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Early Postoperative Neurological Changes After Surgical Treatment of Traumatic Spinal Injury: A Retrospective Cohort Study

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Abstract

Introduction: Early neurological changes after surgical treatment of traumatic spinal injury are heterogeneous and may be influenced by baseline neurological status, injury characteristics, and the timing of assessment. This study aimed to describe early postoperative changes in American Spinal Injury Association Impairment Scale (AIS) grade and explore factors associated with neurological improvement.

Methods: This retrospective observational cohort study included adults who underwent surgery for documented traumatic spinal injury at a tertiary spine center in Mexico City, Mexico, between February 2025 and May 2026. The primary outcome was an increase of at least one AIS grade between the preoperative examination and the latest documented postoperative assessment. Associations between anatomical region and neurological improvement were examined, and an exploratory multivariable logistic regression model was fitted. Bootstrap resampling with 1,000 requested samples was used to examine coefficient uncertainty; the available bias-corrected and accelerated (BCa) 95% confidence interval was reported for the relevant coefficient estimate.

Results: Fifty-two patients were included (mean age, 39.9 ± 12.2 years; 43 (82.7%) male). Baseline AIS grades were A in 18 patients (34.6%), B in two (3.8%), C in one (1.9%), D in 29 (55.8%), and E in two (3.8%). At the latest documented postoperative assessment, 24 patients (46.2%) had improved by at least one AIS grade, 27 (51.9%) remained unchanged, and one (1.9%) experienced neurological deterioration. Improvement rates ranged from 30.0% in cervical/cervicothoracic injuries to 53.8% in lumbar injuries; the association between anatomical region and improvement was not statistically significant (Pearson $\chi^2 = 1.418$, df = 3, p = 0.701). The exploratory multivariable model, which included 50 patients, was not statistically significant overall ($\chi^2 = 5.930$, df = 6, p = 0.431; Nagelkerke $R^2 = 0.149$), and no individual predictor was statistically significant. Bootstrap analysis showed substantial uncertainty in some coefficient estimates. Four recorded transitions from AIS A to AIS E could not be independently validated from all required examination components. Median postoperative follow-up was 33 days (interquartile range, 21-55.5 days).

Conclusions: Nearly half of the cohort had a recorded increase of at least one AIS grade during postoperative follow-up. However, the short and variable assessment interval, uncertainty surrounding several AIS grade transitions that could not be confirmed through the available clinical documentation, and instability of exploratory multivariable estimates limit interpretation. These findings describe early postoperative neurological changes and do not establish long-term recovery, independent prognostic associations, or a causal effect of surgery.

Categories: Trauma, Orthopedics, Neurosurgery
Keywords: ais scale, neurological recovery, retrospective cohort, spinal decompression, spinal stabilization, traumatic spinal cord injury

Introduction

Traumatic spinal cord injury (TSCI) can cause motor, sensory, and autonomic impairment, disability, and long-term socioeconomic consequences. Surgical decompression and stabilization are considered when spinal instability, persistent neural compression, or other structural indications are present. Decompression is intended to address ongoing compression, whereas stabilization supports spinal alignment and mechanical integrity [1,2].

The timing of decompressive surgery has received considerable attention in acute TSCI. Clinical practice guidelines suggest that early decompression (within 24 hours) may be offered as an option for adults with acute spinal cord injury. However, the strength of recommendations and available evidence must be considered [2]. Observed neurological changes are also influenced by baseline severity, injury characteristics, anatomical level, medical management, and rehabilitation [2-5]. The Surgical Timing in Acute Spinal Cord Injury Study provided evidence regarding early decompression in cervical TSCI [3].

The International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI) and the associated American Spinal Injury Association Impairment Scale (AIS) provide a standardized framework for describing neurological impairment. AIS grades range from A, indicating a complete injury under the classification criteria, to E, indicating normal sensory and motor function on examination [6,7]. Previous studies have examined baseline neurological severity, surgical timing, and magnetic resonance imaging (MRI) characteristics in relation to neurological change [4,8-10].

Anatomical terminology requires particular care in lumbar injuries because lesions at or below the conus medullaris may involve the cauda equina rather than the spinal cord. These conditions may differ in anatomy and recovery patterns. In addition, a baseline AIS E classification indicates normal sensory and motor findings on examination and requires careful interpretation when included in a cohort labelled as traumatic spinal cord injury.

Regional data from Mexico remain limited. Martínez-Padilla et al. described preoperative and postoperative neurological changes in patients with traumatic spinal injury using sequential clinical records [11]. This study aimed primarily to describe early postoperative changes in AIS grade by comparing the preoperative examination with the latest documented postoperative assessment. The secondary objective was to explore selected demographic, baseline neurological, and anatomical characteristics in relation to improvement. Given the retrospective design and sample size, these association analyses were exploratory.

Materials And Methods

Study design and setting

This retrospective observational cohort study included adults who underwent surgical treatment for documented traumatic spinal injury between February 2025 and May 2026 at Hospital General “La Villa,” Clínica de Columna “Dr. Manuel Dufoo Olvera,” IMSS-Bienestar, Mexico City, Mexico. The study was reported with reference to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) recommendations for cohort studies [12].

Eligibility and patient selection

Patients were eligible if they were aged 18 years or older, had a traumatic spinal injury documented in the medical record, underwent surgical treatment, and had documented preoperative and postoperative AIS assessments. Traumatic etiology was established from the documented clinical diagnosis and supporting clinical and imaging information available in the medical record. AIS/ISNCSCI assessments were used to characterize neurological impairment, while the AO Spine classification was used to describe injury morphology when documented. Patients with documented non-traumatic degenerative conditions or suspected neoplastic pathology were excluded.

For this study, TSCI was used as the operational term for the traumatic injuries included in the cohort, based on the documented clinical diagnoses and neurological assessments. However, the retrospective records did not consistently distinguish injuries involving the conus medullaris from those involving the cauda equina in the lumbar subgroup; therefore, these anatomical subgroups could not be systematically differentiated in the analysis.

A total of 60 medical records were screened for eligibility. Eight records were excluded because they did not meet the predefined eligibility criteria, including non-traumatic degenerative spinal disease, suspected vertebral neoplasia, or insufficient documentation to establish eligibility or confirm the availability of the required preoperative and postoperative AIS assessments. The remaining 52 patients met the eligibility criteria and had documented preoperative and postoperative AIS assessments. Patients who died before hospital discharge were not included among the 60 records identified for screening. Therefore, the 60 records represent the available eligibility-screening set rather than a verified count of all surgically treated patients during the study period, and the cohort should not be considered a complete consecutive surgical series. The patient selection process and the resulting analytical cohorts are illustrated in Figure *1*.

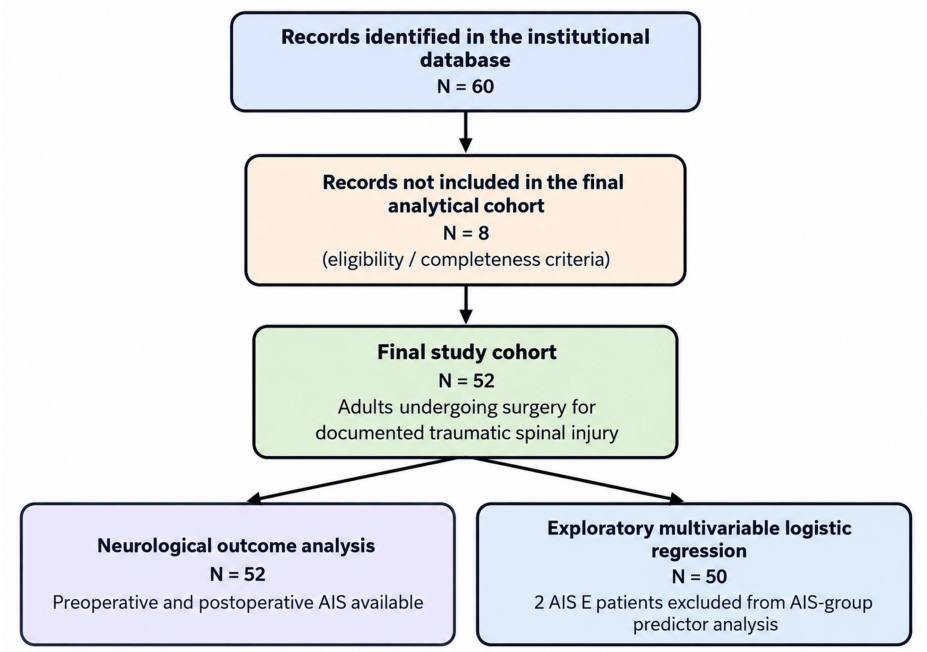


FIGURE 1: Patient Selection and Analytical Cohorts.

AIS, American Spinal Injury Association Impairment Scale. The figure was created using Microsoft PowerPoint (Microsoft Corporation, Redmond, USA).

The two patients classified as AIS E at baseline were retained in the descriptive cohort because they were present in the finalized dataset. Because AIS E denotes normal sensory and motor function on examination, these patients could not meet the primary outcome definition of an increase in AIS grade. A sensitivity analysis excluding these two patients was therefore considered separately from the primary descriptive analysis.

Neurological assessment and outcomes

Preoperative and postoperative neurological classifications were retrospectively abstracted from examinations documented in the medical records. During hospitalization, neurological examinations were performed every eight hours as part of routine clinical monitoring and documented in the medical record. Examinations were conducted by licensed physicians with backgrounds in orthopedics or neurosurgery who were completing a two-year specialized training program in spine surgery under the supervision of physicians with postgraduate qualifications in spine surgery. After discharge, patients were scheduled for reassessment every six days. The preoperative AIS grade was defined as the documented examination before surgery, whereas the postoperative AIS grade corresponded to the latest documented examination available for each patient. The median interval from surgery to the latest postoperative assessment was 33 days (interquartile range: 21-55.5 days). The records did not consistently establish whether all components required for formal ISNCSCI classification, including sacral sensory and motor findings, were documented at every assessment, and examiner training could not be independently verified retrospectively. The exact interval between injury or admission and the preoperative examination was also not consistently available. These limitations are particularly relevant to the interpretation of extreme AIS grade transitions.

AIS grades were coded A=1, B=2, C=3, D=4, and E=5 solely to describe the direction of ordinal change; this coding does not imply equal clinical distance between grades. ΔAIS was calculated as the postoperative grade minus the preoperative grade. The primary outcome was an increase of at least one AIS grade at the latest documented postoperative assessment. Patients with no change were classified as unchanged, and a decrease in grade was classified as neurological deterioration. Given the short and variable follow-up, this outcome is referred to as early postoperative AIS change rather than long-term recovery.

Anatomical classification

The principal anatomical region documented in the clinical record was classified into four groups: cervical/cervicothoracic, thoracic/thoracolumbar, lumbar, and multilevel. Injuries involving more than one distinct spinal region were classified as multilevel. The records did not consistently permit lumbar cases to be separated into conus medullaris and cauda equina injuries; this limits the clinical homogeneity of the lumbar category.

Surgical treatment

Surgical management was individualized according to the documented injury, spinal instability, morphology, neurological status, and neural compression. Procedures included anterior and posterior approaches, combined anterior-posterior procedures, fusion and/or instrumentation, laminectomy, discectomy, and corpectomy. Categories were not mutually exclusive because individual patients could undergo more than one procedure. For one patient, the dedicated procedure field was incomplete and the procedure was abstracted from the detailed operative description.

Timing of surgery and follow-up

The exact interval between injury and surgery could not be reliably determined for all patients because injury dates and times were inconsistently documented, particularly for patients transferred from other facilities. No injury-to-surgery intervals were imputed. Postoperative assessments were not performed at a uniform time point; the latest documented examination was used. The median interval from surgery to this assessment was 33 days (IQR, 21-55.5 days).

Statistical analysis

Analyses were performed using IBM SPSS Statistics for Windows, Version 25 (Released 2017; IBM Corp., Armonk, New York, United States). Continuous variables were summarized as means and standard deviations or medians and interquartile ranges, as appropriate, while categorical variables were summarized as counts and percentages. Preoperative and postoperative AIS grades were compared using the Wilcoxon signed-rank test. This paired comparison was interpreted as a within-cohort assessment of recorded neurological change rather than evidence of a causal surgical effect. Associations between ΔAIS and age or follow-up duration were explored using Spearman's rank correlation. The association between anatomical region and neurological improvement was assessed using Pearson's chi-square test, with Monte Carlo simulation used to estimate the p-value because of the small regional subgroup sizes.

An exploratory multivariable logistic regression analysis was performed in 50 patients to examine the association between neurological improvement, defined as an increase of at least one AIS grade, and baseline AIS grade, age, sex, and anatomical region. The two patients with baseline AIS grade E were excluded because further improvement in AIS grade could not be assessed. Given the limited sample size, the 24 improvement events, and the number of parameters included in the model, the analysis was considered exploratory because of the potential for overfitting and sparse-data bias. Model fit was assessed using the likelihood-ratio chi-square test and the Hosmer-Lemeshow test, and explanatory performance was summarized using Nagelkerke's R^2. Adjusted odds ratios (ORs) and 95% confidence intervals (CIs) were reported.

Bootstrap resampling was requested for 1,000 samples to examine coefficient uncertainty. BCa 95% CIs were reported for coefficients for which valid estimates were available. The number of valid resamples was recorded for the relevant coefficient calculations. Bootstrap results were interpreted as an assessment of coefficient uncertainty rather than as evidence of model validation or predictive performance. Descriptive sensitivity analyses were conducted to assess the potential influence of classification uncertainty and anatomical heterogeneity on the observed neurological improvement proportion. These analyses included treating the four recorded AIS A-to-E transitions as unconfirmed improvements, excluding the two patients with baseline AIS grade E, and excluding patients with lumbar-region injuries. The resulting proportions were compared descriptively with the primary recorded improvement estimate. These analyses were not intended to establish causal effects or independently validate the neurological classifications. All statistical tests were two-sided, with $p < 0.05$ considered statistically significant.

Ethical considerations

The study was reviewed and approved by the Research Ethics Committee of Hospital General La Villa (registration number 2060101725; approval date March 20, 2026). The committee classified the study as no-risk research involving retrospective review of existing medical records and waived the requirement for informed consent. Patient confidentiality was maintained throughout the study.

Results

Study population

A total of 60 medical records were screened for eligibility. Eight records were excluded because they did not meet the predefined eligibility criteria, including non-traumatic degenerative spinal disease, suspected vertebral neoplasia, or insufficient documentation to establish eligibility or confirm the availability of the required preoperative and postoperative AIS assessments. The remaining 52 patients had documented preoperative and postoperative AIS assessments and were included in the final cohort. Patients who died before hospital discharge were not included among the 60 records identified for screening; therefore, the study population does not represent a verified consecutive series of all surgically treated patients during the study period.

The mean age was 39.9 ± 12.2 years (range: 18-68), and 43 patients (82.7%) were male, and nine (17.3%) were female. Baseline AIS grade was D in 29 patients (55.8%), A in 18 patients (34.6%), B in two patients (3.8%), C in one patient (1.9%), and E in two patients (3.8%). Anatomical regions were cervical/cervicothoracic in 10 patients (19.2%), thoracic/thoracolumbar in 25 patients (48.1%), lumbar in 13 patients (25.0%), and multilevel in four patients (7.7%). According to the AO Spine morphology classification recorded in the dataset, 39 injuries (75.0%) were type A (A1, A3, or A4), six (11.5%) were type B (B1 or B2), and seven (13.5%) were type C. The recorded AO subtypes were A1 in four patients (7.7%), A3 in nine patients (17.3%), A4 in 26 patients (50.0%), B1 in two patients (3.8%), B2 in four patients (7.7%), and C in seven patients (13.5%). The median interval from surgery to the latest documented postoperative assessment was 33 days (IQR: 21-55.5; range: 1-358 days). The baseline demographic, neurological, anatomical, and injury-morphology characteristics of the cohort are summarized in Table *1*.

Characteristic	Overall (n=52)
Age, years, mean ± SD	39.9 ± 12.2
Age range, years	18–68
Male sex, n (%)	43 (82.7)
Female sex, n (%)	9 (17.3)
Baseline AIS A, n (%)	18 (34.6)
Baseline AIS B, n (%)	2 (3.8)
Baseline AIS C, n (%)	1 (1.9)
Baseline AIS D, n (%)	29 (55.8)
Baseline AIS E, n (%)	2 (3.8)
Cervical/cervicothoracic, n (%)	10 (19.2)
Thoracic/thoracolumbar, n (%)	25 (48.1)
Lumbar, n (%)	13 (25.0)
Multilevel, n (%)	4 (7.7)
AO Spine type A, n (%)	39 (75.0)
AO Spine type B, n (%)	6 (11.5)
AO Spine type C, n (%)	7 (13.5)
AO Spine subtype A1, n (%)	4 (7.7)
AO Spine subtype A3, n (%)	9 (17.3)
AO Spine subtype A4, n (%)	26 (50.0)
AO Spine subtype B1, n (%)	2 (3.8)
AO Spine subtype B2, n (%)	4 (7.7)
AO Spine subtype C, n (%)	7 (13.5)
Postoperative follow-up, days, median (IQR)	33 (21–55.5)
Postoperative follow-up range, days	1–358

TABLE 1: Baseline Demographic, Neurological, Anatomical, and Injury-Morphology Characteristics.

AIS, American Spinal Injury Association Impairment Scale; AO Spine, AO Foundation/Spine classification; IQR, interquartile range; SD, standard deviation.

Surgical procedures

A posterior surgical approach was documented in 45 patients (86.5%), whereas an anterior approach was documented in 23 (44.2%); 18 patients (34.6%) underwent combined anterior and posterior procedures.

Posterior-only procedures were documented in 27 patients (51.9%), and anterior-only procedures in five patients (9.6%). Two additional records described corpectomy or removal of osteosynthesis material without specifying an anterior or posterior approach in the procedure field; therefore, these cases could not be assigned to a specific approach category based on the available documentation. Regarding specific surgical procedures, laminectomy was documented in 15 patients (28.8%), discectomy in 11 patients (21.2%), corpectomy in 10 patients (19.2%), and costotransversectomy in four patients (7.7%). Exploration or decompression of the spinal canal was documented in four patients (7.7%), and spinal fusion procedures were recorded in 49 patients (94.2%). Because several patients underwent multiple procedures, these categories were not mutually exclusive. The documented surgical approaches and procedures in the final cohort are summarized in Table 2.

Procedure/approach	n (%)
Posterior approach documented	45 (86.5)
Anterior approach documented	23 (44.2)
Combined anterior and posterior	18 (34.6)
Posterior-only	27 (51.9)
Anterior-only	5 (9.6)
Laminectomy	15 (28.8)
Discectomy	11 (21.2)
Corpectomy	10 (19.2)
Costotransversectomy	4 (7.7)
Spinal canal exploration/decompression	4 (7.7)
Fusion procedure documented	49 (94.2)
Removal of osteosynthesis material	1 (1.9)

TABLE 2: Documented Surgical Procedures in the Final Cohort.

Approach and procedure categories were not mutually exclusive because several patients underwent multiple procedures, including combined anterior and posterior approaches. Two records did not specify an anterior or posterior approach in the procedure field.

Neurological outcomes

At the latest documented postoperative assessment, 12 patients (23.1%) were classified as AIS A, four (7.7%) as AIS B, two (3.8%) as AIS C, 12 (23.1%) as AIS D, and 22 (42.3%) as AIS E. The preoperative-to-postoperative distribution of recorded AIS grades is presented in Table 3. Overall, 24 patients (46.2%) had an increase of at least one AIS grade, 27 (51.9%) had no grade change, and one (1.9%) experienced neurological deterioration. The median change in AIS grade (ΔAIS) was 0 (IQR: 0-1), with a range from −4 to +4.

Preoperative AIS	Post-op A	Post-op B	Post-op C	Post-op D	Post-op E	Total
A	11	2	1	0	4	18
B	0	2	0	0	0	2
C	0	0	1	0	0	1
D	0	0	0	12	17	29
E	1	0	0	0	1	2
Total	12	4	2	12	22	52

TABLE 3: Preoperative-to-Postoperative AIS Transition Matrix.

Rows indicate preoperative AIS grade, and columns indicate the latest documented postoperative AIS grade. AIS, American Spinal Injury Association Impairment Scale. Transitions represent recorded classifications and should not be interpreted as independently verified neurological conversions.

Four patients had recorded transitions from AIS A to AIS E (Table 3). The available records described early management, within 48 hours as reported in the clinical documentation, and improvement in sphincter function. However, improvement in sphincter function alone does not establish AIS E, which requires normal sensory and motor findings on a standardized ISNCSCI examination. Because all required examination components could not be independently verified retrospectively, these cases are reported as recorded transitions rather than confirmed AIS conversions. In a conservative sensitivity scenario in which these four transitions were treated as unconfirmed improvements, 20 of 52 patients (38.5%) would have been classified as improved, compared with the primary recorded estimate of 24 of 52 (46.2%). This scenario illustrates the potential influence of uncertainty in the retrospective documentation and does not replace verification of the original patient-level records.

The single recorded transition from AIS E to AIS A (1/52, 1.9%) was documented in association with an intraoperative complication and an adverse functional outcome. The transition matrix also permits assessment of recorded neurological improvement according to baseline AIS grade. Improvement was documented in 7 of 18 patients with baseline AIS A (38.9%), none of the two patients with AIS B (0%), none of the patients with AIS C (0%), 17 of 29 patients with AIS D (58.6%), and none of the two patients with AIS E (0%). After excluding the two patients classified as AIS E at baseline, the proportion with recorded improvement was 24 of 50 (48.0%). In a separate descriptive sensitivity analysis excluding all 13 patients with lumbar-region injuries, improvement was recorded in 17 of 39 patients (43.6%). These analyses are descriptive and do not establish treatment effects.

The Wilcoxon signed-rank test indicated a statistically significant difference between the recorded preoperative and postoperative AIS grades (Wilcoxon $Z = -3.968$, $p < 0.001$). This finding reflects changes in the recorded classifications and should not be interpreted as evidence that surgery caused neurological improvement. Age was not significantly correlated with ΔAIS (Spearman $\rho = -0.171$, $p = 0.224$), nor was the follow-up duration (Spearman $\rho = 0.206$, $p = 0.143$).

Neurological improvement by anatomical region

Improvement was recorded in three of 10 cervical/cervicothoracic cases (30.0%), 12 of 25 thoracic/thoracolumbar cases (48.0%), seven of 13 lumbar cases (53.8%), and two of four multilevel cases (50.0%). The association between anatomical region and neurological improvement was not statistically significant (Pearson $\chi^2 = 1.418$, $df = 3$, Monte Carlo-estimated $p = 0.701$). These rates are presented primarily descriptively because the regional groups were small. The available records did not consistently distinguish conus medullaris from cauda equina injuries within the lumbar category.

Exploratory multivariable logistic regression

An exploratory multivariable logistic regression analysis was performed in 50 patients; the two patients with baseline AIS grade E were excluded from the predictor analysis. The overall model was not statistically significant ($\chi^2 = 5.930$, $df = 6$, $p = 0.431$; Nagelkerke $R^2 = 0.149$). The Hosmer-Lemeshow test was also not statistically significant ($\chi^2 = 5.895$, $df = 8$, $p = 0.659$), and the overall classification accuracy was 68.0%. None of the individual predictors showed a statistically significant association with neurological improvement. Given the small sample size, 24 improvement events, nine female patients, and wide CIs, the model was vulnerable to overfitting and sparse-data bias. Accordingly, these estimates should be interpreted as exploratory and do not establish independent prognostic associations. Adjusted ORs and 95% CIs are presented in Table 4.

Predictor	Adjusted OR	95% CI	p-value
AIS B-D vs AIS A	1.196	0.323-4.424	0.789
Age, per year	0.964	0.912-1.019	0.191
Male vs. female	0.358	0.058-2.213	0.269
Thoracic/thoracolumbar vs. cervical/cervicothoracic	2.545	0.456-14.197	0.287
Lumbar vs. cervical/cervicothoracic	2.044	0.317-13.168	0.452
Multilevel vs. cervical/cervicothoracic	2.732	0.241-30.922	0.417

TABLE 4: Exploratory Multivariable Logistic Regression for Neurological Improvement.

The model included 50 patients; two patients with baseline AIS grade E were excluded from the predictor analysis. AIS, American Spinal Injury Association Impairment Scale; OR, odds ratio; CI, confidence interval.

Bootstrap analysis

Bootstrap resampling was requested for 1,000 samples using the same 50 patients included in the exploratory logistic regression. The BCa 95% CI for the male-sex coefficient ranged from −21.124 to 0.315 on the regression coefficient scale, based on 988 valid resamples for the relevant coefficient calculation. This wide interval indicates substantial uncertainty in the estimated coefficient. Although instability was also a concern for anatomical-region indicators, BCa CIs for all model coefficients were not available for reporting. Accordingly, the bootstrap findings were interpreted as evidence of uncertainty in the available coefficient estimates, not as evidence of internal validation or predictive performance.

Discussion

This retrospective cohort study describes early postoperative neurological changes among 52 adults who underwent surgical treatment for traumatic spinal injury. At the latest documented postoperative assessment, 24 patients (46.2%) had an increase of at least one AIS grade, 27 (51.9%) remained unchanged, and one (1.9%) experienced neurological deterioration. Although these findings indicate that changes in recorded neurological classification occurred during the postoperative observation period, they should be interpreted as early documented changes rather than evidence of sustained neurological recovery or a causal effect of surgery. The median follow-up was 33 days, and the timing of postoperative assessments varied among patients.

The distinction between early postoperative neurological changes and long-term recovery is clinically important. Neurological recovery after TSCI is influenced by multiple factors, including baseline neurological severity, injury level and morphology, secondary injury processes, medical management, and rehabilitation. Natural-history studies indicate that most AIS grade conversions and motor recovery occur within the first 6-9 months after injury, with the fastest motor recovery generally occurring during the first three months [13]. Accordingly, the short and variable follow-up in this cohort limits comparisons with studies assessing outcomes at six months or later. Although current guidelines recommend considering early surgical decompression as an option for adults with acute spinal cord injury [14], injury-to-surgery intervals could not be reliably established for all patients in this retrospective dataset, precluding an assessment of the relationship between surgical timing and neurological outcomes. Furthermore, because all patients underwent surgical treatment and no nonsurgical comparison group was available, the observed improvement proportion of 46.2% should be interpreted as a descriptive finding rather than an estimate of the treatment effect of decompression or stabilization or of long-term neurological recovery.

The cohort included injuries across cervical/cervicothoracic, thoracic/thoracolumbar, lumbar, and multilevel regions. Neurological improvement was recorded in 30.0% of patients with cervical/cervicothoracic injuries, 48.0% with thoracic/thoracolumbar injuries, 53.8% with lumbar injuries, and 50.0% with multilevel injuries. The association between anatomical region and improvement was not statistically significant (Pearson χ^2 = 1.418, df = 3, Monte Carlo-estimated p = 0.701). These findings do not establish that neurological improvement is equivalent across anatomical regions; rather, the small subgroup sizes limit the precision and statistical power of these comparisons. The lumbar category also included injuries for which the available records did not consistently distinguish conus medullaris involvement from cauda equina injury. This anatomical heterogeneity complicates the interpretation of neurological outcomes because these conditions differ in their underlying neural structures and may have different patterns of recovery.

Fracture morphology was described using the AO Spine classification. Type A injuries accounted for 39 patients (75.0%), type B for six (11.5%), and type C for seven (13.5%). These categories characterize fracture

morphology and should be distinguished from the anatomical-region groups used in the regional outcome analysis. The present study was not designed or powered to determine whether AO Spine fracture type independently predicts neurological improvement. Accordingly, the distribution of fracture patterns provides descriptive information about the cohort but does not support conclusions regarding the comparative neurological prognosis of individual fracture types.

The exploratory multivariable logistic regression analysis included 50 patients because the two patients classified as AIS E at baseline were excluded from the predictor analysis. The overall model was not statistically significant ($\chi^2 = 5.930$, df = 6, p = 0.431; Nagelkerke $R^2 = 0.149$). The Hosmer-Lemeshow test was also not statistically significant ($\chi^2 = 5.895$, df = 8, p = 0.659), and the overall classification accuracy was 68.0%. None of the included predictors-baseline AIS group, age, sex, or anatomical region-showed a statistically significant association with neurological improvement. These results should not be interpreted as evidence that these characteristics lack prognostic relevance. Instead, the limited sample size, the number of outcome events, the small number of female patients, and the wide CIs reduce the precision of the adjusted estimates and increase the risk of overfitting and sparse-data bias. The model was therefore exploratory and was not intended to establish an independently validated prognostic model.

Bootstrap resampling was used to examine the stability of the regression coefficients. Although 1,000 resamples were requested, SPSS reported 988 valid resamples for the relevant individual coefficient calculations. The substantial uncertainty observed in some coefficients, particularly those for sex and anatomical-region indicators, further limits the interpretation of the multivariable results. The BCa interval reported for the male-sex coefficient ranged from −21.124 to 0.315 on the log-odds coefficient scale, illustrating the instability of this estimate. Bootstrap resampling does not eliminate the limitations associated with a small sample or sparse data and should not be interpreted as external validation, proof of predictive performance, or evidence that the model will generalize to other populations.

The recorded transitions between AIS grades warrant particular consideration. Four patients were documented as transitioning from AIS A preoperatively to AIS E postoperatively. Although these transitions contributed to the overall proportion of patients classified as having neurological improvement, their validity could not be independently established from the available retrospective documentation. AIS A requires the absence of sacral sensory and motor sparing, whereas AIS E requires normal sensory and motor findings on a standardized ISNCSCI examination [6,7]. Although the clinical records described management within 48 hours and subsequent improvement in sphincter function, these findings alone are insufficient to confirm an AIS E classification or establish a causal relationship between early treatment and the recorded neurological changes. Furthermore, spinal shock may temporarily alter reflex activity following acute spinal cord injury, underscoring the importance of examination timing and careful assessment of sacral sensory and motor function [15]. The retrospective dataset did not consistently permit verification of all required ISNCSCI examination components or examiner qualifications. Accordingly, these four cases should be interpreted as recorded AIS grade transitions that could not be confirmed through the available clinical documentation, rather than as independently verified neurological conversions. In a conservative sensitivity scenario treating these transitions as unconfirmed improvements, the observed improvement proportion decreased from 46.2% (24/52) to 38.5% (20/52). This scenario illustrates the potential influence of classification uncertainty on the estimated improvement rate but does not substitute for verification against the original clinical records.

One patient was recorded as deteriorating from baseline AIS E to postoperative AIS A in association with a documented intraoperative complication. This event highlights the importance of reporting neurological deterioration alongside improvement. However, a single event in a small retrospective cohort cannot establish a reliable complication rate or support conclusions about the neurological risks of a particular surgical procedure.

The principal contribution of this study is its description of early postoperative AIS changes in a surgically treated cohort and its identification of issues that affect the interpretation of retrospective neurological classifications. The regional comparisons and multivariable analyses provide exploratory information but do not establish independent prognostic associations. Future prospective studies should include clearly defined injury populations, standardized ISNCSCI examinations performed by appropriately trained examiners, verified preoperative and postoperative classifications, prespecified assessment intervals, detailed injury characterization, and follow-up extending to at least six months. Larger cohorts would also be required to evaluate the independent contributions of neurological severity, anatomical region, fracture morphology, and treatment-related factors to neurological outcomes [2,3,13,14].

Limitations

This study has several limitations. First, its retrospective, single-center design introduces potential selection and information bias and limits the generalizability of the findings. Second, the sample size was relatively small, comprising 52 patients and 24 recorded neurological improvement events. This limited the precision of subgroup comparisons and the reliability of multivariable estimates.

Third, postoperative neurological assessments were not obtained at a standardized time point. The median

follow-up was 33 days, with substantial variation in assessment timing; therefore, the primary outcome reflects early documented neurological changes rather than long-term recovery. Patients with different observation periods may also have had different opportunities to demonstrate AIS grade conversion.

Fourth, the absence of a nonsurgical comparison group prevents attribution of the observed neurological changes specifically to surgical treatment. The cohort also included heterogeneous anatomical regions, fracture morphologies, and surgical procedures, preventing meaningful comparisons of the neurological effects of individual interventions. In addition, the available records did not consistently distinguish conus medullaris injuries from cauda equina injuries within the lumbar category.

Fifth, the exploratory multivariable logistic regression was based on a limited number of patients and outcome events relative to the number of model parameters. The wide CIs and instability observed during bootstrap resampling indicate substantial uncertainty in some coefficient estimates. Accordingly, the model should not be interpreted as a validated prognostic tool, and the absence of statistically significant predictors should not be taken as evidence that the examined factors have no prognostic relevance.

Sixth, the completeness of the original ISNCSCI examinations, including the sensory and motor findings required to verify AIS classification, and the training of the examiners could not be independently confirmed retrospectively. This limitation is particularly important for the four recorded AIS A-to-E transitions. The single AIS E-to-A transition was documented in association with an intraoperative complication. These cases require careful interpretation because the available dataset cannot fully distinguish genuine neurological change from potential examination, classification, or documentation uncertainty.

Finally, some potentially relevant clinical variables and time intervals were not consistently available for systematic analysis. These included detailed injury-to-surgery timing, standardized motor scores, functional outcomes, and sufficiently detailed neurological examinations to characterize all injury patterns. These limitations constrain the interpretation of observed associations and emphasize the need for prospective studies with standardized assessments, complete clinical documentation, and longer follow-up.

Conclusions

In this retrospective cohort of adults undergoing surgical treatment for traumatic spinal injury, early postoperative changes in recorded AIS grades were observed. These findings highlight the variability of neurological outcomes and should be interpreted cautiously given the retrospective design, short and variable follow-up, and limitations in the verification of neurological classifications. The association between anatomical region and neurological improvement was not statistically significant, and the exploratory multivariable logistic regression did not identify statistically significant independent predictors. Bootstrap resampling demonstrated substantial uncertainty in some model coefficients.

These findings describe early postoperative changes in recorded neurological classification and should not be interpreted as evidence of long-term neurological recovery or a causal effect of surgery. The short and variable follow-up, small sample size, instability of multivariable estimates, and uncertainty surrounding several extreme AIS transitions warrant cautious interpretation. Larger prospective studies using standardized and verified ISNCSCI examinations, clearly characterized injury patterns, and consistent follow-up are needed to better evaluate neurological outcomes and potential prognostic factors after traumatic spinal injury.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

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Disclosures

Human subjects: Informed consent for treatment and open access publication was obtained or waived by all participants in this study. Research Ethics Committee of Hospital General La Villa issued approval 2060101725, dated March 20, 2026. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

References

1. Ahuja CS, Badhiwala JH, Fehlings MG: "Time is spine": the importance of early intervention for traumatic spinal cord injury. Spinal Cord. 2020, 58:1037-9. 10.1038/s41393-020-0477-8
2. Fehlings MG, Hachem LD, Tetreault LA, et al.: Timing of decompressive surgery in patients with acute spinal cord injury: systematic review update. Global Spine J. 2024, 14:38S-57S. 10.1177/21925682231197404
3. Fehlings MG, Vaccaro A, Wilson JR, et al.: Early versus delayed decompression for traumatic cervical spinal cord injury: results of the Surgical Timing in Acute Spinal Cord Injury Study (STASCIS). PLoS One. 2012, 7:e32037. 10.1371/journal.pone.0032037
4. Hosman AJ, Barbagallo G, van Middendorp JJ: Neurological recovery after early versus delayed surgical decompression for acute traumatic spinal cord injury. Bone Joint J. 2023, 105-B:400-11. 10.1302/0301-620X.105B4.BJJ-2022-0947.R2
5. Kalampokis A, Benetos IS, Vasiliadis E, Pneumaticos SG: A review of the literature on surgical management in the acute phase of spinal cord injury: expected outcomes and the influence of surgical timing. Cureus. 2025, 17:e84066. 10.7759/cureus.84066
6. Marino RJ, Barros T, Biering-Sorensen F, et al.: International standards for neurological classification of spinal cord injury. J Spinal Cord Med. 2003, 26 Suppl 1:S50-6. 10.1080/10790268.2003.11754575
7. The 2019 revision of the International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI)-what's new?. Spinal Cord. 2019, 57:815-7. 10.1038/s41393-019-0350-9
8. Aarabi B, Sansur CA, Ibrahimi DM, et al.: Intramedullary lesion length on postoperative magnetic resonance imaging is a strong predictor of ASIA Impairment Scale grade conversion following decompressive surgery in cervical spinal cord injury. Neurosurgery. 2017, 80:610-20. 10.1093/neuros/nyw053
9. Qadir I, Riew KD, Alam SR, Akram R, Waqas M, Aziz A: Timing of surgery in thoracolumbar spine injury: impact on neurological outcome. Global Spine J. 2020, 10:826-31. 10.1177/2192568219876258
10. Kamal R, Verma H, Narasimhaiah S, Chopra S: Predicting the role of preoperative intramedullary lesion length and early decompressive surgery in ASIA Impairment Scale grade improvement following subaxial traumatic cervical spinal cord injury. J Neurol Surg A Cent Eur Neurosurg. 2023, 84:144-56. 10.1055/s-0041-1740379
11. Martínez-Padilla LA, Dufoo-Olvera M, García-López OF, López-Palacios JJ, Carranco-Toledo GA, Aburto-Trejo JA: Pre- and post-surgical neurological changes in patients with traumatic spinal cord injury based on the analysis of their sequential medical history (Article in Spanish). Acta Ortop Mex. 2008, 22:374-83.
12. von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP: The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. Lancet. 2007, 370:1453-7. 10.1016/S0140-6736(07)61602-X
13. Kirshblum S, Snider B, Eren F, Guest J: Characterizing natural recovery after traumatic spinal cord injury . J Neurotrauma. 2021, 38:1267-84. 10.1089/neu.2020.7473
14. Fehlings MG, Tetreault LA, Wilson JR, et al.: A clinical practice guideline for the management of patients with acute spinal cord injury and central cord syndrome: recommendations on the timing (≤24 Hours Versus >24 Hours) of decompressive surgery. Global Spine J. 2017, 7:195S-202S. 10.1177/2192568217706367
15. Wang TY, Park C, Zhang H, et al.: Management of acute traumatic spinal cord injury: a review of the literature. Front Surg. 2021, 8:698736. 10.3389/fsurg.2021.698736