


Can a relatively large spinal cord for the dural sac influence severity of paralysis in elderly patients with cervical spinal cord injury caused by minor trauma?

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Abstract

Retrospective review

The degree of spinal cord compression and bony spinal canal stenosis are risk factors for the occurrence of spinal cord injury (SCI) without major fracture or dislocation, but they do not affect the severity of neurological symptoms. However, whether a relatively large spinal cord for the dural sac influences the severity of symptoms in SCI cases is unknown.

The purpose of this study was to verify the influence of spinal cord size relative to dural sac on the severity of paralysis in elderly patients with cervical SCI caused by minor trauma.

Subjects were 50 elderly patients with SCI caused by falls on flat ground. At 72 hours after injury, neurological assessment was performed using the Japanese Orthopaedic Association (JOA) scoring system. Bony canal anteroposterior diameters (APD) at mid C5 vertebral body were measured with computed tomography. We measured dural sac and spinal cord APD at the injured level and mid C5 with magnetic resonance imaging. Spinal cord compression ratio was calculated by dividing spinal cord at the injured level by spinal cord at mid C5. As the evaluation of spinal cord size relative to the dural sac, spinal cord/dural sac ratio was calculated at the injured level and mid C5. To clarify the factors influencing the severity of paralysis, the relationships between JOA score and those parameters were examined statistically.

A significant negative correlation was observed between JOA score and spinal cord/dural sac ratio at mid C5. No clear relationship was observed between JOA score and bony canal APD or spinal cord compression ratio.

In elderly patients with SCI caused by minor trauma, a relatively large spinal cord for the dural sac was shown to be a factor that influences the severity of paralysis. This result can be useful for the treatment and prevention of SCI in the elderly.

Abbreviations: APD = anteroposterior diameter, CT = computed tomography, ICC = intraclass correlation coefficient, JOA = Japanese Orthopaedic Association, MRI = magnetic resonance imaging, SCI = spinal cord injury.

Keywords: cervical spine, elderly, magnetic resonance imaging, minor trauma, severity of paralysis, spinal cord injury, spinal cord/dural sac ratio

1. Introduction

As society continues to age, the number of cases of cervical spinal cord injury (SCI) without radiographic abnormality, in which no fracture or dislocation is clearly observable on X-ray, is increasing.^[1] In the elderly, the mechanism of injury is often a minor trauma such as falls on flat ground resulting in cervical

hyperextension.^[2,3] This is because many elderly individuals have spondylotic conditions such as disc bulging, osteophytes and hypertrophy of the ligamentum flavum.^[4–6] Bony cervical canal anteroposterior diameters (APD) are known to be smaller in Japanese than in Westerners,^[7] placing Japanese at a higher risk of SCI without major fracture or dislocation. Degenerative and

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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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developmental spinal canal stenosis are risk factors for the occurrence of SCI; however, they do not influence the severity of paralysis after SCI without major fracture or dislocation.^[8]

Several reports have noted that a relatively large spinal cord compared with spinal canal size may influence spinal cord damage.^[9–12] Using magnetic resonance imaging (MRI) to examine asymptomatic cases, Nakashima et al^[10] investigated the influence of a large spinal cord/dural sac ratio on developing spinal cord compression. The larger the spinal cord relative to the dural sac, the smaller the subarachnoid space, which acts as a shock absorber. It has been postulated that, under these conditions, the same degree of external pressure on cervical vertebrae results in more spinal cord damage than would normally be the case. Nevertheless, there are few reports of the relationship between MRI assessment of spinal cord/dural sac ratio and clinical symptoms of cervical SCI.^[12]

This was a retrospective study performed to verify whether a relatively large spinal cord size for the dural sac influences the severity of paralysis in elderly cases of SCI caused by minor trauma.

2. Materials and methods

Approval for this single-center study at the hospital of Japanese Red Cross Kyoto Daini was obtained from the local ethics committee.

Subjects were 50 consecutive patients aged 65 years or older (28 males, 22 females; mean age, 75.4 years) with SCI without major fracture or dislocation caused by falls on flat ground that occurred from 2009 to 2017. Patients experiencing SCI with minor bony injury were included in this study. As previously reported by Maeda et al^[8] a small avulsion fracture of the vertebral body, a spinous process fracture, or a bone bruise in the

vertebral body without noticeable vertebral collapse were considered to be minor bony injuries. All cases were transported to our hospital within 24 hours of injury, underwent X-ray, computed tomography (CT), MRI and neurological assessment at 72 hours after injury. Cases with associated ossification of the posterior longitudinal ligament were excluded. All patients had evidence of SCI with an intraspinal signal change identified on T2-weighted MRI. Neurological assessment was performed using the Japanese Orthopedic Association (JOA) scoring system for cervical myelopathy (Table 1). CT images (0.5-mm-thick axial helical) were obtained with sagittal reconstruction using an 80-line, multi-slice unit (Aquilion prime; Canon Medical, Tokyo, JPN). MRI scans were performed using a 1.5-Tesla superconductive magnet (MAGNETOM Avanto 1.5T a TIM VB19A, SIEMENS, GER). Scans were acquired at a slice thickness of 3 mm in the sagittal plane. T2-weighted images (turbo spin echo TR, 3000 ms; TE, 91 ms) were acquired during sagittal scans. Axial scans were performed using T2-weighted images (turbo spin echo TR, 4000 ms; TE, 95 ms).

Imaging measurements were performed by 3 spinal surgeons to obtain the following parameters. Bony canal APD was measured

Table 1
Evaluation of cervical myelopathy using the scoring system proposed by the Japanese Orthopaedic Association (JOA).

JOA Score	Points
I, Motor function of the upper extremity	
Impossible to eat with cutlery or button shirt	0
Possible to eat with spoon, but not with chopsticks	1
Possible to eat with chopsticks and to button shirt with difficulty	2
Possible to eat with chopsticks and to button shirt, awkward	3
Normal	4
II, Motor function of the lower extremity	
Impossible to walk	0
Need cane or aid on flat ground	1
Need cane or aid only on stairs	2
Possible to walk without cane or aid but slowly	3
Normal	4
III, Sensory function	
A, Upper extremity	
Apparent sensory loss	0
Minimal sensory loss	1
Normal	2
B, Lower extremity (same as A)	0–2
C, Trunk (same as A)	0–2
IV, Bladder function	
Complete retention	0
Severe disturbance (sense of retention, dribbling, incomplete continence)	1
Mild disturbance (urinary frequency, urinary hesitancy)	2
Normal	3
Total	0–17



Figure 1. Anteroposterior diameter of cervical spinal canal. Sagittal view on computed tomography. Anteroposterior diameter of the spinal canal was measured at mid C5 vertebral body.



Figure 2. Spinal cord compression ratio. T2-weighted magnetic resonance imaging with sagittal view. Anteroposterior diameter of the spinal cord at the injured level (white line; a) and at mid C5 vertebral body (white line; b). Spinal cord compression ratio was calculated as a divided by b.

at mid C5 vertebral body with CT in the sagittal view (Fig. 1) and dural sac and spinal cord APD were measured at the injured level and mid C5 vertebral body using T2-weighted sagittal view MRI. Spinal cord compression ratio was calculated by dividing the spinal cord APD at the injured level by spinal cord APD at mid C5 vertebral body (Fig. 2). Dural sac and spinal cord APD at the injured level and mid C5 vertebral body were measured with T2-weighted axial view MRI, and the spinal cord/dural sac ratio was calculated as the spinal cord APD divided by the dural sac APD (Fig. 3). To assess the intra- and interobserver reliability of the CT and MRI measurements, all parameters were measured twice by 3 observers for 10 randomly chosen cases.

The relationship between bony spinal canal and dural sac or spinal cord APD at mid C5 vertebral body was examined using Spearman rank correlation coefficient. To clarify factors influencing the severity of paralysis, the relationship between JOA score and age, bony canal APD, spinal cord compression ratio or spinal cord/dural sac ratio was examined statistically using Spearman rank correlation coefficient. Multiple regression analysis was performed to assess the combined influence of variables on the severity of paralysis. To examine the effects of

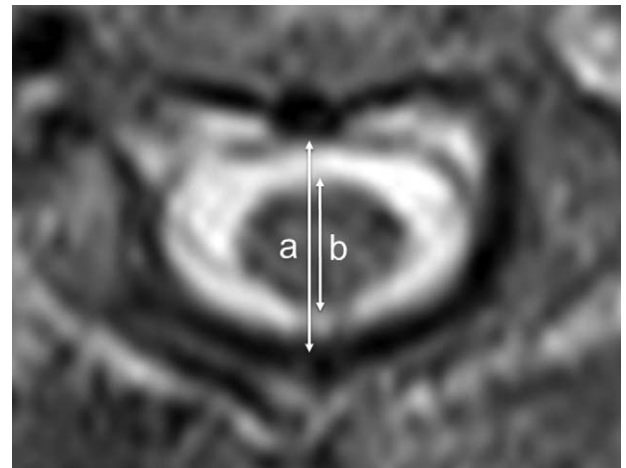


Figure 3. Ratio of spinal cord/dural sac. T2-weighted magnetic resonance imaging in the axial plane at mid C5 vertebral body. Anteroposterior diameter of the dural sac (a) and the spinal cord (b). The spinal cord/dural sac ratio was calculated as b divided by a.

various factors on the severity of paralysis, the following factors were considered as independent variables: age, sex (male=1, female=2), bony canal APD, spinal cord compression or spinal cord/dural sac ratio. The intra- and interobserver reliability of the measurements were examined using intraclass correlation coefficients (ICCs) and their 95% confidence intervals (CIs). All data values are expressed as mean ± standard deviation. All data were analyzed using SPSS version 21.0 (SPSS, Chicago, Illinois) and significance was set at 5%.

3. Results

The clinical characteristics of the 50 patients who participated in this study are shown in Table 2. Mean JOA score was 7.8 ± 4.0. The injured level was C3–4 in 24 cases, C4–5 in 11 cases, C5–6 in 12 cases and C6–7 in 3 cases (Table 2). With CT in the sagittal view, mean bony canal APD at mid C5 was 11.4 ± 0.7 mm. Sagittal MRI showed a mean spinal cord compression ratio at the injured level of 80.3 ± 9.6%, mean dural sac APD of 10.1 ± 1.0 mm and mean spinal cord APD of 7.1 ± 0.8 mm at mid C5. With axial MRI, mean spinal cord/dural sac ratio was 73.2 ± 11.1% at the injured level and 65.4 ± 7.8% at mid C5.

Examination of the relationship between bony canal and dural sac or spinal cord APD at mid C5 showed a weaker correlation between bony canal and spinal cord APD ($r=0.32, P=.022$) than

Table 2
Clinical characteristics of patients.

Characteristics	
n	50
Sex (male/female)	28/22
Age (yr)	75.4 ± 6.9
JOA score (points)	7.8 ± 4.0
Injured level	C3/4: 24
	C4/5: 11
	C5/6: 12
	C6/7: 3

JOA = Japanese Orthopaedic Association.

Table 3**Multiple regression analysis on the Japanese Orthopaedic Association (JOA) score.**

VS JOA score	β	<i>P</i>
Age	0.01	.99
Sex	0.29	.03
Bony canal APD	0.06	.64
Spinal cord compression ratio	0.06	.64
Spinal cord/dural sac ratio (injured level)	-0.24	.07
Spinal cord/dural sac ratio (C5)	-0.50	<.001

APD = anteroposterior diameter.

the correlation between bony canal and dural sac APD ($r=0.58$, $P<.001$).

Univariate analysis showed no significant relationship between JOA score and age, bony canal APD, spinal cord compression or spinal cord/dural sac ratio at the injured level ($r=-0.014$, $P=.92$ [age], $r=-0.002$, $P=.99$ [bony canal APD], $r=0.007$, $P=.96$

[spinal cord compression], $r=-0.26$, $P=.07$ [spinal cord/dural sac ratio at the injured level], respectively) and a significant negative correlation with spinal cord/dural sac ratio at mid C5 only ($r=-0.51$, $P<.001$). Multiple regression analysis showed a significant negative correlation between JOA score and spinal cord/dural sac ratio at mid C5 ($\beta=-0.50$, $P<.001$) (Table 3). The intra- and interobserver reliability of the measurements ranged from 0.70 to 0.96 (Table 4).

4. Case presentation

Male aged 74 years. Fell while walking, bruising of the forehead, immediately transported to our hospital. JOA score was -0.5 at hospital admission. No clear fracture or dislocation was observed on X-ray or CT; MRI showed signal change at C3-4. With CT in the sagittal view, bony canal APD was 12 mm at mid C5, sagittal MRI showed a spinal cord compression ratio of 78.5% at the injured level, and axial MRI showed a spinal cord/dural sac ratio of 70.9% at mid C5 (Fig. 4).

Table 4**Interobserver and intraobserver reliability for computed tomography and magnetic resonance imaging.**

Variable	Intraobserver ICC (95% CI)			Interobserver ICC (95% CI)	
	Rater 1	Rater 2	Rater 3		
APD					
canal	CT (C5)	0.92 (0.72-0.98)	0.83 (0.48-0.95)	0.81 (0.42-0.95)	0.95 (0.84-0.99)
dural sac	Axial MRI (C5)	0.91 (0.71-0.98)	0.83 (0.49-0.96)	0.99 (0.99-1.00)	0.86 (0.60-0.96)
cord		0.80 (0.40-0.95)	0.72 (0.24-0.92)	0.89 (0.65-0.97)	0.72 (0.17-0.92)
dural sac	Sagittal MRI (C5)	0.83 (0.47-0.95)	0.75 (0.29-0.93)	0.95 (0.82-0.99)	0.73 (0.27-0.92)
cord		0.88 (0.60-0.97)	0.79 (0.40-0.94)	0.96 (0.85-0.99)	0.70 (0.15-0.92)
cord	Sagittal MRI (injured level)	0.89 (0.64-0.97)	0.93 (0.75-0.98)	0.88 (0.62-0.97)	0.83 (0.19-0.96)

presence of sex (male = 1, female = 2).

APD = anteroposterior diameter, CI = confidence interval, ICC = intraclass correlation coefficient.

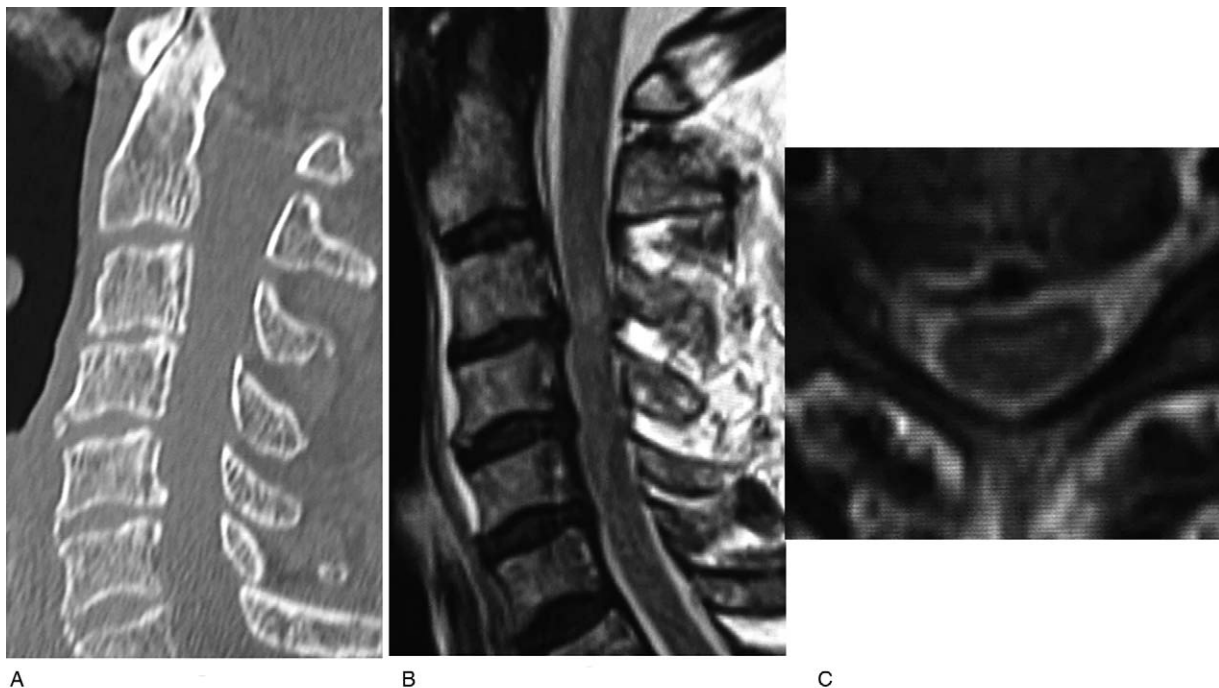


Figure 4. Representative case. Sagittal view on computed tomography (A). T2-weighted magnetic resonance imaging with sagittal view (B) and axial view (C) at mid C5 vertebral body.

5. Discussion

It has been previously reported that developmental bony canal stenosis and cord compression factors caused by degenerative changes are risk factors for progression of the neurological symptoms of cervical spondylotic myelopathy.^[13,14] They have also been identified as risk factors for the occurrence of SCI without major fracture or dislocation.^[4,6] Since many elderly people have age-related degenerative changes leading to compression, it has been reported that cervical hyperextension due to minor trauma, resulting in disc bulging and buckling of the ligamentum flavum, could easily lead to SCI in this group.^[3,5,15] Nevertheless, it was reported that developmental stenosis of the bony canal and cord compression due to degenerative changes do not influence the severity of paralysis following the onset of SCI.^[8] This study was limited to examining SCI in the elderly caused by minor trauma. C3–4 was the most frequent injured segment and the distribution of injured levels was similar to previous studies.^[6,8] Like other reports, the results show that the severity of paralysis had no relationship with bony canal APD or spinal cord compression ratio. In addition, since spinal cord compression due to degenerative changes increases with age, paralysis could be expected to become more severe, but no clear relationship between age and severity of paralysis was observed in this study.

In a study using cadaveric specimens, Kameyama et al^[16] reported that there are individual differences in spinal cord size that make comparisons of cross-sectional area and APD only problematic. Inoue et al^[17] reported that there was no strong correlation between the bony canal APD and the APD of dural sac or spinal cord. Nakashima et al^[10] conducted a study of asymptomatic healthy subjects to investigate the correlation between the APD of spinal canal and dural sac or spinal cord, and found a higher correlation between spinal canal and dural sac APD than between spinal canal and spinal cord APD. Similar results were obtained in the current study, even in elderly symptomatic subjects; thus, there are individual differences in spinal cord size, and relative evaluation is appropriate.

In consideration of the degree of spinal cord damage, the concept of relative evaluation of the spinal cord and dural sac was previously proposed.^[17,18] Regarding the vertebral level for relative evaluation of the spinal cord and dural sac using cervical MRI, measurements in this study were taken at mid C5 vertebral body. This is the same level used for image evaluation of developmental bony canal APD.^[19] Since this is a mid vertebral body that is not easily influenced by compression factors, such as intervertebral discs and ligamentum flavum, it was judged to be appropriate. In this study, a large spinal cord/dural sac ratio in elderly patients with SCI caused by minor trauma was shown to be a factor influencing severity of paralysis. It was previously reported that spinal cord/dural sac ratio is a risk factor for the progression of spinal cord compression seen on MRI in asymptomatic cases,^[10] but few reports have examined the relationship between relative spinal cord size and clinical symptoms in symptomatic cases. In fact, the only report is by Ruegg et al.^[12] In their study, the authors retrospectively reviewed patients who sustained a cervical SCI after a minor trauma to determine if there were differences in MRI measurements in those who developed acute SCI and those who did not. They reported that a spinal cord/dural sac ratio of 80% or higher can reliably identify patients at risk of acute SCI after minor trauma. However, imaging characteristics of the spinal canal do

not seem to be associated with the severity of, or recovery from, SCI. A characteristic of our study is that the subjects were elderly patients who were injured by falls on flat ground. This is the first study to show the relationship between spinal cord/dural sac ratio and severity of paralysis in such cases.

The 3 parameters examined in this study were: bony canal APD; spinal cord/dural sac ratio; and spinal cord compression ratio. Of these, only spinal cord/dural sac ratio at mid C5 influenced the severity of paralysis. The view is that the spinal cord is easily damaged because of its large size relative to the spinal canal enclosing it. Spinal cord compression ratio and spinal cord/dural sac ratio at the injured level does not influence severity of paralysis. These measurements were determined by spinal cord edema and compression factors, such as intervertebral discs and ligamentum flavum. We propose that this was because dynamic factors are also involved in determining the degree of severity. Specifically, since dynamic factors have little influence at locations where segmental motion is limited by the progression of spondylosis, it is possible that, with the same degree of external force, even considerable cord compression causes less spinal damage.

The number of cervical SCI cases among the elderly is increasing, not only in Japan,^[1,20] but also worldwide.^[2,21,22] The life expectancy of elderly cervical SCI cases is poor and the medical costs are extremely high, causing social problems. This situation calls for effective treatment and preventive measures.^[2,21,22] The results of this study suggest it would be prudent to implement fall prevention measures in asymptomatic elderly cases if screening shows that the spinal cord/dural sac ratio is high. Since residential characteristics and living conditions differ nationally and regionally, a comprehensive assessment of measures and methods to prevent falls, including consideration of cost-effectiveness, is required.

A limitation of this study is the potential for unintentional selection bias because it was a single-center, retrospective study with a small number of subjects from a single ethnic group. Further studies should be conducted to determine whether spinal cord/dural sac ratio in the elderly influences the prognosis for paralysis due to trauma. Large-scale cohort studies are also necessary to verify whether screening for spinal cord/dural sac ratio using MRI can prevent trauma in the elderly.

Author contributions

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