Clinical Neurology and Neurosurgery 178 (2019) 1–6

Contents lists available at ScienceDirect

Clinical Neurology and Neurosurgery

journal homepage: www.elsevier.com/locate/clineuro

The relationship between preoperative factors and the presence of intramedullary increased signal intensity on T2-weighted magnetic resonance imaging in patients with cervical spondylotic myelopathy

Leixin Wei[1], Peng Cao[1], Chen Xu[1], Yang Liu, Huajiang Chen, Xinwei Wang, Ye Tian*, Wen Yuan*

Department of Orthopaedic Surgery, Changzheng Hospital, Second Military Medical University, Shanghai, China

ARTICLE INFO

Keywords:
Preoperative factors
Clinical manifestations
Increased signal intensity
Magnetic resonance imaging
Cervical spondylotic myelopathy
Multivariate analysis

ABSTRACT

Objective: To investigate preoperative factors affecting the presence of intramedullary increased signal intensity (ISI) on T2-weighted magnetic resonance imaging (MRI) in patients with cervical spondylotic myelopathy (CSM) and the impact of ISI on clinical manifestations.

Patients and methods: Eighty-nine patients with CSM were retrospectively reviewed from January 2013 to December 2016 in our hospital. Based on the presence or absence of ISI on axial and sagittal T2-weighted MRI, patients were divided into ISI group (48 cases) and non-ISI group (41 cases). Factors such as age, sex, body mass index (BMI), duration of symptoms, clinical symptoms and signs, number and distribution of spinal cord compression levels, preoperative Japanese Orthopedic Association (JOA) score, preoperative C2-C7 lordotic angle, preoperative C2-C7 range of motion (ROM), maximal canal compromise (MCC) and maximal spinal cord compression (MSCC) were initially compared using univariate analysis. Factors with significant result in univariate analysis were included in multivariate logistic regression analysis. Receiver operating characteristic (ROC) curve and the area under the curve (AUC) were applied to evaluate the reliability of multivariate logistic regression model.

Results: Univariate analysis showed that the number of spinal cord compression levels, preoperative JOA score, MCC and MSCC might be related to the presence of ISI ($P < 0.05$). Furthermore, multivariate logistic regression analysis revealed that the number of spinal cord compression levels (OR = 0.203, $P < 0.05$), preoperative JOA score (OR = 4.274, $P < 0.05$) and MSCC (OR = 0.250, $P < 0.05$) were independent preoperative risk factors associated with the presence of ISI, yielding an AUC of 0.9558. Patients with ISI showed a trend of increasing clinical symptoms and signs, and also exhibited statistically significantly increased frequencies of clumsy hands, lower limb spasticity, impairment of gait, broad-based, unstable gait, weakness and motor deficits ($P < 0.05$).

Conclusion: Multilevel spinal cord compression, lower preoperative JOA score and greater MSCC are independent preoperative risk factors related to the presence of ISI on T2-weighted MRI in patients with CSM. Patients with ISI tend to have more clinical symptoms and signs, especially in lower limb manifestations and motor deficits.

1. Introduction

Cervical spondylotic myelopathy (CSM) is a leading and progressive spine disease caused by degenerative changes of cervical spine [1,2]. Patients with CSM have various symptoms and signs, including numb hands, bilateral arm paresthesia, impairment of gait, hyperreflexia, positive Hoffmann sign and atrophy of muscles [3,4]. Although the diagnosis of CSM is mainly based on the clinical symptoms and signs, magnetic resonance imaging (MRI) is an invaluable and irreplaceable tool for radiographic neurological assessment by visualizing the degree of spinal cord compression and the signal changes of spinal cord [1,5].

The presence of intramedullary increased signal intensity (ISI) on T2-weighted MRI is a well-known signal change in patients with CSM [6]. Since Takahashi et al [7] first reported ISI on T2-weighted MRI in 1987, the histopathological and clinical significance of ISI has been broadly studied. ISI on T2-weighted MRI reflects a wide range of

* Corresponding author. Present/permanent address: Department of Orthopaedic Surgery, Changzheng Hospital, Second Military Medical University, No. 415 Fengyang Road, Shanghai, 200003, China.
E-mail addresses: hrs918@163.com (Y. Tian), smmuyuanwen@126.com (W. Yuan).
[1] These authors contributed equally to this work.

https://doi.org/10.1016/j.clineuro.2019.01.006
Received 19 October 2018; Received in revised form 3 January 2019; Accepted 13 January 2019
Available online 14 January 2019
0303-8467/

chronic intramedullary compression lesions such as gliosis, demyelination and necrosis [5,7,8]. Many researches have revealed that ISI on T2-weighted MRI was associated with poor prognosis for patients with CSM [9–11].

However, risk factors for the presence of ISI and impact of ISI on the clinical manifestations have not been illustrated clearly. This study aims to find the preoperative factors related to the presence of ISI on T2-weighted MRI in patients with CSM and investigate the impact of ISI on the clinical manifestations.

2. Patients and methods

2.1. Patient population

We retrospectively reviewed 89 patients (56 males and 33 females) with CSM in our hospital between January 2013 and December 2016. All patients underwent preoperative cervical lateral X-rays and MRI diagnosis. The inclusion criteria included: (1) aged 18 years or older; (2) at least 1 symptom of CSM; (3) evidence of cervical spinal cord compression on MRI; (4) normal signal intensity of spinal cord on T1-weighted MRI. The exclusion criteria included: (1) ossification of the posterior longitudinal ligament; (2) cervical kyphosis angle > 13°; (3) acute spinal injuries; (4) thoracic or lumbar spinal diseases; (5) previous spinal surgery; (6) history of rheumatoid arthritis, cerebral palsy or tumors. All patients underwent anterior cervical discectomy and fusion (ACDF) as described by previous studies [12,13]. Extensive decompression was performed by removing herniated nucleus pulposus, osteophytes, and posterior longitudinal ligament. Postoperative results were not collected as our study was designed to focus exclusively on the preoperative factors affecting the presence of ISI on T2-weighted MRI. Based on the presence or absence of ISI on axial and sagittal T2-weighted MRI, patients were categorized into two groups as follows: ISI group consisted of 48 patients (31 males and 17 females); non-ISI group consisted of 41 patients (25 males and 16 females).

2.2. Neurofunctional assessment

The preoperative neurological function was assessed by using the Japanese Orthopaedic Association (JOA) score (Table 1).

2.3. Radiographic assessment

All the patients underwent preoperative lateral X-rays and MRI diagnosis. All radiographic images were analyzed via ImageJ software (National Institutes of Health, Bethesda, MD, USA).

The lordotic angles between C2 and C7 were measured using Cobb method in the neutral and maximal flexion-extension lateral radiographs (Fig. 1). Cervical range of motion (ROM) was defined as the difference between flexion and extension in the alignment. Cervical ROM in flexion was calculated by adding the angles in the neutral and maximal flexion positions. Cervical ROM in extension was determined by subtracting the angles in maximal extension and neutral positions. Total ROM was calculated by adding the ROM in flexion and extension (Fig. 1) [14,15].

All patients underwent high-resolution MRI varied from 1.5-T to 3.0-T, either at our hospital or from others. Only the sagittal T2-weighted images were quantitatively analyzed in this study. We used maximum canal compromise (MCC) and maximum spinal cord compression (MSCC) to assess cervical canal stenosis and cord compression more reliably, which have been confirmed by Karpova's prospective study [16]. MCC was applied to assess the maximal canal stenosis, while MSCC was used to measure the maximal degree of spinal cord compression. MCC was defined as the anteroposterior canal diameter at the level of maximal canal stenosis (Di) divided by the averaged diameters of 2 nonpathological canals, including one above (Da) and one below (Db) (Fig. 2A). The formula for MCC was as follows: MCC (%) = (1– [Di/{Da + Db}/2]) × 100%. MSCC was defined as the anteroposterior spinal cord diameter at the level of the maximal spinal cord compression (di) divided by the average of the diameters of 2 non-pathological cord levels, including one above (da) and one below (db) (Fig. 2B) [3,16]. The formula for MSCC was as follows: MSCC (%) = (1– [di/{da + db}/2]) × 100%.

Table 1
The 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
0. Apparent sensory loss
1. Minimal sensory loss
2. Normal
C. Trunk
0. Apparent sensory loss
1. Minimal sensory loss
2. Normal
IV. Bladder function
0. Complete retention
1. Severe disturbance (sense of retention, dribbling, incomplete continence)
2. Mild disturbance (urinary frequency, urinary hesitancy)
3. Normal

JOA, Japanese Orthopedic Association.

2.4. Statistical analysis

Data were collected and analyzed in SPSS 18.0 (SPSS, Inc., Chicago, IL, USA). Means and standard deviations were calculated for continuous variables, while frequencies and percentages were generated for categorical variables. The Student's *t*-test was used to compare continuous variables. The Chi-square or Fisher's exact test was conducted to compare categorical variables. Multivariate logistic regression analysis was performed to find potential independent preoperative factors correlated with the presence of ISI on T2-weighted MRI. Adjusted odds ratios (OR) with 95% confidence intervals (CI) were presented with respective *P* values. Preoperative factors with *P* values less than 0.20 in univariate analyses were entered into the multivariate analysis. Receiver operating characteristic (ROC) curve was applied to measure the reliability of multivariate logistic regression model. The area under the ROC curve (AUC) was used to test the overall ability of multivariate logistic regression model to discriminate the presence and absence of ISI on T2-weighted MRI. *P* value less than 0.05 was considered to represent a statistically significant difference.

3. Results

3.1. Baseline characteristics

Baseline characteristics and clinical features of all patients were summarized in Table 2. The mean age was 54.76 years (range, 34–78 years); the mean duration of symptoms was 17.82 months (range, 1 month–10 years); the mean preoperative JOA score was 10.13 (range, 8–12); and the mean body mass index (BMI) was 22.57 kg/m^2 (range,

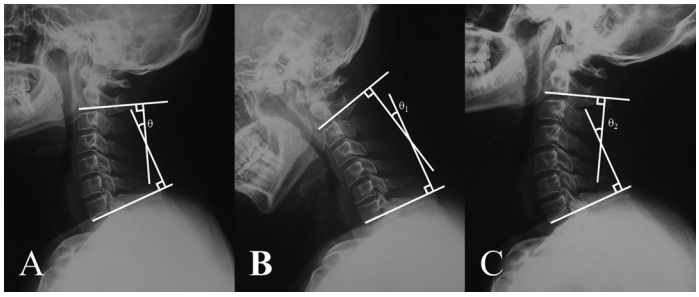

Fig. 1. Measurements of C2-C7 lordotic angle (the Cobb method) in neutral (A, θ), flexion (B, θ1) and extension position (C, θ2).

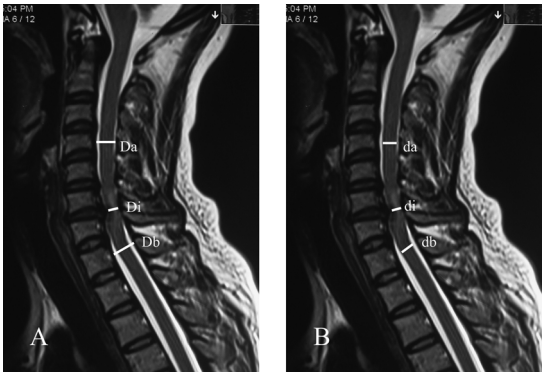

Fig. 2. Measurements of MCC (A) and MSCC (B) in sagittal cervical MRI.

Table 2
Patients characteristics and clinical manifestations.

Patients characteristics (n = 89)	
Age (years)	54.76 ± 10.82
Gender (% of Male, M/F)	62.9% (56/33)
Duration of symptoms (months)	17.82 ± 26.27
Number of spinal cord compression levels	2.07 ± 0.71
BMI (kg/m^2)	22.57 ± 1.91
Preoperative JOA score	10.13 ± 0.91
Clinical symptoms and signs	
Numb hands	86.5% (77/12)
Clumsy hands	55.1% (49/40)
Bilateral arm paresthesia	53.9% (48/41)
Atrophy of intrinsic hand muscles	25.8% (23/66)
Hoffmann sign	62.9% (56/33)
Babinski sign	25.8% (23/66)
Lower limb spasticity	32.6% (29/60)
Impairment of gait	55.1% (49/40)
Broad-based, unstable gait	43.8% (39/50)
Lhermitte phenomenon	19.1% (17/72)
Weakness	73.0% (65/24)
Motor deficits	48.3% (43/46)
Hyperreflexia	75.3% (67/22)

BMI, Body mass index, JOA, Japanese Orthopedic Association.

18.59 kg/m^2–26.72 kg/m^2). The numbers of spinal cord compression levels at C3/4, C4/5, C5/6 and C6/7 were 19, 56, 79 and 30, respectively.

3.2. Relationship between preoperative factors and the presence of ISI

On the basis of the presence or absence of ISI on axial and sagittal T2-weighted MRI, 48 patients were divided into the ISI group, and 41 patients were divided into the non-ISI group. Univariate analyses were conducted for both demographic and radiological factors. There were no significant differences between two groups regarding the age, gender, duration of symptoms, distribution of spinal cord compression levels and BMI ($P > 0.05$). Nevertheless, patients in ISI group tended to have multilevel spinal cord compression and lower preoperative JOA score than that of non-ISI group ($P < 0.05$) (Table 3). For preoperative radiological characteristics, no significant intergroup differences were observed with regard to preoperative C2-C7 lordotic angle and C2-C7 ROM ($P > 0.05$), whereas patients in ISI group had higher preoperative MCC and MSCC than those in non-ISI group ($P < 0.05$) (Table 4).

6 preoperative factors with P values < 0.20 in univariate analyses (including age, duration of symptoms, number of spinal cord compression levels, preoperative JOA score, MCC and MSCC) were selected for the multivariate logistic regression model. The resulted showed that the odds for the presence of ISI were greater when patients had multilevel spinal cord compression (OR = 0.203, 95% CI 0.050–0.832, P = 0.027), lower preoperative JOA score (OR = 4.274, 95% CI 1.396–13.090, P = 0.011), and higher MSCC (OR = 0.250, 95% CI

Table 3
Comparison of demographics characteristics between two groups.

	ISI group	Non-ISI group	p Value
Number of patients	48	41	
Age (years)	56.54 ± 10.82	52.68 ± 10.56	0.094
Gender (Male/Female)	31/17	25/16	0.725
Duration of symptoms (months)	22.56 ± 32.95	12.27 ± 13.54	0.052
Number of spinal cord compression levels	2.27 ± 0.74	1.83 ± 0.59	0.002
Distribution of spinal cord compression levels			0.261
C3-4	14	5	
C4-5	36	20	
C5-6	41	38	
C6-7	18	12	
BMI (kg/m^2)	22.79 ± 1.87	22.31 ± 1.95	0.235
Preoperative JOA score	9.69 ± 0.75	10.66 ± 0.79	< 0.001

ISI, Increased signal intensity; BMI, Body mass index, JOA, Japanese Orthopedic Association.

Table 4
Comparison of preoperative radiological characteristics between two groups.

	ISI group	Non- ISI group	p Value
C2-C7 lordotic angle (°)			
Neutral	12.64 ± 5.89 (lordotic)	12.78 ± 2.76 (lordotic)	0.889
Flexion	11.02 ± 4.88 (kyphotic)	11.69 ± 2.78 (kyphotic)	0.416
Extension	25.37 ± 6.52 (lordotic)	26.02 ± 4.57 (lordotic)	0.589
C2-C7 ROM (°)			
Flexion	23.66 ± 7.58	24.47 ± 3.58	0.512
Extension	12.72 ± 5.08	13.25 ± 3.63	0.573
Total	36.38 ± 8.02	37.72 ± 5.12	0.441
MCC (%)	45.78 ± 12.08	27.19 ± 12.32	< 0.001
MSCC (%)	34.25 ± 11.83	13.39 ± 9.46	< 0.001

ISI, Increased signal intensity; ROM, Range of motion; SCR, Signal change ratio; MCC, maximal canal compromise; MSCC, maximal spinal cord compression.

Table 5
Logistic regression analysis of preoperative risk factors for the presence of ISI on T2-weighted MRI.

Variables	OR	95% CI	p Value
Age	0.530	0.203-1.385	0.195
Duration of symptoms	1.006	0.595-1.702	0.982
Number of spinal cord compression levels	0.203	0.050-0.832	0.027
Preoperative JOA score	4.274	1.396-13.090	0.011
MCC	0.597	0.232-1.537	0.285
MSCC	0.250	0.111-0.565	0.001

JOA, Japanese Orthopedic Association; ISI, Increased signal intensity; SCR, Signal change ratio; OR, Odds ratio; CI, Confidence interval.

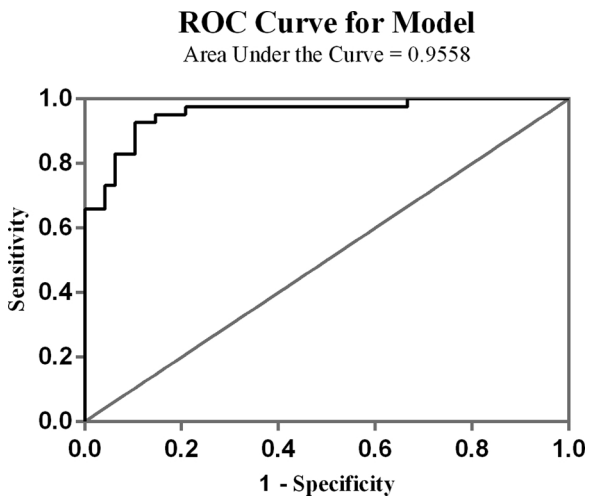

Fig. 3. ROC curve of multivariate logistic regression model. AUC of 0.9558 indicated an excellent ability to discriminate the presence of ISI on T2-weighted MRI.

0.111–0.565, $P = 0.001$) (Table 5). The AUC for the multivariate logistic regression model was 0.9558 (Fig. 3).

3.3. Impact of ISI on the clinical manifestations

There was a tendency of increasing frequency of clinical symptoms and signs when altering from no signal change to ISI on T2-weighted MRI (Table 6). Lower limb signs and symptoms were much more common in patients with ISI on T2-weighted MRI, who also showed statistically significantly higher risk of clumsy hands, lower limb spasticity, impairment of gait, broad-based, unstable gait, weakness and motor deficits ($P < 0.05$).

Table 6
Impact of ISI on the presence of specific clinical symptoms and signs.

Clinical symptoms and signs	ISI group	Non- ISI group	p Value
Upper limb			
Numb hands	87.5% (42/6)	85.4% (35/6)	0.769
Clumsy hands	66.7% (32/16)	41.5% (17/24)	0.017
Bilateral arm paresthesia	58.3% (28/20)	48.8% (20/21)	0.367
Atrophy of intrinsic hand muscles	31.3% (15/33)	19.5% (8/33)	0.207
Hoffmann sign	64.6% (31/17)	61.0% (25/16)	0.725
Lower limb			
Babinski sign	37.5% (18/30)	12.2% (5/36)	0.007
Lower limb spasticity	43.8% (21/27)	19.5% (8/33)	0.015
Impairment of gait	72.9% (35/13)	34.1% (14/27)	< 0.001
Broad-based, unstable gait	64.6% (31/17)	19.5% (8/33)	< 0.001
Other clinical manifestations			
Lhermitte phenomenon	22.9% (11/37)	14.6% (6/35)	0.322
Weakness	87.5% (42/6)	56.1% (23/18)	0.001
Motor deficits	58.3% (28/20)	36.6% (15/26)	0.041
Hyperreflexia	77.1% (37/11)	73.2% (30/11)	0.670

ISI, Increased signal intensity.

4. Discussion

CSM is a common cause of spinal cord dysfunction. Risk factors for the progression of CSM include canal stenosis beyond a critical size, degree of spinal cord compression, signal changes of spinal cord such as low signal intensity on T1-weighted MRI and ISI on T2-weighted MRI, as well as dynamic mechanical factors [6,17]. Additionally, recent evidence also indicates genetic predisposition as a risk factor for the development of CSM [18,19]. Single nucleotide polymorphism (SNP) in the ε4 allele of APOE gene, 6007C > T of BMP-4 gene, 1790 G > A of HIF-1α gene and Val66Met of BDNF gene was significantly associated with the development of CSM and negatively related to the surgical outcomes [17,20–23]. In the present study, we focused exclusively on the clinical issues regarding to ISI on T2-weighted MRI.

ISI on T2-weighted MRI was commonly observed in patients with CSM. From histopathological view, the presence of ISI reflects a wide spectrum of spinal cord lesions, from mild to severe [24,25]. Zhang et al [26] found that patients with ISI usually had lower preoperative JOA score and less improved neurologic function after surgery. However, the relationship between preoperative factors and the presence of ISI on T2-weighted MRI remained unclear. The present study investigated the association between preoperative factors and the presence of ISI on T2-weighted MRI in patients with CSM and the impact of ISI on clinical manifestations. The results demonstrated that multilevel spinal cord compression, lower preoperative JOA score and greater MSCC were independent preoperative factors related to the presence of ISI in patients with CSM. Patients with ISI tend to have more clinical symptoms and signs, especially in lower limb manifestations and motor deficits.

4.1. Preoperative factors for the presence of ISI

Previous authors have found T2-weighted ISI within the cervical cord in 41–97.2% of patients with CSM [27]. And the incidence of ISI was 53.9% in our study, complying with the previous studies. From univariate analysis, we found patients with ISI on T2-weighted MRI tended to have multilevel spinal cord compression, lower preoperative JOA score, greater preoperative MCC and MSCC. Analogous associations were found in Nouri's study [3] but no further analysis was performed in Nouri's research.

In order to investigate the independent preoperative factors affecting the presence of ISI in patients with CSM, we then conducted the multivariate logistic regression, which revealed that multilevel spinal cord compression, lower preoperative JOA score and greater MSCC were significant factors. The mean number of spinal cord compression levels was higher in ISI group (2.27 ± 0.74) than that in non-ISI group. The potential explanation may be that multilevel compression would leave little space for the movement of the spinal cord and thus spinal cord was easy to be injured. Many studies demonstrated that the preoperative JOA score was an important prognostic factor in patients with CSM [28,29]. In our study, we found preoperative JOA score was associated with the presence of ISI on T2-weighted MRI, which could be explicated by the fact that patients with lower preoperative JOA score tend to suffer more severe histopathological changes in the spinal cord. Besides, we found that greater MSCC, rather than MCC, was related to the presence of ISI on T2-weighted MRI. It is reasonable that MSCC may be more precise and reliable measurement of spinal cord compression than MCC. Our findings were in accordance with Karpova et al [16], in whose study MSCC were also correlated better with the severity of spinal cord compression than MCC.

To test the reliability of multivariate logistic regression model, we employed the ROC curve and its AUC which could assess the ability of this model to discriminate the presence or absence of ISI on T2-weighted MRI. The value of AUC ranges from 0.5 to 1.0 and is graded

as: worthless (0.5–0.6), poor (0.6–0.7), fair (0.7–0.8), good (0.8–0.9) and excellent (0.9–1.0). [30,31]. Our model showed an AUC of 0.9558, indicating an excellent discrimination ability.

4.2. Impact of ISI on the clinical manifestations

Our results demonstrated that ISI on T2-weighted MRI increased the frequency of clinical symptoms and signs. This finding was reasonable enough, because the absence of signal change indicated no obvious histopathological changes. However, the presence of ISI on T2-weighted MRI reflected a variety of histopathological lesions, from mild to severe alternations. Compared with patients without signal change, patients with ISI on T2-weighted MRI exhibited a tendency of increased incidence of every clinical symptoms and signs, implying the presence of ISI on T2-weighted MRI indeed had some clinical significance. In addition, it was also found that patients with ISI showed exclusively increased frequencies in lower limb symptoms and signs, which were consistent with Nouri et al [3].

It is important for patients with CSM to receive early surgical interventions before the presence of ISI on T2-weighted MRI, as patients with ISI usually have lower preoperative JOA score, more clinical symptoms, and worse improvement in neurologic function after surgical operation. Law et al [32] reported that the absolute indications for surgery were the progression of signs and symptoms, presence of myelopathy for six months or longer and compression ratio approaching 0.4. In our study, we found that multilevel spinal cord compression, lower preoperative JOA score and greater MSCC were independent preoperative factors associated with the presence of ISI on T2-weighted MRI in patients with CSM. Accordingly, when patients tend to have multilevel spinal cord compression, lower preoperative JOA score and greater MSCC before the presence of ISI on T2-weighted MRI, they would benefit more regarding the neurological improvement from early surgical interventions.

Our study is mainly limited by its retrospective design. Further work with prospective study is needed. Besides, high-resolution MRI varied in the field strength and working parameters.

5. Conclusion

Multilevel spinal cord compression, lower preoperative JOA score and greater MSCC are independent preoperative factors related to the presence of ISI on T2-weighted MRI in patients with CSM. Patients with ISI tend to have more clinical symptoms and signs, especially in lower limb manifestations and motor deficits.

Conflict of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Funding

This study was funded by the Shanghai Municipal Commission for Science and Technology (No. 17140901500, 18ZR1438900).

Declarations of interest

None.

References

[1] S. Kato, A. Nouri, H. Reihani-Kermani, Y. Oshima, J. Cheng, M.G. Fehlings, Postoperative resolution of magnetic resonance imaging signal intensity changes and the associated impact on outcomes in degenerative cervical myelopathy: analysis of a global cohort of patients, Spine 43 (2018) 824–831.

[2] M. Machino, K. Ando, K. Kobayashi, K. Ito, M. Tsushima, M. Morozumi, S. Tanaka, K. Ota, K. Ito, F. Kato, N. Ishiguro, S. Imagama, Alterations in intramedullary T2-weighted increased signal intensity following laminoplasty in cervical spondylotic myelopathy patients: comparison between pre- and postoperative magnetic resonance images, Spine 43 (22) (2018) 1595–1601.

[3] A. Nouri, L. Tetreault, K. Dalzell, J.J. Zamorano, M.G. Fehlings, The relationship between preoperative clinical presentation and quantitative magnetic resonance imaging features in patients with degenerative cervical myelopathy, Neurosurgery 80 (2017) 121–128.

[4] M. Machino, S. Imagama, K. Ando, K. Kobayashi, K. Ito, M. Tsushima, A. Matsumoto, M. Morozumi, S. Tanaka, K. Ito, F. Kato, Y. Nishida, N. Ishiguro, Image diagnostic classification of magnetic resonance T2 increased signal intensity in cervical spondylotic myelopathy: clinical evaluation using quantitative and objective assessment, Spine 43 (2018) 420–426.

[5] K. Uchida, H. Nakajima, N. Takeura, T. Yayama, A.R. Guerrero, A. Yoshida, T. Sakamoto, K. Honjoh, H. Baba, Prognostic value of changes in spinal cord signal intensity on magnetic resonance imaging in patients with cervical compressive myelopathy, Spine J. 14 (2014) 1601–1610.

[6] A. Nouri, A.R. Martin, D. Mikulis, M.G. Fehlings, Magnetic resonance imaging assessment of degenerative cervical myelopathy: a review of structural changes and measurement techniques, Neurosurg. Focus 40 (2016) E5.

[7] M. Takahashi, Y. Sakamoto, M. Miyawaki, H. Bussaka, Increased MR signal intensity secondary to chronic cervical cord compression, Neuroradiology 29 (1987) 550–556.

[8] O. Al-Mefty, L.H. Harkey, T.H. Middleton, R.R. Smith, J.L. Fox, Myelopathic cervical spondylotic lesions demonstrated by magnetic resonance imaging, J. Neurosurg. 68 (1988) 217–222.

[9] F. Li, Z. Chen, F. Zhang, H. Shen, T. Hou, A meta-analysis showing that high signal intensity on T2-weighted MRI is associated with poor prognosis for patients with cervical spondylotic myelopathy, J. Clin. Neurosci. 18 (2011) 1592–1595.

[10] M. Takahashi, Y. Yamashita, Y. Sakamoto, R. Kojima, Chronic cervical cord compression: clinical significance of increased signal intensity on MR images, Radiology 173 (1989) 219–224.

[11] E. Wada, K. Yonenobu, S. Suzuki, A. Kanazawa, T. Ochi, Can intramedullary signal change on magnetic resonance imaging predict surgical outcome in cervical spondylotic myelopathy? Spine 24 (1999) 455–461 discussion 462.

[12] V.H. Hillard, R.I. Apfelbaum, Surgical management of cervical myelopathy: indications and techniques for multilevel cervical discectomy, Spine J. 6 (2006) 242S–251S.

[13] T.J. Stewart, R.P. Schlenk, E.C. Benzel, Multiple level discectomy and fusion, Neurosurgery 60 (2007) S143–S148.

[14] L. Wei, P. Cao, C. Xu, B. Hu, Y. Tian, W. Yuan, Clinical and radiologic results of anterior cervical discectomy and fusion for cervical spondylotic myelopathy in elderly patients with T2-Weighted increased signal intensity, World Neurosurg. 112 (2018) e520–e526.

[15] M. Machino, Y. Yukawa, T. Hida, K. Ito, H. Nakashima, S. Kanbara, D. Morita, F. Kato, Cervical alignment and range of motion after laminoplasty: radiographical data from more than 500 cases with cervical spondylotic myelopathy and a review of the literature, Spine 37 (2012) E1243–E1250.

[16] A. Karpova, R. Arun, A.M. Davis, A.V. Kulkarni, D.J. Mikulis, C. Sooyong, D. Rabin, S. Craciunas, S.R. Smith, M.A. Hansen, J. George, M.G. Fehlings, Reliability of quantitative magnetic resonance imaging methods in the assessment of spinal canal stenosis and cord compression in cervical myelopathy, Spine 38 (2013) 245–252.

[17] M. Setzer, F.D. Vrionis, E.J. Hermann, V. Seifert, G. Marquardt, Effect of apolipoprotein E genotype on the outcome after anterior cervical decompression and fusion in patients with cervical spondylotic myelopathy, J. Neurosurg. Spine 11 (2009) 659–666.

[18] L. Tetreault, C.L. Goldstein, P. Arnold, J. Harrop, A. Hilibrand, A. Nouri, M.G. Fehlings, Degenerative cervical myelopathy: a Spectrum of related disorders affecting the aging spine, Neurosurgery 77 (Suppl. 4) (2015) S51–S67.

[19] A. Nouri, L. Tetreault, A. Singh, S.K. Karadimas, M.G. Fehlings, Degenerative cervical myelopathy: epidemiology, genetics, and pathogenesis, Spine 40 (2015) E675–693.

[20] M. Setzer, E. Hermann, V. Seifert, G. Marquardt, Apolipoprotein E gene polymorphism and the risk of cervical myelopathy in patients with chronic spinal cord compression, Spine 33 (2008) 497–502.

[21] D. Wang, W. Liu, Y. Cao, L. Yang, B. Liu, G. Yao, Z. Bi, BMP-4 polymorphisms in the susceptibility of cervical spondylotic myelopathy and its outcome after anterior cervical corpectomy and fusion, Cell. Physiol. Biochem. 32 (2013) 210–217.

[22] Z.C. Wang, X.W. Hou, J. Shao, Y.J. Ji, L. Li, Q. Zhou, Mao Y.L. Yu SM, H.J. Zhang, P.C. Zhang, H. Lu, HIF-1alpha polymorphism in the susceptibility of cervical spondylotic myelopathy and its outcome after anterior cervical corpectomy and fusion treatment, PLoS One 9 (2014) e110862.

[23] K.O. Abode-Iyamah, K.E. Stoner, A.J. Grossbach, S.V. Viljoen, C.L. McHenry, M.A. Petrie, N.S. Dahdaleh, N.M. Grosland, R.K. Shields, M.A. Howard 3rd, Effects of brain derived neurotrophic factor Val66Met polymorphism in patients with cervical spondylotic myelopathy, J. Clin. Neurosci. 24 (2016) 117–121.

[24] W.L. Ramanauskas, H.I. Wilner, J.J. Metes, A. Lazo, J.K. Kelly, MR imaging of compressive myelomalacia, J. Comput. Assist. Tomogr. 13 (1989) 399–404.

[25] T.F. Mehalic, R.T. Pezzuti, B.I. Applebaum, Magnetic resonance imaging and cervical spondylotic myelopathy, Neurosurgery 26 (1990) 217–226 discussion 226-217.

[26] P. Zhang, Y. Shen, Y.Z. Zhang, W.Y. Ding, L.F. Wang, Significance of increased signal intensity on MRI in prognosis after surgical intervention for cervical spondylotic myelopathy, J. Clin. Neurosci. 18 (2011) 1080–1083.

[27] A. Vedantam, V. Rajshekhar, Does the type of T2-weighted hyperintensity influence surgical outcome in patients with cervical spondylotic myelopathy? A review, Eur. Spine J. 22 (2012) 96–106.

[28] L.-Q. Sun, M. Li, Y.-M. Li, Predictors for surgical outcome of laminoplasty for cervical spondylotic myelopathy, World Neurosurg. 94 (2016) 89–96.
[29] J.S. Ahn, J.K. Lee, B.K. Kim, Prognostic factors that affect the surgical outcome of the laminoplasty in cervical spondylotic myelopathy, Clin. Orthop. Surg. 2 (2010) 98–104.
[30] J.V. Carter, J. Pan, S.N. Rai, S. Galandiuk, ROC-ing along: evaluation and interpretation of receiver operating characteristic curves, Surgery 159 (2016) 1638–1645.
[31] D.L. Streiner, J. Cairney, What's under the ROC? An introduction to receiver operating characteristics curves, Can. J. Psychiatry 52 (2007) 121–128.
[32] M.D. Law Jr, M. Bernhardt, A.A. White 3rd, Cervical spondylotic myelopathy: a review of surgical indications and decision making, Yale J. Biol. Med. 66 (1993) 165–177.