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Biomechanical analysis of low back load when sneezing

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ABSTRACT

Background: Although sneezing is known to induce low back pain, there is no objective data of the load generated when sneezing. Moreover, the approaches often recommended for reducing low back pain, such as leaning with both hands against a wall, are not supported by objective evidence.
Methods: Participants were 12 healthy young men (mean age 23.25 ± 1.54 years) with no history of spinal column pain or low back pain. Measurements were taken using a three-dimensional motion capture system and surface electromyograms in three experimental conditions: normal for sneezing, characterized by forward trunk inclination; stand, in which the body was deliberately maintained in an upright posture when sneezing; and table, in which the participants leaned with both hands on a table when sneezing. We analyzed and compared the intervertebral disk compressive force, low back moment, ground reaction force, trunk inclination angle, and co-contraction of the rectus abdominis and erector spinae muscles in the three conditions.
Findings: The intervertebral disk compressive force and ground reaction force were significantly lower in the stand and table conditions than in the normal condition. The co-contraction index value was significantly higher in the stand condition than in the normal and table conditions.
Interpretation: When sneezing, body posture in the stand or table condition can reduce load on the low back compared with body posture in the normal sneezing condition. Thus, placing both hands on a table or otherwise maintaining an upright body posture appears to be beneficial for reducing low back load when sneezing.

1. Introduction

Low back pain (LBP) is a common and major health problem, which can have sizeable socioeconomic impacts due to substantial direct and indirect social costs associated with LBP-related disability and loss of work [1,2]. In fact, most adults at some point in their lives experience some degree of LBP, of which approximately 85–90% of cases are classified as non-specific LBP [3,4]. In some instances, LBP is characterized as recurrent [5,6]. A recent report in Japan suggested that the lifetime prevalence of LBP was as high as 83% and the 4-week prevalence was 36%, making it the fifth-most common reason for medical consultation among outpatients [7].

Various factors can cause acute onset of non-specific LBP, including lifting and bending [8], and strategies for reducing low back load during such actions have been investigated from a biomechanical viewpoint using indicators for low back load such as the low back moment (LBM) and intervertebral disk compressive force (CF) in the lower back [9,10]. In clinical practice, sneezing is often reported to aggravate LBP. Indeed, Walker et al. reported sneezing to be an indicator of mechanical LBP [11], and Vroomen et al. [12] observed that 33% (40/122) of patients with LBP radiating in the leg but without radicular syndrome felt more pain on coughing, sneezing, or straining.

Sneezing occurs frequently as a respiratory reflex triggered to expel foreign bodies that mechanically irritate the nasal mucosa [13,14]. Characterized by explosive exhaling, sneezing is said to

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cause strong concentric contraction of the rectus abdominis (RA) muscles and often sudden forward inclination of the trunk when in an upright posture. This forward inclination increases the lever arm from the center of rotation of the lower back to the center of mass in the upper body, thereby increasing the LBM. Moreover, since the forward trunk inclination angle (TA) is suddenly increased while sneezing, it is assumed that the acceleration applied to the center of gravity (COG) of the trunk also increases. This increase in acceleration entails a strong increase in the force that bends the trunk, so the erector spinae (ES) muscles must contract to maintain posture. Forward trunk inclination and ES contraction are reported to increase the CF [15], and therefore sneezing can be regarded as an action that increases low back load. However, no studies to date have reported objective measurement and biomechanical analysis of the low back load when sneezing.

Various types of media targeting people with LBP often recommend maintaining an upright posture or leaning with both hands on a table when sneezing to counter such pain [16]. These recommendations are made despite the lack of evidence for their efficacy. In this study, we conducted biomechanical tests to verify the hypothesis that maintaining an upright position or leaning with both hands on a table when sneezing reduces the low back load.

2. Methods

2.1. Subjects

Participants were 12 healthy young men (mean age, 23.25 SD 1.54 years; mean height, 170.30 SD 4.00 cm; mean weight, 60.90 SD 7.39 kg) with no history of LBP or spinal column pain. All provided written consent to participate after the study protocol was approved by institutional ethics committees.

2.2. Experimental conditions

Measurements were conducted under the following three conditions (Fig. 1): NORMAL condition for sneezing, characterized by forward trunk inclination; STAND condition, deliberately maintaining an upright posture of the trunk when sneezing; and TABLE condition, bending the trunk and leaning with both hands on a table when sneezing. Subjects stood on force plates and freely chose the distance between their feet and the position of their hands on the table. Subjects induced sneezing by irritating the nasal mucosa with a long, thin strip of tissue paper [17]. Measurements were taken 3 times under each experimental condition. In total, 9 trials with 1-min recovery intervals were conducted.

2.3. Experimental setup

Fig. 1 shows the measurement system used. Movement was recorded with a three-dimensional (3D) motion capture system (Vicon 612, Vicon, Oxford, UK) consisting of four force plates (AMTI, Watertown, MA) and 12 infrared cameras with a sampling rate of 120 Hz. Thirty-two infrared (IR)-reflective markers (diameter, 14 mm) were attached to each subject: top of the head, C7 spinous process, T10 spinous process, L5 spinous process, manubrium sterni, xiphoid process and bilaterally on the acromion process, lateral epicondyle, ulnar styloid process, anterior and posterior superior iliac spine, iliac crest, acetabulofemoral joint, medial knee joint, lateral knee joint, medial and lateral malleoli, and the first and fifth metacarpophalangeal joints. The obtained physical coordinates and ground reaction force (GRF) data were processed with a 6 Hz and 18 Hz second-order low-pass Butterworth filter (dual-pass for zero lag), respectively [18].

To measure muscle activity during movement, electromyograms were obtained (Biometrics, Newport, UK) at a sampling rate of 1000 Hz for the right RA (1 cm to the side of the umbilical region and 2 cm to the side of the medial line) [19] and the right ES (2 cm to the side between the L4 and 5 vertebrae) [20]. Electrodes were attached to only the right side because the left and right sides were expected to behave in a similar manner. Electromyography signals were prefiltered, producing a bandwidth of 20–460 Hz, and amplified with a differential amplifier (common-mode rejection ratio > 96 dB at 60 Hz, input impedance > 10 TΩ). Subjects wore a wristband connected to the grounding electrodes on the right hand. Subjects performed in the supine position against gravity with maximum resistance applied by the experimenter to obtain the maximum voluntary contraction of the RA (sit-up with straight leg while imposing resistance to the breast region) and in the prone position to obtain the maximum voluntary contraction of the ES (back extension with their hand resting on their head while imposing resistance to the scapular region) [21]. The subjects were required to produce maximal isometric extension efforts while resistance was provided by a single examiner with a physical therapy license.

Pressure sensors (DKH, Tokyo, Japan) were connected to the electromyographs and force plates to synchronize the

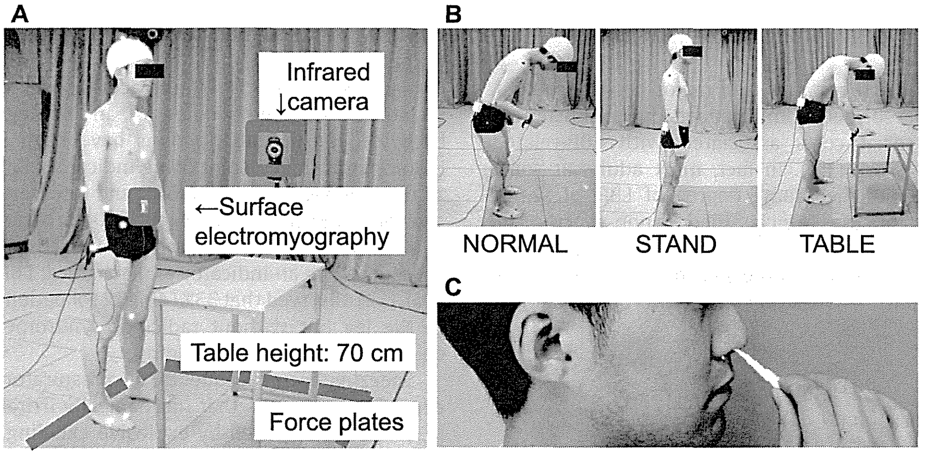

Fig. 1. (A) Experimental setup. (B) The three experimental sneezing conditions examined. In the NORMAL condition, subjects sneezed with no instructions. In the STAND condition, subjects were instructed to maintain an upright position as long as possible. In the TABLE condition, subjects were instructed to immediately place both hands on the table when they felt they would sneeze. (C) To promote sneezing, each volunteer irritated his nasal area using a roll made by twisting a sheet of tissue paper.

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electromyograms and graphs obtained with the Vicon system. The observer input an analog electrical pulse as the synchronization marker to send to all systems to identify a common temporal reference point at the beginning of the measurement.

2.4. Data analysis

Data were analyzed using the 3D motion analysis software package Vicon Body Builder (Vicon). The method of Katsuhira et al. [9,10] was used to calculate the LBM. Briefly, the LBM was calculated using inverse dynamic analysis based on the Newton–Euler method from the GRF data obtained from the coordinates of the IR-reflective markers and force plates. In the analysis, segments were regarded as rigid and the joint moment was calculated using a link segment model in which segments were connected together at nodal points. To compute the joint moment, muscle coordinate data were added to the GRF data, in which the position of the center of mass, the weight portion, and the moment of inertia of each segment were used as parameters. The measurement data reported by Winter et al. [18], Okada et al. [23] and Jorgensen et al. [24] were used as the body parameters necessary for calculating the LBM. The method by Katsuhira et al. [25] was used to calculate the CF. Because LBP is often reported to occur between L4 and L5 [26], the L4–5 interspace was taken as the center of rotation for the LBM. The moment arm of the intervertebral disks and muscles was taken as the distance between the intervertebral disks and RA upon generation of the low back flexion moment and as the distance between the disks [23] and ES upon generation of the low back extension moment [24].

When calculating the CF in TABLE, the table was set to straddle the force plates, and the weight of the table was excluded from the calculations. In addition, the GRF readings obtained from the force plates on which the table was mounted were decomposed in accordance with the TA, and the reaction force obtained from the table was calculated by subtracting the result from the CF. Formula 1 refers to the CF [25]. Here, 20, 13, 8, and 23 are inverse numbers of the moment arms [23–25]. The low back joint compression force was obtained by multiplying the inverse number of the moment arms by the absolute value of the low back joint moments for each axis and adding the resolved gravitational force applied to the COG of the head, arm, and trunk (HAT) and the TA (θ):

$$\begin{aligned}&\text{Intervertebral disk CF}\\&+20|\text{Extension moment}|\text{or}13|\text{Flexion moment}|\\&+8|\text{Side flexion moment}|\\&+23|\text{Rotation moment}|\\&+\text{Gravitational force applied to COG of HAT}\cdot\cos\theta\\&-\text{Reaction force from table}\cdot\cos\theta\end{aligned} \qquad (1)$$

The LBM and CF calculated with the above methods were taken as indicators of low back load. By taking the markers on both shoulders and manubrium sterni as indicators, the TA was measured as the change in angle when standing and the angle at peak CF when sneezing.

The co-contraction index (CCI) was calculated according to Falconer and Winter [27] to evaluate the co-contraction of the RA and ES when sneezing. Electromyographic data from these muscles were integrated over 1000 frames from a 1-s period (0.5 s before to 0.5 s after) of the peak CF recorded when sneezing. Using the obtained integral value, we calculated the portion corresponding to co-contraction of the muscles, which was taken as CCI. The computation of I_{ant}, which refers to the integral of the electromyogram of the antagonist muscle, shows the signal was stronger for the RA than for the ES between $t1$ and $t2$, and vice versa between $t2$ and $t3$, where t is timing. EMG_{AB} and EMG_{ES} indicate the activities of the RA and ES, respectively.

Consequently, the calculation was as follows:

$$I_{\text{ant}} = \int_{t1}^{t2} \text{EMG}_{\text{AB}}(t)dt + \int_{t2}^{t3} \text{EMG}_{\text{ES}}(t)dt \qquad (2)$$

here I_{total} denotes the added integral values for these muscles, and EMG_{agon} and EMG_{ant} denote the electromyogram of the agonist and antagonist muscles, respectively. CCI was calculated from these values as follows:

$$I_{\text{total}} = \int_{t4}^{t3} [\text{EMG}_{\text{agon}} + \text{EMG}_{\text{ant}}](t)dt \qquad (3)$$

$$\text{CCI} = \frac{2I_{\text{ant}}}{I_{\text{total}}} \times 100\% \qquad (4)$$

Data for the CF, GRF, LBM, and TA were extracted at peak CF, and the CF, GRF, and LBM were normalized by body weight (mean of three measurements) to decrease individual differences.

2.5. Statistical analysis

Statistical analysis was performed using the mean values of the parameters for each participant and comparing the CF, LBM, GRF, TA, and CCI for the three experimental conditions. Verification was performed using repeated measures ANOVA, and variables showing a significant difference were subjected to multiple comparisons with Bonferroni correction. Significance was set at 5%. Intra-class correlation coefficients (ICC) of peak low back CF from the three trials were calculated for each condition. Statistical analysis was performed using SPSS 20 (SPSS Inc., Chicago, IL).

3. Results

3.1. Intervertebral disk compressive force and low back moment

The CF waveform in NORMAL shows two peaks, peak 1 and peak 2 (Fig. 2). The LBM waveform shows the flexion moment generated first, followed by the extension moment. Both the CF and LBM showed similar tendencies in all conditions.

Fig. 3 shows the mean CF for each condition. ICCs indicated moderate reliability in each condition. The force in STAND and TABLE was about half that in NORMAL. Table 1 shows the CF for peak 1, peak 2, and over a sneeze normalized by each subject's weight. Compared with NORMAL, these forces were significantly lower in STAND and TABLE ($p < 0.05$).

Table 1 shows the values for the LBM normalized by subject weight at peak CF. The force peaked when the low back extension moment was generated in NORMAL and TABLE and when the low back flexion moment was generated in STAND.

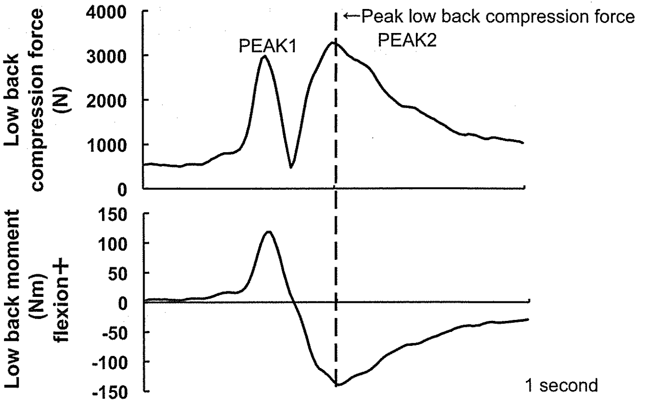

Fig. 2. Single data for low back compression force and joint moment when sneezing in the normal condition. Wave patterns 0.5 s before and after peak low back compression force are shown because this duration included the start and end of the sneeze in all subjects using a wave form of compressive force. The start and end of the sneeze was therefore defined as 0.5 s before and 0.5 s after peak intervertebral disk compressive force.

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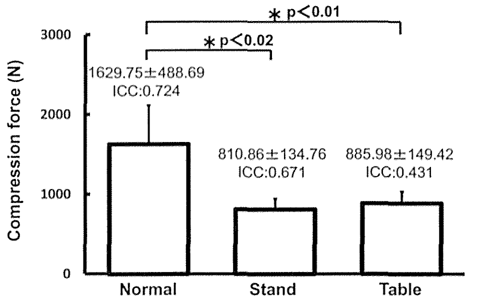

Fig. 3. Comparison of intervertebral disk compressive force of mean peak values and intra-class correlation coefficients (ICCs) in each experimental condition.

3.2. Vertical ground reaction force

Table 1 shows the GRF values normalized by subject weight at peak CF. The vertical component decreased significantly in STAND and TABLE compared with NORMAL ($p < 0.001$). No significant difference was seen between STAND and TABLE.

3.3. Change in trunk inclination angle

Table 1 shows the changes in the TA between standing posture and at peak CF. The positive direction is taken in the direction of flexion. The change was in the direction of flexion in NORMAL and TABLE, but in the direction of extension in STAND ($p < 0.001$). No significant difference was observed between NORMAL and TABLE.

3.4. Electromyograms and CCI

The electromyogram waveform for NORMAL indicates high activity for both the RA and ES when sneezing (Fig. 4). Furthermore, the CF and ES activity peaked at roughly the same time, and CCI was significantly higher in STAND than in NORMAL and TABLE ($p < 0.001$) (Table 1).

4. Discussion

4.1. Low back moment and intervertebral disk compressive force when sneezing

Two peaks were found in the plots of CF and LBM when sneezing, indicating that the RA is highly active during the characteristic forceful exhalation of sneezing. Such muscle activity induces flexion of the trunk, which activates the ES to maintain posture. Electromyograms also showed that since the activity of the RA peaked before that of the ES, the former is predominantly active during generation of the low back flexion moment, while the latter is more active during generation of the low back extension moment.

The mean CF when sneezing in NORMAL for a young man of approximately 60 kg is about 1600 N. This is roughly equivalent to holding a 20-kg load in a stationary upright position, which results in an estimated 3- or 4-fold increase in CF on the L4–5 intervertebral disks during static standing [15]. In other words, although sneezing is a momentary action, the load exerted on the intervertebral disks might aggravate or cause recurrent LBP.

Among the three experimental conditions, the CF and LBM were significantly lower in STAND and TABLE. The LBM was estimated from the GRF using the inverse dynamics method. This moment is influenced by the TA, and the GRF reflects the acceleration generated as a result of trunk movement. For this reason, the CF can probably be decreased by reducing these two parameters. There are a number of possible reasons for the significantly lower CF in STAND and TABLE. First, the change in TA was comparatively small in STAND, meaning that the moment arm of the center of mass of the upper body with respect to the intervertebral disks is small, so it can be considered to reduce the LBM. In the aforementioned study measuring the CF [15], the force increased with flexion of the trunk, a tendency similar to that observed in the present study. In addition, the vertical GRF was small compared with NORMAL. This might have resulted from deliberately maintaining an upright posture, where the acceleration of the trunk was suppressed by consciously stopping the trunk from moving.

Second, the CF peaked during generation of the flexion moment only in STAND. This force is considered to peak when the RA is active. Because this moment arm is about 1.5-fold longer than that for the ES [24], the tensile force exerted by the RA is smaller, which reduces the CF.

Third, in TABLE, the vertical GRF was reduced and the LBM was significantly reduced compared with NORMAL. No significant difference was seen in the magnitude of TA change. Furthermore, compared with NORMAL, the GRF acting on the feet as a result of leaning with both hands on the table was reduced, which suppressed movement of the trunk when sneezing.

Table 1
Comparison with the normal sneezing posture of mean peak values at peak intervertebral disk compressive force and standard deviations of each of the parameters measured in the standing upright posture and leaning with hands on a table posture. The waveform of intervertebral disk compressive force shows two peaks. PEAK1 and PEAK2 indicate the first and second peak of the compression force, respectively. Verification was performed with repeated measures ANOVA using the different sneeze conditions as factors.

	Normal	Stand	Table	*p*-value
Compression force (N/kg) (PEAK1)	16.37 SD 5.09	12.36 SD 1.99[a1]	8.88 SD 3.50[a2]	$p < 0.001^*$ a1: $p < 0.001$ a2: $p < 0.031$
Compression force (N/kg) (PEAK2)	26.09 SD 6.16	11.198 SD 2.65[a1]	9.37 SD 3.00[a2]	$p < 0.001^*$ a1: $p < 0.001$ a2: $p < 0.001$
Compression force (N/kg) (Over sneezing)	26.75 SD 6.44	13.24 SD 2.32[a1]	14.04 SD 1.50[a2]	$p < 0.001^*$ a1: $p < 0.001$ a2: $p < 0.001$
Moment (Nm/kg) (Extension+)	−0.90 SD 0.38	0.27 SD 0.21[b]	−0.45 SD 0.33	$p < 0.001^*$ b: $p < 0.001$
Ground reaction force (N/kg)	10.77 SD 0.55	9.67 SD 0.58[a1]	8.93 SD 0.86[a2]	$p < 0.001^*$ a1: $p < 0.001$ a2: $p < 0.001$
Co-contraction index (%)	31.99 SD 8.07	44.83 SD 8.15[b]	31.00 SD 7.71	$p < 0.001^*$ b: $p < 0.001$
Trunk angle (°) (Flexion+)	31.05 SD 12.24	−4.44 SD 6.25[a]	36.47 SD 6.29	$p < 0.001^*$ a: $p < 0.001$

[*] One-way analysis of variance: (a) significantly smaller than in the normal condition on multiple comparison ($p < 0.05$); (b) larger than the other two conditions on multiple comparison ($p < 0.05$).

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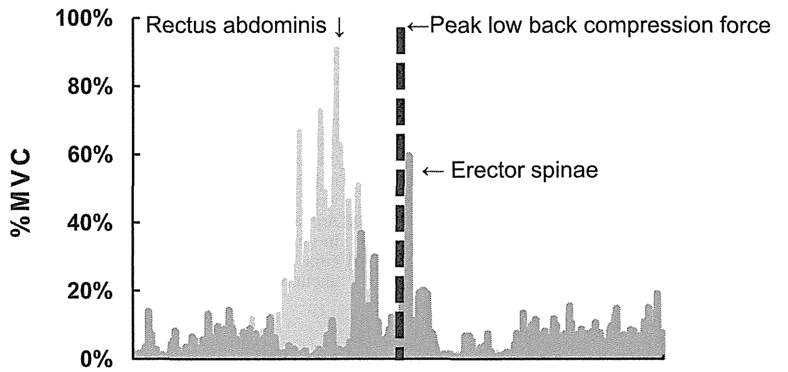

Fig. 4. Surface electromyography of the erector spinae and rectus abdominis muscles showing maximal voluntary contraction. During acquisition, we performed full-wave rectification using WAD analysis software (DKH, Tokyo, Japan) and a band-pass filter (20–420 Hz) to decrease noise according to the methods reported by Cholewicki et al. [22]. The obtained electromyograms were normalized using maximal voluntary contraction during isometric contraction. The wave pattern shows 0.5 s before and after the peak low back compression force.

4.2. Differences between conditions induced by muscle activity

Comparing the three conditions from the viewpoint of muscle activity, we found that CCI was significantly higher in STAND. In other words, there is greater co-contraction of the RA and ES in STAND. Co-contraction of antagonist muscles in the trunk increases the CF and stabilizes the upper trunk [28,29]. Arjmand et al. [29] suggested that co-contraction of antagonist muscles in the trunk is effective for stabilizing the upper trunk while lifting a heavy load. However, the low back load while sneezing was not as large as that when lifting a heavy load.

The present calculations transforming joint moment to muscle force did not separately clarify the magnitude of muscle force generated by the agonist and antagonist muscles. The CF might be greater in STAND than in NORMAL due to the CF generated by muscle co-contraction. Given that CCI was significantly higher in the STAND, greater CF seems to be generated by muscle co-contraction. Therefore, this force is more likely to be reduced in TABLE than in STAND. In other words, leaning with both hands on a table is more suitable for reducing the risk of low back load generated when sneezing than deliberately maintaining an upright posture.

This study has some limitations. First, the subjects were healthy young men, so it will be necessary to conduct a further study considering sex, age, and morphological differences and include subjects with LBP. Second, since the tensile forces exerted by the agonist and antagonist trunk muscles were not calculated separately, the CF generated by muscle co-contraction would not be entirely correct. Third, a previous study reported that high intra-abdominal pressure (IAP) might harm the lumbar tissues and cause LBP. Our biomechanical model accounted for the LBM including the effect of IAP but not the direct effect of IAP on low back load. Fourth, other factors, such as neck position and internal muscular or cardiovascular pressures, while sneezing should be examined.

Prevention measures for low back disability require continuous awareness of the fear avoidance (FA) model, because making the patient aware of posture while sneezing might cause an opposite effect to that desired [30]. Although we could not show the effect of FA in this study, future studies should consider the FA model when observing the effects of preventive measures for low back load while sneezing.

Conflicts of interest statement

None.

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ORIGINAL ARTICLE

Prospective multicenter surveillance and risk factor analysis of deep surgical site infection after posterior thoracic and/or lumbar spinal surgery in adults

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Abstract
Background Surgical site infection is a serious and significant complication after spinal surgery and is associated with high morbidity rates, high healthcare costs and poor patient outcomes. Accurate identification of risk factors is essential for developing strategies to prevent devastating infections. The purpose of this study was to identify independent risk factors for surgical site infection among posterior thoracic and/or lumbar spinal surgery in adult patients using a prospective multicenter surveillance research method.
Methods From July 2010 to June 2012, we performed a prospective surveillance study in adult patients who had developed surgical site infection after undergoing thoracic and/or lumbar posterior spinal surgery at 11 participating hospitals. Detailed preoperative and operative patient characteristics were prospectively recorded using a standardized data collection format. Surgical site infection was based on the definition established by the Centers for Disease Control and Prevention.
Results A total of 2,736 consecutive adult patients were enrolled, of which 24 (0.9%) developed postoperative deep surgical site infection. Multivariate regression analysis indicated four independent risk factors. Preoperative steroid therapy ($P = 0.001$), spinal trauma ($P = 0.048$) and gender (male) ($P = 0.02$) were statistically significant independent

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patient-related risk factors, whereas an operating time ≥3 h ($P < 0.001$) was a surgery-related independent risk factor.
Conclusion Preoperative steroid therapy, spinal trauma, male gender and an operating time ≥3 h were independent risk factors for deep surgical site infection after thoracic and/or lumbar spinal surgery in adult patients. Identification of these risk factors can be used to develop protocols aimed at decreasing the risk of surgical site infection.

Introduction

Surgical site infection (SSI) after spinal surgery is one of the most serious complications that occurs in 0.7–12% of patients and can lead to high morbidity, mortality and increased healthcare costs [1, 2]. In this regard, various risk factors for SSI have been investigated to prevent this devastating complication. Risk factors were separated into two main categories: patient-related risk factors and surgery-related risk factors. Patient-related risk factors include advanced age [3], male gender [4], obesity [5, 6], previous spinal surgery [5], diabetes [5–7], malnutrition [3], smoking [5], spinal trauma [8, 9] and corticosteroid use [5, 10]. Surgery-related risk factors include spinal instrumentation [11], posterior surgical approach [2], tumor resection [2], fusion extending to the sacrum [12], increased estimated blood loss [4, 7] and prolonged operating time [4, 11, 13]. However, many of these studies were performed retrospectively at individual institutions, and they are limited by their relatively small sample size that restricts the power to perform a multivariate analysis.

High quality studies based on a prospective design and a large sample size are required to identify precise independent risk factors for SSI following spinal surgery. Multivariate analysis should also be performed to adjust for the occurrence of multiple risk factors within individual patients. In addition, standardized, hospital-based, multicenter surveillance methods utilizing a standard definition of SSI have been recommended to help determine risk factors and are considered useful in reducing infection rates [14–16].

Therefore, the purpose of this study was to identify independent risk factors for adult patients who develop deep SSI after posterior thoracic and/or lumbar spinal surgery using a prospective multicenter surveillance research method.

Materials and methods

Study design and selection criteria

This surveillance study for SSI following posterior thoracic and/or lumbar spinal surgery in adult patients was conducted in a prospective manner from July 1, 2010 to June 30, 2012 at 11 participating Japanese hospitals. Patients included in the study had undergone surgery by orthopedic service only. Each patient had undergone follow-up for a minimum of one year. Detailed preoperative patient characteristics and operative characteristics were recorded prospectively using a standardized data collection format. The institutional review board at participating hospitals approved the present study and informed consent was obtained from each patient. Patients who underwent surgery for the treatment of spinal infection were excluded from the present analysis. For homogeneity of the study group, we also excluded patients aged <20 years, those who underwent posterior instrumentation removal, vertebroplasty (percutaneous or open surgery), endoscopic surgery or single-stage anterior-posterior surgery.

Identification of SSI

A patient was considered to have an infection on the basis of the SSI definition put forth by the Centers for Disease Control and Prevention [17]. Superficial SSI was defined as an infection occurring within 30 days after the operation and involving the skin or subcutaneous tissue only. Deep SSI was defined as an infection occurring within 30 days after the operation if no implant was left in place or within one year if the implant was left in place, if the infection appeared to be operation-related and involved deep soft tissues. A deep SSI was further characterized by the presence of one or more of the following [17]: (1) purulent drainage from the deep incision; (2) a deep incision spontaneously dehisces or is deliberately opened by a surgeon when the patient has at least one of the following signs or symptoms: fever (>38 °C), localized pain, or tenderness, unless the site is culture-negative; (3) an abscess or other evidence of infection involving the deep incision that is found on direct examination, during reoperation or by a histopathologic or radiologic examination; and (4) diagnosis of a deep incisional SSI by a surgeon or attending physician.

The incidence of SSI was confirmed after double-checking by the attending surgeons and colleagues involved in this study at the participating hospitals. Microbiologic culture results of each patient with deep SSI were recorded and assembled. In cases in which open debridement was performed, microbiologic cultures were taken to confirm the presence of SSI and to determine further treatment.

Data collection

At each study hospital, the medical records of eligible adult patients who had undergone posterior thoracic and/or lumbar spinal procedures were prospectively collected utilizing standardized patient charts.

The recorded preoperative patient characteristics included age at time of surgery, sex, height, weight and diagnosis (spinal trauma, disc herniation, spinal stenosis, tumor or cancer, inflammatory arthritis, osteoporosis or spinal deformity). Preoperative patient-related risk factors for SSI included smoking, diabetes mellitus, body mass index (BMI), the patient's American Society of Anesthesiologists (ASA) score [18], previous surgery and steroid use. In addition, surgery-related factors considered as possible risk factors for SSI were collected and analyzed. These included operating time, estimated blood loss, anatomic location (thoracic, lumbar and/or sacral), emergency surgery, use of instrumentation, iliac crest bone grafting, dural tear and use of intraoperative fluoroscopy.

Statistical analysis

Associations between deep SSI and potential risk factors were analyzed. Fisher's exact test was used for categorical variables and the Wilcoxon test was used for continuous variables. Multivariate analysis was performed to evaluate the risk factors for SSI. Significant variables and the variables that correlated ($P < 0.20$) with SSI in univariate analysis were entered into a stepwise multiple logistic regression model. Furthermore, to adjust for confounding factors, the BMI and anatomic location of the surgery were entered into this model, as in previous reports BMI [5, 6] and anatomic location of the surgery [12] were identified as risk factors of SSI after spinal surgeries. All analyses were performed using SPSS Statistics version 19 (IBM Corporation, Armonk, NY) with the significance threshold set at $P < 0.05$.

Results

From July 2010 to June 2012, a total of 2,736 consecutive patients (1,164 female, 1,572 male; mean age, 64.6 years; age range, 20–94 years) in 11 Japanese hospitals were enrolled. Overall, 24 patients (0.9%) developed postoperative deep SSI. The demographic characteristics of the patients included in the study are shown in Table 1.

The statistical relationships of all variables to deep SSI are reported in Table 2. Univariate analysis indicated several significant risk factors, including an ASA score ≥3, preoperative steroid use, spinal trauma, spinal instrumentation, use of intraoperative fluoroscopy and an operating time ≥3 h. The significant factors in the univariate analysis and the factors with a P value <0.20 in the univariate analysis (male sex, diabetes mellitus, previous surgery and emergency surgery) were included in a multivariate analysis to further examine the risk factors for deep SSI. Although the BMI and anatomic location of the surgery were not significantly associated with deep SSI in the univariate analysis, they were included in the multivariate models. The final multivariate model shown in Table 2 is the most parsimonious model, showing the independent risk factors for deep SSI after adjusting for other risk factors. According to logistic regression models, men had a higher risk of deep SSI than women [odds ratio (OR), 3.01; 95% confidence interval (CI), 1.15–8.94; $P = 0.02$]. The preoperative diagnosis was also found to be associated with an increased risk of SSI; patients with spinal trauma had a 4.04 times higher risk than patients with other diagnoses (95% CI, 1.01–14.49; $P = 0.048$). Patients with preoperative steroid therapy (oral intake) had an 8.53 times higher risk than patients without steroid therapy (95% CI, 2.49–25.82; $P = 0.001$). An operating time ≥3 h was also found to be significantly associated with an increased risk of SSI (OR, 10.28; 95% CI, 3.31–39.36; $P < 0.0001$).

Microbiologic cultures were routinely taken in all 24 patients who developed deep SSI and 87.5% (21/24) of the patients had a positive culture. Twenty-one of the 24 patients (87.5%) underwent open debridement. In three patients, no organisms were isolated; antibiotics were administered intravenously prior to open debridement in these three patients, after which open debridement was performed. Abscess formation in the deep soft tissues was observed in the thee patients. Twenty of 21 patients with positive cultures (95.2%) had a single organism isolated, while only one case demonstrated polymicrobacterial growth [methicillin-resistant *Staphylococcus aureus* (MRSA) + *Propionibacterium acnes*]. *Staphylococcus aureus* was present in 57.1% (12/21) of the positive cultures (including the case of polymicrobacterial growth), with 66.7% (8/12) of these isolates demonstrating MRSA. Coagulase-negative *Staphylococcus* was the next most common organism, with occurrence in 33.3% (7/21) of the positive cultures; methicillin resistance was noted in 71.4% (5/7) of the patients (Table 3).

Discussion

In this study, we identified independent risk factors for adult patients who develop a deep SSI after posterior thoracic and/or lumbar spinal surgery using a prospective multicenter surveillance research method. An operating time ≥3 h was the strongest independent risk factor for postoperative deep SSI after adjusting for all other variables. This result is consistent with those of previous studies that described a prolonged surgical procedure as a significant risk factor for SSI [4, 13]. Frequent release of the tension on self-retractors [13] can minimize tissue ischemia and necrosis caused by intraoperative wound retraction during long-duration operations. A longer operating time also

Table 1 Demographic characteristics of the patients included in the study

Characteristics	Deep SSI (n = 24)	Non-deep SSI (n = 2,712)	P value[a]
Age at surgery, mean (SD), year	67.5 (13.2)	64.0 (15.0)	0.34
Male, n (%)	18 (75.0)	1,554 (57.3)	0.08
BMI, mean (SD), kg/m^2	23.9 (3.3)	23.8 (3.6)	0.88
ASA score, n (%)			
I and 2	18 (75.0)	2,462 (90.8)	0.008
≥3	6 (25.0)	250 (9.2)	
Diabetes mellitus, n (%)	5 (20.8)	308 (11.4)	0.14
Smoking, n (%)	4 (16.7)	332 (12.2)	0.51
Preoperative steroid therapy (oral intake), n (%)	5 (20.8)	89 (3.3)	<0.0001
Previous surgery, n (%)	7 (29.2)	420 (15.5)	0.07
Diagnosis, n (%)			
Spinal trauma	5 (20.8)	117 (4.3)	<0.0001
Other	19 (79.2)	2,595 (95.7)	
Anatomic location of the surgery, n (%)			
Sacrum included	2 (8.3)	212 (7.8)	0.72
Other	22 (91.7)	2,500 (92.2)	
Surgical variables, n (%)			
Instrumentation	18 (75.0)	1,388 (51.2)	0.02
Emergency surgery	3 (12.5)	107 (4.0)	0.03
Use of intraoperative fluoroscopy	4 (16.7)	135 (5.0)	0.009
Dural tear	3 (12.5)	274 (10.1)	0.70
Iliac crest bone graft	3 (12.5)	215 (8.0)	0.41
Operating time ≥3 h	20 (83.3)	952 (35.1)	<0.0001

ASA American Society of Anesthesiologists, *BMI* body mass index, *SSI* surgical site infection

[a] Fisher's exact test was used for categorical variables and the Wilcoxon test was used for continuous variables

increases the risk for bacterial contamination in the surgical wounds [19]; frequent saline irrigation of the surgical wound during the procedure can help prevent this complication [9].

Preoperative steroid use as a risk factor for SSI has been described in several previous studies on spinal surgery patients [5, 10]. On the other hand, there are other studies reporting that steroid use was not a risk factor for SSI [2, 6]. In our study, multivariate analysis showed a strong association between preoperative steroid therapy (oral intake) and postoperative deep SSI. Many of these previous studies were conducted at individual hospitals and, to our knowledge, this is the first study evaluating the association between preoperative steroid therapy and SSI following spinal surgery using a prospective multicenter design. There appears to be a paucity of literature on the relationship between steroid dosage and SSI following spinal surgeries and steroid dosage was not included in our study. For a more detailed evaluation of steroid use and SSI risk, additional high-quality research is needed in the future.

Several studies have reported on patients with spinal trauma and the incidence of SSI [8, 9, 20]. Watanabe et al. reported a strong association between trauma and SSI using multivariate analysis, as compared to patients who underwent elective surgery (OR, 9.42; 95% CI, 1.59–55.73) [9]. The results of our analysis are consistent with previous reports. Patients with a traumatized spine tend to include multisystem trauma, concomitant open wounds, head injury and/or cardiopulmonary instability. Since multisystem trauma can cause severe general conditions, the preoperative hospital stay for patients with spinal trauma tends to be long. Blam et al. [8] reported that surgical treatment of the spine >160 h after injury increased the incidence of infection by more than 8 times, compared with cases in which treatment began within 48 h after injury. Blam et al. [8] also reported that the duration of the postoperative intensive care unit stay was an independent significant risk factor for SSI. In patients with a traumatized spine, it is important to perform the surgery immediately after general conditions are stabilized and decrease the perioperative stay in the intensive care unit.

Male gender was also found to be significantly associated with an increased risk of deep SSI in our current multivariate analysis, even though it was not significant in the univariate analysis. To our knowledge, only one previous study found a statistically significant association between being male and SSI after spinal surgery [4], but this relationship has been reported in several studies on total knee arthroplasty [21, 22] and gastric surgery [23]. In order to evaluate the association of the male gender with SSI more precisely, additional prospective studies with large sample sizes are needed.

Table 2 Univariate and multivariate logistic regression analyses for the odds ratios (ORs) and 95 % confidence interval (CI) of risk factors for deep SSI

Demographic characteristics	Univariate		Multivariate	
	OR (95 % CI)	*P* value	OR (95 % CI)	*P* value
Sex				
Female	1.00	0.07	1.00	0.02
Male	2.24 (0.93–6.18)		3.01 (1.15–8.94)	
BMI				
+1 kg/m^2	0.99 (0.90–1.11)	0.88	0.98 (0.88–1.10)	0.69
ASA score				
1 and 2	1.00	0.02	1.00	0.42
≥ 3	3.28 (1.81–7.91)		1.55 (0.51–4.13)	
Diabetes mellitus				
Yes	2.05 (0.68–5.15)	0.19	1.16 (0.36–3.14)	0.78
No	1.00		1.00	
Smoking				
Yes	1.43 (0.41–3.82)	0.53		
No	1.00			
Preoperative steroid therapy (oral intake)				
Yes	7.76 (2.53–19.80)	0.001	8.53 (2.49–25.82)	0.001
No	1.00		1.00	
Previous surgery				
Yes	2.25 (0.86–5.24)	0.16	2.03 (0.73–5.15)	0.16
No	1.00		1.00	
Diagnosis				
Spinal trauma	5.84 (1.91–14.81)	0.037	4.04 (1.01–14.49)	0.048
Other	1.00		1.00	
Anatomic location of the surgery				
Sacrum included	1.07 (0.17–3.67)	0.49	1.00	0.49
Other	1.00		1.42 (0.24–1.87)	
Instrumentation				
Yes	2.86 (1.20–7.91)	0.017	1.70 (0.50–5.31)	0.38
No	1.00		1.00	
Emergency surgery				
Yes	3.48 (0.81–10.29)	0.085	2.93 (0.51–12.58)	0.21
No	1.00		1.00	
Use of intraoperative fluoroscopy				
Yes	3.81 (1.10–10.29)	0.037	3.34 (0.90–9.92)	0.07
No	1.00		1.00	
Dural tear				
Yes	1.27 (0.29–3.72)	0.71		
No	1.00			
Iliac crest bone graft				
Yes	1.66 (0.39–4.86)	0.44		
No	1.00			
Operating time				
≥3 h	9.24 (3.49–31.85)	<0.0001	10.28 (3.31–39.36)	<0.0001
<3 h	1.00		1.00	

ASA American Society of Anesthesiologists, *BMI* body mass index, *SSI* surgical site infection

Contrary to some reports [11, 24], the use of instrumentation was not an independent risk factor for SSI in the current analysis. According to the univariate analysis, the use of instrumentation showed a significant association with deep SSI; however, the instrumentation and operating time factors may be confounding in relation to the occurrence of

Table 3 Microbiologic characteristics of deep SSI

Organism(s)	No. of cases
MRSA	7
Methicillin-resistant CNS	5
Staphylococcus aureus	4
CNS	2
Pseudomonas aeruginosa	1
Corynebacterium sp.	1
MRSA + *Propionibacterium acnes*	1
Unknown	3

CNS coagulase-negative staphylococci, *MRSA* methicillin-resistant *Staphylococcus aureus*, *SSI* surgical site infection

deep SSI in our data. In fact, the operating time was ≥3 h in all patients who received spinal instrumentation and developed deep SSI in the current study. Reducing the surgical time may help prevent SSI following posterior thoracolumbar instrumentation fusion surgery. However, in instrumentation surgery, biofilm formation and treatment difficulty in cases of deep wound infections have been reported [24]. Therefore, care and attention should be paid particularly to patients undergoing instrumentation surgery for the prevention of SSI.

Several reports have described diabetes as a risk factor for SSI after spinal surgeries [5–7]; however, diabetes was not a significant risk factor for deep SSI in the present study according to univariate and multivariate analyses. There is a possibility that the diabetes patients in our study included well-controlled and poor-controlled cases. Hikata et al. [7] reported that poorly-controlled diabetes (HbA1c $\geq$ 7.0%) was statistically significantly associated with the development of SSI after posterior thoracolumbar spinal instrumentation surgeries compared to well-controlled diabetes (6.1 $\leq$ HbA1c < 7.0%), and SSI occurred in none of the patients (0%) with well-controlled diabetes (6.1 $\leq$ HbA1c < 7.0%) in their operated case series.

Several studies have demonstrated that obesity is a patient-related risk factor for SSI [5, 6]; however, BMI was not a significant factor according to univariate and multivariate analyses in our study. Yoshiike et al. [25] reported that the prevalence of obesity in Japanese adults, which is estimated using international criteria (BMI $\geq$ 30), is lower than that of Western populations. Flegal et al. [26] described that 33.8% of adults in the United States were obese (BMI $\geq$ 30, 2007 to 2008); whereas, in our case series, 167 of 2,736 patients (6.1%) were obese. This difference in the prevalence of obesity between Japanese and Western populations may affect our study findings. Mahta et al. [27, 28] demonstrated that the thickness of subcutaneous fat at the surgical site was an important risk factor for SSI in posterior spine surgeries, and they described that the thickness of subcutaneous fat at the surgical site is more significant for predicting SSI than BMI.

No patients in our study underwent intrawound application of vancomycin powder, although recent studies have reported its effectiveness in preventing SSI after spinal surgery [29, 30]. In patients considered at high risk for SSI, the use of this treatment may be effective for reducing the incidence of devastating wound infections following spinal surgery.

A limitation of this study is the relatively small sample size of infected patients (n = 24), as only patients with deep SSI following specific types of procedures (posterior thoracic and/or lumbar surgery) were included. This contrasts with previous research on SSI that generally focused on a wide variety of spinal procedures and all types of infection [2, 6]. Another limitation is the fact that malnutrition and the number of the operated levels were not included in the factors we assessed. The occurrence of selection bias in patient enrollment cannot be denied; however, we made an effort to minimize this bias by enrolling consecutive patients from multiple centers and not from a single center. The strengths of this study are the relatively large number of surgical procedures. In addition, the prospective multicenter surveillance design allowed for a detailed study of independent risk factors for SSI after spinal surgery by using multivariate logistic regression.

In conclusion, we identified that an operative time ≥3 h, preoperative steroid use, spinal trauma and male gender were independent risk factors for deep SSI following posterior thoracic and/or lumbar spinal surgery in adult patients. The SSI risk factors identified in this study may facilitate the design of protocols for reducing the incidence of SSI in the future.

Conflict of interest The authors declare no conflicts of interest.

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ORIGINAL ARTICLE

Patient satisfaction with double-door laminoplasty for cervical compression myelopathy

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Abstract

Background Patient satisfaction with posterior laminoplasty for cervical compression myelopathy is not yet established. Moreover, postoperative patient-reported outcomes (PROs) associated with patient satisfaction remain unclear. This study aimed to investigate patient satisfaction after double-door laminoplasty for cervical compression myelopathy, and to identify the postoperative patient-reported outcomes associated with patient satisfaction.

Methods This retrospective study included 97 patients with cervical compression myelopathy who underwent double-door laminoplasty between 2002 and 2010 in our institution [mean follow-up: 58 months (range 12–123 months)]. We assessed postoperative PROs from questionnaires administered before surgery and at the latest follow-up. These questionnaires included the Neck Disability Index, physical and mental component summary of Short Form-36, EuroQol-5 dimension, Japanese Orthopaedic Association Cervical Myelopathy Evaluation Questionnaire (JOACMEQ), and a numerical rating scale of pain or numbness in the neck, arms, and scapular lesion. Satisfaction was evaluated on the basis of a seven-point scale. Patients were divided into two groups: satisfied (very satisfied, satisfied, slightly satisfied) and dissatisfied (neither satisfied nor dissatisfied, slightly dissatisfied, dissatisfied, very dissatisfied). All PROs and the effectiveness of surgical treatment assessed by JOACMEQ were compared between both groups.

Results The satisfied group comprised 69 patients (71 %). Univariate analysis revealed a significant difference in scapular pain, Neck Disability Index, physical component summary of Short Form-36, postoperative mental component summary of Short Form-36, and improvement of lower extremity function postoperatively between both groups. Multivariate analysis revealed that there was a significantly higher proportion of patients with improved lower extremity function in the satisfied group than in the dissatisfied group.

Conclusions In conclusion, 71 % of the patients who underwent double-door laminoplasty for cervical compression myelopathy were satisfied. The findings of this study, which examines the association between patient satisfaction and PROs, suggest that improvement in lower extremity function following surgical intervention affects patient satisfaction in those with cervical compression myelopathy.

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Introduction

Posterior laminoplasty has been established as one of the primary interventions in patients with cervical compression myelopathy due to cervical spondylotic changes and ossification of the posterior longitudinal ligament (OPLL) [1, 2]. Although previous literature has reported satisfactory long-term results of laminoplasty, most of these evaluations conducted in the past relied upon the physicians' point of view using the Japanese Orthopaedic Association (JOA) scoring system and image findings such as range of motion [3–6]. Based on the concept that ultimately the evaluation

Table 1 Characteristics of the study population

	$N = 97$
Age (year), mean (SD)	64.3 (10.6)
Gender	
Male	61
Female	36
Follow-up (m), mean (range)	58 (12–123)
Diagnosis (*N*)	
CSM	59
OPLL	36
OYL	1
CDH	1
Surgical levels (*N*)	
C3–7	62
C2–7	18
C3–6	6
Others	11

SD standard deviation, *CSM* cervical spondylotic myelopathy, *OPLL* ossification of the posterior longitudinal ligament, *OYL* ossification of the yellow ligament, *CDH* cervical disc hernia

of treatment results is best done by the patient, the use of several patient-reported outcomes (PROs), such as the visual analog scale, numerical rating scale (NRS), and Short-Form 36 (SF-36), after surgical intervention has become popular in the field of spine surgery [7–9].

A high level of patient satisfaction should be the most important goal following surgery. Although there have been many reports regarding the level of patient satisfaction following other surgeries [10–14], the level after cervical posterior laminoplasty remains to be established [15, 16]. In addition, PROs associated with patient satisfaction after surgical intervention for cervical compression myelopathy remain unclear.

This study aimed to investigate patient satisfaction with double-door laminoplasty for cervical compression myelopathy and to identify the PROs associated with postoperative patient satisfaction.

Materials and methods

Patient population

We reviewed 106 consecutive patients with cervical compression myelopathy who underwent double-door laminoplasty between 2002 and 2010 in our institution. Of these, four patients were lost to follow-up before evaluation of the postoperative outcome. Five patients developed complications, which included C5 motor palsy in four patients and concurrent reoperation for postoperative deterioration due to suboptimal decompression in one patient; these influenced patient satisfaction. The patients with complications were excluded from the study so as to evaluate the association between PROs and patient satisfaction in the population that had an uneventful postoperative course. Finally, 97 patients [mean follow-up 58 months (range 12–123 months)] were included. Of these, 59 had cervical spondylotic myelopathy, 36 had cervical ossification of the posterior longitudinal ligament, one had cervical ossification of the yellow ligament, and one had cervical disc hernia. The most common surgical levels were C3/C7 in 62 patients, followed by C2/C7 in 18 patients and C3/C6 in six patients (Table 1).

Informed consent was obtained from each patient, and the study was approved by the institutional review board of the University of Tokyo.

Double-door laminoplasty

We performed double-door laminoplasty as described in a previous report [6]. Cervical laminae were exposed laterally to the medial aspect of the facet joints, and the interspinous ligaments were removed. The spinous processes were split sagittally. After bilateral gutters for the hinges were carefully made at the transitional area between the facet joint and laminae, spinal canal enlargement was achieved by bilateral opening of the laminae. HA spacers (Boneceram; Olympus Terumo Biomaterials Corp., Tokyo, Japan) were placed between the opening laminae and fixed with nonabsorbable sutures. Patients wore a soft cervical orthosis for approximately 3 weeks.

Outcome measures and questionnaires

We assessed the preoperative outcome of patients from the questionnaires administered before surgery, during their hospital admission. Questionnaires included several PROs, as follows: the Neck Disability Index (NDI) [17], physical component summary (PCS) and mental component summary (MCS) of SF-36 [18], EuroQol-5 dimension, Japanese Orthopaedic Association Cervical Myelopathy Evaluation Questionnaire (JOACMEQ) [19], and NRS of pain or numbness in the neck, arms, and scapular lesion. Postoperatively, questionnaires that included the above-mentioned PROs in addition to the original satisfaction scales that assessed the postoperative outcome were sent to the patients. Satisfaction was evaluated based on a seven-point scale as follows: very satisfied, satisfied, slightly satisfied, neither satisfied nor dissatisfied, slightly dissatisfied, dissatisfied, and very dissatisfied. Patients were divided into two groups: satisfied (very satisfied, satisfied, slightly satisfied) and dissatisfied (neither satisfied nor dissatisfied, slightly dissatisfied, dissatisfied, very dissatisfied). The postoperative PROs were evaluated using questionnaires administered at the latest follow-up.

Assessment of the effectiveness of surgical intervention

Effectiveness of the treatment was assessed using the JOA scoring system administered by a physician and JOACMEQ.

The recovery rate of the JOA scoring system was calculated using Hirabayashi's method as follows [2]: Recovery rate (%) = (postoperative JOA score − preoperative JOA score) × 100/(17 − preoperative JOA score). Effectiveness of surgical treatment based on the JOA score was defined as a recovery rate ≥50 % [20].

According to a previous report [19], effectiveness of surgical treatment in each domain of the JOACMEQ was defined as follows: (1) the post-treatment score was higher than the pretreatment score by ≥20 points, and (2) the pretreatment score was <90 and the post-treatment score reached ≥90 points. Patients with preoperative and postoperative scores >90 were excluded from this analysis.

Statistical analysis

All PROs and the effectiveness of surgical treatment were compared between both groups. Continuous outcomes were compared using the one-factor analysis of variance, and categorical outcomes were compared using the Chi square test and Fisher's exact test. Multivariate logistic regression models were prepared to estimate patient satisfaction associated with potential predictors including demographic variables and postoperative PROs, which were significantly different between the two groups in univariate analysis. All statistical analyses were conducted using JMP Pro 10 (SAS Institute, Cary, NC). The threshold for significance was a *p* value <0.05.

Results

Table 2 demonstrates PROs compared between preoperative and postoperative assessments. NDI, PCS of SF-36, EQ-5D, arm pain, and arm numbness were improved between preoperative and postoperative assessment. The preoperative and postoperative differences in neck pain, scapular pain, neck numbness, and scapular numbness were not significant. The satisfied group comprised 69 patients (71 %) and the dissatisfied group comprised the remaining 28 patients (29 %). Table 3 demonstrates the pathology of cervical compression myelopathy (the presence or absence of OPLL), surgical level (including C2 or C7, or neither), and the preoperative PROs of the two groups. None of the preoperative PROs were significantly different between the two groups. There was no significant difference in the pathology of cervical compression myelopathy and surgical level between the two groups.

Table 2 Patient reported outcomes compared between preoperative and postoperative assessments [mean (SD)]

	Preoperative assessment	Postoperative assessment	*p* value
NDI	36.0 (20.7)	27.3 (16.1)	<0.0001
PCS	20.6 (18.6)	32.1 (18.6)	<0.0001
MCS	49.6 (10.6)	50.9 (9.5)	0.44
EQ-5D	0.55 (0.21)	0.70 (0.19)	<0.0001
NRS (pain)			
Neck	3.4 (3.2)	2.9 (2.6)	0.17
Arms	4.2 (3.2)	2.9 (2.7)	<0.01
Scapular lesion	2.0 (2.6)	2.2 (2.6)	0.19
NRS (numbness)			
Neck	2.2 (2.9)	1.9 (2.5)	0.20
Arms	5.2 (3.0)	4.0 (3.0)	<0.01
Scapular lesion	2.0 (2.4)	1.9 (2.5)	0.96

SD standard deviation, *NDI* Neck Disability Index, *PCS* physical component summary of Short-Form 36, *MCS* mental component summary of Short-Form 36, *EQ-5D* EuroQol 5 dimension, *NRS* numerical rating scale

Univariate analysis revealed that the postoperative scapular pain, NDI, PCS of SF-36, MCS of SF-36, and effectiveness of treatment in the lower extremity evaluated using the JOACMEQ were significantly different between the two groups (Table 4). Patients in the satisfied group showed a tendency toward a higher recovery rate of the JOA score, as evaluated by a physician, compared to the dissatisfied group; however, the difference was not significant. Table 5 demonstrates the results of multivariable logistic regression models for satisfaction with double-door laminoplasty. After adjusting for confounders, the effectiveness of treatment in the lower extremity, evaluated using the JOACMEQ, was significantly higher in the satisfied group than in the dissatisfied group (Odds ratio = 3.77; 95 % CI, 1.13–15.3; $p = 0.03$).

Discussion

This study had two main findings. First, 71 % of the patients who underwent double-door laminoplasty for cervical compression myelopathy were satisfied. Additionally, several PROs, including NDI, SF-36, NRS of pain in the scapular lesion, and effectiveness of treatment in the lower extremity, which was evaluated using the JOACMEQ, were associated with patient satisfaction. In particular,

Table 3 Pathology of cervical compression myelopathy, surgical level, and preoperative patient-reported outcomes compared between the two groups [mean (SD)]

	Satisfied group $N = 69$	Dissatisfied group $N = 28$	p value[a]
Pathology of myelopathy OPLL presence [N (%)]	27 (39)	9 (32)	0.52
Surgical level including C2 or C7 [N (%)]	63 (91)	28 (100)	0.18[b]
NDI	37.5 (20.8)	31.9 (20.1)	0.23
PCS	20.4 (19.1)	21.0 (17.7)	0.89
MCS	49.9 (10.9)	48.9 (9.9)	0.67
EQ-5D	0.54 (0.21)	0.58 (0.21)	0.45
NRS (pain)			
Neck	3.4 (3.3)	3.6 (3.1)	0.77
Arms	4.3 (3.1)	3.9 (3.6)	0.60
Scapular lesion	1.8 (2.5)	2.5 (2.7)	0.25
NRS (numbness)			
Neck	2.1 (2.9)	2.7 (2.9)	0.43
Arms	5.6 (2.9)	4.4 (3.0)	0.16
Scapular lesion	1.7 (2.3)	2.6 (2.6)	0.15

SD standard deviation, *OPLL* ossification of the posterior longitudinal ligament, *NDI* Neck Disability Index, *PCS* physical component summary of Short-Form 36, *MCS* mental component summary of Short-Form 36, *EQ-5D* EuroQol 5 dimension, *NRS* numerical rating scale

[a] For continuous outcomes, the comparisons were made by the one-factor analysis of variance. For categorical outcomes, the comparisons were made by the Chi square test

[b] Fisher's exact test

multivariate logistic regression analysis revealed that effectiveness of treatment in the lower extremity evaluated using the JOACMEQ was a significant independent factor associated with patient satisfaction.

Although several studies on postoperative satisfaction in patients with cervical compression myelopathy have been previously conducted, evidence of patient satisfaction with the posterior operative approach is limited. With regard to cervical myelopathy due to multilevel compression, Sampath et al. [21] reported a 75 % satisfaction rate after surgery in their prospective multicenter study. However, their study was limited by a small sample size of 20 patients who underwent surgical intervention, and also included several procedures, including decompression through a posterior approach, anterior cervical discectomy, and spinal fusion with or without internal fixation with instrumentation. Although Fujimori et al. [15] found that 80 % of patients with cervical myelopathy due to multilevel compression by OPLL were satisfied with the surgical results, this study also included both posterior and anterior procedures. The present study was superior compared to previous reports regarding patient satisfaction following posterior cervical surgery in that it used data from approximately 100 patients following double-door laminoplasty as a single procedure. Moreover, the satisfaction scale in this study was classified into seven categories, whereas previous classifications in other studies had only five categories. The detailed questionnaire in this study may reflect patient satisfaction with more accuracy.

This study found that several PROs, such as NDI, SF-36, scapular pain, and effectiveness of treatment in the lower extremity assessed using the JOACMEQ, were associated with patient satisfaction. In particular, the effect of surgical intervention on the lower extremity, which was evaluated using the JOACMEQ, was reflected in patient satisfaction with double-door laminoplasty independently. Fujimori et al. [15], in their study of 69 patients with cervical OPLL, found that lower extremity function correlated with patient satisfaction, which was similar to the findings of this study. With regard to the reason why lower extremity function was identified as an independent factor of satisfaction, we speculate the following possibilities. The patients who did not feel improvement in lower extremity function might be dissatisfied because lower extremity function reportedly correlates more directly with quality of life than upper extremity function [22]. Fujimori et al. [15] found that many patients who were dissatisfied reported inability to move around independently as the reason in their response to open-type questions. This study confirmed the postulate that lower extremity function correlated more strongly with patient satisfaction. Moreover, a previous study demonstrated that following surgery, neurological recovery in the lower extremity was less likely to achieve neurological improvement compared to the upper extremity [23, 24]; this may play a role in the dissatisfaction experienced by the patients. Furthermore, patients in the current study might have suffered from degenerative diseases that affect

Table 4 Postoperative outcomes compared between the two groups [mean (SD)]

	Satisfied group	Dissatisfied group	p value[a]
NDI	24.4 (15.8)	34.3 (14.8)	<0.01
PCS	34.8 (18.8)	25.6 (16.8)	0.03
MCS	52.2 (9.6)	47.7 (8.7)	0.04
EQ-5D	0.72 (0.21)	0.64 (0.14)	0.05
NRS (pain)			
Neck	2.6 (2.6)	3.6 (2.5)	0.12
Arms	2.6 (2.7)	3.5 (2.5)	0.14
Scapular lesion	1.8 (2.5)	3.2 (2.6)	0.01
NRS (numbness)			
Neck	1.7 (2.6)	2.3 (2.3)	0.29
Arms	3.9 (3.0)	4.4 (3.0)	0.46
Scapular lesion	1.6 (2.5)	2.5 (2.6)	0.12
JOA score recovery rate	46.8 % (41.5)	32.1 % (31.4)	0.10
Effectiveness of surgical treatment evaluated using JOACMEQ [N (%)]			
Cervical spine function	20 (34)	7 (29)	0.80
Upper extremity function	27 (44)	7 (28)	0.23
Lower extremity function	30 (49)	4 (16)	<0.01
Bladder function	15 (26)	2 (8)	0.08
Quality of life	14 (23)	4 (16)	0.57

SD standard deviation, *NDI* Neck Disability Index, *PCS* physical component summary of Short-Form 36, *MCS* mental component summary of Short-Form 36, *EQ-5D* EuroQol 5 dimension, *NRS* numerical rating scale, *JOA* Japanese Orthopaedic Association, *JOACMEQ* Japanese Orthopaedic Association Cervical Myelopathy Evaluation Questionnaire

[a] For continuous outcomes, comparisons were made by the one-factor analysis of variance. For categorical outcomes, the comparisons were made by the Fisher's exact test

Table 5 Multivariable logistic regression models for patient satisfaction after double-door laminoplasty

	Patient satisfaction		
	OR	95 % CI	p value
Age	0.99	0.93–1.05	0.64
Female (ref. male)	0.99	0.30–3.47	0.99
Postoperative NDI	1.01	0.96–1.07	0.69
Postoperative PCS	0.99	0.94–1.03	0.55
Postoperative MCS	0.94	0.87–1.02	0.13
Postoperative scapular pain	1.05	0.83–1.34	0.65
Effective in LE (ref. non-effective)	3.77	1.13–15.3	0.03

OR odds ratio, *CI* confidence interval, *NDI* Neck Disability Index, *PCS* physical component summary of Short-Form 36, *MCS* mental component summary of Short-Form 36

lower extremity function (e.g., knee osteoarthritis or lumbar spinal stenosis). Prior study revealed a high prevalence of knee osteoarthritis and lumbar spinal stenosis in the Japanese elderly [25, 26], which may be one of the reasons for insufficient improvement in lower extremity function compared to that in upper extremity function.

Although several factors have been reported to affect the outcome following laminoplasty, so far, the predictor for optimal timing of laminoplasty remains unknown. Age, preoperative JOA, signal intensity change on MRI, and cervical lordotic angle were reportedly associated with postoperative outcome in a previous study [27–30]. However, the prognostic significance of these factors has not been established. Timing of surgical intervention should be decided according to the expected postoperative satisfaction in addition to neurological improvement. This study found that the improvement of lower extremity function following surgical intervention was as an independent factor associated with patient satisfaction, which suggests that the factors reflecting severity of myelopathy in the lower extremity is important. Two clinical tests were reported for evaluation of lower extremity function in patients with cervical myelopathy. Mihara et al. [31] demonstrated that the triangle step test was a very useful method for evaluation of lower extremity function in patients with cervical myelopathy. Nakashima et al. [20] reported the 10-s step test as a simple physical assessment for severity of cervical compression myelopathy, particularly for lower extremity dysfunction. These tests can be candidate predictors for patient satisfaction following laminoplasty. Further research regarding predictors reflecting satisfaction to decide optimal timing of surgical intervention is expected in the future.

According to previous studies, satisfaction in patients with cervical myelopathy following anterior approach procedures ranges from 80.6 to 94.7 % [11, 13]. In the current study, postoperative patient satisfaction following posterior approach procedures was 71 %, and including the five patients with complications (one patient in the satisfied group and four patients in the dissatisfied group) in the analysis, it was 69 %. Despite recognition of posterior laminoplasty as an established treatment for cervical compression myelopathy, our data revealed that patient satisfaction following double-door laminoplasty was relatively low compared to that following the anterior approach. One of the reasons for this might be that patients undergoing laminoplasty often complain of axial pain, which may play a role in decreasing the level of patient satisfaction. Indeed, the satisfied group had a significantly lower postoperative numerical scapular pain scale in this study. Several factors, including different surgical techniques, radiological assessment, and postoperative management, were reportedly associated with axial pain following posterior cervical surgery [32]. Further surgical modification, such as less invasive surgery and postoperative management including medication and early removal of cervical orthosis, should be attempted for improvement of postoperative scapular pain.

This study had several limitations. First, the surgery was not performed by the same surgeon in all patients, nor was it performed to the same surgical level. Surgical invasion may vary slightly between surgeons and surgical level. The inconsistency of surgical techniques performed can affect postoperative outcome. Indeed, such surgical factors were reported to be associated with axial pain after posterior cervical spine surgery [32, 33]. However, the preservation of muscles attached at C2 or C7 was not associated with patient satisfaction in this study. Second, the questionnaire used in this study did not assess the outcomes immediately after the surgical procedure. In particular, perioperative pain immediately after surgical procedure may cause decreased satisfaction. Further study with perioperative evaluation that includes use of a numerical pain scale and medication and cervical immobilization is required to verify the influence of perioperative management on patient satisfaction. Third, although we examined the patients with cervical compression myelopathy, including those with and without OPLL, the difference in the pathomechanism of myelopathy between those with OPLL and others may have affected the surgical outcome. Although there was no significant difference in the pathology of cervical compression myelopathy between the satisfied and dissatisfied groups, further large-scale studies that take these differences in the pathology into consideration are warranted. Finally, the relationship between the physician and the patient was not evaluated in this study. There may be bias related to this factor. We used a questionnaire for evaluation of satisfaction instead of directing the questions to the physician to decrease this bias. Despite these limitations, we believe that this study has valuable information that is of clinical importance.

In conclusion, 71 % of the patients who underwent double-door laminoplasty for cervical compressive myelopathy were satisfied. The findings in this study suggest that improvement in lower extremity function following surgical intervention affects patient satisfaction.

Conflict of interest The authors declare that they have no conflict of interest.

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