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Differences between spinal cord injury and cervical compressive myelopathy in intramedullary high-intensity lesions on T2-weighted magnetic resonance imaging

A retrospective study

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Abstract

Increases in aging populations have raised the number of patients with cervical spinal cord injury (SCI) without fractures due to compression of the cervical spinal cord. In such patients, it is necessary to clarify whether SCI or cervical compressive myelopathy (CCM) is the cause of disability after trauma. This study aimed to clarify the differences in magnetic resonance imaging (MRI) features between SCI and CCM.

Overall, 60 SCI patients and 60 CCM patients with intramedullary high-intensity lesions on T2-weighted MRI were included in this study. The longitudinal lengths of the intramedullary T2 high-intensity lesions were measured using sagittal MRI sections. Snake-eye appearance on axial sections was assessed as a characteristic finding of CCM. The T2 values of the high-intensity lesions and normal spinal cords at the first thoracic vertebra level were measured, and the contrast ratio was calculated using these values.

The longitudinal length of T2 high-intensity lesions was significantly longer in SCI patients than in CCM patients. Snake-eye appearance was found in 26 of the 60 CCM patients, but not in SCI patients. On both the sagittal and axial images, the contrast ratio was significantly higher in the SCI group than in the CCM group. Based on these results, a diagnostic scale was created. This scale made it possible to distinguish between SCI and CCM with approximately 90% accuracy.

Abbreviations: AIS = American spinal injury association impairment scale, ANOVA = analysis of variance, CCM = cervical compressive myelopathy, CR = contrast ratio, FA = flip angle, ICC = intraclass correlation coefficient, MRI = magnetic resonance imaging, ROI = regions of interest, SCI = spinal cord injury, SEA = snake-eye appearance, SI = signal intensity, TE = echo time, TR = repetition time, WAD = whiplash-associated disorder.

Key words: MRI, myelopathy, spinal cord injury, T2, whiplash

1. Introduction

Whiplash injury is caused by sudden movements of the neck such as extension and flexion.[1] Whiplash injury presents with major symptoms, such as neck tenderness, pain upon movement, restricted movement, and various other symptoms, such as headache, dizziness, weakness, tinnitus, and visual impairment. These symptoms are collectively known as whiplash-associated disorder (WAD).[2,3] WAD often becomes chronic and incurs high financial costs.[4–6] Several studies have discussed the presence of mild spinal cord injuries (SCIs) in WAD patients.[7–9] The presence of SCI is important in determining the treatment for whiplash injury. However, SCI can occur despite the absence of fractures. With the aging of the population, the number of patients with cervical SCI without fractures is increasing.[10] In such cases, it is necessary to differentiate between SCI and cervical compressive myelopathy (CCM). The number of patients with CCM is also increasing owing to aging populations.[11,12] It is often difficult to determine whether the cause of disability after an accident in the

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elderly is preaccident CCM or accidental SCI. Recently, early surgical decompression has been recommended for cervical SCI without fracture or dislocation in patients with preexisting cervical spinal stenosis.[13–15] Therefore, detecting the presence of acute SCI is important when choosing a treatment modality.

Intramedullary high-intensity lesions in the cervical spinal cord detected on T2-weighted magnetic resonance imaging (MRI) are a possible sign of SCI.[16] The range of intramedullary T2 high-intensity lesions has been associated with the severity and prognosis of cervical spinal cord injury.[17] However, intramedullary T2 high-intensity lesions have also been observed in patients with CCM. In patients with CCM, intramedullary T2 hyperintensity may be associated with postoperative prognosis.[18–20] Although physicians familiar with spinal surgery use empirical knowledge to distinguish between SCI and CCM, there is currently no clear identification method. Therefore, the present study aimed to identify differences in the features of intramedullary T2 high-intensity lesions to distinguish between SCI and CCM.

2. Methods

This retrospective study was approved by the Institutional Review Board of Hiroshima University Hospital. The requirement for informed consent was waived due to the retrospective nature of the anonymized data.

2.1. MRI assessments

In this study, 3.0 Tesla MRI scanners (Ingenia 3.0T; Ingenia CX Quasar Dual, Philips, Amsterdam, the Netherlands) were used. MRI scans were taken by several radiologists. MR images of 60 patients with cervical SCI who underwent inpatient treatment at our hospital between February 2012 and April 2021 were evaluated (SCI group). This study included patients who presented to our hospital for emergency treatment of acute spinal cord injury. The degree of SCI was graded according to the American SCI Association Impairment Scale (AIS).[21,22] All MR images were obtained within 2 days of injury. For comparison, we also evaluated the MR images of 60 patients with intramedullary T2 high-intensity lesions in the cervical spinal cord among those diagnosed with CCM who underwent surgery at our hospital between April 2016 and February 2021 (CCM group). Patients whose symptoms suddenly worsened because of trauma, such as falls, were excluded. Sagittal or axial T2-weighted images were used for evaluations. T2-weighted images were acquired in the following sequence: repetition time (TR), 3000 to 4500 ms; echo time (TE), 90 to 120 ms; flip angle (FA), 90°.

Signal intensity (SI) values were acquired using ShadeQuest/ViewR-DG software (Fujifilm, Tokyo, Japan) with regions of interest (ROI) set in the intramedullary high-intensity lesions and in the spinal cord at the level of the first thoracic vertebra (Fig. 1A–F). Patients with T2 high-intensity lesions extending to the first thoracic vertebral level were excluded from the study. To evaluate intramedullary high-intensity lesions, the slice with the largest high-intensity lesion was selected for both the sagittal and axial images. A midline slice was used to evaluate the spinal cord at the level of the first thoracic vertebra on the sagittal image. ROIs of more than 50 pixels were taken for each point to decrease the bias of the image. The ROI was placed to maximize the mean value of the signal in the ROI. The SI value of intramedullary high-intensity lesions was evaluated as a ratio to the SI value of the spinal cord at the level of the first thoracic vertebra according to previous reports.[23,24] Contrast ratio (CR) was used as the formula to calculate the above ratio.[25–27] The SI values of the intramedullary high-intensity lesion (H) and the spinal cord at the level of the first thoracic vertebra (C) were used to calculate the CR using the following formula:

$$CR = (H\text{-}C)/(H + C)$$

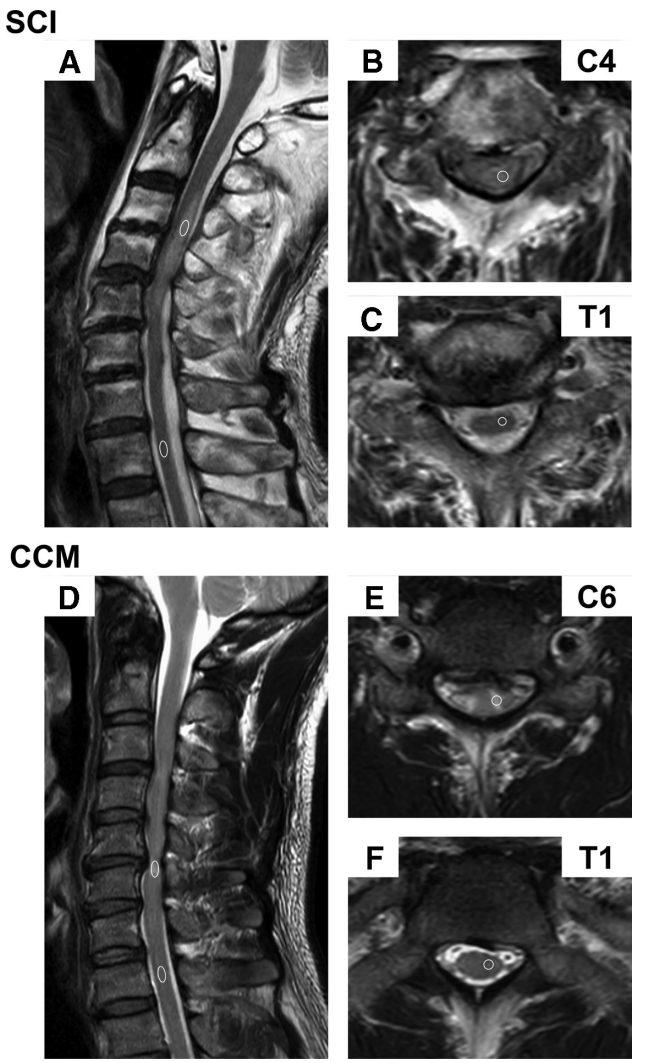

Figure 1. Areas where the T2 signal intensities were measured in the spinal cord injury (SCI) group (a–c) and the cervical compressive myelopathy (CCM) group (d–f). The White circles on the sagittal and axial T2-weighted images indicate regions of interest (ROI) in the intramedullary high-intensity lesions (a, b, d, and e) and in similar parts of the normal spinal cord at the level of the first thoracic vertebra (a, c, d, and f).

The longitudinal lengths of intramedullary high-intensity lesions were measured using sagittal images. The longitudinal length of the T2 high-intensity lesion was measured as a straight-line distance between the upper and lower edges of the lesion using ShadeQuest/ViewR-DG software (Fujifilm) according to a previous report.[28]

Snake-eye appearance (SEA) was assessed as a feature of intramedullary high-intensity lesions. SEA was characterized as a symmetrical bilateral small high-intensity lesion on axial T2-weighted MRI (Fig. 1e).[29] Spinal surgeons with >15 years of experience (KN and TN) performed the MRI evaluations for each patient. The observers were blinded to patient data. The average SI values of the 2 observers were used in this study.

2.2. Diagnostic scale

A diagnostic scale was devised to account for differences in the features of SCI and CCM, including the length and CR of intramedullary T2 high-intensity lesions, and the presence of SEA (Table 1). The mean values of length and CR were used as

Table 1

Diagnostic scale

		Score
Vertical length (mm)	< 9	1
	9–15	2
	>15	3
Contrast ratio	<0.13	1
	0.13–0.19	2
	>0.19	3
SEA	–	0
	+	–3

the reference values for the diagnostic scale. Each patient was scored and evaluated using a diagnostic scale.

2.3. Statistical analysis

The data are expressed as the mean ± standard deviation. The Mann–Whitney *U* test or chi-square test was used to compare the 2 groups, as appropriate. 1-way analysis of variance (ANOVA) followed by Tukey post hoc test was performed for multiple comparisons. Multivariate ordinal logistic regression analysis was used to analyze the association of AIS grade with the length of intramedullary high-intensity lesions and CR. Multiple regression analysis was used to analyze the association of sex, age, hypertension, and diabetes with the length of intramedullary high-intensity lesions and CR. Nominal logistic regression analysis was used to analyze the association of sex, age, hypertension, and diabetes with SEA. The relationship between continuous variables was assessed using Pearson product moment correlation coefficient. Inter-rater reliability was assessed using the intraclass correlation coefficient [ICC (2,1)]. Low reliability was defined as an ICC value <0.50, moderate reliability as an ICC of 0.50–0.75, good reliability as an ICC of 0.75–0.89, and excellent reliability as an ICC of 0.90 or higher.[30] The data were analyzed using SPSS (version 22.0; IBM Corporation, Armonk, NY) and JMP® version 16 (SAS Institute Inc., Cary, NC). Statistical significance was set at $P < .05$.

3. Results

3.1. Demographic data

The demographics of the patients are summarized in Table 2. The SCI group comprised 60 patients (47 men and 13 women) with a mean age of 64.3 ± 17.5 years. The degree of SCI was AIS grade A in 22 patients, AIS grade B in 9, AIS grade C in 16, and AIS grade D in 13. The CCM group also comprised 60 patients (43 men and 17 women), with a mean age of 70.3 ± 12.4 years. There were no significant differences in age ($P = .063$) or sex ($P = .399$) between the SCI and CCM groups. However, comorbidities tended to be more frequent in the CCM group than in the SCI group, and hypertension and diabetes were particularly prevalent in both groups. T2 high-intensity lesions were located somewhere between C2–3 and C5–6 in all patients.

3.2. Sagittal extent of the t2 high-intensity lesions

On MRI, the intramedullary T2 high-intensity SCI lesions often spread vertically, and the CCM lesions were mainly localized between the vertebrae (Fig. 1). The longitudinal length of the T2 high-intensity lesion on sagittal MR images was 30.7 ± 18.8 mm in the SCI group and 8.6 ± 4.5 mm in the CCM group (Fig. 2). T2 high-intensity lesions in the SCI group were significantly longer than those in the CCM group ($P < .001$). The inter-rater reliability of length was excellent (Table 3).

3.3. Snake-eye appearance

On axial MRI, T2 high-intensity lesions in SCI often spread from the gray matter to the white matter with unclear borders. However, in CCM, they had clear borders and were localized in the gray matter (Fig. 1). However, these features can only be subjectively evaluated. Therefore, the presence of SEA was used as an objective feature of the CCM. Twenty-six of the 60 patients with CCM showed the presence of SEA on axonal MRI, but none of the patients with SCI did (Table 4). All judgments regarding the presence or absence of SEA were consistent between raters.

3.4. Contrast ratio of intramedullary T2 high-intensity lesions

T2 values on MR images of intramedullary T2 high-intensity lesions were quantified using CR. The average CR values were 0.20 ± 0.07 on the sagittal images and 0.19 ± 0.07 on the axial images of the SCI group. The average CR values were 0.13 ± 0.06 on the sagittal images and 0.13 ± 0.06 on the axial images of the CCM group. 1-way ANOVA revealed significant differences between the groups [F (3236) = 17.532, $P < .001$]. The CR values in the SCI group were significantly higher than those in the CCM group on both sagittal and axial images (Fig. 3, $P < .001$). The inter-rater reliability of the CR was excellent for both sagittal and axial images (Table 3).

3.5. Diagnostics determined using the scale

A diagnostic scale was devised considering the differences in the features of T2 high-intensity lesions between the SCI and CCM groups (Table 1). There were no significant differences in the length of intramedullary T2 high-intensity lesions or CR among the different AIS grades (length F = 1.4, $P = .267$; sagittal CR F = 0.8, $P = .495$; axial-CR F = 1.9, $P = .139$) (Table 5). Furthermore, multivariate ordinal logistic regression analysis showed no significant relationship between the AIS grade and these parameters (Table 6). As the T2 high-intensity lesions were significantly longer in SCI than in CCM, patients with longer high-intensity lesions were assigned more points for the diagnosis of SCI. In addition, given the finding that the CR value was significantly higher in SCI than in CCM, patients with larger CR values were assigned more points for SCI diagnosis. The mean length in the CCM and the mean CR values in the SCI and CCM groups were used to determine the boundaries between points. Because SEA was observed only in the CCM group, the points for

Table 2

Demographics of patients with spinal cord injury and cervical compressive myelopathy.

	SCI	CCM
Men/women	47/13	43/17
Age	64.3 ± 17.5 (range 15–90)	70.3 ± 12.4 (range 36–90)
Comorbidities	hypertension 15, diabetes 10, hyperlipidemia 9, cancer 7 (colon, gaster, mamma, esophagus, prostate), asthma 2, cerebral infarction 2, chronic hepatitis 2, prostatic hypertrophy 2 atr ial fibrillation 1, epilepsy 1, glaucoma 1, sleep apnea 1	hypertension 19, diabetes 15, hyperlipidemia 9, renal dysfunction 9, angina 7 cancer 6 (colon, liver, mamma, esophagus, prostate, thyroid, uterus), atrial fibrillation 4, prostatic hypertrophy 4 asthma 3, cerebral infarction 3, hyperuricemia 3 myocardial infarction 3, chronic hepatitis 2, hypothyroidism 2 glaucoma 1, hyperthyroidism 1, sleep apnea 1, valvular disease 1

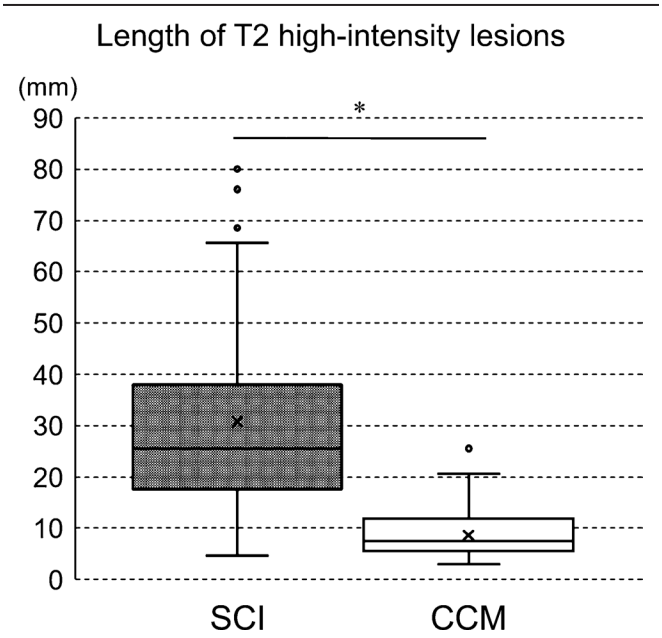

Figure 2. The longitudinal length of intramedullary T2 high-intensity lesions. The length in the spinal cord injury (SCI) group was significantly longer than that in the cervical compressive myelopathy (CCM) group. *Significant difference, $P < .05$ (Mann–Whitney U test).

Table 3

Intraclass correlation coefficients (ICCs) with a 95% confidence interval (CIs) for length and contrast ratio (CR) of intramedullary T2 high-intensity lesions.

	ICC (95% CI)	*P* value
Length	0.995 (0.993–0.997)	<0.001
Sagittal-CR	0.992 (0.988–0.994)	<0.001
Axial-CR	0.986 (0.980–0.991)	<0.001

Table 4

Presence of snake-eye appearance (SEA).

	SEA +	SEA –
SCI	0	60
CCM	26	34

SCI diagnosis were subtracted among patients with SEA. When the CR of the sagittal section was adopted, 54 patients in the SCI group and 6 patients in the CCM group scored ≥4 points on this diagnostic scale, while 6 patients in the SCI group and 54 patients in the CCM group scored ≤3 points. When the CR of the axial section was adopted, 55 patients in the SCI group and 6 patients in the CCM group scored ≥4 points on this diagnostic scale, while 5 patients in the SCI group and 54 patients in the CCM group scored ≤3 points. When patients with a score of ≥4 points were diagnosed with SCI, both the sensitivity and specificity were 90% or better (Table 7).

3.6. Relationship of sex, age, and comorbidities with the length of T2 high-intensity lesions, CR, and SEA

The association of sex, age, hypertension, and diabetes with the length of intramedullary T2 high-intensity lesions, CR, and SEA was evaluated by multiple regression analysis or nominal logistic regression analysis in the SCI and CCM groups, respectively.

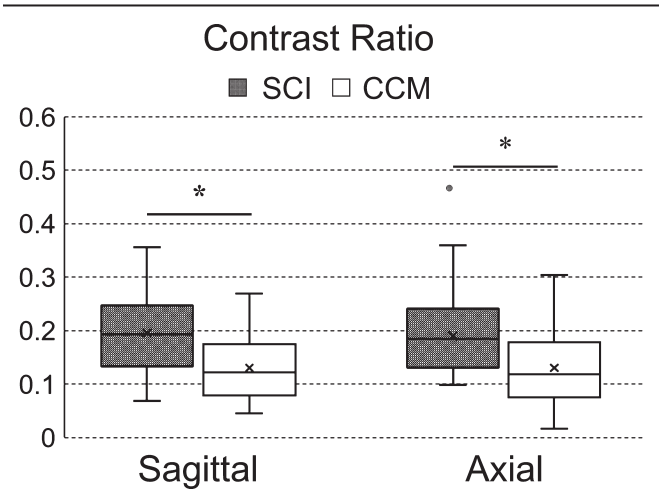

Figure 3. Box plot of the contrast ratio calculated from T2 values of intramedullary T2 high-intensity lesions and the normal spinal cord at the level of the first thoracic vertebra on sagittal and axial images. The contrast ratio of the spinal cord injury (SCI) group was significantly higher than that of the cervical compressive myelopathy (CCM) group on both the sagittal and axial sections. *Significant difference, $P < .05$ (one-way analysis of variance with Tukey post hoc test).

Hypertension and diabetes in particular were included in the evaluation as they were the most common comorbidities. There was a significant association between sex and the presence of SEA in the CCM group, but no other significant associations were noted (Table 8). Results of the chi-square test showed that the presence of SEA was significantly more common in women ($P = .012$).

4. Discussion

This study demonstrated a difference in the MRI features of intramedullary T2 high-intensity lesions in the cervical spinal cord between patients with SCI and CCM. The longitudinal lengths of high-intensity lesions were longer in patients with SCI than in those with CCM. In addition, the T2 values of the high-intensity lesions were quantified by CR using the T2 values of the normal spinal cord. CR in patients with SCI was significantly higher than that in patients with CCM. In addition to the length and CR of high-intensity lesions, a scale based on the presence or absence of SEA distinguished SCI from CCM, with an accuracy of approximately 90%.

With the widespread availability of MRI, patients with WAD with relatively severe symptoms are becoming more commonly evaluated by MRI of the cervical spine early after injury. If there is compression of the spinal cord due to cervical spinal canal stenosis, the spinal cord can be damaged by whiplash injury without fracture or dislocation of the cervical spine.[12,31] When intramedullary T2 high-intensity lesions in the cervical spinal cord are observed on MRI, it is necessary to distinguish between SCI and CCM, because the presence of SCI is important in determining the course of treatment and insurance coverage. The existing diagnostic method is based on the empirical knowledge of specialists because there are no clear diagnostic criteria.

In the present study, some features of intramedullary T2 high-intensity lesions were assessed to establish diagnostic criteria by distinguishing between SCI and CCM. SCI and CCM have different pathologies in the intramedullary T2 high-intensity lesions. In SCI, trauma causes primary injury followed by secondary injury, including bleeding, ischemia, edema, inflammatory cell infiltration, and neuronal and glial cell death.[32] Intramedullary T2 high-intensity lesions in acute SCI have been reported to primarily reflect edema.[33,34] In a previous study, MR images of acute and subacute SCI showed T2 high-intensity lesions with unclear boundaries

Table 5

Comparison of longitudinal length of intramedullary T2 high-intensity lesions and contrast ratios (CRs) and by American Spinal Cord Injury Association Impairment Scale (AIS) grade (mean ± SD).

AIS grade	A (n = 22)	B (n = 9)	C (n = 16)	D (n = 13)
Length (mm)	35.9 ± 20.5	31.7 ± 21.2	28.9 ± 17.4	23.2 ± 13.5
Sagittal-CR	0.19 ± 0.08	0.23 ± 0.06	0.19 ± 0.06	0.18 ± 0.09
Axial-CR	0.20 ± 0.08	0.22 ± 0.06	0.17 ± 0.06	0.17 ± 0.05

Table 6

Multivariate ordinal logistic regression analysis on the association of length of intramedullary T2 high-intensity lesions and contrast ratios (CRs) with American Spinal Cord Injury Association Impairment Scale grade.

						95%CI	
	Estimate	Standard error	Wald	Degrees of freedom	*P*-value	Lower	Upper
Length	0.024	0.015	2.591	1	0.108	–0.003	0.053
Sagittal-CR	–4.532	4.074	1.238	1	0.266	–12.943	3.678
Axial-CR	7.929	4.609	2.959	1	0.085	–1.154	17.605

Table 7

Accuracy of distinguishing between spinal cord injury (SCI) and cervical compressive myelopathy (CCM) by score.

	Sagittal-CR		Axial-CR	
Score	≤3	4 ≤	≤3	4 ≤
SCI	6	54	5	55
CCM	54	6	54	6
Sensitivity	90.0%		91.7%	
Specificity	90.0%		90.0%	

spread in the sagittal direction.[27] In the present study, similar features to those of T2 high-intensity lesions in SCI were observed. In contrast, intramedullary T2 high-intensity lesions with sharp boundaries are often confined to the interbody region in CCM. Previous studies have reported this feature.[35,36] Intramedullary T2 high-intensity lesions in CCM have been reported to reflect myelomalacia, edema, demyelination, and microcavity formation.[37] In the present study, the sagittal extent of intramedullary T2 high-intensity lesions was evaluated based on the longitudinal length. This evaluation showed that the sagittal spread of intramedullary T2 high-intensity lesions was significantly greater in SCI than CCM. In addition, SEA has been previously reported as a characteristic MRI finding in CCM.[29,36] Moreover, it was the most objectively recognizable feature of CCM in the present study. A previous autopsy study demonstrated that SEA reflects cystic necrosis in the gray matter of the spinal cord.[29] In the present study, assessments of T2 values using CR showed a significant difference between SCI and CCM on sagittal and axial images. However, the difference was not clear enough to distinguish between SCI and CCM based on CR values alone. Therefore, in the present study, an algorithm was devised to distinguish between SCI and CCM by combining the longitudinal length of T2 high-intensity lesions, presence of SEA, and CR values. Additionally, a diagnostic scale was created to further simplify the diagnostic algorithm. Diagnosis using this scale made it possible to distinguish between SCI and CCM with an accuracy of ≥90%.

When sex, age, hypertension, and diabetes were evaluated in relation to the length of T2 high-intensity lesions, CR, and SEA, a significant association was found between sex and SEA, with SEA being more prevalent in women. However, SEA was not observed in patients with SCI regardless of sex, suggesting that SEA is a feature of patients with CCM.

Nevertheless, our study has some limitations. The number of cases may not be sufficient to demonstrate the high diagnostic accuracy of our diagnostic scale. Patients with severe SCI were included in the SCI group. Although patients with mild SCI may be suitable for this study, there was no evidence that SCI severity affected the parameters assessed in this study. Further comparative studies with larger numbers of patients are required. As the location and shape of T2 high-intensity lesions vary from patient to patient, the method for selecting slices to measure lesions was qualitative. Depending on the observer, there may have been variations in the ROI values. To reduce image bias in this study, ROIs > 50 pixels were taken at each point, and radiological examinations were performed by 2 senior spine surgeons. The inter-rater reliability was sufficiently high. In severe SCI, the changes caused by Walerian degeneration may extend to the spinal white matter at the level of the first thoracic vertebra, which was used as a control.[38] However, in this study, the control ROIs were placed mainly in the gray matter, which is less susceptible to Wallerian degeneration.

Table 8

Assessment of the relationship of sex, age, hypertension, and diabetes with the length of intramedullary T2 high-intensity lesions, CR, and SEA.

		Sex	Age	Hypertension	Diabetes
SCI	Vertical length	0.406	0.137	0.415	0.091
	Sagittal CR	0.066	0.688	0.473	0.638
	Axial CR	0.369	0.357	0.305	0.438
CCM	Vertical length	0.365	0.754	0.584	0.918
	Sagittal CR	0.069	0.475	0.832	0.844
	Axial CR	0.462	0.137	0.833	0.899
	SEA	0.011	0.145	0.280	0.743

The *P*-values in multiple regression analysis (vertical length, sagittal-CR, axial-CR) and nominal logistic regression analysis (SEA).

5. Conclusion

The present study proposes a new diagnostic method to distinguish between SCI and CCM based on the features of intramedullary T2 high-intensity lesions on MRI. Our diagnostic scale uses the longitudinal length of high-intensity lesions, presence of SEA, and CR of the T2 values.

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