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Intensity of Intraoperative Spinal Cord Hyperechogenicity as a Novel Potential Predictive Indicator of Neurological Recovery for Degenerative Cervical Myelopathy

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Objective: To analyze the correlations between intraoperative ultrasound and MRI metrics of the spinal cord in degenerative cervical myelopathy and identify novel potential predictive ultrasonic indicators of neurological recovery for degenerative cervical myelopathy.

Materials and Methods: Twenty-two patients who underwent French-door laminoplasty for multilevel degenerative cervical myelopathy were followed up for 12 months. The Japanese Orthopedic Association (JOA) scores were assessed preoperatively and 12 months postoperatively. Maximum spinal cord compression and compression rates were measured and calculated using both intraoperative ultrasound imaging and preoperative T2-weight (T2W) MRI. Signal change rates of the spinal cord on preoperative T2W MRI and gray value ratios of dorsal and ventral spinal cord hyperechogenicity on intraoperative ultrasound imaging were measured and calculated. Correlations between intraoperative ultrasound metrics, MRI metrics, and the recovery rate JOA scores were analyzed using Spearman correlation analysis.

Results: The postoperative JOA scores improved significantly, with a mean recovery rate of 65.0 ± 20.3% ($p < 0.001$). No significant correlations were found between the operative ultrasound metrics and MRI metrics. The gray value ratios of the spinal cord hyperechogenicity was negatively correlated with the recovery rate of JOA scores ($\rho = -0.638$, $p = 0.001$), while the ventral and dorsal gray value ratios of spinal cord hyperechogenicity were negatively correlated with the recovery rate of JOA-motor scores ($\rho = -0.582$, $p = 0.004$) and JOA-sensory scores ($\rho = -0.452$, $p = 0.035$), respectively. The dorsal gray value ratio was significantly higher than the ventral gray value ratio ($p < 0.001$), while the recovery rate of JOA-motor scores was better than that of JOA-sensory scores at 12 months post-surgery ($p = 0.028$).

Conclusion: For degenerative cervical myelopathy, the correlations between intraoperative ultrasound and preoperative T2W MRI metrics were not significant. Gray value ratios of the spinal cord hyperechogenicity and dorsal and ventral spinal cord hyperechogenicity were significantly correlated with neurological recovery at 12 months postoperatively.

Keywords: *Degenerative cervical myelopathy; Hyperechogenicity; Intraoperative ultrasound; Neurological recovery; Predictive indicator*

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INTRODUCTION

Degenerative cervical myelopathy (DCM) occurs when age-related disc degeneration and osteoarthritic changes cause narrowing of the cervical spinal canal, leading to chronic spinal cord compression, and is the most common nontraumatic disorder leading to neurological dysfunction in adults [1,2]. For patients with multilevel DCM, the preferred surgical method is to decompress the spinal cord via the cervical posterior approach [3,4]. French-door laminoplasty (FDL), which involves opening the "door" in the cervical posterior midline and creating a symmetrical enlargement of the cervical canal (Fig. 1), is considered to be a highly effective surgery for multilevel DCM [4,5]. However because of the inherent visual limitation of posterior surgery, the anterior structures of the spinal cord are easily misjudged, even for experienced surgeons [6]. In order to overcome this limitation, intraoperative ultrasound (IOUS) has been used to guide and evaluate real-time decompression, with reportedly good results [6-10]. Our experience with IOUS not only uncovered the positional correlations between the spinal cord and the adjacent structures in real-time, but also revealed the intramedullary pathological state in detail. Just as MRI reveals the different diameters and signal intensities of the spinal cord [11-13], the IOUS also manifests different diameters and hyperechogenicity of the spinal cord according to different levels of compression. In a previous explorative study, we pointed out that the gray value of the spinal cord hyperechogenicity at the narrowest level predicts neurological recovery of DCM after FDL [14]. Both radiological methods differ in principle and timing of observation; however, it is still unclear whether IOUS can be integrated with MRI in the evaluation of the spinal cord. The values of ultrasonic features of the spinal cord in predicting the postoperative neurological recovery of DCM are still unclear. The purpose of the present study was to evaluate correlations between IOUS and MRI metrics and identify novel predictive indicators of IOUS for neurological recovery of DCM.

MATERIALS AND METHODS

Study Population

The study protocol was approved by the Institutional Review Board of the study hospital. Signed informed consent was obtained from all participants in the study.

A total of 26 consecutive patients with multilevel DCM (≥ 3) were prospectively enrolled between October 2018 and May 2019. Patients with a history of other spinal disorders, neurological injury, infection, tumor, and rheumatoid arthritis were excluded. Finally, 22 patients (17 males and 5 females) who had been followed for 12 months were included in this study. The mean age at surgery was 61.2 ± 10.8 years and the average symptom duration was 42.95 ± 40.05 months (Table 1).

Table 1. The Demographic Data of Patients

Indicator	Result
Number of cases	22
Sex (male/female)	17/5
Age at surgery, years*	61.2 ± 10.8
Symptom durations, months*	42.95 ± 40.05

*Data are mean ± standard deviation.

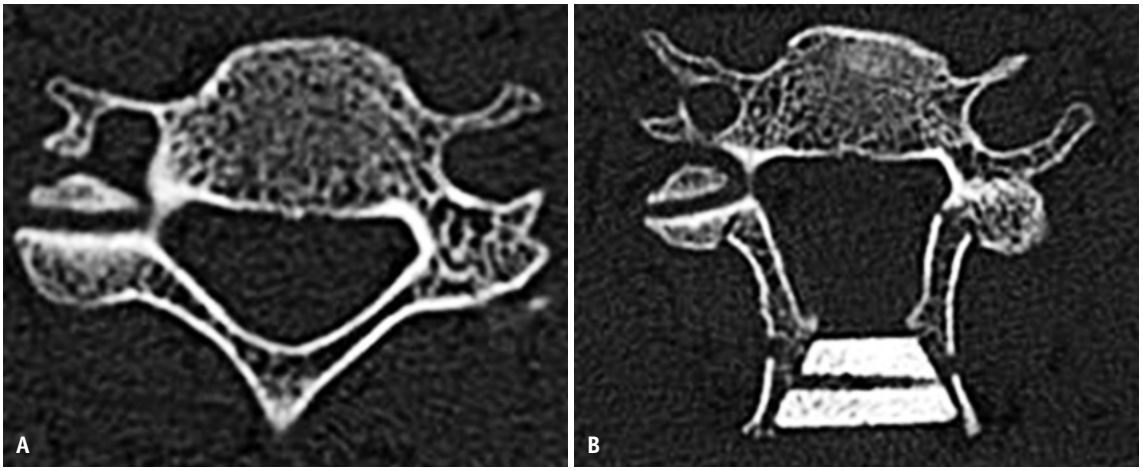

Fig. 1. French-door laminoplasty.
Preoperative **(A)** and **(B)** postoperative cross-sectional CT images of the cervical spine.

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Surgical Techniques

All patients received FDL from the same chief spine surgeon, performed according to the method of Kurokawa [5] with a few modifications. After the bilateral paravertebral muscles from the spinous processes were detached, the centers of spinous processes were cut using a fretsaw. Bilateral gutters were created as hinges at the border of the laminae and facets. After the halves of the laminae were elevated and fixed to the bilateral skin provisionally, normal saline was infused to form an acoustic window, and a linear array transducer of IOUS was used to observe the spinal cord and record the images. If residual compression was observed, further decompression under IOUS guidance was performed. After observation, the appropriately sized hydroxyapatite spacers were tied in place to bridge the bilateral edges of the laminae and were fixed with wires. Finally, a drainage tube was placed, and the wound was closed in layers.

Neurofunctional Assessments

Neurological function was evaluated using the Japanese Orthopedic Association (JOA) score before surgery and at each follow-up (Table 2). The recovery rate (RR) of the JOA score was calculated using the previously described formula [15]. The JOA score was also divided into motion, sensory, and bladder function. The scores of each part were recorded, and the RR of JOA-motion (JOA-M) and JOA-sensory (JOA-S) scores were calculated according to the following formulas:

RR of JOA score = (postoperative JOA score - preoperative JOA score) / (17 - preoperative JOA score) x 100%.

RR of JOA-M score = (postoperative JOA-M score - preoperative JOA-M score) / (8 - preoperative JOA-M score) x 100%.

RR of JOA-S score = (postoperative JOA-S score - preoperative JOA-S score) / (6 - preoperative JOA score) x 100%.

Radiological Measurements

The anteroposterior diameter (APD) and transverse diameter (TD) of the spinal cord on the IOUS image (IOUSI) were measured using Adobe Photoshop (Adobe Systems). The intensity of hyperechogenicity was quantified as a gray value by ImageJ (National Institutes of Health). The APD, TD, and signal intensity of the spinal cord on preoperative T2-weight (T2W) MRI were measured using an MRI workstation (DJ HealthUnion Systems Corporation). All patients' images were assessed independently by the same two researchers who did not participate in the neurological

Table 2. The JOA Score for Cervical Myelopathy

Motor function (8 points)	
Upper extremity (4 points)	
0	Complete function loss
1	Possible to eat with spoon, but not with chopsticks and impossible to write
2	Possible to eat with chopsticks or to write, but inadequate
3	Possible to eat with chopsticks or to write, awkward
4	Normal
Function of shoulder-elbow (-2 points)	
-2	Strength of biceps brachii and deltoid ≤ Grade 2
-1	Strength of biceps brachii and deltoid = Grade 3
-0.5	Strength of biceps brachii and deltoid = Grade 4
-0	Strength of biceps brachii and deltoid = Grade 5
Lower extremity (4 points)	
0	Impossible to stand and walk
0.5	Possible to stand, impossible to walk
1	Needs cane or aid to walk on flat ground
1.5	Possible to walk independently on flat ground, awkward
2	Needs cane or aid on stairs
2.5	Needs cane or aid on downward stairs only
3	Possible to walk without cane or aid, but slowly
4	Normal
Sensory function (6 points)	
Upper extremity (2 points), lower extremity (2 points) and trunk (2 pints)	
0	Complete sensory loss
0.5	Apparent disturbance, less than 5/10 sensory was present, unbearable pain or numbness
1	Moderate disturbance, more than 6/10 sensory was present, moderate numbness, zonesthesia, hypersensitivity
1.5	Mild disturbance, mild numbness, normal touch
2	Normal
Bladder function (3 points)	
0	Complete retention
1	Severe disturbance (sense of retention, dribbling, incomplete continence)
2	Mild disturbance (urinary frequency, urinary hesitancy)
3	Normal

The recovery rate of JOA score = (postoperative JOA score - preoperative JOA score) / (17 - preoperative JOA score) x 100%.
JOA = Japanese Orthopedic Association

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assessments, and assessments were repeated three times, using the mean for statistical analysis.

The midsagittal APD of the spinal cord on IOUSI (the midsagittal slice was determined by the visualization of the central echo complex of the spinal cord) and on T2W MRI at the narrowest level (APD_{min}), and the compression-free level (APD_{normal}) were measured and then the maximum spinal cord compression (MSCC) (MSCC = APD_{min}/APD_{normal}) was calculated. The APD and TD of the spinal cord on IOUSI and on T2W MRI at the narrowest transverse slices were measured as $APD_{transverse}$ and $TD_{transverse}$ and then the compression rate (CR) (CR = $APD_{transverse}/TD_{transverse}$) was calculated.

The signal change rate (SCR) of the spinal cord on T2W MRI was measured and calculated according to the methods described in previous studies with few modifications [16]. In brief, a circle was drawn with the point of maximum increased signal intensity as the center at the narrowest level, and another circle was drawn on the cerebrospinal fluid of the cisterna magna in the midsagittal T2W MRI. The signal intensity values were generated from the MRI workstation, and the SCR of T2W MRI was calculated.

The gray value ratio (GVR) of the spinal cord on IOUSI was measured and calculated referring to the method of SCR. Interestingly, the whole central canal of the cervical spinal cord was visible on the IOUSI so that the spinal cord was divided into the dorsal and ventral parts on IOUSI. We also measured the dorsal gray value (DGV) and ventral gray value (VGR) and calculated the dorsal and ventral GVR of the spinal cord, respectively. The larger GVR between the dorsal and ventral parts was used as the spinal cord GVR (SCGVR). In brief, for patients with macroscopic hyperechogenicity on IOUSI, circle 1 was drawn with the maximum brightness point within the dorsal part as the center, circle 2 was drawn with the maximum brightness point within the ventral part as the center, and circle 3 was drawn on the dorsal dural sac at the same level. For patients without different echogenicities within the spinal cord, two circles were drawn within the dorsal and ventral parts of the spinal cord at the most compressed level, and another circle was drawn on the dural sac at the same level. Then, the maximum gray values of each circle were measured by ImageJ and recorded as DGV, VGV, and dural sac gray value (DSGV). Then, the GVR was calculated according to the following formula: the dorsal GVR (DGVR) = DGV/DSGV and the ventral GVR (VGVR) = VGV/DAGV. The larger one between DGVR and VGVR was recorded as the SCGVR (Figs. 2, 3).

Statistical Analysis

Data were analyzed using SPSS statistical software (SPSS 24.0, IBM Corp.). All values are expressed as the mean ± standard deviation. A paired *t* test was used to compare the differences between pre- and post-operative JOA scores, JOA-M scores, JOA-S scores; differences between the RR of JOA-M scores and JOA-S scores at 12 months after surgery; and differences between VGVR and DGVR. Spearman correlation analysis was used to analyze correlations between the IOUSI MSCC, CR, and SCGVR and preoperative T2W MRI MSCC, CR, and SCR; between preoperative T2W MRI MSCC, CR, and SCR and the RR of JOA scores; between IOUSI MSCC, CR, and SCGVR and the RR of JOA scores; between the SCGVR and the RR of JOA scores; between VGVR and the RR of JOA-M

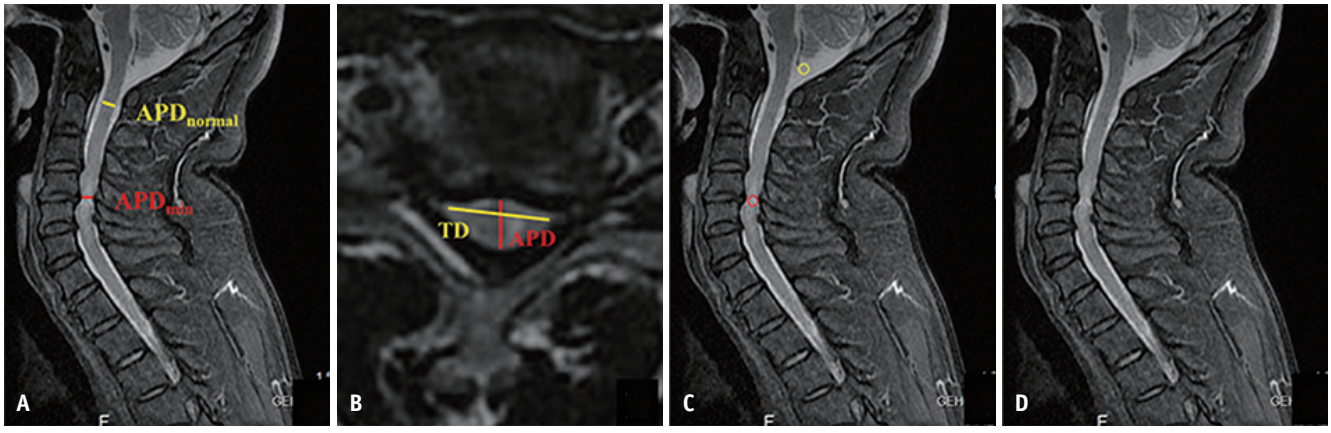

Fig. 2. Preoperative T2-weight MRI measurements.
A. Measurements of the APD at the midsagittal narrowest level (APD_{min}) and the lesion-free level (APD_{normal}). **B.** Measurements of the APD and the TD in the narrowest cross-sectional image. **C.** Measurements of the signal intensity of the spinal cord at the site of the maximum compression level and at the cisterna magna (cerebrospinal fluid). **D.** The original image of **(C)** without marks. APD = anteroposterior diameter, TD = transverse diameter

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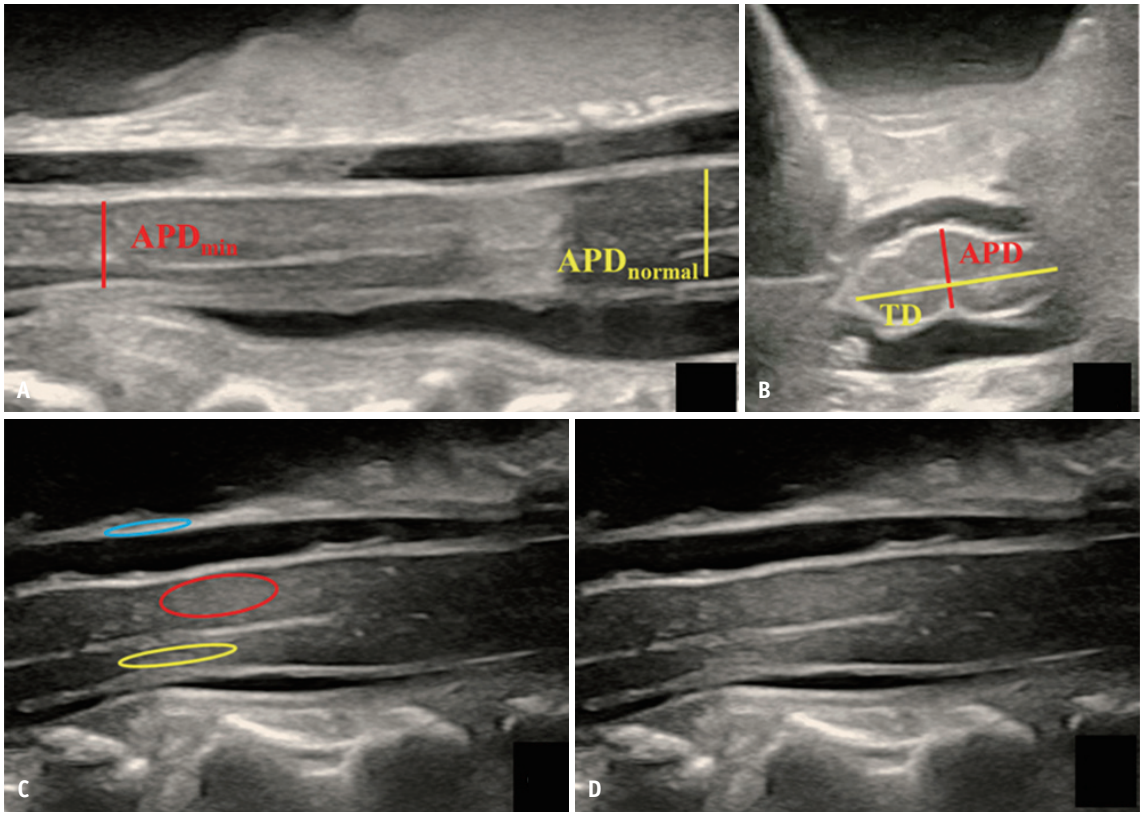

Fig. 3. Intraoperative ultrasound image measurements.
A. Measurements of the APD at the midsagittal narrowest level (APD_{min}) and the lesion-free level (APD_{normal}). **B.** Measurements of the APD and the TD in the narrowest cross-sectional image. **C.** Measurements of the intensity of echogenicity at the site of the maximum compression level: yellow circle indicates the ventral gray value, red circle indicates the dorsal gray value, and blue circle indicates the dural sac gray value. **D.** The original image of **(C)** without marks. APD = anteroposterior diameter, TD = transverse diameter

scores; and between DGVR and the RR of JOA-S scores. *P* values < 0.05 were considered statistically significant.

RESULTS

The mean application time of IOUS was 13.18 ± 1.59 minutes. The mean JOA score increased significantly from 11.82 ± 2.22 before surgery to 15.11 ± 1.40 at 12 months after surgery ($p < 0.001$). The mean RR of the JOA score was 65.0 ± 20.3%. The mean JOA-M score increased significantly from 5.41 ± 1.47 to 7.14 ± 0.99 ($p < 0.001$) at 12 months after surgery with a mean RR of 70.6 ± 30.0%, the mean JOA-S score increased significantly from 3.55 ± 1.00 to 5.02 ± 0.50 ($p < 0.001$) at 12 months after surgery with a mean RR of 56.4 ± 23.9%, and the RR of JOA-M score was better than the RR of JOA-S score at postoperative 12 months ($p = 0.028$). The DGVR (0.68 ± 0.15) was significantly higher than the VGVR (0.60 ± 0.14), $p < 0.001$. No complications were reported at 12 months after surgery.

Spearman correlation analysis showed that the correlations between the IOUSI MSCC and MRI MSCC, IOUSI CR and MRI CR, IOUSI SCGVR and MRI SCR, MRI MSCC, CR, SCR, and the RR of JOA score were not significant ($p > 0.05$). The SCGVR correlated negatively with the RR of JOA score with a coefficient of -0.638 ($p = 0.001$); the VGVR correlated negatively with the RR of JOA-M score with a coefficient of -0.582 ($p = 0.004$), and the DGVR correlated negatively with the RR of JOA-S score with a coefficient of -0.452 ($p = 0.035$). The values of the indexes of compression (MSCC and CR) using IOUS showed no significant correlations with the RR of JOA score before surgery and at 12 months after surgery, neither with the RR of JOA-M nor the JOA-S score (Tables 3, 4, Fig. 4).

DISCUSSION

In the present study, the IOUS and preoperative T2W MRI metrics were evaluated quantitatively, and correlations between IOUS metrics, MRI metrics, and neurological recovery were analyzed. The results revealed that the

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Table 3. The Neurological and Ultrasonic Assessments of Patients

No.	Preoperative JOA Score	Preoperative JOA-M Score	Preoperative JOA-S Score	Postoperative JOA Score	Postoperative JOA-M Score	Postoperative JOA-S Score	RR of JOA Score (%)	RR of JOA-M Score (%)	RR of JOA-S Score (%)	SCGVR	VGVR	DGVR
1	11.0	4.00	5.0	15.0	7.0	5.0	66.7	75.0	0	0.93	0.93	0.93
2	12.0	5.00	4.0	14.0	6.0	5.0	40.0	33.3	50.0	0.93	0.73	0.93
3	11.5	5.00	3.5	14.5	7.0	4.5	54.6	66.7	40.0	0.86	0.67	0.86
4	8.5	4.00	2.5	15.0	7.0	5.0	76.5	75.0	71.4	0.86	0.73	0.86
5	13.0	6.00	4.0	15.0	7.0	5.0	50.0	50.0	50.0	0.84	0.84	0.84
6	13.5	7.00	4.5	15.0	7.0	5.0	42.9	0	33.3	0.82	0.70	0.82
7	12.5	6.00	3.5	15.0	7.0	5.0	55.6	50.0	60.0	0.81	0.71	0.81
8	9.5	3.00	3.5	11.0	4.0	4.0	20.0	20.0	20.0	0.73	0.59	0.73
9	13.0	7.00	3.0	16.0	8.0	5.0	75.0	100.0	66.7	0.68	0.50	0.68
10	9.0	4.00	2.0	13.5	6.0	4.5	56.3	50.0	62.5	0.67	0.67	0.61
11	11.0	5.00	3.0	15.5	7.0	5.5	75.0	66.7	83.3	0.65	0.56	0.65
12	11.0	5.00	3.0	16.0	8.0	5.0	83.3	100.0	66.7	0.63	0.56	0.63
13	15.0	7.00	5.0	16.5	8.0	5.5	75.0	100.0	50.0	0.63	0.51	0.63
14	9.0	4.00	2.0	13.5	6.0	4.5	56.3	50.0	62.5	0.61	0.50	0.61
15	15.0	7.00	5.0	16.5	8.0	5.5	75.0	100.0	50.0	0.59	0.37	0.59
16	13.0	6.00	4.0	14.5	7.0	4.5	37.5	50.0	25.0	0.59	0.58	0.59
17	7.0	2.00	2.0	16.0	8.0	5.0	90.0	100.0	75.0	0.57	0.47	0.57
18	10.5	6.00	2.5	15.5	8.0	4.5	76.9	100.0	57.1	0.57	0.56	0.57
19	15.0	7.00	5.0	16.5	8.0	5.5	75.0	100.0	50.0	0.55	0.55	0.47
20	14.0	7.00	4.0	17.0	8.0	6.0	100.0	100.0	100.0	0.55	0.54	0.55
21	10.0	5.00	3.0	15.0	7.0	5.0	71.4	66.7	66.7	0.52	0.43	0.52
22	14.0	7.00	4.0	17.0	8.0	6.0	100.0	100.0	100.0	0.45	0.45	0.42

DGVR = dorsal gray value ratio, JOA = Japanese Orthopaedic Association, JOA-M = JOA-motor, JOA-S = JOA-sensory, RR = recovery rate, SCGVR = spinal cord gray value ratio, VGVR = ventral gray value ratio

IOUS metrics did not correlate with those of preoperative T2W MRI, neither did the T2W MRI metrics correlate with neurological recovery. However, the intensity of spinal cord hyperechogenicity correlated significantly with postoperative neurological recovery in the treatment of DCM.

The echogenicity of IOUS is based on the different densities of tissues [17]. In DCM, the cervical spinal cord suffers from dynamic and static chronic compression, and these factors trigger a series of pathological changes in the spinal cord, including ischemia, edema, proliferation of fibroblasts, and cystic necrosis [18,19]. We speculated that these pathological changes would lead to the uneven density of the spinal cord and would finally be reflected as hyperechogenicity with different gray values. In addition to this speculation, we discovered in our previous study that the position of the hyperechogenic areas on IOUSI was in line with the increased signal intensity on T2W MRI [14]. Based on these observations, we believe that the intensity of hyperechogenicity on IOUSI could also reflect impairment of the spinal cord. The results of the present study revealed that the IOUSI indicators did not correlate with those of T2W MRI, neither the T2W MRI SCR and the RR of JOA score. However, the IOUSI GVR correlated significantly with the RR of JOA scores. The intensity of the spinal cord hyperechogenicity was evaluated quantitatively instead of classifying the hyperechogenicity as different degrees and was able to avoid the deviations caused by the variations between machines and operators effectively. In comparison with the preoperative MRI, the IOUS detected the real-time status of the decompressive spinal cord, resulting in a status more similar to the postoperative status. In addition to the different timing of observation, the different identification ability on the parenchymatous degeneration and cystic necrosis between IOUS and MRI may also lead to differences in predicting the neurological recovery in the treatment of DCM. Many different neuropathologic alterations of the spinal cord, including parenchymatous degeneration (ischemia and edema) and cystic necrosis, which may lead to different neurological recoveries after decompression, were reflected as increased signal intensity on T2W MRI [13]. The superior identification ability of

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IOUS on the parenchymatous and cystic lesions may also contribute to the prediction of neurological recovery.

With the high resolution of IOUS, the central canal of the cervical spinal cord was clearly visible, and this feature was still unfulfilled on the clinical application of MRI or CT. With visualization of the central canal, the spinal cord can be divided into dorsal and ventral parts. It is known that the main function of the dorsal spinal cord is crucial for sensory relay, while the ventral part is responsible for motor control [20-23]. A prior study that measured the shortest distance from the anterior and posterior spinal cord border to the boundary of increased signal intensity as dorsal and ventral tissue bridges on midsagittal T2W MRI suggested that the dorsal and ventral tissue bridges could be predictors of sensory and motor recovery in traumatic spinal cord injury [24]. Similarly, in the present study, VGVR and DGVR correlated moderately with motor and sensory recovery, respectively. The correlation analysis showed that VGVR and DGVR correlated moderately with motor and sensory recovery, respectively. To the best of our knowledge, this is the first study to analyze the correlation between the dorsal spinal cord impairment and sensory recovery and ventral spinal cord impairment and motor recovery by IOUSI in the treatment of DCM. The application of IOUS presented an opportunity to predict neurological recovery in greater detail.

Table 4. Neurological Function, Ultrasonic Data and Correlation Coefficient

Indicator	Result
Neurological function	
Preoperative JOA score	11.82 ± 2.22
Preoperative JOA-M score	5.41 ± 1.47
Preoperative JOA-S score	3.55 ± 1.00
Postoperative JOA score	15.11 ± 1.40*
Postoperative JOA-M score	7.14 ± 0.99*
Postoperative JOA-S score	5.02 ± 0.50*
The RR of JOA score, %	65.0 ± 20.3
The RR of JOA-M score, %	70.6 ± 30.0
The RR of JOA-S score, %	56.4 ± 23.9
Ultrasonic assessments	
Application time, minutes	13.18 ± 1.59
SCGVR	0.68 ± 0.14
VGVR	0.60 ± 0.14
DGVR	0.68 ± 0.15
Correlation coefficient	
SCGVR and the RR of JOA score	-0.638†
VGVR and the RR of JOA-M score	-0.582†
DGVR and the RR of JOA-S score	-0.452†

Data are mean ± standard deviation, unless specified otherwise. *Compared with that of preoperative, $p < 0.05$, †$p < 0.05$. DGVR = dorsal gray value ratio, JOA = Japanese Orthopaedic Association, JOA-M = JOA-motor, JOA-S = JOA-sensory, RR = recovery rate, SCGVR = spinal cord gray value ratio, VGVR = ventral gray value ratio

The present study also revealed that hyperechogenicity in the dorsal part was more severe than that of the ventral spinal cord, while the RR of the JOA-S score was not as good as that of the JOA-M score. Previous studies that focused on the prevalence of pre- or post-operative symptoms of DCM also reported that sensory impairment was more common and more persistent [25,26]. For DCM, compression of the spinal cord is always from the ventral aspect, but the impairment based on IOUSI occurred more often and was more severe in the dorsal part. This may be attributed to the differences in the distribution of the blood supply and the dynamic compression between the dorsal and ventral spinal cord [18,27-31]. The status of blood supply is closely correlated with neurological function [18]. An anatomical study has revealed that the blood supply of the ventral spinal cord

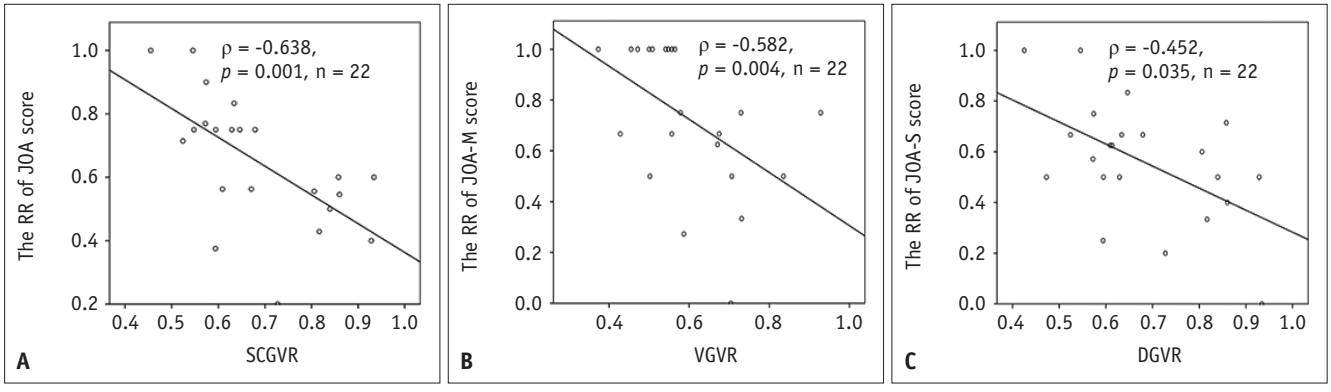

Fig. 4. Correlation between the RR of JOA score and spinal cord gray value ratio.
Correlation between **(A)** the SCGVR and the RR of JOA score, **(B)** the VGVR and the RR of JOA-M score, **(C)** the DGVR and the RR of JOA-S score. DGVR = dorsal gray value ratio, JOA = Japanese Orthopaedic Association, JOA-M = JOA-motor, JOA-S = JOA-sensory, RR = recovery rate, SCGVR = spinal cord gray value ratio, VGVR = ventral gray value ratio

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is better than the dorsal part [27-29], which may partly explain why hyperechogenicity was more common in the dorsal spinal cord. Additionally, the different changes between the dorsal and ventral spinal cord secondary to cervical movements may play another important role in the different hyperechogenicity distribution [18,30,31]. The dorsal spinal cord was more severely stretched in neck flexion and pinched in extension, whereas these changes in the ventral spinal cord were relatively less affected by cervical movement [32]. The roles of these factors are still unexplored, and further large-sample clinical studies and basic scientific research are necessary to further elucidate this phenomenon.

The present study has several limitations. As a prospective exploratory study, the sample size was small and the follow-up period was relatively short. With the JOA score as the only neurological indicator, subjectivity may lead to biased results. Based on the findings of this preliminary study, future studies with multicenter, large samples and long-term follow-up integrated with objective evaluations such as the 10 seconds grip-and-release test, the 10 seconds step test, and the electrophysiological evaluation should be carried out.

Recently, medical researchers are interested in the correlation of intraoperative findings with other preoperative biomarkers [33]. IOUS reveals more intramedullary details of the spinal cord, suggesting the potential value of this intraoperative tool to be considered for the formulation, definition, and validation of more sophisticated biosignatures.

In conclusion, For DCM patients, the correlations between IOUS metrics and preoperative T2W MRI metrics were not significant. The GVRs of the spinal cord hyperechogenicity, dorsal and ventral spinal cord hyperechogenicity, correlate significantly with neurological recovery at 12 months after surgery. We suggest that the intensity of the spinal cord hyperechogenicity could become a novel predictive indicator of surgical outcomes for DCM in the future.

Conflicts of Interest

The authors have no potential conflicts of interest to disclose.

Author Contributions

Conceptualization: Guoliang Chen, Fuxin Wei, Xizhe Liu, Xuenong Zou, Shaoyu Liu. Data curation: Guoliang Chen, Liangyu Shi, Wei Zhang. Formal analysis: Jiachun Li. Funding acquisition: Shaoyu Liu. Investigation: Guoliang Chen, Liangyu Shi, Wei Zhang. Methodology: Guoliang Chen, Jiachun Li. Project administration: Xizhe Liu, Zuofeng Xu, Shaoyu Liu. Resources: Xizhe Liu, Zuofeng Xu, Shaoyu Liu. Software: Xianxiang Wang, Zuofeng Xu. Supervision: Xizhe Liu, Zuofeng Xu, Shaoyu Liu. Validation: Guoliang Chen, Xizhe Liu. Visualization: Guoliang Chen, Xizhe Liu. Writing—original draft: Guoliang Chen, Fuxin Wei. Writing—review & editing: Xizhe Liu, Zuofeng Xu, Shaoyu Liu.

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