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ROLE OF MAGNETIC RESONANCE IMAGING IN THE EVALUATION OF SPINAL TRAUMA: A CROSS-SECTIONAL STUDY

Original Research

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ABSTRACT

Background: Spinal trauma remains a leading cause of morbidity and long-term neurological disability worldwide, particularly among young and middle-aged adults. Early and accurate evaluation of spinal cord and associated soft tissue injuries is essential to prevent secondary neurological deterioration and to guide appropriate management. Conventional imaging modalities primarily assess osseous injuries and may fail to detect clinically significant cord and ligamentous damage. Magnetic Resonance Imaging offers superior soft tissue contrast and has emerged as a key modality for comprehensive spinal trauma assessment and prognostication.

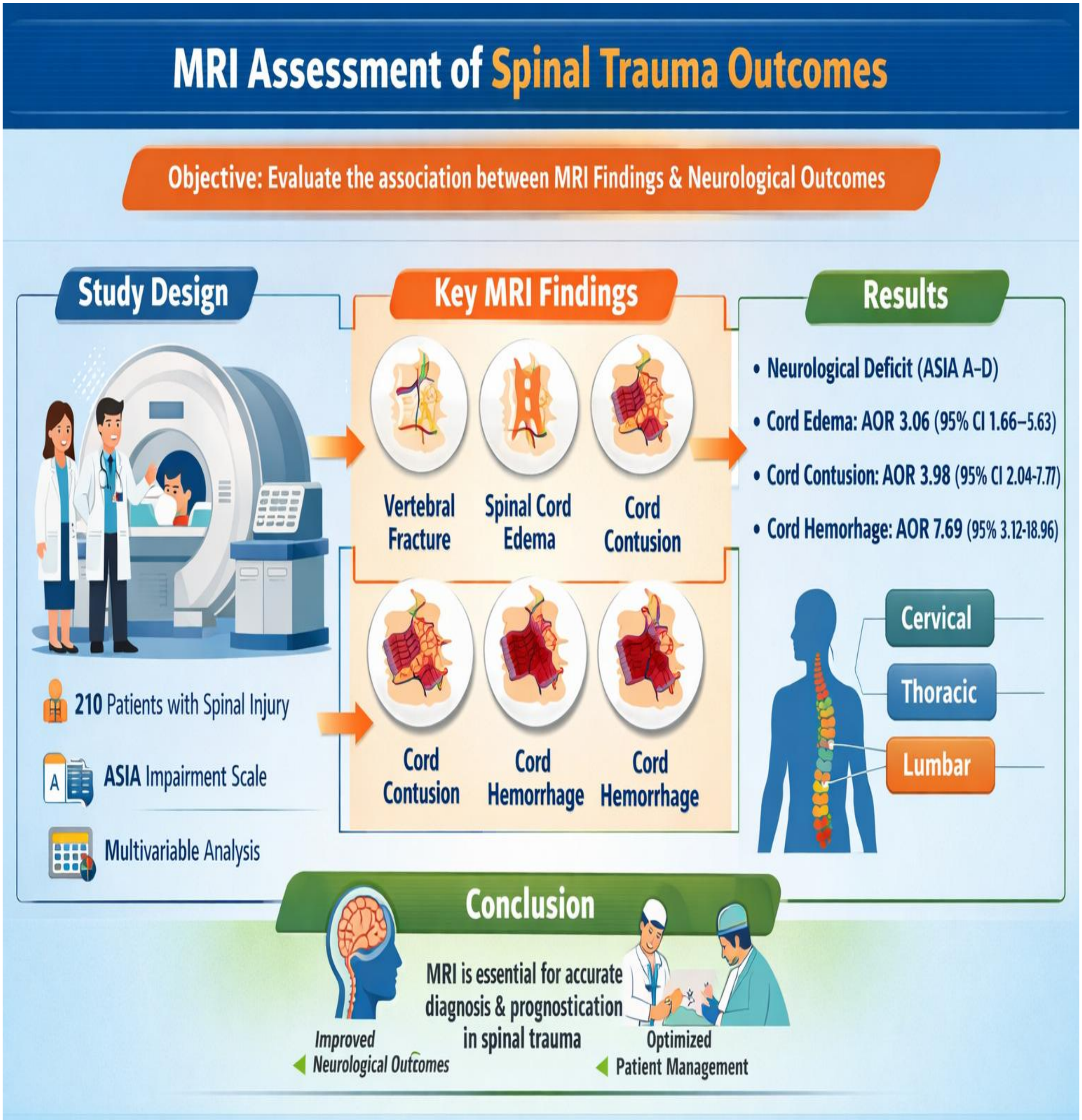
Objective: To evaluate the role of Magnetic Resonance Imaging in the assessment of spinal trauma and to determine the association between MRI findings and neurological outcomes.

Methods: A cross-sectional analytical study was conducted on 210 patients with suspected acute spinal trauma who underwent MRI evaluation. Demographic data, mechanism of injury, spinal level involved, and time to imaging were recorded. MRI was performed using a 1.5 Tesla scanner with standard sagittal and axial T1-weighted, T2-weighted, STIR, and gradient echo sequences when indicated. Neurological status was assessed at presentation using the American Spinal Injury Association impairment scale. Associations between MRI findings and neurological deficits were analyzed using Chi-square testing, followed by multivariable logistic regression to identify independent predictors.

Results: The study population was predominantly male (69.5%), with road traffic accidents accounting for 45.7% of injuries. Cervical spine involvement was observed in 35.2% of patients. MRI demonstrated vertebral body fractures in 61.0%, spinal cord edema in 45.7%, cord contusion in 35.2%, cord hemorrhage in 15.2%, ligamentous injury in 39.0%, and paraspinal soft tissue injury in 49.5%. Neurological deficits (ASIA A–D) were present in a significantly higher proportion of patients with MRI-detected cord abnormalities ($p < 0.001$). On multivariable analysis, spinal cord hemorrhage (AOR 7.69; 95% CI 3.12–18.96), cord contusion (AOR 3.98; 95% CI 2.04–7.77), and cord edema (AOR 3.06; 95% CI 1.66–5.63) were independent predictors of neurological deficit.

Conclusion: Magnetic Resonance Imaging plays a central role in the accurate diagnosis and prognostic assessment of spinal trauma by reliably identifying spinal cord and soft tissue injuries. Its integration into routine trauma evaluation enhances clinical decision-making and supports optimized patient management.

Keywords: Ligamentous Injuries, Magnetic Resonance Imaging, Neurological Deficit, Spinal Cord Injuries, Spinal Trauma, Spine, Wounds and Injuries.


MRI Assessment of Spinal Trauma Outcomes
Objective: Evaluate the association between MRI Findings & Neurological Outcomes
Study Design
210 Patients with Spinal Injury
ASIA Impairment Scale
Multivariable Analysis
Key MRI Findings
Vertebral Fracture
Spinal Cord Edema
Cord Contusion
Cord Contusion
Cord Hemorrhage
Cord Hemorrhage
Results
• Neurological Deficit (ASIA A–D)
• Cord Edema: AOR 3.06 (95% CI 1.66–5.63)
• Cord Contusion: AOR 3.98 (95% CI 2.04-7.77)
• Cord Hemorhage: AOR 7.69 (95% 3.12-18.96)
Cervical
Thoracic
Lumbar
Conclusion
MRI is essential for accurate diagnosis & prognostication in spinal trauma
Improved Neurological Outcomes
Optimized Patient Management

INTRODUCTION

Spinal trauma remains a critical public health concern worldwide, contributing substantially to morbidity, mortality, and long-term neurological disability, with far-reaching socioeconomic consequences for patients, families, and healthcare systems (1). These injuries most frequently arise from road traffic accidents, falls from height, sports-related incidents, and interpersonal violence, disproportionately affecting young and middle-aged adults who represent the most economically productive segment of the population (2). The clinical course of spinal trauma is highly time-sensitive, as delays or inaccuracies in diagnosis can result in irreversible spinal cord damage, prolonged disability, and diminished quality of life, underscoring the necessity for timely and precise diagnostic evaluation (3). Initial imaging assessment traditionally relies on plain radiography and computed tomography, which are effective for identifying fractures, malalignment, and other osseous abnormalities in the acute trauma setting (4). However, these modalities provide limited information regarding the spinal cord, intervertebral discs, ligaments, and surrounding soft tissues—structures that are often central to neurological compromise and patient prognosis (5). Consequently, patients may present with normal or inconclusive CT findings despite significant neurological deficits, a phenomenon described as spinal cord injury without radiographic abnormality, highlighting a critical diagnostic gap in conventional imaging approaches (6). Magnetic Resonance Imaging has therefore assumed a pivotal role in the comprehensive evaluation of spinal trauma due to its superior soft-tissue contrast and multiplanar imaging capabilities (7). MRI enables direct visualization of spinal cord edema, contusion, hemorrhage, ligamentous disruption, disc herniation, epidural hematoma, and paraspinal soft-tissue injuries, all of which are essential for accurate injury characterization and informed clinical decision-making (8).

Importantly, multiple studies have demonstrated a strong association between MRI-detected spinal cord abnormalities and the severity of neurological impairment, as graded by the American Spinal Injury Association impairment scale, reinforcing MRI's value beyond mere anatomical assessment (9). Beyond diagnosis, MRI findings carry significant prognostic and therapeutic implications. The presence of cord hemorrhage and extensive contusion has been consistently linked with poor neurological recovery, whereas isolated cord edema may reflect potentially reversible injury when managed appropriately and in a timely manner (10). Such distinctions are crucial in guiding the choice between conservative and surgical management strategies and in counseling patients and families regarding expected functional outcomes during follow-up (11). Despite the recognized advantages of MRI, variability remains in how imaging findings are correlated with neurological status and outcomes across different clinical settings, indicating a need for further evidence to standardize its role in routine spinal trauma assessment. In this context, the present study was designed to evaluate the role of Magnetic Resonance Imaging in the assessment of spinal trauma and to determine the association between MRI findings and neurological outcomes in affected patients, thereby addressing an important gap in trauma imaging and clinical prognostication.

METHODS

A cross-sectional analytical study was conducted to evaluate the role of Magnetic Resonance Imaging in the assessment of spinal trauma and its association with neurological outcomes. The study was carried out over a six-month period in the Department of Radiology, in collaboration with the Departments of Neurosurgery and Orthopedics, at a tertiary care teaching hospital. The study population comprised patients presenting with suspected acute traumatic spinal injury who were referred for MRI evaluation as part of their routine clinical management. A total of 210 patients of both genders, aged 18 years and above, were included using a non-probability consecutive sampling technique (4). Patients with non-traumatic spinal pathologies, a history of previous spinal surgery, congenital spinal anomalies, or contraindications to MRI such as cardiac pacemakers or ferromagnetic implants were excluded to avoid confounding and ensure diagnostic accuracy. Following initial clinical stabilization, eligible patients underwent MRI of the spine according to a standardized imaging protocol. Demographic variables, including age and gender, along with clinical details such as mechanism of injury, anatomical region of spinal involvement, and the time interval between injury and MRI examination, were recorded using a structured data collection proforma. Neurological status at presentation was assessed by a qualified clinician using the American Spinal Injury Association impairment scale, which served as the standardized tool for grading neurological deficit. MRI examinations were performed on a 1.5 Tesla scanner. The imaging protocol included sagittal and axial T1-weighted, T2-weighted, and Short Tau Inversion Recovery sequences for comprehensive evaluation of osseous, ligamentous, discal, and spinal cord structures (12,13). Gradient echo sequences were additionally obtained in cases where spinal cord hemorrhage was suspected. All MRI images were independently reviewed by two experienced radiologists who were blinded to the patients' neurological status to minimize observer bias. Imaging findings assessed included vertebral body fractures, intervertebral disc herniation, ligamentous injury, spinal cord edema, contusion, hemorrhage, epidural hematoma, and paraspinal soft-tissue injury. Any discrepancies between observers were resolved through mutual consensus to ensure consistency in image interpretation.

The primary outcome measure was the presence of neurological deficit, defined as ASIA grades A to D, while ASIA grade E was categorized as absence of neurological deficit. Secondary outcomes included the association between specific MRI findings, particularly spinal cord abnormalities, and the severity of neurological impairment. Data were entered and analyzed using the Statistical Package for Social Sciences version 26.0. Continuous variables were summarized as mean with standard deviation, whereas categorical variables were expressed as frequencies and percentages. Associations between MRI findings and neurological status were evaluated using the Chi-square test, and cross-tabulation was employed to explore relationships between individual MRI cord abnormalities and ASIA grades. Variables demonstrating statistical significance on univariate analysis were subsequently entered into a multivariable logistic regression model to identify independent predictors of neurological deficit, with adjusted odds ratios and 95% confidence intervals calculated. A p-value of less than 0.05 was considered statistically significant. Ethical considerations were addressed in accordance with the principles of the Declaration of Helsinki. As the study involved analysis of imaging and clinical data obtained as part of routine patient care and did not involve any additional intervention, individual informed consent was not sought. However, patient confidentiality and data anonymity were strictly maintained throughout the study process.

RESULTS

A total of 210 patients with suspected spinal trauma were evaluated. The study population was predominantly male (69.5%), with females comprising 30.5% of cases. The most frequently affected age group was 31–40 years (29.5%), followed by 18–30 years (25.7%) and 41–50 years (22.9%), indicating that spinal trauma largely involved individuals in their economically productive years. Road traffic accidents emerged as the leading mechanism of injury, accounting for 45.7% of cases, followed by falls from height in 34.3%, while sports-related injuries and assault were less common. Anatomically, cervical spine involvement was most frequent (35.2%), followed by lumbar (32.4%) and thoracic regions (21.9%), with 10.5% of patients sustaining injuries at multiple spinal levels. MRI was performed within 24 hours of trauma in 41.9% of patients, while 35.2% underwent imaging within 24–72 hours and 22.9% after 72 hours. Neurological assessment demonstrated a wide distribution of impairment, with ASIA grades D (24.8%) and E (23.8%) being most common, while complete neurological deficit (ASIA A) was observed in 16.2% of patients. MRI evaluation revealed a broad spectrum of traumatic findings. Vertebral body fractures were the most frequent abnormality, identified in 61.0% of patients. Paraspinal soft-tissue injury was observed in 49.5%, while spinal cord edema was present in 45.7%. Ligamentous injury was detected in 39.0% of cases, highlighting the added diagnostic value of MRI for soft-tissue assessment. More severe spinal cord pathologies were less frequent but clinically significant, with cord contusion observed in 35.2% and cord hemorrhage in 15.2% of patients. Disc herniation was identified in 27.6%, and epidural hematoma in 12.4%, with many patients demonstrating more than one MRI abnormality.

A strong association was observed between MRI-detected spinal cord signal changes and neurological status. Neurological deficits were present in 81.3% of patients with cord edema, 89.2% of those with cord contusion, and 93.8% of patients with cord hemorrhage. In contrast, among patients without MRI-visible cord signal abnormalities, 75.5% had no neurological deficit. These findings indicated a statistically significant relationship between the presence of cord abnormalities on MRI and neurological impairment, with cord hemorrhage showing the strongest association. Further stratification of neurological status demonstrated that severe deficits (ASIA A–B) were predominantly associated with spinal cord hemorrhage (68.8%) and contusion (45.9%). Patients with cord edema more commonly exhibited moderate to mild deficits, whereas the majority of patients without cord signal abnormalities had normal neurological status. The association between the type of MRI-detected cord injury and the severity of neurological impairment was statistically significant across all categories, reinforcing the prognostic relevance of MRI in spinal trauma assessment. Multivariable logistic regression analysis identified several independent predictors of neurological deficit. MRI evidence of spinal cord hemorrhage showed the highest odds of neurological impairment (adjusted odds ratio 7.69, 95% confidence interval 3.12–18.96), followed by cord contusion (adjusted odds ratio 3.98, 95% confidence interval 2.04–7.77) and cord edema (adjusted odds ratio 3.06, 95% confidence interval 1.66–5.63). Cervical spine involvement was also a strong predictor (adjusted odds ratio 2.48, 95% confidence interval 1.44–4.27), while ligamentous injury significantly increased the likelihood of neurological deficit (adjusted odds ratio 2.10, 95% confidence interval 1.24–3.56). Age above 40 years and road traffic accidents demonstrated moderate but significant associations, whereas gender was not an independent predictor of neurological outcome.

Table 1: Demographic Characteristics of Patients with Spinal Trauma (n = 210)

Variable	Category	Frequency (n)	Percentage (%)
Age Group (years)	18–30	54	25.7
	31–40	62	29.5
	41–50	48	22.9
	51–60	32	15.2
	>60	14	6.7
Gender	Male	146	69.5
	Female	64	30.5
Mechanism of Injury	Road Traffic Accident	96	45.7
	Fall from Height	72	34.3
	Sports Injury	22	10.5
	Assault	12	5.7
	Other	8	3.8
Region of Spine Involved	Cervical	74	35.2
	Thoracic	46	21.9
	Lumbar	68	32.4
	Multiple Levels	22	10.5
Time to MRI After Trauma	≤24 hours	88	41.9
	24–72 hours	74	35.2
	>72 hours	48	22.9
Neurological Status (ASIA Grade)	A	34	16.2
	B	28	13.3
	C	46	21.9
	D	52	24.8
	E	50	23.8

Table 2: MRI Findings in Patients with Spinal Trauma (n = 210)

MRI Finding	Frequency (n)	Percentage (%)
Vertebral Body Fracture	128	61.0
Spinal Cord Edema	96	45.7
Spinal Cord Contusion	74	35.2
Spinal Cord Hemorrhage	32	15.2
Disc Herniation	58	27.6
Ligamentous Injury	82	39.0
Epidural Hematoma	26	12.4

MRI Finding	Frequency (n)	Percentage (%)
Paraspinal Soft Tissue Injury	104	49.5

Table 3: Association Between MRI Cord Findings and Neurological Deficit (ASIA Grade)

MRI Cord Finding	Neurological Deficit Present (ASIA A–D) n (%)	No Neurological Deficit (ASIA E) n (%)	Total	p-value
Cord Edema	78 (81.3)	18 (18.7)	96	<0.001
Cord Contusion	66 (89.2)	8 (10.8)	74	<0.001
Cord Hemorrhage	30 (93.8)	2 (6.2)	32	<0.001
No Cord Signal Change	26 (24.5)	80 (75.5)	106	—

Table 4: Cross-Tabulation Between MRI Spinal Cord Findings and Neurological Status (ASIA Grade)

MRI Cord Finding	ASIA A–B (Severe Deficit) n (%)	ASIA C–D (Moderate/Mild Deficit) n (%)	ASIA E (No Deficit) n (%)	Total (n)	p-value
Cord Edema	38 (39.6)	40 (41.7)	18 (18.7)	96	<0.001
Cord Contusion	34 (45.9)	32 (43.3)	8 (10.8)	74	<0.001
Cord Hemorrhage	22 (68.8)	8 (25.0)	2 (6.2)	32	<0.001
No Cord Signal Abnormality	6 (5.7)	20 (18.9)	80 (75.5)	106	<0.001
Total	100	100	108	210	—

Table 5: Multivariable Logistic Regression Analysis Predicting Neurological Deficit in Spinal Trauma Patients (n = 210)

Predictor Variable	β Coefficient	Standard Error (SE)	Adjusted Odds Ratio (AOR)	95% CI for AOR	p-value
Age (>40 years)	0.62	0.24	1.86	1.17 – 2.95	0.008
Male Gender	0.41	0.29	1.51	0.86 – 2.66	0.152
Road Traffic Accident	0.58	0.26	1.79	1.07 – 3.01	0.026
Cervical Spine Injury	0.91	0.28	2.48	1.44 – 4.27	0.001
Spinal Cord Edema (MRI)	1.12	0.31	3.06	1.66 – 5.63	<0.001
Spinal Cord Contusion (MRI)	1.38	0.34	3.98	2.04 – 7.77	<0.001
Spinal Cord Hemorrhage (MRI)	2.04	0.46	7.69	3.12 – 18.96	<0.001
Ligamentous Injury (MRI)	0.74	0.27	2.10	1.24 – 3.56	0.006

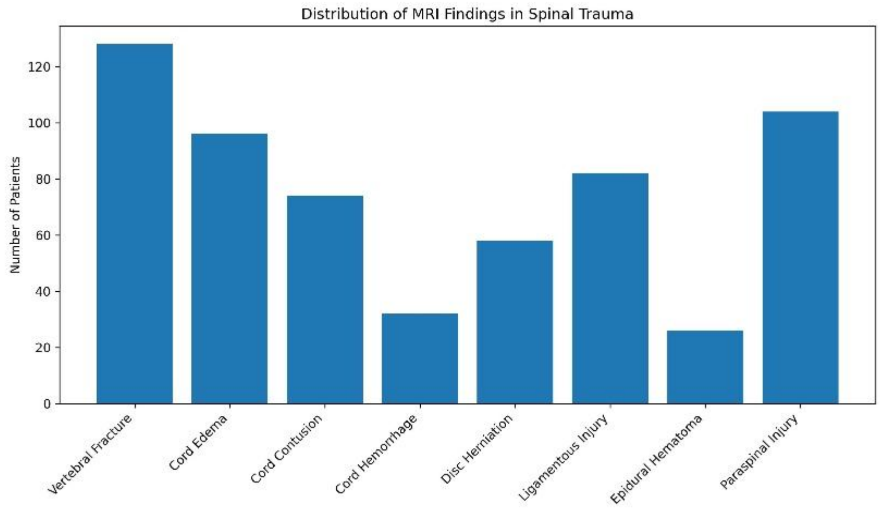


Figure 1 Distribution of MRI Findings in Spinal Trauma

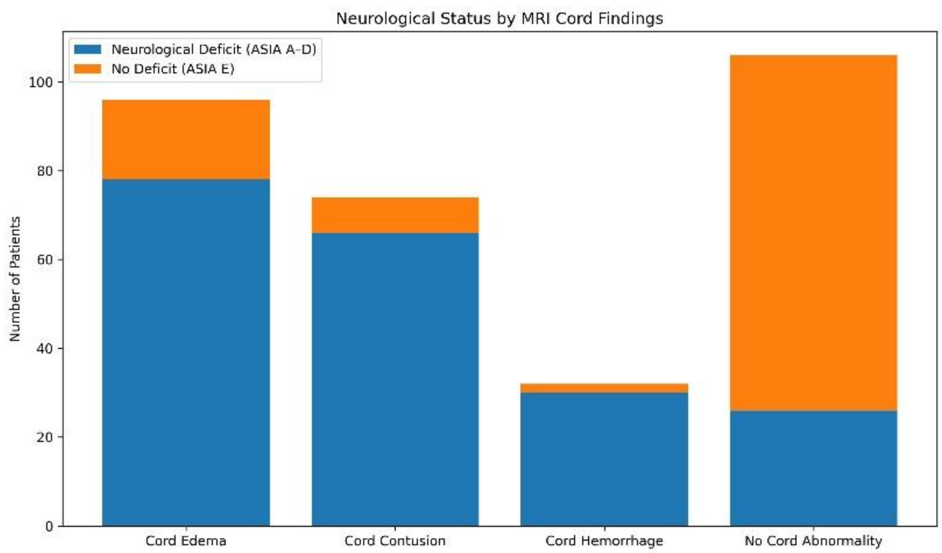


Figure 2 Neurological Status by MRI Cord Findings

DISCUSSION

The present study demonstrated the critical role of Magnetic Resonance Imaging in the comprehensive evaluation of spinal trauma, particularly in the detection of spinal cord and soft tissue injuries and in the prediction of neurological outcomes. The demographic profile, characterized by a predominance of young and middle-aged males, was consistent with existing literature that has reported higher exposure of this population to high-energy mechanisms such as road traffic accidents and falls from height (11,12). This pattern reflects a well-recognized global trend and highlights the disproportionate impact of spinal trauma on the economically productive segment of society, thereby amplifying its socioeconomic and healthcare burden. The spectrum of MRI findings observed in this study further reinforced the diagnostic superiority of MRI in spinal trauma. The high prevalence of vertebral body fractures, spinal cord edema, ligamentous injury, and paraspinal soft tissue involvement aligned closely with prior reports emphasizing MRI's ability to detect non-osseous injuries that may not be apparent on conventional imaging modalities (13,14). In particular, the detection of ligamentous injuries was clinically significant, as such findings are strongly associated with spinal instability and frequently influence decisions regarding surgical versus conservative management (15). These observations support the growing consensus that MRI should be considered an essential component of spinal trauma assessment when neurological deficit or instability is suspected. A key finding of this study was the strong association between MRI-detected spinal cord abnormalities and neurological impairment as assessed by the ASIA grading system. Patients with cord edema, contusion, and hemorrhage exhibited markedly higher rates of neurological deficit compared with those without cord signal changes, a relationship that has been consistently reported in earlier studies (16,17). Among these abnormalities, cord hemorrhage emerged as the most severe form of injury and was associated with the poorest neurological outcomes, whereas cord contusion and edema appeared to represent a spectrum of injury with variable and potentially reversible outcomes when managed promptly (18). These findings underscored the prognostic value of MRI in differentiating injury severity and guiding early clinical decision-making.

The cross-tabulation of MRI cord findings with neurological grades further strengthened the observed correlations between imaging features and functional status. Severe neurological deficits were predominantly associated with cord hemorrhage and contusion, while patients without MRI-visible cord abnormalities largely maintained normal neurological function. Similar associations have been described in previous work, suggesting that MRI signal characteristics of the spinal cord closely reflect the underlying pathophysiological severity of injury and subsequent functional impairment (19). Such correlations are of particular clinical relevance, as they enable risk stratification and facilitate individualized patient counseling regarding expected outcomes. Multivariable analysis in this study identified spinal cord hemorrhage, contusion, and edema as independent predictors of neurological deficit, even after adjustment for demographic and injury-related factors. Cervical spine involvement and ligamentous injury were also significant predictors, which was in line with earlier evidence indicating that cervical injuries carry a higher risk of severe neurological compromise due to the anatomical vulnerability and limited space available for cord accommodation in this region (20). The lack of a significant association between gender and neurological outcome suggested that injury characteristics and MRI findings were more influential determinants of neurological impairment than demographic variables alone.

Several strengths of this study merit consideration. The relatively large sample size, standardized MRI protocol, blinded image interpretation by experienced radiologists, and use of a validated neurological grading system enhanced the robustness and clinical relevance of the findings. Additionally, the incorporation of multivariable regression analysis allowed identification of independent predictors of neurological deficit, strengthening the prognostic inferences drawn from MRI findings. However, certain limitations should also be acknowledged. The cross-sectional design limited the ability to assess longitudinal neurological recovery and functional outcomes over time. The absence of follow-up MRI or serial ASIA assessments precluded evaluation of dynamic changes in cord pathology and neurological improvement. Furthermore, the study was conducted at a single tertiary care center, which may limit the generalizability of the findings to other healthcare settings. Future research would benefit from prospective, multicenter studies incorporating long-term follow-up to evaluate neurological recovery and functional outcomes in relation to initial MRI findings. The inclusion of quantitative MRI parameters and advanced techniques such as diffusion tensor imaging may further refine prognostic accuracy. Despite these limitations, the findings of this study contributed to the growing body of evidence supporting MRI as both a diagnostic and prognostic modality in spinal trauma. By enabling detailed characterization of spinal cord and soft tissue injuries, MRI played a crucial role in guiding clinical management, informing surgical planning, and predicting neurological outcomes, in accordance with contemporary spinal trauma management recommendations (21,22).

CONCLUSION

Magnetic Resonance Imaging emerged as an indispensable tool in the comprehensive assessment of spinal trauma by enabling accurate visualization of spinal cord, ligamentous, and soft tissue injuries that are frequently missed on conventional imaging. The study demonstrated that MRI-detected spinal cord abnormalities closely reflect the severity of neurological impairment and provide meaningful prognostic insight, thereby directly supporting informed clinical decision-making. Integrating MRI into the routine evaluation of spinal trauma allows clinicians to better stratify injury severity, guide timely therapeutic interventions, and optimize patient management, ultimately contributing to improved neurological outcomes and more effective trauma care.

AUTHOR CONTRIBUTIONS

Author	Contribution
Hadeeba Kaleem	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Bushra Kaleem	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing Has given Final Approval of the version to be published
Sadaqat Ullah Khan	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Nida Rasheed	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Taimoor Riaz Ullah	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Haider Umar*	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published

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