ORIGINAL ARTICLE

The Additive Value of MRI in Evaluating Thoracic and Lumbar Spine Trauma

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Abstract

Background: ***One of the most distressing injuries in humans is traumatic spinal cord injury (TSCI). It is correlated with a high rate of death, disability, and the need for long-term, expensive rehabilitation therapy.***

Aim: ***To assess the additive value of MRI in the assessment of thoracolumbar spine injury in the setting of spinal trauma.***

Patients and methods: ***The prospective research was conducted on 30 patients with thoracolumbar spine trauma in magnetic resonance imaging at Damanhur Medical National Institute throughout the period from April 2023 to April 2024.***

Results: ***The TLICS averaged 7.4 ± 2.1, indicating severe injuries requiring surgery in 90% of cases. Morphology and PLC integrity scores reflected significant damage (2.9 ± 1.1 and 1.9 ± 1.3). Neurological status at admission averaged 2.6 ± 0.5, with 50% improving at discharge, including 13.3% achieving ASIA E. Complete cord transection and hemorrhage showed no recovery (ASIA A), while cord edema had the highest recovery rate (58%), with 17% achieving ASIA E. Spinal stenosis and epidural hematoma showed 67% recovery. A strong positive correlation was found between injury type, discharge AIS (r-value = 0.668, p-value < 0.001), and recovery rates (r-value = 0.464, p-value = 0.010), emphasizing injury severity's role in outcomes.***

Conclusion: ***MRI is crucial for evaluating traumatic spinal cord injuries (TSCI), providing superior soft-tissue contrast and accurate diagnosis, despite limitations in correlating signal changes with functional outcomes.***

Keywords: TSCI; Magnetic Resonance Imaging; Spinal Trauma

1. Introduction

One of the most distressing injuries in humans is traumatic spinal cord injury (TSCI). It is correlated with a high rate of death, disability, and the need for long-term, expensive rehabilitation therapy. The life rate and efficiency of these cases can be significantly impacted by the level, severity, and extent of the injury, which determines the degree of eventual neurological damage and deficit.[1,2]

Magnetic resonance imaging (MRI) is more effective in identifying neural and extraneural injuries, including disc herniations, epidural hematomas, spinal cord edema, contusion, bleeding, and ischemia. This is due to its multiplanar capabilities, high-contrast resolution, and diverse pulse sequences, which render it an optimal diagnostic tool for spinal trauma .[3,4]

Conventional magnetic resonance imaging provides limited insights into functional cord complications post-trauma, which is crucial for outcome prognostication. Advanced magnetic resonance imaging methods, involving Diffusion Tensor Imaging (DTI) and functional magnetic resonance imaging (fMRI), show promise in refining the diagnosis and management of spinal cord injuries (SCIs). While DTI has the most robust evidence, further standardization and validation are needed before widespread clinical adoption. Despite challenges like cost, availability, and specificity, both conventional and advanced MRI techniques are increasingly utilized in spinal injury assessments .[5]

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The aim of this research was to evaluate the additive value of magnetic resonance imaging in thoracolumbar spine injury evaluation in the setting of spinal trauma.

2. Patients and methods

This prospective research was conducted on 30 patients with thoracolumbar spine trauma with equivocal conventional and/or CT scan in magnetic resonance imaging unit at Damanhur Medical National Institute throughout the period from April 2023 to April 2024.

Hemodynamically unstable patients, patients with cardiac pacemakers, cochlear implants, or surgical aneurysmal clips incompatible with MRI, Claustrophobic cases, and uncooperative cases with behavioral and mental conditions were excluded from the study. The involved patients underwent full history taking, medical consent, and general and local examination. The local research ethical committee at the Faculty of Medicine for Girls, Al-Azhar University, was presented with the research protocol for approval. The investigation ensured the confidentiality of data and the privacy of subjects.

Cases involved in the research will be subjected to the following: History taking, medical consent, medical examination (general-local), Xray - CT scan and thoracolumbar Spine MRI.

Methods

All cases would exposed to full history taking, general investigation, local examination, conventional and CT scanning, thoracolumbar Spine MRI.A standardized protocol and would be conducted using SIGNA (GA) Explorer 1.5 Tesla MRI scanner system with dedicated spine software, a phased -array surface receiver coil.

Patient Preparation: It was always recommended that any jewellery and metallic substances, like hair clips, be removed before entering the MR machine to avoid hair burns. It was recommended that the patient wear a gown. Reassurance of the patient and a clear explanation were provided before the examination was done. Patients were informed that they must remain motionless during the exam. The case could be positioned within the magnet of the MRI unit. The exam could be administered by the technologist while they are operating a computer located outside the room. An intercom could help the case by communicating with the technologist. Once the examination was concluded, the technologist may request that the case remain in the waiting area while the radiologist reviews the images to determine if additional ones are required.

Technique of examination

The GA Explorer 1.5 Tesla MRI system, which is equipped with dedicated spine software, a phased-array surface receiver coil, and an electrocardiogram, will be utilized to conduct a standardized protocol. The standard MRI protocol for spinal injury comprises sagittal T1-weighted (T1W) and T2-weighted (T2W) spin echo sequences, T2* -weighted (T2*W) gradient-recalled echo (GRE) sequences, sagittal short tau inversion recovery (STIR) sequences, and axial T2W and T2*W GRE sequences. The primary purpose of T1W images was to illustrate osseous fractures and anatomy. STIR images were highly sensitive in detecting edema and were especially useful in the diagnosis of soft tissue and ligamentous injuries, especially those affecting the interspinous or supraspinous ligaments. Fat-suppressed T2W images might additionally be utilized to identify edema. T2W images were highly effective in identifying cord edema, while T2*W GRE images were utilized to identify hemorrhage in and around the cord.

Ethical Considerations

The local research ethical committee at the Faculty of Medicine for females, Al-Azhar University, was presented with the research protocol for approval. Before enrollment in the investigation, each participant or their legal guardians provided informed consent. The investigation ensured the confidentiality of data and the privacy of subjects.

Statistical analysis

The statistical package for social sciences, version 23.0 (SPSS Inc., Chicago, Illinois, USA), was utilized for analyzing the recorded data. The quantitative data are expressed as mean±standard deviation and ranges. Additionally, qualitative variables were expressed as percentages and numbers. One-way ANOVA with Tukey's test for multiple comparisons, independent t-tests for two means, Chi-square/Fisher's exact tests for qualitative data, and Pearson's correlation for correlations were all involved in the tests. A p-value of less than 0.05 and a 95% confidence interval were regarded as significant.

3. Results

The mean age of enrolled patients was 34.8 ± 10 years, ranging between 20 and 50 years. As shown in Figure 47, 24 (80%) patients were males, while 6 (20%) were females, leading to a man-to-woman ratio of 4:1. Regarding the cause of spinal injuries, 19 (63%) patients reported injuries due to falling from heights, 8 (27%) patients had road traffic accidents, and 3 (10%) patients sustained injuries from heavy objects (as in Table 1).

Table 1. Baseline characteristic (Number = 30)

VARIABLES	NO.	%
AGE, YEARS	34.8 ± 10 (Range, 20- 50)	
GENDER		
MALE	24	80
FEMALE	6	20
MECHANISM OF INJURY		
FALLING FROM HEIGHT	19	63.3
ROAD TRAFFIC ACCIDENT	8	26.7
HEAVY OBJECTS	3	10

The dorsal level was the most frequent injury site (63.3%), after that the level of lumbar (36.7%). 70% of patients had burst fractures, while 30% had compression fractures. At admission, ASIA A (complete injury) was the most common (36.7%), followed by ASIA B (26.7%), ASIA C (20%), and ASIA D (16.7%) (Table 2).

Table 2. Spinal Injury Characteristics (N = 30)

VARIABLES	NO.	%
LEVEL OF INJURY		
DORSAL	19	63.3
LUMBAR	11	36.7
PATTERN OF INJURY		
COMPRESSION	10	30
BURST	20	70
ASIA IMPAIRMENTS SCALE (ADMISSION)		
A	11	36.7
B	8	26.7
C	6	20
D	5	16.7
E	0	0

Complete cord transection was discovered in three cases (10%), cord hemorrhage in two cases (6.7%), cord contusion in 5 patients (16.7%), cord compression in 5 patients (16.7%), and cord edema in 12 patients (40%). Additionally, cord compression without abnormal signal, spinal canal stenosis, and epidural hematoma were each found in 3 patients (10%). Regarding the posterior ligamentous complex (PLC), 15 patients (50%) showed apparent injury, 6 patients (20%) had suspected injury, and 9 patients (30%) had an intact PLC (Table 3).

Table 3. MRI Findings (N = 30)

VARIABLES	NO.	%
CORD INJURY		
CORD TRANSECTION	3	10
CORD HAEMORRHAGE	2	6.7
CORD CONTUSION	5	16.7
CORD OEDEMA	12	40
CORD COMPRESSION	5	16.7
EPIDURAL HEMATOMA	3	10
PLC INJURY		
SUSPECTED	10	30
INJURED	20	70

The TLICS (Thoracolumbar Injury Classification and Severity Score) averaged 7.4 ± 2.1, indicating severe injuries requiring surgery in 90% of cases. Morphology and PLC (Posterior Ligamentous Complex) integrity scores showed significant damage (2.9 ± 1.1 and 1.9 ± 1.3, respectively). Neurological status at admission averaged 2.6 ± 0.5, with 50% showing improvement at discharge, including 13.3% achieving ASIA E (American Spinal Injury Association Impairment Scale - Normal function). The average hospital stay was 14.6 ± 5.1 days, emphasizing the need for timely surgical intervention and the potential for recovery (Table 4).

Table 4. Outcome Parameters (N = 30)

VARIABLES	NO.	%	MEAN ± SD	RANGE
TLICS	-	-	7.4 ± 2.1	4 - 10
MORPHOLOGY			2.9 ± 1.1	1 - 4
PLC INTEGRITY			1.9 ± 1.3	0 - 3
NEUROLOGICAL STATUS			2.6 ± 0.5	2 - 3
MANAGEMENT			-	-
CONSERVATIVE	3	10		
SURGICAL	27	90		
HOSPITAL STAY, DAYS	-	-	14.6 ± 5.1	7 - 21
ASIA IMPAIRMENTS SCALE (DISCHARGE)			-	-
A	8	26.7		
B	5	16.7		
C	6	20		
D	7	23.3		
E	4	13.3		
NEUROLOGICAL IMPROVEMENT			-	-
NO	15	50		
YES	15	50		

The table shows that complete cord hemorrhage and cord transection have been exclusively correlated with ASIA A (complete injury). Cord edema had the most varied distribution, with ASIA B being the most common. A powerful positive correlation (r -value= 0.625, p-value < 0.001) has been found among cord injury type and neurological impairment severity at admission (Table 5).

Table 5. MRI Findings and Admission Neurological Status (N = 30)

VARIABLES	ASIA IMPAIRMENTS SCALE (ADMISSION)			
	A	B	C	D
CORD INJURY				
CORD TRANSECTION	3 (100)	0 (0)	0 (0)	0 (0)
CORD HAEMORRHAGE	2 (100)	0 (0)	0 (0)	0 (0)
CORD CONTUSION	4 (80)	0 (0)	1 (20)	0
CORD OEDEMA	2 (16.7)	5 (41.7)	2 (16.7)	3 (25)
SPINAL STENOSIS	0 (0)	0 (0)	2 (66.7)	1 (33.3)
EPIDURAL HEMATOMA	0 (0)	3 (100)	0 (0)	0 (0)
NORMAL CORD	0 (0)	0 (0)	1 (50)	1 (50)
CORRELATION COEFFICIENT	0.625			
P VALUE	< 0.001			

Complete cord transection and cord hemorrhage remained at ASIA A (100%), with no recovery observed. Cord contusion showed partial recovery, with 40% of patients improving. Cord edema had the highest recovery rate (58%), with some patients achieving ASIA E (17%). Spinal stenosis and epidural hematoma also showed significant recovery (67%). A strong positive association was discovered among injury type & discharge AIS (r -value= 0.668, p-value < 0.001), in addition to recovery (r -value = 0.464, p -value = 0.010), indicating that injury type significantly influences outcomes (Table 6).

Table 6. MRI Findings and Discharge Neurological Status (N = 30)

VARIABLES	ASIA IMPAIRMENTS SCALE (DISCHARGE)					RECOVERY
	A	B	C	D	E	
CORD INJURY						
CORD TRANSECTION	3 (100)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
CORD HAEMORRHAGE	2 (100)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
CORD CONTUSION	3 (60)	1 (20)	0 (0)	1 (20)	0 (0)	2 (40)
CORD OEDEMA	0 (0)	3 (25)	4 (33)	3 (25)	2 (17)	7 (58)
SPINAL STENOSIS	0 (0)	0 (0)	1 (33)	1 (33)	1 (33)	2 (67)
EPIDURAL HEMATOMA	0 (0)	1 (33)	1 (33)	1 (33)		2 (67)
NORMAL CORD	0 (0)	0 (0)	0 (0)	1 (50)	1 (50)	2 (100)
CORRELATION COEFFICIENT			0.668			0.464
P VALUE			< 0.001			0.010

CASE PRESENTATION

Case No 1:

Clinical background

32 years old female presented after car accident with back pain and difficulty of walking.

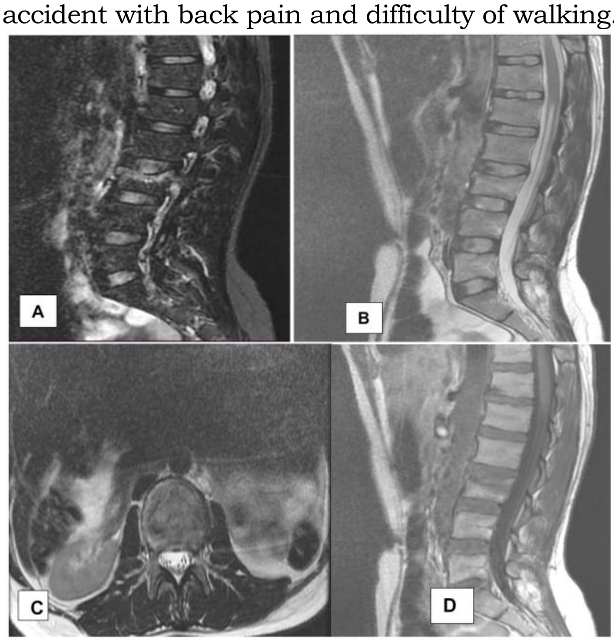

Figure 1. (A): Sagittal STIR(B): Sagittal T2WI(C): axial T2WI (D): Sagittal T1WI shows Wedge shape compression fracture of L3 vertebral body with edema extended to right pedicle .TILCS 1=Non-Surgical(conservative ttt with medical ttt for osteoporosis).

Case No 2:

Clinical background

21 years old man presented following falling from height with back pain and difficulty of walking.

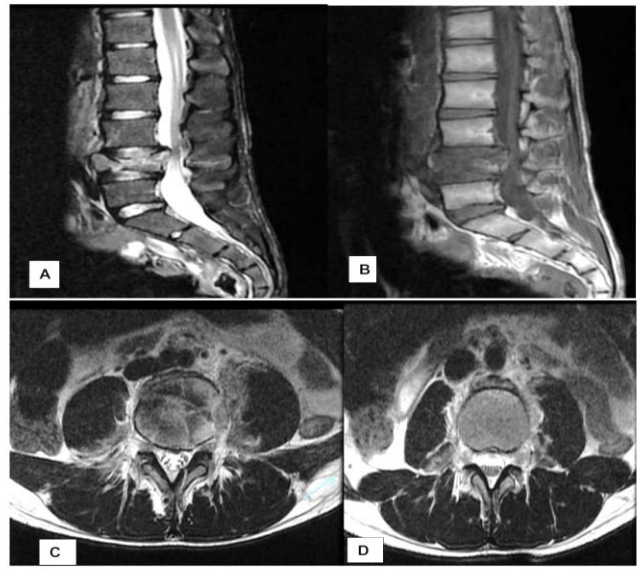

Figure 2. (A):Sagittal STIR, (B): sagittal T1WI, (C): axial T2WI(D): axial T2WI showsL4 burst fracture with vertebral body edema extended to transverse process of the vertebrae, retropulsion upon spinal canal causing significant spinal canal stenosis, PLL partial tear, ALL tear with related prevertebral haematoma, left ligamentum flavum tear, edema of psoas muscle, focal interruption of annulus fibrosus at level of L3-4 and minimal free fluid noted at pelvis.TILCS 8=Surgical (Posterior decompressive laminectomy and transpedicular fixation with vertebroplasty to restore vertebral height and lateral bone fusion).

4. Discussion

In our study, the mean age of enrolled cases was 34.8 ± 10 years, varying from 20 to 50 years. The Patients were males, while six (20%) were females. 19 (63%) patients reported spinal injuries secondary to falling from heights, eight (27%) patients had road traffic accidents, and three (10%) patients reported spinal injuries by heavy objects.

Our study can be supported by Boyles et al.,[6] who reported that the overall incidence rate of spinal cord injury in the male population aged sixteen to twenty-four years. Most spinal cord injury cases from 1997 to 2012 were caused by falls, motor vehicle crashes, and firearm injuries. Nevertheless, they discovered that the incidence rate of spinal cord injury was highest in individuals aged eighty-five years or older for the majority of the years; however, the rates demonstrated a slight rise over time. Additionally, the proportion of spinal cord injuries caused by falls among elderly individuals increased.

In our study showed that, regarding injury Characteristics, Dorsal levels were the most frequently injured. Of the thirty cases, nineteen (63.3%) suffered injuries at the dorsal level, while eleven (36.7%) suffered injuries at the lumbar level. There ten (30%) patients had compression vertebral fractures, twenty (70%) patients had burst vertebral fractures.

In harmony with our findings by Choi et al.,[7] reported that the prevalence and incidence of traumatic SCI in the United States are greater than those in the rest of the world. The average age at injury is rising in tandem with the aging of the general population at risk. The proportion of thoracolumbar injuries is on the rise, while the proportion of neurologically complete injuries is on the decline. The number of injuries resulting from falls is on the rise. The SCI population does not reflect the most current advancements in the life expectancy of the general population. The results of therapy are changing as a consequence of the changing delivery of health care in the United States and the aging population.

In our investigation, spinal trauma cases were classified into five categories according to the ASIA impairment scale (AIS) at the time of admission. Each case showed either complete or incomplete neurological deficits. In eleven cases (36.7%), the most prevalent presentation was ASIA A, subsequent to ASIA B in eight (26.7%), AISA C in six (20%), and ASIA D in five (16.7%) cases.

Our findings are in concordance with van den Hauwe et al.,[8] who reported that 258 (37.1%) patients were AIS grade A, 115 (16.5%) AIS grade B, 119 (17.1%) AIS grade C and 204 (29.3%) were AIS grade D. while of the followup cohort 136 (36.2%) were AIS grade A, 63 (16.8%) AIS grade B, 58 (15.4%) AIS grade C, 119 (31.7%) were AIS grade D.

Our study showed that all 30 patients (100%) showed cord abnormalities on MRI. ASIA A (complete paralysis) was correlated with cord transection (ten percent) and cord hemorrhage (6.7%). Cord edema (40%) had varied presentations: 16.7% ASIA A, 41.7% ASIA B, 16.7% ASIA C, and 25% ASIA D. Cord contusion (16.7%) was mostly ASIA A (80%), with one case of ASIA C. Epidural hematoma (10%) presented as ASIA B, while spinal stenosis (16.7%) showed ASIA C and D. Patients with normal cord (6.7%) had ASIA C and D. Posterior ligamentous complex (PLC) injury was apparent in 70% and suspected in 30% of cases.

Our study is consistent with Bozhko et al.,[9] who reported that 43 (14.8%) had No signal change, 149 (51.6%) were consistent with edema and 97 (33.6%) were consistent with hemorrhage. While of the follow up cohort 24 (14.7%) had No signal change, 84 (51.5%) were consistent with edema and 55 (33.7%) were consistent with hemorrhage.

Hakimjavadi et al.,[10] reported that a focal post-traumatic lesion on either the sagittal or GRE sequences was found in 23 (82.1%) of the patients, of which 3 patients had two separate lesions. Five (17.9%) patients demonstrated no visible spinal cord lesions.

In our research, we demonstrated that, regarding patient outcomes, the average TLIC score was 7.4 ± 2.1, varying between 4 and 10. The mean score of the morphology subscale was 2.9 ± 1.1, varying between 1 and 4; the mean score of the PLC subscale was 1.9 ± 1.3, varying between zero and three; and the mean score of the neurological subscale was 2.6 ± 0.5, ranging from 2 to 3. Only three (10%) patients were managed conservatively, whereas 27 (90%) patients underwent transpedicular screw fixation and posterior decompression via laminectomy. The mean length of hospitalization was 14.6 ± 5.1 days, ranging from 7 to 21 days.

Our study agrees with Guérout, N.,[11] who reported that all SCIs resulted from blunt trauma, with 28% being complete injuries (AIS Grade A). Cases were predominantly male (seventy percent), with a mean age of fifty-six years. The most common injury mechanism was falls (53%), and the average time from admission to MRI was 8.6 ± 6 hours, with 85% undergoing MRI within 12 hours. The average hospital stay was 23 days.

Our research demonstrated that out of thirty cases, 15 (50%) showed neurological improvement, while 15 (50%) showed no improvement. Four patients (13.3%) achieved complete recovery (ASIA E), and eight (26.7%) remained with complete paralysis (ASIA A). Among patients with cord edema, 7 (58%) improved, while those with cord transection and cord hemorrhage showed no improvement. Patients with epidural hematoma and spinal stenosis improved in 67% of cases, and all patients with normal cord showed improvement. Improvement rates varied by initial ASIA grade: 27.3% of ASIA A patients improved to ASIA B/D, 62.5% of ASIA B improved to ASIA C/D, 66.7% of ASIA C improved to ASIA D, and 80% of ASIA D improved to ASIA E.

In line with our study, Lu et al.[12] found that cases with single-level edema had improved initial neurological status and improved by two ASIA grades, compared to one grade for those with diffuse edema. 22% of single-level edema patients recovered to ASIA E, while only 2% with diffuse edema achieved this. Cases with edema had a significantly improved prognosis compared to those with hemorrhage, who were initially ASIA A (95%) and improved only 5% of the time.

In line with our results, Tabarestani et al.[13] reported that the majority of cases demonstrated clinical enhancement, and their recovery stabilized at two years. The rate of cord atrophy decreased, whereas cortical atrophy advanced. The accumulation of thalamic iron was elevated, while myelin content reduced over time. A improved motor recovery was expected by smaller cord and corticospinal tract atrophy at six months, whereas worse sensory results and neuropathic pain were estimated by greater cord atrophy and cerebellar alterations at two years.

Recommendations: The study recommends MRI sequences for assessing spinal cord injuries, particularly STAIR images. It suggests further research to understand underlying mechanisms and risk factors, improve patient care quality, and continuously check patient records. Larger sample sizes are needed for confirmation.

4. Conclusion

Traumatic spinal cord injury is a severe condition with high mortality and long-term disability. MRI is crucial for evaluating spinal trauma, especially in patients with neurological deficits or unclear CT findings. It effectively detects spinal cord injuries (e.g., edema, hemorrhage), ligamentous damage, and disc herniations, providing superior soft-tissue contrast compared to CT or X-rays. However, conventional MRI has limitations in correlating signal changes with functional outcomes. Despite this, MRI remains essential for accurate diagnosis, prognosis, and guiding urgent management in TSCI patients.

Disclosure

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Authorship

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References

1. Alkadeem RM, El-Shafey MH, Eldein AE, Nagy HA. Magnetic resonance diffusion tensor imaging of acute spinal cord injury in spinal trauma. Egyptian Journal of Radiology and Nuclear Medicine. 2021 Dec;52:1-3. DOI: 10.1186/s43055-021-00450-z
2. Stocchetti N, Zanier ER. Chronic impact of traumatic brain injury on outcome and quality of life: a narrative review. Crit Care. 2016 Jun 21;20(1):148.
3. Ishaque AH, Alvi MA, Pedro K, Fehlings MG. Imaging protocols for non-traumatic spinal cord injury: current state of the art and future directions. Expert Rev Neurother. 2024 Jul;24(7):691-709.
4. Boraiah G, Chhabra A. Conventional and Advanced Imaging Evaluation of Spine. InMultidisciplinary Spine Care 2022 Jun 28 (pp. 73-107). Cham: Springer International Publishing.
5. Izzo R, Al Qassab S, Popolizio T, Balzano RF, Perri M, Cassar-Pullicino V, et al . Imaging of thoracolumbar spine traumas. Eur J Radiol. 2022 Sep;154:110343.
6. Boyles RH, Alexander CM, Belsi A, Strutton PH. Are Clinical Prediction Rules Used in Spinal Cord Injury Care? A Survey of Practice. Top Spinal Cord Inj Rehabil. 2024 Winter;30(1):45-58. doi: 10.46292/sci23-00069. Epub 2024 Feb 29. PMID: 38433737; PMCID: PMC10906376.
7. Choi Y, Leigh JH. Epidemiology of Traumatic and Non-Traumatic Spinal Cord Injury in Korea: A Narrative Review. Korean J Neurotrauma. 2023 Nov 9;19(4):434-445. doi: 10.13004/kjnt.2023.19.e54. PMID: 38222829; PMCID: PMC10782106.
8. van den Hauwe L, Flanders AE. Spinal Trauma and Spinal Cord Injury (SCI). 2024 Feb 11. In: Hodler J, Kubik-Huch RA, Roos JE, editors. Diseases of the Brain, Head and Neck, Spine 2024-2027: Diagnostic Imaging [Internet]. Cham (CH): Springer; 2024. Chapter 19. PMID: 39495874.
9. Bozhko OV, Akhadov TA, Ublinsky MV, Meshcheryakov SV, Manzhurtsev AV, Melnikov IA, et al. Magnetic resonance imaging in acute traumatic injuries of ligaments and soft tissues of cervical spine in children. Russian Pediatric Journal. 2022;25(5):326-32.
10. Hakimjavadi R, Basiratzadeh S, Wai EK, Baddour N, Kingwell S, Michalowski W, et al. Multivariable Prediction Models for Traumatic Spinal Cord Injury: A Systematic Review. Top Spinal Cord Inj Rehabil. 2024 Winter;30(1):1-44.
11. Guérout N. Combined Treatments and Therapies to Cure Spinal Cord Injury. Biomedicines. 2024 May 15;12(5):1095. doi: 10.3390/biomedicines12051095. PMID: 38791057; PMCID: PMC11118184.
12. Lu Y, Shang Z, Zhang W, Pang M, Hu X, Dai Y, et al . Global incidence and characteristics of spinal cord injury since 2000-2021: a systematic review and meta-analysis. BMC Med. 2024 Jul 8;22(1):285.
13. Tabarestani TQ, Lewis NE, Kelly-Hedrick M, Zhang N, Cellini BR, Marrotte EJ, et al. Surgical Considerations to Improve Recovery in Acute Spinal Cord Injury. Neurospine. 2022 Sep;19(3):689-702.