Table 6. Coefficient for each item of the formula for measurement scale

Item	1 Social function	2 Mental health	3 Lumbar function	4 Walking ability	5 Low back pain
Q1-1					20
Q1-2	2				
Q1-3					20
Q1-4			10		
Q1-5			10		
Q1-6			20		
Q1-7					20
Q1-8			10		
Q1-9			30		
Q1-10				30	
Q1-11					10
Q1-12				20	
Q1-13		3			
Q1-14				10	
Q2-1		−4			
Q2-2				10	
Q2-3			20		
Q2-4	4			30	
Q2-5	6				
Q2-6	10				
Q2-7		6			
Q2-8		6			
Q2-9		−3			
Q2-10		−3			
Q2-11		3			

the five factors' scores; rather, they should be treated by nonparametric analysis. The reliability of the questionnaire including 25 items for the JOABPEQ was confirmed in Part 2 of this project. The validity of the questionnaire was evaluated using factor analysis, and the measurement scale was established in Part 3 of this study. Further studies must be performed to confirm the responsiveness of the calculations of the severity score.

Conclusions

We confirmed the validity of the JOA Back Pain Evaluation Questionnaire (JOABPEQ) and established a measurement scale.

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Appendix 1. Items selected for the draft of a JOABPEQ document

With regard to your health condition during the last week, please choose the item number among the answers for the following questions that best applies as your condition varies depending on the day or time. Circle the item number when your condition is at its worst.

Q1-1 To alleviate low back pain, you often change your posture.
1) Yes
2) No

Q1-2 Because of low back pain, you do not do any routine housework these days.
1) No
2) Yes

Q1-3 Because of low back pain, you lie down more often than usual.
1) Yes
2) No

Q1-4 Because of low back pain, you sometimes ask someone to help you when you do something.
1) Yes
2) No

Q1-5 Because of low back pain, you refrain from bending forward or kneeling down.
1) Yes
2) No

Q1-6 Because of low back pain, you have difficulty standing up from a chair.
1) Yes
2) No

Q1-7 Your lower back aches most of the time.
1) Yes
2) No

Q1-8 Because of low back pain, turning over in bed is difficult.
1) Yes
2) No

Q1-9 Because of low back pain, you have difficulty putting on socks or stockings.
1) Yes
2) No

Q1-10 Because of low back pain, you walk only short distances.
1) Yes
2) No

Q1-11 Because of low back pain, you cannot sleep well. (If you take sleeping pills because of the pain, select "No.")
1) No
2) Yes

Q1-12 Because of low back pain, you stay seated most of the day.
1) Yes
2) No

Q1-13 Because of low back pain, you become irritated or angry at other persons more often than usual.
1) Yes
2) No

Q1-14 Because of low back pain, you go up stairs more slowly than usual.
1) Yes
2) No

Q2-1 How is your present health condition?
1) Excellent
2) Very good
3) Good
4) Fair
5) Poor

Q2-2 Do you have difficulty in climbing stairs?
1) I have great difficulty
2) I have some difficulty
3) I have no difficulty

Q2-3 Do you have difficulty with any one of the following motions: bending forward, kneeling, stooping?
1) I have great difficulty
2) I have some difficulty
3) I have no difficulty

Q2-4 Do you have difficulty walking more than 15 minutes?
1) I have great difficulty
2) I have some difficulty
3) I have no difficulty

Q2-5 Have you been unable to do your work or ordinary activities as well as you would like?
1) I have not been able to do them at all.
2) I have been unable to do them most of the time.
3) I have sometimes been unable to do them.
4) I have been able to do them most of the time.
5) I have always been able to do them.

Q2-6 Has your work routine been hindered because of the pain?
1) Greatly
2) Moderately
3) Slightly (somewhat)
4) Little (minimally)
5) Not at all

Q2-7 Have you been discouraged or depressed?
1) Always
2) Frequently
3) Sometimes
4) Rarely
5) Never

Q2-8 Do you feel exhausted?
1) Always
2) Frequently
3) Sometimes
4) Rarely
5) Never

Q2-9 Do you feel happy?
1) Always
2) Almost always
3) Sometimes
4) Rarely
5) Never

Q2-10 Do you think you are in reasonable health?
1) Yes (I am healthy)
2) Fairly (my health is better than average)
3) Not very much (my health is average)
4) Barely (my health is poor)
5) Not at all (my health is very poor)

Q2-11 Do you feel your health will get worse?
1) Very m uch so
2) A little bit at a time
3) Sometimes yes and sometimes no
4) Not very much
5) Not at all

Appendix 2. Measurement scale for JOABEPQ

Social life function
('Q1-2' × 2 + 'Q2-4' × 4 + 'Q2-5' × 6 + 'Q2-6' × 10 − 22) × 100 ÷ 74

Mental health
('Q1-13' × 3 + 'Q2-1' × 4 + 'Q2-7' × 6 + 'Q2-8' × 6 + 'Q2-9' × 3 + 'Q2-10' × 3 + 'Q2-11' × 3 − 28) × 100 ÷ 103

Lumbar function
('Q1-4' × 10 + 'Q1-5' × 10 + 'Q1-6' × 20 + 'Q1-8' × 10 + 'Q1-9' × 30 + 'Q2-3' × 20 − 100) × 100 ÷ 120

Walking ability
('Q1-10' × 30 + 'Q1-12' × 20 + 'Q1-14' × 10 + 'Q2-2' × 10 + 'Q2-4' × 30 − 100) × 100 ÷ 140

Low back pain
('Q1-1' × 20 + 'Q1-3' × 20 + 'Q1-7' × 20 + 'Q1-11' × 10 − 70) × 100 ÷ 70

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Original article

Japanese Orthopaedic Association Cervical Myelopathy Evaluation Questionnaire (JOACMEQ): part 4. Establishment of equations for severity scores

Subcommittee on Low Back Pain and Cervical Myelopathy, Evaluation of the Clinical Outcome Committee of the Japanese Orthopaedic Association

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Abstract

Background. To establish a patient-oriented outcome measure for cervical myelopathy, a subcommittee of the Japanese Orthopaedic Association (JOA) developed a new scoring system to evaluate the overall clinical status of patients, which could be completed by patients themselves. The subcommittee completed three large-scale studies to select and modify questions derived from various preexisting outcome measures including Short Form-36, and then finalized and validated the questionnaire, which comprised 24 questions.

Methods. The finalized questionnaire was administered to 369 patients with cervical myelopathy due to disc herniation, spondylosis, or ossification of posterior longitudinal ligament by randomly selected board-certified spine surgeons. Patients with different severities of myelopathy were included to insure accuracy and responsiveness of this questionnaire against patients' different neurological status.

Results. Data of 236 patients were employed and were subjected to rigorous statistical analyses. There was no question that was difficult to answer and distribution of answers for each question was not concentrated to one choice, indicating the appropriateness of all 24 questions. Results of factor analysis suggested that the 24 questions could be divided into five different factors or functional domains. The factors were defined as follows: factor 1, lower extremity function; factor 2, quality of life; factor 3, cervical spine function; factor 4, bladder function; and factor 5, upper extremity function. Finally, equations that would yield scores for the five factors were assembled. The score to be used to represent the degree of patients' disability or status in each domain can be calculated by multiplying prefixed numbers of selected answers to questions by preassigned coefficients. Coefficients were defined to make the minimum score 0 and the maximum score 100.

Conclusions. We have successfully established a questionnaire that is able to demonstrate the status of patients suffering cervical myelopathy from five different aspects represented by five intuitive numerical scores. The final issue to be confirmed is the responsiveness of this questionnaire to changes in patients' status after various surgical and nonsurgical treatments.

Introduction

The Japanese Orthopaedic Association scoring system for the evaluation of cervical myelopathy (JOA score)

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was first established by a committee of the JOA chaired by Hirabayashi.[1] Since then, this scoring system has been accepted universally in Japan as a tool to measure the outcomes of surgical and nonsurgical treatments for various cervical spinal disorders that cause cervical myelopathy. The JOA score first appeared in the English literature in 1980 when Hirabayashi published an article describing surgical results in patients with ossification of the posterior longitudinal ligament of the cervical spine (OPLL) that underwent expansive open-door laminoplasty.[2] The JOA score underwent the first revision in 1994 to reflect the deficits in shoulder and elbow functions, which are often caused by cervical root lesions, and this revised version was officially translated into English.[3] Various modified versions of the JOA score have also been introduced in the western countries.[4–6] The JOA score is a disease-specific and physician-oriented system that mainly assesses the neurological status of the patient and enables surgeons to compare the changes in the neurological status of the patient before and after certain treatments. Due to emerging needs to evaluate the impairments in patients' activities of daily living (ADL), which is related directly to their quality of life (QOL), various patient-oriented outcome measures, for example, the Short Form (SF)-36, have been developed and adopted into clinical practices in different medical fields.[7] To take up such needs, the JOA together with the Japanese Society of Spine Surgery and Related Research (JSSR), formerly called the Japanese Spine Research Society (JSRS), has appointed several members of the Clinical Outcomes Committee of the JOA to organize a subcommittee, the aim of which is to develop a completely new patient-oriented scoring system for the evaluation of clinical results in patients with back pain and cervical myelopathy. The subcommittee decided to construct a self-rating questionnaire that could be filled out by patients themselves. Candidates of the questions to be included in the questionnaire were selected and modified from various preexisting outcome measures including the SF-36, the Rolland and Morris Disability Questionnaire, and the Oswestry Disability Index.[8,9] The subcommittee completed three large-scale studies to select and validate the questions that would ultimately become parts of the new JOA scoring system and as a result, the questionnaires including 25 and 24 questions for the evaluation of back pain and cervical myelopathy respectively were finalized.[10–12] In the present study, the cervical version of the finalized questionnaires was administered to patients with cervical myelopathy of different severity to insure the accuracy and responsiveness of this questionnaire and the obtained data were subjected to factor analysis in order to divide the 24 questions into different functional domains. The titles of the domains were designated according to the context of the questions in each domain. Finally, the equations that would yield scores based on the answers to the questions, selected by the patients, in the different domains were established. The scores would represent the degree of patient disability in the functional domains.

Table 1. Sex and age distribution of patients

Sex	Age groups (years)	Severity of myelopathy				Total
		Mild	Moderate	Severe	NA	
Male	20–29	0	0	1		1
	30–39	5	6	3		14
	40–49	5	5	8		18
	50–59	16	18	6	1	41
	60–69	24	26	9		59
	70–79	7	9	7		23
	80–89	3	1	2		6
	>90	0	0	0		0
	Total	60	65	36	1	162
Female	20–29	0	0	0		0
	30–39	2	1	0		3
	40–49	3	6	0		9
	50–59	4	8	2		14
	60–69	11	8	4		23
	70–79	5	8	7		20
	80–89	2	2	1		5
	>90	0	0	0		0
	Total	27	33	14		74
Total		87	98	50	1	236

Table 2. Distribution of scores for subdomains in original scoring system of Japanese Orthopaedic Association

Domain	Function	Score	Response number
Motor	Upper extremity: feeding		
	Impossible	0	5
	Severe	1	22
	Moderate	2	56
	Mild	3	92
	Normal	4	61
Motor	Upper extremity: shoulder and elbow function		
	Severe	–2	8
	Moderate	–1	14
	Mild	–0.5	45
	Normal	0	166
	Unknown		3
Motor	Lower extremity: gait		
	Impossible	0	9
		0.5	1
	Severe	1	26
		1.5	23
	Moderate	2	39
		2.5	20
	Mild	3	59
	Normal	4	59
Sensory	Upper extremity		
	Severe	0	9
		0.5	40
	Moderate	1	111
	Mild	1.5	60
	Normal	2	16
Sensory	Trunk		
	Severe	0	1
		0.5	5
	Moderate	1	39
	Mild	1.5	26
	Normal	2	165
	Unknown		
Sensory	Lower extremity		
	Severe	0	4
		0.5	24
	Moderate	1	69
	Mild	1.5	46
	Normal	2	93
Bladder	Urinary dysfunction		
	Severe	0	3
	Moderate	1	40
	Mild	2	55
	Normal	3	138
	Unknown		

n = 236

Materials and methods

The subcommittee randomly chose 369 out of 829 board-certified spine surgeons who were registered in the JSSR database and asked them to participate in the present survey. Each surgeon was asked to administer the questionnaire to patients with cervical myelopathy due to disc herniation, spondylosis, or OPLL. The surgeons were required to include at least one patient each with mild, moderate, and severe myelopathy according to the discretion of each surgeon. Patients with (1) myelopathy due to nondegenerative diseases, such as trauma, tumor, and rheumatoid arthritis; (2) other musculoskeletal diseases that would affect the evaluation of myelopathy; (3) difficulties filling the questionnaire due to their specific physical (e.g., defects or impairments in the limbs) or mental conditions (e.g., dementia, disorientation); and (4) a history of previous spinal surgery, were excluded from the analysis. Those who participated in our previous studies were also excluded. The surgeons were also asked to assess the neurological status of the patients using the original JOA scoring system. This study was approved by the Ethics Committee of the JSSR, and informed consent was obtained

Table 3. Distribution of answers for 24 questions

Question	Response				
	1	2	3	4	5
Q1-1	108 (45.8)	103 (43.6)	25 (10.6)		
Q1-2	171 (72.5)	56 (23.7)	9 (3.8)		
Q1-3	154 (65.3)	49 (20.8)	23 (9.7)	10 (4.2)	
Q1-4	107 (45.3)	82 (34.7)	24 (10.2)	15 (6.4)	8 (3.4)
Q1-5	107 (45.3)	72 (30.5)	57 (24.2)		
Q1-6	153 (64.8)	49 (20.8)	19 (8.1)	12 (5.1)	3 (1.3)
Q1-7	77 (32.6)	114 (48.3)	45 (19.1)		
Q1-8	127 (53.8)	83 (35.2)	26 (11.0)		
Q1-9	143 (60.6)	73 (30.9)	20 (8.5)		
Q1-10	120 (50.8)	86 (36.4)	30 (12.7)		
Q1-11	140 (59.3)	70 (29.7)	26 (11.0)		
Q1-12	161 (68.2)	53 (22.5)	22 (9.3)		
Q1-13	91 (38.6)	90 (38.1)	55 (23.3)		
Q2-1	6 (2.5)	14 (5.9)	87 (36.9)	100 (42.4)	29 (12.3)
Q2-2	48 (20.3)	113 (47.9)	75 (31.8)		
Q2-3	43 (18.2)	126 (53.4)	67 (28.4)		
Q2-4	46 (19.5)	98 (41.5)	92 (39.0)		
Q2-5	25 (10.6)	45 (19.1)	95 (40.3)	51 (21.6)	20 (8.5)
Q2-6	38 (16.1)	49 (20.8)	75 (31.8)	50 (21.2)	24 (10.2)
Q2-7	24 (10.2)	31 (13.1)	105 (44.5)	53 (22.5)	23 (9.7)
Q2-8	24 (10.2)	38 (16.1)	113 (47.9)	40 (16.9)	21 (8.9)
Q2-9	14 (5.9)	46 (19.5)	104 (44.1)	50 (21.2)	22 (9.3)
Q2-10	26 (11.0)	68 (28.8)	51 (21.6)	56 (23.7)	35 (14.8)
Q2-11	38 (16.1)	76 (32.2)	73 (30.9)	36 (15.3)	13 (5.5)

Numbers given in parentheses are percentages of the total response

from each subject. The completed questionnaires and the results of the original JOA scoring system were collected and sent to the independent central organization where biostatisticians compiled the results and input patient data into a spreadsheet. Rigorous statistical analyses including factor analysis were performed using SPSS software (Version 12, SPSS, Chicago, IL, USA).

Results

Three hundred and sixty-nine patients were initially recruited for this survey. Among them, 106 patients were excluded because they had other musculoskeletal disorders that could affect the evaluation of cervical myelopathy. Most of them had nonspecific low-back pain without neurological symptoms ($n = 70$) and mild knee joint pain due to osteoarthritis ($n = 22$). Twenty-six patients gave no answers to one or more questions and were also excluded. One other patient was excluded because of the discretion of the surgeon in charge. The data of the remaining 236 patients were employed. The sex and age distributions of patients and the distributions of the scores for different subdomains in the original JOA scoring system are given in Tables 1 and 2. Because the majority of the excluded patients were those having other musculoskeletal diseases due to spondylosis or osteoarthritis, the average age was significantly higher in the excluded patients than those that were included. The average scores for shoulder/elbow function and lower motor function in the JOA scoring system were significantly lower in the excluded patients than those for the included subjects.

The incidence of unanswered questions was less than 5%, indicating that there was no question that was difficult to answer. There also was no question for which the distribution of the answer was concentrated to one choice (Table 3), indicating the appropriateness of all 24 questions.

Results of factor analysis revealed that there were six common factors whose eigenvalues exceeded 1.0, which are thought to be the factor having significant contributions to the result. We decided to employ the first five factors because the cumulative contribution rate of the first five factors reached 60% and the contribution of the sixth factor was less than 5% (Table 4).

According to the calculation of the factor loadings after orthogonal rotation using the direct oblimin method with the Kaiser normalization, correlations among the 24 questions and the selected five factors were reexamined. When the maximum factor loading of a question exceeded 0.40, that question was supposed to be correlated with the factor. All 24 questions were judged to have correlation with at least one of the five

Table 4. Results of factor analysis

Factor	Eigenvalue	Contribution rate (%)	Cumulative contribution rate (%)
1	**8.86**	36.9	36.9
2	**2.02**	8.4	45.3
3	**1.56**	6.5	51.8
4	**1.36**	5.6	57.5
5	**1.20**	5.0	62.5
6	**1.08**	4.5	67.0
7	0.81	3.4	70.3
8	0.71	3.0	73.3
9	0.67	2.8	76.1
10	0.62	2.6	78.7
11	0.53	2.2	80.9
12	0.51	2.1	83.0
13	0.48	2.0	85.0
14	0.43	1.8	86.8
15	0.41	1.7	88.5
16	0.40	1.7	90.2
17	0.38	1.6	91.7
18	0.35	1.5	93.2
19	0.32	1.4	94.6
20	0.30	1.3	95.8
21	0.28	1.2	97.0
22	0.27	1.1	98.1
23	0.24	1.0	99.1
24	0.22	0.9	100.0

$n = 236$
Bold typeface indicates eigenvalues over 1.0

factors, except for Q1-4 and Q1-12. Q1-4 had relatively higher factor loadings for both factor 1 and 5 and this question was judged to be correlated with both factors. Q1-12 was first judged to be weakly correlated with factor 5 with a factor loading of 0.37; however, the committee decided to correlate this question also to factor 3 after reading the context of the question and given that the factor loading of 0.32 was also moderately high (Table 5).

According to the interpretations of the context of the questions that were divided into the five factors, each factor was categorized as follows; factor 1: lower extremity function; factor 2: quality of life; factor 3: cervical spine function; factor 4: bladder function; and factor 5: upper extremity function.

To establish an equation to calculate the individual score for each factor/domain that would intuitively indicate the status of a patient with regard to the designated function, the questions that had the maximum absolute factor loading value were used to calculate the score for the factor. For example, Q1-5 was used to calculate the score for factor 1 (lower extremity function), because the factor loading of this question for factor 1 was markedly larger (0.58) than those for the other four factors (−0.10, −0.14, −0.12, 0.11). As described above, Q1-4 and Q1-12 were used to calculate the scores for both factors 1 and 5, and 3 and 5, respectively (Table 5). The score was derived by multiplying the prefixed number of the

Table 5. Factor loading after orthogonal rotation

Question	Factors 1	2	3	4	5
Q1-5	**0.58**	−0.10	−0.14	−0.12	0.11
Q1-4	**0.55**	0.05	−0.08	−0.12	**0.40**
Q2-3	**−0.39**	0.25	0.16	0.18	−0.04
Q2-4	**−0.39**	0.24	0.10	0.33	−0.09
Q2-2	**−0.52**	0.20	0.13	0.24	−0.03
Q2-7	0.10	**0.79**	0.00	0.08	−0.01
Q2-8	0.14	**0.73**	0.06	0.12	−0.06
Q2-11	−0.01	**0.68**	−0.21	0.03	0.01
Q2-6	0.05	**0.55**	0.25	−0.06	−0.06
Q2-5	−0.27	**0.39**	0.19	0.04	−0.13
Q2-10	0.23	**−0.49**	0.08	−0.10	0.15
Q2-1	0.12	**−0.60**	−0.04	0.01	0.09
Q2-9	0.13	**−0.66**	−0.13	0.10	−0.06
Q1-11	−0.02	0.03	**−0.57**	−0.24	0.10
Q1-13	0.05	−0.06	**−0.75**	0.00	0.05
Q1-10	0.04	−0.01	**−0.87**	0.07	−0.06
Q1-12	0.10	0.04	−0.32	−0.21	**0.37**
Q1-9	0.08	−0.05	−0.07	**−0.43**	−0.01
Q1-7	0.14	−0.04	0.09	**−0.53**	−0.03
Q1-6	0.00	0.02	0.01	**−0.58**	0.03
Q1-8	−0.11	0.01	−0.06	**−0.61**	0.00
Q1-2	0.12	0.02	0.02	0.10	**0.73**
Q1-1	0.24	−0.13	0.01	0.02	**0.60**
Q1-3	−0.27	−0.11	−0.05	−0.11	**0.60**

Method of factor extraction: unweighted least-squares method. Orthogonal rotation: direct oblimin method with Kaiser normalization
Bold typeface indicates absolute value of the factor loading of more than 0.35

Table 6. Coefficients for calculation of severity score

Question	Factors				
	1 Lower extremity function	2 Quality of life	3 Cervical spine function	4 Bladder function	5 Upper extremity function
Q1-1					−10
Q1-2					−15
Q1-3					−5
Q1-4	−10				−5
Q1-5	−10				
Q1-6				−10	
Q1-7				−5	
Q1-8				−10	
Q1-9				−5	
Q1-10			−20		
Q1-11			−10		
Q1-12			−5		−5
Q1-13			−15		
Q2-1		−3			
Q2-2	15				
Q2-3	5				
Q2-4	5				
Q2-5		2			
Q2-6		2			
Q2-7		5			
Q2-8		4			
Q2-9		−3			
Q2-10		−2			
Q2-11		3			

Table 7. Equations to calculate scores for different factors

Factor	Equation
1 Lower extremity function	(Q1-4 × 10 + Q1-5 × 10 + Q2-2 × 15 + Q2-3 × 5 + Q2-4 × 5 − 45) × 100 ÷ 105
2 Quality of life	(Q2-1 × 3 + Q2-5 × 2 + Q2-6 × 2 + Q2-7 × 5 + Q2-8 × 4 + Q2-9 × 3 + Q2-10 × 2+ Q2-11 × 3 − 24) × 100 ÷ 96
3 Cervical spine function	(Q1-10 × 20 + Q1-11 × 10 + Q1-12 × 5 + Q1-13 × 15 − 50)
4 Bladder function	(Q1-6 × 10 + Q1-7 × 5 + Q1-8 × 10 + Q1-9 × 5 − 30) × 100 ÷ 80
5 Upper extremity function	(Q1-1 × 10 + Q1-2 × 15 + Q1-3 × 5 + Q1-4 × 5 + Q1-12 × 5 − 40) × 100 ÷ 95

answer, selected by the patient, by the coefficient that were defined to make the difference between the minimum and maximum scores to be approximately 100 points (Table 6). The additional coefficients were also assigned to adjust the minimum score to be 0 and the maximum score to be 100. The final equations for the scores for the five domains are shown in Table 7.

Discussion

In our previous studies, the questionnaires were constructed by referring to various preexisting outcome measures including the SF-36, the Roland and Morris Disability Questionnaire, and the Oswestry Disability Index,[7–9] which have commonly been used for patients with different spinal disorders. We also took extra care to maintain relevance to the original JOA scoring systems by carefully assessing the correlation between the new and original systems. The new questionnaires have been revised several times and underwent many validation processes using rigorous statistical analyses. As a result, 24 questions were selected as the items of the finalized questionnaires for back pain and cervical myelopathy.[10–13]

In the present study, patients with different severity of cervical myelopathy were examined using the cervical version of the questionnaires to insure the accuracy and responsiveness of this questionnaire against various neurological states of the patient. Factor analysis was used to divide the 24 questions into different factorial domains, and the domains were categorized by inter-

preting the context of the questions that were divided into each domain. The five domains into which the 24 questions were divided were designated as: (1) lower extremity function, (2) quality of life, (3) cervical spine function, (4) bladder function, and (5) upper extremity function. Then the equations to calculate the score for each domain were assembled in order to intuitively indicate the status of patients in the five different functional domains. The numbers prefixed to the answers chosen by the patients were multiplied by the coefficients so that the difference between the minimum score representing the worst condition and the maximum score representing the best condition would become 100. The equations were further manipulated by other supplemental coefficients so that the minimum score became 0 and the maximum score became 100 to make recognition of the status of the patient as intuitive as possible.

Because the previous JOA scoring system was a preference-based system, and the scores for different neurological functions (i.e., upper and lower extremity motor function, upper and lower extremity and trunk sensory function, and bladder function) were added up to represent overall status of the patients by one simple score, the new system was initially supposed to use a similar manner. However, because the five factors derived from factor analysis were completely independent statistically, and it was considered impractical to evaluate the multidimensional aspects of the patient suffering cervical myelopathy by one digit, we decided to use the scores in different domains independently without simply adding them.

We have successfully assembled the final questionnaire that is capable of demonstrating the status of the patient suffering cervical myelopathy in five different functional aspects with five intuitive numerical scores, after rigorous yet sophisticated statistical analyses. The remaining issue to be confirmed is the responsiveness of this finalized questionnaire against the changes in patient status after various surgical and nonsurgical treatments. We have investigated if the changes in the patient functional status after surgical treatment would be accurately reflected by the changes in the scores in the different domains. The results will be shown and discussed in part V of our study.

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ORIGINAL ARTICLE

Indirect posterior decompression with corrective fusion for ossification of the posterior longitudinal ligament of the thoracic spine: is it possible to predict the surgical results?

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Abstract To investigation of the outcomes of indirect posterior decompression with corrective fusion for myelopathy associated with thoracic ossification of the longitudinal ligament, and prognostic factors. Conservative treatment for myelopathy associated with thoracic ossification of the longitudinal ligament (OPLL) is mostly ineffective, and treatment is necessary. However, many authors have reported poor surgical outcomes, and no standard surgical procedure has been established. We have been performing indirect spinal cord decompression by posterior laminectomy and simultaneous corrective fusion of the thoracic kyphosis. Twenty patients underwent indirect posterior decompression with corrective fusion, and were included in this study. The follow-up period was minimum 2 years and averaged 2 years and 9 months (2–5 years 6 months). Operative results were examined using JOA scoring system (full marks: 11 points) and Hirabayashi's recovery rate, as excellent (100–75%), good (74–50%), fair (49–25%), unchanged (24–0%) and deteriorated (i.e., decrease in score less than 0%). Cases in which the spinal cord is floating from OPLL on intraoperative ultrasonography were defined as the floating (+) group, and those without floating as the floating (−) group. In addition, we used compound muscle action potentials (CMAP) as intraoperative spinal cord monitoring and the cases were divided into three groups: Group A, no change in potential; Group B, potential decreased, and Group C, potential improved. The mean pre- and postoperative JOA scores were 6.2 and 8.9 points, respectively, and the recovery rate was 56%. The outcome was rated excellent in three, good in eight, fair in six, unchanged in two, and deteriorated in one. The mean preoperative thoracic kyphosis measured 58°, and was corrected to 51° after surgery. On intraoperative ultrasonography, 12 cases were included in the floating (+) and 8 in the floating (−) groups; the recovery rates were 58 and 52%, respectively, showing no significant difference between the recovery rates of the two groups. Regarding intraoperative CMAP, the outcome was excellent in one, good in seven, fair in four, and unchanged in one in Group A; fair in one, unchanged in one, and deteriorated in one in Group B, and excellent in two and good in one in Group C. The recovery rates were 50, 48 and 68.3% in Groups A, B and C, respectively, showing that the postoperative outcome was significantly poorer in Group B. Although indirect posterior decompression with corrective fusion using instruments obtained satisfactory outcomes, not all cases achieved good outcomes using this procedure. We consider that additional application of anterior decompressive fusion is preferable when improvement of symptoms occurs not satisfactory after indirect posterior decompression with corrective fusion using instruments. Intraoperative spinal cord monitoring of CMAP demonstrated that the spinal cord was already impaired during the laminectomy via the posterior approach. Concomitant intraoperative monitoring of CMAP to avoid impairment of the vulnerable spinal cord and corrective posterior spinal fusion with indirect spinal cord decompression is recommendable as a method capable of preventing postoperative neurological aggravation.

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Keywords Ossification of the posterior longitudinal ligament · Thoracic myelopathy · Spinal cord monitoring · Intraoperative ultrasonography

Introduction

Conservative treatment for myelopathy associated with thoracic ossification of the longitudinal ligament (OPLL) is mostly ineffective, and surgical treatment is necessary. However, many authors have reported poor surgical outcomes, and no standard surgical procedure has been established. Many cases of aggravation following laminectomy have been reported, and we have earlier also reported five aggravated cases [3]. There are two types, the flat type and beak type, for which surgery is difficult, in thoracic OPLL [3, 5]. We have been performing indirect spinal cord decompression by primary wide laminoplastic decompression and correction of kyphosis using instruments via a posterior approach for the beak type and flat type accompanied by ossification of the ligamentum flavum and facet destruction in posterior decompression since 1999 [7]. The objective of this study was to investigate the outcomes of indirect posterior decompression with corrective fusion, and prognostic factors in cases with poor outcomes.

Materials and methods

Of 37 patients with thoracic OPLL who underwent surgery between March 1985 and July 2006, 20 patients who underwent indirect posterior decompression with corrective fusion using instruments after 1999 were included. The average age was 58 years (37–67 years), and the follow-up period was minimum 2 years, and averaged 2 years and 9 months (2–5 years 6 months). Operative results were examined at 6 months after the surgery using Japanese Orthopaedic Association Scoring System (JOA score). This has a total of 17 points, consisting of four points for motor dysfunction of the upper and lower extremities, respectively; two points for sensory dysfunction of the upper and lower extremities and trunk, respectively; and three points for bladder dysfunction. The results of thoracic spine disease were evaluated using the same score excluding evaluation of upper-limb function (maximum 11 points). Postoperative recovery rate was determined by Hirabayashi's method as follows: recovery rate = (postoperative JOA score − preoperative JOA score) × 100/(full score − preoperative JOA score).

Based on Hirabayashi's recovery rate, we defined as excellent (100–75%), good (74–50%), fair (49–25%), unchanged (24–0%) and deteriorated (i.e., decrease in score; ≤0%). The investigated points were the JOA score, recovery rate, fusion range, pre- and postoperative Cobb angle of thoracic kyphosis, intra- and postoperative blood losses, operative time, intraoperative ultrasonography findings, intraoperative spinal cord monitoring (CMAP), and complications. The basic fusion area was three vertebrae above and below the OPLL lesion. Cases in which the spinal cord free from OPLL on intraoperative ultrasonography were defined as the floating (+) group, and those without as the floating (−) group. Regarding CMAP, the cases were divided into three groups: Group A: no change in potential, Group B: potential decreased, and Group C: potential improved.

The unpaired t test, Mann–Whitney U tests, or Fisher's exact probability test was used for statistical analysis. A P value of less than 0.05 was considered to indicate statistical significance.

Ethical consideration

Surgery was performed after the natural course of the disease without surgery and the possibility of surgical complications: (1) palsy, (2) infection, (3) transfusion, etc., were explained to the patients, and an informed consent was obtained.

Results

The average pre- and postoperative JOA scores were 6.2 (3–8) and 8.9 (3–10), respectively, and the recovery rate was 56%. The clinical outcome was excellent in three, good in eight, fair in six, unchanged in two, and deteriorated in one case (Table 1). The fusion area was T1–T4 in one, T1–T6 in one, T1–T9 in two, T2–T10 in three, T2–T11 in three, T3–T9 in three, T3–T10 in one, T4–T11 in three, and T6–T12 in three. Cervical laminoplasty was performed in 14 cases simultaneously. The preoperative thoracic kyphosis averaged 58° (48–72), and corrected to 51° (43–65) after surgery. The mean operative time was 7 h and 30 min (5 h 50 min–8 h 45 min), and the blood loss was 926 ml (670–1,135 ml) (Table 2).

Table 1 Clinical results

JOA score	
Preoperative 6.2 (3–8)	
Postoperative 8.9 (3–10)	
Recovery rate 56%	
Excellent	3 cases
Good	8 cases
Fair	6 cases
Poor	2 cases
Deteriorate	1 cases

Table 2 Operative results

Thoracic kyphosis	Preoperative 58° (48–72)
	Postoperative 51° (43–65)
Operative time	7 h 30 min (5 h 50 min–8 h 45 min)
Bleeding	926 ml (670–1,135 ml)

On intraoperative ultrasonography, 12 cases were included in the floating (+) and 8 in the floating (−) groups, and the recovery rates were 58 and 52%, respectively, showing no significant difference between the recovery rates of the two groups (Fig. 1). Regarding intraoperative CMAP, the derivation rate before decompression was 99%. In only one patient, the monitoring of spinal cord was impossible just prior to surgery and immediately thereafter; 13, 3 and 3 patients were included in the Groups A, B and C, respectively. In Group B, the potential was improved by 10 min arrest of decompression procedure in one case, the potential decreased immediately after laminectomy and recovered by correction of kyphosis with instruments in one case, and the operative procedure proceeded with overlooking of decreased spinal cord potential in one case.

In all three patients of Group C, the spinal cord potential did not change following the decompression procedure alone, but improved immediately subsequent to the correction of kyphosis with instruments (Table 3). The clinical outcome was excellent in one, good in seven, fair in four, and unchanged in one in Group A, fair in one, unchanged in one, and deteriorated in one in Group B, and excellent in two and good in one in Group C. The pre- and postoperative JOA scores of Groups A, B and C were 6.8 and 8.9, 6.0 and 8.4 and 5.8 and 9.4, respectively; the recovery rate was 50% in Group A, 48% in Group B and 68.3% in Group C, respectively, indicating that the postoperative outcome was significantly poorer in Group B (Table 4).

Table 3 Detail of group B and C

Group B
Case 1: amplitude getting down while laminectomy procedure after 10 min rest, amplitude was recovered
Case 2: just after laminectomy, wave was disappeared after correction of kyphosis, wave was appeared
Case 3: just after laminectomy, wave was disappeared after correction of kyphosis, wave was not appeared
Group C
3 Cases: while laminectomy, no wave change, after correction of kyphosis, amplitude of the wave improved

Regarding intra- and postoperative complications, cerebrospinal fluid leakage was noted in ten cases with adhesion between the dura and ossified ligamentum flavum or ossification of the dura, but it was treatable with postoperative lumbar drainage using autologous fibrin glue.

Typical case: Group B

The patient was a 53-year-old male with the chief complaint of gait disturbance. Stenosis from C3 to C7 and beak-type OPLL of T4–T5 and T5–T6 were noted. OYL of T4–T5 was also present, and the spinal cord was severely compressed (Fig. 2a). Laminoplasty from C3 to T2 was performed for cervical canal stenosis, followed by laminectomy of T3–T5. As the potential of CMAP began to

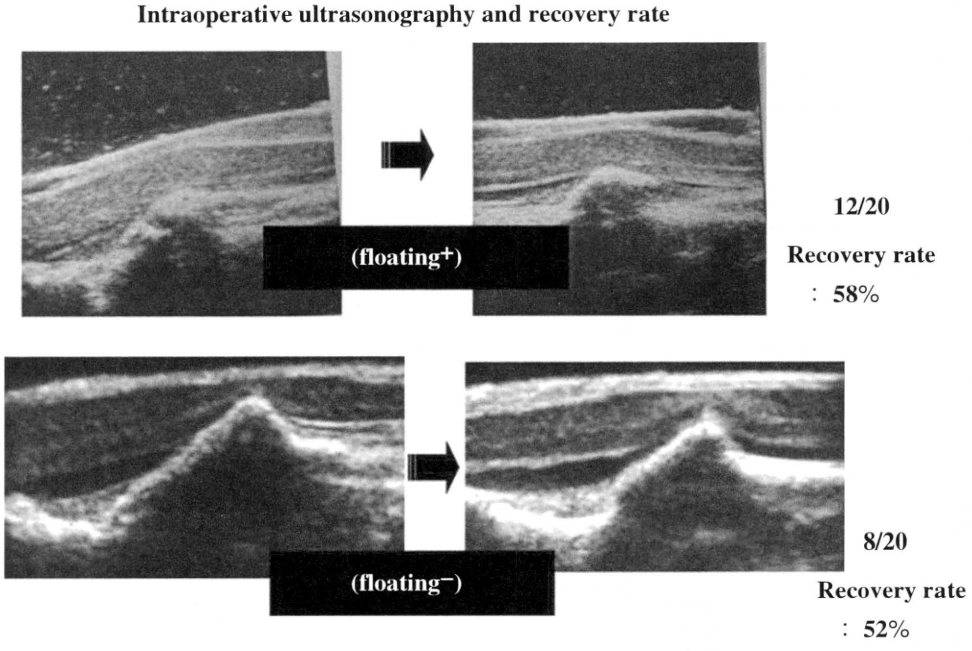

Fig. 1 Intraoperative ultrasonography and recovery rate. In the floating (+) group, 12 of the 20 patients were included and the JOA recovery rate was 58%. In the floating (−) group, 8 of the 20 patients were included and the JOA recovery rate was 52%. There was no significant difference between the recovery rates of two groups

Table 4 Clinical results of three groups

Group	A	B	C
Excellent	1		2
Good	7		1
Fair	4	1	
Poor	1	1	
Deteriorate		1	
Preoperative JOA	6.8	6.0	5.8
Postoperative JOA	8.9	8.4	9.4
Recovery rate (%)	50	48	68

decrease immediately following laminectomy of T3–T5, intraoperative ultrasonography was performed immediately. The compression of the spinal cord by OPLL from anteriorly was noticed. We applied pedicle screws at T3, T4, T7, and T8, and the kyphosis was corrected and fixed with cantilever and compression force with instruments (Fig. 2b). Intraoperative ultrasonography revealed that the compression of the spinal cord by OPLL decreased following the correction of kyphosis. CMAP recovered 1 min after correction of kyphosis (Fig. 2c). Neither neurological aggravation nor improvement occurred after the surgery.

Discussion

Conservative treatment for myelopathy associated with OPLL is mostly ineffective, and surgical treatment is necessary. However, many authors [1–3, 10–16] have

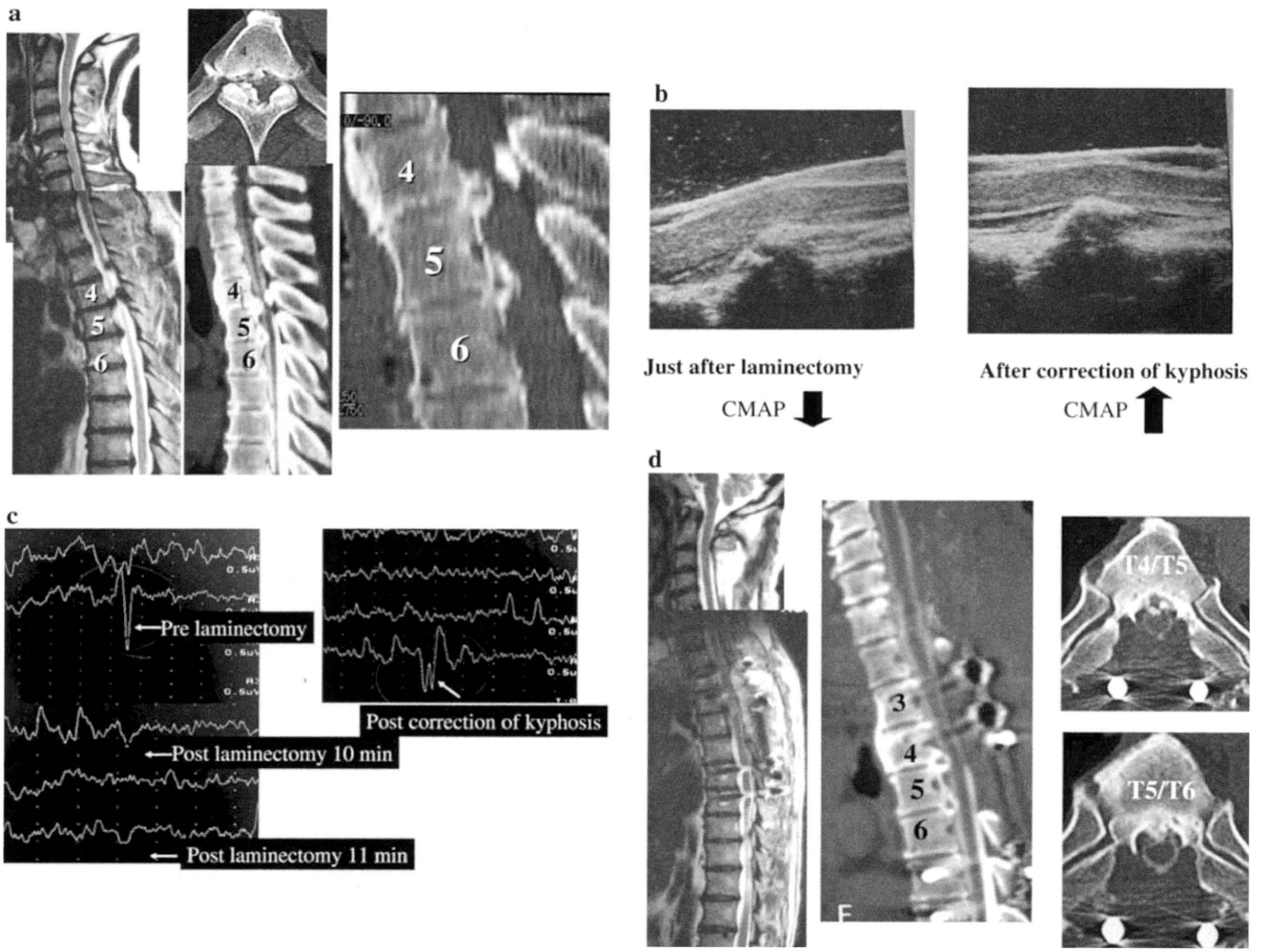

Fig. 2 **a** MRI and myelo CT. Cervical canal stenosis from C3 to C7 and beak-type OPLL of T4/T5 and T5/T6 were detected. Severe spinal compression by OYL and OPLL was noted at T4/T5. **b** Intraoperative ultrasonography after laminectomy and after correction of kyphosis. On ultrasonography immediately after laminectomy, the spinal cord was raised by OPLL in the anterior region. The spinal cord was free from OPLL after correction of kyphosis. **c** CMAP decreased 10 min after laminectomy. Since intraoperative ultrasonography detected that the spinal cord was pushed up by OPLL in the anterior region, kyphosis was corrected rapidly, and indirect spinal decompression was performed. The intraoperative CMAP recovered immediately after the decompression. **d** Spinal cord decompression was sufficient on MRI and myelo CT

reported poor surgical outcomes, and no standard surgical procedure has been established. Since physiological kyphosis is present in the thoracic spine, unlike the cervical and lumbar spine, spinal cord decompression through the posterior approach alone is difficult. Anterior decompression by the anterior approach is also technically difficult because of the presence of adhesion between the dura and ossified ligament, a narrow visual field requiring a longitudinal section of sternum in the upper thoracic area, and the necessity of an anterolateral approach by cost-transversectomy in the middle-lower thoracic region [1, 13, 14, 16]. Tsuzuki [14] reported pan-laminoplasty, namely, laminoplasty to a wide region from the cervical to the thoracic region via the posterior approach to decompress the thoracic spinal cord; Otsuka et al. [13] reported anterior decompression via the posterior approach by laminectomy with transpedicular resection of the OPLL, but postoperative neurological aggravation occurred in some cases with both procedures. We morphologically classified thoracic OPLL into the flat and beak types, and compared the postoperative outcome between the anterior and posterior approaches as well as anterior decompression through the posterior approach in each type. Neurological aggravation after surgery was found in four cases, and the common point was a localized beak shape of ossification [3, 5]. Yamasaki et al. [15] reported a neurological deteriorated case after laminectomy, and the neurological status improved upon stabilizing the fusion using instruments in a second operation.

As causes of neurological deterioration associated with the posterior approach, ossification and adhesion of the ligamentum flavum with the dura, the presence of severe compression of the spinal cord, impairment of the vulnerable spinal cord by laminectomy, and development of thoracic kyphosis by laminectomy, resulting in spinal cord injury, were considered. There are no reports of neurologically aggravated cases wherein the dangerous intraoperative procedure or the period of onset of neurological deterioration was closely investigated. We have been performing wide laminoplasty and correction of kyphosis using instruments via the posterior approach, regardless of the ossification morphology, to indirectly decompress the spinal cord [ ]. To prevent damage of the vulnerable spinal cord, CMAP was measured continuously, and when and by what procedure the spinal cord potential was altered was closely investigated [, ,]. Furthermore, we attempted to predict the postoperative outcome from the condition of spinal cord decompression on intraoperative ultrasonography, but no significant difference was noted between the cases in which the spinal cord free and not free from the OPLL, unlike the findings reported by Tokuhashi et al.[ ]. However, the recovery rate was significantly lower in group B in which the potential decreased during surgery. In one patient in group B, the spinal cord was compressed by OPLL in the anterior region on intraoperative ultrasonography, which decreased the spinal cord potential, but immediate decompression of the spinal cord by correction of kyphosis using instruments restored the potential. However, once the potential decreased, such as the decrease in group B, the recovery rate was low, and persistent decrease results in neurological aggravation, as in these patients. Monitoring of CMAP facilitates early check of impairment of the vulnerable spinal cord, and arrest of the decompression procedure until recovery of the potential when instruments for prevention of kyphosis have been placed, or correction of kyphosis acquires indirect spinal cord decompression that prevents permanent spinal cord palsy. Although indirect posterior decompression with corrective fusion using instruments obtained satisfactory outcomes in our study, not all cases achieved good outcomes by this procedure.

Kawahara et al. performed decompressive fusion via the posterior approach as the first step, and when spinal cord decompression on MRI was insufficient at 3 weeks after surgery, they performed anterior decompressive fusion as the second step regardless of the degree of improvement of symptoms, and reported that the outcome was better in the group also treated with anterior decompressive fusion, than in the group treated with posterior decompression with corrective fusion alone [ ]. However, the improvement of symptoms was good after the posterior decompression with corrective fusion, designated as the first step by Kawahara et al., in the long-term follow-up in many patients; most patients were satisfied without the second step anterior decompression. We consider the additional application of anterior decompression when improvement of symptoms at 6 months after indirect posterior decompression with corrective fusion is not satisfactory. In any procedure, surgical treatment of thoracic OPLL is difficult. Intraoperative monitoring of CMAP clarified that the spinal cord was already impaired during laminectomy via the posterior approach. Concomitant intraoperative monitoring of CMAP [1, , , 9] to avoid impairment of the vulnerable spinal cord and corrective posterior spinal fusion with indirect spinal cord decompression is recommendable as a method capable of preventing postoperative neurological aggravation.

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High-Resolution Magnetic Resonance Imaging and ^{18}FDG-PET Findings of the Cervical Spinal Cord Before and After Decompressive Surgery in Patients With Compressive Myelopathy

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Study Design. Evaluation of cervical spinal cord (CSC) of patients with compressive myelopathy by magnetic resonance imaging (MRI) and high-resolution (^{18}F)fluoro-deoxyglucose (^{18}FDG) positron emission tomography (PET).

Objective. To determine changes in morphology, intramedullary signal intensity, and glucose metabolic rate in CSC after decompression, and to assess the utility of ^{18}FDG-PET in evaluation of patients with cervical myelopathy.

Summary of Background Data. The significance of CSC enlargement after decompression and signal intensity changes within the cord remain elusive. No data are available on metabolic activity of the compressed CSC. Only a few studies have examined correlation between high-resolution MRI and ^{18}FDG-PET neuroimaging in cervical myelopathy.

Methods. We studied 24 patients who underwent cervical decompressive surgery in terms of postoperative neurologic improvement and changes in MRI and ^{18}FDG-PET. Neurologic status was assessed by the Japanese Orthopedic Association scoring system (17-point scale). Signal intensity change in the cord was qualitatively assessed on both T1- and T2-weighted images. The transverse area of the CSC on MRIs and glucose metabolic rate (standardized uptake value [SUV]) from ^{18}FDG-PET were measured digitally.

Results. Neurologic improvement correlated with preoperative CSC transverse area at maximal compression ($P < 0.01$) and at follow-up ($P < 0.001$) and with mean SUV before surgery ($P < 0.01$) and at follow-up ($P < 0.05$). Preoperative signal intensity change on MRIs (low intramedullary signal intensity abnormality on T1-weighted image and high intramedullary on T2-weighted image) correlated negatively with neurologic improvement rate ($P < 0.05$). The transverse area of the CSC was significantly smaller after surgery in patients with preoperative MRI signal intensity changes ($P < 0.05$). The SUV at follow-up tended to normalize in association with neurologic improvement.

Conclusion. Our results showed that postoperative neurologic improvement in patients with cervical compressive myelopathy correlated with increased transverse area of the spinal cord, signal intensity change on both T1- and T2-weighted image, and the mean SUV.

Key words: cervical myelopathy, MRI, (^{18}F)fluoro-deoxyglucose (FDG)-positron emission tomography (PET), spinal cord, ossified posterior longitudinal ligament (OPLL). **Spine 2009;34:1185–1191**

It is important to assess spinal cord function in patients amenable to neurosurgical treatment for cervical compressive myelopathy. Most conventional tests focus on evaluating neural conductivity across the damaged spinal cord,[1] or morphologic and pathologic changes to the compressed cord that can be identified on magnetic resonance imaging (MRI). MRI is a valuable tool before surgical decompression because it visualizes not only the magnitude of spinal cord compression but also the intramedullary signal intensity. Many investigators have examined the correlation between the magnitude of compression on MRIs and signal intensity and neurologic symptoms.[2–6] In fact, most studies suggested that preoperative MRI findings could be used to predict surgical outcome and prognosis. On the other hand, Baba *et al*[7,8] suggested the potential significance of cervical spinal cord (CSC) enlargement (mechanical plasticity) as a marker of favorable postsurgical neurologic improvement. However, the relationship between morphologic plasticity and intramedullary signal changes on MRIs remains controversial.

(^{18}F)fluoro-deoxyglucose (FDG)-positron emission tomography (PET) has been used to investigate neural tissue metabolic activity including that of the spinal cord.[9] We also used high-resolution ^{18}FDG-PET to visualize CSC and quantify its metabolic activity.[10] We also reported that patients with cervical myelopathy have a variable degree of glucose utilization rate in the cervical spinal cord,[11] and that impaired metabolic activity in these patients at the affected spinal cord level correlated closely with the severity of preoperative neurologic dys-

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function.[12] It is possible that the combination of MRI and high-resolution ^{18}FDG-PET could uncover new features of cervical compressive myelopathy.

The present study was designed to define the morphologic and intramedullary signal changes on MRIs and the glucose metabolic rate measured on ^{18}FDG-PET in relation to the neurologic status and neurologic improvement in these parameters after surgery.

■ Materials and Methods

Patient Data and Neurologic Assessment

We studied 24 patients who underwent decompressive surgery for cervical compressive myelopathy. They included 16 men and 8 women with a mean age at surgery of 65.3 years (range, 54–77). Ten patients had cervical spondylotic myelopathy and 14 had ossified posterior longitudinal ligament (OPLL). The mean duration of neurologic symptoms was 6.1 month (range, 4–20). None of the patients had diabetes mellitus or history of CSC injury. Anterior decompression with autogenous iliac bone grafting was performed in 11 patients, while *en bloc* open-door laminoplasty was performed in 13. All surgeries were performed by 1 senior author (H.B.) using uniform techniques.[13,14] During surgery, none of the patients developed iatrogenic spinal cord injury and the peri/postoperative course was uneventful in all. All patients underwent high-resolution MRI and ^{18}FDG-PET at final follow-up. The mean follow-up period was 2.6 years (range, 2.1–3.5). All examinations including ^{18}FDG-PET study strictly followed the Ethics Review Committee Guidelines of Fukui University and a written informed consent was obtained from all patients. ^{18}FDG-PET study was undertaken as an Advanced Medical Technology Development Project at Fukui University.

Neurologic assessment was performed by independent observers (H.N., T.Y.) and conducted in accordance with the Japanese Orthopedic Association (JOA) scoring system for cervical myelopathy.[12] The rate of neurologic improvement was calculated by the following equation: ([postoperative JOA score–preoperative JOA score]/[17–preoperative JOA score] × 100). An improvement rate of 100% was the best possible postoperative recovery. Patients were classified into 2 groups after surgery based on the rate of neurologic improvement: group A (improvement group: rate ≥ 50%), group B (less improvement group: rate < 50%).

Radiologic Assessment

High-Resolution MRI. MRI examination of the spinal cord was performed before surgery and at follow-up, using 1.5-Tesla Signa system (General Electric, Milwaukee, WI). On the transaxial T1-weighted image (TR, 350 milliseconds; TE, 19 milliseconds), we measured the transverse area of the spinal cord at the level of severest impingement of the compressive lesion, and on the sagittal T1- and T2-weighted sequences (TR, 4000 milliseconds; TE, 98 milliseconds), we evaluated intramedullary signal intensity changes. The transverse area of the spinal cord was measured directly on pictures converted from the stored MRI data using the NIH imaging software (ver. 1.59; Ohlandorf Research, Ottawa), as described previously.[7] The expansion rate of the transverse area of the spinal cord after decompression was calculated using the following equation: ([postoperative transverse area of the cord/preoperative transverse area of the cord] × 100). Based on the grading system of Mehalic *et al*,[15] and our group,[16] we categorized qualitatively the changes in intramedullary signal intensity into 3 grades: grade I (N/N); normal intensity on both T1- and T2-weighted images, grade II (N/Hi); no intramedullary signal intensity abnormality on T1-weighted image and high intramedullary on T2-weighted image, grade III (Lo/Hi); low intramedullary signal intensity abnormality on T1-weighted image and high intramedullary on T2-weighted image. Two observers (S.K., T.T.) who did not participate in decompressive surgery and were not involved in neurologic assessment, measured the transverse area of the cord and assessed intramedullary signal changes.

^{18}FDG-PET Study. ^{18}FDG-PET examination of the CSC was performed before surgery and at follow-up using the GE Advance system (General Electric).[11,12] This system allows the simultaneous acquisition of 35 transverse slices with interslice spacing of 4.25 mm with septums (two-dimensional mode). Images were reconstructed to a full width at half maximum of 4.2 mm in both transaxial and axial directions. The field of view and pixel size of reconstructed images were 256 and 2 mm, respectively. Subjects were studied after fasting for at least 4 hours. Transmission scans were obtained over 10 minutes using a standard pin source of ^{68}Ge/^{68}Ga for attenuation correction of the emission images. A dose of 244 to 488 MBq of ^{18}F-FDG was injected into the antecubital vein over a period of 10 seconds. Dynamic scans were obtained up to 60 minutes after injection with arterial sampling. Arterial blood was sampled from a distal artery on the opposite side of the injection. Following injection, 2-mL blood samples were obtained every 15 seconds in the first 2 minutes, and then at 2.5, 3, 5, 10, 15, 20, 30, 45, and 60 minutes after injection. Plasma radioactivity was measured by the scintillation counter against which the PET camera was cross-calibrated, using a cylindrical phantom filled with ^{18}F-FDG solution. The image was processed using DoctorView software (Asahikasei, Nobeoka, Japan) on SPARC 20 workstation (Sun Microsystems, Mountain View, CA). Using the latter software and hardware, ^{18}FDG-PET images were visualized and conformed in axial, coronal, and sagittal sections (three-dimensional mode). To determine the aforementioned parameters of CSC glucose metabolism, round regions of interest (ROI), each 10.3 mm in diameter (21 pixels), were placed onto the spinal cord in transaxial slice, and sagittal images were used as an "on-line" reference to place ROI. During placement of ROI, the sagittal MRI image served as reference to match the level of ROI placed with the entire cervical spinal cord. The maximal count in the ROI was then adopted as the tissue radioactivity to eliminate the partial volume effect caused by the slightly larger size of the ROI than the diameter of the spinal cord.[17,18] ROI values at each level of the CSC from C2–C3–C6–C7 disc (total 13 slices) were averaged to obtain the mean standardized uptake value (SUV). These values represented the metabolic activity of the CSC as a whole. The average SUV for healthy Japanese subjects aged 40 to 70 years is 1.93 ± 0.23.[10] The metabolic rate of glucose in ^{18}FDG-PET was quantified by the principal author (K.U.).

Statistical Analysis

All values are expressed as mean ± SD. The nonparametric Mann-Whitney *U* test was used to analyze differences between 2 groups. Kruskal-Wallis test and Games-Howell *post hoc* test were used to analyze differences among 3 groups. A *P* value less than 0.05 was considered statistically significant. All statistical

Table 1. Surgical Outcome in 24 Patients

	Preoperative	Postoperative	Rate of Change (%)*	*P*
JOA score (points)	12.1 ± 2.8 (6–16)	14.8 ± 2.0 (11–17)	62.6 ± 22.6 (20–100)	<0.001
TA of spinal cord (mm^2)	47.3 ± 7.2 (30.2–58.1)	64.9 ± 9.2 (49.8–79.3)	138 ± 14 (114–173)	<0.001
SUV	2.2 ± 0.4 (1.6–2.8)	2.1 ± 0.2 (1.8–2.5)	—	<0.05

Data are mean ± SD and (range).
*Rate of change (%) in JOA score and TA of spinal cord indicates the neurological improvement rate and the expansion rate of the cord, respectively.
TA indicates transverse area measured at the most compressed level.

analyses were conducted using SPSS software (version 15.0, SPSS, Chicago, IL).

■ Results

Table 1 provides a summary of the surgical outcome. The JOA score improved significantly after surgery. However, the neurologic improvement was not significantly different between anteriorly operated and posteriorly decompressed groups, and between cervical spondylotic myelopathy and OPLL groups. There was no residual compression in any patient on follow-up MRI. The transverse area of the spinal cord at the most compressed level increased significantly after surgery (Table 1). Furthermore, SUV decreased significantly after surgery (Table 1) and appeared to approach the normal value in each patient (Figure 1).

Table 2 summarizes the neurologic status, transverse area of the spinal cord, and the SUV before and after surgery, according to the rate of neurologic improvement. Patients in group B had significantly low JOA scores ($P < 0.01$) and small transverse area ($P < 0.001$) of the spinal cord at follow-up, compared with those of in group A. The SUV values before and after surgery were significantly lower in group B than group A ($P < 0.01$, $P < 0.05$, respectively).

Before surgery, 12 (50%) patients showed grade I signal intensity on MRIs, 8 showed grade II, and 4 showed grade III abnormality (Table 3). No changes were seen at follow-up in patients with grade I signal intensity. With regard to the 8 patients with grade II, 4 (cases 4, 9, 10, and 17) showed regression of hyperintensity on T2-weighted image, although no change in grade was noted and 3 showed no change in hyperintensity. Neurologic improvement, postoperative transverse area, and morphologic restoration rate were not significantly different between patients exhibiting regression (n = 4) and those without regression of hyperintensity (n = 3). While 1 patient (case 21) showed a change in grade II before surgery, this patient with OPLL at C2–C5 improved to grade I by only 1 point on the JOA score but the transverse area of the cord increased by 125% after surgery. Four patients with grade III showed no change at follow-up and no regression of low intensity on T1- or hyperintensity on T2-weighted image. The neurologic improvement rate and transverse area of the spinal cord at follow-up were significantly different in patients with grade III signal intensity than those with grade I.

Two illustrative cases are shown in Figures 2 and 3. A 75-year-old women (case 23, group A; grade I; Figure 2) with cervical spondylotic myelopathy underwent C3–C7 *en bloc* open-door laminoplasty and subsequently showed 100% neurologic improvement rate at follow-up. The transverse area of the cord at follow-up had increased by 136% compared with preoperative area. The average SUV before surgery was markedly high but it approached normal value at follow-up. Another male patient aged 61 years (case 2, group B; grade III; Figure 3) with C2–C5 OPLL underwent anterior decompression with interbody fusion. The patient gained a 4-point

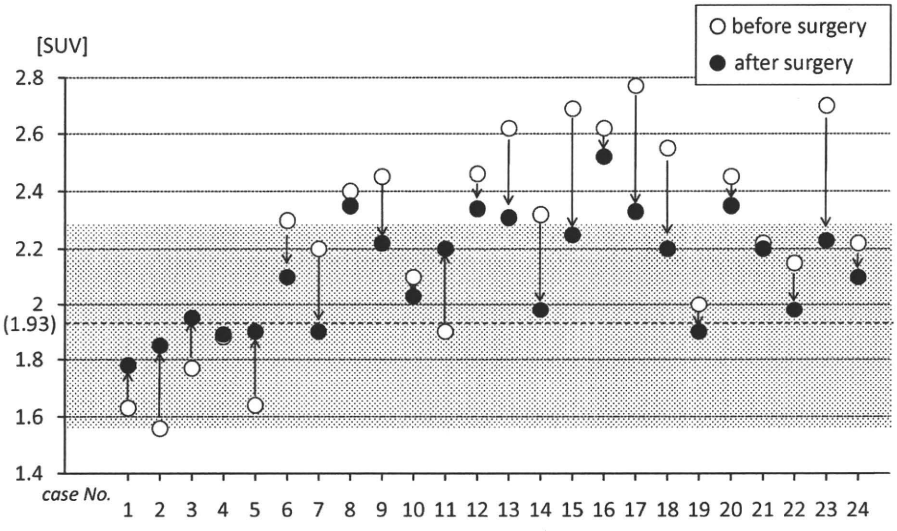

Figure 1. SUV for each patient before surgery and at follow-up. The mean SUV appeared to approach the normal value at follow-up. The dotted line and dotted area represent the mean (1.93) ± SD of SUV of normal subjects reported by Kamoto *et al.*[10]

Table 2. Neurological Status and Radiological Data

Clinical/Radiological Data	Neurological Improvement at Follow-Up		
	Group A (>50%)	Group B (≤50%)	*P**
No. cases	15	9	—
JOA score (points)			
Before surgery	13.3 ± 1.8	10.2 ± 3.6	NS
At follow-up	15.9 ± 0.9	12.9 ± 2.0	<0.01
Neurological improvement rate (%)	76.6 ± 15.9	39.2 ± 10.5	<0.001
Transverse area of the cord (mm^2)			
Before surgery	51.0 ± 4.6	41.1 ± 7.0	<0.01
At follow-up (mm^2)	71.4 ± 4.3	54.2 ± 3.9	<0.001
Expansion rate of the cord (%)	40.7 ± 8.3	34.6 ± 20.0	NS
SUV			
Before surgery	2.36 ± 0.25	1.94 ± 0.33	<0.01
At follow-up	2.17 ± 0.17	2.00 ± 0.21	<0.05

Data are mean ± standard deviation.
*By Mann-Whitney *U* test.
NS indicates not significant ($P > 0.05$).

Table 3. Changes in Signal Intensity on MRIs and Relevant Data

Clinical/Radiological Data	Grade of Increased Signal Intensity Before Surgery		
	Grade I (N/N)	Grade II (N/Hi)	Grade III (Lo/Hi)
No. cases	12	8	4
JOA score (points)			
Before surgery	13.0 ± 2.7	12.3 ± 2.6	9.50 ± 3.5
At follow-up	15.7 ± 1.7	14.8 ± 1.8	12.3 ± 1.5
Neurological improvement rate (%)	77.3 ± 19.6	55.5 ± 12.3	32.6 ± 12.1*
Transverse area of the spinal cord (mm^2)			
Before surgery	50.9 ± 6.1	46.1 ± 5.8	39.0 ± 7.2
At follow-up	70.9 ± 7.3	62.3 ± 6.9	52.4 ± 2.0*
Expansion rate of the cord (%)	39.9 ± 9.6	35.8 ± 10.7	38.4 ± 28.7
SUV			
Before surgery	2.27 ± 0.27	2.21 ± 0.39	2.01 ± 0.48
After surgery	2.14 ± 0.19	2.07 ± 0.18	2.08 ± 0.31

Data are mean ± SD.
*$P < 0.05$, compared with grade I (by Kruskal-Wallis test and Games-Howell *post hoc* test). Unmarked values denote no significant differences between grade I and grade II, grade II and grade III, and between grade II and grade III. Grade I (N/N): no intramedullary signal intensity abnormality on T1- and T2-weighted images; grade II (N/Hi): no intramedullary signal intensity abnormality on T1-weighted image and high intramedullary on T2-weighted image; grade III (Lo/Hi); low intramedullary signal intensity abnormality on T1-weighted image and high intramedullary on T2-weighted image.

increase in JOA score at follow-up (rate of neurologic improvement, 40%) and the transverse area of the cord had increased by 151% at follow-up. The average SUV was 1.56 before surgery and approached normality (1.85) at follow-up.

■ Discussion

Elucidation of factors that contribute to prognosis of patients with cervical spondylotic myelopathy and OPLL has been investigated by several groups.[4,6,19,20] Recognition of the functional capacity and functional normalization of the chronically damaged spinal cord are important clinical issues. It is important to know those factors that determine neurologic improvement after surgery. Toward this aim, we previously reviewed those factors that contribute to spinal cord neurologic reversibility in spondylotic myelopathy and OPLL, and conducted multivariate and multiple regression analyses to elucidate the significance and order of importance of those factors affecting neurologic recovery after cervical decompressions.[16] Radiologically, as suggested by others,[3–6] we studied the importance of spinal cord morphologic plasticity (restoration of lordotic alignment and postoperative expansion of the cord) as well as changes in intramedullary signal intensity and neuronal plasticity using ^{18}FDG-PET in cervical myelopathy. Increased intramedullary signal intensity of the spinal cord and cyst formation may be signs of advanced spinal cord damage,[16] since they represent diffuse neuronal cell loss, replacement by glial cells in the stroma followed by cicatrix tissue formation, as well as axonal and spongy degeneration in the white matter. Neuronal damage can be visualized also by ^{18}FDG-PET. Hence, it is clinically important to study these issues to discuss prognosis and neurologic improvement in patients amenable to neurosurgical treatment.

The spinal cord is considered to possess viscoelastic properties that allow it to restore its original configuration following decompression, and a return of physiologic function to sensorimotor pathways. However, our results in the spinal hyperostotic *twy/twy* mouse showed that long-term spinal cord compression results in reduced viscoelastic properties of the spinal cord in association with stromal fibrosis and parenchymal atrophy.[21,22] Spinal cord atrophy is associated with significantly reduced extensibility, and in the presence of profound paresis the spinal cord fails to restore its original configuration even after anterior and/or posterior decompression. Taking into consideration these histopathological findings in chronic spinal cord compression, our group investigated previously the clinical significance of viscoelastic elasticity of the spinal cord and reported that patients who show early postoperative expansion tend to have favorable neurologic outcome.[7] On the other hand, several groups have discussed the significance of sagittal plane shift of the dural tube and expansion of the intramedullary area of the cord especially on postoperative neurologic outcome.[23,24] For example, Fukushima *et al*[25] reported that significant restoration of the transverse area correlated with neurologic function even in patients with cervical myelopathy and an area measuring <45 mm^2 on MRI. Furthermore, Yone *et al*[26] reported that increment in the sagittal diameter of the spinal cord correlated with better surgical results. The present study showed that patients with better neurologic improvement (group A) had significant postoperative ex-