Original Article

Magnetic Resonant Imaging Features of Acute Traumatic Cervical Spinal Cord Injury: Its Correlation with American Spinal Injury Association Impairment Scale and Prediction of Neurological Improvement using a Low Tesla Magnetic Resonant Imaging in a Resource-Constrained Environment

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Abstract

Context: Traumatic spinal cord injury (TSCI) is a devastating disease, hence the need to identify clinical and radiological injury features that can predict neurological improvement. **Aims:** This study aims to identify magnetic resonant imaging (MRI) features in cervical TSCI that correlates with neurological status at admission, and also predict early neurological improvement. **Settings and Design:** This was a prospective cohort study. **Subjects and Methods:** Admission MRI features of 47 patients with cervical TSCI and their neurological assessments at admission and 3 months post-injury were reviewed prospectively over a period of 18 months. Correlational and regression analyses were done using SPSS® version 25 software. $P < 0.05$ was used as the level of significance. **Results:** Spinal cord oedema and cord contusion (78.0%) constitute the majority of injury patterns seen on MRI. There was a significant association between spinal cord contusion and cord oedema on MRI and incomplete TSCI. Likewise, spinal cord haemorrhage, compression and transection were associated with complete TSCI. Maximum canal compromise (MCC), maximum spinal cord compression (MSCC) and length of cord lesion significantly correlate with American Spinal Injury Association Impairment Scale at admission ($P = 0.033$, $P = 0.015$ and $P < 0.001$, respectively). Increasing values of these variables were found to be independent predictors of complete TSCI. However, length of cord lesion was the only independent predictor of neurological improvement, 3 months post-injury ($P = 0.025$). **Conclusions:** Spinal cord haemorrhage, compression, transection and higher values of MCC, MSCC and increased length of cord lesion were predictive of complete TSCI. However, the length of spinal cord lesion was a better predictor of early neurological improvement.

Keywords: American Spinal Injury Association, cervical spinal cord, injury, magnetic resonant imaging, neurological improvement, trauma

Introduction

Cervical spinal cord is the most frequently injured segment of the spinal cord following trauma to the spine; this injury is often associated with significant morbidity and far-reaching physical, emotional and economic consequences for the patients, their families and the society at large.[1-8] The most important aspect of caring for these patients is a quick, accurate and comprehensive assessment for possible spinal instability and determination of the extend of neurological deficit. However, the initial neurological examination may be fraught with difficulty, because some of these patients are obtunded by sedation or may be multiply injured resulting

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in poor cooperation and difficulty in achieving a satisfactory neurological examination, upon which the prognosis of this injury is largely based.[9,10]

It is often difficult, to accurately predict the extent of neurological recovery at presentation, due to our inability to non-invasively visualise and characterise the type and extent of damage sustained by the spinal cord.[9,11-13] Plain radiographs and computed tomography scans are valuable in demonstrating skeletal injuries to the spine but are limited in demonstrating soft-tissue injuries or internal architectural changes in the spinal cord such as spinal cord oedema, cord contusions, transections, disk herniation, epidural haematoma and external compression of the spinal cord.[14-17] As a result, clinical, therapeutic and prognostic decisions are largely dependent on physical examination and bony pattern of injury.[13-15] On the contrary, magnetic resonant imaging (MRI) has been shown to demonstrate and characterise different types of injury patterns sustained by the spinal cord, as well as other soft-tissue injuries around the cord following trauma to the spine. This makes MRI a valuable diagnostic tool in the evaluation of patients with traumatic spinal cord injury (TSCI).[13,15,17-19]

The correlations between MRI features of cervical TSCI and neurological outcome have been studied extensively in the literatures using high tesla MRI machines.[8,14,15,17,20-25] Moreover, these studies demonstrated that these MRI features of cervical TSCI correlate with the American Spinal Injury Association Impairment Scale (AIS) during follow-up.[15,17-19,21,25-28] These MRI features need to be evaluated in a resource-constrained setting with low tesla MRI scans, to see if these features can be used to complement clinical parameters in predicting outcome, especially in patients that clinical assessment may be difficult or unreliable. The goal of this study is to identify MRI features of cervical TSCI that correlates with neurological status at admission, and also predict early neurological improvement using a low tesla MRI machine in a resource-constrained environment.

Subjects and Methods

This is a prospective cohort study, conducted between May 2016 and December 2017. Approval was obtained from the Research and Ethics Committee of our institution (Research code NHA/EC/005), and a desired sample size was calculated using Fisher's formula.[29] The participants were patients brought to the emergency room of our hospital with clinical and or radiological features of acute cervical TSCI. Patients who met the inclusion criteria after review and gave consent were recruited for the study. However, patients who were unconscious, at the time of presentation and review at the emergency room or those who were unable to follow or obey instructions and those who presented 2 weeks after injury were excluded. Patients who could not do MRI due to financial constraints, patients with implants or foreign bodies that were not MRI compatible and those who leave against medical advice (LAMA) were also excluded from the study.

Information on the biodata of the patients, mechanism of injury and MRI features of TSCI were obtained at admission. Results of neurological examination of the patients at admission, at discharge and at 3 months were documented on an AIS/ International Spinal Cord Society or AIS form. A 0.3 tesla MRI machine was used for imaging, and a RadiAnt DICOM Viewer 4.0.3 (64 bits) was used for viewing and measuring of MRI features.

The review of MRI injury features was done by one of the authors in collaboration with a radiologist, with the radiologist completely blinded from the neurological status and outcome of treatment of the patients. Different patterns or types of spinal cord injury as described by Ramon *et al*.[14] were identified from a midsagittal and axial T2W sequence [Figures 1 and 2]. The maximum canal compromise (MCC) and maximum spinal cord compression (MSCC) were calculated from a midsagittal T2W sequence, as shown in Figure 2, using the formula: (i) $MCC= (1 - [Di/½ [Da + Db]]) \times 100$ and (ii) $MSCC = (1 - [di/½ [da + db]]) \times 100$

where Di and di are the spinal canal and spinal cord diameters in millimetres, measured at the epicentre of spinal cord injury, respectively; Da and da are the spinal canal and spinal cord diameters in millimetres, measured at a normal level immediately above the level of the spinal cord injury, respectively; and Db and db are the spinal canal and spinal cord diameters in millimetres, measured at a normal level immediately below the level of spinal cord injury, respectively [Figure 2], while the length of spinal cord lesion was measured as the length of spinal cord signal changes.

The patients were managed, based on the neurosurgical unit protocol, used in the management of cervical TSCI; this consist of maintaining blood pressure above 90/60 mmHg within the 1st week of admission, immediate cervical spine stabilisation with Philadelphia cervical collar, analgesia, early physiotherapy and rehabilitation, deep venous thrombosis prophylaxis and pressure ulcer prevention. Cervical spine X-rays or computed tomography (CT) scan and MRI were done as soon as possible. Patients whose cervical X-rays/MRI or CT/MRI revealed cord compression or cervical spine instability were counselled, and had anterior cervical discectomy or corpectomy and fusion (ACDF/ACCF) with or without lateral mass screw fusion, depending on the integrity of posterior ligamentous complex.

The neurological status of these patients was assessed again at discharge and at 3 months post-injury using the AIS forms on the ward and in outpatient clinic, respectively. Patients who were still on admission as at 3 months post-injury were assessed on the ward. However, those patients who could not come to the outpatient department for follow-up were assessed via WhatsApp video call. Eight patients who died before 3 months and nine patients with ASIA E injury at admission were excluded from the analysis for neurological improvement at 3 months post-injury.

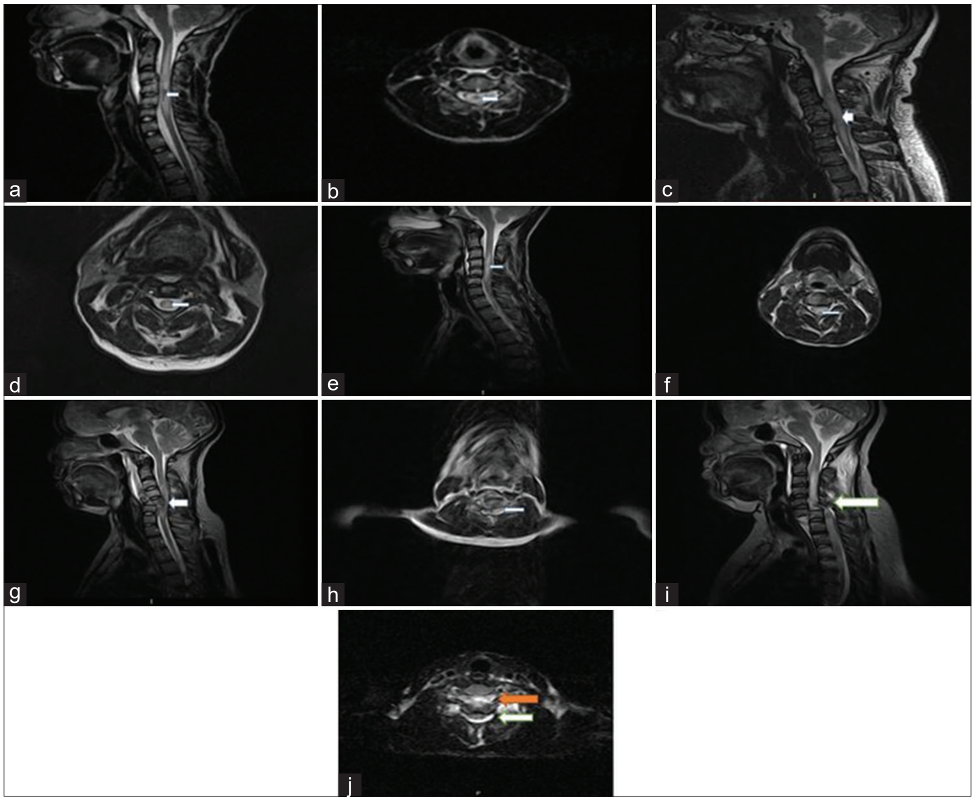

Figure 1: (a and b) Sagittal and axial magnetic resonant imaging showing cord haemorrhage; a central large hypodensity with thin rim of hyperdensity within the spinal cord. (c and d) Sagittal and axial magnetic resonant imaging showing cord oedema; a homogeneous hyperdensity within the spinal cord. (e and f) Sagittal and axial magnetic resonant imaging showing cord contusion; a small hypodensity within the cord with a thick rim of hyperdensity. (g and h) Sagittal and axial magnetic resonant imaging showing cord compression, a compression of the cord such that it is difficult to make out the complete outline of the spinal cord. (i) Sagittal imaging of cord transection and (j) axial imaging of complete separation of proximal spinal cord (red arrow) from distal cord (white arrow)

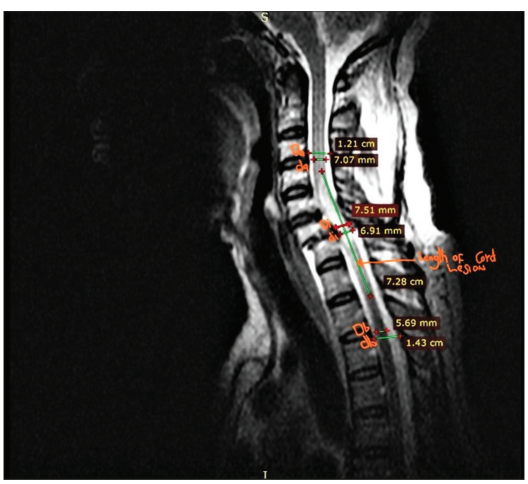

Figure 2: Midsagittal, cervical magnetic resonant imaging showing distances of spinal canal, spinal cord and length of spinal cord lesion; at injury site, Di and di, respectively. One segment above, Da and da, respectively. One segment below, Db and db, respectively

Data analysis was done using the IBM SPSS Statistics for Windows, Version 25.0. (Armonk, NY: IBM Corp). Tables and charts were used for descriptive analysis of demographics. Quantitative variables were expressed as mean ± standard deviation. Inferential statistical was done using Fisher's exact test, and Spearman's rank correlation coefficient. Simple and stepwise binary logistic regression was used to determine the predictors of neurological recovery. A two-tailed $P < 0.05$ was used as the level of significance.

Results

A total of 60 patients with cervical TSCI were seen within the study period, however, 13 patients were excluded from the study; most of them LAMA on financial ground to seek care from traditional healthcare providers. The remaining 47 patients with cervical TSCI were reviewed and analysed. Most of the patients were male (40, 85.1%). The mean age of the patients was 37.68 ± 13.7, with almost half (22, 46.8%) of this injury occurring in young adults between 20 and 39 years. Motor vehicular crash was the most common cause of injury (39, 83.0%), followed by falls from height (mostly trees) (7, 14.9%). More than half of the injuries occurred in the lower, subaxial cervical spine (C5–7) (27, 57.4%), with axial cervical spine injury being the least (3, 6.4%) [Table 1]. Most (41, 87.2%) of the patients presented within 48 h of injury, with an average time from injury to presentation of 23.71 ± 35.99.

Table 1: Demographics and injury characteristics

Variables	Frequency, *n* (%)
Sex	
Male	40 (85.1)
Female	7 (14.9)
Age	
<20	5 (10.6)
20-29	5 (10.6)
30-39	17 (36.2)
40-49	9 (19.1)
50-59	8 (17.0)
>60	3 (6.4)
Aetiology	
MVC	39 (83.0)
Falls	7 (14.9)
Stab	1 (2.1)
Level of cervical spine injury	
C 1-2 (axial)	3 (6.4)
C 3-4 (high subaxial)	17 (36.2)
C 5-7 (low subaxial)	27 (57.4)
Total	47 (100.0)

MVC: Motor vehicular crash

Complete cervical TSCI (ASIA A) was the most common injury seen (19, 40.4%), with ASIA C (5, 10.6%) being the least type of injury at admission. At 3 months post-injury, 41 (87.2%) of the patients survived, whereas 6 (12.8%) of the patients died (all of them had ASIA A and TSCI). Ten (24.4%) of the patients who survived remained as ASIA A, whereas more than half of the patients 25 (61.0%) had good neurological function (ASIA D and E) [Figure 3].

Majority (31, 66.0%) of the patients had their MRI done within 72 h of injury. All patients with spinal cord haemorrhage (3, 100%), spinal cord transection (1, 100%) and 4 (80.0%) of the patients with spinal cord compression type of injury seen on MRI had a complete spinal cord injury (ASIA A). Spinal cord contusion and oedema was the most common (32, 68.1%) type of injury pattern seen on MRI, and more than half (21, 65.63%) of these patients presented with incomplete spinal cord injury. This association was significant ($P = 0.01$) [Tables 2 and 3]. Moreover, the Spearman's correlation coefficient showed a moderately significant correlation ($\rho = 0.509$, $P = 0.000$) [Table 4].

The mean value of MCC was 32.06 ± 25.37%, MSCC was 17.08% ± 18.23% and the mean length of spinal cord lesion was 57.15 ± 41.94 mm. Patients with ASIA A (complete) spinal cord injury had the highest mean values of MCC, MSCC and length of spinal cord lesion (41.53% ± 26.86%, 24.83% ± 22.46% and 93.47% ± 34.57%, respectively), whereas patients with ASIA E had the lowest mean value of MCC, MSCC and length of spinal cord lesion (9.58% ± 9.21%, 7.16% ± 10.86% and 7.74% ± 9.97%, respectively) [Tables 2 and 3]. These findings showed a significant correlation between AIS and quantitative MRI features [Table 4]. The type of vertebral column injury and ligamentous injury did not show any significant association or correlation with AIS at admission and type of spinal cord injury [Table 4]

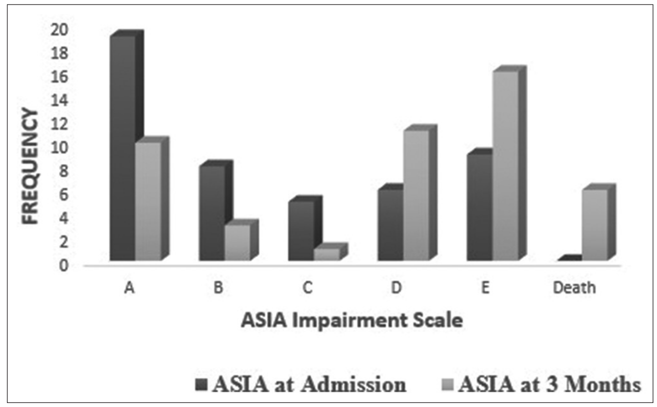

Figure 3: A bar chart of ASIA Impairment Scale at admission and at 3 months post-injury, at 3 months post-injury most of the patients were AIS D and E

At 3 months post-injury, nine patients with ASIA E injury at admission and six patients who died were excluded from the analysis. Thirty-two patients were analysed for neurological improvement, 19 (59.4%) of the patients showed improvement in their AIS, whereas 13 (40.6%) did not. The mean time from injury to surgical intervention (ACDF/ACCF ± lateral mass screw) was 64.90 ± 54.53 h, only one of the patients had surgery within 48 h of injury and there was no significant relationship between patients who had surgery and their neurological improvement. Likewise, there was no significant correlation ($\rho = 0.283$, $P = 0.054$) between the time lapse from injury to presentation and improvement in AIS at 3 months. Spinal cord oedema and cord contusion were observed in most of the patients 18 (94.7%) who improved in their AIS, but none of the patients with spinal cord haemorrhage or cord transection and 3 (75%) of the patients with cord compression improved in their AIS. This association, though significant ($P = 0.019$) with Fisher's exact test and the Spearman's rank correlation, was not significant ($\rho = -0.019$, $P = 0.917$) [Tables 4 and 5].

The mean values of MCC, MSCC and length of spinal cord lesion in patients who improved in their AIS were 30.10% ± 23.57%, 12.90% ± 13.32% and 53.78% ± 39%, respectively; these values were lower than the MCC, MSCC and length of spinal cord lesion in patients who did not improve in their AIS (43.27% ± 24.12%, 22.79% ± 21.42% and 85.28% ± 35.31%, respectively). However, this association was only significant for the length of spinal cord lesion ($\rho = -0.391$, $P = 0.027$). The type of vertebral injury and ligamentous injury was not significantly associated with improvement in AIS.

A simple binary logistic regression analysis to determine the predictors of the type of spinal cord injury based on severity (complete or incomplete injury) at admission showed that the MCC ($P = 0.039$, odds ratio [OR]: 1.027, 95% confidence interval [CI]: 1.001, 1.053), MSCC ($P = 0.026$,

Table 2: Relationship between qualitative and quantitative magnetic resonant imaging features with American Spinal Injury Association Impairment Scale at admission

Qualitative parameters	AIS at admission						P
	A, n (%)	B, n (%)	C, n (%)	D, n (%)	E, n (%)	Total, n (%)	
MRI spinal cord injury pattern							
Normal (type 0)	0	0	0	0	6 (100.0)	6 (100.0)	0.011*
Haemorrhage (type I)	3 (100.0)	0	0	0	0	3 (100.0)	
Oedema (type II)	6 (35.3)	3 (17.6)	2 (11.8)	4 (23.5)	2 (11.8)	17 (100.0)	
Contusions (type III)	5 (33.3)	5 (33.3)	2 (13.3)	2 (13.3)	1 (6.7)	15 (100.0)	
Compression (type IV)	4 (80.0)	0	1 (20.0)	0	0	5 (100.0)	
Transection (type V)	1 (100.0)	0	0	0	0	1 (100.0)	
Type of vertebral injury							
A	7 (33.3)	3 (14.3)	3 (14.3)	4 (19.0)	4 (19.0)	21 (100.0)	0.815
B	2 (28.6)	2 (28.6)	1 (14.3)	1 (14.3)	1 (14.3)	7 (100.0)	
C	10 (52.6)	3 (15.8)	1 (5.3)	1 (5.3)	4 (21.1)	19 (100.0)	
Ligamentous injury							
ALL	3 (50.0)	1 (16.7)	1 (16.7)	1 (16.7)	0	6 (100.0)	0.158
PLL	0 (0.0)	0 (0.0)	0 (0.0)	1 (33.3)	2 (66.7)	3 (100.0)	
ALL+PLL	11 (57.9)	4 (21.1)	1 (5.3)	2 (10.5)	1 (5.3)	19 (100.0)	
None	5 (26.3	3 (15.8)	3 (15.8)	2 (10.5)	6 (31.6)	19 (100.0)	
Total	19 (40.4)	8 (17.0)	5 (10.6)	6 (12.8)	9 (31.6)	47 (100.0)	
Quantitative parameter	**A (n=19)**	**B (n=8)**	**C (n=5)**	**D (n=6)**	**E (n=9)**		**P**
MCC	41.53±26.86	33.68±23.74	26.50±28.00	38.25±21.02	9.58±9.21		0.027*
MSCC	24.83±22.25	13.47±10.33	22.18±20.65	7.99±6.95	7.16±10.86		0.074
Length of cord lesion	93.47±34.57	44.24±19.73	38.32±30.32	49.20±18.36	7.74±9.97		0.000*

*Statistically significant. AIS: American Spinal Injury Association Impairment Scale, MRI: Magnetic resonant imaging, ALL: Anterior longitudinal ligament, PLL: Posterior longitudinal ligament, MCC: Mean canal compromise, MSCC: Mean spinal cord compression

OR: 1.045, 95% CI: 1.005, 1.086) and length of spinal cord lesion (P = 0.001, OR: 1.077, 95% CI: 1.032, 1.123) were independent predictors of type of injury, however, the length of spinal cord lesion (P = 0.001, OR: 1.077, 95% CI: 1.032, 1.123) contributed more significantly as a predictor of type of spinal cord injury in a stepwise regression analysis. The length of spinal cord lesion was the only independent predictor of improvement in AIS at 3 months after injury (P = 0.025, OR: 0.974, 95% CI: 0.956–0.999) [Table 6].

Discussion

Several types of spinal cord signal intensity changes were identified on cervical MRI of majority (41, 87.2%) of these patients with TSCI. These changes were similar to different types of injury patterns described by Bondurant *et al*. and Ramon *et al*., using a 1.5 tesla MRI machine.[13,19] These injury types or patterns observed using a low tesla MRI (0.3 tesla) in our practice are shown in Figure 1. Patients who had normal spinal cord (type 0) on MRI had transient neurological deficit (ASIA E injury) at initial assessment. Most (32,78.0%) of the patients with spinal cord signal intensity changes had spinal cord oedema and cord contusion, and two-third of them had an incomplete injury with neurological deficits (ASIA B, C and D). However, all the patients with spinal cord haemorrhage, cord transection and most of the patients with cord compression had complete TSCI, which suggest a severe form of injury.

This observation is similar to publications by several authors who reported that traumatic intramedullary haemorrhage or haematoma and cord transection were severe types of spinal cord injury that correlated significantly with complete TSCI, with these patients having poor chance of neurological recovery during follow-up.[8,13,15-17,19,23] Although a higher tesla MRI machine provides a better image quality, the finding from this study suggest that resource-constrained setting with low tesla MRI machine could also use this machine to better define spinal cord injuries in their patients. Most especially, in patients whose AIS cannot be determined in the early phase of TSCI.

This study also found that significantly higher mean values of MCC, MSCC and length of cord lesion were observed in patients with complete spinal cord injury (ASIA A). While patients with incomplete spinal cord injury with neurological deficit (ASIA B, C and D) have slightly lower mean values of these parameters, patients with ASIA E (spinal cord injury without neurological deficits) had the lowest mean value of MCC, MSCC and length of spinal cord lesion. This observation significantly correlated with AIS at admission and type spinal cord injury. These findings were achievable with our low tesla MRI machine, as shown in Figure 2. Several authors have reported similar findings using a higher (1.5) tesla MRI machine.[8,16,17,21] The explanation for these findings could be that, severe cord compression or spinal canal compromise is more likely to cause severe and extensive damage to the spinal cord from either ischaemia or disruption

Table 3: Relationship between qualitative and quantitative magnetic resonant imaging features and type of spinal cord injury at admission

Qualitative parameters	Type of spinal cord injury at admission			*P*
	Incomplete injury, *n* (%)	Complete injury, *n* (%)	Total, *n* (%)	
MRI spinal cord injury pattern				
Normal (type 0)	6 (100.0)	0	6 (100.0)	0.010*
Haemorrhage (type I)	0	3 (100.0)	3 (100.0)	
Oedema (type II)	11 (64.7)	6 (35.3)	17 (100.0)	
Contusions (type III)	10 (66.7)	5 (33.3)	15 (100.0)	
Compression (type IV)	1 (20.0)	4 (80.0)	5 (100.0)	
Transection (type V)	0 (0.0)	1 (100.0)	1 (100.0)	
Type of vertebral injury				
A	14 (66.7)	7 (33.3)	21 (100.0)	0.434
B	5 (71.4)	2 (28.6)	7 (100.0)	
C	9 (47.4)	10 (52.6)	19 (100.0)	
Ligamentous injury				
ALL	3 (50.0)	3 (50.0)	6 (100.0)	0.126
PLL	3 (100.0)	0	3 (100.0)	
ALL+PLL	8 (42.1)	11 (57.9)	19 (100.0)	
None	14 (73.7)	5 (26.3)	19 (100.0)	
Total	28 (59.6)	19 (40.4)	47 (100.0)	
Quantitative parameter	**Mean±SD**			***P***
	Incomplete injury	**Complete injury**		
MCC	25.63±22.56	41.53±26.86		0.033*
MSCC	11.82±12.88	24.83±22.25		0.015*
Length of cord lesion	32.51±10.33	93.47±34.57		0.000*

*Statistically significant. SD: Standard deviation, AIS: American Spinal Injury Association Impairment Scale, MRI: Magnetic resonant imaging, ALL: Anterior longitudinal ligament, PLL: Posterior longitudinal ligament, MCC: Mean canal compromise, MSCC: Mean spinal cord compression

Table 4: Relationship between qualitative and quantitative magnetic resonant imaging features with American Spinal Injury Association Impairment Scale at admission, type spinal cord injury and American Spinal Injury Association Impairment Scale improvement at 3 months

Variables	Correlation coefficient (ρ)	*P*
Correlation between AIS at admission and qualitative and quantitative MRI features		
AIS at admission and MRI injury pattern	−0.509	0.000*
AIS at admission and MCC	−0.400	0.005*
AIS at admission and MSCC	−0.375	0.009*
AIS at admission and length of cord lesion	−0.724	0.000*
AIS at admission and type of ligamentous injury	+0.136	0.363
AIS at admission and type of vertebral injury	−0.284	0.053
Correlation between AIS improvement at 3 months and qualitative and quantitative MRI features		
AIS improvement at 3 months and MRI injury pattern	−0.019	0.917
AIS improvement at 3 months and MCC	−0.270	0.135
AIS improvement at 3 months and MSCC	−0.283	0.117
AIS improvement at 3 months and Length of cord lesion	−0.391	0.027*
AIS improvement at 3 months and type of ligamentous injury	+0.082	0.656
AIS improvement at 3 months and type of vertebral injury	−0.164	0.369

*Statistically significant. AIS: American Spinal Injury Association Impairment Scale, MRI: Magnetic resonant imaging, MCC: Mean canal compromise, MSCC: Mean spinal cord compression

of nerve fibres with much more severe consequences than mild form of cord compression or canal compromise.

A simple regression analysis model to determine the predictor of severity of injury showed that the types of spinal cord injury pattern, MCC, MSCC and length of spinal cord lesion were independent predictors of severity of injury (complete versus incomplete injury) at admission. However, in a multistage or stepwise regression model, only the length of spinal cord lesion contributed significantly as a predictor of severity of injury.

Table 5: Relationship between qualitative and quantitative magnetic resonant imaging features with American Spinal Injury Association Impairment Scale improvement at 3 months

Parameters	AIS improvement at 3 months			*P*
	No, *n* (%)	Yes, *n* (%)	Total, *n* (%)	
MRI spinal cord injury pattern				
Haemorrhage (type I)	3 (100)	0 (0.0)	3 (100.0)	0.019*
Oedema (type II)	4 (30.8)	9 (69.2)	13 (100.0)	
Contusions (type III)	2 (18.2)	9 (81.8)	11 (100.0)	
Compression (type IV)	3 (75.0)	1 (25.0)	4 (100.0)	
Transection (type V)	1 (100)	0	1 (100.0)	
Type of vertebral injury				
A	5 (35.7)	9 (64.3)	14 (100.0)	0.445
B	1 (20.0)	4 (80.0)	5 (100.0)	
C	7 (53.8)	6 (46.2)	13 (100.0)	
Ligamentous injury				
ALL	2 (50.0)	2 (50.0)	4 (100.0)	0.873
PLL	0 (0.0)	1 (100)	1 (100.0)	
ALL+PLL	7 (46.7)	8 (53.3)	15 (100.0)	
None	4 (33.3)	8 (66.7)	12 (100.0)	
Total	13 (40.6)	19 (59.4)	32 (100.0)	
Quantitative parameters				
MCC	43.27±24.12	30.10±23.57		0.135
MSCC	22.79±21.42	12.90±13.32		0.117
Length of cord lesion	85.28±35.31	53.78±39.02		0.027*

*Statistically significant. AIS: American Spinal Injury Association Impairment Scale, MRI: Magnetic resonant imaging, ALL: Anterior longitudinal ligament, PLL: Posterior longitudinal ligament, MCC: Mean canal compromise, MSCC: Mean spinal cord compression

Table 6: Simple and stepwise binary logistic regression showing predictor of type of spinal cord injury at admission and predictor of American Spinal Injury Association Impairment Scale improvement at 3 months post-injury

Variable	β	SE	Wald statistic	*P*	Crude odds ratio	95% CI (lower-upper)
Simple binary logistic regression						
MCC	0.026	0.013	4.249	0.039*	1.027	1.001-1.053
MSCC	0.044	0.020	4.968	0.026*	1.045	1.005-1.086
Length of cord lesion	0.074	0.022	11.875	0.001*	1.077	1.032-1.123
Stepwise binary logistic regression						
Step 1						
Length of cord lesion	0.073	0.023	10.497	0.001*	1.076	1.029-1.124
MSCC	0.034	0.027	1.585	0.208	1.035	0.981-1.091
Step 2						
Length of cord lesion	0.077	0.023	10.796	0.001*	1.080	1.031-1.130
MSCC	0.056	0.038	2.254	0.133	1.058	0.983-1.139
MCC	−0.023	0.026	0.793	0.373	0.977	0.928-1.028
Predictor of ASIA improvement at 3 months post-injury						
Length of cord lesion	−0.023	0.011	5.058	0.025*	0.974	0.956-0.999

*Statistically significant. MCC: Mean canal compromise, MSCC: Mean spinal cord compression, SE: Standard error, CI: Confidence interval

At 3 months post-injury, all the patients with cervical spinal cord haemorrhage, cord transection and most 3 (75%) of the patients with cord compression, showed no improvement in their admission AIS. Whereas, 18 (75.0%) out of 24 patients with cervical spinal cord oedema and cord contusion improved by at least one level in their initial AIS. Higher values of MCC, MSCC and length of cord lesion were seen in patients who did not improve in their AIS, however, the only independent predictor of neurological improvement was the length of spinal cord lesion ($P = 0.025$, OR: 0.974, 95% CI: 0.956–0.999).

Although, several studies, published in the literature, showed that, spinal cord haemorrhage is associated with poor neurological recovery, with spinal cord oedema and cord contusion, associated with good recovery.[13,15,18,19] However, there were no studies in which regression analysis model was used to show how quantitative MRI features can be used to predicted neurological improvement, as done in our study.

Although some authors reported that the best model that predicted unadjusted follow-up ASIA motor score was MSCC, intramedullary haemorrhage and cord swelling,[17] others found that the length of spinal cord lesion and intramedullary haemorrhage were predictors of Frankel score on admission, with MSCC, length of lesion and intramedullary haemorrhage, predicting Frankel score at follow-up.[8]

The findings in this study and that from other authors show a similar pattern, where the presence of intramedullary haemorrhage, higher mean values of length of spinal cord lesion and MSCC are strong predictors of complete TSCI with poor potential for neurological recovery. However, spinal cord oedema, cord contusion and lower values of length of spinal cord lesion and MSCC are predictors of incomplete injury with good potential for recovery.[8,13,15-17,21,30] The possible explanation for these findings could be that traumatic cord compression, often from disc herniation, displaced or dislocated fractured vertebrae or haematoma, results in secondary injury. This further worsens the primary injury caused by the initial energy transfer to the cord at the time of primary injury, leading to permanent spinal cord damage with less likelihood of recovery.[31,32] This is further supported by the STASIS study where early decompression resulted in improvement in AIS by at least two levels.[33]

Limitation

Delay in carrying out MRI scan was a major challenge, because most of our patients fund their health services; as a result, financial constraint and frequent breakdown of the MRI machine affected the timing of image acquisition and limited our ability to do follow-up of MRI. Although some authors suggested that the best timing for performing a prognostic MRI should be within 24–72 h after trauma,[13] others reported that the ideal timing should be at the time of injury and 2–3 weeks later.[34] However, no substantial evidence exists to support this precise guideline.[35,36]

Second, our MRI machine is a low (0.3) tesla, spin-echo MR imaging, with limited pathophysiological image characterisation, especially in trauma. More so that, there are higher tesla MRI with advanced imaging technique such as diffusion tensor imaging that has the ability to show axonal injury and additional shearing injuries that are not visible on low tesla and conventional MR images.[17,37,38]

Conclusions

Low tesla MRI can also be used to determine different types of cervical spinal cord injury characteristics. Spinal cord haemorrhage, compression, transection and higher values of MCC, MSCC and increased length of spinal cord lesion were significantly associated with complete TSCI at admission. Whereas, cord contusion and lower values of MCC, MSCC and shorter length of cord lesion are predictive of incomplete TSCI, with length of cord lesion being a better predictor of outcome at 3 months post-injury.

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Conflicts of interest

There are no conflicts of interest.

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