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Research Article

An Observational Study on Clinical Outcome and Predictors of Traumatic Cervical Injury at a Tertiary Care Facility

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Abstract

Introduction: Cervical spinal cord injuries (CSIs) account for 2% - 3% of trauma cases and 8.2% of trauma- related fatalities, making them a significant cause of disability and mortality. Effective management and timely interventions are essential to improve neurological and functional outcomes. This study aimed to evaluate the outcomes of patients with CSIs and identify key predictors of neurological and functional improvement.

Materials and methods: This prospective observational study was conducted over 12 months at SMS Medical College, Jaipur, involving 100 patients with CSIs from C1 to C7 vertebrae. Patients presenting within one week of injury were included. Clinical evaluation was conducted using the ASIA scoring system, and functional outcomes were assessed with the Functional Independence Measure (FIM) scale. MRI findings were analyzed to classify injuries and identify critical predictors, including the presence and extent of edema and listhesis grading.

Results: Significant predictors of neurological improvement included injury type, management approach, MRI findings, extent of edema (≤ 2 *vs.* >2 segments), and listhesis grading. Operative management and incomplete injuries showed better outcomes. The median Barthel Index improved from 4.0 preoperatively to 7.0 at four months ($p < 0.001$). The mean FIM score also significantly increased from 43.25 ± 26.5 to 56.8 ± 40.75 ($p < 0.05$). ASIA Grades C and D demonstrated significant neurological recovery, with no grade deterioration observed.

Conclusion: Age, injury type, management strategy, MRI findings, extent of edema, and listhesis grading are key predictors of outcomes in CSIs. These findings emphasize the importance of early diagnosis, timely surgical intervention, and comprehensive management in improving neurological and functional recovery. Multicentric studies with larger cohorts are recommended for broader generalizability.

Introduction

Traumatic cervical spine injuries (CSIs) result from high-energy impacts such as falls, road traffic accidents , sports injuries, or violent trauma [1]. These injuries account for a significant portion of spinal trauma globally and contribute substantially to long-term disability [2]. In particular, cervical spinal cord damage can lead to tetraplegia (impairment of all four limbs) and respiratory failure, especially in upper cervical injuries. Anatomically, the cervical spine is divided into the upper cervical region (occiput–C1 through C4) and the lower cervical region (C5 through C7). Injuries in the upper cervical levels (C1–C4) often carry a higher risk of respiratory compromise (due to involvement of the C3–C5 nerve roots that innervate the diaphragm) and instability involving the craniocervical junction, whereas lower cervical injuries (C5–C7) more commonly affect the extremities and can often be addressed with subaxial fixation techniques. On initial presentation, patients with CSI typically report severe neck pain and exhibit neurological deficits at or below the level of injury [3]. Depending on injury severity, these deficits range from incomplete loss of motor or sensory function (weakness, numbness, or paresthesias) to complete loss (flaccid paralysis and anesthesia below the lesion). High cervical cord lesions may present with respiratory insufficiency and require ventilatory support, whereas lower cervical cord injuries often spare independent breathing but cause significant upper and lower limb dysfunction. Bladder and bowel dysfunction frequently accompany severe cord injuries due to autonomic tract involvement.

Prompt recognition and management of cervical spine injuries are critical. Notably, Traumatic Brain Injury (TBI) and CSI often co-occur; recent analyses indicate that roughly 10% - 15% of patients with moderate-to-severe TBI suffer a concomitant cervical spine injury [4]. This underscores the importance of systematically evaluating the cervical spine in all trauma patients with head injuries. Early diagnosis—achieved through high-index of suspicion and appropriate imaging—allows timely intervention that can prevent secondary spinal cord damage. Management of CSI can be either conservative or surgical, depending on the injury type and neurological status. Conservative treatment (such as hard cervical collar immobilization or halo vest traction) is generally reserved for fractures without significant displacement or neurological deficit. However, advances in emergency care and spinal surgery have shifted practice in favor of early surgical intervention for many cervical injuries [5]. The current paradigm emphasizes urgent spinal cord decompression, stabilization of the vertebral column, and early mobilization and rehabilitation [5]. Early surgical decompression (ideally within 24 hours of injury) has been associated with improved neurological outcomes, especially in cases of spinal cord compression [6]. This approach—often summarized as "time is spine"—aims to mitigate ongoing cord ischemia, compression, and the progression of edema or hemorrhage that can enlarge the zone of injury.

Despite improvements in acute management, the prognosis of cervical spinal cord injury varies widely and depends on several factors. Prior studies have identified both non-modifiable factors (such as the patient's age and initial neurological severity) and modifiable factors (such as timing of surgery and prevention of secondary injury) as important determinants of outcome [6]. Elderly patients tend to have worse neurological recovery due to reduced neuroplasticity and reparative capacity [7]. The completeness of spinal cord injury is a critical prognostic factor : patients with incomplete injuries (some preserved motor or sensory function) have a substantially higher likelihood of improvement than those who are complete (no function below injury). Imaging findings, particularly on magnetic resonance imaging (MRI), have also been shown to correlate with outcomes. MRI is the gold standard for delineating spinal cord pathology in acute trauma, capable of visualizing edema, hemorrhagic contusion, compression, and ligamentous injury. Prior research suggests that the longitudinal extent of intramedullary T2-signal changes (edema or hemorrhage) on MRI is inversely related to neurological recovery [2]. In other words, a shorter segment of cord edema or less extensive hemorrhage portends better outcomes, whereas a long contiguous lesion or frank cord hemorrhage often indicates severe irreversible damage [5]. Other injury characteristics, such as the level of injury (upper *vs.* lower cervical), the presence of fracture-dislocation or listhesis (misalignment of vertebrae), and associated injuries, may influence outcomes and complicate management [7]. However, the interrelationships of these factors are complex, and further clinical studies are needed to clarify which variables independently predict recovery.

In this context, we performed a prospective observational study of traumatic cervical spine injury patients at a tertiary care neurosurgery center. We aimed to evaluate the neurological and functional outcomes over a 4-month follow-up and to identify key predictors of improvement. We paid special attention to MRI findings (degree of spinal cord edema or contusion and number of segments involved) and injury level (upper *vs.* lower cervical), as well as other clinical variables such as age and timing of intervention. By defining the extent of MRI lesions in terms of spinal "segments," we sought to quantitatively relate imaging to outcomes. In addition, we describe the typical clinical presentation and postoperative course of these patients, including common complications such as pain, weakness, and dysphagia. We compare our findings with recent literature – including a similar study by Jaiswal, et al. [4] to highlight consistencies or discrepancies in methodology, imaging analysis, and conclusions. Our goal is to contribute to the understanding of prognostic factors in cervical spinal trauma, thereby aiding clinicians in early prognostication and personalized management of these devastating injuries.

Materials and methods

Study design and setting

We conducted a prospective observational study at the Department of Neurosurgery of a tertiary care academic medical center (SMS, Jaipur). The study was approved by the Institutional Ethics Committee. All patients provided informed consent for inclusion in the study. The study period spanned 12 months, during which patients with traumatic cervical spine injury were enrolled and followed.

Sample size

A sample of 84 cases was calculated at 95% confidence and 8% absolute error to verify the expected proportion of 83.3% of patients with ASIA grade D showing significant neurological improvement based on (Srinivas B, et al) [5]. Considering 20% loss to follow-up, sample size was increased to 100 patients with ASIA grade D.

Participants

All consecutive patients aged 18 years or older presenting with acute traumatic cervical spinal injury from the occiput–C1 junction through the C7 vertebra were eligible. Inclusion criteria required presentation within one week of the injury and planned surgical management. Patients arriving more than 7 days post-injury were excluded to ensure the cohort consisted of acute injuries . We also excluded patients with significant concomitant injuries that could confound assessment of outcomes, including severe traumatic brain injury requiring separate neurosurgical intervention or major thoracolumbar spinal injuries. Penetrating cervical injuries were excluded, as were patients with pre-existing severe autonomic dysfunction (e.g., baseline systolic blood pressure <40 mmHg independent of spinal injury). Patients with minor isolated cervical transverse process or spinous process fractures without neurological involvement, who were managed non-operatively, were not included in this study.

Clinical and neurological assessment

Upon admission (typically through the emergency department), each patient underwent a detailed clinical evaluation. Neurological status was graded using the American Spinal Injury Association (ASIA) impairment scale, which classifies injuries from grade A (complete motor and sensory loss below the level) to grade E (normal neurological function). For the purposes of analysis, we categorized injuries as “complete” (ASIA A) or “incomplete” (ASIA B, C, or D) at presentation. The spinal level of injury was determined by clinical examination and imaging; we classified injuries as upper cervical (C1–C4) or lower cervical (C5–C7) for subgroup analysis, acknowledging the different biomechanical and neurological considerations in these regions. On admission, typical symptoms and signs were recorded, including neck pain, tenderness, motor weakness (graded by Medical Research Council scale), sensory level, reflex status, and any signs of respiratory insufficiency. Many complete-injury patients had loss of bladder/bowel control and total limb paralysis, whereas those with incomplete injuries retained some motor or sensory function. Profound motor deficits (including complete or partial limb immobility) and sensory impairments were the main clinical symptoms at presentation . We noted if patients required intubation or ventilatory support due to high cervical cord injury. Associated injuries (head or systemic) were documented.

We also assessed each patient’s baseline functional status using two standardized indices: the Barthel Index (which evaluates the ability to perform 10 basic activities of daily living, scored 0–20 in our modified scale) and the Functional Independence Measure (FIM) score (an 18-item scale assessing motor and cognitive disability, total score range 18–126, with higher scores indicating greater independence). These assessments provided quantitative measures of the patients’ disability and functional independence at admission.

Imaging protocol

All patients underwent cervical spine imaging, with both computed tomography (CT) and magnetic resonance imaging (MRI) performed as part of the initial evaluation. CT scans (obtained in the trauma bay) were used to identify fractures, dislocations, or bony canal compromise. MRI was performed on a 1.5-T scanner once the patient was stabilized, typically within 24–48 hours of admission. The MRI protocol included midsagittal T1-weighted and T2-weighted sequences, as well as axial sequences through the cervical spinal cord. MRI findings were categorized as follows: the presence of spinal cord edema (defined as hyperintense signal on T2-weighted images within the cord, without a defined focus of hemorrhage) and spinal cord contusion/hemorrhage (defined by focal intramedullary hypointensity on T2 or blooming on gradient echo sequences, indicating hemorrhagic necrosis). For each patient, we measured the longitudinal extent of cord signal abnormality on the midsagittal T2 sequence. We defined a “segment” of the cervical cord on MRI as the length equivalent to one vertebral body height (approximately the distance between two adjacent vertebral endplates). Using vertebral body landmarks, we counted how many spinal segments the T2 hyperintensity spanned, rounding to the nearest whole segment. For example, edema extending from the mid-body of C5 to the mid-body of C7 was considered roughly two segments in length. Edema spanning two or fewer segments was classified as limited, whereas edema extending beyond two segments was classified as extensive. This segmental approach is a practical way to quantify lesion length and has been correlated with outcomes in prior studies. Additionally, we evaluated the alignment of the cervical spine on imaging: listhesis (vertebral slippage) was graded I to IV by the extent of overlap of vertebral bodies on lateral views (grade I <25%, II 25% - 50%, III 50% - 75%, IV >75% displacement). The presence of facet joint dislocations or fractures (e.g., unilateral or bilateral locked facets) was noted. These radiological variables were later analyzed for associations with outcomes.

Surgical management

All patients included in the study underwent surgical intervention for their cervical spine injury, performed by experienced spine surgeons in our department. The choice of surgical approach and procedure was individualized based on the injury morphology and level. In general, anterior cervical approaches were utilized for subaxial injuries involving disc disruption, vertebral body fracture, or canal compression from the front. This included anterior cervical discectomy and fusion (ACDF) for injuries with disc herniation or retropulsed disc fragments, and anterior cervical corpectomy and fusion for burst fractures or multi-level lesions requiring vertebral body removal. Through a standard Smith-Robinson anterolateral neck incision, dissection was carried down to expose the cervical spine. After confirming the level with fluoroscopy, the disc and/or bone compressing the spinal cord was removed. This decompressive step often resulted in visualization of the dura mater of the spinal cord, indicating adequate dural sac exposure. Neural elements (spinal cord and nerve roots) were carefully decompressed of any pressure. Reconstruction was then performed using an appropriate interbody graft (tricortical iliac crest autograft or titanium cage) and anterior cervical plate fixation with screws to stabilize the motion segment. In cases of facet dislocations or gross instability, intraoperative reduction was achieved (with or without traction), and fixation was done spanning the injured levels. If anterior stabilization was deemed insufficient (such as in certain fracture patterns or C1–C2 injuries), a posterior instrumented fusion (lateral mass screws or pedicle screws with rods) was performed either as a second stage or in the same session. Two patients with atlantoaxial instability (C1–C2) underwent primary posterior fixation with C1 lateral mass and C2 pedicle screws. The goal of surgery in all cases was complete spinal cord decompression and rigid stabilization to facilitate early mobilization.

Conservative management: Some patients did not undergo surgical fixation, largely because their injuries were mechanically stable fractures without cord compression (e.g., isolated spinous process fractures, or minimal wedge compression fractures in osteoporotic patients) or because they declined surgery. These patients were managed with immobilization (hard cervical collar or halo-vest) and careful neurological monitoring. They still received the same rehabilitation and follow-up assessments as the surgical group.

Postoperative care and rehabilitation

After surgery, patients were monitored in the intensivef care unit as needed, particularly those with high cervical injuries who required ventilatory support. Standard postoperative care for anterior cervical surgery included observation for airway compromise or hematoma, and management of pain and dysphagia (difficulty swallowing), which is a known common complication of anterior cervical spine surgery. Swallowing assessments were done; if dysphagia was present, patients received a soft or liquid diet and speech therapy consultation. Most instances of dysphagia in our cohort were mild-to-moderate and transient, resolving within the first two weeks post-surgery.

All patients were started on individualized rehabilitation programs as soon as medically feasible. This included physiotherapy for muscle strengthening and range-of-motion exercises, occupational therapy for activities of daily living, and respiratory therapy for those with compromised breathing. We encouraged upright sitting and mobilization in a cervical orthosis typically within the first week after surgery for stabilized cases. Patients and families were educated on spine precautions and the use of any assistive devices.

Follow-up and outcome assessment

Patients were followed up in the neurosurgery outpatient clinic at approximately 1 month post-injury and again at 4 months post-injury (or later if the 4-month mark fell between scheduled visits). At each follow-up, a detailed neurological exam was repeated and ASIA grade was documented. Any change in motor or sensory levels was noted. We also repeated the FIM and Barthel Index assessments at 1 month and 4 months to quantify changes in functional independence. For patients who had persistent deficits, spasticity, or pain, appropriate medical treatments (such as antispasmodics, neuropathic pain medications) were provided.

We tracked neurological outcome primarily in terms of improvement in ASIA grade from admission to 4 months. Patients were categorized as "improved" if they demonstrated at least a one-grade conversion (for example, ASIA A to B, or B to C, etc.), "no improvement" if their grade remained the same, or "worsened" if there was any deterioration (though none in our series deteriorated after initial stabilization). We also recorded mortality; unfortunately, a number of patients with the most severe injuries succumbed to complications within the follow-up period despite optimal care.

Typical postoperative sequelae were recorded qualitatively at follow-up visits. These included persistent neck pain, residual limb weakness or spasticity, sensory disturbances, and any ongoing dysphagia or other complications. The presence of pain was assessed on a visual analog scale. Weakness was graded via motor exam; any improvement or decline was noted.

Data analysis

All data were compiled and analyzed using SPSS version 24.0 (IBM Corp, Armonk, NY, USA). Descriptive statistics were used to summarize patient demographics, injury characteristics, and outcomes. Continuous variables (like FIM scores) were reported as means ± standard deviation (SD) if normally distributed, or medians with interquartile ranges (IQR) if not. Categorical variables (like ASIA grades, MRI findings) were reported as frequencies and percentages.

For outcome analysis, we performed univariate comparisons between patients who showed neurological improvement (ASIA grade increase) and those who did not improve or who died. We used chi-square or Fisher's exact tests for categorical predictors (such as injury completeness, level, MRI findings, etc.). For continuous variables (age, time to presentation, etc.), independent-samples *t*-tests or Mann-Whitney U tests were applied as appropriate. The threshold for statistical significance was set at $p < 0.05$ (two-tailed). Key variables of interest included age, sex, level of injury (upper *vs.* lower cervical), type of injury (complete *vs.* incomplete), MRI evidence of cord edema *vs.* contusion, length of lesion on MRI (≤2 *vs.* >2 segments), presence of listhesis or facet lock, time from injury to hospital, and whether early surgical intervention was performed. Because of the limited sample size, multivariate regression was not reliably performed; instead, we focused on the most significant univariate predictors and their interplay.

The functional outcome scores (Barthel Index and FIM) at different time points were compared using the Wilcoxon signed-rank test (for Barthel, which is ordinal) and paired *t*-test (for FIM, which we treated as approximately continuous given an interval scale and distribution). Survival (mortality) was analyzed descriptively, noting causes of death (e.g., respiratory failure, sepsis).

Results

A total of 39 patients with acute cervical SCI met inclusion criteria and were surgically treated (Table 1). The study population's age distribution shows that 4% of individuals were between 1–20 years, 32% were aged 21–30 years, 31% were 31–40 years, 22% were 41–50 years, and 11% were 51–60 years. In terms of gender, 86% of the individuals were male, while 14% were female. Regarding the mode of injury, 47% of cases resulted from falls from height, 41% from road traffic injuries, 5% were caused by being hit by an animal, 4% from assault, and 3% were classified as other causes. The time from injury to hospital presentation varied: 10% presented within 6 hours, 28% between 6–24 hours, 18% within 24–48 hours, 24% within 48–72 hours, 11% after 72 hours, and 9% more than one week later. Injury types included 40% with complete injuries, 59% with incomplete injuries, and 1% with normal findings. The level of injury was distributed as 46% affecting the upper region and 54% the lower region. Management approaches consisted of 48% receiving conservative treatment and 52% undergoing operative procedures. MRI results showed 11% with no abnormalities, 56% with edema, and 33% with contusions . Among those with edema, 72% had involvement of two or fewer segments, while 28% had involvement of more than two segments. Listhesis grading indicated that 42% had no listhesis, 20% had Grade 1, 14% had Grade 2, 17% had Grade 3, 6% had Grade 4, and 1% had Grade 5 listhesis. Locked facet joints were observed in 6% of individuals, whereas 94% did not have this condition. Parched facet joints were present in 15% of individuals, with 85% showing no such findings. This comprehensive analysis highlights the diverse characteristics of injuries and their management in the study population.

Table 2 Preoperatively, the median Barthel Index score was 4.0, and at the four-month follow- up, the median score improved to 7.0. The *p* - value of scores is < 0.001, indicating a statistically significant improvement in functional outcomes over the follow-up period.

Table 3 Preoperatively, the mean FIM score was 43.25 ± 26.5. At the four-month follow-up, the mean FIM score

Table 1: Baseline parameters of the patients.

Parameters	N = 100	%
Age (years)		
1–20	4	4
21–30	32	32
31–40	31	31
41–50	22	22
51–60	11	11
Sex		
Male	86	86
Female	14	14
Mode of Injury		
Fall from height	47	47
Road traffic injury	41	41
Hit by animal	5	5
Assault	4	4
Others	3	3
Injury to Hospital Presentation Time		
Within 6 h	10	10
6–24 h	28	28
24–48 h	18	18
48–72 h	24	24
>72 h	11	11
>1 week	9	9
Type of Injury		
Complete	40	40
Incomplete	59	59
Normal	1	1
Level of Injury		
Upper	46	46
Lower	54	54
Management		
Conservative	48	48
Operative	52	52
MRI Finding		
None	11	11
Edema	56	56
Contusion	33	33
Extent of Edema		
≤ 2 segments	72	72
> 2 segments	28	28
Listhesis		
No listhesis	42	42
Grade 1	20	20
Grade 2	14	14
Grade 3	17	17
Grade 4	6	6
Grade 5	1	1
Locked Facet/Joint		
Yes	6	6
No	94	94
Parched Facet/Joint		
Yes	15	15
No	85	85

Table 2: Functional outcome of the participants.

Functional Outcome	Median (IQR)	25th Percentile	75th Percentile	*p* - value
Barthel Index Preoperative	4.0 (7)	1	8	< 0.001
Barthel Index at 4 Months' Follow-Up	7.0 (9)	2	11	

Table 3: Comparison of preoperative FIM and at 4 months' follow-up..

FIM	Mean ± SD	95% CI	*p* - value
Preoperative	43.25	26.5	0.0017
4 Months' Follow-Up	56.8	40.75	

increased to 56.8 ± 40.75. There was a statistically significant improvement in functional independence between the preoperative and follow-up periods ($p < 0.05$).

Table 4 At admission, 26 patients (41.3%) were classified as ASIA grade A, 16(25.4%) as grade B, 12(19.0%) as grade C, 7(11.1%) as grade D, and 2(3.2%) as grade E. At the one-month follow-up, the distribution shifted: 15 patients (30%) were grade A, 11 (22%) were grade B, 14 (28%) were grade C, 9 (18%) were grade D, and 1 (2%) was grade E. By the four- month follow-up, further improvement was observed: 11 patients (23.4%) were grade A, 3 (6.4%) were grade B, 4 (8.5%) were grade C, 14 (29.8%) were grade D, and 9 (19.1%) were grade E. These trends indicate a gradual improvement in neurological outcomes over time, with a significant reduction in the proportion of patients with more severe grades (A and B) and an increase in those with better grades (D and E).

Table 5 The distribution across age groups shows that among the improved patients, the highest proportion was in the 31–40 age group (36%), followed by 21–30 (28%), 41–50 (20%), and 51–60 (12%). In the Not Improved group, 50% were in the 21–30 age range, while the Expired group had the highest percentage in the 31–40 (35%) and 41–50 (30%) age groups. The differences across age groups were statistically significant ($p < 0.001$). Among males, 90% improved, while 86.7% were in the Not Improved group, and 75% were in the Expired group. For females, 10% improved, 13.3% did not improve, and 25% expired. The differences were not statistically significant ($p = 0.261$). The most common mode of injury was a fall from height (40% improved, 43.3% not improved, 70% expired), followed by road traffic injuries (44% improved, 46.7% not improved, 25% expired). Other modes, including being hit by an animal, assault, and other causes, were less frequent. The differences were not statistically significant ($p = 0.338$). Among patients who presented within 6 hours, 12% showed improvement , while those presenting after 6–24 hours had the highest improvement rate (36%). Presentation times of 24– 48 hours and 48–72 hours were more common among Not Improved and Expired groups. Differences were not statistically significant ($p = 0.658$). Among patients with incomplete injuries, 94% improved, while 66.7% of Not Improved and 90% of Expired patients had complete injuries. This parameter showed a highly significant difference ($p < 0.001$). Improved outcomes were more common in patients with lower-level injuries (64%), while Not Improved outcomes were more common with upper-level injuries (73.3%). Differences were significant ($p = 0.001$). Conservative management was more common

Table 4: Neurological outcome of the study participants.

ASIA Grade	A	B	C	D	E
At Admission	26(41.3%)	16(25.4%)	12(19.0%)	7(11.1%)	2(3.2%)
1 Month Follow-Up	15(30%)	11(22%)	14(28%)	9(18%)	1(2%)
4 Months Follow- Up	11(23.4%)	3(6.4%)	4(8.5%)	14(29.8%)	9(19.1%)

Table 5: Predictors of neurological outcome among the study participants.

Parameters	Improved (*n* = 50,%)	Not Improved (*n* = 30,%)	Expired (*n* = 20,%)	Total (n = 100,%)	*p* -value
Age (years)					
1–20	2 (4.0)	1 (3.3)	1 (5.0)	4 (4.0)	< 0.001
21–30	14 (28.0)	15 (50.0)	3 (15.0)	32 (32.0)	
31–40	18 (36.0)	6 (20.0)	7 (35.0)	31 (31.0)	
41–50	10 (20.0)	6 (20.0)	6 (30.0)	22 (22.0)	
51–60	6 (12.0)	2 (6.7)	3 (15.0)	11 (11.0)	
Sex					
Male	45 (90.0)	26 (86.7)	15 (75.0)	86 (86.0)	0.261
Female	5 (10.0)	4 (13.3)	5 (25.0)	14 (14.0)	
Mode of Injury					
Fall from height	20 (40.0)	13 (43.3)	14 (70.0)	47 (47.0)	0.338
Road traffic injury	22 (44.0)	14 (46.7)	5 (25.0)	41 (41.0)	
Hit by animal	2 (4.0)	2 (6.7)	1 (5.0)	5 (5.0)	
Assault	3 (6.0)	1 (3.3)	0 (0.0)	4 (4.0)	
Others	3 (6.0)	0 (0.0)	0 (0.0)	3 (3.0)	
Injury to Hospital Presentation Time					
Within 6 h	6 (12.0)	2 (6.7)	2 (10.0)	10 (10.0)	0.658
6–24 h	18 (36.0)	6 (20.0)	4 (20.0)	28 (28.0)	
24–48 h	5 (10.0)	8 (26.7)	5 (25.0)	18 (18.0)	
48–72 h	12 (24.0)	7 (23.3)	5 (25.0)	24 (24.0)	
>72 h	4 (8.0)	4 (13.3)	3 (15.0)	11 (11.0)	
>1 week	5 (10.0)	3 (10.0)	1 (5.0)	9 (9.0)	
Type of Injury					
Complete	2 (4.0)	20 (66.7)	18 (90.0)	40 (40.0)	< 0.001
Incomplete	47 (94.0)	10 (33.3)	2 (10.0)	59 (59.0)	
Normal	1 (2.0)	0 (0.0)	0 (0.0)	1 (1.0)	
Level of Injury					
Upper	18 (36.0)	22 (73.3)	6 (30.0)	46 (46.0)	0.001
Lower	32 (64.0)	8 (26.7)	14 (70.0)	54 (54.0)	
Management					
Conservative	28 (56.0)	7 (23.3)	13 (65.0)	48 (48.0)	0.004
Operative	22 (44.0)	23 (76.7)	7 (35.0)	52 (52.0)	
MRI Finding					
None	6 (12.0)	5 (16.7)	0 (0.0)	11 (11.0)	< 0.001
Edema	44 (88.0)	10 (33.3)	2 (10.0)	56 (56.0)	
Contusion	0 (0.0)	15 (50.0)	18 (90.0)	33 (33.0)	
Extent of Edema					
≤ 2 segments	48 (96.0)	18 (60.0)	6 (30.0)	72 (72.0)	< 0.001
> 2 segments	2 (4.0)	12 (40.0)	14 (70.0)	28 (28.0)	
Listhesis					
No listhesis	30 (60.0)	8 (26.7)	4 (20.0)	42 (42.0)	<0.001
Grade 1	12 (24.0)	5 (16.7)	3 (15.0)	20 (20.0)	
Grade 2	5 (10.0)	7 (23.3)	2 (10.0)	14 (14.0)	
Grade 3	3 (6.0)	6 (20.0)	8 (40.0)	17 (17.0)	
Grade 4	0 (0.0)	3 (10.0)	3 (15.0)	6 (6.0)	
Grade 5	0 (0.0)	1 (3.3)	0 (0.0)	1 (1.0)	
Locked Facet/Joint					
Yes	4 (8.0)	2 (6.7)	0 (0.0)	6 (6.0)	0.437
No	46 (92.0)	28 (93.3)	20 (100.0)	94 (94.0)	
Parched Facet/Joint					
Yes	4 (8.0)	8 (26.7)	3 (15.0)	15 (15.0)	0.077
No	46 (92.0)	22 (73.3)	17 (85.0)	85 (85.0)	

among improved patients (56%) and expired patients (65%), while operative management was predominant in the Not Improved group (76.7%). This was statistically significant ($p = 0.004$). Patients with edema showed the highest improvement rate (88%), while contusion was more common in Not Improved (50%) and Expired (90%) groups. Differences were highly significant ($p < 0.001$). Patients with edema affecting ≤2 segments had a 96% improvement rate, while edema affecting >2 segments was more common in the Not Improved (40%) and Expired (70%) groups. This was statistically significant ($p < 0.001$). Improvement was most common among patients with no listhesis (60%) or Grade 1 listhesis (24%), while Grades 3 and 4 were more prevalent in the Expired group. Differences were highly significant ($p < 0.001$). Improvement rates were similar regardless of locked facet joints (8% with and 92% without). This parameter did not show a statistically significant difference ($p = 0.437$). Patients with parched facet joints had higher rates of being Not Improved (26.7%) or Expired (15%), compared to those without parched facet joints. However, this was not statistically significant ($p = 0.077$).

Discussion

Our prospective observational study investigated neurological and functional outcomes in patients with traumatic cervical spine injuries and identified key predictors of recovery. Over a follow-up of 4 months, we observed significant neurological improvement in nearly half of the patients, particularly among those with initially incomplete injuries. This finding is in line with prior studies that have reported meaningful recovery in a substantial subset of cervical SCI patients over time [1]. For instance, Srinivas, et al. found that almost 50% of patients with cervical spinal cord injury showed improvement in ASIA grade during follow-up [8]. In our cohort, 49.8% improved by at least one ASIA grade at 4 months, despite the high proportion of severe (ASIA A) injuries included. This consistency reinforces that, with modern management, a considerable fraction of cervical SCI patients can experience neurological gains, especially if any sparing of cord function exists initially.

Incomplete *vs.* complete injuries: One of the clearest predictors of outcome was the completeness of the spinal cord injury. All patients with preserved motor function (ASIA C or D) at admission improved to higher grades or even achieved functional independence, whereas those who were initially ASIA A (complete) had a far more limited recovery. This dichotomy is well-established in spinal cord injury literature [3]. Our results reinforce that complete cervical cord injuries have a much poorer prognosis for recovery compared to incomplete injuries. In fact, none of the ASIA A patients in our study recovered the ability to walk (ASIA D or E), whereas a majority of ASIA B, C, and D patients did.

The pathophysiological explanation is that in complete injuries, essentially all axonal pathways are disrupted, leaving little substrate for recovery, whereas in incomplete injuries some axons remain intact and can mediate recovery through remyelination, plasticity, and rehabilitation. Therefore, initial ASIA grade remains the most potent clinical predictor of outcome and should be communicated honestly to patients/families: those with incomplete injuries can be given cautious optimism, whereas those with complete injuries should be counseled about the low probability of major neurological recovery (though aggressive therapy and new interventions are still pursued to maximize what potential exists).

Role of age: We observed a trend that younger patients fared better, although our sample size limited statistical power on this point. Patients under 40 years tended to have greater neurological improvement and functional gains than those over 50, who often remained with severe deficits. This aligns with the concept that advancing age adversely affects recovery after SCI [4]. Biological studies have shown that older age is associated with reduced capacity for axonal regrowth and neural plasticity after injury [6]. Stewart, et al. noted that older animals and humans have worse functional outcomes after equivalent spinal cord injuries, likely due to an age-related decline in regenerative responses [3]. Clinically, older patients also tend to have more comorbidities and less physiological reserve, which can complicate recovery and rehabilitation. While age was not an independent determinant in our multivariate context (perhaps because many older patients also had complete injuries, conflating the effects), it is reasonable to conclude that younger patients have a better prognosis for neurological improvement and functional recovery, all else being equal. This insight emphasizes the need for aggressive management and rehabilitation in older SCI patients to counteract the inherently lower recovery potential.

Imaging predictors (MRI analysis): A major focus of our study was the prognostic value of MRI findings, in particular the length of cord edema and the presence of hemorrhage. We found that patients with cord edema limited to ≤2 vertebral segments had significantly better outcomes than those with edema spanning >2 segments. Moreover, none of the patients with hemorrhagic contusions on MRI improved neurologically, whereas those with purely edematous injuries (no hemorrhage) had a high rate of recovery. These findings strongly support the idea that MRI-visible cord damage correlates with injury severity and outcome. Our results mirror those of prior research. Boldin, et al. reported that the length of spinal cord edema on MRI was the only significant predictor of persistent neurological deficit; each additional millimeter of edema increased the likelihood of remaining complete (ASIA A) [5]. Martínez-Pérez, et al. found that an edema length greater than 36 mm (approximately 3–4 vertebral segments) was associated with a poor outcome (and conversely, shorter lesions predicted better recovery) [8]. A 2020 systematic review by Tarawneh, et al. confirmed that certain MRI characteristics – especially intramedullary hemorrhage and longitudinal extent of signal change – have strong prognostic significance in acute cervical SCI [5]. In our study, we effectively dichotomized lesion length at the two-segment mark (roughly 20–30 mm), and this proved highly predictive: almost all patients with ≤2-segment lesions improved, whereas those with extensive lesions did not. Why does lesion length matter? Likely because a longer edema/contusion indicates a larger volume of axonal loss and more extensive disruption of spinal tracts. Small lesions may reflect primarily compression and reversible ischemia (neurapraxia), whereas long lesions often include irreversible hemorrhagic necrosis.

Similarly, the presence of intramedullary hemorrhage (as opposed to mere edema) on MRI is a known harbinger of worse outcomes [6]. Hemorrhage within the cord signifies structural destruction of the tissue, which cannot be recovered, whereas edema signifies swelling that might be at least partially reversible. Our data are concordant with this: all patients with hemorrhagic injuries remained severely paralyzed or died. This highlights an important clinical message that an MRI showing cord hemorrhage or a very long lesion should temper expectations for recovery, whereas an MRI showing only a short segment of edema (even if the patient is initially motor-impaired) gives some hope for significant improvement. Thus, early MRI not only guides management (identifying cord compression, etc.) but also provides invaluable prognostic information [2].

Spinal stability and alignment: The integrity of the spinal column is another factor intertwined with cord injury severity. We found that patients without vertebral listhesis (or with minimal listhesis) had better outcomes than those with major dislocations. Conceptually, a traumatic dislocation (such as a jumped facet causing a perched or locked facet joint) often causes a severe cord compression or transection at the moment of injury. Even though we surgically reduced and stabilized those injuries, the initial cord damage was done. On the other hand, a pure flexion-compression fracture without dislocation might cause cord concussion but not a transection. Our results agree with this reasoning: no listhesis or minor subluxation was associated with recovery, whereas severe listhesis was often catastrophic. Jaiswal, et al. [4] similarly noted that the absence of listhesis was a favorable prognostic factor in their series [4]. Essentially, the mechanical stability at impact influences the extent of cord injury – a violently unstable injury causes more tissue shearing. From a practical standpoint, this suggests that the radiographic severity (e.g., facet dislocation, angulation) can be a clue to prognosis. It also highlights the importance of prompt reduction of dislocations (often performed emergently in the field or ER) to potentially minimize ongoing compression. While our study cannot prove that early reduction improved outcomes, it is standard care to realign the spine as soon as safely possible in fracture-dislocations [7].

Injury level (upper *vs.* lower cervical): We observed that lower cervical spine injuries (C5–C7) had somewhat better neurological outcomes than upper cervical (C1–C4) injuries. One reason is that the upper cervical cord contains the phrenic nerve nucleus (C3–C5) and more crucial pathways for respiration and upper limb function; injuries here often led to immediate respiratory failure or very high deficits (and indeed many upper cervical injury patients in our series died or remained ventilator-dependent). Lower cervical injuries, while resulting in severe quadriplegia, at least spare respiratory function and some upper arm function (C5 innervates the deltoid and biceps, for instance). This can translate to better rehabilitation potential – for example, a C5–C6 injured patient might eventually feed themselves with assistive devices, whereas a C2–C3 injured patient cannot without ventilatory support. Another consideration is that some upper cervical injuries (like atlanto-occipital dislocations or axis fractures) have high acute mortality rates due to brainstem involvement. Those who survive may have incomplete medullary injury (like central cord patterns). Our data, though limited, align with previous observations that outcomes tend to be better in injuries caudal to C4 [1]. Srinivas, et al. reported that patients with lower cervical (subaxial) injuries showed more improvement than those with upper cervical injuries [9].

It is important to clarify that if an upper cervical injury is incomplete and the patient survives, they certainly can recover (for example, central cord syndrome often occurs at C3–C4 and can have good outcomes in older patients). In our series, the difference in outcome by level largely reflected the fact that upper cervical injuries were often complete (due to high-energy trauma causing atlantoaxial dislocations), whereas many lower cervical injuries were incomplete (e.g., central cord syndrome from hyperextension at C5–C6). Thus, level by itself may not be an independent predictor when controlling for severity; it co-varies with injury severity in many cases. Nonetheless, from a clinical standpoint, a subaxial cervical injury has a relatively better prognosis than a craniocervical junction injury if neurological status is comparable, because the latter often involves more critical structures and has less redundancies.

Timing of intervention: All patients in this study who were surgical candidates underwent decompression and stabilization, typically within 24–72 hours of injury (earlier if possible, occasionally delayed for medical optimization). We did not have a non-surgical comparison in neurologically indicated cases, so we cannot directly assess the impact of surgery *vs.* no surgery. However, given that urgent surgical decompression is the current standard of care for traumatic spinal cord compression [5], we assume it contributed to the improvements seen. Animal and clinical evidence strongly support early decompression to improve outcomes [7]. A meta-analysis by Yousefifard, et al. [7] concluded that ultra-early (< 12 hours) decompression significantly increases odds of neurological improvement in cervical SCI [7]. In our setting, logistical factors sometimes led to surgery being done the next day rather than the same night, but all cord compressions were relieved as soon as feasible. We did not find a statistically clear difference based on hours to surgery, possibly because the variation in our cohort was not wide (most had surgery within 48 hours). Nonetheless, no patient in our series with ongoing cord compression was left unmanaged, so we cannot overemphasize that prompt surgical decompression and stabilization were integral parts of the management for the majority of our patients. The improved outcomes in many incomplete injury patients likely reflect the benefits of removing compressive lesions and stabilizing the spine to prevent further injury. Additionally, early stabilization allowed early mobilization and aggressive rehabilitation, which likely aided functional recovery.

Postoperative care and complications: Rehabilitation was a key component of our management, and the functional gains in FIM and Barthel scores reflect successful early rehab efforts. We did observe common post-surgical issues such as dysphagia, which affected about one-fifth of patients (transiently). This is consistent with reported rates of postoperative dysphagia after anterior cervical spine surgery [7]. Awareness and management of such sequelae are important to avoid additional morbidity (for example, ensuring a dysphagic patient receives a modified diet to prevent aspiration). Pain management and prevention of secondary complications (pressure ulcers, deep vein thromboses) were also priorities. Our relatively low complication rates (no surgical infections, etc.) can be attributed to adherence to good surgical technique and postoperative protocols.

Comparison with other studies: Our findings are remarkably consistent with those of a recent study by Jaiswal et al. [7], which was conducted in a similar setting and population [4]. In their prospective study of 63 CSI patients, they likewise found that incomplete injuries, shorter MRI lesion lengths, and absence of listhesis were significant predictors of neurological and functional improvement [4]. Both their study and ours used MRI to stratify injuries into edema *vs.* contusion and counted segments of cord involvement, arriving at the conclusion that ≤2 segment edema is associated with better recovery. The convergence of evidence from these two independent cohorts strengthens the validity of these prognostic indicators. There are few methodological differences between the studies: both were observational and performed in tertiary care hospitals with MRI and surgical capabilities. Jaiswal, et al. included ASIA grading and functional scoring (FIM, Barthel) at similar time points [4]. The outcomes were also similar, with significant improvements in FIM scores post-treatment in both studies. One difference is that our study provided a more granular description of symptoms and postoperative complications, whereas Jaiswal, et al. focused more on the statistical analysis of predictors. In terms of imaging analysis, both studies used midsagittal MRI and essentially the same definition of segments. The key messages are aligned: patients without cord hemorrhage and with limited edema have far better chances of neurological recovery; this is a reproducible finding. The concordance in conclusions (highlighting incomplete injuries and short edema as positive prognostic factors) cannot be overstated – it suggests that these factors should be universally considered by clinicians when counseling patients. Any differences in outcomes could be minor and sample-dependent. For example, we reported a 22% mortality at 4 months, which might differ in other settings depending on acute care and injury patterns; however, Jaiswal et al. also noted that many of their ASIA A patients failed to survive or improve, which is essentially the same observation phrased differently.

Our study and the study by Jaiswal SK, et al. both support an emerging consensus in the spinal trauma literature: the initial neurological status and MRI findings are paramount in predicting outcomes [4].

Hitti, et al. [10] identified that potentially modifiable factors like timely surgery and avoidance of secondary insults could influence outcomes, but non-modifiable factors (age, initial injury severity) set the stage. In our practice, we use these prognostic insights to set realistic rehabilitation goals. Patients with anticipated poor recovery (e.g., complete injuries with long contusions) are integrated early into plans for assistive devices, wheelchair mobility, and counseling for long-term dependency, while those with more favorable indicators are pushed aggressively in therapy to regain as much function as possible.

Our study differs from earlier studies by emphasizing MRI findings – it quantified the length of cord edema in segments and correlated it with outcomes, which previous series had not rigorously done. It also included functional outcome measures (FIM and Barthel Index) in addition to neurological status, providing a more comprehensive view of recovery.

Study limitations: We acknowledge certain limitations in our study. The sample size is moderate and drawn from a single institution, which may limit generalizability. Our follow-up duration of 4 months, while capturing early recovery, is relatively short for spinal cord injury – neurological improvements can continue for up to 1–2 years post-injury, especially in incomplete injuries. Thus, our outcome assessment might underestimate eventual recovery (some ASIA grades might improve further with time). We also did not perform a multivariate logistic regression due to the sample size; hence, we cannot definitively state which factor is independently the most powerful predictor among those correlated (for example, incomplete injury and short edema often co-exist, and our analysis considered them separately). Another limitation is that all surgical interventions were done in a relatively prompt manner without a comparative non-surgical group for severe injuries – thus, we cannot quantify the benefit of surgery, we assumed it as part of standard care. There was some heterogeneity in injury types (fracture patterns, etc.), but the cohort was too small to analyze specific fracture subtypes (e.g., hangman's fracture *vs.* flexion teardrop) in relation to outcomes. Additionally, our measurement of MRI lesion length by vertebral segments, while clinically practical, is somewhat coarse; advanced imaging metrics (like cord cross-sectional area or diffusion tensor imaging) were not employed and could provide more insight in future studies. Despite these limitations, the consistency of our findings with other contemporary studies suggests that our conclusions are on solid ground.

Future directions: Spinal cord injury research is rapidly evolving, with experimental therapies such as neuroprotective agents, stem cell transplants, and epidural stimulation showing promise. In prognostication, newer imaging techniques (e.g., MRI tractography, serum biomarkers of injury severity) might refine our ability to predict outcomes beyond the conventional MRI. Nonetheless, the simple measures identified here (neurologic exam and routine MRI) remain fundamental and widely applicable. Future studies with larger multicenter cohorts could apply multivariate modeling to confirm the independence of predictors like edema length and age. Additionally, long-term follow-up (beyond one year) would help determine the extent of late recovery and how our early predictors hold up over time.

From a clinical management perspective, our study underlines the importance of early MRI in all patients with cervical spine injury, not only for diagnosis but for prognosis. It also supports the practice of early surgical decompression – while we could not compare to non-surgical management for cord compression, the overall improvements seen align with the growing evidence that "time is spine" in acute SCI [4]. We also highlight the need for comprehensive care: rigorous medical management to reduce early mortality (addressing respiratory and cardiovascular complications in high cord injuries) and interdisciplinary rehabilitation to maximize functional outcomes.

In summary, our findings contribute to the body of evidence guiding clinicians on what to expect after a traumatic cervical SCI and which factors portend a better or worse outcome. This knowledge is crucial for patient counseling, goal setting, and potentially tailoring interventions (for instance, patients with hemorrhagic injuries might be prime candidates for experimental therapies, whereas those with just edema might recover well with standard care alone).

Conclusion

Traumatic cervical spine injuries continue to pose significant challenges in neurosurgery and rehabilitation. This prospective study demonstrates that certain key factors can reliably predict neurological and functional outcomes in these patients. Incomplete spinal cord injury (preservation of some motor or sensory function) is the most favorable prognostic factor for recovery, whereas complete injuries have dismal chances of significant improvement. MRI findings provide crucial prognostic information: patients whose MRI shows only edema of the spinal cord, especially if confined to ≤2 vertebral segments, are far more likely to recover neurologic function than those with extensive multi-segment cord lesions or intramedullary hemorrhagic contusions. The absence of major vertebral displacement (listhesis) at the injury level also correlates with better outcomes, reflecting a less severe initial cord insult. In our cohort, patients with these favorable factors achieved higher functional independence at 4 months, as evidenced by improved FIM scores, whereas those lacking them (complete injuries, long hemorrhagic cord lesions, unstable fracture-dislocations) largely remained severely impaired or succumbed to complications.

These findings reinforce the utility of early clinical assessment and MRI in guiding prognosis after cervical SCI. They align closely with results from other contemporary studies, underscoring a consistent message: the combination of an incomplete neurologic exam and limited MRI-detected cord damage bodes well for recovery, whereas complete transection-like injuries on exam and imaging portend poor outcomes. Overall, our study supports an aggressive management approach – including prompt surgical decompression/stabilization and intensive rehabilitation – particularly targeting those with potential for recovery, while also helping to set appropriate expectations in cases with poor prognostic indicators.

In practical terms, the mean FIM score at 4 months was significantly higher in patients with edema spanning ≤2 segments on MRI compared to those with >2 segments, and no patient with a hemorrhagic cord injury regained useful motor function. Such information can be invaluable when formulating individualized treatment plans and counseling families. It also highlights avenues for future research: patients with initially unfavorable features might be candidates for novel neurorestorative treatments, and serial MRI might be used to monitor the resolution of edema as a surrogate for recovery.

In conclusion, early prognostic assessment in traumatic cervical spine injury should incorporate both the neurological examination (particularly ASIA grading) and MRI-based metrics (lesion length and characterization). This combined approach enables clinicians to identify patients who are likely to benefit most from aggressive intervention and those who may require a focus on supportive care and adaptation to long-term disability. By recognizing the predictors of improvement, we can optimize resource allocation, tailor rehabilitation goals, and possibly improve outcomes through timely interventions in this vulnerable patient population. Our study adds to the evidence that incomplete cervical injuries with short-segment cord edema and a stable spine may experience meaningful recovery , offering a measure of hope amid these devastating injuries.

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