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Association between swallowing disorder and prevertebral hyperintensity on magnetic resonance imaging in patients after cervical cord injury without major fracture

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Abstract

This study aimed to clarify the association between swallowing disorder and prevertebral hyperintensity on magnetic resonance imaging (MRI) in patients with cervical spinal cord injury (CSCI) without a major fracture. This retrospective observational study included 30 patients who were diagnosed with acute CSCI without a major fracture (mean age: 69.3 years, 27 men). Swallowing disorder was defined as tube-dependent nutrition because of obvious aspiration 28 days after injury. The high-intensity area (HIA) and anteroposterior width (HIW) of the prevertebral space at C1–7 levels were measured using MRI short-TI inversion recovery midsagittal images. Receiver operating characteristic curve analysis was used to determine the optimal cutoff values of the HIA for predicting swallowing disorder. The incidence of swallowing disorder after CSCI was 16.7%. The HIA was significantly higher in the swallowing disorder group (median, 409.0 mm^2) than in the non- swallowing disorder group (median, 159.1 mm^2) ($P = .04$). There was no significant difference in HIW between the two groups. The optimal cutoff point of the HIA was measured at 203.2 mm^2 with 80.0% and 20.0% sensitivity and specificity, respectively, with an area under the curve of 0.848 (95% confidence interval, 0.657–1.000, $P = .01$). The prevertebral hyperintensity area on MRI for swallowing disorder in patients after cervical cord injury without skeletal injury is associated with swallowing disorder. The optimal cutoff point of the area was determined to be 203.2 mm^2.

Abbreviations: AIS = American Spinal Injury Association Impairment Scale, CSCI = cervical spinal cord injury, CT = computed tomography, HIA = high-intensity area, HIW = high-intensity anteroposterior width, MRI = magnetic resonance imaging, PVST = prevertebral soft tissue thickness, RSST = repetitive saliva swallowing test, STIR = short T1 inversion recovery.

Keywords: cervical spinal cord injury, dysphagia, magnetic resonance imaging, prevertebral hyperintensity

1. Introduction

In recent years, a national survey revealed that the proportion of cervical spinal cord injuries (CSCI) without major fractures has increased in Japan, reflecting an aging society.[1] The overall rate of cervical cord injuries has been found to be 88.1% among surveyed individuals (62.3% cervical TSCI without skeletal injury, 25.8% with skeletal injury). A nation- wide multicenter retrospective study showed the recent incidence and characteristics of TSCI in Japan. A total of 4603 individuals with TSCI from all over Japan. who were acutely hospitalized or emergency-treated between January 1, 2018 and December 31, 2018, were retrospectively investigated. Cervical cord injuries occurred in 88.1%, while cervical cord injuries without skeletal injuries occurred in 70.7% of surveyed persons. Japanese are thus considered to have a high risk of cervical TSCI without skeletal injury caused by minor trauma of the cervical stenosis due to falls.[2] The level of spinal cord injury, impairment in body structure, and disability related to activities and participation constructs have been reported to be significantly associated with quality of life after spinal cord injuries.[3]

Dysphagia after CSCI can increase the risk of pulmonary complications that adversely affect the recovery process of independent daily activities during rehabilitation. Several studies have revealed that the incidence of dysphagia in patients with traumatic cervical injury or tetraplegia is 7% to 41%.[4]

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The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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However, these studies did not focus on patients with CSCI without skeletal injury. Older age[4–7] tracheotomy[4–6] and a combination of multiple factors (level of tetraplegia, severity of paralysis, tracheotomy, and accompanying injuries)[8] have been reported as risk factors for dysphagia in patients with CSCI. Furthermore, swelling in the retropharyngeal space, evaluated using computed tomography (CT), has been reported as a possible risk factor for swallowing dysfunction.[6,9] This mechanism is believed to occur when the pharyngeal plexus and pharyngeal constrictor from part of the prevertebral soft tissue thickness (PVST) after sustaining damage.[6] Hayashi et al suggested that preventing swelling can be a considerable strategy for preventing or overcoming swallowing disorder.[6] Starting exercise early on and performing ice massage inside the oral cavity may help to treat dysphagia caused by PVST damage after CSCI. However, it is difficult to measure exactly how much benefit these strategies provide due to the difficulty in measuring the swelling in the retropharyngeal space using CT. This has been pointed out by Mitsuishi et al in their discussion on the difficulty of setting the upper limit for PVST anterior to C4 and C5 owing to the characteristics of the soft tissue.[9]

Magnetic resonance imaging (MRI) is useful for diagnosing and assessing discoligamentous cervical spine injuries in patients without skeletal injuries. In particular, prevertebral hyperintensity on T2-weighted MRI, which reflects prevertebral edema, fluid collection, or hemorrhage, is associated with initial cervical segmental instability in patients with CSCI without major bone injury. Studies have shown that short T1 inversion recovery (STIR) MRI is helpful in the diagnosis of soft tissue and ligamentous injuries because STIR images are highly sensitive for the detection of edema.[10] Although fat-suppressed T2 weighted images can also be used for detection of edema, STIR images provide more uniform fat suppression.[10] A recent study reported that soft tissue damage detected by STIR mid-sagittal MRI predicted neurological improvements in patients with traumatic CSCI without major fractures.[11] Although conventional X-ray, CT, and MRI are usually performed on diagnostic imaging when planning treatment for CSCI patients without major fracture,[12] the association between dysphagia and these imaging remains unclear.

The present study aimed to clarify the association between swallowing disorder and prevertebral hyperintensity on MRI in patients without major fractures after CSCI.

2. Materials and methods

2.1. Participants

This was a retrospective observational study designed to evaluate the association between MRI findings and dysphagia in patients after CSCI without a major fracture. This study was approved by the Institutional Review Board of Hirosaki University Hospital and conformed to the Declaration of Helsinki (approval number: 2018-1002). This manuscript also adheres to the STROBE guidelines. We recruited 249 patients who were treated for acute spinal cord injury between January 2011 and October 2022 and were admitted to our hospital immediately after injury. After obtaining written informed consent, 30 patients without major fractures who had undergone CSCI were included in this study (Fig. 1). The inclusion criteria were as follows: age > 50 years, cervical trauma episode, acute CSCI symptoms, and radiological confirmation of CSCI through CT and MRI. A small avulsion fracture of the vertebral body, spinous process fracture, or bone bruise in the vertebral body without noticeable vertebral collapse was considered a minor bony injury, which was included, as previously described.[11] Patients with thoracic and lumbar spine injuries, skeletal injuries, dislocated injuries, brain injuries, cerebral infarctions, or insufficient data were excluded. Instrumentation surgeries for patients with cervical fracture and dislocated injuries may affect swallowing disorders after surgery, so we excluded these patients. Data were obtained by reviewing patient records over a 9-year interval. The average age at admission was 69.6 (range, 52–82) years. All the patients received conservative treatment including physical, occupational, and speech and language therapy with a rigid collar brace during the acute phase. Speech and language therapy included secretion management, oral care, and rehabilitation of swallowing, depending on swallowing dysfunction. Three patients underwent decompression surgery, about three months after the initial surgery, for preventing re-injury due to spinal canal stenosis. According to the American Spinal Injury Association Impairment Scale (AIS), 3, 6, 12, and 5 patients had grade A, B, C, and D injuries, respectively. Demographic data, including age, sex, body mass index, medical history, AIS score, injury level, and CT and MRI findings, were collected from medical records.

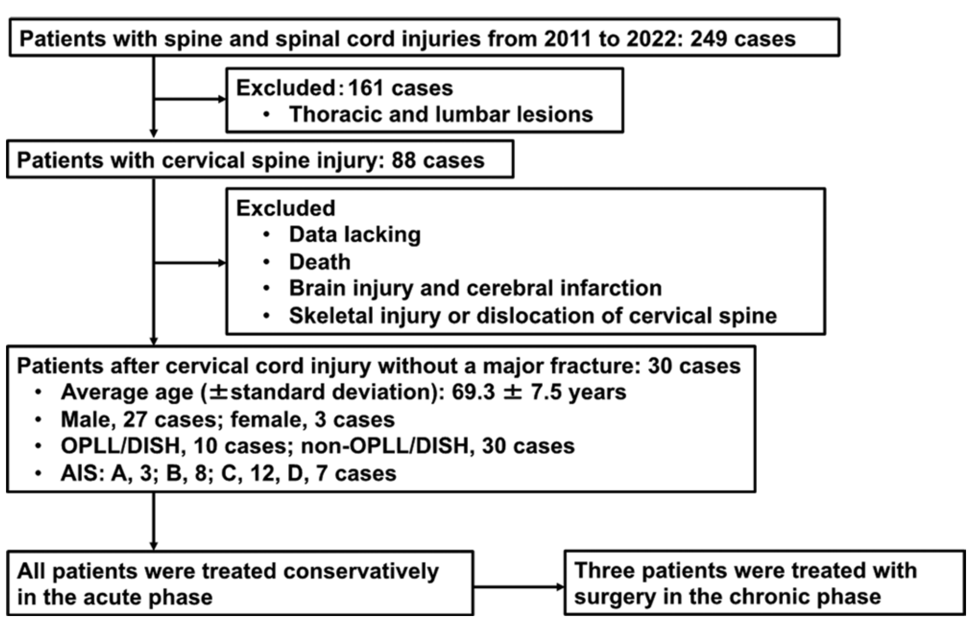

Figure 1. Flow diagram of the study. Twenty-four patients were selected. AIS = American Spinal Injury Association Impairment Scale, DISH = diffuse idiopathic skeletal hyperostosis, OPLL = ossification of posterior longitudinal ligament.

2.2. Radiographic evaluation

All patients underwent computed tomography (CT) and magnetic resonance imaging (MRI) for cervical spine examination on the day of injury. Prevertebral soft tissue thickness (PVST) was measured using midsagittal sections on cervical CT (GE Healthcare, Waukesha, WI, USA) at C2, C3, and C6, as previously described.[9] The prevalence of high-intensity in the prevertebral space was evaluated using STIR midsagittal MR images (Exelart 1.5 T MRI System; Toshiba Co., Ltd., Tokyo, Japan). We assessed the prevertebral high-intensity area (HIA) and high-intensity anteroposterior width (HIW) at each vertebral level from C1 to C7 (Fig. 2A and B) using a method modified by Maeda et al,[13] and defined the maximum HIW as the widest value from the C1 to C7 levels. All measurements were performed using stored digitalized radiogram data on a picture-achieving computer software system. Two examiners with 19 and 10 years of experience as spine surgeons measured the PVST on CT images and the HIA and HIW on MR images. The examiners were blinded to the demographic data, such as patient age and sex.

2.3. Dysphagia screening test

For the dysphagia screening test, we used the repetitive saliva swallowing test (RSST), which is one of the most well-known methods for this diagnosis;[14] it was performed by a speech therapist within seven days after injury. The RSST was designed to examine the ability of patients to voluntarily swallow repeatedly, which correlates highly with aspiration as previously described.[14] The patient was placed in a supine position and instructed to swallow air repeatedly and count the number of swallows. A count of ≥ 3 dry swallows within 30 seconds was considered normal and < 3 dry swallows within 30 seconds were considered impaired. The number of swallows was counted by palpating the hyoid bone and the thyroid cartilage.

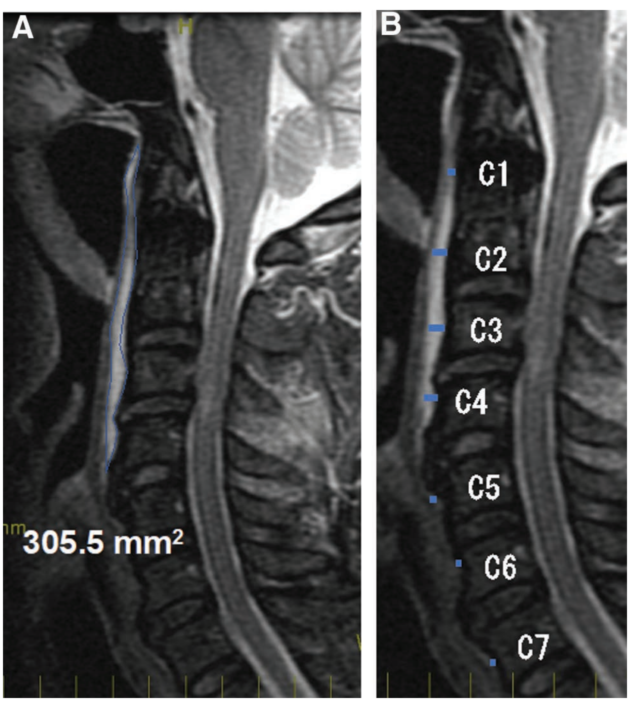

Figure 2. The prevalence of the prevertebral high-intensity area (A) and high-intensity anteroposterior width (B) at C1–C7 vertebral level was evaluated by short T1 inversion recovery midsagittal magnetic resonance images.

2.4. Definition of swallowing disorder

The functional oral intake scale was used to evaluate oral intake function.[15] Levels 1 to 3 relate to varying degrees of non-oral feeding, and levels 4 to 7 relate to varying degrees of oral feeding without non-oral supplementation. Swallowing disorder was defined as an functional oral intake scale level 1 to 3, which included patients who were tube-dependent for nutrition due to obvious aspiration 28 days after injury, according to a previous study.[4]

2.5. Statistical analysis

All statistical analyses were performed using SPSS version 29.0.1 (SPSS Inc., Chicago, IL). Age, body mass index, HIA, HIW, and PVST were compared between the swallowing disorders and non- swallowing disorders groups using the Mann–Whitney *U* test. Sex, medical history, AIS score, and injury level were compared between the dysphagia and non-dysphagia groups using the chi-square test. The reliability of the PVST, HIA, and HIW was determined using the intraclass correlation coefficient.[16] We employed a receiver operating characteristic curve to evaluate the association between HIA and swallowing disorders. Values are expressed as medians and interquartile ranges. Statistical significance was set at $P < .05$.

3. Results

The incidence of swallowing disorders after CSCI in the absence of major fractures was 16.7%. Table 1 describes cases of swallowing disorders, defined as tube-dependent nutrition because of obvious aspiration. Age, sex, BMI, AIS score, and injury level did not differ significantly between the swallowing disorders and non- swallowing disorders groups (Table 2).

The intraclass correlation coefficients for the measurement of the HIA and HIW were 0.965, 0.877, 0.945, 0.839, 0.882, 0.968, and 0.992 at the vertebral level from C1 to C7, respectively, indicating high interobserver reliability. The intraclass correlation coefficients for the PVST measurements were 0.736, 0.759, and 0.686 at C2, C3, and C6, respectively, indicating substantial interobserver reliability. There were no significant differences in the background characteristics and RSST between the 2 groups (Table 2). The HIA was significantly higher in the swallowing disorders group (median, 409.0 mm²) than

Table 1

Cases of swallowing disorders were defined as tube-dependent nutrition because of obvious aspiration.

Age (yr), gender	AIS	Comorbidities	Smoking	HIA (mm²)	RSST	Pneumonia (Date of onset)	Tracheotomy
67, male	C	Hypertension	Yes	203.3	Normal	No	No
65, male	A	Hypertension	Yes	409.0	Normal	Yes (4 d)	Yes
76, male	C	Bladder cancer	Yes	907.7	Abnormal	Yes (4 d)	No
81, male	B	Atrial fibrillation	No	2296.8	Normal	No	No
70, male	B	None	No	142.7	Abnormal	Yes (4 d)	Yes

AIS = American Spinal Injury Association Impairment Scale, HIA = high-intensity area, RSST = repetitive saliva swallowing test.

Table 2

Comparison between characteristics of patients with and without swallowing disorders.

Variable	Swallowing disorders (n = 5)	Non-swallowing disorders (n = 25)	P value*
Age, years	71.8 (66.0–78.5)	70.0 (63.5–75.5)	.415
Female sex	0 (0)	3 (12.0)	1.000
BMI, kg/m^2	22.9 (19.0–26.7)	23.3 (20.7–25.5)	.676
Hypertension, N (%)	4 (80.0)	12 (48.0)	.336
Diabetes, N (%)	0 (0)	7 (28.0)	.304
Smoking, N (%)	3 (60.0)	5 (20.0)	.112
Ossification of the spine, N (%)	0 (0)	10 (40.0)	.140
AIS			
A	1 (20.0)	2 (8.0)	.492
B	2 (40.0)	6 (24.0)	
C	2 (40.0)	10 (40.0)	
D	0 (0)	7 (28.0)	
Above C4 level, N (%)	5 (100)	23 (92.0)	1.000
Tracheotomy, N (%)	2 (40.0)	1 (4.0)	.064
Accompanying injuries, N (%)	2 (40.0)	5 (20.0)	.565
Abnormal on RSST, N (%)	2 (40.0)	5 (22.7)	.622

Values are presented as median and interquartile range.

AIS = American Spinal Injury Association Impairment Scale, BMI = body mass index, RSST = repetitive saliva swallowing test.

*Significant differences ($P < .05$) between values for patients with and without swallowing disorders were calculated using the using the Mann–Whitney *U* test.

Table 3

Comparison of radiographic evaluation between patients with and without swallowing disorders.

Variable	Swallowing disorders (n = 5)	Non-swallowing disorders (n = 25)	P value*
Measurement on MRI			
HIA (mm^2)	409.0 (173.0–1602.2)	159.1 (71.0–197.4)	.045*
HIW C1 (mm)	0 (0–2.9)	0 (0–0)	.157
HIW C2 (mm)	2.0 (0–4.8)	0 (0–1.9)	.259
HIW C3 (mm)	5.3 (3.2–4.8)	3.0 (0–4.9)	.273
HIW C4 (mm)	6.6 (4.5–9.4)	3.8 (0–5.1)	.189
HIW C5 (mm)	2.8 (0–5.4)	1.4 (0–4.1)	.816
HIW C6 (mm)	0 (0–8.9)	0 (0–0)	.471
HIW C7 (mm)	0 (0–3.5)	0 (0–0)	.157
PVST			
C2 (mm)	3.6 (0–5.0)	3.1 (0–5.7)	.642
C3 (mm)	6.4 (2.2–8.4)	5.0 (3.5–6.8)	1.000
C6 (mm)	7.6 (3.2–12.5)	10.4 (1.7–13.0)	.330

Values are presented as median and interquartile range.

HIA = high-intensity area, HIW = high-intensity width, MRI = magnetic resonance imaging, PVST = prevertebral soft tissue thickness.

*Significant differences ($P < .05$) between values for patients with and without swallowing disorders were calculated using the using the Mann–Whitney *U* test (indicates a significant difference).

in the non- swallowing disorders group (median, 159.1 mm^2) ($P = .04$) (Table 3). There were no significant differences in HIW and PVST thicknesses between the two groups (Table 3). The optimal cutoff point of the HIA was measured at 203.2 mm^2 with 80.0% and 20.0% sensitivity and specificity, respectively, with an area under the curve of 0.848 (95% CI: 0.657–1.000, $P = .01$, Fig. 3).

4. Discussion

The incidence of swallowing disorders after CSCI in the absence of major fractures was 16.7%. This is the first study to clarify the cutoff value of prevertebral hyperintensity on STIR-MRI for predicting swallowing disorders in patients after CSCI.

Several studies have shown that the incidence of dysphagia in patients with traumatic cervical injury or tetraplegia varies widely, from 7% to 41%.[4–8] The studies included patients with and without skeletal injuries caused by various levels of trauma. As the proportion of patients with CSCI without major fractures has increased in Japan, reflecting the aging society,[1] dysphagia is a crucial issue for these patients.

Age, tracheotomy, and motor dysfunction have been reported to be risk factors for dysphagia in patients with CSCI. In our study, there was no significant difference in age or motor dysfunction (AIS) between the patients with and without dysphagia. This may be explained by the fact that our study included only patients with CSCI without major skeletal injury, and most of them were older adults. The average age was 69.3 years (minimum age, 52 years) on admission, which is higher than that reported in the previous studies, which included young patients.[4–8] Swelling of the prevertebral space was an independent risk factor for dysphagia. Regarding tracheotomy, only two patients (one from each group) underwent the procedure; thus, no significant difference was detected.

Swelling in the retropharyngeal space in patients undergoing anterior cervical surgery[17] and CSCI have also been reported as possible risk factors for dysphagia.[6,9] Hayashi et al reported that the retropharyngeal space measured by MRI was significantly associated with swallowing disorders.[6] Mitsuishi et al[9] measured swelling in the retropharyngeal space using CT and pointed out that it is difficult to set the upper bounds for PVST thickness anterior to C4 and C5 because of the soft tissue characteristics. There was no significant difference in the PVST thickness between the groups with and without swallowing disorders in this study. Furthermore, the ICC for the measurement of PVST on CT showed substantial interobserver reliability. However, the ICC for the measurement of HIA and HIW on the STIR of MRI showed high interobserver reliability. The STIR of MRI has been reported to be sensitive for detecting edema and effective for the diagnosis of soft tissue and ligament damage.[10] Aburakawa et al[11] suggested that STIR-MRI can evaluate paraspinal soft tissue damage more clearly than T2-weighted MRI in patients with traumatic CSCI without a major fracture. Therefore, our predictive value of HIA at 203.2 mm^2 was more specific for the diagnosis of swallowing disorders after CSCI.

In this study, there was no significant difference in RSST between the dysphagia and non-dysphagia groups. The positivity rate of dysphagia for the RSST was low (40%).

Instrumental assessments, such as Videofluoroscopic Swallow Study (VFSS), Flexible Endoscopic Evaluation of Swallowing (FEES), and High-resolution Impedance Manometry (HRIM), have gained popularity in recent years for diagnosing dysphagia, evaluating swallowing biomechanics, and monitoring progress for successful management and rehabilitation.[18] Therefore, combination assessments of these instrumentation and MRI findings for diagnosis of dysphagia after CSCI should be evaluated in the future.

This study has several limitations. First, the sample size is small. Therefore, we could not conduct univariate or multivariate logistic analyses for the risk factors of swallowing disorders. However, this study included only patients with spinal cord injury without major fractures. Therefore, the MRI findings can exclude the effects of spinal dislocation or instability. Second, we did not evaluate the time course of swallowing disorders using MRI after the injury, as in a previous study.[6] Third, the mechanisms underlying swallowing disorders after CSCI remain

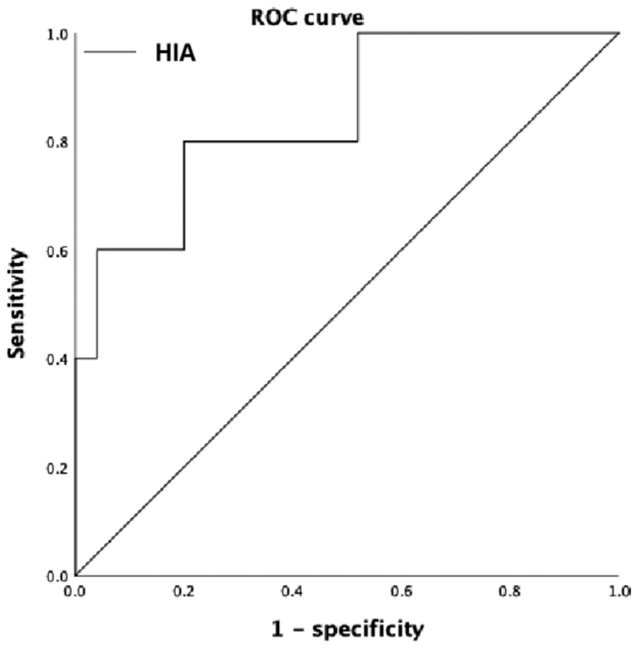

Figure 3. The receiver operating characteristic (ROC) curve to determine the cutoff value of the high intensity area (HIA), which was correlated with swallowing disorders.

unclear. Despite certain limitations, these cutoff values may be useful guidelines for the diagnosis and therapeutic assessment of swallowing disorders after CSCI.

5. Conclusion

The incidence of swallowing disorders after CSCI in the absence of major fractures was 16.7%. The prevertebral hyperintensity area on MRI for swallowing disorders in patients after CSCI without skeletal injury is associated with swallowing disorders. The optimal cutoff point of the area was determined to be 203.2 mm^2.

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