Using a Combined Classification of Increased Signal Intensity on Magnetic Resonance Imaging (MRI) to Predict Surgical Outcome in Cervical Spondylotic Myelopathy

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Source of support: Departmental sources

Background: The aim of this study was to verify whether the combined classification of increased signal intensity (ISI) on magnetic resonance imaging is more closely related to surgical outcomes than signal quality changes or signal longitudinal extent changes alone and to evaluate whether the combined classification ISI method could be used to predict surgical outcomes in cervical spondylotic myelopathy.

Material/Methods: Eighty-four patients (61 men and 23 women) who underwent surgery for cervical spondylotic myelopathy were included in this retrospective study. The patterns of ISI were classified into 3 categories based on (1) the quality of ISI into Grade 0: none, Grade 1: faint (fuzzy), and Grade 2: intense (sharp); (2) the longitudinal extent of ISI into none, focal, and multisegmental; and (3) the combined classification of the quality and longitudinal extent into Type 1 (none/none), Type 2 (focal/faint), Type 3 (focal/intense), Type 4 (multisegmental/faint), and Type 5 (multisegmental/intense). The multifactorial effects of variables were studied. A stepwise regression analysis was performed to verify whether this combined classification could predict outcome.

Results: Of the 3 categories, the combined classification type of ISI was most closely related to recovery rate. Stepwise regression analysis confirmed the significance of combined classification of ISI as a predictor for surgical outcome.

Conclusions: A combined classification of ISI is more closely related to surgical outcomes than either signal quality changes or signal longitudinal extent changes alone and it could be used as a meaningful indicator for predicting surgical outcomes. We recommend further studies to confirm this finding.

MeSH Keywords: **Magnetic Resonance Imaging • Spondylosis • Treatment Outcome**

Full-text PDF: https://www.medscimonit.com/abstract/index/idArt/929417

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Background

Cervical spondylotic myelopathy (CSM) is a progressive degenerative disease, and surgical intervention has been shown to be superior to conservative options for the treatment of moderate to severe CSM [1]. Increased signal intensity (ISI) of the spinal cord on T2-weighted magnetic resonance imaging (MRI) can reflect pathological change within the spinal cord [2–4], which has been reported in many studies to be a poor prognostic indicator for neurological and functional outcome after surgical decompression in patients with CSM [5,6]. However, this conclusion is controversial since other studies have had conflicting results [7,8]. One reason for this inconsistency may be that most studies did not categorize the signal intensity changes on the MRI [9]. More recently, some researchers have used different methods to classify intramedullary signal changes, since the type of signal intensity changes appears to be important in predicting clinical outcome. The 2 classifications used most frequently are based on the quality (none, faint or fuzzy, intense or sharp) or longitudinal extent (focal and multisegmental) of the MR image [7,10,11]. Unfortunately, to our knowledge, there is still no consensus on the most important type of signal intensity changes for prognostication. We think one of the important reasons for this deviation may be that each classification focuses on only a single aspect of quality or longitudinal extent. Conceivably, the signal changes can be divided into 5 different types if the 2 classifications are applied together. It remains unclear whether cross combinations of different qualities and longitudinal extent have different roles in predicting clinical outcome. The purpose of this study was to verify whether the combined classification of ISI relates more closely to surgical outcomes than either signal quality changes or signal longitudinal extent changes alone and to evaluate whether this method could be used as an indicator for predicting surgical outcomes.

Material and Methods

Eighty-four patients (61 men and 23 women) who underwent surgery for CSM between February 2014 and August 2016 were included in this retrospective study. The mean age of patients was 52.9 years (range, 45–80 years) at the time of surgery. The mean duration of disease was 10.7 months (range, 2-21 months) before surgery. All patients have been followed up for more than 12 months. The mean postoperative follow-up period was 22 months (range, 15–30 months). This research study was approved by the institutional review board of the authors' affiliated institution. Patients with traumatic cervical myelopathy, neoplasm, vitamin B12 deficiency, infection, amyotrophic lateral sclerosis, arteriovenous malformations, congenital deformations, and neurodegenerative diseases were excluded from the study. All patients were treated with either

anterior (56 patients), posterior (21 patients), or posterior-anterior united decompression (7 patients). The type of surgical approach was chosen on the basis of the location of the spinal cord compression, number of levels involved, sagittal alignment, instability, associated axial neck pain, and physical condition of the patient. All operations were performed by a senior spine surgeon, and the spinal cord was decompressed adequately in each patient.

Radiological assessment

MRI scanning was performed with a 1.5T system (Siemens Magnetom Symphony) before surgery. ISI was defined as a high-intensity area in contrast to the adjacent iso-intensity portion of the spinal cord in the sagittal and axial plane on T2-weighted images [12]. The patterns of ISI were classified in 3 ways: (1) based on the quality of ISI into Grade 0: none, Grade 1: faint (fuzzy), and Grade 2: intense (sharp) [10]; (2) based on the longitudinal extent of ISI into none, focal (when ISI was confined to 1 disc level with spinal cord compression), and multisegmental (more than 1 disc level) [11]; and (3) based on the combined classification of both the quality and longitudinal extent in which Type 1 (none/none) displayed normal intensity, Type 2 (focal/faint) displayed focal and faint ISI, Type 3 (focal/intense) displayed focal and intense ISI, Type 4 (multisegmental/faint) displayed multisegmental and faint ISI, and Type 5 (multisegmental/intense) displayed multisegmental and intense ISI (**Figure 1**). Intramedullary ISI changes on the T2-weighted images were evaluated by 2 independent observers who were blinded to the patients' clinical data. They independently interpreted the T2-weighted images to determine the type of signal intensity changes.

The compression ratio was measured by dividing the smallest anteroposterior dimension of the spinal cord by the broadest transverse diameter at the same level on axial MRI scans [13].

Functional outcome measures

Neurologic status was assessed with the modified Japanese Orthopedic Association (JOA) scoring system for CSM before and after surgery [6]. The JOA score has a total of 17 points which quantifies neurological impairment by evaluating upper extremity function, lower extremity function, sensory function, and bladder function. The improvement of symptoms after surgery was evaluated as recovery rate of the JOA score, which was calculated as follows: recovery rate=(postoperative JOA score-preoperative JOA score)/(17−preoperative JOA score)×100% [14].

Statistical analysis

The following patient parameters were obtained and studied: age, duration of symptoms, compression ratio, surgical
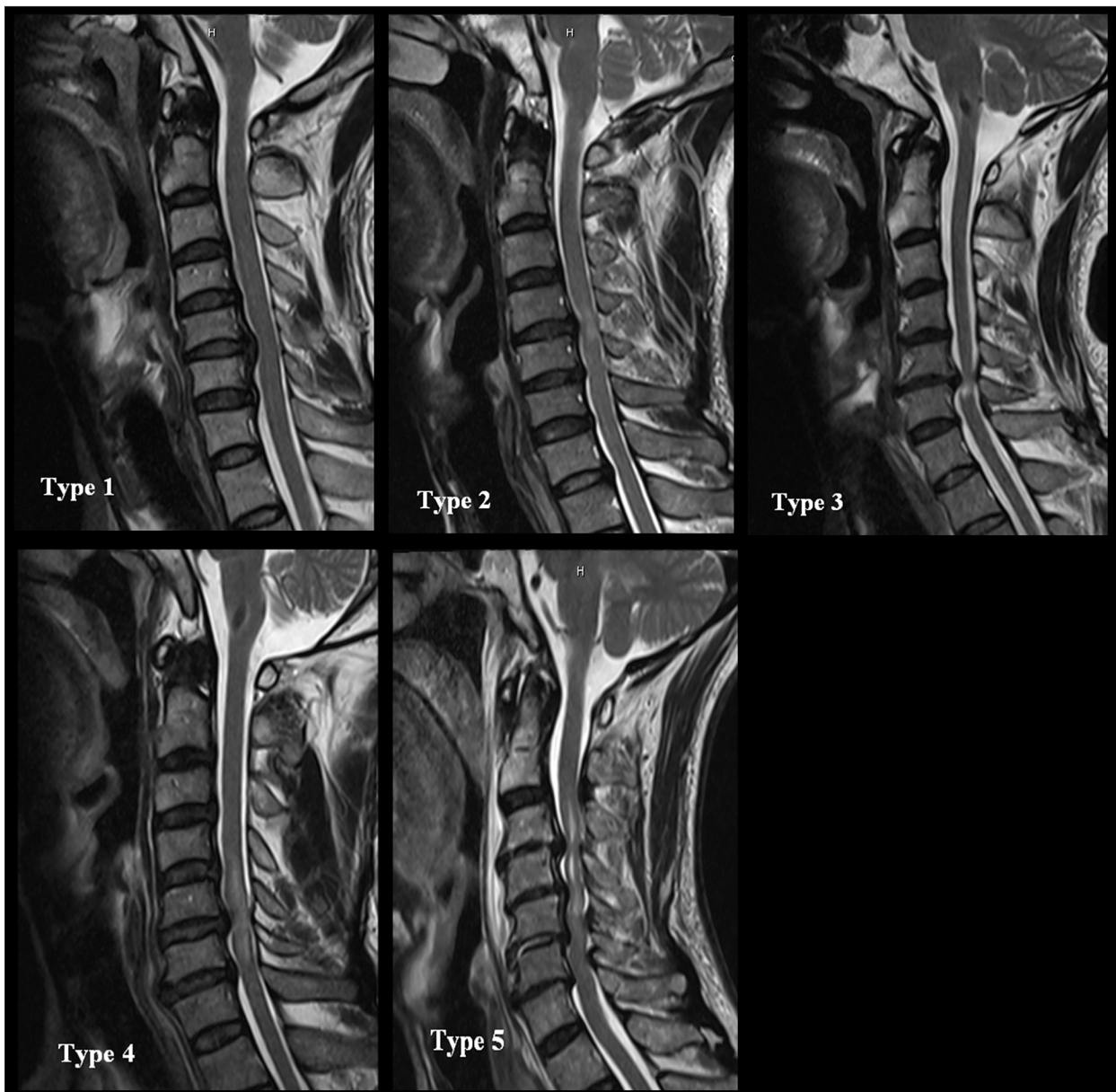
Figure 1. The combined classification of both the quality and longitudinal extent of increased signal intensity (ISI) on T2-weighted images: Type 1 (none/none) displayed normal intensity; Type 2 (focal/faint) displayed focal and faint ISI; Type 3 (focal/intense) displayed focal and intense ISI; Type 4 (multisegmental/faint) displayed multisegmental and faint ISI; and Type 5 (multisegmental/intense) displayed multisegmental and intense ISI.

approach, preoperative JOA score, preoperative types of ISI on T2-weighted images, postoperative JOA score, and recovery rate of the JOA score. Statistical analysis was performed using SPSS for Windows, version 17.0 (SPSS Inc, Chicago, IL). The analysis of variance (ANOVA) and the Student-Newman-Keuls (SNK) test were used for differences among more than 2 groups. Univariate analysis was performed using Spearman's rank correlation test to measure the relationship between neural recovery rate and each independent variable. A stepwise regression analysis was performed to verify whether this combined

classification could be used to predict outcome. A P value less than 0.05 indicated a statistically significant difference.

Results

Neurological outcomes for patients with CSM were improved in the mean follow-up period. Overall, the mean preoperative and postoperative JOA scores at the final follow-up were 10.1±2.3 and 13.2±2.4, respectively ($P<0.05$), and the mean

Table 1. Clinical feature and surgical outcome in each of the 5 types.

	Type 1 (n=30)	Type 2 (n=19)	Type 3 (n=11)	Type 4 (n=13)	Type 5 (n=11)	F	P
Age (year)	46.7±8.1	53.4±10.7	53.5±9.3	58.6±8.3	61.5±9.7	7.205	<0.001
Duration of symptoms (months)	7.4±3.2	10.1±2.6	10.6±2.2	14.1±3.5	16.8±2.0	27.769	<0.001
Compression ratio (%)	35.3±9.2	35.5±5.6	34.5±2.3	34.1±3.1	33.8±12.4	0.142	0.966
Preoperative JOA score	10.8±1.9	10.5±2.0	9.7±2.1	9.4±2.5	8.6±2.5	2.842	0.029
Postoperative JOA score	14.8±1.5	13.9±1.9	12.1±2.0	11.4±2.4	10.6±1.6	16.393	<0.001
Recovery rate (%)	67.9±18.8	54.5±22.8	34.3±16.4	26.6±21.7	22.5±6.9	19.403	<0.001

recovery rate of the JOA score was 48.1±26.0%. The mean compression ratio on axial MRI scans was 34.8±7.6%. The preoperative MRI scan results showed that there were 30 patients who did not have ISI and 54 patients who demonstrated ISI on T2-weighted images.

According to the quality of ISI, the preoperative MRI showed 30 patients with Grade 0, 32 patients with Grade 1, and 22 patients with Grade 2. The ANOVA results showed significant differences in the recovery rate among the 3 groups (Grade 0, 67.9±18.8%; Grade 1, 43.2±26.0%; Grade 2, 28.4±13.7%). The SNK test showed significant differences between Grades 0 and 1 ($P<0.001$), Grades 0 and 2 ($P<0.001$), and Grades 1 and 2 ($P=0.028$). A higher quality of ISI was associated with worse clinical outcomes after surgery.

According to the longitudinal extent of ISI, there was no ISI in 30 patients, focal ISI in 30 patients, and multisegmental ISI in 24 patients. ANOVA results showed significant differences in the recovery rate among the 3 groups (none, 67.9±18.8%; focal, 47.1±22.6%; and multisegmental, 24.7±16.4%). The SNK test showed significant differences between the none and focal groups ($P=0.001$), none and multisegmental groups ($P<0.001$), and focal and multisegmental groups ($P<0.001$). The results indicated that the longitudinal extent of ISI was associated with clinical outcomes after surgery.

According to the combined classification of ISI, there were 30 patients in Type 1, 19 patients in Type 2, 11 patients in Type 3, 13 patients in Type 4, and 11 patients in Type 5. The ANOVA results for age, duration of symptoms, preoperative JOA score, postoperative JOA score, and recovery rate showed significant differences among the 5 types (**Table 1**). The age and duration of symptoms gradually increased with increasing ISI type. The preoperative JOA score, postoperative JOA score, and recovery rate of the JOA score gradually decreased with increasing ISI type. There were no significant differences in compression ratio among the 5 ISI types. The SNK test on recovery rate
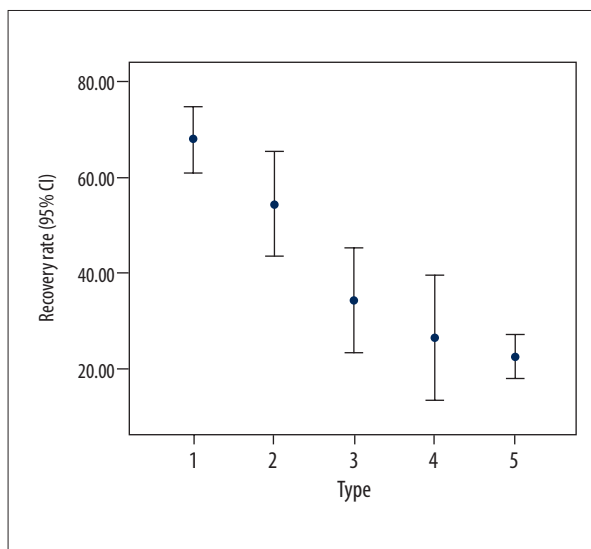

Figure 2. Relationship between recovery rate after surgery for cervical spondylotic myelopathy and preoperative combined classification of increased signal intensity on T2-weighted images.

showed significant differences between Type 1 and Type 2 and between Type 3, Type 4, and Type 5 ($P<0.05$), but no significant difference was observed between Type 1 and Type 2, Type 3 and Type 4, Type 3 and Type 5, or Type 4 and Type 5 ($P>0.05$) (**Figure 2**).

The Spearman's rank correlation test showed that the factors closely related to the recovery rate included the combined classification type of ISI ($r_s=-0.714$; $P<0.001$), duration of symptoms ($r_s=-0.690$; $P<0.001$), longitudinal extent of ISI ($r_s=-0.683$; $P<0.001$), quality of ISI ($r_s=-0.637$; $P<0.001$), age ($r_s=-0.529$; $P<0.001$), and preoperative JOA score ($r_s=0.444$; $P<0.001$). No significant relationship was observed between recovery rate and compression ratio ($r_s=-0.099$; $P=0.370$) or surgical approach ($r_s=-0.159$; $P=0.148$) (**Table 2**). Stepwise regression analysis confirmed the significance of the combined classification of

Table 2. Univariate analysis between the recovery rate and clinical features using Spearman's rank correlation test.

	Descriptive statistics	r_S value	P value
Age (year)	52.9±10.4	−0.529	<0.001
Duration of symptoms (months)	10.7±4.3	−0.690	<0.001
Compression ratio (%)	34.8±7.6	0.099	0.370
Preoperative JOA score	10.1±2.3	0.444	<0.001
Surgical approach (number)	56/21/7	−0.159	0.148
Quality of ISI (number)	30/32/22	−0.637	<0.001
Longitudinal extent of ISI (number)	30/30/24	−0.683	<0.001
Combined classification of ISI (number)	30/19/11/13/11	−0.714	<0.001

ISI on T2-weighted images as a predictor for surgical outcome. The multiple linear regression equation (R^2=0.599; P<0.05) was as follows: recovery rate=90.118−5.625 (combined classification of ISI)−0.569 (age)−1.637 (duration of symptoms)+1.933 (preoperative JOA score).

Discussion

Various factors that may influence the neurological outcome after decompression surgery for CSM have been discussed by many authors [15,16]. Among these factors, the value of ISI on T2-weighted MRI remains controversial [17]. Some authors have proposed that ISI on T2-weighted images coincided with pathological changes of the spinal cord [6,18,19]. Takahashi et al. speculated that signal intensity changes reflect myelomalacia or cord gliosis secondary to sustained compression of the spinal cord and can be used to predict neurological recovery after surgical decompression [2]. However, from a clinical perspective, the earlier studies that focused only on whether or not the signal intensity changed had conflicting results. Some scholars speculated that ISI on T2-weighted images includes a broad spectrum of compressive myelomalacic pathology, from edema to syrinx formation, and reflects a broad spectrum of spinal cord recuperative potentials, which are nonspecific [20]. The pathological changes in the spinal cord cannot be accurately reflected according to this simple classification method.

To improve this situation, there has been more emphasis placed on classifying these signal intensity changes, since the type of ISI appears to be more important in determining patient outcome than merely its presence or absence. Two of these classification methods are most widely used. The first method is based on a qualitative description of ISI, which was provided by Chen et al. in 2001 to grade the signal intensity change patterns on T2-weighted MR images as follows: Grade 0: no signal change, Grade 1: faint or fuzzy signal, and Grade 2: intense or sharp signal [10]. Their study demonstrated that a predominantly intense and sharp bordered ISI on T2-weighted MR images was associated with a poorer prognosis than those with faint and fuzzy or no change in signal intensity. It is assumed that the faint or fuzzy signal intensity on T2-weighted MR images may be associated with potentially reversible changes such as edema, Wallerian degeneration, demyelination, and ischemia. T2 imaging showing intense or sharp signal changes considered to be irreversible include cavitation, neural tissue loss, myelomalacia, necrosis, and spongiform changes in gray matter [21]. Although some subsequent studies, including the present one, confirmed the above conclusions, there are still differing views. Avadhani et al. found that there was no significant difference in the recovery rates of patients with different signal intensity changes on the T2-weighted MR images [9]. Machino et al. also found there was no significant relationship between ISI grades and surgical outcomes after they prospectively studied 505 consecutive patients with CSM [22]. The second main classification method assesses the longitudinal extent of ISI, which classifies ISI changes as absent, focal, and multisegmental [7]. Some studies reported that patients with multisegmental ISI showed a poorer prognosis after surgical decompression than patients with local ISI [7,23,24]. However, there are authors who have refuted the above finding, stating that the longitudinal extent of the ISI on T2-weighted images has no predictive value [25,26].

We think one of the important reasons for the above disagreement may be that each classification focuses only on a single aspect of quality or longitudinal extent, and the superposition of these 2 factors has not been considered together. According to the above independent classification method, our study also reached the same conclusion that the quality or longitudinal extent of the ISI could reflect surgical outcomes. Our findings demonstrated significant differences in the recovery rate among the 3 groups. Postoperative recovery rate declined as the ISI quality and longitudinal extent increased. However, if the 2 classifications are applied together, the signal changes can be divided into 5 different types, which is normal in clinical work.

Although this classification method may sound subjective, whether it is more closely related to surgical outcomes than signal quality changes or signal longitudinal extent changes alone and whether it could be used as an indicator for predicting surgical outcomes remain unclear. These questions constitute the main purpose of this study.

In the present study, univariate analysis showed that the most closely related factor among the 3 categories to the recovery rate was the combined classification type of ISI (r_s=−0.714), followed by the longitudinal extent of ISI (r_s=−0.683), and the quality of ISI (r_s=−0.637). The stepwise regression analysis showed that the best combination of surgical outcome predictors included combined classification of ISI, age, duration of symptoms, and preoperative JOA score. We speculate that this combined classification may more accurately quantify signal intensity changes in the spinal cord and is more valuable for predicting the outcome of surgery than other methods.

In addition, according to further analysis, our data showed that multisegmental ISI in patients was correlated with a poorer prognosis after surgical decompression than focal and faint ISI, which supports the view that the longitudinal extent of the ISI could reflect surgical outcomes. More importantly, we identified 2 major differences from previous studies. First, the patients with multisegmental ISI had no significant differences in recovery rate when compared with the patients with focal and intense ISI, although they appear to have had different longitudinal extent. Second, the patients with focal or multisegmental and intense ISI experienced significantly less improvement through surgery than patients with focal and faint ISI or no change in signal intensity; however, there was no significant difference in surgical outcome between patients with focal or multisegmental and intense ISI compared with the patients with multisegmental and faint ISI. At the same time, our data showed that the age, duration of symptoms, and preoperative JOA score varied across different groups, as previous studies have confirmed that MRI signal changes tended to be associated with clinical characteristics [11,12,27]. But also because of this reason, it may be difficult to separate out the isolated effect of MRI signal changes since the other confounding variables were not clearly addressed. We recommend further research be conducted to control for other clinical variables to investigate the difference of recovery rate between the 5 groups.

There are some limitations to our study. First, it was a retrospective study and the number of patients included in the study was small, which may have caused data bias in the statistical analysis. Nevertheless, we believe that this study provides some meaningful information for practical work and future research directions. Further high-quality clinical studies with large samples are needed to explore this combined classification of the longitudinal extent and quality for CSM. Second, this study did not conduct further analyses on other predictors of surgical outcome, such as age, duration of symptoms, compression ratio, and preoperative JOA score, because these were not the main purpose of this study. But what we need to emphasize is that the neurological outcome of cervical decompressive surgery is influenced by multiple factors and the basic radiographic features alone cannot predict surgical outcome in individual patients. Only in combination with clinical features can it play a better role.

Conclusions

In summary, we categorized signal changes on T2-weighted MR images into 5 types: Type 1 displayed normal intensity, Type 2 displayed focal and faint ISI, Type 3 displayed focal and intense ISI, Type 4 displayed multisegmental and faint ISI, and Type 5 displayed multisegmental and intense ISI. Our study showed that this combined classification of ISI was more closely related to surgical outcomes than either signal quality changes or signal longitudinal extent changes alone and it could be used as a meaningful indicator for predicting surgical outcomes. We recommend further studies to confirm this finding.

Conflict of interest

None.

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