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MR T2 image classification in adult patients of cervical spinal cord injury without radiographic abnormality: A predictor of surgical outcome☆

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ABSTRACT

Objectives: Although patients with cervical spinal cord injury without radiographic abnormality (SCIWORA) present increased signal intensity (ISI) on magnetic resonance imaging (MRI), its degree has not been examined. This study evaluated the clinical effectiveness of MRI-based ISI in adult patients of SCIWORA. Its predictive value for symptom severity was also evaluated.

Patients and methods: One-hundred consecutive SCIWORA patients who had undergone expansive laminoplasty were enrolled. Among them, 79 were male and 21 were female. The mean age was 55 years (range 20–87). All patients underwent MRI in the acute phase, and ISI was classified into three groups based on sagittal T2-weighted MRI: Grade 0, none; Grade 1, light (obscure); and Grade 2, intense (bright). The pre- and postoperative neurological status was evaluated using the Japanese Orthopaedic Association scoring system for cervical myelopathy (JOA score) and the ASIA impairment scale (AIS).

Results: Preoperative MRI showed Grade 0 in 8 patients, Grade 1 in 49 patients, and Grade 2 in 43 patients. There were no differences in age and gender among three groups. The pre- and postoperative JOA scores decreased significantly with an increasing ISI grade. The recovery rate of JOA score decreased with the ISI grade. The ISI grade tended to increase with the pre- and postoperative AIS grades. ISI Grade 2 on MRI was observed in severely paralyzed cases.

Conclusions: MRI-based ISI classification is correlated with preoperative symptom severity in adult patients with SCIWORA and can be a predictor of surgical outcome.

1. Introduction

Over the last decades, population aging is causing the incidence of spinal stenosis to rise, leading to a consequent increase of the number of spinal cord injuries without radiographic abnormality (SCIWORA), caused by minor trauma. SCIWORA is a syndrome that involves spinal cord injury without evidence of spine fracture or dislocation on plain radiographs or computed tomography (CT) [1]. The incidence, pathogenesis, and severity of SCIWORA differ across age groups due to anatomical and biomechanical differences in the spine [2].

Magnetic resonance imaging (MRI) is currently the state-of-the-art clinical tool to evaluate traumatic spinal cord injury. As such, MRI is crucial to examine patients with SCIWORA as it shows both the degree of spinal stenosis and the detailed intramedullary state of the spinal cord [3]. MRI is useful to diagnose and establish a prognosis for SCIWORA due to its better contrast resolution, absence of bony artifacts, and multiplanar imaging capability.

To our knowledge, reports on the imaging features on MRI of patients with cervical SCIWORA are scarce [4,5]. The present study focused on the findings of MR T2-weighted images (T2WI) during the acute phase. Although patients with cervical SCIWORA often present intramedullary high-signal intensities (increased signal intensities: ISI), the prognostic significance of the ISI degree remains controversial. The progress of MRI techniques has enabled the detection of two different

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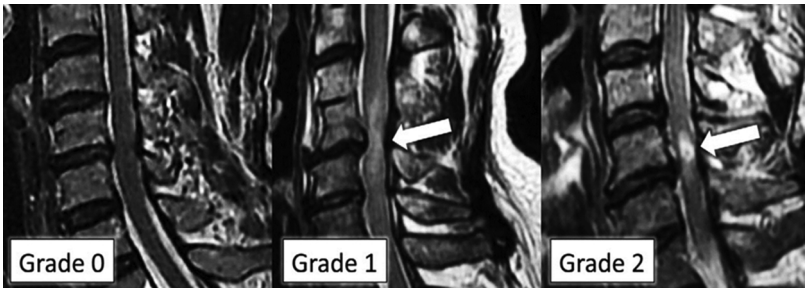

Fig. 1. Increased signal intensity (ISI) classification of the spinal cord in T2-weighted MRI. The arrows indicate ISI sites.

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

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

Table 2
Patient demographics, summary details in each grade of increased signal intensity.

	Grade0	Grade1	Grade2	*P* value
Number of patients	8	49	43	
Age (years)	54.1 ± 12.7	54.6 ± 15.4	56.8 ± 10.8	0.8747
Gender (Males/Female)	6/2	40/9	33/10	0.8131
Injury mechanism, no. of patients (%)				
Fall or jump	5 (62.5%)	29 (59.2%)	28 (65.1%)	0.8424
Motor vehicle collision	3 (37.5%)	15 (30.6%)	10 (23.3%)	0.6053
Sports accident	0 (0%)	2 (4.1%)	4 (9.3%)	0.4357
Other	0 (0%)	3 (6.1%)	1 (2.3%)	0.5428
Time from injury to MRI (hours)	25.5 ± 48.3	25.2 ± 46.9	27.1 ± 44.5	0.3296
Time from injury to operation (days)	15.7 ± 3.2	17.4 ± 3.3	17.6 ± 3.1	0.2321

Values given are mean ± SD unless otherwise specified.
MRI indicates magnetic resonance imaging; SD, standard deviation.

types of ISI: light (obscure) and intense (bright) signal changes [6,7]. However, the relationship between ISI classification and severity in cervical SCIWORA remains to be fully understood. The present study, therefore, evaluated the clinical efficacy of MRI and investigated whether MRI-based ISI classification reflects symptom severity in adult patients of cervical SCIWORA.

Table 3
The neurological levels based on increased signal intensity or narrowest levels in each grade.

	Total	Grade0	Grade1	Grade2	*P* value
Number of patients	100	8	49	43	
Neurological levels, no. of patients (%)					
C3/4	39 (39%)	2 (25%)	19 (38.8%)	18 (41.9%)	0.6676
C4/5	39 (39%)	3 (37.5%)	20 (40.8%)	16 (37.2%)	0.9354
C5/6	22 (22%)	3 (37.5%)	10 (20.4%)	9 (20.9%)	0.5431

2. Material and methods

2.1. Study population

A total of 100 consecutive SCIWORA patients who had undergone expansive laminoplasty were enrolled. Participants included 79 males and 21 females, with a mean age of 55.5 ± 13.3 years. All patients underwent preoperative functional X-ray in the acute phase. Patients with fracture or traumatic instability such as dislocation/subluxation were excluded from the study. All patients presented symptoms of cervical spinal cord injury (SCI) and MRI findings consistent with symptoms secondary to cervical spinal canal stenosis. For each patient, SCI was confirmed by physical examination and MRI-confirmed cord compression. Patients with profound neurological deficit and persistent spinal cord compression due to cervical spinal canal stenosis were indicated for surgery. This study was approved by the Institutional Review Board, and written informed consent was obtained from each patient prior to study participation or surgery.

All patients underwent preoperative high-resolution MRI in the acute phase, which was performed with a 1.5 T MRI unit (Signa; GE Healthcare, Chicago, IL). Most patients underwent MRI within 24 h after trauma (average 26.0 ± 45.6 h). T1- and T2-weighted images of the cervical cord's sagittal views were obtained using a spin echo sequence system for T1-weighted images and a fast spin echo sequence system for T2-weighted images, with a surface coil. The slice width was 4 mm, and the acquisition matrix was 512 × 256. The sequence parameters were repetition time (TR) 400 ms/echo time (TE) 11 ms for T1-weighted images, and TR 4000 ms/TE 126 ms for T2-weighted images. In sagittal T2 images, the ISI of the spinal cord at the narrowest level was classified into three groups based on the reports by Yukawa et al.: Grade 0, none; Grade 1, light (obscure); and Grade 2, intense (bright) (Fig. 1) [8], where intense ISI was considered as similar to the signal from the cerebrospinal fluid. ISI classifications were performed by two independent radiologists, experienced in spinal imaging. The level of agreement between the two observers when evaluating the signal change on T2-weighted images was 0.94 (kappa = 0.85; $P < 0.001$), and they established the final classification by consensus.

The groups were compared for the following parameters: age, gender, injury mechanism, time from injury to MRI examination, and time from injury to surgical intervention. The neurological levels based

Table 4
Clinical and radiographic outcomes in each grade of increased signal intensity.

	Grade0	Grade1	Grade2	*P* value
Follow-up period (months)	25.5 ± 18.4	22.6 ± 11.0	27.3 ± 23.8	0.8130
Surgery time (minutes)	94.6 ± 28.3	89.3 ± 38.9	99.0 ± 49.0	0.4905
Blood loss (ml)	68.8 ± 67.3	81.3 ± 99.1	89.7 ± 98.2	0.9377
Preoperative JOA score (points)	12.3 ± 2.7	8.5 ± 3.6	7.6 ± 3.4	0.0057[a]
Postoperative JOA score at final follow-up (points)	15.1 ± 1.5	11.9 ± 3.3	10.6 ± 3.6	0.0010[a]
Recovery rate of the JOA score (%)	59.0 ± 21.6	42.3 ± 25.8	33.9 ± 25.4	0.0163[a]

Values given are mean ± SD unless otherwise specified.
JOA score indicates Japanese Orthopaedic Association score for cervical myelopathy; SD, standard deviation.
[a] Statistically significant values.

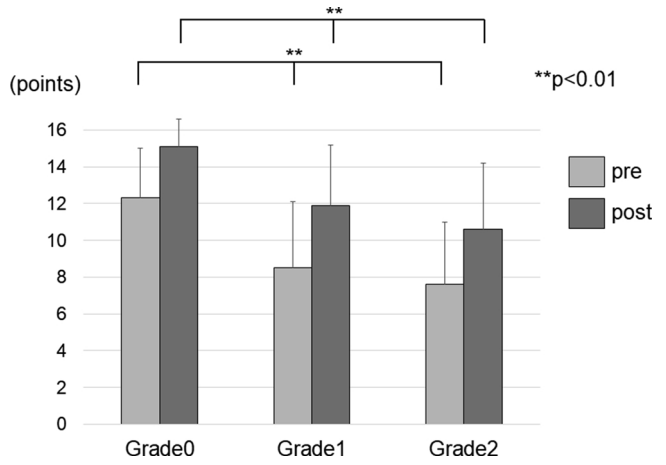

Fig. 2. Pre- and postoperative Japanese Orthopaedic Association for cervical myelopathy (JOA) score.
A significant difference was observed among the three groups, regarding the pre- and postoperative JOA scores, whereupon the pre- and postoperative JOA score decreased significantly with an increasing ISI grade.

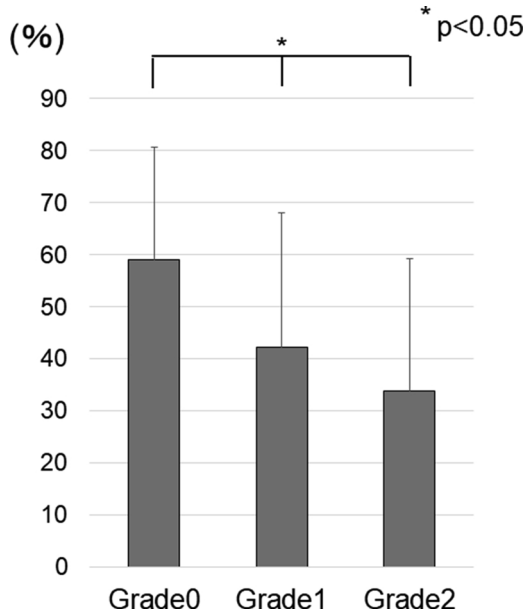

Fig. 3. Recovery rate (RR) of the Japanese Orthopaedic Association for cervical myelopathy (JOA) score in the three groups.
A significant difference was observed among the three groups regarding the JOA score RR, whereupon it decreased significantly with the ISI grade.

on ISI or narrowest levels were evaluated from the MRI.

2.2. Surgical technique for modified double-door laminoplasty

Double-door laminoplasty was performed as described by Kurokawa with some modifications [9,10]. The muscles attached to the C2 spinous process were preserved without detachment. Surgical exposure was as limited as possible. The spinous processes between C3 and C7 were resected at their bases, and the laminae were cut at the center with a high-speed drill. Bilateral gutters were created as hinges at the border between the laminae and the facets, in a slightly more medial fashion than originally described, thus minimizing invasion of the facets. After elevating the halves of the laminae like a French door, the bone graft struts (16–18 mm long) created from the C6 or C7 spinous process were tied to bridge the bilateral edges of the laminae.

2.3. Postoperative considerations

From postoperative day 1, all patients were allowed to sit up and walk while wearing a Philadelphia collar. The collars were fitted to the patients but could be removed at the patients' discretion. Cervical ROM exercises were performed as soon as possible during the rehabilitation program, and patients were instructed on ideal spinal alignment.

2.4. Clinical outcome

Surgery time, blood loss, and postoperative follow-up duration were evaluated. Symptom severity before and after surgery was assessed based on the scoring system of the Japanese Orthopaedic Association for cervical myelopathy (JOA score) [11,12], and the postoperative JOA score was determined at the final follow-up. JOA recovery rate (RR) was calculated using the formula suggested by Hirabayashi et al. [12] [RR = postoperative JOA score − preoperative JOA score) / (17 − preoperative JOA score) × 100%] (Table 1), with 100% corresponding to the best possible postoperative improvement. The American Spinal Injury Association (ASIA) impairment scale (AIS) was also evaluated [13].

2.5. Statistical analysis

Data were analyzed using the SPSS statistical software (version 18.0; SPSS, Inc., Chicago, IL, USA). Results are presented as mean ± standard deviation. Differences between two groups were analyzed with the Mann–Whitney U test, whereas differences among three groups were analyzed using the Kruskal–Wallis test. Analyses of repeated measures within the same group were performed using a Wilcoxon test. The chi-square test was used to analyze differences between groups. A level of $P < 0.05$ was considered statistically significant.

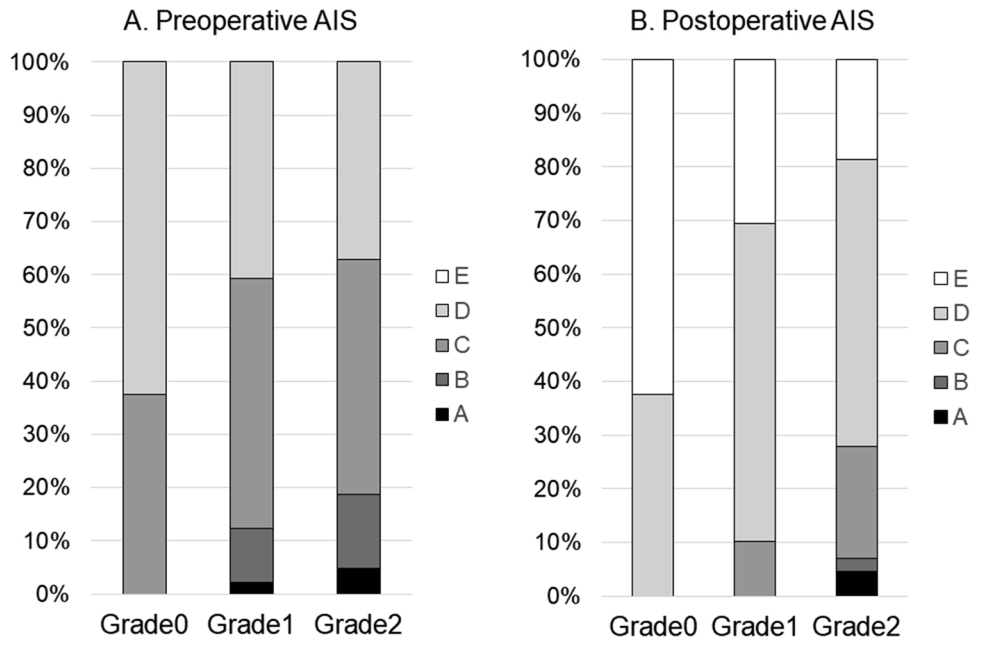

Fig. 4. Pre- and postoperative American Spinal Injury Association impairment scale (AIS) in the three groups.
The ISI grade tended to increase with the pre- and postoperative AIS grades. ISI Grade 2 on MRI was observed in severely paralyzed cases.

3. Results

The neurological levels based on ISI or narrowest levels were C3/4 in 39 cases, C4/5 in 39 cases, and C5/6 in 22 cases. All patients underwent expansive laminoplasty, which was performed on C3–C7 in 94 patients and C3–C6 in 6 patients. The mean period from injury to operation was 17.4 ± 3.3 days. The mean operative time was 94.5 ± 42.9 min, and the mean blood loss was 83.9 ± 119.6 mL. All patients were followed up for > 12 months after surgery, and the mean follow-up period was 24.9 ± 18.4 months. The mean pre- and postoperative JOA scores were 8.4 ± 3.6 and 11.6 ± 3.5 points, respectively. The mean RR was 40.1 ± 26.1%, and 67% of the patients showed one or more grades of improvement in the ASIA impairment scale.

Ninety-two patients (92.0%) presented preoperative ISI. The preoperative MRI showed Grade 0 in 8 patients, Grade 1 in 49 patients, and Grade 2 in 43 patients. No differences were found among the three groups regarding age and gender, injury mechanism, time from injury to MRI, and time from injury to surgery (Table 2). No differences were found among the three groups regarding the neurological levels based on ISI or narrowest levels (Table 3).

No significant differences were found among the three groups regarding follow-up duration, surgery time, and blood loss. The pre- and postoperative mean JOA scores for Grades 0, 1, and 2 were 12.3, 8.5, 7.6 and 15.1, 11.9, 10.6, respectively (Table 4) and decreased significantly with an increasing ISI grade ($P < 0.01$) (Fig. 2). The mean RR of the JOA score were 59.0%, 42.3%, and 33.9%, respectively. Grade 2 had a significantly lower mean (Table 4). The JOA score RR decreased with the ISI grade ($P < 0.05$) (Fig. 3). The ISI grade tended to increase with the pre- and postoperative AIS grades. ISI Grade 2 on MRI was observed in severely paralyzed cases (Fig. 4).

4. Discussion

Patients with SCIWORA often present ISI of the spinal cord on T2-weighted MRI [14,15], and recent advances in MRI technology and software have enabled the identification of various degrees of ISI. There is currently no consensus regarding the association among the presence of ISI, symptom severity, and surgical outcome [4–6]. The relationship between ISI classification in SCIWORA and symptom severity remains controversial [16–18]. The present study classified preoperative ISI in adult SCIWORA patients and investigated whether ISI classification reflected symptom severity and surgical outcome. Results showed that increased ISI grade in patients with SCIWORA was associated with a decline on postoperative RR and greater paresis severity, indicating that ISI Grade 2 is related to a poorer outcome. Therefore, ISI classification may comprise a possible indicator of symptom severity in SCIWORA patients.

SCIWORA is associated with hyperextension injury of the cervical spine and is commonly observed in patients with minor trauma without bony injury, patients with preexisting pathology such as cervical spondylosis, patients with ossification of the posterior longitudinal ligament, or canal stenosis [19–21]. In elderly patients, the narrowing of the canal is commonly observed. This is important in the context of SCIWORA since the mechanism underlying central cord syndrome probably differs from that seen in young patients [2]. In a hyperextension injury, the cord is compressed between the enfolded ligamentum flavum and the anterior vertebral osteophyte [5,19].

SCIWORA diagnosis is based on physical symptoms, neurological examination, and radiographic imaging. Regardless of the population assessed, there is no doubt that MRI is the best clinical tool to evaluate traumatic SCI [4]. MRI provides a detailed view of both the degree of spinal canal stenosis and the intramedullary state of the spinal cord, which is useful to diagnose SCI [5]. MRI is being increasingly used in the evaluation of post-traumatic myelopathy [14,15], where it enables to image the injured cord and to predict the outcome [16]. Significant changes in signal intensity, due to hemorrhage, contusion, or edema, are best seen in T2WI. However, no reports have focused on the association between the grade of signal change on MRI and the functional outcome in patients with SCIWORA.

The predictive value of abnormal signal intensity on MRI is well reported in the literature [16]. Abnormal signal intensity in the spinal cord is used as an umbrella term, meant to include intramedullary hematoma, hemorrhage, and edema [14]. Fehlings proposed the use of quantitative radiographic measures of SCI and demonstrated that spinal cord hemorrhage and maximum spinal cord compression are associated with a poor prognosis of neurological recovery [22]. Other factors have been shown to predict the final outcome such as age, spasticity, good

hand function, and injury type [23]. However, there have been few reports about MRI features in patients with SCIWORA [16–18].

In the present study, 92 patients (92.0%) showed preoperative ISI. Preoperative MRI showed Grade 0 in 8 patients, Grade 1 in 49 patients, and Grade 2 in 43 patients. The preoperative MRI classification was consistent with the clinical symptoms and surgical outcomes. The pre- and postoperative JOA scores decreased significantly with an increasing ISI grade, and a significant association was found between the preoperative MRI classification and the RR of the JOA score, whereupon patients with ISI Grade 2 had the worst surgical outcome.

Available data suggest that light ISI reflects mild neuropathologic alterations in the spinal cord and a higher recovery potential, whereas intense ISI reflects severe alterations and a lower recovery potential [6,13]. In SCIWORA, the spinal cord signal intensity changes with disease progression from none to light ISI, then from light to intense ISI, leading to decreased RRs after surgery [6–8].

SCIWORA causes irreversible paralysis and sensory damage [19], and controversy remains as to whether conservative or surgical treatment strategies are best for adult patients with SCIWORA [23]. When considering surgery, associated risks should be fully disclosed and explained, and the patient's general condition should be thoroughly ascertained. There are surgical indications for patients with ISI Grade 2, although it is advisable to treat before the spinal cord loses its recuperative potential.

To date, no definitive management protocol has been established for SCIWORA [24]. In our institution, we perform radiography and CT imaging to identify cervical spine fractures or dislocations, and when instability is not evident on extension-flexion radiographs, patients are allowed to sit up and walk while wearing a Philadelphia collar. Rehabilitation is then started immediately after injury. Moreover, the role of surgical in SCIWORA patients remains controversial [25]. In our institution, patients with spinal cord compression in delayed MRI are offered cervical laminoplasty to achieve a more favorable outcome and prevent symptom deterioration.

There are limitations to this study. The follow-up duration was relatively brief and patient-based objective outcomes, such as quality of life as determined by the Short-Form Health Survey 36, were not assessed. Future prospective and well-controlled studies are needed to further validate the prognostic value of the presented classification system.

In conclusion, we present a novel, simple, and reliable classification system to grade adult SCIWORA based on the pattern of T2 signal abnormality. The grade of ISI significantly reflected symptom severity and prognosis of neurological outcome. MRI-based ISI classification is, therefore, correlated with preoperative symptom severity in adult SCIWORA patients, which can be a predictor of the surgical outcome.

Conflict of interest

The authors have no financial conflicts of interest.

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