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UNVEILING THE INVISIBLE: ADVANCED MRI TECHNIQUES FOR PRECISE EVALUATION OF SPINE AND SPINAL CORD INJURIES

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Abstract

Spinal trauma and associated spinal cord injuries (SCI) necessitate precise evaluation for effective diagnosis, treatment, and prognosis. Magnetic Resonance Imaging (MRI) has emerged as a powerful tool in this context, offering superior soft tissue visualization compared to other imaging modalities. This study aimed to investigate the utility of advanced MRI techniques in assessing spinal trauma and SCI, focusing on their ability to identify specific injury characteristics and predict neurological outcomes. A cross-sectional observational study was conducted involving 36 patients with suspected spinal injuries who underwent MRI scans. Various MRI sequences, including T1-weighted, T2-weighted, and STIR imaging, were employed to evaluate spinal abnormalities and associated neurological impacts. MRI findings revealed a spectrum of spinal pathologies, with disc bulging being the most prevalent (50%), followed by disc protrusion (16%) and lumbar spondylosis with multilevel disc bulges (14%). Traumatic injuries, including compression fractures and vertebral collapse, were also identified. Notably, cord edema visualised on MRI was associated with promising neurological recovery, while cord contusion or hemorrhage indicated poorer outcomes. Advanced MRI techniques play a crucial role in the comprehensive assessment of spinal trauma and SCI. The ability of MRI to visualise soft tissue structures, identify specific injury patterns, and predict neurological outcomes underscores its significance in guiding clinical decision-making and optimising patient management.

Keywords: Spinal Trauma, Magnetic Resonance Imaging, Spinal Cord Injury, Neurological Recovery, Imaging Techniques, Diagnosis, Prognosis.

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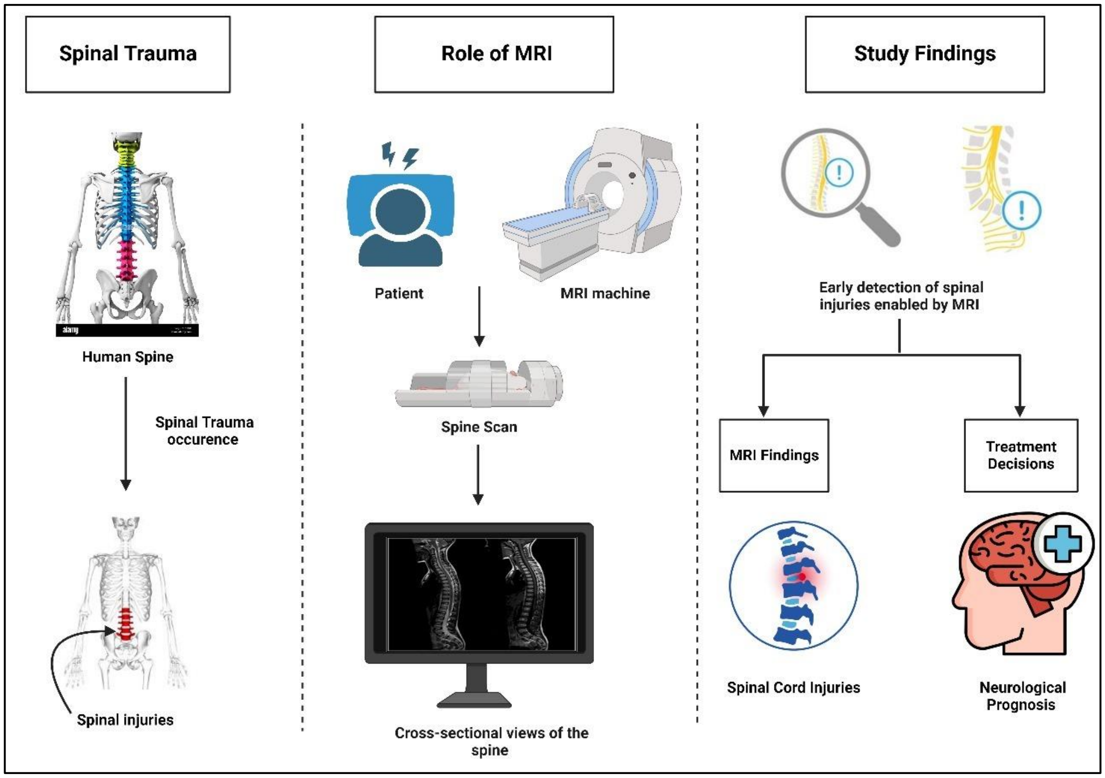
Graphical Abstract



INTRODUCTION

The spinal cord, a bony structure with a flexible structure of vertebrae, is responsible for the structural support and protection of the spinal cord. (Morin, 2018). It also helps in bearing load on the body weight and muscle attachment, which is an important tool in the movement of human beings. The spinal cord is a long, thin, cylinder structure located within the vertebral column and transmits nerve impulses between the brain and body. (de Magalhães, 2022). Several imaging techniques have evolved in diagnosing and managing spinal injuries, especially MRI, which has displayed enormous capacity in diagnosing injury. (Freund et al., 2019)The noninvasive nature of MRI makes it particularly useful in interpreting spinal cord and soft tissues to assess and identify fractures, ligamentous injuries, and spinal cord injuries. (Ishaque et al., 2024). Spinal trauma can be defined as abrupt and sometimes violent damage to the vertebral column, which might be limited to only the bony structures or may involve the spinal cord as well. (Dunn & Kruger, 2017). The vertebral fractures can affect processes, articular, transverse, vertebral body, lamina, and pedicle. (Mahadevan, 2018). Other lesser forms of dislocation, such as facet dislocations and subluxations, involve ligamentous disruption with or without facet displacement. Potential injuries that this manoeuvre can have been neurological injuries to the spinal cord (Shukla & Singh, 2022).

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Spinal cord injury (SCI) involves the partial or complete damage of the nerves that make up the spinal cord responsible for conveying messages from the brain to the rest of the body. (Guérin, 2020). Based on the extent of damage, SCIs are complete and incomplete; in the broad type, there is no motor or sensory function below the zone of the injury. (Zhao et al., 2021). Spinal cord injury, therefore incomplete, presents with some form of disability depending on the level of cord involvement. (Gaspar et al., 2019). The effects of SCI can be long-reaching, impacting bowel and bladder movements, breathing, heart rate, metabolism, muscle contractions, reflexes, and sensation. (Ashwell, 2013). There are two kinds of causes of SCI: traumatic causes, including accidents and falls, and non-traumatic causes, including diseases and infections, such as polio and meningitis. (Ko, 2022). MRI is crucial in the determination of spinal cord injuries and the categorization of bleeds, disc herniation and other soft tissues that are not well identified by other imaging studies (Lavi et al., 2018)However, MRI should not be used to assess SCI since it may delay surgical intervention and carrying the patients may pose some risks; the modality is more sensitive than CT in identifying conditions. (Izzo et al., 2019). Such disc herniation may be important in deciding on treatment and prevention of further neurological deterioration. (Court et al., 2018). The choice of proper imaging studies, assessment, and timely intervention is critical in patients with spinal trauma and SCI to least affect the neurological damage and improve the global results of the patient. (Fehlings et al., 2022).

2. MATERIALS AND METHODS

This cross-sectional, observational study was conducted at the National Hospital Faisalabad and Allied Hospital Faisalabad between March and June 2022. Data were collected from 36 participants who underwent MRI scans using a pre-designed proforma approved by the Head of Department and Medical Superintendent. Participants were selected using a simple (non-probability) sampling approach.

2.1 Sample Collection

The study recruited an equal number of patients with suspected neurological defects and acute spinal injuries. Exclusion criteria included non-operative spinal cord injuries, non-compliant or acutely/chronically ill patients, and those dependent on pacemakers or cochlear implants or with claustrophobia. Additionally, patients with a history of neurological disorders were also potentially excluded. Data collection involved referring eligible participants to the National Hospital Faisalabad radiology department for MRI scans conducted and interpreted by radiologists. Further data were collected for patients with positive MRI findings. The study utilized both Siemens 0.2 Tesla and General Electric 1.5 Tesla MRI scanners.

2.2 MRI Techniques in Spinal Trauma

Spine MRI was conducted using pulse sequences on the Hitachi Aires 0.25T and General Electric 1.5T scanners. Axial and sagittal images were captured while patients lay in the supine position using the abdominal band compression technique. Coronal STIR, axial

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T2 and T1-weighted fast spin echo, STIR, and fat saturation images were obtained (Figure 1). Various imaging sequences, including slice thickness, field of view (FOV), echo train durations, matrix size, flip angle, and TR/TE values, were changed according to protocol. Fat suppression was used in STIR sequences to enhance the depiction of oedema. Axial images were captured using fast spin echo (FSE) or gradient-echo (GRE) pulse sequences. In addition, acute intramedullary bleeding was detected using FLAIR and at least one GRE sequence. Extracranial vasculature subgroup analysis utilized two-dimensional and three-dimensional time-of-flight (TOF) magnetic resonance angiography (MRA) to study post-traumatic carotid and vertebral artery dissection or blockage. No contrast material was administered throughout the imaging procedure (Table 1).

2.3 Ethical Issues:

Ethical concerns were addressed in consultation with the relevant authorities. Informed consent was obtained from all participants, and any potential ethical issues were discussed with the patients and resolved through the consent process.

3. RESULTS

This study investigated the demographics and clinical presentations of individuals who presented at the hospital with suspected spinal injuries. A total of 36 patients had spine MRIs due to symptoms such as back discomfort, limb stiffness, numbness, or pain radiating down the spinal column. The specific MRI sequences varied depending on the clinical findings and instructions from the referring physician (Table 1).

3.1 General Findings

The MRI scans suggested a variety of spinal abnormalities. Disc bulging was the most prominent finding in 50% of patients, followed by lumbar spondylosis with multilevel disc bulges, which was observed in 14% of cases. Disc protrusion was observed in 16% of the patients, but acute compression of the lumbar spine was documented in 14%. Diffuse disc bulging and traumatic collapse and fusion of vertebrae were identified in 3% of the cases, respectively (Table 2).

3.2 Lumbar Spine Findings

The most typically detected abnormalities in the lumbar spine were extensive disc bulges, disc protrusions, and lumbar spondylosis with multilayer disc bulges (Figure 1). These disorders cause significant indentation on the spinal canal with neural foramen stenosis and nerve root damage, which brings about considerable neurological manifestations. The cervical spine was also affected in terms of disc bulges and protrusions, resulting in neural foramen stenosis and nerve root compression, which caused pain and neurological dysfunction in the upper trunk and limbs.

3.3 Cervical Spine Findings

The cervical spine also exhibited significant pathologies, with disc bulge and protrusion common findings. These deformities led to neural foramen stenosis, with the latter often

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associated with nerve root compression. Consequently, the patients suffered pain and neurological deficits involving the upper limbs and the rest of the body (Figure 2).

3.4 Traumatic Injuries

Different findings were observed in the traumatized spinal injury patients. Compression fractures were commonly observed in the vertebral bodies, which led to varying degrees of spinal canal stenosis and cord compression. Some patients exhibited severe abnormalities, including vertebral body collapse and fusion. Additionally, several cases showed evidence of spinal contusion, further complicating the patients' neurological outcomes and contributing to poor predictions (Figure 3).

Table 1: MRI Findings and Associated Stenosis in Neural Foramina in Patients with Spinal Injuries

Patient. No	Gender	Age	Scan type	Abnormality	Stenosis
1	Female	39years	MRI L/S	Bulges in the non-compressive discs L4/5 and L5/S1.	Bilateral neural exiting nerve roots have mild stenosis that is intact.
2	Male	30years	Lumbosacral Spine MRI	Non-compressive disc bulges in L4/5 and L5/S1.	Both sides have mild bilateral neurological stenosis that is preserved.
3	Female	50years	Lumbosacral Spine MRI	Bulge in the diffuse disc at L4/5 next to both exiting nerve roots.	More to the right, there is a significant stenosis in both neural foramina surrounding leaving nerve roots.
4	Female	58years	Lumbosacral Spine MRI	spondylosis of the lumbar spine with several disc bulges	Bilateral neural foramen with moderate stenosis encroaching on the left and bordering the right, leaving nerve root
5	Female	45years	Lumbosacral Spine MRI	Disc protrusion near bilaterally exiting nerve roots at L4/5	Bilateral neural foramina that border the bilateral exiting nerve roots has moderate stenosis.
6	Female	37years	Lumbosacral Spine MRI	Disc protrusion at L4/5 bordering bilateral nerve roots that exit.	Bilateral neural foramina that border the bilateral exiting nerve roots has moderate stenosis.
7	Male	45years	Lumbosacral Spine MRI	Multiple disc bulges in lumbar spondylosis resulting in varying degrees of neural impairment	More on the left abutting bilateral exiting nerve root, both neural foramen have mild stenosis.
8	Female	22years	Lumbosacral Spine MRI	Central disc protrusion at L4/5 level. Bulge in the diffuse disc at L5/S1, next to both outgoing nerve roots	Slight stenosis of both neural foramen with the abutment of bilateral exiting nerve root.

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9	Male	42Years	Lumbosacral Spine MRI	L4-5-disc is bulging, moderate uncovering of bilateral nerve root, which is about to exit the spinal canal.	Increase the size of the non-compressive disc at the L5–S1 level. There was moderate stenosis of bilateral neural foramen touching bilateral exiting nerve roots.
10	Male	41year	Lumbosacral Spine MRI	Non-compressive disc protrusion at L5/S1, which encircles the right nerve root's outflow on the left, and disc bulging at L4-5	Moderate bilateral neural foramen stenosis. Nerve roots that exit are retained.
11	Male	42years	Lumbosacral Spine MRI	Wide disc bulge at L4/5 next to the nerve root that leaves the body. Diffuse disc bulging at L5/S1, next to bilateral nerve roots that escape.	Little neural foramen constriction on each nerve root's side leaves the body.
12	Male	32Years	Lumbosacral Spine MRI	Bulging discs abutting bilaterally exiting nerve roots in L4/5 and L5/S1.	Bilateral neural foramina that border the bilateral nerve roots that exit the body have moderate stenosis.
13	Fale	50years	Lumbosacral Spine MRI	Lumbosacral spinal stenosis with disc herniation at L5/S1 level intruding on the right and close to the left nerve root as it exits. The non-compressing discs have bulges at L2/3, L3/4 and L5/S1.	Moderate bilateral neural foramen stenosis. Bilateral nerve roots that exit the body are retained.
14	Female	36years	Lumbosacral Spine MRI	At L2/3, there was a disc bulge, which was as near as touching the exiting nerve roots on both sides. L4/5 and L5/S1 are herniated discs which cannot be compressed.	Mild neural foramina stenosis. Bilateral nerve roots that exit the body are retained.
15	Male	82years	Lumbosacral Spine MRI	The condition described is lumbar spondylosis with multilayer disc bulges generating varying neurological impairment.	Bilateral neural foramina that border the bilateral nerve roots that exit have little stenosis.
16	Male	44years	Lumbosacral Spine MRI	Disc bulges next to the left exiting nerve root at levels C4/5 and C5/6.	At these levels, there is mild stenosis of the bilateral neural foramen next to the left exiting nerve roots. Nerve roots that exit to the right are retained.

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17	Male	68Years	MRI Cervical Spine	Bulges at the C3/4 and C6/7 levels of the non-compressing discs.	The C4/5 and C5/6 Disc bulges push upon the nerve roots exiting on both sides. There are bulges at the C3/4 and C6/7 levels of the non-compressing discs. The C4/5 and C5/6-disc bulges are pushing upon the nerve roots exiting on both sides.
18	Male	82Years	L/S SPINE	Multiple disc bulges in lumbar spondylosis resulting in varied neurological impairment as documented.	moderate neural foramen stenosis and modest spinal canal constriction
19	Female	44Years	MRI Cervical Spine	Disc bulges next to the left exiting nerve root at levels C4/5 and C5/6.	bilateral neural foramen next to left, leaving nerve roots with mild stenosis
20	Female	55Years	MRI Cervical Spine	Nerve-ending disc bugle non-compressive at C4/5 levels.	mild bilateral neural foramen stenosis
21	Female	30Years	MRI L/S SPINE	Disc bulging around the left exiting nerve root at L5/S1.	Bilateral neural foramina that border the left exiting nerve root has mild stenosis.
22	Female	47Years	MRI L/S SPINE	L4-5-disc protruding on both sides surrounding the nerve roots that leave the body. The discs at L3/4 and L5/S1 levels are bulging and not compressing.	Bilateral neural foramina that border the bilateral nerve roots that exit have little stenosis.
23	Male	52Years	MRI L/S SPINE	Multilevel disc bulges generate varied neurological impairments, as reported.	Bilateral neural foramen mild stenosis. Bilateral nerve roots that exit the body are retained.
24	Male	41Years	MRI C/ SPINE	A protrusion of the disc at C6-7 borders both exiting nerve roots.	Bilateral neural foramina that border the bilateral nerve roots that exit the body have moderate stenosis.
25	Male	45Years	MRI L/S SPINE	The bumpy L5/S1 disc is adjacent to the nerve root exiting on the left.	L5/S1 disc protruding adjacent to the left bilateral neural foramina that borders the left exiting nerve roots has mild stenosis.
26	Female	30Yeras	MRI L/S SPINE	Near departing nerve roots at the L4/5 and L5/S1 levels are diffuse disc bulges.	Bilateral neural foramina that border the bilateral nerve roots that exit have little stenosis.
27	Male	22Years	MRI L/S SPINE	The lumbar curvature has straightened	Mild neural foramen constriction on both sides.

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				out. Bulges at the L4/5 and L5/S1 levels in the non-compressing discs.	Nerve roots that exit are retained.
28	Male	46Years	MRI L/S SPINE	At L4/5, a considerable narrowing of the spinal canal and noticeable stenosis of the bilateral neural foramen, more so on the left side abutting the right than the left, were created by disc desiccation and disc protrusion.	Bilateral neural foramen bilateral outgoing nerve roots with moderate stenosis.
29	Male	45Years	MRI L/S SPINE	Wide-based disc protrusion at L5/S1 bordering both exiting nerve roots on either side.	Significant bilateral neural foramen stenosis, with a greater degree of stenosis on the left, next to both bilaterally exiting nerve roots.
30	Male	42Years	MRI L/S SPINE	Disc bulging at L4/5, bordering the left, leaving nerve root and infringing on its right.	bilateral brain foramen significantly stenotic, more to the right

Note: MRI = Magnetic Resonance Imaging; TR = Time to Relaxation; TE = Time to Echo; STIR = Short Tau Inversion Recovery; FOV = Field of View; FSE = Fast Spin Echo; GRE = Gradient Echo; FLAIR = Fluid-Attenuated Inversion Recovery; MRA = Magnetic Resonance Angiography

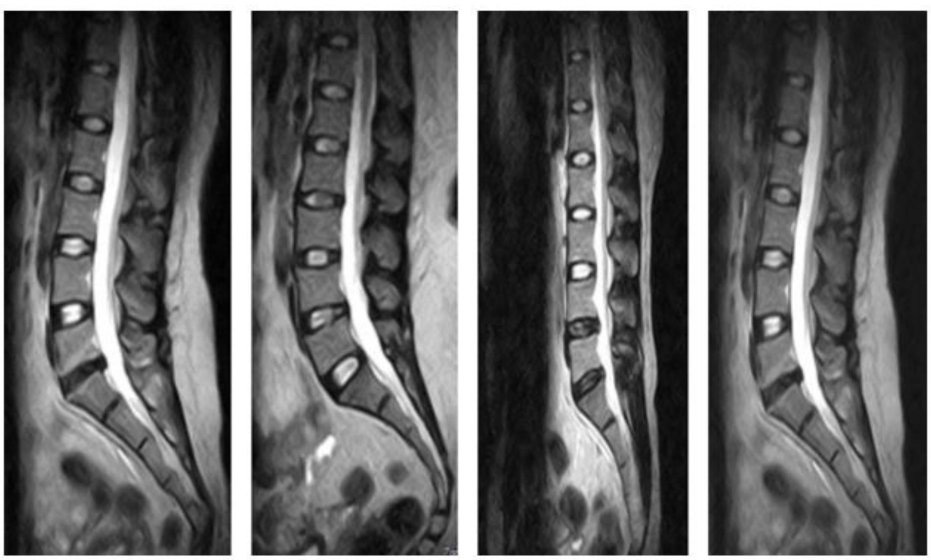

Figure 1: T2 sagittal images were obtained from several scans showing disc bulging and spinal cord injuries.

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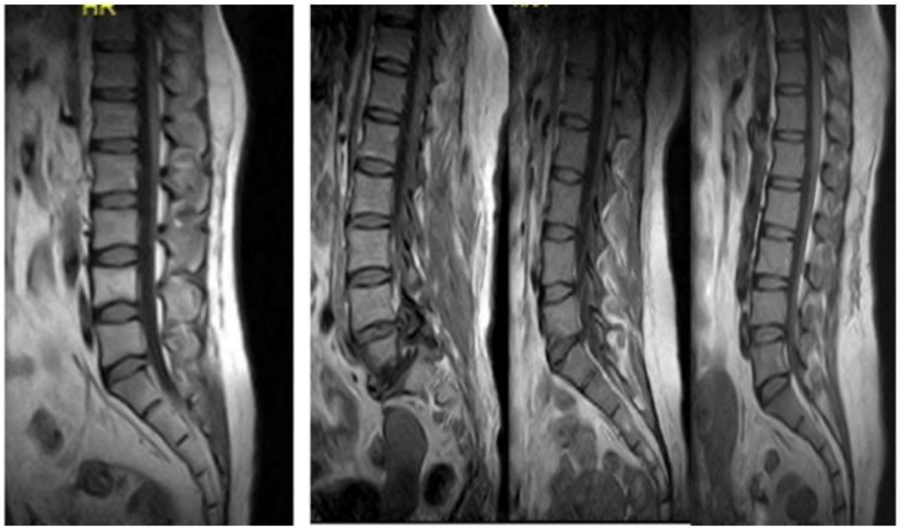

Figure 2: T1 sagittal images showing cord oedema and haemorrhage in different patients

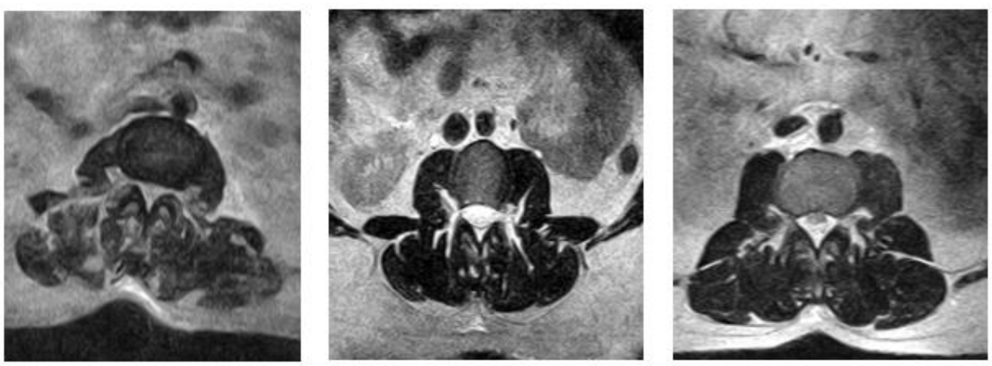

Figure 3: (A) Weighted axial T2 images showing spinal trauma-related abnormalities

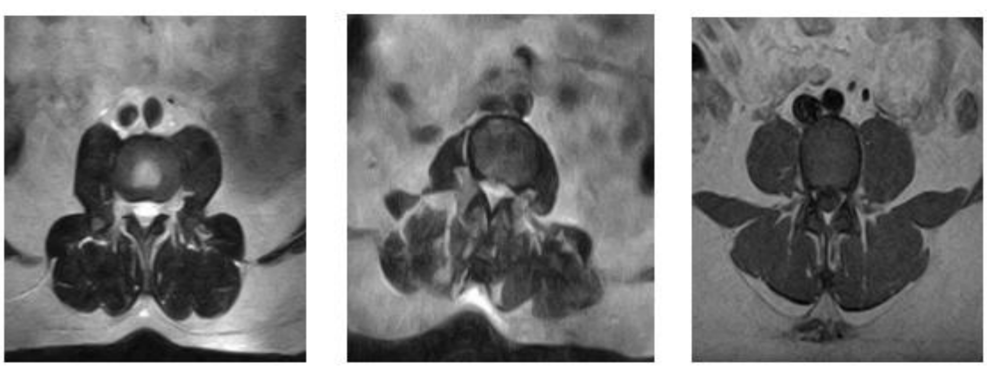

Figure 3: (B) Weighted axial T1 images showing spinal trauma-related abnormalities

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Table 2: MRI findings in patients with traumatic injuries

Patients. No	Sex	Age	Scan Type	Site of injury trauma	Other Abnormalities
1.	Male	**5**6years	Dorsal Spine MRI	Post-infectious/post-traumatic D6 and D7 collapse and fusion	Localised focal midline cord contusion at D6 level
2.	Female	73Years	Lumbar Spine MRI	Trauma L4 wedge compression due to destroyed disc L3/L4 Circumferential	left apophyseal joint disc protrusion paracentral protrusion nerve root entrapment at L4/5 level
3.	Male	65Years	Lumbar Spine MRI	It also observed that after the trauma, there was a partial compression of D12.	There is bilateral massive disc protrusion and multilevel disc degeneration at L2/L3, L3/L4, L4/L5, and recess stenosis.
4.	Female	65Years	Lumbar Spine MRI	Herein, intrahepatic D11–D12 is partially compressed after traumatic injuries.	Interspace degenerative changes were seen on many levels, and lateral left Neural foramina stenosis at L4-L5 with paracentral and lateral disc protrusion with lateral recess.
5.	Male	55Years	Lumbar Spine MRI	L1 vertebral partial compression in case of trauma.	Disc degeneration, in part but not to a great extent, changes the disk
6.	Female	25Years	Dorsal MRI	Severe compression fracture T 12 vertebral body.	Careful advancement of posteriorly disrupted segments that produced localised thecal sac stenosis and spinal cord contusions related to paravertebral fluid collections.

MRI = Magnetic Resonance Imaging; CT = Computed Tomography; SCI = Spinal Cord Injury

4. DISCUSSION

This paper sought to determine the role of MRI in diagnosing patients with suspicious spinal injuries or spinal cord abnormalities who had reported to the hospital complaining of symptoms like back pain, stiff limbs, and absent touch sensation. Fifty per cent of patients had disc bulging, 16 per cent had disc protrusion, and 14 per cent had lumbar spondylosis with multilevel disc bulges. The results of the present work concordance with evidence literature regarding the increased value of MRI in diagnosing spinal pathologies that may trigger neural compression and substantial neurological impairment (Table 1) . This study's detected high frequency of disc bulging and lumbar spondylosis is worthy of attention as these pathological states may exert considerable influence on the neural

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foramina and produce nerve root compression and corresponding symptoms, including pain, paresthesia, and motor dysfunction. The T2 weight sagittal MRI scan images proved useful in core soft tissue lesion detection, disc protrusion and spinal cord trauma, as depicted in Figure 1, hence demonstrating the diagnostic usefulness of the imaging modalities in identifying early signs of spinal degenerative change. In addition, other accidental injuries such as fractures (14%) and vertebral collapse (3%) were witnessed by the group of patients who comprised the study. Such injuries are very dangerous because, when not properly managed, the injured patient is likely to develop severe spinal canal stenosis and cord compression, outcomes which may, however, worsen the prognosis of a patient. The T1 weighted sagittal image helped to define the cord oedema and haemorrhage, as shown in Figure 2. However, patients with cord oedema had better neurological outcomes compared to patients with cord contusions or haemorrhages, which remain poor. Thus, the results obtained in this investigation emphasise the significance of MRI as a tool for estimating patient rehabilitation outcomes and choosing appropriate therapeutic approaches.

This study also pointed out the prevalence of T2-weighted imaging as the singular modality for spinal imaging; this technique insufficiently covers all the pathologies. MRI and modifications in the TR and TE sequences could be further refined, as other journals recommend in this line of literature. Future research should include these sequences to increase the sensitivity in detecting slight but potentially significant spinal morphological changes that are not reachable even with conventional imaging protocols. These findings also suggest the part played by neural foramen stenosis in different patients' profiles and the necessity of early diagnosis to avoid the progression of neurological deficits. For instance, several patients enrolled in the study showed various levels of neural foramina stenosis in MRI scans; if untreated, the condition can cause persistent pain and long-term disability (Table 2). These results support the utility of MRI in diagnostic and prognostic phases of spinal injury treatment. Therefore, MRI continues to play a central role in evaluating spinal trauma and other spinal cord injury cases. Consequently, its potential to generate images of soft tissues and offer crucial information about the neural consequences of spinal lesions makes it practically mandatory in clinical management. Currently, with almost continuous developments in MRI technology, it is quite likely that the accuracy of the diagnostic results obtained will improve over time, providing even better outcomes for patients and their quality of life.

5. CONCLUSION

The present research highlights how MRI is essential in assessing, diagnosing, and treating spinal or spinal cord injuries. MRI is a valuable tool for diagnosing common spinal conditions like disc bulging, protrusions, and spondylosis due to its ability to fully examine soft tissues, spinal discs, and neural structures. Additionally, MRI enables the identification of specific abnormalities, such as cord oedema and bleeding, that may influence the neurological prognosis and thus allows early patient intervention and tailored management. While it reveals the importance of T2 and T1 variation in diagnosing and treating spinal injuries, it also implies that extra sequences of TR and TE would be needed to provide a more comprehensive assessment of spinal disorders. This fact only underlines the versatility of MRI as the technology continues to improve, making the method even more useful in preventing and treating spinal injuries. There is rare evidence comparing new imaging techniques with traditional methods for refining patient diagnostic procedures. MRI remains relevant in spinal injury treatment to facilitate decision-making and assist patient recovery and quality of life.

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Conflict of Interest

The authors declare that they have no conflicts of interest.

Author Contributions

All authors contributed equally to this study's conception, design, data collection, analysis, and interpretation. All authors participated in drafting and revising the manuscript and approved the final version for submission.

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