REVIEW ARTICLE SPINE SURGERY AND RELATED RESEARCH

A Systematic Review of Scoring System Based on Magnetic Resonance Imaging Parameters to Predict Outcome in Cervical Spinal Cord Injury

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Abstract:

Background: Magnetic resonance imaging (MRI) is a potential tool for the objective assessment of spinal cord injury (SCI) because it correlates well with the spatial and temporal extension of spinal cord pathology. This study aimed to systematically identify currently available scoring system based on MRI parameters, including measurement of the spinal cord lesion length in sagittal view (intramedullary lesion length (IMLL)) and morphology of the lesion in axial view (Brain and Spinal Injury Center (BASIC) score).

Methods: A systematic search was conducted using the PubMed/MEDLINE database for English-language studies with the keywords "cervical," "spinal cord injury," "scoring system," "scoring," "classification," and "magnetic resonance imaging" to systematically identify the scoring system based on MRI parameters. The main outcomes of interest are the scoring system's inter- and intraobserver reliabilities and its predictive accuracy of neurological outcome.

Results: After assessing the full text and applying the inclusion and exclusion criteria, 13 articles were found to be eligible. The inter- and intraobserver reliabilities were rated as good until perfect for increased signal intensity (ISI), maximum canal compromise (MCC), maximum spinal cord compression (MSCC), BASIC score, cord-canal-area ratio, space available for the cord, and the compression ratio. The weighted mean difference of IML between the group with converted ASIA Impairment Scale (AIS) grade and the group without conversion is 31.79 (I^2=93%, P=0.008). The percentage of agreement between the initial BASIC score of 4 with AIS grade of A at follow-up is 100%.

Conclusions: Certain MRI parameters, including IML and BASIC score, have good reliability and correlate well with neurological outcome, making them candidates for building simple and objective scoring system for cervical SCI.

Level of Evidence: 2A

Keywords:

Cervical injury, spinal cord injury, scoring system, classification system, magnetic resonance imaging

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Background

Spinal cord injury (SCI) is one of the most significant challenges in medicine owing to its generally bad outcome, especially in patients with cervical illness. The prognosis of SCI is usually assessed with patient's initial American Spinal Injury Association (ASIA) score when first admitted to the emergency room. The ASIA scoring system is irreplaceable in the initial assessment, yet it still has limitations[1,2)]. Therefore, to improve treatment decision and prediction of outcome, magnetic resonance imaging (MRI) can be used to provide additional objective assessment of the injury severity. Even though there is currently an array of methods to measure pathological signal changes in the MRI of traumatic cervical SCI cases, there is still no clear guideline regarding the best parameters that can be employed.

MRI is a potential tool for the objective assessment of pathology in the spinal cord. Despite the patient's conscious-

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Table 1. Inclusion and Exclusion Criteria Based on PICO.

	Inclusion criteria	Exclusion criteria
Population	Spinal Cord Injury • Traumatic • Cervical level • Adult 18–65 years old	• Animal studies • Thoracic, thoracolumbar, lumbar, and lumbosacral levels • Underlying congenital condition or neoplasm
Intervention	• Classification system and scoring system based on quantitative measurement of parameters in magnetic resonance imaging (MRI) for traumatic cervical SCI • MRI performed preoperatively and/or less than 48 h	• Functional MRI • Diffuse tensor imaging (DTI) • Qualitative MRI parameters
Control	• No comparison needed	NA
Outcome	Primary outcome measures • Scoring system characteristic • Correlation between the MRI scoring system and clinical outcome parameters including AIS conversion and AIS at follow-up • Reliability	• Study is ongoing and no results have been reported • Outcome measures not reported in completion

ness or ability to follow instructions, MRI will display the exact pathology in the spinal cord, including the precise level of pathology. This can later be used to predict neurological outcomes. For example, normal spinal cord appearance on MRI upon admission has been linked to full recovery to ASIA E, whereas the hemorrhagic pattern on MRI has been linked with worst neurological outcomes. This relationship between spinal cord imaging in MRI and neurological outcomes is not influenced by the patient's initial neurological status[3-5]. The difficulty of determining incomplete or complete ASIA status in emergency setting might contribute to the inaccuracy of the initial ASIA status to predict neurological recovery[6].

Additional advantages of MRI include its high correlation with the spatial and temporal extensions of spinal cord pathology[3]. MRI can also show the dynamic process of SCI, including the progression of hemorrhage and edema in the spinal cord. Rupture of the microvasculature in the central gray area initially results in a focal hemorrhage at the injury epicenter, followed later by expansion of the hemorrhage, edema formation, and spinal cord swelling. According to animal studies, these histopathology changes over time can be illustrated by the dynamic changes of signal abnormality shown in the MRI images[3]. Clinical studies also found that the timing of MRI is crucial for the use of an MRI image to predict the neurological outcome[6].

With the increasing number of methods to assess MRI images in SCI patients quantitatively, it is pertinent to have a clear guideline on what and how to assess MRI, which will help clinicians in making treatment decision. Early studies described sagittal T2-weighted sequences to be the only images beneficial in the diagnosis and prognosis of SCI. Recently, axial sequences were also found to have significant clinical benefits[7]. Therefore, the objective of this study was to systematically review preoperative MRI parameters in traumatic cervical SCI cases, which correlate best with the treatment outcome.

Methods

This systematic review was registered in PROSPERO and conducted in accordance with the PRISMA guidelines.

Search strategy and selection criteria

We searched MEDLINE, Embase, CINAHL, Web of Science, Cochrane Central Register of Controlled Trials (CENTRAL), and ClinicalTrials.gov. The language was limited to English. Our search terms were as follows: "cervical" AND "spinal cord injury" AND ("score" OR "scoring" OR "scoring system" OR "classification" OR "classification system") AND ("MRI" OR "magnetic resonance imaging"). The terms "scoring system" and "classification system" are used as they describe a systematic way of calculating certain MRI parameters to produce a range of numerical values and classifying each certain range.

The articles were selected based on the inclusion and exclusion criteria according to PICO (Population, Intervention, Comparison, Outcome), as presented in Table 1. Data were collected from each article by two independent reviewers, with disagreements resolved by reaching a consensus and, if required, consultation with a third reviewer. Data were recorded in a form developed previously. The Joanna Briggs Institute checklist for diagnostic articles[8] was used to assess the quality of the included studies.

Data extraction

Data were collected from each article by two independent reviewers, with disagreements resolved by reaching a consensus and, if required, consultation with a third reviewer. Data were recorded in a form developed previously in an Excel spreadsheet.

The data extracted include participant demographics, baseline characteristics of surgical treatment and the MRI classification system used, inter- and intraobserver reliabilities, and percentage of agreement with clinical outcome such as ASIA score improvement and recovery rate.

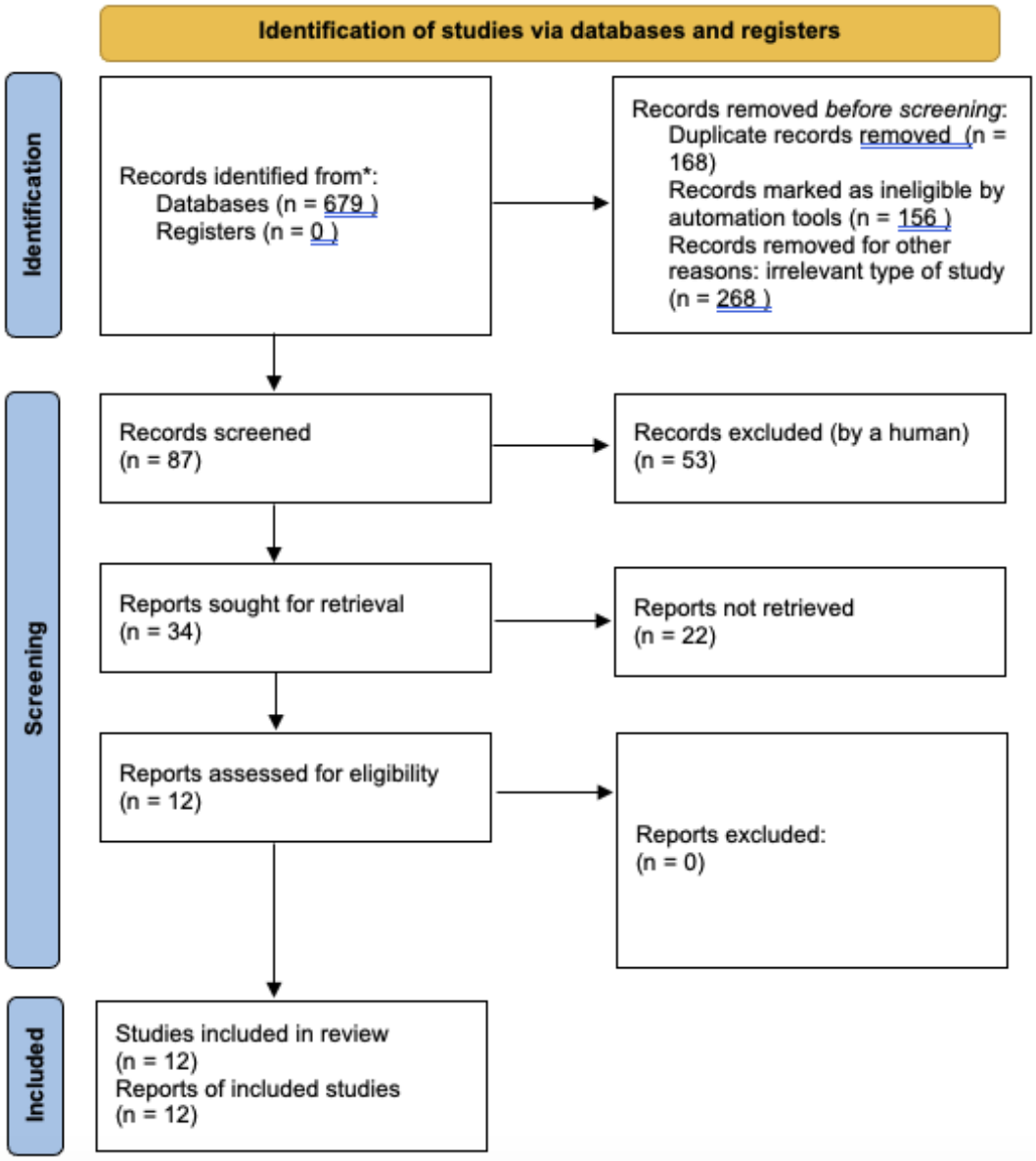

Figure 1. Flow diagram of the selection process.

Data synthesis

Data from all studies were extracted and categorized based on the method of assessing MRI, the factors considered in the classification system, and the interpretation of the scoring system.

To synthesize the outcome data, we extracted data regarding (1) classification system reliability (inter- and intraobserver reliabilities, as expressed in kappa values) and (2) predictive values (percentage of agreement with the clinical outcome, specificity, sensitivity, and correlation coefficient). To assess the value of the MRI scoring system, we checked its correlation with the clinical outcome parameters, such as the ASIA Motor Score (AMS) and AIS.

Data were analyzed using Review Manager (RevMan) version 5.3. For comparison of continuous data, the mean difference (MD) with 95% confidence interval was estimated. A *P*-value of <0.05 was considered statistically significant. The heterogeneity among the cohort studies was assessed by Cochrane's Q (χ^2, P<0.10) and quantified by I^2. The random-effects model was applied to address the high degree of heterogeneity (>50%).

Results

Literature search and study characteristics

The preliminary electronic search of all databases resulted in 679 records, which were screened for duplicates, publication period, and language. The 87 remaining articles were subsequently studied by two independent investigators based on a form developed previously. This selection process yielded 12 articles to be assessed for eligibility based on the full texts (Fig. 1).

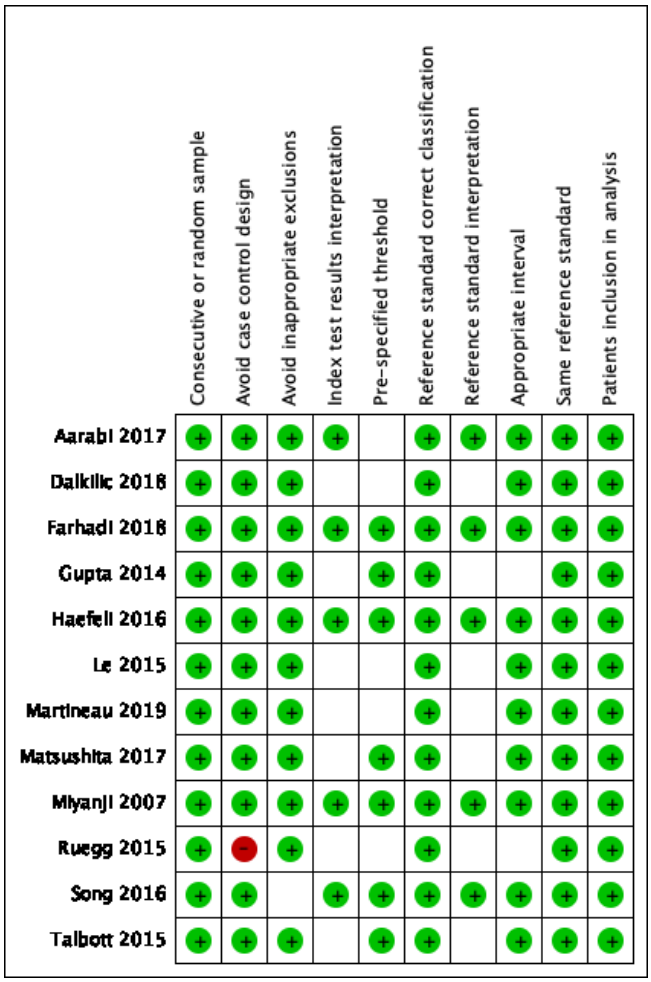

Figure 2. Risk of bias from all studies.

Quality assessment

Among 12 studies, 11 had less than three invalid parameters. One study was considered to have high risk of bias owing to its case-control design (Fig. 2). Most of the studies did not have a pre-specified threshold and observed specific characteristics or measure parameters on the MRI.

Baseline characteristics

From 12 studies, there were 3 prospective studies, and the earliest was published in 2007. In this study, a total of 929 SCI patients were analyzed. Several clinical scoring systems were used in the previous studies, including the AMS and AIS. The follow-up period ranged from 23 days to 94 months. The level of cervical injury was mostly subaxial, and the timing of examination was less than 48 h after injury. The longest MRI timing was 3 days, and the shortest was 1 h. In the MRI assessment from axial view (Brain and Spinal Injury Center (BASIC) score)[9,10], a short follow-up period of less than 3 months was adopted. Only one study combined the use of radiological assessment and laboratory assessment[11] (Table 2). The description summary of all MRI parameters and classifications is presented in Table 3.

Reliability

One study concluded that their system is reliable based on the intra- and interclass correlation coefficient (ICC)[12]. Another study concluded that their Interobserver CC ranged from good (transverse spinal cord diameter measurement) to perfect (transverse spinal cord area measurement)[13]. The interobserver reliability depends on the number of observers, with a large number of observers related to lower kappa values. One study with seven observers had an excellent interobserver reliability (Table 4).

Percentage of agreement with clinical scores

There were more cervical MRI images assessed from the sagittal window, and the MRI parameters included increased signal intensities (ISI), lesion length, maximum spinal cord compression (MSCC), maximum canal compromise (MCC), intramedullary lesion (IML), and rate of IML expansion. From the axial window, the MRI parameters included BASIC score, cord canal ratio, and space available for the cord. One scoring system combined the axial and sagittal views: Combined Axial and Sagittal score.

Several studies found a significant correlation between ISI and pre- and postoperative AIS grade as early as 2 weeks and in the long-term follow-up. As for the lesion length, there was a significant correlation with follow-up AIS, AMS, and AIS grade conversion. The parameters most measured from the T2 sagittal view were MSCC and MCC. Recent studies found no association between MSCC and neurological outcome[14], and another study found MSCC to be worse than the other MRI parameters in predicting neurological outcome[15]. Older studies found a strong correlation between MSCC and MCC with AIS and baseline neurological status. IML is correlated better than MCC/MSCC with neurological outcomes such as AIS grade conversion. The weighted MD of IML between the group with converted AIS grade and the group without conversion was 31.79 (I^2= 93%, P=0.008) (Fig. 3). A weighted mean IML difference of 31.79 was significant between the population who eventually underwent AIS conversion and the population who did not. In multiple regression analysis, the rate of IML expansion was also highly correlated with AIS grade. As for the MRI axial view assessment, the BASIC score was highly correlated with neurological outcome, based on 100% agreement between the initial BASIC score of 4 with AIS grade of A at follow-up. However, the follow-up period in two out of three studies about the BASIC score was as short as 1 month[9] (Table 5 and Table 6).

Discussion

To provide a commonly accepted classification that might guide treatment, two crucial elements should be adopted: (1) the classification needs to create a worldwide common language concerning the recognition of injury types (accuracy), and (2) the treatment recommendation by the classification

Table 2. Baseline Characteristics.

No	Author (year)	Type of study	Population	Injury level	MRI timing	MRI score	Clinical score	Follow-up
1	Martineau J (2019)[14]	Retrospective	Cervical traumatic SCI (n=82)	C0-C4: 46.3% C5-C8: 53.7%	14.7±10.7 hours	Presence of an intramedullary hemorrhage, IMLL, and MSCC	AMS	6–12 months
2	Farhadi HF (2018)[15]	Retrospective	Acute cervical traumatic SCI (n=99)	C0-C2: 3% C3-C5: 75.8% C6-C8: 21.2%	9.9±14.3 hours	MCC, MSCC, longitudinal length of IML, BASIC score, and CASS	AIS	6 and 12 months
3	Dalkilic T (2018)[11]	Prospective	Acute cervical SCI (n=36)	C1: 1 C2: 1 C3: 1 C4: 10 C5: 14 C6: 8 C7: 1	12:52 (range, 2:59 to 23:50 hours)	IML, hematoma length, hematoma extent, CSF effacement, cord expansion, and MSCC	Baseline and 6-month post-injury AIS grade and motor score	6 months
4	Matsushita A (2017)[21]	Retrospective	Cervical SCI (n=102)	NA	0–1 day and 2–3 days	Vertical diameter of intramedullary high-intensity changed area with T2-weighted images at the injured segment	AMS and Frankel grade	168 days (range, 25–496 days)
5	Aarabi B (2017)[10]	Retrospective	SCI (n=73)	NA	1–2 hours	IMLL	AMS	6 months
6	Haefeli J (2016)[9]	Retrospective	Acute SCI (n=95)	NA	6.97±5.15 hours	BASIC score, length of injury, MCC, and MSCC	AIS	25.15–35.31 (days)
7	Song KJ (2016)[12]	Retrospective	Cervical spine extension injury (n=102)	NA	Within 12 hours	MSCC, MCC, and lesion length showing intramedullary signal changes	AIS	Complete SCI: 36 (13–66) months Incomplete SCI: 45 (12–85) months Neurologically intact: 48 (14-94) months
8	Talbott JF (2015)[7]	Retrospective	Acute blunt traumatic cervical SCI (n=60)	NA	8.6±6 (1–39) hours	BASIC score: 5-point ordinal MRI score based on axial T2-weighted imaging	AIS	23±24 days
9	Le E (2015)[22]	Retrospective	Subaxial SCI and AIS Grade A, B, C, or D (n=78)	Subaxial	10±8.7 (3–67.2) hours	IML expansion	AIS	21.4 months
10	Gupta R (2014)[23]	Prospective	Acute cervical or dorsal spinal trauma (n=50)	NA	NA	Lesion length, MCC, and MSCC	Baseline and final ASIA score	3–6 months
11	Rüegg TB (2015)[13]	Retrospective	Cervical SCI (n=52)	NA	NA	CCAR, SAC, and CR	Motor index scores of 10 key muscles	12 months

Table 2. continued.

No	Author (year)	Type of study	Population		Injury level	MRI timing	MRI score	Clinical score	Follow-up
12	Miyanji F (2007)[4]	Prospective	Traumatic cervical (n=100)	SCI	C1/2: 2 C2/3: 1 C3/4: 6 C4/5: 12 C5: 5 C5/6: 25 C6: 3 C6/7: 21 C7: 8 Multiple level: 17 Unknown: 2	24-48 hours (median, 24 hours)	MSCC and MCC	AMS	7.3 months

Abbreviations: MRI, magnetic resonance imaging; ISI, increased signal intensity; AIS, ASIA Impairment Scale; AMS, ASIA Motor Score; IML, intramedullary lesion; MCC, maximum canal compromise; MSCC, maximum spinal cord compression; BASIC, Brain and Spinal Injury Center score; CASS, Combined Axial and Sagittal score; CCAR, cord-canal-area ratio CCAR; SAC, space available for the cord; CR, compression ratio; PVH, prevertebral hyperintensity

should be highly correlated with the actual treatment (clinical usefulness)[16]. There are currently a number of scoring or classification systems for cervical SCI, including the commonly utilized ASIA, AIS, Frankel scale, and AMS[6]. This study focused on a scoring system based on radiology imaging instead of a clinical assessment. MRI is an ideal choice owing to its superiority in assessing spinal cord and the structures surrounding it[17]. It is also commonly available and provides objective assessment.

The principal finding of our study was that the effort exerted in the quantitative assessment of MRI results in the development of a reliable classification system that correlates well with the neurological outcome in patients with cervical SCI. However, there are still controversies regarding which method of measurement best predicts the neurological outcome. There are two factors that should be considered: (1) timing of the MRI examination and (2) anatomical view to assess the extension of injury[18].

Timing of MRI examination and MRI changes after SCI

The pathophysiological changes in the spinal cord after an insult have spatial and temporal components that should be fully considered. As a dynamic process, SCI is initiated by rupture of the capillaries in the central gray matter, extravasation of red blood cells to the injury epicenter, and permeation of serum constituents into the extracellular space. It is followed by expansion of the hemorrhage, loss of membrane integrity, and formation of edema. Subsequently, parenchymal ischemia develops, resulting in a series of molecular cascades and spinal cord swelling[19].

Animal studies demonstrated that hemorrhage and edema in the spinal cord can be observed at the injury epicenter as early as 12 min after the initial trauma. During the acute stage (from 8 h to 2 days after injury), components containing blood would appear in MRI as a decreased signal on T2-weighted and gradient-echo images due to intracellular deoxyhemoglobin. Contrarily, T2-hyperintense signal intensity was correlated with areas of edema formation, white matter myelin degeneration surrounding the hemorrhage, and necrotic and inflammatory changes[18].

Subsequently, 3 days or more after the injury, extravasated blood would be demonstrated by a methemoglobin-related increased signal on the T1-weighted spin-echo MR images. The surrounding white matter edema worsened within 48-72 h after injury in the low-severity contusions. In more severe contusions, the necrotic and infiltrative changes continued to progress in sections obtained at 72 and 96 h, suggesting that the time course of lesion evolution is dependent on the injury severity[18].

In clinically severe cases, it is important to distinguish between hematoma and swelling because hematoma is correlated with poor prognosis[20]. The presence of hematoma can be detected as areas of iso-signal T1, low signal T2, and central area of low signal surrounded by high signal T2[11]. In the transverse section, the presence of macroscopic intramedullary hemorrhage was shown by discrete foci of intrame-

Table 3. Summary of MRI Classification and Parameters for Cervical Spinal Cord Injury.

MRI Parameters	Formula	Classification
T2 Sagittal		
Increased signal Intensities (ISI)	Intramedullary high signal intensities measured at the narrowest level	- Grade 0, none; - Grade 1, light (obscure); - Grade 2, intense (bright or similar to the signal from the cerebrospinal fluid)
Lesion length	Maximum cranio-caudal length of signal abnormality	Hemorrhage <4 mm has good prognosis.[19]
Maximum spinal cord compression (MSCC)	Percentage decrease in the sagittal diameter of the spinal cord at the level of maximum spinal cord compression with respect to the expected sagittal diameter of the spinal cord (mean value of the sagittal diameter measured at the uninjured levels directly above and below the level of maximum spinal cord compression)	MSCC values divided into 2 categories (<0% and >0%)[15]
Maximum canal compromise (MCC)	Cord diameter at maximum stenosis (Di) measured at the point of maximum cord compression, diameter at the nearest normal cranial level (Da), and diameter at the nearest normal caudal level (Db). These values are used to calculate MCC: (1–Di/ (Da+Db) /2)×100%[11]	MCC values divided into 3 categories (<25%, 25%–50%, >50%)[15]
Intramedullary Lesion (IML)	The rostrocaudal length of T2 signal change was measured in the mid-sagittal section	IML values were divided into 5 (0–4) categories based on length (<10 mm, 10.1–20 mm, 20.1–30 mm, 30.1–40 mm, and >40 mm)
Rate of IML expansion[22]	Rate=(IML2–IML1) / (Interval 2–Interval 1)	NA
T2 axial		
Brain and Spinal Injury Center (BASIC) score	A single axial image with the most severe SCI was identified for the scoring.	0: normal spinal cord T2 relaxivity without appreciable pathological intramedullary signal 1: Pathological T2 hyperintensity confined to the spinal gray matter 2: Hyperintensity extended beyond the margins of the central gray matter and obscured the gray-white margins but did not involve the entire transverse extent of the spinal cord 3: Hyperintensity involved the entire transverse extent of the spinal cord, without any residual normal-appearing white matter 4: BASIC score 3 injury with additional superimposed discrete foci of intramedullary T2 hypointensity attributed to the presence of macroscopic intramedullary hemorrhage
Cord-canal-area ratio	Division of transverse cord area by the transverse canal area	NA
Space available for the cord	Subtraction of the sagittal canal diameter from the sagittal cord diameter	NA
T2 sagittal and axial		
Combined Axial and Sagittal score (CASS)	Combining the BASIC score (0-4) and the IML ordinal categories (denoted as 1, 2, or 3, respectively)	Ranges from 1 to 7, which was further sub-divided into ≤3, 4–5, or ≥6

dullary T2 hypointensity superimposed on T2 hyperintensity, and it indicates the worst prognosis. Swelling has been associated with T2 hyperintensity, even though it is nonspecific.

In all the studies presented here, MRI examination was conducted in an acute setting, mostly before 48 h. The main practical reason of very early MRI examination is for surgical decompression to be performed as early as possible. However, one study found a more significant correlation between the parameters and neurological outcome when MRI was performed 2-3 days after injury rather than 0-1 day[21]. It has been demonstrated that edema and hemorrhage are best detected in T2-weighted image during the subacute phase. Due to the dynamic process, it is mandatory to consider the timing of MRI examination before obtaining the MRI parameters. MRI examination conducted in the acute phase, that is, 48-72 h after injury, is desirable for guiding prognosis.

MRI anatomical view: Sagittal or axial?

Longitudinal expansion of hemorrhage as seen in the sag-

Table 4. Reliability.

No	Author (year)	Intraobserver reliability	Interobserver reliability	Number of observers
1	Song KJ (2016)[12]	Intraclass Correlation Coefficient=0.63 (reliable)	Interclass Correlation Coefficient=0.62 (reliable)	2
2	Talbott JF (2015)[7]	NA	The mean and median kappa scores were 0.83 and 0.81, respectively (both P<0.00001) (Excellent)	7
3	Rüegg TB (2015)[13]	ICC (95% CI) ranged from good (0.72) to perfect (0.99) in rater 1 and from good (0.75) to perfect (0.99) in rater 2	ICC (95% CI) ranged from good (0.72) to perfect (0.98)	2

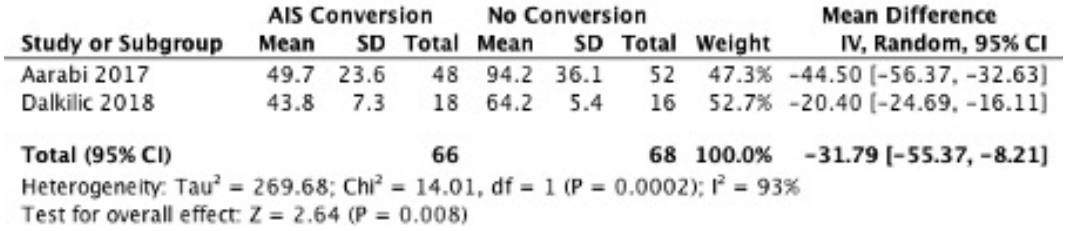

Figure 3. The weighted mean difference of IML between the group with converted AIS grade and the group without conversion.

ittal view is proportional to the severity of injury because greater length of the spinal cord is involved. However, this length measurement is considered to be arbitrary and does not reflect the true mechanism of injury in the spinal cord. The transverse extent of signal abnormality in the axial view might have better correlation with its pathophysiology and thus results in better neurological outcome prediction[22].

The importance of longitudinal signs of injury expansion was initially shown in a study that introduced the segmental correlation between SCI and neurological outcome[23]. Intramedullary edema in multiple levels of the spinal cord is correlated with poor motor recovery. The risk of retaining a complete SCI is also known to increase with each millimeter increase in hematoma length[24]. Therefore, patients with complete SCI tended to have a longer hematoma length than those with incomplete injuries and did not exhibit a change in AIS grade at follow-up[19]. Not only the absolute measurement of the lesion length but also the expansion rate of edema rostral and caudal to the injury epicenter can be predictive. For example, the expansion rate is known to be close to 920 μm/h in complete SCI and almost static in incomplete SCI.

In clinical practice, aside from knowing which formula is the best, which value of IML measurement best correlates with AIS conversion should also be known. In this study, we pooled the results from two studies. The population who underwent AIS conversion had lower IML value (49.7[10] and 43.8[11]) than those who did not (94.2[10] and 64.2[11]). The weighted MD of IML measurement between the converted and nonconverted group from the two studies was 31.79, with higher IML value associated with no conversion. Even though more research is needed to verify the formula and threshold value, this initial result might be used as guidance and alert the surgeons about the group of patients with worse prognosis.

The proponents of axial imaging suggest that it is more relevant for the assessment of SCI than sagittal imaging. The measurement of signal abnormality in the sagittal plane is arbitrary and does not fully describe the injured part anatomically. Recently, a grading system based on pathophysiology changes observed in the transverse section of the spinal cord (BASIC score) was developed. This review found that BASIC score has a good correlation with the neurological outcome. Even though it is inherently subjective due to the nature of the assessment, the reliability study for this parameter yielded good result. The limitation of the BASIC score was that in the case of severe fracture dislocation, it is challenging to acquire accurate axial images, thus making IML assessment preferable in such a case. Another consideration was that the follow-up period of two out of three studies about BASIC score was less than a month. This might create risk of bias when compared with the studies on other MRI parameters. More studies in the future are needed to investigate the best axial level for interpretation and to ameliorate the objectivity of this assessment.

Limitations

This study had several limitations. The first was the possibility of missing relevant studies, despite the extensive electronic search. There was a wide variation of keywords used to describe the MRI parameters, which can be used to assess the severity of SCI. However, the keyword "classification system" was pertinent in the current study because it describes the studies' effort on quantifying and objectively as-

Table 5. Percentage of Agreement with Clinical Outcome.

No	Author (year)	AIS conversion	AIS follow-up	AMS follow-up	MIS follow-up	Recovery rate	Conclusion
1	Martineau J (2019)[14]	Lesion length: 34.6±13.14 (*P*=0.049) MSCC: 20.6±16.3 (*P*=0.713)	NA	Lesion length (r=–0.463, *P*=0.00004) MSCC (r=–0.271, *P*=0.020)	NA	NA	Initial neurological status remains the most important predictor of the neurological outcome
2	Farhadi HF (2018)[15]	AUC: MCC: 0.59 MSCC: 0.59 MCC and MSCC: 0.64 IML: 0.84 BASIC: 0.94 BASIC and IML: 0.97 CASS: 0.91	NA	NA	NA	NA	IML or BASIC significantly better predict neurologic outcomes as compared with MCC/MSCC at 1 year following cervical tSCI BASIC significantly better predicts AIS than IML
3	Dalkilic T (2018)[11]	IMLL: 43.8±7.3 mm (*P*=0.031)	NA	NA	NA	NA	In a direct comparison of MRI and CSF biomarkers, the CSF biomarkers discriminate better between different injury severities and are stronger predictors of neurologic recovery in terms of AIS grade and motor score improvement
4	Matsushita A (2017)[21]	NA	NA	Correlation coefficient 0.5293 (*P*<0.05)	NA	NA	There is a significant relationship between ISI on T2-weighted MRI at 2–3 days 10 after injury and neurological recovery prognosis at discharge
5	Aarabi B (2017)[10]	IMLL: 49.7±23.6 (*P*=0.0001)	NA	NA	NA	NA	IMLL was the only and strongest variable that correlated with the AIS grade conversion
6	Haefeli J (2016)[9]	NA	Lesion length (*P*=–0.66), sagittal grade (*P*=–0.70), BASIC score (*P*=–0.85) All 10 patients with a BASIC score of 4 were discharged with an AIS grade of A (100%)	NA	NA	NA	The intrinsic measures of cord signal abnormality were most predictive of neurologic impairment in acute spinal cord injury
7	Song KJ (2016)[12]	NA	MSCC was observed in 23.05%, 19.5%, and 9.94 % of the complete (AIS A), incomplete (AIS B, C, and D), and normal (AIS E) (*P*=0.085) The MCC for complete, incomplete, and normal AIS categories were 22.05 (*P*<0.001), 15.32, and 9.2%, respectively	NA	NA	NA	MSCC and IMLL are MRI parameters that are strongly related to poor neurologic prognoses in patients with cervical spinal extension injury
8	Talbott JF (2015)[7]	BASIC score in groups with: -Improvement: 3.6±0.5 -Without improvement: 2.6±0.5 (*P*<0.01)	All 4 patients with a BASIC score of 4 were discharged with an AIS grade of A. (100%)	NA	NA	NA	The BASIC score will help distinguish patients who present with an AIS Grade A that improves before discharge from those who will not recover significant function

Table 5. continued.

No	Author (year)	AIS conversion	AIS follow-up	AMS follow-up	MIS follow-up	Recovery rate	Conclusion
9	Le E (2015)[22]	NA	Rate of IML expansion: AIS Grade A or B was found to be 918 μm/hour (SD 828 μm/hour), whereas that in those with AIS Grade C or D was much lower (21 μm/hour [SD 304 μm/hour])	NA	NA	NA	After traumatic subaxial cervical spine or spinal cord injury, patients with motor-complete injury (AIS Grade A or B) had a significantly higher rate of IML expansion than those with motor-incomplete injury (AIS Grade C or D)
10	Gupta R (2014)[23]	NA	Lesion length (P=0.07) MCC and MSCC not predictive factors	NA	NA	NA	Cord hemorrhage, MCC, and cord edema were the best predictors of baseline neurological status at presentation. The baseline ASIA score and cord hemorrhage were the best predictors of final neurological outcome
11	Rüegg TB (2015)[13]	NA	NA	NA	Initial and improvement: correlation coefficient r<0.5 and not significant (P>0.05)	Correlation coefficient r<0.5 and not significant (P>0.05)	The cord-canal-area ratio (>0.8) or the space available for the cord (<1.2 mm) measured on MR images can be used to identify patients at risk for acute CSCI after a minor trauma to the cervical spine; the sensitivity and specificity of these parameters are high. However, imaging characteristics of the spinal canal do not seem to be associated with the severity of or recovery from CSCI after a minor trauma
12	Miyanji F (2007)[4]	NA	NA	MCC: Complete SCI R^2=0.222, P=0.005 MSCC: Complete SCI R^2=0.171, P=0.002	NA	NA	The best model for predicting the follow-up ASIA motor score adjusted for baseline ASIA motor score included only intramedullary hemorrhage and cord swelling

Abbreviations: MRI, magnetic resonance imaging; ISI, increased signal intensity; AIS, ASIA Impairment Scale; AMS, ASIA Motor score; IML, intramedullary lesion; MCC, maximum canal compromise; MSCC, maximum spinal cord compression; BASIC, Brain and Spinal Injury Center score; CASS, Combined Axial and Sagittal score; CCAR, cord-canal-area ratio CCAR; SAC, space available for the cord; CR, compression ratio; PVH, prevertebral hyperintensity, AUC: Areas under curve

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Table 6. The Predictive Ability of MRI Parameters for Cervical Spinal Cord Injury.

MRI parameters	AIS conversion[a]	AIS and AMS follow-up[b]
T2 sagittal		
Increased signal Intensities (ISI)[12]	NA	Matsushita A[21]: Correlation coefficient 0.5293 (P<0.05)
Lesion length[24]	Martineau J[14]: 34.6±13.14 mm (P=0.049)	Martineau J[14]: r=−0.463, P=0.00004
Maximum spinal cord compression (MSCC)[4, 9, 11, 12, 14, 15, 23]	Martineau J[14]: 20.6±16.3 mm (P=0.713)	Martineau J[14]: r=−0.271, P=0.020 Miyanji F[4]: Complete SCI R^2=0.171, P=0.002
Maximum canal compromise (MCC)[4, 9, 11, 12, 14, 15, 23]	NA	Miyanji F[4]: Complete SCI R^2=0.222, P=0.005
Intramedullary lesion (IML)[10, 11, 15, 21]	Dalkilic T[11]: 43.8±7.3 mm (P=0.031) Aarabi B[10]: 49.7±23.6 mm (P=0.0001)	NA
T2 Axial		
Brain and Spinal Injury Center (BASIC) score[7, 9, 15]	Talbott JF[7]: 3.6±0.5 (P<0.01)	Haefeli J[9]: BASIC score of 4 correlates with AIS grade of A (100%) Talbott JF[7]: BASIC score of 4 correlates with AIS grade of A (100%)

[a]AIS Conversion: Improvement of at least 1 ASIA grade. The values in this column describe the mean value of each MRI parameter, which is related to improved AIS score. [b]The values in this column describe how each MRI parameter relates to ASIA grade at follow-up.

sessing the MRI. There was also no standardized reference in the diagnostic neurological outcome of cervical SCI, thus hindering us from synthesizing our data. Finally, unlike the scoring system based on physical examination, it is difficult to perform MRI when the patient first arrives in the emergency room. In this case, physical examination is irreplaceable. It is thus recommended for future scoring system to be a combination of radiological imaging, physical examination, and biological markers.

Conclusion

MRI can be a very powerful tool in aiding the management of cervical SCI. Aside from being a diagnostic tool, it has the potential of prognostic benefit. The first step is to study how the change in MRI correlates with the pathophysiology of SCI and then to formulate methods for recognizing the patterns and associating them with a certain condition. With the advent of computational science, there is renewed interest on the identification of the MRI parameters that are most relevant to the outcome of SCI. In this study, we found intramedullary lesion length (based on the sagittal view of MRI) and Brain and Spinal Injury Center (BASIC) score (axial view) to be reliable and correlate well with neurological outcome, making them candidates for the development of a simple and objective classification system.

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Ethical Approval: Ethical approval was waived by the ethics committee due to the systematic review design.

Informed Consent: Consent was not required because this study involved no human subject.

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