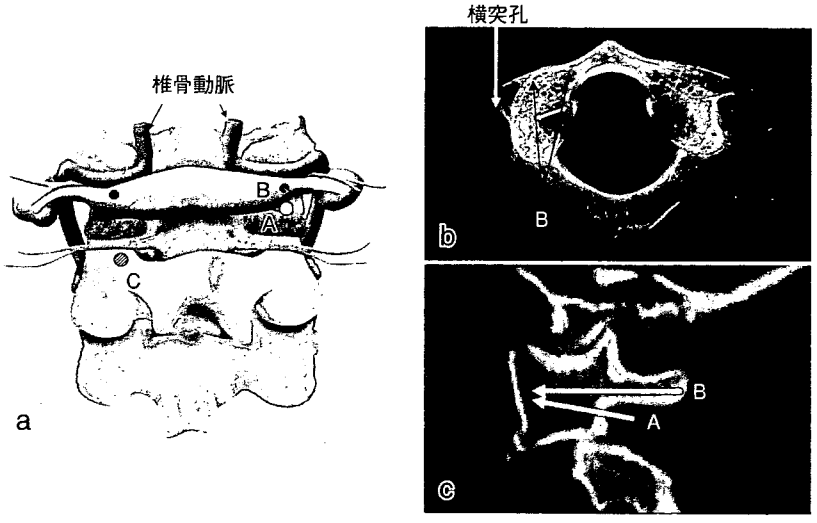

図 2　環椎と椎骨動脈の位置関係，環椎外側塊スクリューの刺入点と刺入方向
椎骨動脈は横突孔を通過した後，後内側に方向を変え，外側塊の後方で椎骨動脈溝を通って脊柱管方向に向かう。
a　A：A 点は Goel や Harms らの環椎外側塊スクリューの刺入点は後弓の基部で静脈叢を尾側によけて刺入される。B：Tan らが提唱したスクリュー刺入点で，椎骨動脈を頭側に静脈叢を尾側によけて刺入する。C：軸椎椎弓根スクリューの刺入点。
b　B 点から刺入した場合の横断面におけるスクリュー方向の許容範囲。
c　A，B 各点から刺入した場合の矢状面におけるスクリュー方向。

定の成績を報告し，環椎外側塊スクリューを使用した再建固定は広く知られるようになった。Goel はその後，彼の大きなシリーズ[8]や様々な病態への応用を報告した[9][10]。

現在，環椎外側塊スクリューを固定アンカーとする上位頚椎固定の報告の数は著しく増えている。スクリューの安全な刺入に関する工夫や関連した形態学的，生体力学研究も輩出している。ま