Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

# Fifteen-Year Trends in Case-Mix, Management, and Outcomes of Traumatic Spinal Cord Injury: a Swedish Single-Center Study

**Linus Tegenborg Sjöström**

linus.tegenborg@gmail.com

Uppsala University

**Modar Alhamdan**

Uppsala University

**Anders Lewén**

Uppsala University

**Fartein Velle**

Uppsala University

**Per Enblad**

Uppsala University

**Lovisa Gerdhem**

Uppsala University

**Elham Rostami**

Uppsala University

**Paul Gedhem**

Uppsala University

**Konstantin Salci**

Uppsala University

**Mattias K. Sköld**

Uppsala University

**Andreas Fahlström**

Uppsala University

**Jimmy Sundblom**

Uppsala University

**David Fröjd Révész**

Uppsala University

**Teodor Svedung Wettervik**

Uppsala University

**Research Article**

**Keywords:** Epidemiology, mortality, neurointensive care, outcome, traumatic spinal cord injury

**Posted Date:** November 23rd, 2026

**DOI:** https://doi.org/10.21203/rs.3.rs-11681744/v1

**License:** This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

**Additional Declarations:** Competing interest reported. PG has received lecture fees from Johnson and Johnson Medtech. The other authors declare that they have no competing interests.

## Abstract

# Background

Traumatic spinal cord injury (t-SCI) is associated with substantial morbidity, long-term disability, and mortality. Population-based studies suggest a shift towards older patients and more fall-related injuries, while recommendations for acute management have changed regarding corticosteroid use, surgical timing, and hemodynamic optimization. Detailed real-world cohort data are needed to assess how these epidemiological and guideline-related changes are reflected in acute care and outcomes over time.

# Methods

This retrospective single-center tertiary cohort study included all adult patients with t-SCI treated at the neuro-intensive care (NIC) unit at Uppsala University Hospital, Sweden, between 2008 and 2022. Demographic, injury-related, management, and outcome variables were extracted from medical records. Temporal trends were analyzed across three five-year periods. Logistic regression was used to explore factors associated with 6-month mortality and neurological improvement at NIC discharge and follow-up.

# Results

In total, 188 patients were included. Median age was 65 years, 73% were male, and falls were the most common injury mechanism. Over the 15-year period, median age increased from 48 to 71 years, while the proportion of AIS grade A injuries decreased from 66% to 42%. Surgical timing remained largely unchanged, whereas corticosteroid use decreased from 26% to 3% and vasopressor use increased from 53% to 81%. Neurological improvement occurred in 25% of patients at NIC discharge and 57% of patients with available data at follow-up, without significant temporal change. Six-month mortality increased from 10% to 29%. Higher age and co-occurring traumatic brain injury were independently associated with 6-month mortality. Earlier surgery and absence of vasopressor use were associated with neurological improvement at discharge.

# Conclusions

In this 15-year t-SCI cohort, patients became older and management changed substantially. Although 6-month mortality increased, neurological outcome in survivors remained stable despite increased age.

## Introduction

Traumatic spinal cord injury (t-SCI) is a severe neurological condition associated with substantial long-term morbidity, functional impairment, and societal burden. Globally, t-SCI affects hundreds of thousands

of individuals each year and contributes to millions of years lived with disability [1]. Acute management aims to prevent secondary neurological injury. Surgical treatment is performed to decompress the spinal cord and/or stabilize the spine, whereas neurointensive care (NIC) focuses on preventing secondary insults by optimizing systemic physiology, including arterial blood pressure and oxygenation [2].

The epidemiology of t-SCI appears to be changing. Historically, t-SCI was mainly associated with high-energy trauma, such as road traffic accidents, and often affected younger individuals. However, contemporary studies increasingly report larger proportions of older patients and fall-related injuries, and a higher burden of age-related comorbidity and ankylosing spinal disorders [1], [3], [4]. These changes are clinically important, as patient age, frailty, injury mechanism, and pre-existing spinal pathology may influence surgical decision-making, NIC needs, rehabilitation potential, and long-term outcome. Detailed real-world data from different healthcare systems are therefore needed to understand how the changing epidemiology of t-SCI translates into management and prognosis.

At the same time, acute t-SCI management has evolved. The use of high-dose corticosteroids, historically considered a potential neuroprotective treatment, has declined substantially as later evidence questioned their neurological benefit and highlighted the risk of adverse effects [5], [6], [7]. In contrast, increasing emphasis has been placed on early surgical decompression and hemodynamic optimization. Several studies suggest that earlier surgery, particularly within 24 hours, may improve neurological recovery [8], [9] and that maintenance of an adequate mean arterial pressure (MAP) has been associated with improved neurological outcome [10], [11], [12], [13]. Nevertheless, important uncertainties remain regarding the optimal timing of surgery in heterogeneous real-world populations, hemodynamic support in routine care, and implementation of evolving recommendations outside trial settings [14].

Long-term prognosis after t-SCI also remains incompletely understood. Although many patients survive the acute NIC period, persistent neurological deficits may lead to pulmonary complications, spasticity, autonomic dysreflexia, reduced independence, and long-term mortality [15], [16]. Consequently, the goals of t-SCI care extend beyond survival to include complication prevention, neurological recovery, and preservation of function. Identifying clinical factors associated with short- and long-term outcomes in contemporary cohorts may help contextualize current management strategies and identify areas where care can be improved to retain quality of life.

Although several registry-based and population studies have described changing epidemiology of t-SCI, fewer studies have simultaneously evaluated how evolving demographics, management strategies, and neurological outcomes have changed over time within the same NIC cohort. Thus, to address this need for real-world data on how changing t-SCI epidemiology and evolving acute management recommendations translate into clinical practice and outcome, this study was undertaken. It aimed to describe temporal trends in case-mix, surgical and NIC management, neurological recovery, and mortality among adult t-SCI patients treated at a Swedish NIC unit over a 15-year period. We also

explored demographic, injury-related, and treatment-related factors associated with neurological improvement and mortality.

## Materials and Methods

# Patients and study design

This retrospective observational tertiary cohort study included adult patients with t-SCI treated at the NIC unit at Uppsala University Hospital, Sweden, between 1 January 2008 and 31 December 2022. Potentially eligible patients were identified through a predefined set of ICD codes related to spinal fractures and spinal cord injury: S14.0-S14.2, S19.7, S12.0-S12.2, S12.7, S24.0-S24.2, S22.0, S22.1, S34.0-S34.2, T02.0, T02.1, T06.0, T06.1, G95.2 and G82.0-G82.5. Patients were eligible for inclusion if they were aged ≥ 18 years, had a t-SCI, and received their main NIC treatment at Uppsala University Hospital. Patients were excluded if they were younger than 18 years at the time of injury, did not have t-SCI despite screening positive by ICD code (e.g., spinal fractures alone), had a non-traumatic SCI, or received their main NIC at another center.

In total, 314 patients were identified through the ICD-code screening. Of these, 126 were excluded: 10 because they were younger than 18 years, 110 because they did not have a SCI, two because they had a non-traumatic SCI, and four because their main NIC treatment was provided at another unit. The final study cohort therefore comprised 188 patients.

## Management protocol

Uppsala University Hospital provides neurosurgical care and NIC for the central healthcare region of Sweden, comprising seven counties and approximately two million inhabitants. As the regional referral center, the NIC received virtually all patients with t-SCI. Most of them were initially assessed and managed at a local hospital according to Advanced Trauma Life Support principles and were subsequently referred urgently to Uppsala University Hospital. Initial diagnostic work-up included trauma computed tomography, followed by magnetic resonance imaging of the affected spinal region. The imaging was reviewed by neuroradiologists. Imaging findings and treatment strategy were discussed, and the surgery was performed as early as possible (especially in incomplete injuries) in collaboration with orthopedic spine surgeons. Patients were managed according to local NIC guidelines, which were modified during the study period in accordance with emerging evidence. Peripheral oxygen saturation above 95% was generally targeted. During most of the study period, arterial blood pressure management was guided by a systolic blood pressure target of > 120 mmHg; after revision of the local guideline in 2022, this was replaced by a MAP target of > 80 mmHg. Arterial hypotension was primarily treated with crystalloid fluids and Albumin 20%, followed by vasopressors when needed. Patients received thromboprophylaxis with low-molecular-weight heparin and compression stockings unless contraindicated. Respiratory physiotherapy was initiated early to support pulmonary function.

Endotracheal intubation and mechanical ventilation were used in patients with respiratory failure related to the t-SCI and in patients with impaired consciousness due to concomitant traumatic brain injury (TBI), systemic injuries, secondary complications or other medical conditions, respectively. Ventilatory support was reduced and discontinued as soon as clinically reasonable. At the beginning of the study period, high-dose methylprednisolone administered within 6–8 hours of injury was part of the local treatment protocol as a neuroprotective intervention. This practice was gradually abandoned during the study period as accumulating evidence questioned methylprednisolone's neurological benefit and highlighted the risk of adverse effects, though some referring hospitals would continue to administer methylprednisolone even before consultation with the neurosurgical department until the final years of the study.

## Data collection

Medical records from the NIC stay were reviewed, together with records from neurorehabilitation and neurosurgical follow-up when available. Extracted variables included demographic data, injury characteristics, acute management, complications, and outcomes. Demographic variables included age, sex, and comorbidity. Comorbidity was assessed using the Charlson Comorbidity Index, an index developed to quantify comorbidity and predict mortality. Age-related points from the index were excluded to decrease age-related confounding. Therefore, the index ranged from 0–33 with a higher score indicating increased morbidity [17]. The presence of ankylosing spinal disease (defined as ankylosing spondylitis, Diffuse Idiopathic Skeletal Hyperostosis or Ossification of the Posterior Longitudinal Ligament) was determined based on medical records and available radiological reports. Injury-related variables included injury mechanism, neurological level of injury (C1-C4 being defined as "high cervical", C5-C8 being defined as "low cervical" and Th1-Th12 being defined as "thoracic"), presence and type of spinal fracture or disc herniation, and co-occurring traumatic injuries. Co-occurring TBI was defined as radiological findings (intracranial bleeding and/or diffuse axonal injury) of TBI. Classification of injury severity was made through the American Spinal Injury Association Impairment Scale (AIS) grade at admission, ranging from A-E where A means complete spinal cord injury and E means that motor/sensory function is completely intact in a patient with previous neurological symptoms [18]. Injury mechanism was divided into falls (accounting for both same- and high-level falls), road traffic accidents, sports accidents and other (including diving). Available CT and MRI examinations were reviewed, and spinal injuries were classified according to the AO Spine injury classification systems [19], [20], [21], by the first author based on the neuroradiological report in combination with image review. Complex cases were discussed between the first and last author. Management variables included surgical timing (defined as time from moment of injury to start of surgery), surgical approach, NIC, and complications. For surgical approach, surgical decompression was defined as removal of e.g., lamina, disc or spinal ligaments. Neurological outcome was assessed using the AIS grade at discharge from the NIC unit and, when available, at follow-up [18]. Follow-up data were obtained from neurorehabilitation and/or neurosurgical records. If follow-up was not obtainable, the follow-up data was counted as missing. Neurological improvement at NIC discharge and follow-up, respectively, was defined as an

increase of at least one AIS grade compared with admission. Mortality was assessed at NIC discharge, at 6 months, and at the end of follow-up.

# Statistical analysis

Statistical analyses were performed using SPSS version 31.0 (IBM Corp., Armonk, NY, USA). R version 4.6.1 and RStudio version 2026.6.0.242 were used for visualizations. Categorical variables are presented as numbers and percentages, and ordinal or continuous variables as medians with interquartile ranges (Q1–Q3). Temporal trends in demographic, injury-related, management, and outcome variables were analyzed across three predefined time periods: 2008–2012, 2013–2017, and 2018–2022. The time periods were split into three 5-year periods for pragmatic reasons. Group comparisons were performed using the chi-square test for categorical variables and the Kruskal-Wallis test for ordinal or continuous variables. Associations between demographics, injury-related variables, and treatments in relation to clinical outcomes were analyzed using logistic regression. The outcomes of interest were 6-month mortality, neurological improvement at NIC discharge, and neurological improvement at follow-up. Univariable logistic regression analyses were first performed for each outcome. Variables associated with the outcome in univariable analyses were considered for inclusion in multivariable logistic regression analyses. Final model selection also accounted for clinical relevance and the number of available outcome events to reduce the risk of overfitting. Results are presented as odds ratios (ORs) with 95% confidence intervals (CIs) and p-values. Long-term survival was visualized using Kaplan-Meier curves stratified by age group, injury severity, neurological level of injury, and surgical timing. A p-value $< 0.05$ was considered statistically significant.

## Ethics

The study was approved by the Swedish Ethical Review Authority (Number: 2024-05969-01. Date: 2024-10-09). Written informed consent was waived by the ethical committee.

## Results

The main findings of the conducted study are presented in Fig. 1.

## Demography and injury-related variables – temporal trends

A total of 188 patients were included (Table 1). The median age was 65 (46–74) years, and 137 patients (73%) were male. The median Charlson Comorbidity Index was 0 (0–1), and 25% had ankylosing spinal disease. Falls were the most common injury mechanism, accounting for 101 cases (54%). At admission to our NIC unit, 94 patients (50%) were classified as AIS A, and the most common neurological level of injury was low cervical injury (C5–C8), observed in 119 patients (63%). Co-occurring traumatic injuries were present in 94 patients (50%), with thoracic injuries being the most frequent (31%).

Table 1
Demography and injury-related variables – temporal trends

| Variables | All | 2008–2012 | 2013–2017 | 2018–2022 | P-value |
|---|---|---|---|---|---|
| Patients, n (%) | 188 (100%) | 61 (32%) | 65 (35%) | 62 (33%) | NA |
| Demography | | | | | |
| Age (years), median (Q1–Q3) | 65 (46–74) | 48 (37–67) | 70 (57–75) | 71 (57–77) | **< 0.001** |
| Sex (male/female), n (%) | 137/51 (73/27%) | 41/20 (67/33%) | 50/15 (77/23%) | 46/16 (74/26%) | 0.453 |
| Charlson comorbidity index (scale), median (Q1–Q3). | 0 (0–1) | 0 (0–1) | 0 (0–1) | 0 (0–1) | 0.476 |
| Ankylosing disease (yes), n (%) | 40 (25%) | 10 (20%) | 11 (21%) | 19 (31%) | 0.364 |
| Injury-related variables | | | | | |
| *Injury mechanism* | | | | | |
| Fall, n (%) | 101 (54%) | 28 (46%) | 37 (57%) | 36 (58%) | 0.240 |
| Road traffic accidents, n (%) | 29 (15%) | 11 (18%) | 11 (17%) | 7 (11%) | |
| Sports accidents, n (%) | 22 (12%) | 6 (10%) | 5 (8%) | 11 (18%) | |
| Other, n (%) | 36 (19%) | 16 (26%) | 12 (19%) | 8 (13%) | |
| *AIS at admission* | | | | | |
| A, n (%) | 94 (50%) | 40 (66%) | 28 (43%) | 26 (42%) | **0.025** |
| B, n (%) | 18 (10%) | 5 (8%) | 9 (14%) | 4 (7%) | |
| C, n (%) | 54 (29%) | 8 (13%) | 23 (35%) | 23 (37%) | |
| D, n (%) | 21 (11%) | 7 (12%) | 5 (8%) | 9 (15%) | |
| E, n (%) | 1 (1%)* | 1 (2%) | 0 (0%) | 0 (0%) | |
| *Neurological level of injury* | | | | | |
| High cervical (C1–4), n (%) | 40 (21%) | 11 (18%) | 17 (26%) | 12 (19%) | 0.784 |

Bold and italics indicate statistical significance.

*=One patient had spinal cord edema and symptoms at moment of injury but intact motor+sensory function at NIC admission, the patient was therefore graded as AIS E.

Missing data: Ankylosing disease (n = 25), AO Spine fracture (n = 30).

AIS = American Spinal Injury Association Impairment Scale. TBI = Traumatic brain injury.

| Variables | All | 2008–2012 | 2013–2017 | 2018–2022 | P-value |
|---|---|---|---|---|---|
| Low cervical (C5–8), n (%) | 119 (63%) | 39 (64%) | 39 (60%) | 41 (66%) | |
| Thoracic (Th1–Th12), n (%) | 29 (15%) | 11 (18%) | 9 (14%) | 9 (15%) | |
| *AO spine fracture (worst)* | | | | | |
| A, n (%) | 23 (15%) | 9 (19%) | 4 (8%) | 10 (16%) | 0.552 |
| B, n (%) | 26 (16%) | 6 (13%) | 11 (22%) | 9 (15%) | |
| C, n (%) | 102 (65%) | 29 (62%) | 33 (67%) | 40 (65%) | |
| No fracture or disc herniation, n (%) | 7 (4%) | 3 (6%) | 1 (2%) | 3 (5%) | |
| *Co-occurring injuries* | | | | | |
| Traumatic injuries to other organs (yes), n (%) | 94 (50%) | 31 (51%) | 32 (49%) | 31 (50%) | 0.984 |
| TBI (yes), n (%) | 35 (19%) | 8 (13%) | 12 (19%) | 15 (24%) | 0.288 |
| Viscerocranial injuries (yes), n (%) | 25 (13%) | 8 (13%) | 7 (11%) | 10 (16%) | 0.673 |
| Thoracic injuries (yes), n (%) | 59 (31%) | 24 (39%) | 17 (26%) | 18 (29%) | 0.249 |
| Abdominal injuries (yes), n (%) | 9 (5%) | 3 (5%) | 4 (6%) | 2 (3%) | 0.741 |
| Extremity injuries (yes), n (%) | 14 (7%) | 4 (7%) | 8 (12%) | 2 (3%) | 0.142 |
| Bold and italics indicate statistical significance. | | | | | |
| *=One patient had spinal cord edema and symptoms at moment of injury but intact motor+sensory function at NIC admission, the patient was therefore graded as AIS E. | | | | | |
| Missing data: Ankylosing disease (n = 25), AO Spine fracture (n = 30). | | | | | |
| AIS = American Spinal Injury Association Impairment Scale. TBI = Traumatic brain injury. | | | | | |

Over the study period, median age increased significantly from 48 (37–67) years in 2008–2012 to 71 (57–77) years in 2018–2022 ($p < 0.001$). Admission AIS grade also changed, with the proportion of AIS A injuries decreasing from 66% in 2008–2012 to 42% in 2018–2022 ($p = 0.025$). The proportion of fall-related injuries tended to increase from 46% to 58% across the same periods, although this trend was not significant ($p = 0.240$).

## Management and complications – temporal trends and relation to injury characteristics

As described in Table 2, 173 patients were operated upon. Surgical intervention within 24 hours of injury was performed in 59 patients (34%). The most common decompressive approach was from anterior alone with 71 patients (41%). Corticosteroids for neuroprotection were administered to 20 patients (11%), but usage decreased from 16 patients (26%) in 2008–2012 to 2 patients (3%) in both 2013–2017 and 2018–2022 ($p < 0.001$). 129 patients (69%) received vasopressors and use increased from 53% to 81% from 2008–2012 to 2018–2022 ($p = 0.003$). 120 patients (64%) required mechanical ventilation and 36 patients (19%) received tracheostomy. The median duration of mechanical ventilation was 2 (0–8) days. The percentage of patients receiving surgery did not differ significantly across the study periods ($p = 0.499$). However, the decompressive surgical approach changed over time, with combined anterior and posterior decompression increasing from 3 patients (5%) in 2008–2012 to 12 patients (22%) in 2018–2022 ($p = 0.015$).

Table 2
Surgical and neurointensive care management – temporal trends

| Variables | All | 2008–2012 | 2013–2017 | 2018–2022 | P-value |
|---|---|---|---|---|---|
| Surgical management and complications | | | | | |
| *Surgical intervention, n (%)* | 173 (92%) | 57 (93%) | 61 (94%) | 55 (89%) | 0.499 |
| *Surgical timing* | | | | | |
| Within 24 hours, n (%) | 59 (34%) | 23 (40%) | 15 (25%) | 21 (38%) | 0.267 |
| Between 25 to 48 hours, n (%) | 54 (31%) | 19 (33%) | 20 (33%) | 15 (27%) | |
| Later than 49 hours, n (%) | 60 (35%) | 15 (26%) | 26 (43%) | 19 (35%) | |
| *[If surgical intervention]: Surgical decompressive approach* | | | | | |
| Anterior, n (%) | 71 (41%) | 28 (49%) | 21 (34%) | 22 (40%) | **0.015** |
| Posterior, n (%) | 56 (32%) | 14 (25%) | 23 (38%) | 19 (35%) | |
| Combined, n (%) | 25 (14%) | 3 (5%) | 10 (16%) | 12 (22%) | |
| No decompression, n (%) | 21 (12%) | 12 (21%) | 7 (11%) | 2 (4%) | |
| *[If surgical intervention]: Surgical fusion approach* | | | | | |
| Anterior, n (%) | 39 (23%) | 17 (30%) | 11 (18%) | 11 (20%) | 0.324 |
| Posterior, n (%) | 78 (45%) | 26 (46%) | 30 (49%) | 22 (40%) | |
| Combined, n (%) | 56 (32%) | 14 (25%) | 20 (33%) | 22 (40%) | |

Bold and italics indicate statistical significance.

Surgical timing and multiple surgeries: 15 patients received no surgical intervention and are excluded from the variables.

Autonomic dysreflexia: 13 patients had an injury below Th6 and were excluded from the variable.

Steroids: 9 patients received steroids for other indications and in other regimes than neuro protective regimes and are counted as not receiving steroids.

| Variables | All | 2008–2012 | 2013–2017 | 2018–2022 | P-value |
|---|---|---|---|---|---|
| Multiple surgeries (yes), n (%) | 17 (10%) | 6 (11%) | 2 (3%) | 9 (16%) | 0.060 |
| *Surgery due to long-term complications* | | | | | |
| Tethered cord (yes), n (%) | 3 (2%) | 3 (5%) | 0 (0%) | 0 (0%) | **0.042** |
| Phrenic stimulator (yes), n (%) | 2 (1%) | 1 (2%) | 0 (0%) | 1 (2%) | 0.586 |
| Neurointensive care management and complications | | | | | |
| Steroids (yes), n (%) | 20 (11%) | 16 (26%) | 2 (3%) | 2 (3%) | **< 0.001** |
| Vasopressors (yes), n (%) | 129 (69%) | 32 (53%) | 47 (72%) | 50 (81%) | **0.003** |
| Mechanical ventilation (yes), n (%). | 120 (64%) | 37 (61%) | 42 (65%) | 41 (66%) | 0.808 |
| Duration in respirator (days), median (Q1–Q3) | 2 (0–8) | 2 (0–13) | 1 (0–6) | 3 (0–7) | 0.882 |
| Tracheostomy (yes), n (%) | 36 (19%) | 16 (26%) | 11 (17%) | 9 (15%) | 0.218 |
| Dialysis (yes), n (%) | 2 (1%) | 1 (2%) | 0 (0%) | 1 (2%) | 0.586 |
| Venous thromboembolism (yes), n (%). | 5 (3%) | 2 (3%) | 0 (0%) | 3 (5%) | 0.223 |
| [If injury at/above Th6]: Autonomic dysreflexia (yes), n (%) | 8 (5%) | 1 (2%) | 3 (5%) | 4 (7%) | 0.421 |
| Infection (yes), n (%) | 106 (56%) | 34 (56%) | 35 (54%) | 37 (60%) | 0.797 |
| Bold and italics indicate statistical significance. | | | | | |
| Surgical timing and multiple surgeries: 15 patients received no surgical intervention and are excluded from the variables. | | | | | |
| Autonomic dysreflexia: 13 patients had an injury below Th6 and were excluded from the variable. | | | | | |
| Steroids: 9 patients received steroids for other indications and in other regimes than neuro protective regimes and are counted as not receiving steroids. | | | | | |

# Neurological outcome and prognostic variables

At discharge from our NIC unit (Table 3), 47 patients (25%) were improved by at least one AIS grade compared with admission. This proportion decreased from 31% in 2008–2012 to 19% in 2018–2022, although the difference was not statistically significant (p = 0.318). At follow-up after a median of 8

months (3–41), 61 patients (57% of patients with available data) had improved by at least one AIS grade compared with admission, with no significant change across the study periods (p = 0.110).

Table 3
Mortality and neurological outcome

| Variables | All | 2008–2012 | 2013–2017 | 2018–2022 | P-value |
|---|---|---|---|---|---|
| Mortality at NIC discharge, n (%) | 4 (2%) | 0 (0%) | 1 (2%) | 3 (5%) | 0.163 |
| Mortality 6 months post-injury, n (%) | 32 (17%) | 6 (10%) | 8 (12%) | 18 (29%) | **0.008** |
| Neurological improvement at discharge, n (%) | 47 (25%) | 19 (31%) | 16 (25%) | 12 (19%) | 0.318 |
| Neurological improvement at follow-up, n (%)* | 61 (57%) | 19 (50%) | 25 (71%) | 17 (50%) | 0.110 |
| Bold and italics indicate statistical significance. | | | | | |
| Neurological improvement at discharge: 4 patients had a worse AIS-grade at discharge compared to admission. | | | | | |
| *=Median follow-up time 8 months (3–41) | | | | | |
| Missing data: Neurological improvement at follow up: (n = 81) | | | | | |

In univariable logistic regression (Table 4), female sex and thoracic neurological level of injury were associated with higher odds of neurological improvement at NIC discharge, whereas delayed surgical timing and vasopressor use were associated with lower odds. In the multivariable model, surgery within 24 hours and absence of vasopressor use remained significantly associated with neurological improvement at NIC discharge. Compared with surgery within 24 hours, surgery between 25–48 hours and surgery later than 49 hours were both associated with lower odds of improvement, though results were non-significant for the over 48 hour group (p = 0.035 and p = 0.054, respectively). Vasopressor use was also associated with lower odds of improvement (p = 0.023).

Table 4
Demographic, injury-related, and management variables in relation to neurological improvement at discharge – uni- and multivariable logistic regressions

| **Variables** | **Univariable analysis** | | **Multivariable analysis*** | |
|---|---|---|---|---|
| | **OR (95% CI)** | **P-value** | **OR (95% CI)** | **P-value** |
| Demography | | | | |
| Age (years) | 1.00 (0.98–1.01) | 0.605 | - | - |
| Sex (reference=male) | **2.03 (1.00–4.11)** | **0.049** | 2.04 (0.92–4.50) | 0.079 |
| Charlson comorbidity index (scale) | 0.90 (0.61–1.33) | 0.604 | - | - |
| Ankylosing disease (yes) | 0.74 (0.31–1.78) | 0.504 | - | - |
| Injury-related | | | | |
| AIS A at NIC admission (yes) | 0.84 (0.44–1.63) | 0.614 | - | - |
| *Neurological level of injury (high cervical -reference)* | | | | |
| Low cervical | 1.91 (0.73–5.00) | 0.187 | 1.07 (0.38–3.03) | 0.900 |
| Thoracic | **3.46 (1.10–10.91)** | **0.034** | 2.46 (0.70–8.67) | 0.161 |
| Traumatic injuries to other organs (yes) | 0.58 (0.31–1.17) | 0.131 | - | - |
| TBI (yes) | 0.44 (0.16–1.21) | 0.112 | - | - |
| Management | | | | |
| *Surgical timing (within 24 hours – reference)* | | | | |
| Between 25 to 48 hours (yes) | **0.40 (0.17–0.93)** | **0.034** | **0.39 (0.16–0.94)** | **0.035** |
| Later than 49 hours (yes) | **0.43 (0.19–0.97)** | **0.042** | 0.43 (0.18–1.02**)** | 0.054 |
| Surgical decompressive approach (anterior – reference) | | | | |
| Posterior (yes) | 0.82 (0.37–1.79) | 0.605 | - | - |
| Combined (yes) | 0.42 (0.13–1.38) | 0.155 | - | - |

| Variables | Univariable analysis | | Multivariable analysis* | |
|---|---|---|---|---|
| | OR (95% CI) | P-value | OR (95% CI) | P-value |
| Steroids (yes) | 1.33 (0.48–3.68) | 0.586 | - | - |
| Mechanical ventilation (yes) | 0.62 (0.32–1.21) | 0.163 | - | - |
| Vasopressors (yes) | **0.46 (0.23–0.91)** | **0.025** | **0.41 (0.19–0.89)** | **0.023** |
| Autonomic dysreflexia (yes) | 1.02 (0.20–5.27) | 0.977 | - | - |
| Bold and italics indicate statistical significance. | | | | |
| *: R2 (Nagelkerke) = 0.127, AUROC = 0.676 | | | | |
| Missing data: Ankylosing disease (n = 25). | | | | |
| Surgical timing: 15 patients received no surgery and are excluded from the calculation. | | | | |
| Surgical decompressive approach: 36 patients received no decompressive surgery (15 patients received no surgery, 21 patients received fusion but not decompressive surgery) and are excluded from the variable | | | | |
| Steroids: 9 patients received steroids for other indications and in other regimes than neuro protective regimes and are counted as not receiving steroids. | | | | |
| Autonomic dysreflexia: 13 patients had an injury below Th6 and were excluded from the variable. | | | | |
| AIS = American Spinal Injury Association Impairment Scale. TBI = Traumatic brain injury. OR= Odds ratio. CI= Confidence interval | | | | |

For neurological improvement at the follow-up at median of 8 months (Supplementary Table 1), female sex was associated with higher odds of improvement in univariable analysis, whereas higher Charlson Comorbidity Index and AIS A grade at NIC discharge were associated with lower odds. In the multivariable model, higher Charlson Comorbidity Index (p = 0.017) and remaining AIS A grade at NIC discharge (p = 0.001) remained significantly associated with lower odds of neurological improvement at follow-up.

# Mortality and prognostic variables

Four patients (2%) died during NIC (Table 3). NIC mortality increased from 0 patients in 2008–2012 to 3 patients (5%) in 2018–2022, although this difference was not statistically significant (p = 0.163). At 6 months after injury, 32 patients (17%) had died, and 6-month mortality increased significantly over time from 6 patients (10%) in 2008–2012 to 18 patients (29%) in 2018–2022 (p = 0.008).

In univariable logistic regression, higher age, higher Charlson Comorbidity Index, ankylosing spinal disease, and co-occurring traumatic brain injury were associated with higher odds of 6-month mortality

(Table 5). Low cervical neurological level of injury was associated with lower odds of 6-month mortality compared with high cervical injury. To reduce the risk of overfitting, three variables were included in the multivariable model. Age, neurological level of injury, and co-occurring TBI were selected to represent chronological age, injury severity, and associated intracranial trauma, respectively. In the multivariable analysis, higher age ($p < 0.001$) and co-occurring TBI ($p = 0.010$) remained significantly associated with higher odds of 6-month mortality.

Table 5
Demographic, injury-related, and management variables in relation to mortality at 6 months – uni- and multivariable logistic regressions

| **Variables** | **Univariable analysis** | | **Multivariable analysis*** | |
|---|---|---|---|---|
| | **OR (95% CI)** | **P-value** | **OR (95% CI)** | **P-value** |
| Demography | | | | |
| Age (years) | **1.10 (1.05–1.14)** | **< 0.001** | **1.11 (1.06–1.16)** | **< 0.001** |
| Sex (reference=male) | 1.52 (0.67–3.43) | 0.314 | - | - |
| Charlson comorbidity index (scale) | **1.91 (1.32–2.76)** | **0.001** | - | - |
| Ankylosing disease (yes) | **2.64 (1.16–6.00)** | **0.021** | - | - |
| Injury-related | | | | |
| AIS A at NIC admission (yes) | 0.86 (0.40–1.84) | 0.698 | - | - |
| AIS A at NIC discharge (yes) | 1.28 (0.59–2.76) | 0.531 | - | - |
| *Neurological level of injury (high cervical -reference)* | | | | |
| Low cervical C5–C8 | **0.41 (0.17–0.98)** | **0.045** | 0.43 (0.16–1.17) | 0.099 |
| Thoracic Th1–Th12 | 0.55 (0.17–1.80) | 0.323 | 0.74 (0.18–3.04) | 0.674 |
| Traumatic injuries to other organs (yes) | 1.58 (0.73–3.42) | 0.247 | - | - |
| TBI (yes) | **2.88 (1.23–6.74)** | **0.015** | **3.87 (1.38–10.86)** | **0.010** |
| Management | | | | |
| *Surgical timing (within 24 hours – reference)* | | | | |
| Between 25 to 48 hours (yes) | 0.76 (0.23–2.55) | 0.654 | - | - |
| Later than 49 hours (yes) | 1.86 (0.68–5.11) | 0.230 | - | - |
| Surgical decompressive approach (anterior – reference). | | | | |
| Posterior (yes) | 1.15 (0.41–3.20) | 0.791 | - | - |

| Variables | Univariable analysis | | Multivariable analysis* | |
|---|---|---|---|---|
| | OR (95% CI) | P-value | OR (95% CI) | P-value |
| Combined (yes) | 1.72 (0.52–5.74) | 0.376 | - | - |
| Steroids (yes) | 0.51 (0.11–2.32) | 0.385 | - | - |
| Mechanical ventilation (yes) | 1.88 (0.79–4.44) | 0.153 | - | - |
| Vasopressors (yes) | 1.79 (0.73–4.40) | 0.208 | - | - |
| Autonomic dysreflexia (yes) | 3.25 (0.73–14.46) | 0.121 | - | - |
| Bold and italics indicate statistical significance. | | | | |
| Due to 32 mortalities within 6 months, only 3 variables (age, neurological level of injury, co-occurring TBI) were analyzed in multivariable regression analyses. | | | | |
| *: R2 (Nagelkerke) = 0.357, AUROC = 0.838 | | | | |
| Missing data: Ankylosing disease (n = 25) | | | | |
| Surgical timing: 15 patients received no surgical intervention and are excluded from the variable. | | | | |
| Surgical decompressive approach: 36 patients received no decompressive surgery (15 patients received no surgery, 21 patients received fusion but not decompressive surgery) and are excluded from the variable | | | | |
| Autonomic dysreflexia: 13 patients had an injury below Th6 and were excluded from the variable. | | | | |
| Steroids: 9 patients received steroids for other indications and in other regimes than neuro protective regimes and are counted as not receiving steroids. | | | | |
| AIS = American Spinal Injury Association Impairment Scale. TBI = Traumatic brain injury. OR= Odds ratio. CI= Confidence interval | | | | |
| AIS = American Spinal Injury Association Impairment Scale. | | | | |

Long-term survival was visualized using Kaplan-Meier curves stratified by age group, AIS grade at admission, neurological level of injury, and surgical timing. Survival differed significantly according to age group, neurological level of injury, and surgical timing, but not according to admission AIS grade (Fig. 2).

# Discussion

In this 15-year observational tertiary cohort of 188 patients with t-SCI, we found substantial changes in both epidemiology and acute management, but no corresponding improvement in neurological outcome.

The cohorts' median age increased, while management shifted towards more frequent decompressive surgery, reduced corticosteroid use, and increased vasopressor treatment. However, although patient age increased markedly, neurological improvement at NIC discharge and follow-up remained stable, although 6-month mortality increased. This suggests that contemporary t-SCI prognosis may be increasingly shaped by age, vulnerability, associated injuries, and post-acute factors beyond the initial NIC period. Earlier surgery and absence of vasopressor treatment were associated with neurological improvement at NIC discharge, while higher comorbidity burden and complete injury at discharge were associated with lower odds of neurological improvement at follow-up.

# Epidemiological aspects of t-SCI – temporal trends

Falls were the dominant injury mechanism and, though non-significant, possibly due to limited statistical power, the proportion of falls increased over time. The trend of increased falls has been reported in other contemporary cohorts, suggesting that t-SCI is increasingly a low-energy trauma condition affecting older, more frail patients [4], [22]. This shift has important clinical implications, as older age, comorbidity and frailty may influence surgical decision-making, rehabilitation potential, and survival. In the context of population aging this development will likely continue [1], underscoring the importance of careful interpretation of older t-SCI studies based on younger, high-energy trauma cohorts whilst indicating the need of multi-disciplinary management and fall prevention.

Furthermore, the proportion of patients admitted with AIS A grade decreased significantly, in line with previously reported cohorts [23]. Possible explanations for this are aging patient populations with increased falls, differences in prehospital management, and more granular neurological examination at NIC arrival.

# Management aspects of t-SCI – temporal trends

Corticosteroid use declined markedly, in line with current trends and increasing concerns regarding the imbalance between corticosteroid's neurological benefit and adverse effects [6], [7]. Although earlier guidelines recommended methylprednisolone to selected patients [24], recent recommendations generally discourage routine steroid administration [25]. Furthermore, vasopressor use increased significantly. Though no randomized trials have explored MAP-targets, previous studies present associations between higher MAP and improved neurological recovery after t-SCI [10], [11], and recent guidelines recommend hemodynamic augmentation, although the optimal MAP target, treatment duration, and vasopressor strategy remain uncertain [25], [26]. Moreover, a recent randomized clinical trial found no significant difference in augmented and conventional MAP [27]. Our observed increase in vasopressor use is likely to reflect a growing emphasis on active hemodynamic management in routine care, but our data does not allow for conclusions regarding vasopressor treatment efficacy. Importantly, vasopressor usage may also identify a distinct patient subgroup, characterized by not only more severe autonomic or systemic instability, but also poorer cardiovascular reserve, thereby increasing both likelihood of requiring vasopressors and risk of adverse outcomes.

Over time, more patients received decompressive surgery, though surgical timing remained static. This is notable as current guidelines recommend early decompression following t-SCI [8], [25], [28], [29], although one of few prospective studies failed to show its effect[8], [25], [28], [29], [30]. Static surgical timing may reflect real-world constraints, including delayed referral, medical instability, imaging logistics and guideline implementation delay.

Altogether, these temporal trends suggest a shift away from steroid-based neuroprotection and towards more active surgical and hemodynamic management. This development broadly aligns with current evidence, although evidential strength differs between interventions: early decompression is relatively well supported [8], [9], whereas the optimal strategy for hemodynamic augmentation remains less defined [14], [26] .

# Neurological improvement and prognostic factors

Neurological improvement was observed in 25% of patients at NIC discharge and in 57% of patients with available data (81 cases missing) at follow-up. Comparisons with previous studies are complicated by differences in follow-up duration, case mix, and definitions of neurological recovery. Studies using similar definitions have reported broadly comparable rates of AIS grade conversion [9]. Importantly, AIS grade conversion does not necessarily translate into clinically meaningful functional recovery. Future studies should therefore complement AIS-based outcomes with patient-centered and functionally meaningful measures, such as hand function and quality of life.

Compared to earlier surgery, late surgical timing was associated with lower odds of neurological improvement at NIC discharge. This finding is consistent with previous studies and contemporary guidelines supporting decompressive surgery within 24 hours when feasible [8], [25], [28], [29]. However, surgical timing in observational real-world cohorts is influenced by several factors, including injury severity, age, comorbidity, referral pathways, imaging logistics, and medical stability. Injury severity was certainly a selection bias for surgical timing, as incomplete injury was regarded as a strong indication for immediate operative management compared to complete injuries. The association observed in our cohort should therefore be interpreted as supportive of existing evidence rather than as evidence of independent treatment effects. Moreover, vasopressor use was associated with lower odds of neurological improvement at NIC discharge. This finding likely reflects confounding by indication, where vasopressor treatment is associated with hypotension, autonomic dysfunction, or greater physiological instability and injury severity. Our findings therefore support the clinical relevance of hemodynamic stability after t-SCI, but do not allow conclusions regarding the causal effect of vasopressor treatment.

At follow-up, AIS A grade at NIC discharge and higher comorbidity burden were associated with lower odds of neurological improvement. This is clinically plausible, as most neurological recovery after t-SCI occurs during the first weeks to months after injury, and late recovery from complete injury is uncommon [31]. Comorbidity may further influence neurological recovery indirectly by increasing risk of secondary complications, delaying surgery and limiting rehabilitation. This emphasizes how long-term t-SCI

outcome is shaped not only by the SCI itself, but also by early neurological trajectory, systemic vulnerability, and post-acute recovery potential.

# Mortality and prognostic factors

NIC mortality was low at 2%, whereas 6-month mortality was 17% overall. The latter increased significantly over time from 10% to 29%. This increase occurred despite relatively stable comorbidity burden measured by the Charlson Comorbidity Index, but the index should be interpreted in the context of the changing t-SCI epidemiology. Previous studies report in-hospital mortality rates of around 8–13%, 90-day mortality of 13%, and 6-month mortality of 14% [32], [33], [34]. Possible explanations for the increased 6-month mortality include the significant increase in patient age and non-significant increase in co-occurring TBI, both of which were associated with increased mortality in regression analyses. The combination of low NIC and increasing 6-month mortality also suggests that prognosis in contemporary t-SCI may be increasingly influenced by vulnerability after NIC. Most likely, older and more frail patients may survive the initial injury and NIC but remain susceptible to later deterioration. Further studies including post-acute care, rehabilitation trajectories, and long-term medical events are needed to clarify the mechanisms underlying this finding.

Older age and co-occurring TBI were associated with increased 6-month mortality. The association between age and mortality after t-SCI is well established and likely reflects a combination of higher frailty, increased complication vulnerability, and differences in rehabilitation potential [35], [36], [37]. The association between co-occurring TBI and mortality is also plausible, as concomitant intracranial injury may increase acute physiological instability, complicate NIC, delay rehabilitation, and worsen overall prognosis. Previous studies on concomitant TBI in t-SCI report variable findings, partly due to differences in TBI definition and study populations [38], [39]. Our findings therefore support the relevance of associated intracranial injury when estimating t-SCI prognosis, but further studies with standardized TBI definitions are needed.

Kaplan-Meier analyses showed differences in long-term survival according to age, surgical timing, and neurological injury level. The association between high neurological injury levels and worse survival has been reported previously [40], [41] and is biologically plausible. More rostral injuries may increase risk of respiratory dysfunction, autonomic dysregulation, and pressure ulcers, all of which may worsen prognosis [42]. Pulmonary complications are among the most common acute complications after t-SCI, and their risk may be higher in patients with more rostral neurological injury level [15], [42]. The observed association between earlier surgical timing and better long-term survival should be interpreted cautiously, as delayed surgery may reflect older age, comorbidity, delayed referral, medical instability, or injury characteristics rather than a direct effect of timing itself.

# Methodological considerations

This study has several strengths. First, it includes all adult patients with t-SCI treated at the NIC unit at Uppsala University Hospital over a 15-year period, providing a consecutive real-world cohort from a large Swedish neurosurgical center, allowing findings to reflect routine clinical practice and cohorts rather than

trial-specific inclusion criteria. Second, the long study period enabled assessment of temporal trends in patient characteristics, surgical management, NIC, and outcome. Third, the detailed review of medical records, imaging, surgical management, complications, and neurological status provides a broad description of the multifaceted acute care of t-SCI.

The study also has important limitations. Its retrospective observational design precludes causal inference, and associations should therefore be interpreted as exploratory. Treatment-related variables, such as surgical timing and vasopressor use, are particularly vulnerable to confounding by indication, as they may reflect injury severity, physiological instability, referral pathways, or clinical decision-making rather than independent treatment effects. Moreover, reliance on medical records may have introduced misclassification, particularly for neurological status, as AIS grading was not documented prospectively in a standardized research setting. In uncertain cases, neurological classification was discussed between the first and last authors, and the most plausible AIS grade was assigned based on available clinical documentation. Cases in which reliable classification remained impossible were recorded as missing. Another limitation is that follow-up was dependent on available rehabilitation and neurosurgical records, resulting in incomplete outcome data and variable follow-up duration. Documentation from other Swedish regions were not available and it is possible that some patients were followed up in other centers than Uppsala. Finally, this was a single-center study from a specialized NIC setting, and the findings may not be generalizable to all patients with t-SCI in different healthcare systems.

## Conclusions

In this single-center tertiary NIC cohort of adult patients with t-SCI, patient age increased substantially over the 15-year study period, with falls being the most common injury mechanism. Acute management also changed, with reduced corticosteroid administrations but increased use of vasopressors, while surgical timing remained largely unchanged. Despite the increased proportion of elderly, neurological improvement at NIC discharge and follow-up remained stable, although 6-month mortality increased which could be expected due to increased patient age and concomitant TBI. Earlier surgery was associated with neurological improvement at NIC discharge, whereas vasopressor use, higher comorbidity burden, and complete injury at discharge were associated with poorer neurological recovery. These findings highlight the changing epidemiology of t-SCI and the need for continued real-world evaluation of acute management, post-acute care, and clinically meaningful long-term outcomes.

## Declarations

We confirm that the manuscript complies with all instructions to authors. We confirm that authorship requirements have been met and the final manuscript was approved by all authors. We confirm that this manuscript has not been published elsewhere and is not under consideration by another journal.

# Competing Interests

PG has received lecture fees from Johnson and Johnson Medtech. The other authors declare that they have no competing interests.

# Funding

No funding source was used for this study.

# Author Contribution

Conceptualisation: TSW, LTS. Methodology: All authors. Formal analysis: TSW, LTS, MA. Resources: TSW, PE. Data curation: LTS, MA .Writing—original draft preparation: LTS, TSW, MA.Writing—review and editing: All authors.

# Acknowledgement

We express our gratitude to the personnel at the neurocritical care unit, Uppsala University Hospital, (Uppsala, Sweden), for careful patient care and assistance in data collection.

# Data Availability

Data are available upon reasonable request.

## References

1. Lu Y et al (Jan. 2025) Global, regional, and national burden of spinal cord injury from 1990 to 2021 and projections for 2050: A systematic analysis for the Global Burden of Disease 2021 study. Ageing Res Rev 103:102598. 10.1016/j.arr.2024.102598
2. Adegeest CY, Ter Wengel PV, Peul WC (2023) Traumatic spinal cord injury: acute phase treatment in critical care., *Curr. Opin. Crit. Care*, vol. 29, no. 6, pp. 659–665, Dec. 10.1097/MCC.0000000000001110
3. Josefson C, Rekand T, Lundgren-Nilsson Å, Sunnerhagen KS (2025) Epidemiology of Spinal Cord Injury in Adults in Sweden, 2016–2020: A Retrospective Registry-Based Study. Neuroepidemiology 59(4):334–342. 10.1159/000540818
4. Yokota K et al (2024) Changing trends in traumatic spinal cord injury in an aging society: Epidemiology of 1152 cases over 15 years from a single center in Japan. PLoS ONE 19(5):e0298836. 10.1371/journal.pone.0298836
5. Bracken MB et al (May 1990) A randomized, controlled trial of methylprednisolone or naloxone in the treatment of acute spinal-cord injury. Results of the Second National Acute Spinal Cord Injury Study.

N Engl J Med 322(20):1405–1411. 10.1056/NEJM199005173222001

6. Liu Z et al (Aug. 2019) High-dose methylprednisolone for acute traumatic spinal cord injury: A meta-analysis. Neurology 93(9):e841–e850. 10.1212/WNL.0000000000007998
7. Hejrati N et al (2023) Sep., Trends in the Use of Corticosteroids in the Management of Acute Spinal Cord Injury in North American Clinical Trials Network Sites., *J. Neurotrauma*, vol. 40, no. 17–18, pp. 1938–1947. 10.1089/neu.2022.0409
8. Fehlings MG et al (2012) Early versus delayed decompression for traumatic cervical spinal cord injury: results of the Surgical Timing in Acute Spinal Cord Injury Study (STASCIS). PLoS ONE 7(2):e32037. 10.1371/journal.pone.0032037
9. Nasi D, Ruscelli P, Gladi M, Mancini F, Iacoangeli M, Dobran M (2019) Ultra-early surgery in complete cervical spinal cord injury improves neurological recovery: A single-center retrospective study. Surg Neurol Int 10:207. 10.25259/SNI_485_2019
10. Weinberg JA et al (2021) Mean arterial pressure maintenance following spinal cord injury: Does meeting the target matter? *J. Trauma Acute Care Surg.*, vol. 90, no. 1, pp. 97–106, Jan. 10.1097/TA.0000000000002953
11. Catapano JS et al (Dec. 2016) Higher Mean Arterial Pressure Values Correlate with Neurologic Improvement in Patients with Initially Complete Spinal Cord Injuries. World Neurosurg 96:72–79. 10.1016/j.wneu.2016.08.053
12. Vale FL, Burns J, Jackson AB, Hadley MN (1997) Combined medical and surgical treatment after acute spinal cord injury: results of a prospective pilot study to assess the merits of aggressive medical resuscitation and blood pressure management., *J. Neurosurg.*, vol. 87, no. 2, pp. 239–246, Aug. 10.3171/jns.1997.87.2.0239
13. Levi L, Wolf A, Belzberg H (1993) Hemodynamic parameters in patients with acute cervical cord trauma: description, intervention, and prediction of outcome., *Neurosurgery*, vol. 33, no. 6, pp. 1007–16; discussion 1016–1017, Dec
14. Evaniew N et al (2024) Interventions to Optimize Spinal Cord Perfusion in Patients With Acute Traumatic Spinal Cord Injury: An Updated Systematic Review., *Glob. Spine J.*, vol. 14, no. 3_suppl, pp. 58S-79S, Mar. 10.1177/21925682231218737
15. Aarabi B et al (2012) Sep., Predictors of pulmonary complications in blunt traumatic spinal cord injury., *J. Neurosurg. Spine*, vol. 17, no. 1 Suppl, pp. 38–45. 10.3171/2012.4.AOSPINE1295
16. Sezer N, Akkuş S, Uğurlu FG (Jan. 2015) Chronic complications of spinal cord injury. World J Orthop 6(1):24–33. 10.5312/wjo.v6.i1.24
17. Charlson ME, Pompei P, Ales KL, MacKenzie CR (1987) A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. J Chronic Dis 40(5):373–383. 10.1016/0021-9681(87)90171-8
18. Rupp R et al (2021) Spring., International Standards for Neurological Classification of Spinal Cord Injury: Revised 2019., *Top. Spinal Cord Inj. Rehabil.*, vol. 27, no. 2, pp. 1–22. 10.46292/sci2702-1

19. Vaccaro AR et al (Dec. 2022) AO Spine upper cervical injury classification system: a description and reliability study. Spine J Off J North Am Spine Soc 22(12):2042–2049. 10.1016/j.spinee.2022.08.005
20. Vaccaro AR et al (Jul. 2016) AOSpine subaxial cervical spine injury classification system. Eur Spine J Off Publ Eur Spine Soc Eur Spinal Deform Soc Eur Sect Cerv Spine Res Soc 25(7):2173–2184. 10.1007/s00586-015-3831-3
21. Vaccaro AR et al (2013) AOSpine thoracolumbar spine injury classification system: fracture description, neurological status, and key modifiers., *Spine*, vol. 38, no. 23, pp. 2028–2037, Nov. 10.1097/BRS.0b013e3182a8a381
22. Moschovou M, Antepohl W, Halvorsen A, Pettersen AL, Divanoglou A (2022) Temporal changes in demographic and injury characteristics of traumatic spinal cord injuries in Nordic countries - a systematic review with meta-analysis., *Spinal Cord*, vol. 60, no. 9, pp. 765–773, Sep. 10.1038/s41393-022-00772-3
23. Aarabi B et al (2021) Trends in Demographics and Markers of Injury Severity in Traumatic Cervical Spinal Cord Injury., *J. Neurotrauma*, vol. 38, no. 6, pp. 756–764, Mar. 10.1089/neu.2020.7415
24. Fehlings MG et al (2017) A Clinical Practice Guideline for the Management of Patients With Acute Spinal Cord Injury: Recommendations on the Use of Methylprednisolone Sodium Succinate., *Glob. Spine J.*, vol. 7, no. 3 Suppl, pp. 203S-211S, Sep. 10.1177/2192568217703085
25. Roquilly A et al (Apr. 2020) French recommendations for the management of patients with spinal cord injury or at risk of spinal cord injury. Anaesth Crit Care Pain Med 39(2):279–289. 10.1016/j.accpm.2020.02.003
26. Kwon BK et al (2024) A Clinical Practice Guideline for the Management of Patients With Acute Spinal Cord Injury: Recommendations on Hemodynamic Management., *Glob. Spine J.*, vol. 14, no. 3_suppl, pp. 187S-211S, Mar. 10.1177/21925682231202348
27. Sajdeya R et al (Sep. 2025) Early Blood Pressure Targets in Acute Spinal Cord Injury: A Randomized Clinical Trial. JAMA Netw Open 8(9):e2525364. 10.1001/jamanetworkopen.2025.25364
28. Badhiwala JH et al (Feb. 2021) The influence of timing of surgical decompression for acute spinal cord injury: a pooled analysis of individual patient data. Lancet Neurol 20(2):117–126. 10.1016/S1474-4422(20)30406-3
29. Fehlings MG et al (2024) An Update of a Clinical Practice Guideline for the Management of Patients With Acute Spinal Cord Injury: Recommendations on the Role and Timing of Decompressive Surgery., *Glob. Spine J.*, vol. 14, no. 3_suppl, pp. 174S-186S, Mar. 10.1177/21925682231181883
30. Hosman AJF, Barbagallo G, van Middendorp JJ (2023) Neurological recovery after early versus delayed surgical decompression for acute traumatic spinal cord injury., *Bone Jt. J.*, vol. 105-B, no. 4, pp. 400–411, Mar. 10.1302/0301-620X.105B4.BJJ-2022-0947.R2
31. Steeves JD et al (Feb. 2011) Extent of spontaneous motor recovery after traumatic cervical sensorimotor complete spinal cord injury. Spinal Cord 49(2):257–265. 10.1038/sc.2010.99

32. Brommeland T et al (2024) Traumatic cervical spinal cord injury in southeastern Norway: acute treatment, specialized rehabilitation referral and mortality. Front Neurol 15:1452194. 10.3389/fneur.2024.1452194
33. Mohd Fuad INB, Smith É (Sep. 2024) Epidemiology of traumatic spinal cord injury in Ireland, 2017–2022. Spinal Cord Ser Cases 10(1):69. 10.1038/s41394-024-00683-w
34. Barbiellini Amidei C, Salmaso L, Bellio S, Saia M (2022) Epidemiology of traumatic spinal cord injury: a large population-based study., *Spinal Cord*, vol. 60, no. 9, pp. 812–819, Sep. 10.1038/s41393-022-00795-w
35. Martin ND, Marks JA, Donohue J, Giordano C, Cohen MJ, Weinstein MS (2011) The mortality inflection point for age and acute cervical spinal cord injury., *J. Trauma*, vol. 71, no. 2, pp. 380–5; discussion 385–386, Aug. 10.1097/TA.0b013e318228221f
36. Furlan JC, Fehlings MG (2009) The impact of age on mortality, impairment, and disability among adults with acute traumatic spinal cord injury., *J. Neurotrauma*, vol. 26, no. 10, pp. 1707–1717, Oct. 10.1089/neu.2009.0888
37. Furlan JC, Bracken MB, Fehlings MG (2010) Is age a key determinant of mortality and neurological outcome after acute traumatic spinal cord injury? *Neurobiol. Aging*, vol. 31, no. 3, pp. 434–446, Mar. 10.1016/j.neurobiolaging.2008.05.003
38. Furlan JC (2024) Concomitant traumatic brain injury as a determinant of survival, and neurological and functional outcomes after traumatic spinal cord injury: A retrospective cohort study., *PM R*, vol. 16, no. 8, pp. 804–814, Aug. 10.1002/pmrj.13123
39. Furlan JC, Wang D, Kurban D (May 2026) Effects of concomitant traumatic brain injury on the epidemiology, access to treatment services and outcomes after traumatic spinal cord injury: A retrospective cohort study. Spinal Cord 64(5):438–446. 10.1038/s41393-026-01199-w
40. Savic G, DeVivo MJ, Frankel HL, Jamous MA, Soni BM, Charlifue S (2017) Long-term survival after traumatic spinal cord injury: a 70-year British study., *Spinal Cord*, vol. 55, no. 7, pp. 651–658, Jul. 10.1038/sc.2017.23
41. Wilson JR, Cadotte DW, Fehlings MG (2012) Clinical predictors of neurological outcome, functional status, and survival after traumatic spinal cord injury: a systematic review., *J. Neurosurg. Spine*, vol. 17, no. 1 Suppl, pp. 11–26, Sep. 10.3171/2012.4.AOSPINE1245
42. Grossman RG et al (2012) Sep., Incidence and severity of acute complications after spinal cord injury., *J. Neurosurg. Spine*, vol. 17, no. 1 Suppl, pp. 119–128. 10.3171/2012.5.AOSPINE12127

# Figures

| Subject | Main findings | p-value | Relevance |
|---|---|---|---|
| Median age at injury | Increase from 48 to 71 years during study period | ***<0.001*** | Increased patient age and frailty affects injury patterns, rehabilitation potential and survival |
| Complete injury (AIS A) at neurointensive care admission | Decrease from 66% to 42% during study period | ***0.025*** | Likely reflects injury patterns with increased low energy traumas causing t-SCI |
| Corticosteroid usage for neuroprotection | Decrease from 26% to 3% during study period | ***<0.001*** | Supports the ongoing trend of decreased corticosteroid usage after t-SCI |
| Vasopressor usage for hemodynamic management | Increase from 53% to 81% during study period | ***0.003*** | Displays an increased emphasis on active hemodynamic management in t-SCI management |
| 6-month mortality | Increase from 10% to 29% during study period | ***0.008*** | Possibly explained by increase patient age and TBI incidence but may also be a sign of increased post neurointensive care vulnerability |
| Neurological improvement at follow-up | 50% of patients in both 2008-2012 and 2018-2022 | 0.110 | Static neurological outcome despite significantly older patients and increased 6-month mortality |

## Figure 1

Summary of the main findings from the conducted study and their interpretations.

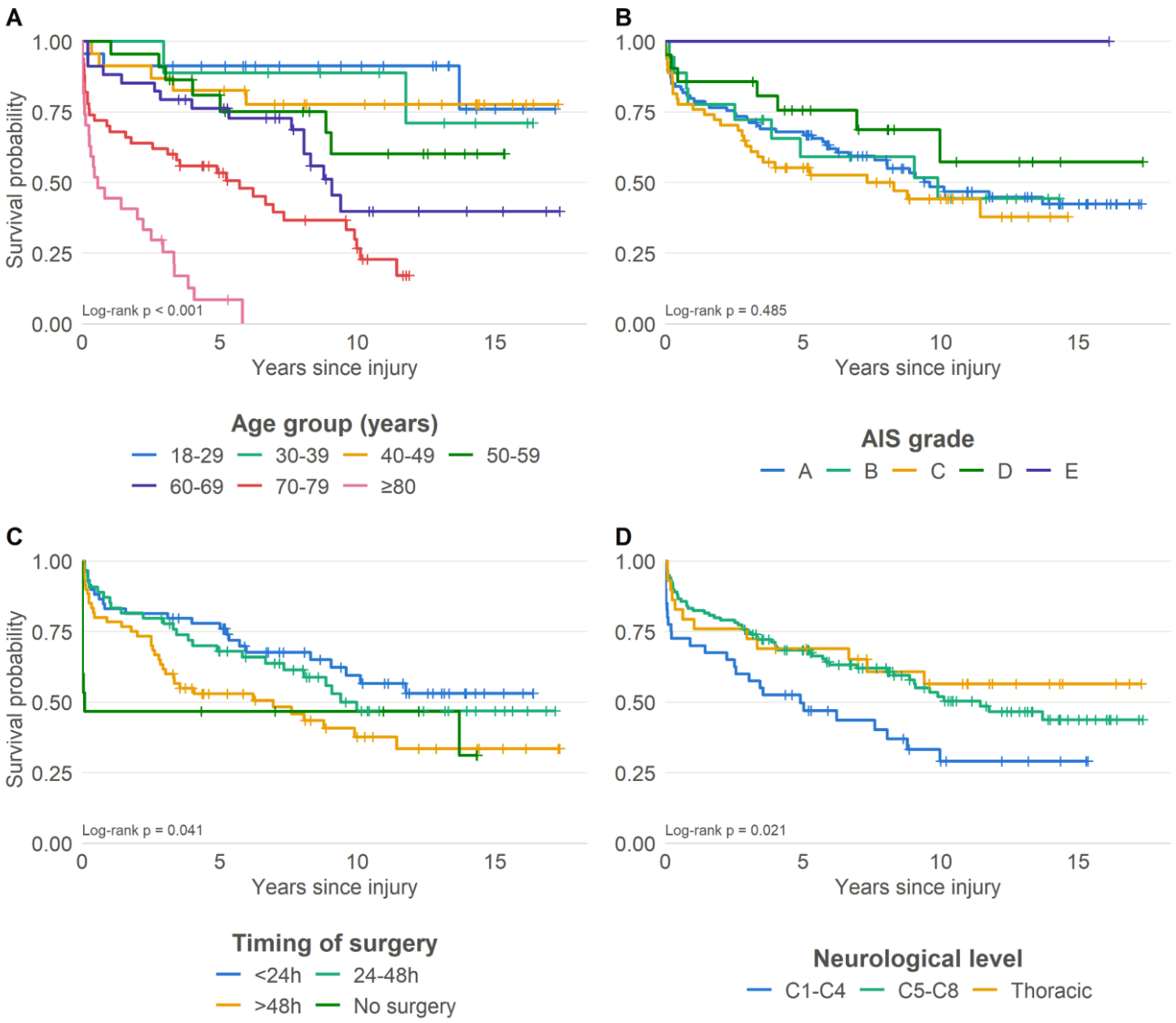


**Figure 2**

Kaplan-Meier analysis of mortality vs age categories, AIS at admission, surgical timing and neurological injury level. A: Age. B: AIS-grade at admission. C: Surgical timing. D: Neurological injury level.

AIS = American Spinal Injury Association Impairment Scale.

# Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Supplementarytable1.docx