Background

Perioperative stroke is a rare but devastating complication which can lead to prolonged hospital stay, persistent neurological impairment, and even death [1–3]. The majority of perioperative strokes are classified as ischemic stroke [4–6], though hemorrhagic strokes have also been reported. Known risk factors for perioperative stroke include advanced age, history of stroke, carotid stenosis, and atherosclerosis of the ascending aorta [1, 3, 5, 7–12]. The risk of perioperative stroke is also known to vary according to the type and complexity of the surgical procedure [3, 8, 10, 13–16].

Despite its significant impact on clinical outcomes, the available information on perioperative strokes following spinal surgery is limited, presumably owing to its rarity [17–21]. Although recent studies estimated the incidence to be 0.05–0.1 % [17, 18], the precise incidence remains unclear. In addition, the pathomechanism of perioperative stroke following spinal surgery remains largely unknown. Although a possible association between postoperative intracranial hemorrhage and cerebrospinal fluid (CSF) leakage subsequent to durotomy has been discussed in several case reports [17, 22–26], this remains to be established.

The purposes of this retrospective analysis using a Japanese national administrative database were: 1) to investigate the incidence of perioperative stroke during hospitalization in patients undergoing elective spinal surgery; and 2) to examine whether its incidence varies among different surgical procedures. We hypothesized that the procedures requiring durotomy (i.e., the resection of spinal tumor) would carry increased risk of perioperative stroke compared with the other procedures.

Methods

Data source

This study used data from the Japanese Diagnosis Procedure Combination (DPC) database [27–32], which includes administrative claims data and discharge abstract data from hospitals across Japan. All 82 university hospitals are obliged to contribute to this system, but adoption by community hospitals is voluntary. In 2011, approximately 50 % of all acute-care admissions in Japan were included in the DPC. The database includes the following information: unique identifier of the hospital and type of hospital (teaching or non-teaching); patient age and sex; main diagnoses; surgical procedures; comorbidities at admission and complications after admission recorded according to the International Classification of Diseases, 10th Revision (ICD-10) codes; length of stay; and in-hospital death. Preexisting comorbidities at admission and complications occurring after admission are recorded separately in the DPC database. The anonymous nature of the data allowed the requirement for informed consent to be waived. Study approval was obtained from the Institutional Review Board of The University of Tokyo.

Patient selection and data

We extracted patient data from the DPC for the period July 1, 2007 to March 31, 2012 for a total of 39 months: July 1 to December 31 of 2007–2010, January 1 to December 31 of 2011, and January 1 to March 31 of 2012 (DPC data were compiled in collaboration with the Ministry of Health, Labour and Welfare between July and December in 2007–2010 and have been compiled throughout the year since January 2011). We included patients aged 20 years or older who underwent elective spinal surgery (discectomy, decompression surgery, fusion surgery, resection of a spinal cord tumor). Patients requiring emergency admission and patients with a metastatic spinal tumor as the primary diagnosis were excluded from the study. The site of surgery was classified as cervical, thoracic, and lumbosacral. We assessed the patients' clinical characteristics, including age, sex, comorbidities at admission, blood transfusion, length of stay, and type of hospital. Comorbidities at admission included a history of cardiac disease (angina, myocardial infarction, and heart failure), diabetes, hypertension, and a history of stroke.

Outcomes

The outcomes included perioperative stroke (ICD-10 codes: I60-63) during hospitalization and in-hospital death. We further classified strokes into two categories: hemorrhagic (I60-62) and ischemic (I63).

Statistical analyses

Continuous variables were compared using analyses of variance or the Kruskal-Wallis test, as appropriate, and proportions were compared using the Chi-square test or Fisher's exact test. Multivariate logistic regression analysis was performed to determine factors associated with the occurrence of perioperative stroke. Because the data were clustered hierarchically (hospital and patient levels), we fitted the regression model with a generalized estimation equation to adjust for within-hospital clustering [33]. Variables that exhibited a significant difference in the univariate analysis were entered into a multivariate logistic regression analysis. The predefined significance for inclusion in the next step of the regression model was $p \leq 0.10$. All statistical analysis were conducted using IBM SPSS version 19.0 (IBM Corp., Armonk, NY, USA). The threshold for significance was a p-value < 0.05.

Results

A total of 167,106 patients were identified (98,445 male, 68,661 female). The mean age was 64.1 years (range, 20 to 101 years). The most common surgical procedure was decompression surgery (84,540 patients; 50.6 %), followed by arthrodesis surgery (52,784; 31.6 %), discectomy (24,595; 14.7 %), and resection of a spinal cord tumor (5187; 3.1 %). The most common surgical level was lumbar (109,669; 65.6 %). Table 1 presents the characteristics of the study participants according to the surgical procedures.

Overall, perioperative stroke occurred in 371 patients (0.22 %) during hospitalization (Table 2). Of these, hemorrhagic stroke occurred in 53 patients (14.2 %) and ischemic stroke in 318 patients (85.7 %). Eighteen patients died of stroke and the case-fatality rate was 4.9 % (18/371).

Table 3 shows the results of the multivariate logistic regression analysis for perioperative stroke. Perioperative stroke was associated with resection of a spinal tumor. Patients who underwent resection of a spinal cord tumor (reference) had a higher risk of stroke compared with those undergoing discectomy (odds ratio (OR), 0.29; 95 % confidence interval (CI), 0.14–0.58; $p = 0.001$), decompression surgery (OR, 0.44; 95 % CI, 0.26–0.73; $p = 0.001$), or arthrodesis surgery (OR, 0.55; 95 % CI, 0.34–0.90); $p = 0.02$). Advanced age (≥80 years; OR, 5.66; 95 % CI, 3.10–10.34; $p \leq 0.001$), a history of cardiac disease (OR, 1.58; 95 % CI, 1.10–2.26; $p = 0.01$), diabetes (OR, 1.73; 95 % CI, 1.36–2.20; $p \leq 0.001$), hypertension (OR, 1.53; 95 % CI, 1.18–1.98; $p = 0.001$), cervical spine surgery (OR, 1.44; 95 % CI, 1.09–1.90; $p = 0.01$), surgery in a teaching hospital (OR, 1.36; 95 % CI, 1.01–1.82; $p = 0.04$), and length of stay (OR, 1.008; 95 % CI, 1.005–1.010; $p \leq 0.001$) were also identified as risk factors for perioperative stroke.

We further examined the proportion of hemorrhagic stroke among perioperative stroke in every surgical procedure. Among perioperative stroke, the proportion of hemorrhagic stroke following elective spinal surgery was 14.3 % (53/371). The proportion of hemorrhagic stroke among perioperative stroke following resection of a spinal tumor was 36.8 % (7/19), which was significantly higher compared with other procedures (vs 46/352, $p = 0.01$, Fisher's exact test).

Table 1 Characteristics of the study population according to surgical procedures (*N* (%))

	Overall (*N* = 167,106)		Resection of spinal cord tumor (*N* = 5187)		Discectomy (*N* = 24,595)		Decompression surgery (*N* = 84,540)		Arthrodesis surgery (*N* = 52,784)		*p*-value[a]
Age, years; mean [SD]	64.1	[14.3]	57.1	[15.8]	50.2	[17.0]	68.2	[11.3]	64.8	[12.8]	<0.001
≤49	26,449	(15.8)	1607	(31.0)	12,395	(50.4)	5663	(6.7)	6784	(12.9)	<0.001
50–59	24,253	(14.5)	993	(19.1)	4088	(16.6)	10,937	(12.9)	8235	(15.6)	
60–69	45,030	(26.9)	1307	(25.2)	4269	(17.4)	23,881	(28.2)	15,573	(29.5)	
70–79	54,107	(32.4)	1011	(19.5)	2902	(11.8)	32,353	(38.3)	17,841	(33.8)	
≥80	17,267	(10.3)	269	(5.2)	941	(3.8)	11,706	(13.8)	4351	(8.2)	
Sex											
Male	98,445	(58.9)	2590	(49.9)	15,866	(64.5)	53,808	(63.6)	26,181	(49.6)	<0.001
Female	68,661	(41.1)	2597	(50.1)	8729	(35.5)	30,732	(36.4)	26,603	(50.4)	
Level of surgery											
Cervical	35,042	(21.0)	564	(10.9)	357	(1.5)	24,596	(29.1)	9525	(18.0)	<0.001
Thoracic	3582	(2.1)	465	(9.0)	345	(1.4)	822	(1.0)	1950	(3.7)	
Lumbosacral	10,9669	(65.6)	884	(17.0)	23,266	(94.6)	50,326	(59.5)	35,193	(66.7)	
Unspecified	18,813	(11.3)	3274	(63.1)	627	(2.5)	8796	(10.4)	6116	(11.6)	
History of cardiac disease	12,332	(7.4)	180	(3.5)	833	(3.4)	7356	(8.7)	3963	(7.5)	<0.001
Diabetes	27,052	(16.2)	453	(8.7)	2367	(9.6)	15,925	(18.8)	8307	(15.7)	<0.001
Hypertension	32,753	(19.6)	740	(14.3)	2511	(10.2)	18,947	(22.4)	10,555	(20.0)	<0.001
History of stroke	3807	(2.3)	70	(1.3)	217	(0.9)	2337	(2.8)	1183	(2.2)	<0.001
Hemodialysis	3340	(2.0)	65	(1.3)	147	(0.6)	1638	(1.9)	1490	(2.8)	<0.001
Blood transfusion	10,382	(6.2)	265	(5.1)	100	(0.4)	2091	(2.5)	7926	(15.0)	<0.001
Teaching institution	35,821	(21.4)	2891	(55.7)	3185	(12.9)	16,652	(19.7)	13,093	(24.8)	<0.001
Length of stay, days, median [IQR]	21	[16–30]	23	[17–33]	16	[12–22]	21	[16–28]	25	[19–37]	<0.001

[a]*p*-value relating to comparison between four groups including resection of spinal cord tumor, discectomy, decompression surgery, and arthrodesis surgery
SD standard deviation, *IQR* interquartile range

Table 2 Perioperative stroke following elective spinal surgery

	Perioperative stroke (*N* (%))						
	Overall		*p*-value*	Hemorrhagic		Ischemic	
Total	371 (0.2)	(0.22)		53	(0.03)	318	(0.19)
Age, years			<0.001				
≤49	15	(0.06)		6	(0.02)	9	(0.03)
50–59	29	(0.12)		8	(0.03)	21	(0.09)
60–69	85	(0.19)		14	(0.03)	71	(0.16)
70–79	156	(0.29)		18	(0.03)	138	(0.26)
≥80	86	(0.50)		7	(0.04)	79	(0.46)
Sex			0.23				
Male	207	(0.21)		30	(0.03)	177	(0.18)
Female	164	(0.24)		23	(0.03)	141	(0.21)
Surgical procedures			<0.001				
Resection of spinal cord tumor	19	(0.37)		7	(0.13)	12	(0.23)
Discectomy	16	(0.07)		6	(0.02)	10	(0.04)
Decompression surgery	193	(0.23)		18	(0.02)	175	(0.21)
Arthrodesis surgery	143	(0.27)		22	(0.04)	121	(0.23)
Cervical spinal surgery	99	(0.28)	0.008	13	(0.04)	86	(0.25)
Others	272	(0.21)		40	(0.03)	232	(0.18)
History of cardiac disease	60	(0.49)	<0.001	6	(0.05)	54	(0.44)
No history	311	(0.20)		47	(0.03)	264	(0.17)
Diabetes	110	(0.41)	<0.001	9	(0.03)	101	(0.37)
No history	261	(0.19)		44	(0.03)	217	(0.15)
Hypertension	129	(0.39)	<0.001	17	(0.05)	112	(0.34)
No history	242	(0.18)		36	(0.03)	206	(0.15)
History of stroke	5	(0.13)	0.29	1	(0.03)	4	(0.11)
No history	366	(0.22)		52	(0.03)	314	(0.19)
Hemodialysis	15	(0.45)	0.01	4	(0.12)	11	(0.33)
No hemodialysis	356	(0.22)		49	(0.03)	307	(0.20)
Blood transfusion	52	(0.50)	<0.001	9	(0.09)	43	(0.41)
No transfusion	319	(0.20)		44	(0.03)	275	(0.18)
Teaching institution	107	(0.30)	0.001	17	(0.05)	90	(0.25)
Non-teaching institution	264	(0.20)		36	(0.03)	228	(0.17)

Discussion

This study had three main findings. First, the incidence of perioperative stroke during hospitalization after elective spinal surgery was 0.22 %. Second, resection of a spinal cord tumor was associated with increased risk of perioperative stroke compared with other procedures. Finally, resection of a spinal cord tumor was associated with a higher incidence of hemorrhage stroke. The analysis of a nationwide database enabled us to investigate the incidence of this rare but devastating complication after elective spinal surgery and to evaluate its relevant risks.

Our findings were in line with previous reports, which showed the incidence of perioperative stroke following spinal surgery was 0.05–0.1 % [17, 18]. Smith et al. examined 108,419 procedures obtained from the Scoliosis Research Society Morbidity and Mortality database [19], which had a comparable sample size to that of our study. However, the exact incidence of postoperative stroke was not clear in that study, because the authors only reported fatal cases. To our knowledge, this study was the first report to compare the incidence of perioperative stroke following spinal surgery with different surgical procedures.

In the literature, perioperative stroke after surgery has been predominately classified as ischemic stroke [4–6]. Hemorrhagic stroke accounts for only 1 % of strokes

Table 3 Adjusted risk of perioperative stroke after elective spinal surgery

	Perioperative stroke		
	OR	95 % CI	*p*-value
Age			
≤49	Reference		
50–59	1.61	0.87–2.97	0.13
60–69	2.27	1.31–3.94	0.004
70–79	3.41	1.91–6.07	<0.001
≥80	5.66	3.10–10.34	<0.001
Sex			
Male	Reference		
Female	0.98	0.78–1.23	0.88
Surgical procedures			
Resection of a spinal cord tumor	Reference		
Discectomy	0.29	0.14–0.58	0.001
Decompression surgery	0.44	0.26–0.73	0.001
Arthrodesis surgery	0.55	0.34–0.90	0.02
Cervical spinal surgery	1.44	1.09–1.90	0.01
History of cardiac disease	1.58	1.10–2.26	0.01
Diabetes	1.73	1.36–2.20	<0.001
Hyper tension	1.53	1.18–1.98	0.001
Hemodialysis	1.51	0.88–2.59	0.13
Blood transfusion	1.23	0.83–1.82	0.30
Teaching institution	1.36	1.01–1.82	0.04
Length of stay (days)	1.01	1.01–1.01	<0.001

OR odds ratio, *CI* confidence interval

occurring after coronary artery bypass grafting surgery [2]. In our study, we observed a higher percentage of hemorrhagic stroke following elective spinal surgery (14.3 %), which suggested that the pathomechanism of perioperative stroke varies according to the type of surgical procedure.

The current study showed that resection of a spinal cord tumor, requiring dural incision to access the tumor, had a higher risk of perioperative hemorrhagic stroke. Although intracranial hemorrhage after spinal surgery complicated by CSF leakage has been reported [17, 22–26], the mechanism of this complication remains speculative. In the presence of CSF leakage, the postulated pathophysiology in previous case reports was that an increase in transluminal venous pressure caused by intracranial hypotension from CSF loss may have resulted in blood vessel rupture [25]. Another possibility is that downward cerebellar sag causes stretching and occlusion of the bridging cerebellar veins [34]. Further investigations are needed to clarify the mechanism of intracranial hemorrhage after spinal surgery in order to prevent this catastrophic complication.

The results of this study showed that cervical spine surgery was also associated with the risk of perioperative stroke. Although cervical spine injury was reported to be a risk factor for blunt cerebrovascular injury [28, 35–37], a large-scale study on the relationship between elective spinal surgery at the cervical region and perioperative stroke has never been reported. However, a few reports regarding the impact of prolonged retraction during cervical anterior spinal surgery on carotid artery blood flow were reported [38, 39]. Moreover, Lunardini et al. showed, in their survey of 163,324 cervical spinal surgeries, that cerebellar infarction occurred in 5.5 % of patients with intraoperative vertebral artery injury [40]. Cervical spinal surgery, with a potential risk of intraoperative vertebral artery injury, may carry a higher risk for perioperative stroke.

There are a few limitations of this study. First, we were unable to investigate strokes occurring after discharge because of the lack of available data. However, according to OECD data, the national average length of hospital stay in Japan is 17.5 days, which is much longer than in other countries [41]. In Japan, hospitals often provide both early postoperative care and subsequent rehabilitation in a single hospitalization. Therefore, we believe that the follow-up period in this study, with a median of 21 days, was sufficient to detect the majority of strokes occurring after surgery, because most perioperative strokes reportedly occur within a few days after surgery. Indeed, approximately 45 % of perioperative strokes are reported within the first day after surgery [14, 42]. Second, the DPC database does not provide detailed clinical information such as severity of preoperative neurological symptoms, the level of fusion, and the presence of an incidental dural tear during spinal surgery. For instance, the DPC database does not include the "surgical level" as an entry field. In this analysis, we determined the surgical level based on the patients' primary diagnosis (i.e., patients with lumbar spinal stenosis as their primary diagnosis were designated to have had lumbar spine surgery). In addition, we were unable to definitely differentiate intradural and extradural tumors from the DPC data. However, we excluded patients with metastatic spinal tumors, which have been reported to account for around 90 % of extradural spinal tumors [43, 44]. We believe the results of this study were unlikely to be affected by any unrecognized cases of extradural spinal tumor in this analysis. Third, the coded diagnoses may be less well validated than in a prospective survey because of possible misclassification or underreporting. However, we believe the rate of miscoding was relatively low because the diagnoses were recorded by the attending physicians. Finally, there may be some selection bias because of differences in participation rates between academic hospitals, which all contribute to the DPC database, and community hospitals, which only contribute voluntarily.

Conclusions

This study revealed that perioperative stroke occurred in 0.22 % of patients who underwent elective spinal surgery. Resection of a spinal cord tumor was associated with a higher risk of perioperative stroke compared with other surgical procedures as well as advanced age, comorbidities at admission, cervical spine surgery, surgery in a teaching hospital, and length of stay. We believe the findings of this study provide useful information for a better understanding of the risk of perioperative stroke following elective spinal surgery.

Competing interests

Each author certifies that they have no commercial associations that might pose a conflict of interest in connection with the submitted article.

Authors' contributions

JO, HC, KT and ST contributed to the conception and design of the study. JO, HC, TO, HH, and HY contributed to the analysis, and all authors contributed to the interpretation of the results. JO drafted the article; all authors revised it critically and approved the final version submitted for publication. All authors read and approved the final manuscript.

Authors' information

Not Applicable.

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Clinical Study

Phosphorylated neurofilament subunit levels in the serum of cervical compressive myelopathy patients

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ABSTRACT

We investigated the serum levels of the phosphorylated form of the high molecular weight neurofilament subunit (pNF-H) in patients with cervical compressive myelopathy. pNF-H is becoming increasingly recognized as a biomarker for axonal injury, however, it remains unclear whether serum pNF-H is elevated in chronic spinal cord compression. We examined 26 patients who underwent surgery for cervical compressive myelopathy. Peripheral blood samples were obtained both preoperatively and 1 week after surgery to evaluate the serum pNF-H levels using an enzyme-linked immunosorbent assay. A history of recent aggravation of myelopathy was also investigated. Of the 26 myelopathy patients, the preoperative serum pNF-H level was negative in 20 patients and moderately elevated in six. Patients who were positive for pNF-H were more likely to have had a recent aggravation of myelopathy compared with the pNF-H negative patients (83 *versus* 25%; $p = 0.02$). All patients who were positive for pNF-H before surgery remained positive after surgery. Two patients who became positive after surgery demonstrated a neurologic deterioration associated with the surgery. In conclusion, the serum pNF-H level was negative in the majority of patients with cervical compressive myelopathy. Our results suggest that an elevated serum level of pNF-H is associated with an acute worsening of myelopathy and that a positive conversion of pNF-H after surgery is a marker of perioperative neural damage.

1. Introduction

Attempts have been made to establish a method for the quantitative evaluation of neural tissue damage using proteins derived from damaged neurons as biomarkers [1–3]. The phosphorylated form of the high molecular weight neurofilament subunit (pNF-H) is an axonal cytoskeleton protein, and it was first reported to be a potential biomarker in 2005 [4]. pNF-H, which is absent in the serum of healthy individuals [5], is known to appear in the serum of patients with various pathologies, including traumatic brain injury, subarachnoid hemorrhage, and febrile seizures [6–9]. More recently, the potential usefulness of pNF-H as a biomarker to evaluate the severity and prognosis of acute traumatic spinal cord injury (SCI) has been reported [10,11].

In pathological conditions associated with acute neural damage, such as traumatic SCI, direct destruction of neural tissue results in the leakage of pNF-H beyond the blood brain barrier and into the peripheral blood. But the association of pNF-H with chronic cord compression pathologies has not been investigated. As SCI sometimes occur due to conditions causing a narrow spinal canal and preexisting cord compression [12,13], understanding the baseline levels of pNF-H in patients with chronic spinal cord compromise is important to better estimate the incremental damage of neural tissue attributable to trauma. In this pilot study, we sought to investigate the role of serum pNF-H in patients with cervical compressive myelopathy.

2. Materials and methods

2.1. Patients

We prospectively and consecutively enrolled patients who underwent decompression surgery for cervical compressive myelopathy at our institution between April 2013 and March 2014. The surgical indication was determined by the senior surgeon according to the clinical symptoms and radiographical findings. Excluded patients included those with systemic diseases

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that could potentially affect the cervical spine and compromise the neurological assessment, including autoimmune diseases, chronic renal failure with hemodialysis, and neurological disorders including Parkinson's disease, cerebral palsy, and myasthenia gravis. The preoperative and 3 month postoperative severity of myelopathy was evaluated using the modified Japanese Orthopaedic Association (mJOA) score [14]. The score ranges from 0 to 18. The recovery rate was calculated using the following formula (Hirabayashi method): recovery rate (%) = (postoperative mJOA – preoperative mJOA)/(18 – preoperative JOA) × 100 [15]. The medical charts were reviewed for the duration of the myelopathic symptoms and their acute aggravation (defined as those observed within 3 months). All patients underwent preoperative MRI, and signal intensity change in the spinal cord was also investigated. Although increased signal intensity on the T2-weighted image is indicative of myelopathy [16], it was not regarded as necessary to recommend surgery. Patients with idiopathic scoliosis without cord compromise, as confirmed by myelography and MRI, were used as a control group.

2.2. Samples and pNF-H assay

In the myelopathy group, blood samples were obtained preoperatively and 1 week after surgery. Some patients were discharged within 1 week and their postoperative blood samples were not available. In the control group, samples were obtained preoperatively. All blood samples were centrifuged to extract the serum, and then stored in a freezer until the measurements were performed. The pNF-H assay was carried out using a commercially available enzyme-linked immunosorbent assay kit (Human Phosphorylated Neurofilament H ELISA; BioVendor, Modrice, Czech Republic), as previously described [11]. The frozen plasma samples were allowed to thaw and were then diluted three-fold with a dilution buffer. The limit of detection was calculated from the mean absorbance of the blank (dilution buffer only) plus three standard deviations of the absorbance of the blank. The values of pNF-H below the limit of detection (70 pg/mL) were reported as negative for the statistical analyses.

2.3. Statistical analyses

All analyses were carried out using SPSS software (version 19; IBM Corporation, Armonk, NY, USA). For comparisons of the parameters between the groups, the Mann–Whitney U-test was used for continuous variables, and Fisher's exact test for proportions. p values less than 0.05 were considered significant for all statistical tests.

2.4. Ethics

The patients were educated about the study protocol on admission, and written consent was obtained from all enrolled patients or their parents if they were minors. The study was approved by the Institutional Review Board. We certify that all applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed during the course of this research.

3. Results

3.1. Patient characteristics

A total of 26 myelopathy patients and eight control patients were consecutively enrolled (Table 1). In the myelopathy group, there were 19 men and seven women with a mean age of 64.4 years (range: 38–86). The most common diagnosis was cervical spondylotic myelopathy (14 patients), followed by ossification of the posterior longitudinal ligament (nine patients) and cervical disc herniation (three patients). The control group consisted of one male and seven females with idiopathic scoliosis. The mean age was 17.9 years (range: 11–27), significantly younger than that of the myelopathy group ($p < 0.001$). All patients in the control group were neurologically intact.

3.2. Preoperative serum pNF-H levels

Of the 26 myelopathy patients, the preoperative serum pNF-H was negative in 20 patients (77%) and moderately elevated in six (range: 115–458 pg/mL). Control samples (n = 8) were all negative for pNF-H. Overall, the median duration of symptoms was 10 months (range: 1 month–13 years). The pNF-H positive group tended to have a shorter duration of symptoms compared with the pNF-H negative group (median 3.5 *versus* 12 months, respectively; $p = 0.07$), although this difference did not reach statistical significance. Patients with elevated pNF-H levels were more likely to have had a recent aggravation of myelopathy within the 3 months prior to the measurement (5/6 [83%] *versus* 5/20 [25%]; $p = 0.02$). In addition, patients with elevated pNF-H levels were more likely to have a lower preoperative mJOA score compared with pNF-H negative patients (median 10.5 *versus* 13.0; $p = 0.005$). The recovery rates of mJOA were not significantly different between the two groups (median 28% *versus* 20%; $p = 0.84$). Regarding the signal intensity change on T2-weighted MRI, there was no significant difference between the two groups (positive group: 5/6 [83%]; negative group: 13/20 [65%]; $p = 0.62$).

3.3. Postoperative serum pNF-H levels

Postoperative blood samples were available for 18 myelopathy patients. Among the 20 myelopathy patients with negative preoperative pNF-H levels, 14 were followed at 1 week postoperatively and their pNF-H levels remained negative in 12; two patients were positive. In one of the positive patients (Patient 5), the postoperative pNF-H level increased to 626 pg/mL. In addition, their intraoperative spinal cord monitoring showed an abnormally low amplitude during the fixation procedure, and the patient developed transient upper limb weakness after surgery. In the other (Patient 25), the patient underwent anterior decompression and fusion and the postoperative pNF-H level increased to 163 pg/mL. On the fourth postoperative day, the patient developed autograft dislodgement and pain in both the upper and lower extremities, requiring revision surgery. Among the six myelopathy patients with positive preoperative pNF-H levels, four were followed-up at 1 week after surgery. All four patients remained positive for pNF-H after surgery. The recovery rates (mJOA) were not different between those with and without elevated pNF-H levels (median 20% *versus* 20%; $p > 0.99$).

4. Discussion

There are two major findings in the present study. First, the serum pNF-H was negative in the majority of patients with cervical compressive myelopathy, as well as in the control patients. Patients who were positive for pNF-H were more likely to have had a recent aggravation of myelopathy compared with the pNF-H negative patients. Second, in most patients, the serum pNF-H level remained unchanged before and after surgery. Therefore, a postoperative elevation of serum pNF-H may be associated with the insult to the spinal cord during surgery.

Table 1
Patient demographics and pre and postoperative serum pNF-H levels

Patient	Age, years	Sex	Diagnosis	Duration of symptoms (months)	Progress in 3 months	Preoperative mJOA	Postoperative mJOA	MRI signal intensity change	Preoperative pNF-H (pg/mL)[a]	Surgical procedure	Postoperative pNF-H (pg/mL)[a]	Remarks
1	65	F	OPLL	24	–	13	14	–	0	LN	0	
2	45	M	CSM	7	–	12	15	–	0	LP	0	
3	42	M	CSM	8	–	17	18	–	0	ADF	0	
4	80	M	OPLL	3	+	10	11	+	458	LP	348	
5	49	F	OPLL	146	+	13	14	+	0	LF	626	Abnormal MEP
6	79	M	CSM	3	+	11	14	+	196	LP	468	
7	77	M	CSM	4	–	13	13	+	0	LN	0	
8	40	M	CDH	6	–	17	N/A	+	0	LP	0	
9	78	F	CSM	12	–	13	14	+	0	LN	0	
10	61	M	OPLL	72	+	15	N/A	+	0	LP	0	
11	75	M	OPLL	23	–	11	11	+	0	LN	0	
12	63	M	OPLL	2	+	17	N/A	–	0	LP	0	
13	81	F	CSM	4	–	11	N/A	+	0	LN	0	
14	66	M	CSM	9	–	16	18	–	0	LN	N/A	
15	77	F	CSM	12	–	11	N/A	–	0	LN	N/A	
16	69	M	CSM	11	+	7	N/A	+	122	LP	131	
17	41	M	CSM	12	+	15	16	+	0	LN	N/A	
18	38	M	CDH	4	–	17	15	+	0	ADF	N/A	
19	55	M	CDH	36	–	12	16	–	0	ADF	N/A	
20	86	M	CSM	12	–	11	N/A	+	0	LN	0	
21	70	M	OPLL	156	–	15	N/A	+	0	LP	0	
22	69	M	OPLL	9	–	9	N/A	+	0	LF	N/A	
23	83	M	CSM	1	+	9	N/A	+	211	LP	351	
24	64	M	CSM	4	–	11	N/A	–	159	LP	N/A	
25	49	F	OPLL	12	+	12	N/A	+	0	ADF	163	Graft dislodgement
26	71	F	CSM	36	+	12	N/A	+	115	LN	N/A	
27	11	F	AIS[b]						0			
28	14	F	AIS[b]						0			
29	24	M	AIS[b]						0			
30	19	F	AIS[b]						0			
31	16	F	AIS[b]						0			
32	13	F	AIS[b]						0			
33	27	F	AIS[b]						0			
34	19	F	AIS[b]						0			

[a] Values "0" of pNF-H level indicate that the level was below the limit of detection (70 pg/mL).
[b] AIS patients = controls.
+ = positive, – = negative, ADF = anterior decompression & fusion, AIS = adolescent idiopathic scoliosis, CDH = cervical disc herniation, CSM = cervical spondylotic myelopathy, F = female, LF = laminectomy and fusion, LN = laminectomy, LP = laminoplasty, M = male, MEP = motor evoked potential, mJOA = modified Japanese Orthopaedic Association score, N/A = not available, OPLL = ossification of the posterior longitudinal ligament, pNF-H = phosphorylated high molecular weight neurofilament subunit.

4.1. Implications of a preoperative pNF-H elevation in myelopathy patients

In line with previous studies [5], serum pNF-H levels of the control patients in our study were negative. Similarly, we found that serum pNF-H levels were also negative in the vast majority of patients with chronic cervical compressive myelopathy, which is known to progress gradually in nature [17]. Only a quarter of the patients with cervical myelopathy were found to be pNF-H positive. Patients with cervical myelopathy may have varying patterns of symptom progression; myelopathic symptoms sometimes deteriorate in a stepwise manner [18]. Interestingly, patients with elevated pNF-H levels were more likely to have had a recent aggravation of myelopathy compared with those who were negative for pNF-H. Therefore, an elevation of the serum pNF-H level may be associated with trigger events or minor trauma to the spinal cord, which could be caused by disc bulging, ligamentum flavum thickening, osteophyte formation or spinal instability at some point before presentation. Presumably, the serum pNF-H level increases due to cord damage, and thereafter it decreases gradually, eventually normalizing to a negative level in the chronic stage. This is in line with the chronological change observed in the pNF-H levels of the rat SCI model [4], and that of other biomarkers in humans [3]. However, pNF-H can be detectable in the cerebrospinal fluid of chronic cervical myelopathy patients [19].

4.2. Clinical usefulness of preoperative pNF-H measurements

Judging from the serum pNF-H levels found in the present myelopathy patients, extremely high pNF-H values may preclude the diagnosis of chronic cervical myelopathy and pNF-H may be useful for distinguishing chronic compressive myelopathy from other neurological disorders that are known to be associated with higher levels of pNF-H [5]. Of note, pNF-H is elevated in serum from patients with amyotrophic lateral sclerosis, a condition which has been misdiagnosed as cervical myelopathy in the past [5,20].

The diagnostic value of elevated pNF-H levels at single-point measurements is limited, because such an elevation may be affected by the time interval from a traumatic event. Therefore, we believe that repeated measurements are required in the diagnostic process, to obtain reliable information for clinical decision making. This would also be helpful for patients with rheumatoid arthritis [21] and athetoid cerebral palsy [22], for whom precise neurological assessments are notoriously difficult to interpret because of their preexisting conditions.

4.3. Implications of a postoperative pNF-H elevation

In the present series, we observed a postoperative elevation of the serum pNF-H level in two patients who were suspected to have had perioperative neurological complications. Marquardt et al. reported that serial measurement of these biomarkers could be meaningful for surgically treated cervical myelopathy patients [23]. Similarly, serial measurements of pNF-H may be useful for detecting or monitoring potential insults to the neural elements.

4.4. Limitations

There are several limitations associated with this study. First limitation is that only a small number of patients were enrolled. Since a preoperative pNF-H elevation in cervical myelopathy was relatively rare, further studies are warranted to determine its precise clinical relevance. Unfortunately, we failed to obtain postoperative samples from eight patients who were discharged within 1 week. Because our aim was to avoid extension of the hospital stay as much as possible, and minimize the need for patients to return immediately after discharge, we did not obtain blood samples from these eight patients. Second, we measured the pNF-H level at only two time points. Repeated measurements over time would provide additional, useful information. Also, we did not obtain postoperative samples from the control patients. Although the operation itself is unlikely to affect the postoperative serum pNF-H level, given the negative results in the majority of the myelopathy patients, the negative control may have provided further support to this speculation.

5. Conclusion

In the present study, the serum pNF-H level was negative in the vast majority of patients with cervical compressive myelopathy. Our results suggest that an elevated serum pNF-H is associated with an acute worsening of myelopathy. The results also indicate that postoperative elevation can be used as a marker of perioperative neural damage.

Conflicts of Interest/Disclosures

The authors declare that they have no financial or other conflicts of interest in relation to this research and its publication.

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PLOS | ONE

RESEARCH ARTICLE

Comparison of the Japanese Orthopaedic Association (JOA) Score and Modified JOA (mJOA) Score for the Assessment of Cervical Myelopathy: A Multicenter Observational Study

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Abstract

Objectives

The Japanese Orthopaedic Association (JOA) score is widely used to assess the severity of clinical symptoms in patients with cervical compressive myelopathy, particularly in East Asian countries. In contrast, modified versions of the JOA score are currently accepted as the standard tool for assessment in Western countries. The objective of the present study is to compare these scales and clarify their differences and interchangeability and verify their validity by comparing them to other outcome measures.

Materials and Methods

Five institutions participated in this prospective multicenter observational study. The JOA and modified JOA (mJOA) proposed by Benzel were recorded preoperatively and at three months postoperatively in patients with cervical compressive myelopathy who underwent decompression surgery. Patient reported outcome (PRO) measures, including Japanese Orthopaedic Association Cervical Myelopathy Evaluation Questionnaire (JOACMEQ), the Short Form-12 (SF-12) and the Neck Disability Index (NDI), were also recorded. The preoperative JOA score and mJOA score were compared to each other and the PRO values. A Bland-Altman analysis was performed to investigate their limits of agreement.

Results

A total of ninety-two patients were included. The correlation coefficient (Spearman's rho) between the JOA and mJOA was 0.87. In contrast, the correlations between JOA/mJOA

and the other PRO values were moderate (|rho| = 0.03 – 0.51). The correlation coefficient of the recovery rate between the JOA and mJOA was 0.75. The Bland-Altman analyses showed that limits of agreement were 3.6 to -1.2 for the total score, and 55.1% to -68.8% for the recovery rates.

Conclusions

In the present study, the JOA score and the mJOA score showed good correlation with each other in terms of their total scores and recovery rates. Previous studies using the JOA can be interpreted based on the mJOA; however it is not ideal to use them interchangeably. The validity of both scores was demonstrated by comparing these values to the PRO values.

Introduction

Cervical compressive myelopathy is a common disorder that frequently results in impairment of a patient's motor, sensory and bladder function. Several scales that measure severity of physical disability have been developed to assess a patient's pre- and post-treatment condition and the effectiveness of intervention. For example, the Japanese Orthopaedic Association (JOA) score was developed by the JOA in 1975. Since then, it has become one of the most frequently used outcome measures to evaluate functional status in patients with cervical myelopathy. Furthermore, and the concept of "recovery rate," advocated by Hirabayashi et al., has been widely accepted as an outcome measure [1]. Currently, the revised version of the JOA score (1994), which includes an assessment of the shoulder and elbow function, is the most frequently used [2, 3].

One of the drawbacks of the JOA score is that it evaluates the degree of motor dysfunction by assessing a patient's ability to use chopsticks. The use of chopsticks is limited to East Asian cultures including Japanese, Korean, Chinese and Vietnamese populations. The issues associated with using questionnaires related to cultural differences in eating methods have already been reported [4, 5]. Although chopsticks are now more widely used for eating, even in Western cultures, questionnaires using chopsticks cannot be readily applied to those who have not used them, or who do not use them regularly. Therefore, the adaptation of the JOA score to a Western population requires translation as well as modification [6]. Currently, there are three different kinds of so-called "modified JOA (mJOA) scores" [7–9]. However, the translation of these scores has not been validated and the scoring structure and content of evaluation items are substantially different. Despite their differences, the JOA score and the various modified scales are frequently confused with each other, and mistakenly discussed as being the same. Few comparisons of these scales have been made in the literature and few studies have assessed the validity of these scores. This causes confusion about which scale should be used in a certain population, and prevents us from comparing results of studies that used different modifications of the JOA score.

Therefore, it is very important to compare the properties of the JOA score and the mJOA score for the assessment of cervical myelopathy; the JOA score and the mJOA score. The objective of this study is to investigate the differences in and interchangeability of the JOA score and the mJOA score and to examine the validity of these scales by assessing correlations with other patient-reported outcome measures.

Materials and Methods

The study protocol was approved by the institutional review board of the Clinical Research Support Center of the University of Tokyo Hospital. In order to secure a sufficient number of participants, we called for volunteers from our research group, "The University of Tokyo Spine Group," and recruited five medical center institutions to participate in this prospective multicenter observational study. Ten surgeons in total were involved in this study. All eligible patients provided their written informed consent to participate in this study. All patients who underwent surgery for cervical compressive myelopathy between April 2013 and March 2014 were enrolled. Those with systemic diseases, including neurological disorders and rheumatoid arthritis, that could potentially affect motor function were excluded. Preoperatively, the surgeons recorded the following two scores.

JOA score (Table A in S1 File) [2, 3]

We used the latest version of the JOA score in Japanese. This scale consists of six domain scores (motor dysfunction in the upper extremities, motor dysfunction in the lower extremities, sensory function in the upper extremities, sensory function in the trunk, sensory function in the lower extremities, and bladder function), scaled from 0 to 4, 4, 2, 2, 2, and 3, respectively, with the minimum total score being 0 and the maximum total score being 17. Yonenobu et al. defined the myelopathy severity as mild if the JOA score is larger than 13, as moderate if the JOA score ranges from 9 to 13 and as severe if the JOA score is less than 9 [3]. Motor function in the fingers was assessed based on the ability to use chopsticks and button clothing. Keller et al. published the modified version in German [9, 10]. The authors did not mention the use of cutlery, but rather simply used the term "fine motor function" for the assessment of motor function in the upper extremities. The score proposed by Chiles et al. is similar, although the authors mentioned the use of a knife and fork [8]. The recovery rate was calculated according to the following formula (Hirabayashi method): Recovery rate (%) = (postoperative JOA −preoperative JOA) / (17 [full score]—preoperative JOA) × 100 [1].

Modified JOA score (Benzel et al.) (Table B in S1 File) [7]

This scale is the most commonly used among the so-called "mJOA" scores. Its scoring system differs from that of the original JOA in that it assesses only motor dysfunction in the upper and lower extremities, sensory function in the upper extremities, and bladder function, and does not include a scale for sensory function in the trunk and lower extremities. Each scale ranges from 0 to 7, 5, 3, and 3, respectively, with a total score of 0 to 18. Fehlings et al. defined the severity of myelopathy as mild if the mJOA score is 15 or larger, moderate if the mJOA score ranges from 12 to 14 or severe if the mJOA score is less than 12 [11]. This scale focused on the use of a spoon instead of chopsticks to evaluate motor function in the upper extremities. The recovery rate is calculated using the same formula as that applied for the original JOA, changing the full score from 17 to 18.

The differences between these scores are summarized in Table 1. The JOA score allocates 8 out of 17 (47%) points of the total score to motor function, while the mJOA score allocates 12 out of 18 (67%) points of the total score to motor function. These two scores were determined by the responsible surgeons at each institution. In addition to these scores, the Japanese Orthopaedic Association Cervical Myelopathy Evaluation Questionnaire (JOACMEQ) [12], Short Form-12 (SF-12) [13] and the Neck Disability Index (NDI) [14] were recorded as patient reported outcome (PRO) measurements. These scales were completed by the patients in the form of questionnaires. The postoperative scores were recorded whenever possible at follow-up visits performed three months after surgery.

Table 1. A summary of the differences between the JOA score and modified JOA score.

	Structure							Assessment of MU
	MU	ML	SU+	ST	SL	BL	Total	
JOA [3]	4	4	2	2	2	3	17	Chopsticks
Modified JOA [7]	5	7	3	N/A	N/A	3	18	Spoon

JOA: Japanese Orthopaedic Association score, MU: motor function in the upper extremities, ML: motor function in the lower extremities, SU: sensory function in the upper extremities, ST: sensory function in the trunk, SL: sensory function in the lower extremities, BL: bladder function, N/A: not applicable

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The preoperative JOA and mJOA scores in each domain were compared with each other. The total scores were also compared with each other and to the PRO measurements. Furthermore, we compared the JOA and mJOA after dichotomizing the patients according to severity of motor function by the median of the JOA motor function scores. A prediction formula for the mJOA score was created using the JOA to enable direct comparisons between studies using these scores by converting the scores. We plotted the individual difference between the mJOA total score and the JOA total score (mJOA–JOA) against the average between the mJOA and JOA scores using a Bland–Altman plot. Bland-Altman analyses are now widely used for comparing two methods of measurement [15–19]. According to Bland and Altman, the limits of agreement can be estimated as the mean between duplicate measurements (the bias) ±1.96 SD, where the SD is the standard deviation of all of the paired differences [20]. This means that 95% of the differences will lie between these limits. Provided that differences within these lines are not clinically important, we could use the two measurement methods interchangeably. Although the minimally clinical important difference (MCID) of the JOA or mJOA has not been established, experts have argued that a difference of at least two points of mJOA is clinically important [21]. Therefore, the limits of agreement below 2 suggests the interchangeability of the two scores in the present study. Finally, among the patients whose postoperative scores at three months were available, the recovery rates for the JOA and mJOA scores were compared, and a Bland-Altman analysis was performed.

All analyses were carried out using the IBM SPSS Statistics Version 19 software package (SPSS, Inc., Somers, NY, USA). Correlations between the scores were analyzed by calculating the Spearman's rank correlation coefficient rho. P-values less than 0.05 were considered to be significant in all statistical tests. We defined the strength of the correlation according to the general guideline (rho $\geq$ 0.70: very strong, $\geq$ 0.50: strong, $\geq$ 0.30: moderate, $\geq$ 0.10: weak) [22].

Results

Ninety-two patients were included in the study. One patient whose bladder function could not be assessed due to anuria resulting from chronic renal failure was excluded. The mean age was 63.3 years (standard deviation: 12.9). The most common diagnosis indicated for surgery was cervical spondylotic myelopathy (58 patients), followed by ossification of the posterior longitudinal ligament (28 patients) and cervical disc herniation (six patients).

Comparisons of the scores in each domain

The correlations between the JOA and mJOA scores in each domain were strong to very strong, with correlation coefficients of 0.84 for motor function in the upper extremities ($p < 0.001$), 0.93 for motor function in the lower extremities ($p < 0.001$), 0.67 for sensory function in the upper extremities ($p < 0.001$) and 0.89 for bladder function ($p < 0.001$). The correlation

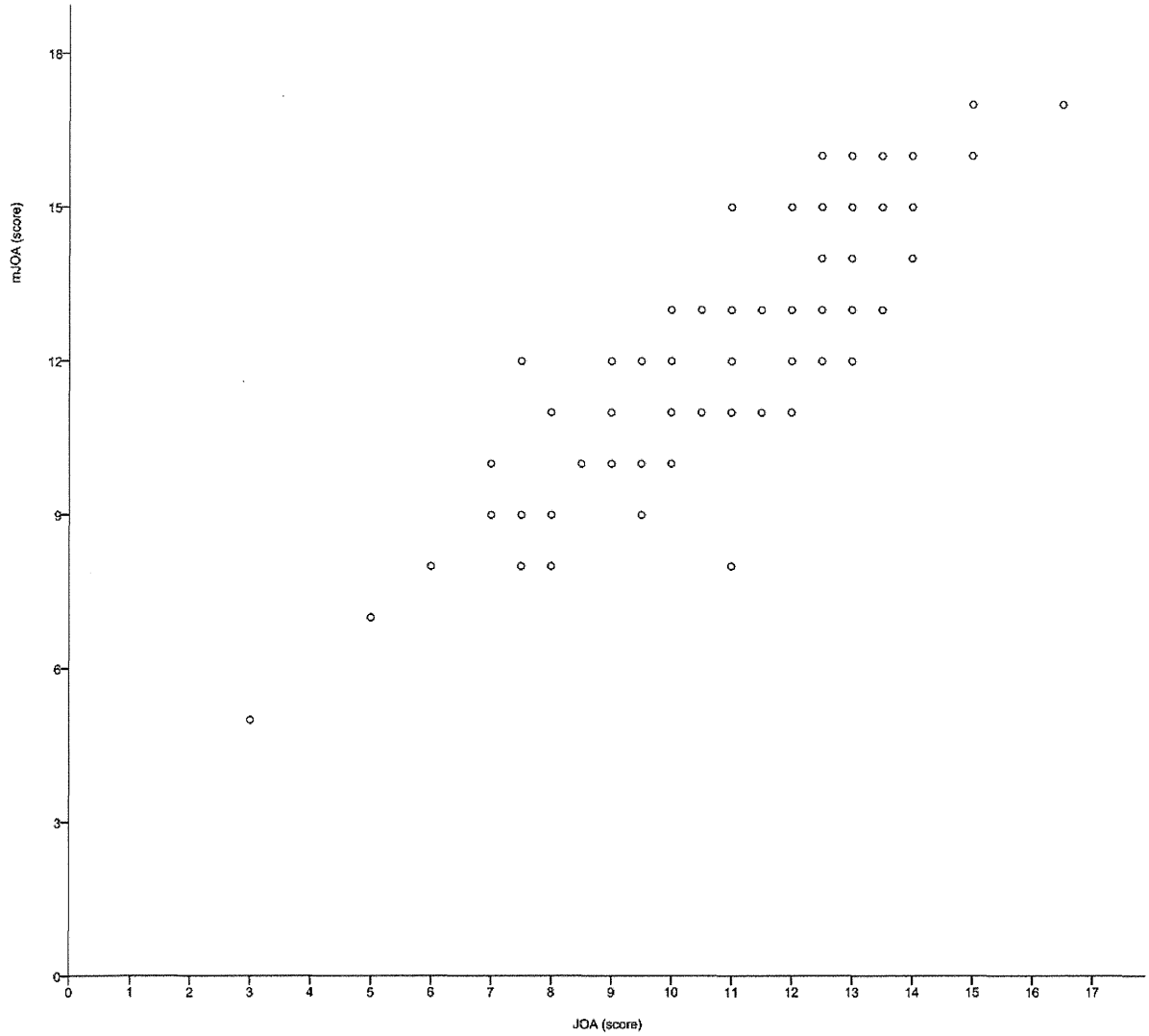

Fig 1. Scatterplot of the total scores for the JOA and mJOA scores (n = 92).

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between the total scores for motor function (the sum of the scores for the upper and lower extremities) was also very strong (rho = 0.90, p <0.001).

Total score

The mean preoperative JOA score was 11.2 (range: 3.0–16.5, standard deviation: 2.5), whereas the mean mJOA score was 12.4 (range: 5–17, standard deviation: 2.5). A scatterplot of the JOA and mJOA scores is shown in Fig 1, and the correlations between the preoperative scores are summarized in Table 2. The JOA and mJOA scores were very strongly correlated with each other (rho = 0.87, p <0.001). The median of the JOA motor function scores was 5. The correlation was found to be weaker in those with a motor function score less than 5 (n = 37,

Table 2. Correlations between the preoperative total scores among the JOA, modified JOA, JOACMEQ QOL score, SF-12 PCS, MCS and NDI (n = 92).

	JOA	Modified JOA	JOACMEQ QOL	SF-12 PCS	SF-12 MCS	NDI
JOA	1	0.87*	0.41*	0.50*	-0.05	-0.50*
Modified JOA		1	0.41*	0.47*	0.03	-0.51*
JOACMEQ			1	0.29*	0.40*	-0.66*
SF-12 PCS				1	-0.29*	-0.47*
SF-12 MCS					1	-0.17
NDI						1

* Statistical significance

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rho = 0.64) than in those with milder motor dysfunction (n = 55, rho = 0.77). On the other hand, the correlations between the JOA/mJOA scores and the other PRO values were not as strong. JOACMEQ QOL score, SF-12 PCS and NDI showed moderate correlations (|rho|: 0.41–0.51), whereas SF-12 MCS did not (|rho|: 0.03–0.05). While the very strong correlation between the JOA and mJOA scores demonstrates convergent validity, the moderate correlation with other PRO values suggests divergent validity. We created a prediction formula to calculate the total scores for the mJOA from the score of the JOA using linear regression analysis. The result is as follows:

$$\text{mJOA total} = 2.39 + 0.89 \times (\text{JOA total})$$

The R^2 of this equation was 0.78.

A Bland–Altman plot showing the differences between the two scores (mJOA–JOA) plotted against the mean of the two scores is shown in Fig 2. The mean difference between the two scores (the bias) was 1.2 (95% confidence interval: 0.9–1.5, standard deviation: 1.21). The upper and lower limits of agreement were 3.6 and -1.2, respectively. This range was well above the threshold we set based on an assumed MCID [21]; from this result, we were able to conclude that it is not ideal to interchange the JOA and mJOA.

Recovery rate (RR)

In 65 patients (71%) followed at three months postoperatively, the recovery rates were calculated using the Hirabayashi method and compared with each other. The mean JOA recovery rate was 45.1% (range: -33%– 100%, standard deviation: 30.8%), whereas the mean mJOA recovery rate was 38.2% (range: -200%– 100%, standard deviation: 43.0%). A scatterplot of the recovery rates for the JOA and mJOA is shown in Fig 3. In this figure, one outlier whose JOA RR was 0 and mJOA RR was -2.0 (deterioration), was omitted. Their correlations were very strong (rho: 0.75, $p < 0.001$). In two cases, one scale showed recovery while the other showed deterioration. Both of these patients had urinary symptoms. We created a prediction formula to calculate the mJOA RR from the JOA RR using linear regression analysis. The result is as follows:

$$\text{mJOA RR} = -0.05 + 0.95 \times (\text{JOA RR})$$

The R^2 value of this equation was 0.46.

A Bland–Altman plot showing the differences between the two recovery rates plotted against the mean of the two recovery rates is shown in Fig 4. The mean bias was -6.9% (95% confidence interval: -14.7%– 1.0%, standard deviation: 31.6%). The upper and lower limits of

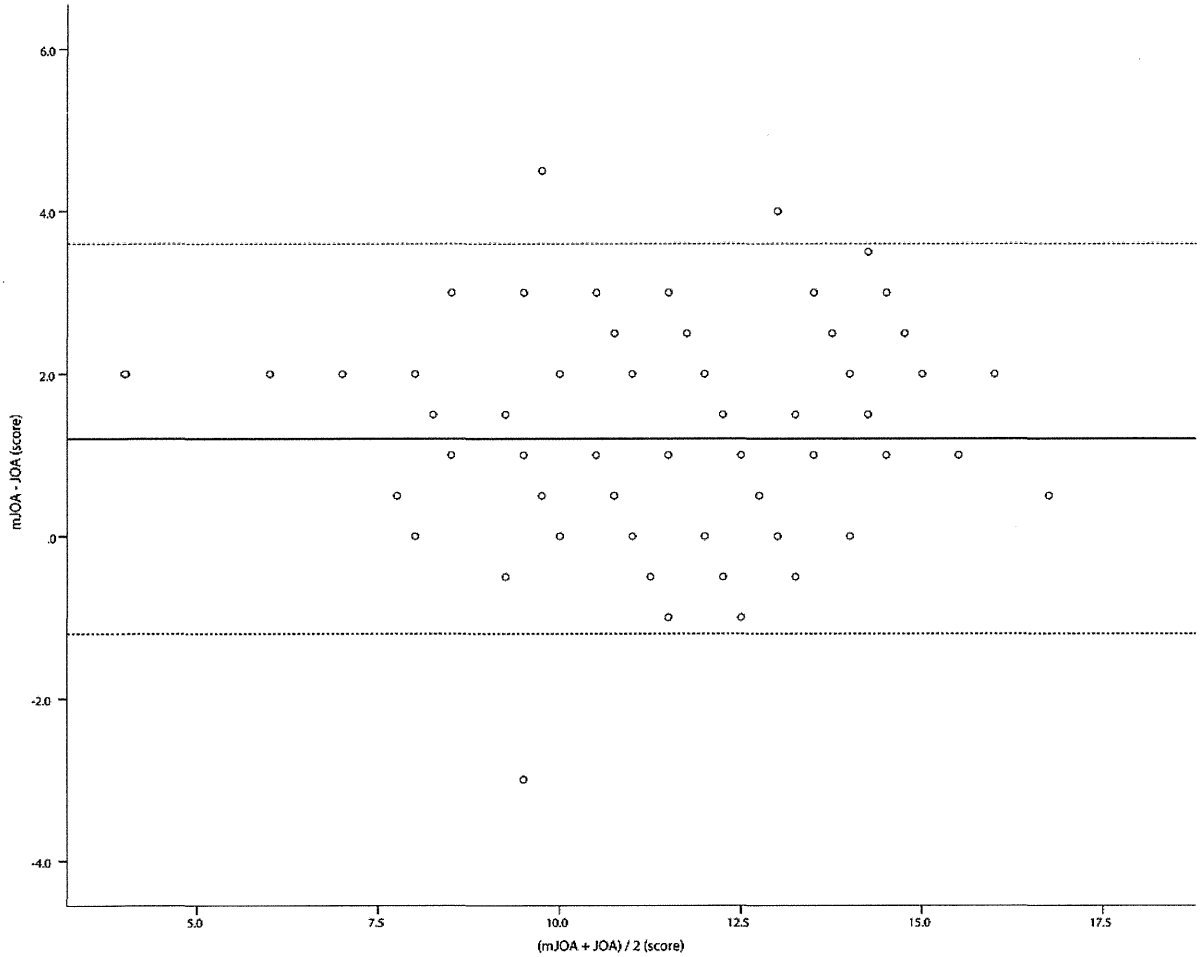

Fig 2. A Bland–Altman plot comparing the JOA and mJOA scores. The bias is shown as a solid line, and the upper and lower limits of agreement are shown as broken lines.

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agreement were 55.1% and -68.8%, respectively. This range is also substantial enough to consider that it is not ideal to interchange the recovery rates of the JOA and mJOA.

Discussion

There are two major findings in the present study. First, the domain and total scores of the JOA and mJOA were strongly correlated with each other. In addition, although the total scores and the recovery rates of the mJOA can be accurately predicted by the conversion formulas using the JOA score and its recovery rate, the Bland-Altman analyses showed they are not interchangeable. Second, the validity of the two types of JOA scores was demonstrated in comparisons with the PRO values.

No previous studies have directly compared the JOA and its modifications. The present study showed that the domain scores of the JOA and mJOA are strongly correlated, although the scoring structures of these scales differ in many domains, and the linearity of the scale is

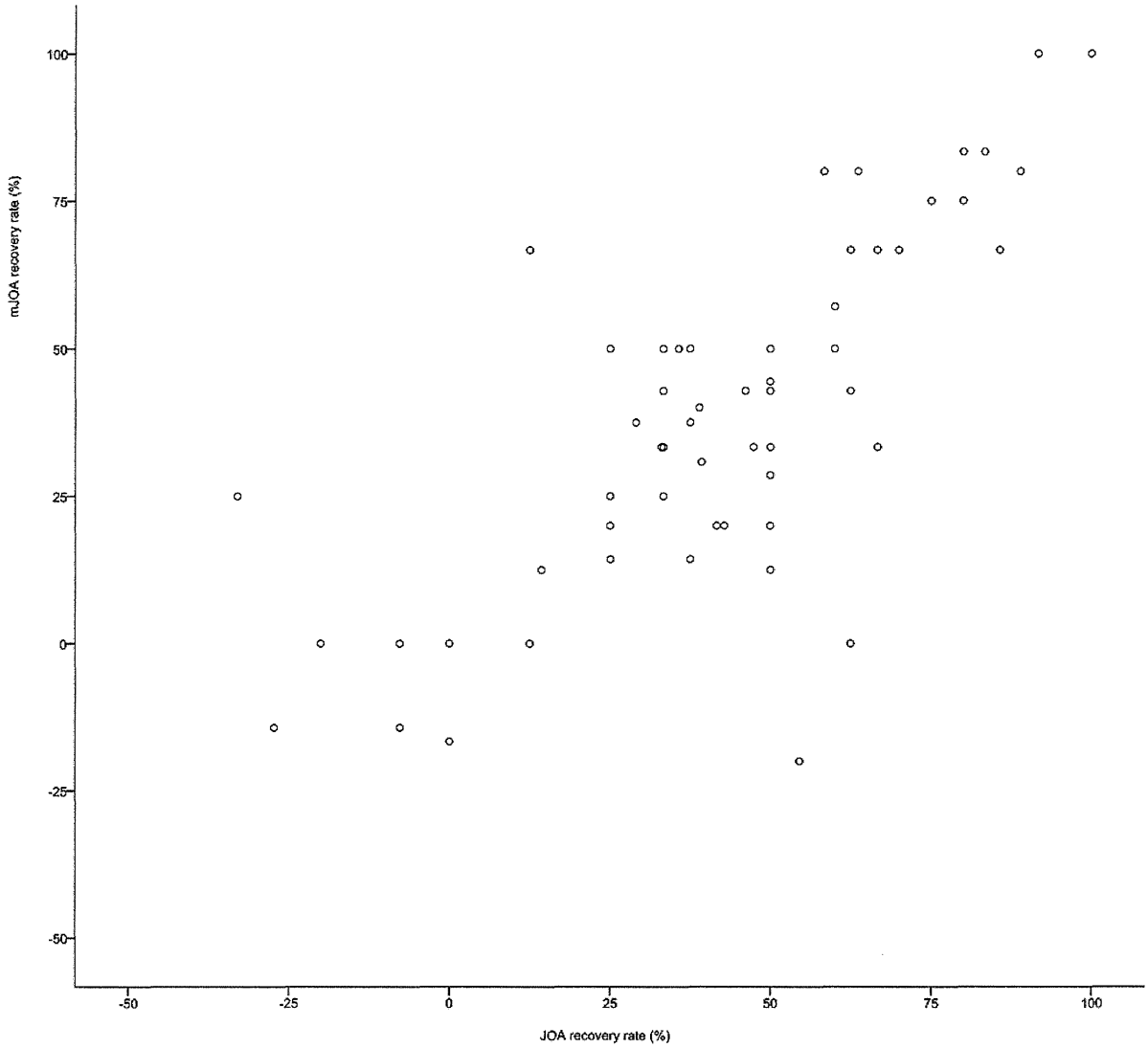

Fig 3. Scatterplot of the recovery rates for the JOA and mJOA scores. This figure includes only cases with a recovery rate from -1.0 to +1.0. Only two outliers were omitted (n = 63).

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not guaranteed. It is of note that the mJOA score exhibited a very strong correlation with the JOA score, despite that the mJOA lacks scores for sensory function in the trunk and lower extremities. This finding may be due to the fact that severe sensory disturbances in the trunk or lower extremities are relatively rare in operative candidates for cervical myelopathy. The correlation between the scores for the sensory function in the upper extremities was lower than that for the other domains. This result may be explained by the exaggerated construct differences in which the JOA has two points and the mJOA has three points. The correlation in the subjects with severer motor dysfunction was weaker. This finding is also understandable given that the mJOA score gives a higher proportion to the motor function score. In the two patients with

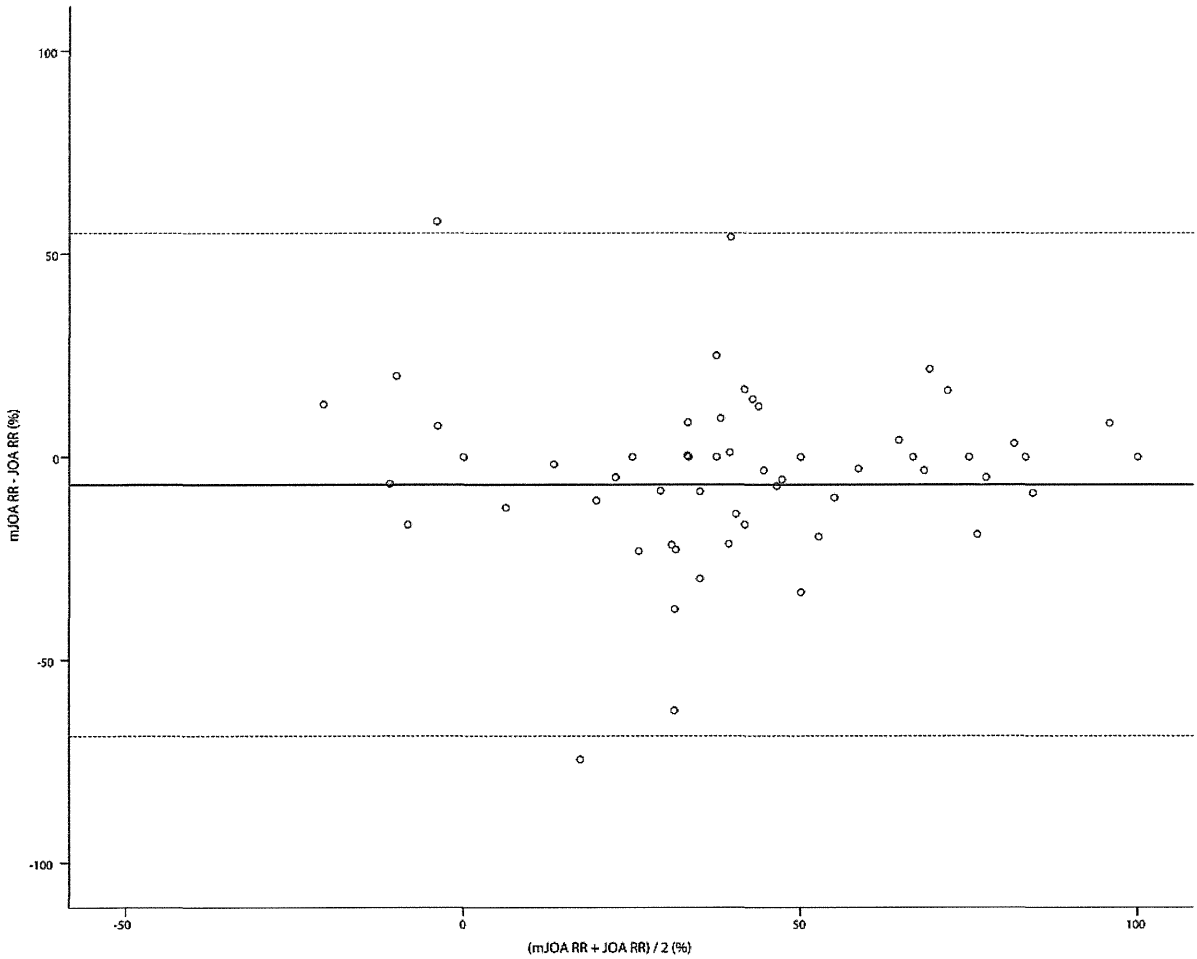

Fig 4. A Bland–Altman plot comparing the JOA and mJOA recovery rates. The bias is shown as a solid line, and the upper and lower limits of agreement are shown as broken lines.

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urinary symptoms, the recovery was not properly reflected in one scale. The bladder function score in the JOA tended to be exaggerated because the JOA criteria are more complicated than those of the mJOA. For example, the sense of urinary retention can lead to the patients receiving a score of 1, and this symptom is very common even in the elderly generation without myelopathy. These comparisons did not lead us to conclude that one scale had significant advantages over the other, and any of them can be used as desired based on the patients' cultural background. The mJOA would be more easily accepted for Asian populations, since many of them now use a spoon, than would the JOA for Western populations, although no validated translations in Asian languages exist, and this would be an obstacle for raters who do not understand English. Using our conversion formulas, it is possible to interpret the results of previous studies that used the mJOA according to the original JOA score. For example, if a study set a certain cut-off point to evaluate the effectiveness of a treatment using the recovery rate, we speculate that the evaluation might be slightly stricter when using the mJOA instead of the JOA.