International Journal of Innovative Technologies in Social Science

e-ISSN: 2544-9435

Operating Publisher
SciFormat Publishing Inc.
ISNI: 0000 0005 1449 8214

2734 17 Avenue SW,
Calgary, Alberta, T3E0A7,
Canada
+15878858911
editorial-office@sciformat.ca

ARTICLE TITLE	TIMING OF SURGICAL DECOMPRESSION IN ACUTE TRAUMATIC SPINAL CORD INJURY: A NARRATIVE REVIEW
DOI	https://doi.org/10.31435/ijitss.2(50).2026.5866
RECEIVED	07 March 2026
ACCEPTED	16 June 2026
PUBLISHED	23 June 2026
LICENSE	

TIMING OF SURGICAL DECOMPRESSION IN ACUTE TRAUMATIC SPINAL CORD INJURY: A NARRATIVE REVIEW

Michał Chylewski *(Corresponding Author, Email: michal.chylewski6@gmail.com)*
University Clinical Hospital No. 1 PMU in Szczecin, Szczecin, Poland
ORCID ID: 0009-0007-4789-1903

Karolina Chudecka
Independent Public Provincial Integrated Hospital in Szczecin, Szczecin, Poland
ORCID ID: 0009-0004-0262-5036

Aleksandra Kędzierska
Independent Public Provincial Integrated Hospital in Szczecin, Szczecin, Poland
ORCID ID: 0009-0008-7050-4139

Jakub Lamorski
Independent Public Provincial Integrated Hospital in Szczecin, Szczecin, Poland
ORCID ID: 0009-0004-5456-7413

Izabela Szubert
Independent Public Provincial Integrated Hospital in Szczecin, Szczecin, Poland
ORCID ID: 0009-0006-7162-6651

Julia Suchecka
Independent Public Provincial Integrated Hospital in Szczecin, Szczecin, Poland
ORCID ID: 0009-0001-9975-355X

Wiktor Nesterak
Pomeranian Medical University, Szczecin, Poland
ORCID ID: 0009-0009-5322-903X

Katarzyna Józwa
University Clinical Hospital No. 1 PMU in Szczecin, Szczecin, Poland
ORCID ID: 0009-0003-5615-2388

Gabriela Stępień
University Clinical Hospital No. 2 PMU in Szczecin, Szczecin, Poland
ORCID ID: 0009-0006-4505-5162

Urszula Przewoźna
University Clinical Hospital No. 2 PMU in Szczecin, Szczecin, Poland
ORCID ID: 0009-0003-2186-6604

ABSTRACT

Background. Traumatic spinal cord injury (tSCI) is a devastating condition with profound neurological, functional, and socioeconomic consequences. The secondary injury cascade — encompassing ischaemia, excitotoxicity, and oedema — provides the biological rationale for time-sensitive surgical decompression. The optimal timing of surgical decompression remains one of the most debated questions in spinal surgery, with ongoing uncertainty regarding injury-level specificity, completeness-dependent effects, and the potential benefit of ultra-early intervention.
Methods. A structured electronic search was performed in PubMed/MEDLINE and the Cochrane Library for studies published between January 2005 and May 2026. Adult patients (≥18 years) with acute blunt-mechanism tSCI at any spinal level were eligible. Included study designs comprised RCTs, prospective and retrospective cohort studies, systematic reviews, and meta-analyses reporting defined surgical timing and at least one relevant neurological or functional outcome. A total of 63 studies were included in the narrative synthesis.
Results. Convergent evidence from prospective cohorts and meta-analyses supports a benefit of early surgical decompression (within 24 hours) on neurological recovery in cervical tSCI, with pooled motor score advantages of approximately two to four points and increased odds of ASIA Impairment Scale (AIS) grade improvement. The benefit declines continuously with each additional hour of delay. For thoracic and thoracolumbar injuries, the evidence is more limited and heterogeneous, though incomplete injuries demonstrate consistent benefit. Contrary to historical assumptions, complete cervical injuries (AIS grade A) appear to benefit most from early and ultra-early (within 8–12 hours) decompression. The principal barriers to timely surgery are systemic rather than patient-related, encompassing inter-hospital transfer delays, absence of dedicated spinal emergency protocols, and competing operative priorities in polytrauma.
Conclusions. Early surgical decompression within 24 hours is supported by the preponderance of available evidence and by current international guidelines. Ultra-early decompression within 12 hours may confer additional benefit in complete cervical injuries. Addressing systemic barriers to timely surgery represents the most immediately actionable opportunity to improve outcomes at a population level. Adequately powered randomized trials, with stratification by injury level and completeness, are required to resolve persistent uncertainties.

KEYWORDS

Traumatic Spinal Cord Injury; Surgical Decompression; Surgical Timing; Early Surgery; ASIA Impairment Scale; Neurological Recovery

CITATION

Michał Chylewski, Karolina Chudecka, Aleksandra Kędzierska, Jakub Lamorski, Izabela Szubert, Julia Suchecka, Wiktor Nesterak, Katarzyna Józwa, Gabriela Stępień, Urszula Przewoźna. (2026) Timing of Surgical Decompression in Acute Traumatic Spinal Cord Injury: a Narrative Review. *International Journal of Innovative Technologies in Social Science*. 2(50). doi: 10.31435/ijitss.2(50).2026.5866

Introduction

Traumatic spinal cord injury (tSCI) represents one of the most devastating consequences of acute trauma, imposing profound physical, psychological, and socioeconomic burdens on individuals, their families, and healthcare systems worldwide. Global estimates place the annual incidence of tSCI at approximately 15 to 40 per million population, translating to 250,000 to 500,000 new cases each year (Bickenbach et al., 2013; GBD 2019 Diseases and Injuries Collaborators, 2020). Prevalence figures are substantially higher given improved long-term survival, with several million individuals living with chronic tSCI-related disability globally (Khorasanizadeh et al., 2019). The condition disproportionately affects young adult males as a consequence of motor vehicle accidents, falls from height, and sports-related trauma, although the demographic profile in high-income countries is shifting toward an older population sustaining low-energy injuries on a pre-existing degenerative spine (Devivo, 2012; Jain et al., 2015). Beyond the immediate neurological impact, tSCI is associated with lifetime costs estimated in the millions of US dollars per patient and represents a major cause of years lived with disability (National Spinal Cord Injury Statistical Center, 2023).

The pathophysiology of tSCI is characterised by a biphasic injury process. The primary mechanical insult disrupts axonal integrity, vascular supply, and cellular architecture at the moment of trauma; this damage is irreversible and not amenable to intervention. The primary injury triggers a cascade of secondary mechanisms — including ischaemia, glutamate-mediated excitotoxicity, oxidative stress, oedema, and progressive demyelination — that evolve over hours to days and represent a potentially modifiable therapeutic target (Ahuja et al., 2017). The temporal dynamics of secondary injury provide the central biological rationale for early surgical decompression: by relieving mechanical compression within a critical early window, surgeons may limit secondary damage and improve the potential for neurological recovery.

Despite the conceptual appeal of this model, the optimal timing of surgical decompression in acute tSCI has remained one of the most debated questions in spinal surgery. For several decades, institutional practice was shaped by concerns that early operative intervention carried prohibitive surgical risk. The publication of the Surgical Timing in Acute Spinal Cord Injury Study (STASCIS) by Fehlings et al. (2012) represented a pivotal moment in the field. That prospective multicentre cohort study demonstrated that patients undergoing decompression within 24 hours of injury were significantly more likely to achieve substantial neurological improvement at six months than those treated later, without a corresponding increase in complications. Ongoing questions persist regarding the generalisability of this threshold across injury levels and completeness, the potential benefit of ultra-early decompression within 8 to 12 hours, and the real-world barriers that prevent timely surgery in a substantial proportion of patients. The aim of this narrative review is to synthesise the available evidence on surgical timing in acute tSCI, with particular focus on clinical and neurological outcomes, injury-level and completeness-specific effects, the emerging evidence for ultra-early decompression, and the practical barriers to timely intervention.

Methodology

This narrative review was conducted to synthesise the available evidence on the timing of surgical decompression in acute traumatic spinal cord injury (tSCI). The literature search and study selection were transparent but informal, consistent with the narrative review design; no protocol was prospectively registered.

An electronic search was performed in PubMed/MEDLINE and the Cochrane Library for studies published between January 2005 and May 2026. The search combined MeSH terms and free-text keywords relating to: injury type (traumatic, acute, cervical, and thoracic spinal cord injury); intervention (surgical decompression, surgical timing); timing qualifiers (early, urgent, emergent, delayed); and outcomes (neurological recovery, AIS grade, motor recovery, functional outcome). Studies involving penetrating mechanisms were excluded at the search level.

Studies were considered for inclusion if they enrolled adult patients (≥18 years) with acute traumatic blunt-mechanism SCI at any spinal level, reported surgical decompression with clearly defined timing, and reported at least one relevant outcome — including AIS grade, motor scores, functional outcomes, complications, or mortality. Eligible designs included RCTs, prospective and retrospective cohort studies, systematic reviews, and meta-analyses available in English full text. Studies were excluded if they concerned penetrating injury, paediatric populations, non-traumatic aetiologies, or did not report surgical timing data. A small number of foundational pre-2005 studies (including seminal animal model experiments and early clinical series) were additionally cited in the Biological Rationale and Historical Context sections to provide mechanistic and historical background; these were not identified through the systematic search but were selected by the author based on established importance in the field. Approximately 330 records were identified across both databases; after removal of those clearly irrelevant at title and abstract level, 67 full-text articles were assessed in detail, of which 63 were included in the narrative synthesis. Given the heterogeneity of study designs, patient populations, and outcome measures across included studies, no quantitative pooling was performed; evidence was instead synthesised narratively and organised by spinal injury level, injury completeness, and surgical timing category.

The methodological quality of included primary studies is discussed qualitatively within each evidence subsection, informed by standard considerations of study design hierarchy — with prospective multicentre cohorts and RCTs weighted more heavily than single-centre retrospective series — as well as sample size, confounder adjustment, and outcome definition. No formal scoring instrument was applied and no overall certainty rating was assigned, consistent with narrative review methodology.

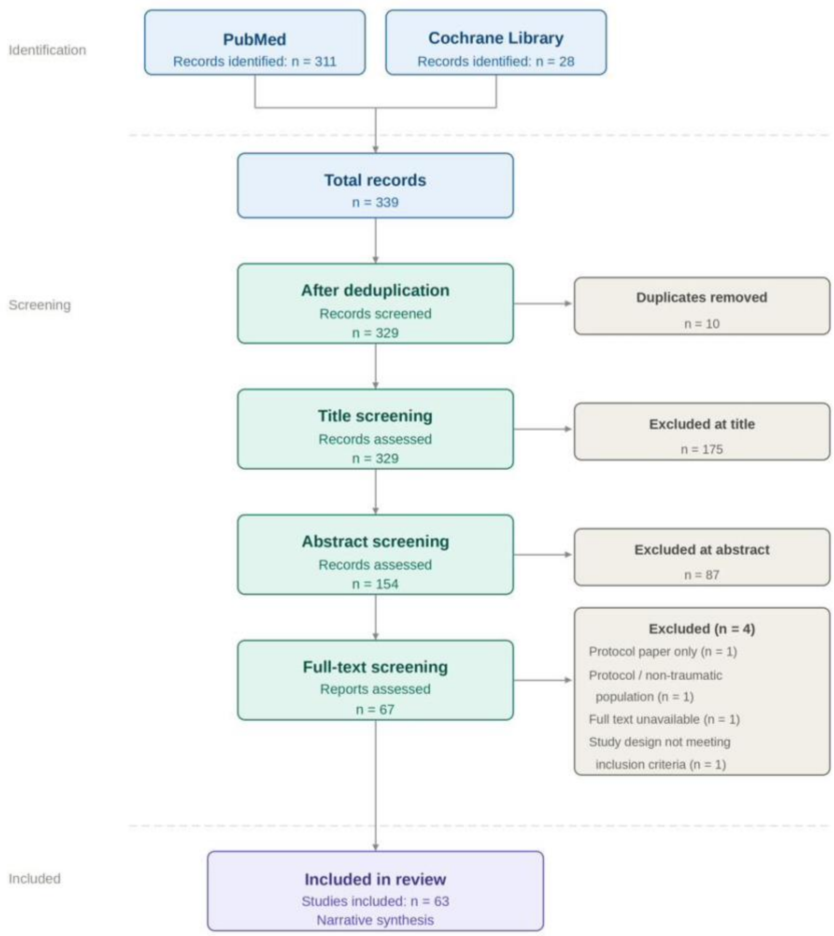

Fig. 1. *PRISMA Flow Diagram — Study Selection*

Figure 1. PRISMA flow diagram illustrating the study identification, screening, eligibility assessment, and inclusion process. A total of 330 records were identified across PubMed/MEDLINE and the Cochrane Library (January 2005 – May 2026). After removal of records irrelevant at title and abstract level, 67 full-text articles were assessed for eligibility, of which 63 were included in the final narrative synthesis.

Results

Biological Rationale for Surgical Timing

The pathological process underlying tSCI is characterised by a biphasic sequence with fundamental implications for treatment strategy. The primary injury occurs at the instant of mechanical insult, when kinetic energy is transmitted to the spinal cord through fracture, dislocation, disc herniation, or bony fragment displacement. The resulting mechanical forces cause immediate disruption of neuronal axons, oligodendrocytes, and blood vessels, with haemorrhage predominantly in the central grey matter and cell death within seconds to minutes in the most severely affected tissue (Ahuja et al., 2017; Tator & Fehlings, 1991). This component of injury is, by definition, complete at the moment of trauma and not amenable to intervention; its severity is the dominant determinant of the initial neurological deficit.

Within minutes of the primary insult, a self-amplifying cascade of secondary injury mechanisms is initiated, evolving over hours to days and collectively extending the zone of tissue destruction well beyond the area damaged by the initial mechanical event (Ahuja et al., 2017). The earliest secondary event is haemorrhagic necrosis of the central cord, driven by microvascular disruption and vasospasm. Ischaemia ensues within the first 30 to 60 minutes as blood flow falls below the threshold required for neuronal survival. The catastrophic failure of ionic pump mechanisms leads to massive influx of sodium, calcium, and water into injured cells, initiating downstream pathways of programmed and non-programmed cell death. The rise in intracellular calcium concentration activates proteases, phospholipases, and endonucleases, triggering both necrotic and apoptotic death in neurons and oligodendrocytes (Ahuja et al., 2017; Tator & Fehlings, 1991).

Glutamate-mediated excitotoxicity represents a second major mechanism. Massive synaptic glutamate release far exceeds the re-uptake capacity of injured astrocytes and oligodendrocytes, and the resulting over-activation of NMDA and AMPA receptors amplifies intracellular calcium loading and extends cellular injury to neurons not directly damaged by the primary event. Concurrent mitochondrial dysfunction generates reactive oxygen species (ROS), precipitating oxidative stress that damages cellular membranes, proteins, and DNA. An intense neuroinflammatory response ensues over subsequent hours and days, with microglial activation, peripheral neutrophil and macrophage invasion, and pro-inflammatory cytokine release; the acute inflammatory milieu further injures neurons and oligodendrocytes and impairs axonal regeneration. Progressive demyelination of structurally intact axons then compromises conduction even where axonal continuity is preserved (Ahuja et al., 2017; Tator & Fehlings, 1991).

Of the secondary injury mechanisms described, ischaemia occupies a central and clinically actionable position. Persistent mechanical compression of the cord sustains the ischaemic cascade through at least three mechanisms: direct physical compression impairs microvascular perfusion pressure; compression-induced oedema increases intramedullary tissue pressure; and persistent compression prevents restoration of normal ionic homeostasis even in axons that survived the primary insult (Ahuja et al., 2017; Tator & Fehlings, 1991; Le et al., 2015).

The time-dependency of ischaemic injury has been formally quantified through measurement of the intramedullary lesion length (IMLL) on MRI. Experimental data indicate that IMLL expands at approximately 900 micrometres per hour in patients with motor-complete (AIS A and B) injuries, compared with approximately 200 micrometres per hour in motor-incomplete (AIS C) injuries (Le et al., 2015). This differential rate of expansion has direct mechanistic implications: in complete injuries, surviving penumbral tissue is under maximal threat, secondary injury propagates substantially faster, and the time available within which to intervene effectively is correspondingly compressed.

The conceptual framework underlying early decompression draws on the principle of the ischaemic penumbra established in cerebral ischaemia: a zone of metabolically compromised but structurally intact tissue surrounding the irreversible injury core, salvageable if perfusion is restored within a finite time window before irreversible cell death occurs. In tSCI, the analogous secondary injury penumbra comprises the neuronal and axonal tissue in the peri-lesional cord that has sustained sufficient ischaemic and excitotoxic stress to be dysfunctional but not yet committed to irreversible death (Ahuja et al., 2017; Tator & Fehlings, 1991).

Clinical translational evidence supports this model. A landmark individual patient data meta-analysis by Badhiwala et al. (2021) employing restricted cubic spline modelling across 1,548 patients demonstrated a continuously improving relationship between earlier decompression and neurological recovery within the first 24 to 36 hours after injury, beyond which further delay produced no incremental neurological benefit. Importantly, even within the 24-hour window, each additional hour of delay was associated with a measurable and statistically significant reduction in the probability of meaningful neurological improvement (Badhiwala et al., 2021). The convergence of mechanistic, experimental, and clinical evidence thus supports a coherent biological model in which surgical decompression — by relieving mechanical compression, improving cord perfusion, and limiting the spatial propagation of secondary injury — offers the greatest potential for neurological salvage when performed as early as safely feasible.

Historical Context and the 24-Hour Threshold

For much of the twentieth century, acute tSCI was managed along broadly conservative lines, with early surgical intervention regarded as inadvisable and potentially harmful (Tator & Fehlings, 1991). This attitude was reinforced by early clinical series reporting neurological deterioration following surgery performed in the immediate post-injury period, and by animal studies demonstrating that the acutely injured cord was sensitive to manipulation and that haemodynamic instability at the time of surgery could compound ischaemic damage (Carlson et al., 1997). A gradual reassessment began with preclinical work during the 1990s. Carlson et al. (1997) demonstrated in a feline model that the duration of spinal cord compression was directly associated with the degree of vascular disruption and neurological deficit. Complementary work by Dimar et al. (1999) in rat contusion models confirmed that longer intervals of ongoing cord compression were associated with worsened neurobehavioural recovery. Early clinical evidence was mixed and methodologically limited; Vaccaro et al. (1997) conducted one of the first prospective randomised studies comparing surgery within 72 hours against delayed decompression in acute cervical SCI, finding no statistically significant neurological benefit for early surgery, though the study enrolled only 62 patients and was substantially underpowered.

The seminal study that operationalised the 24-hour threshold was STASCIS, published by Fehlings et al. (2012). This prospective multicentre cohort enrolled 313 patients with acute cervical tSCI across six North American centres. The principal finding — that patients in the early surgery group had a 2.83-fold higher adjusted odds of achieving at least a two-grade improvement on the AIS at six months (OR 2.83, 95% CI 1.10–7.28) — attracted immediate attention. Complication rates in the early group were comparable to or lower than those in the late surgery group, directly refuting the longstanding concern that urgent surgical intervention was inherently hazardous (Fehlings et al., 2012; Papadopoulos et al., 2002; Wilson et al., 2017). The impact of STASCIS on clinical guidelines was rapid. The 2013 AANS/CNS guidelines incorporated early surgical decompression as a recommendation for acute cervical SCI, and the 2017 AOSpine Clinical Practice Guideline issued a conditional recommendation for decompression within 24 hours (Wilson et al., 2017; Hadley & Walters, 2013).

Most influentially, Badhiwala et al. (2021) published a pooled analysis of individual patient data from four independent prospective multicentre North American cohorts encompassing 1,548 patients in The Lancet Neurology. Treating surgical timing as a continuous variable and employing restricted cubic spline analysis, this study demonstrated that the relationship between time to decompression and neurological recovery was not binary but progressive: the benefit of early surgery declined continuously with each passing hour, the most precipitous reduction occurring within the first 24 to 36 hours post-injury. The 24-hour threshold was thus reframed not as a hard biological boundary but as a clinically pragmatic approximation of a continuously declining benefit curve — introducing what some authors described as a "time is spine" paradigm (Adegeest et al., 2023) by analogy with "time is brain" in stroke management.

Current Evidence: Cervical Injuries

Traumatic cervical SCI accounts for the majority of cases in most reported tSCI series and has been the primary focus of clinical research into surgical timing (ter Wengel et al., 2019a). The STASCIS study remains the landmark reference against which all subsequent cervical evidence is measured, demonstrating a 2.83-fold higher adjusted odds of achieving at least a two-grade AIS improvement at six months with surgery within 24 hours compared with later intervention (Fehlings et al., 2012). Building on STASCIS, the pooled individual patient data analysis by Badhiwala et al. (2021) across 1,548 patients from four independent prospective multicentre cohorts demonstrated significantly greater improvement in total motor score at one year (mean difference 4.0 points, 95% CI 1.7–6.3; $p = 0.0006$) and increased likelihood of a favourable shift in AIS grade (common odds ratio 1.48, 95% CI 1.16–1.89; $p = 0.0019$).

The most methodologically rigorous prospective multicentre evidence presenting a more complex picture is the SCI-POEM study (Hosman et al., 2023). This European multicentre prospective observational cohort enrolled 294 patients across 15 centres and compared outcomes between patients undergoing decompression within 12 hours and those treated later, employing propensity score adjustment. The adjusted between-group difference in Lower Extremity Motor Score at 12 months was 2.2 points in favour of early surgery (95% CI -1.5 to 5.9; $p = 0.245$), which did not reach statistical significance. SCI-POEM did not demonstrate a significant neurological benefit of early decompression at 12 months; however, it also did not establish that early surgery is ineffective.

Quantitative synthesis across the available literature has consistently favoured early surgery. Qiu et al. (2021) conducted a systematic review and meta-analysis of 16 studies encompassing 3,977 patients and reported a pooled mean difference in ASIA motor score improvement of 2.32 points (95% CI 1.07–3.57; $p = 0.0003$) in favour of decompression within 24 hours, alongside an odds ratio of 1.71 for overall neurological improvement and a clinically important 38% reduction in complication rates. A broader systematic review and meta-analysis by ter Wengel et al. (2019b) pooling all published early versus late decompression studies across injury levels likewise identified a significant advantage of early surgery on neurological outcomes, providing cross-level corroboration for the cervical findings. The meta-analysis by ter Wengel et al. (2019a), applying a Bayesian random effects model and restricting the analysis to cervical injuries, identified a significant pooled odds ratio of 2.6 (95% CI 1.4–5.1) for achieving at least a two-grade AIS improvement with early surgery among patients with complete cervical SCI. Vasquez-Paredes et al. (2025), restricting inclusion to randomised controlled trials, found that early surgery was associated with a significantly higher rate of neurological improvement in complete SCI (relative risk 3.65, 95% CI 1.10–12.17; $p = 0.03$) and a significant reduction in postoperative complications (relative risk 0.42, 95% CI 0.20–0.88; $p = 0.02$). The most recent broad meta-analysis by Song et al. (2025) demonstrated that the neurological benefit of early surgery is time-dependent: absent or non-significant at three and six months but statistically robust at 12 months for both one-grade and two-grade AIS improvement, with the benefit persisting and increasing at 24 months. Complementing this, Shetty et al. (2025) — the most recent comprehensive meta-analysis including all three available RCTs alongside 11 observational studies (total n = 2,505) — reported a borderline non-significant trend toward motor score improvement (mean difference 3.64; p = 0.05) and AIS grade improvement (OR 1.37; p = 0.14) with early surgery, alongside a non-significant mortality difference (OR 1.40; p = 0.30) that provides reassurance that early surgery does not increase mortality risk. The consistent directional favouring of early surgery across this diverse pool of studies, even when pooled effects fall short of conventional significance thresholds, strengthens the overall evidentiary narrative.

A clinically important subpopulation requiring separate analysis is acute traumatic central cord syndrome (ATCCS), the most prevalent incomplete cervical SCI phenotype (Sattari et al., 2024). Lenehan et al. (2010) demonstrated a significant advantage of early surgery at 12 months for total motor score improvement (6.31 additional points; p = 0.036) and functional independence measure (7.79 additional points; p = 0.047). The meta-analysis by Sattari et al. (2024) of nine studies encompassing 5,619 ATCCS patients confirmed that early surgery was associated with significantly higher ASIA motor scores at one year (mean difference 4.89, 95% CI 2.89–6.88; p < 0.001), with no significant difference at six months, and was additionally associated with significantly lower rates of venous thromboembolism, total complications, and a nearly three-day reduction in hospital stay.

The only published randomised controlled trial in cervical SCI, the OSCIS trial of Chikuda et al. (2021), enrolled 70 patients with motor-incomplete cervical SCI (AIS grade C) and pre-existing cervical canal stenosis without bone injury. The trial found no statistically significant difference in the three co-primary outcomes — total motor score, grip strength, and the Japanese Orthopaedic Association (JOA) cervical myelopathy score — between early and delayed surgery at 12 months; however, a significant group-by-time interaction was identified, with the early surgery group demonstrating markedly better motor scores at two weeks and three months — consistent with accelerated rather than augmented recovery. Beyond the timing threshold, MRI-based measures of injury severity have emerged as important effect modifiers. Kamal et al. (2023) proposed a clinically useful IMLL-based stratification: patients with IMLL of 30 mm or less showed high rates of improvement regardless of timing, those with IMLL between 31 and 60 mm derived the greatest benefit from early decompression, and those with IMLL exceeding 61 mm showed uniformly poor prognosis irrespective of surgical speed.

In summary, the cervical SCI evidence base is characterised by consistent directionality — early decompression within 24 hours is associated with better neurological outcomes and fewer complications across studies, levels of evidence, and geographical settings (Gupta et al., 2015; Kafle et al., 2022; Du et al., 2019; Mayol et al., 2019) — but by persistent uncertainty about the magnitude of this benefit and the degree to which it varies by injury completeness, patient age, injury morphology, and imaging severity.

Current Evidence: Thoracic and Thoracolumbar Injuries

The evidence base for surgical timing in thoracic and thoracolumbar tSCI is substantially more limited than that for cervical injuries and has historically been characterised by methodological heterogeneity, small sample sizes, and the conflation of anatomically and biologically distinct injury levels under a single umbrella category. The thoracic spinal cord (T1–T10) has distinct pathophysiological characteristics compared with the thoracolumbar junction (T11–L2): it occupies a narrow canal with a relatively poor vascular supply — particularly at the T4–T7 watershed zone — and complete thoracic injuries carry the worst spontaneous recovery rates of any spinal level (ter Wengel et al., 2019c).

Evidence from large multicentre cohorts offers the most methodologically persuasive data. The pooled individual patient data analysis by Badhiwala et al. (2021) included a subgroup of patients with thoracic injuries and identified a significant advantage of early surgery on lower extremity motor score recovery at one year (mean difference 4.4 points, 95% CI 0.3–8.5; p = 0.034). Dvorak et al. (2015), drawing on the Rick Hansen SCI Registry across 31 Canadian centres, found a significant six-point motor score advantage for incomplete injuries (AIS grades B through D) regardless of injury level.

The only published randomised controlled trial addressing thoracic and thoracolumbar SCI timing (Rahimi-Movaghar et al., 2014) was severely underpowered, enrolling only 35 of a planned 328 patients. The quasi-randomised controlled trial of Cengiz et al. (2008) reported 83.3% improvement in the ultra-early surgery group (within eight hours) versus 26.6% in those operated three to fifteen days later (p = 0.011), though the extreme delay in the control group and non-random allocation mechanism limit interpretation.

The largest prospective cohort study addressing thoracolumbar SCI timing, Du et al. (2018) with 721 patients, demonstrated significantly higher rates of one-grade AIS improvement with early surgery overall (51.4% versus 41.6%; $p = 0.009$). Critically, this benefit was not uniformly distributed across injury morphologies: the advantage of early surgery was statistically significant for type B (distraction) and type C (translational/rotational) injuries but absent for type A (compression) fractures, suggesting that surgical urgency should be influenced by the nature of the mechanical disruption. The only available meta-analysis specifically addressing surgical timing in thoracic and thoracolumbar SCI (ter Wengel et al., 2019c), applying a Bayesian random effects model to 14 studies encompassing 1,075 patients, did not identify a statistically significant pooled benefit of decompression within 24 hours on AIS grade improvement, with very high between-study heterogeneity (I^2 approximately 88%) preventing reliable pooling.

Pure thoracic SCI (T1–T10) warrants specific consideration. Wutte et al. (2020) analysed a 43-patient prospective EMSCI registry cohort of isolated thoracic injuries and reported no statistically significant difference in AIS grade conversion between patients operated within eight hours and those operated later. However, ultra-early surgery was independently associated with significantly better functional outcomes on the Spinal Cord Independence Measure at one year, specifically for bladder management and mobility and transfer ability. This finding is clinically important: neurological grade conversion may be an insufficient metric for evaluating the benefit of surgical timing in thoracic SCI, where bladder function and transfer independence — ranked among the highest priorities by patients living with paraplegia — may improve meaningfully even in the absence of formal AIS grade change.

Complete Versus Incomplete Injuries: Does Timing Matter Differently?

The biological logic underlying the surgical management of tSCI has long implied that injury completeness should be a primary determinant of urgency. A complete injury — AIS grade A, with no sensorimotor function preserved below the neurological level — was presumed to carry so little residual cord tissue capable of recovery that the marginal benefit of rapid decompression would be negligible. The available evidence, however, does not straightforwardly support this framework and in several respects actively contradicts it.

The most consequential reappraisal came from the meta-analysis of ter Wengel et al. (2019a), which stratified the neurological effect of early surgical decompression by injury completeness in cervical tSCI. Pooling data from 15 observational cohort studies encompassing 1,126 patients, the authors applied a Bayesian random-effects model and identified a striking dissociation between injury subtypes. For complete cervical SCI (AIS grade A), early surgery within 24 hours was associated with significantly greater neurological improvement (OR 2.6, 95% CI 1.4–5.1), corresponding to class IIa evidence. In the incomplete cervical SCI subgroup, by contrast, no significant association between surgical timing and neurological improvement was identified (OR 0.9, 95% CI 0.5–1.6). The inversion of the expected relationship — where the more severely injured patients appear to derive greater benefit from timing — constitutes a paradigm-shifting finding.

At the individual study level, the most dramatic illustration of a timing-dependent response in complete SCI was provided by Nasi et al. (2019), whose retrospective cohort of 81 cervical tSCI patients compared ultra-early surgery within 12 hours against early surgery in the 12-to-48-hour window. Among the 26 patients with AIS grade A injury, neurological improvement at 12 months was achieved in 61.5% of those operated within 12 hours compared with 7.7% of those operated between 12 and 48 hours ($p = 0.003$). Multivariate logistic regression confirmed surgical timing as the most powerful independent predictor of neurological improvement ($p = 0.005$). The mechanistic basis for this counterintuitive pattern is incompletely understood, but a key explanation is that a substantial proportion of patients classified as AIS A on admission retain some preserved cord tissue whose function is suppressed by haemorrhagic oedema and secondary injury cascades; early decompression may rescue perilesional axons that would otherwise undergo delayed secondary degeneration.

The complete SCI narrative is not uniformly favourable to early surgery. Two major Canadian studies — the Rick Hansen SCI Registry cohort of Dvorak et al. (2015) ($n = 888$) and the prospective multicentre cohort of Wilson et al. (2014) ($n = 84$) — found no significant advantage of early surgery on motor score improvement in AIS grade A patients when analysed separately. In the Dvorak registry study, multivariate regression on 186 AIS A patients demonstrated that early surgery within 24 hours was not associated with greater motor recovery, though it was associated with a significant reduction of 7.5 days in acute hospital length of stay ($p = 0.004$).

For incomplete injuries, the large national Rick Hansen registry analysis by Dvorak et al. (2015) demonstrated that early surgery within 24 hours was associated with approximately six additional motor score points among AIS B, C, and D patients ($p = 0.030$), consistent with the meta-analytic estimate of 5.94 additional motor points from van Middendorp et al. (2013) — a clinically meaningful increment. Acute traumatic central cord syndrome (ATCCS) merits specific consideration as the most prevalent incomplete spinal cord injury phenotype globally (Sattari et al., 2024). The meta-analysis of Sattari et al. (2024), synthesising nine studies encompassing 5,619 ATCCS patients, confirmed that early surgery within 24 hours was associated with significantly higher ASIA motor scores at one year (mean difference 4.89, 95% CI 2.89–6.88; $p < 0.001$), with no significant between-group difference at six months. In a dedicated prospective study of AIS C and D ATCCS patients, Aarabi et al. (2021) demonstrated that early surgery (within 24 hours) with MRI-confirmed decompression was associated with greater neurological improvement compared with late or delayed intervention, reinforcing the value of timely surgery even in this motor-incomplete phenotype.

Special Population: Elderly Patients

The growing demographic shift toward older patients sustaining tSCI on a background of degenerative cervical spine disease necessitates specific consideration of surgical timing in this population. Elderly patients present a distinct clinical profile characterised by reduced physiological reserve, increased anaesthetic risk, higher rates of cardiovascular and respiratory comorbidity, and a spinal cord already compromised by chronic spondylotic stenosis — factors that have historically been invoked to justify delayed or conservative surgical management. Emerging evidence challenges this conservative posture.

Kopp et al. (2022) analysed the interaction between age and surgical timing on neurological outcomes in a prospective multicentre cohort, finding that older age was independently associated with longer intervals to surgery — a phenomenon partly explained by the increased frequency of pre-operative medical optimisation requirements. Importantly, when surgery was performed within 24 hours, older patients achieved neurological improvements comparable to their younger counterparts, suggesting that the lower rates of recovery observed in elderly cohorts may in part reflect system-driven delay rather than irreversible biological differences in injury response. In a nationwide Japanese multicentre study, Segi et al. (2025) examined 387 elderly patients with traumatic cervical SCI and demonstrated that early surgery within 24 hours was associated with significantly greater AIS grade improvement at one year compared with delayed intervention, with a complication profile that did not differ adversely from that observed in non-elderly comparators. Nori et al. (2024), analysing elderly patients with cervical SCI without bone injury — a clinically common and underappreciated subgroup — found that surgical timing within 24 hours was significantly associated with neurological improvement, particularly in motor-incomplete injuries.

Collectively, these data do not support a policy of routine surgical deferral in elderly tSCI patients. Rather, they reinforce the general principle that timely decompression confers neurological benefit across age groups, while acknowledging that pre-operative medical stabilisation may appropriately extend the pre-operative interval in individual cases. Prospective studies with dedicated elderly cohorts, standardised comorbidity adjustment, and patient-reported outcome measures are required to refine timing recommendations for this growing subpopulation.

Ultra-Early Surgery: Emerging Evidence (< 8–12 Hours)

The establishment of surgery within 24 hours as the prevailing standard of care has encouraged a further question: whether compressing the operative window to fewer than 8–12 hours after injury might yield additional neurological benefit. The biological basis for this proposition is compelling. Experimental models have demonstrated that the secondary injury cascade accelerates within the first several hours of compression, with progressive loss of penumbral neural tissue (Ahuja et al., 2017). The substantially faster rate of IMLL expansion in complete injuries further supports the existence of a critical therapeutic window substantially shorter than 24 hours for the most severely injured patients (Le et al., 2015).

The most comprehensive synthesis of ultra-early surgical evidence to date is the systematic review and meta-analysis by Yousefifard et al. (2022), which pooled 16 studies encompassing 868 patients and compared ultra-early surgery — defined as within 12 hours — against early surgery in the 12–24 hour window. Across all injury levels and severities, ultra-early decompression was associated with significantly higher odds of neurological improvement (OR 2.19; 95% CI 1.44–3.33; $I^2 = 49.51\%$). A meta-regression demonstrated that the choice of ultra-early threshold (whether four, six, eight, or 12 hours) did not significantly influence efficacy, supporting the pragmatic adoption of a 12-hour window (Yousefifard et al., 2022).

Subgroup analyses revealed a clinically important pattern of differential benefit. Ultra-early surgery produced significantly superior outcomes in cervical spinal cord injuries (OR 2.25; 95% CI 1.41–3.58), whereas the benefit in thoracolumbar injuries was not statistically significant. A meta-analysis by Bhimani et al. (2023) specifically addressing ultra-early surgery (within eight hours) for thoracolumbar SCI similarly found no significant pooled neurological benefit, reinforcing the conclusion that the magnitude of timing-sensitivity may be less pronounced at infracervical levels. When stratified by initial AIS grade, patients with complete (AIS A) injuries demonstrated the greatest benefit from ultra-early decompression (OR 3.86; 95% CI 1.50–9.91), while no significant benefit was observed for AIS B, C, or D injuries individually (Yousefifard et al., 2022). This paradoxical observation — that complete injuries appear to benefit most from aggressive timing — challenges the clinical nihilism sometimes applied to the most severely injured patients. A complementary meta-analysis by Yu et al. (2025) reported that surgery within eight hours was associated with significantly higher odds of AIS grade improvement compared to later intervention (OR 2.64).

Among individual studies, Nasi et al. (2019) provides some of the most compelling data for ultra-early surgery in complete cervical injuries: ultra-early surgery within 12 hours resulted in neurological improvement in 61.5% of AIS A patients, compared with only 7.7% in the early (12–48 hour) group ($p = 0.003$), with surgical timing identified as the strongest independent predictor in multivariate logistic regression ($p = 0.005$). Complication rates were additionally lower in the ultra-early group (15% versus 34%; $p = 0.03$). Corroborating this, Aarabi et al. (2020), applying MRI-confirmed decompression criteria to a prospective cervical cohort stratified by AIS grade, reported that ultra-early surgery was associated with superior neurological outcomes in AIS A, B, and C patients, with AIS A injuries again demonstrating the most pronounced timing-sensitivity.

The ultra-early surgery evidence base is substantially complicated by conflicting findings and methodological heterogeneity. Several additional single-centre and registry-based studies have examined this question with varying results: Burke et al. (2019) demonstrated that ultra-early surgery within 12 hours was correlated with a higher rate of AIS grade conversion in a cervical SCI cohort; Jug et al. (2015), in a prospective cohort of cervical tSCI patients, reported significantly superior neurological recovery when decompression and instrumented fusion were performed within eight hours compared with the eight-to-24-hour window; Biglari et al. (2016) explored the impact of intervention within four hours, finding a directional but statistically inconclusive benefit; and Bock et al. (2021), in a prospective observational study, similarly identified a trend toward better outcomes with the shortest operative intervals, without achieving significance after adjustment. The meta-analysis by Carr et al. (2024), adopting the most restrictive ultra-early threshold — within five hours — identified only three eligible studies with 140 patients total, yielding a non-significant pooled effect (OR 1.33; $p = 0.761$). The SCI-POEM study (Hosman et al., 2023), the largest prospective multicentre cohort study of surgical timing in tSCI to date, found no statistically significant difference in lower extremity motor scores at 12 months between patients operated within 12 hours versus later, after multivariable adjustment. A further challenge unique to the ultra-early paradigm is the neurological assessment confounder of spinal shock: patients evaluated within hours of injury may still be in spinal shock, rendering the initial AIS classification unreliable.

The current evidence suggests that ultra-early decompression (within 8–12 hours) is associated with superior neurological outcomes compared with later surgery in specific subgroups — most consistently in complete (AIS A) cervical injuries — but does not offer a proven benefit over surgery within 24 hours for incomplete injuries or thoracolumbar pathology. The evidence base remains predominantly retrospective and observational, with no adequately powered RCT specifically targeting the ultra-early window having been completed. The pragmatic equivalence of eight-hour and 12-hour thresholds demonstrated by meta-regression is clinically significant, as a 12-hour window is more consistently achievable within existing trauma systems (Yousefifard et al., 2022).

Practical Barriers to Early Surgery

A consistent gap exists between what the clinical evidence recommends and what is achievable in practice. Studies conducted at specialist Level I trauma centres report early surgery rates substantially higher than those observed in real-world, system-wide analyses. Evidence from prospective logistics studies, retrospective trauma registry analyses, and qualitative clinical reports identifies three principal domains of delay: inter-hospital transfer and triage, haemodynamic instability requiring pre-operative stabilisation, and the presence of concomitant injuries demanding competing operative priorities.

The most granular prospective analysis of surgical delay determinants in tSCI was performed by Thompson et al. (2018) using time-stamped administrative data from the Quebec Trauma Registry for 144 patients. Three independent predictors of late surgery (beyond 24 hours) were identified through multivariate logistic regression: delay in inter-hospital transfer (OR 2.48; $p = 0.001$), delay from the first medical assessment to surgical plan completion (OR 2.82; $p < 0.001$), and delay from surgical plan completion to incision (OR 2.47; $p = 0.001$). Crucially, no patient-related factor — including age, sex, injury severity score, injury level, or AIS grade — independently predicted delayed surgery. The barriers are therefore predominantly systemic rather than biological, a finding with direct policy implications (Thompson et al., 2018).

Only 9.7% of patients in the Thompson et al. (2018) cohort were transported directly from the injury scene to the spinal centre; the remaining 90.3% were first admitted to a community hospital, adding a mean of 8.6 hours to the total pre-operative interval. Dakson et al. (2017) similarly observed that intermediate institution transfer delayed neurosurgical assessment approximately five-fold. Within the specialist centre, the most remediable source of delay was the interval between first medical assessment and surgical plan submission — an interval four times longer in the delayed surgery group (mean 23.3 hours versus 6.0 hours; $p < 0.001$), attributed to the absence of a dedicated spinal emergency protocol (Thompson et al., 2018). A day-of-week effect was documented: patients whose surgical plans were finalised on weekends achieved early surgery at a rate of 75%, compared with only 50% on weekdays, suggesting that high elective surgical volume on weekdays competes with emergency spinal access.

Haemodynamic instability represents one of the most common patient-level reasons for deferring early surgery in tSCI. Neurogenic shock occurs in up to 20% of patients with cervical level injuries and in virtually all patients with severe injury above T6 (Guly et al., 2008). Current guidelines recommend maintaining mean arterial pressure (MAP) of 85–90 mmHg for a minimum of five to seven days after injury. Integrated critical care management of the acute tSCI patient — encompassing haemodynamic optimisation, respiratory monitoring, and thromboprophylaxis — is a prerequisite for safe early surgery and constitutes a distinct and equally important component of the acute treatment pathway (Adegeest et al., 2023b). Dakson et al. (2017) demonstrated that suboptimal MAP maintenance was an independent predictor of failed neurological recovery (OR 11.1 for no improvement) — a stronger predictor than surgical timing itself in multivariate analysis. This finding is critical: even when early surgery is achieved, concurrent haemodynamic mismanagement may negate its benefit, making simultaneous management of both parameters essential.

Traumatic spinal cord injuries rarely occur in isolation. High-energy mechanisms frequently produce polytrauma involving thoracic, abdominal, cranial, and orthopaedic injuries that may carry immediate life-threatening priority (Sewell et al., 2018). Sewell et al. (2018) studied 95 patients with cervical SCI and concomitant chest trauma at three UK spinal centres. Despite the physiological challenge, early surgery (within 24 hours) was not associated with increased mortality or complication rates compared with delayed surgery; on the contrary, early surgery was associated with significantly shorter ICU stay (14 versus 23 days; $p = 0.013$). The authors concluded that in patients with GCS greater than 13 and manageable haemodynamic parameters, early cervical decompression is feasible and beneficial even in the presence of chest trauma.

The barriers to early surgery identified in this literature are, in large part, modifiable. The principal conclusion from system-level analyses is that the major determinants of surgical delay are healthcare organisational factors — transfer pathways, surgical decision protocols, and operating theatre access — rather than intrinsic patient characteristics (Thompson et al., 2018). Direct transport to Level I spinal centres for appropriately triaged patients, implementation of dedicated spinal emergency protocols, formalised rapid assessment and imaging pathways, and extended-hours operative access are all interventions that could substantially increase the proportion of patients receiving early surgery. The simulation analysis by Thompson et al. (2018) projected a 20% increase in the early surgery rate from system redesign alone.

Current Guidelines

The 2013 AANS/CNS guidelines on the management of acute cervical spine and spinal cord injuries issued a Level III recommendation that early decompression within 24 hours of cervical SCI is safe and may be associated with improved neurological outcomes (Hadley & Walters, 2013). The guideline explicitly acknowledged that the recommendation was derived predominantly from Class II and Class III observational data rather than randomised controlled trial evidence, with the primary evidence base being the STASCIS study. The guideline did not extend specific timing recommendations to thoracic or thoracolumbar injuries, reflecting the paucity of data at these levels at the time of publication.

The 2017 AOSpine Clinical Practice Guideline, underpinned by a comprehensive systematic review of 39 studies, issued a conditional recommendation for surgical decompression within 24 hours for patients with acute tSCI at the cervical level (Wilson et al., 2017). For thoracic and thoracolumbar injuries, the evidence was deemed insufficient to support a specific timing recommendation. The conditional nature of the recommendation was explicitly attributed to the predominance of non-randomised evidence rather than to evidence of inefficacy.

The most recent and most consequential guideline update was published in March 2024 in Global Spine Journal as part of a dedicated focus issue co-sponsored by AO Spine and the Praxis Spinal Cord Institute (Fehlings et al., 2024). The guideline was produced by an international, multidisciplinary guideline development group employing the GRADE framework and informed by an updated systematic review that included the landmark individual patient data meta-analysis of Badhiwala et al. (2021) and the European SCI-POEM cohort of Hosman et al. (2023).

The central recommendation is unambiguous: it is recommended that patients with an acute spinal cord injury, regardless of injury level, undergo surgical decompression within 24 hours after injury when medically feasible. This represents a substantive upgrade from the 2017 conditional recommendation to a stronger recommendation, principally driven by the availability of pooled meta-analytic evidence demonstrating consistent benefit of early surgery across multiple independent cohorts. The scope explicitly encompasses all injury levels — including thoracic and thoracolumbar injuries previously excluded — and applies to patients of all injury completeness grades.

On the specific question of ultra-early decompression, the guideline development group adopted a cautious position. Although it acknowledged the biological plausibility of benefits from decompression within eight or 12 hours post-injury and the emerging literature in support of this hypothesis, the group concluded that the available evidence was insufficient to formulate a guideline recommendation regarding ultra-early surgery as a distinct therapeutic category, reflecting both the retrospective design and small sample sizes of most ultra-early studies.

The publication of the 2024 AO Spine/Praxis guidelines precipitated an important controversy. Shortly after publication, the AANS and CNS jointly issued a formal position statement dissenting from the AO Spine/Praxis conclusion (American Association of Neurological Surgeons & Congress of Neurological Surgeons, 2024). The AANS/CNS maintained that there is no prospective Class I evidence — as required by their evidence classification hierarchy — supporting a recommendation regarding the timing of surgical intervention, and that issuing strong recommendations on the basis of observational data risks being misleading and potentially compromising patient safety. This divergence reflects a fundamental methodological tension between two dominant approaches to guideline development. The AANS/CNS framework classifies evidence by study design, treating the absence of randomised controlled trial data as a defining constraint on recommendation strength. The AO Spine/Praxis framework employs the GRADE methodology, which explicitly permits strong recommendations on the basis of non-randomised evidence when the quality, consistency, and directness of that evidence is sufficiently robust. Notwithstanding this institutional disagreement, a point of practical consensus does exist: neither document endorses deliberate surgical delay in the absence of a specific clinical contraindication.

Discussion

This narrative review synthesises six decades of evolving evidence on one of the most consequential and contested questions in acute spinal surgery: when should the injured spinal cord be decompressed? The answer depends on the injury level, the degree of completeness, the patient's physiological state, and the healthcare system in which care is delivered. Yet despite these complexities, several convergent messages emerge with sufficient consistency to support clinically actionable conclusions.

The most consistent finding across study designs, populations, and geographical settings is that surgical decompression within 24 hours of cervical tSCI is associated with superior neurological outcomes compared with delayed intervention, and that this benefit is not purchased at the cost of increased surgical risk. The pooled individual patient data analysis of Badhiwala et al. (2021) provides the methodologically strongest evidence for this conclusion: across 1,548 patients from four independent prospective cohorts, earlier decompression was associated with significantly greater motor score improvement and higher odds of AIS grade improvement, with a benefit curve that declined continuously with each passing hour. Meta-analytic evidence from multiple independent syntheses yields pooled estimates consistently favouring early surgery, with neurological benefit on the order of two to four additional motor score points and odds ratios for AIS grade improvement ranging from approximately 1.7 to 2.8 (Qiu et al., 2021; ter Wengel et al., 2019a; Vasquez-Paredes et al., 2025). The concurrent finding that early surgery is associated with reduced complication rates

— including reduced rates of pneumonia, venous thromboembolism, and wound complications — suggests that its benefit extends beyond neurological recovery to encompass the secondary morbidities that substantially inflate the long-term burden of tSCI.

Perhaps the most clinically important and least intuitively anticipated finding of this review is the evidence that complete cervical SCI — historically regarded as the subgroup least likely to benefit from surgical speed — may in fact be the subgroup for whom timing matters most. The ter Wengel et al. (2019a) meta-analysis and the Nasi et al. (2019) cohort converge on the observation that AIS grade A injuries derive greater benefit from early and ultra-early decompression than incomplete injuries in terms of AIS grade conversion. The mechanistic explanation — that a clinically complete injury may conceal anatomically incomplete cord disruption, with penumbral tissue salvageable if decompression is sufficiently prompt — is biologically plausible and consistent with imaging data on intramedullary lesion expansion rates (Le et al., 2015). This finding demands a reappraisal of the clinical nihilism that has historically attached to AIS grade A injuries, particularly at the cervical level.

The evidence base for thoracic and thoracolumbar SCI timing is substantially less mature than that for cervical injuries, and the conclusions that can be drawn are correspondingly more tentative. The most important nuance from this level is the interaction between injury morphology and timing: the Du et al. (2018) prospective cohort demonstrated that the benefit of early surgery in thoracolumbar incomplete SCI is concentrated in distraction and translational/rotational injury patterns and is absent in compression fractures. The Qadir et al. (2020) data suggest that in resource-constrained settings, a 72-hour rather than 24-hour target may represent the clinically meaningful inflection point below which neurological outcomes are not significantly compromised. Supporting evidence from additional cohorts corroborates the overall direction: Goulet et al. (2020) employed classification and regression tree analysis to demonstrate that a surgical threshold of approximately 12–15 hours optimised neurological outcomes in motor-complete thoracolumbar SCI; Mouchaty et al. (2006) reported that patient selection and early operative planning within dedicated thoracic and lumbar fracture pathways were associated with favourable clinical trajectories; and Lubelski et al. (2017) confirmed that earlier surgery was associated with better neurological and functional outcomes at extended follow-up, further supporting the biological rationale for prompt intervention at these levels.

The emerging literature on ultra-early decompression — broadly defined as surgery within eight to 12 hours of injury — introduces an important new dimension to the timing debate. The meta-analysis of Yousefifard et al. (2022) demonstrates a statistically robust benefit of ultra-early over later surgery for AIS A cervical injuries, and the biological rationale is compelling given the known rate of secondary intramedullary lesion expansion (Le et al., 2015). The pragmatic equivalence of eight-hour and 12-hour thresholds demonstrated by meta-regression suggests that a 12-hour clinical target may capture the majority of achievable neurological benefit while remaining within logistical reach of well-organised trauma systems. However, the SCI-POEM study (Hosman et al., 2023) did not demonstrate a statistically significant advantage of surgery within 12 hours over later surgery on the primary functional outcome at 12 months, and the ultra-early evidence base remains predominantly retrospective and subject to the neurological assessment confounder of spinal shock. Until an adequately powered prospective trial specifically addressing the ultra-early window is completed, clinical advocacy for this threshold should be framed as a biologically motivated aspiration rather than an evidence-mandated standard.

Perhaps the most immediately actionable conclusion of this review is that the principal barriers to early surgery are systemic rather than patient-related. The Thompson et al. (2018) analysis demonstrated that no patient-level factor independently predicts surgical delay, and that the dominant determinants are the absence of dedicated spinal emergency protocols, inter-hospital transfer pathways, and competition between elective and emergency operative access. These are healthcare system design failures, not intrinsic limitations of the patient population or the injury biology. The projected 20% increase in the early surgery rate from protocol-level redesign alone represents a potentially larger population-level gain than any pharmacological or surgical innovation currently in development for tSCI (Thompson et al., 2018). Investment in system redesign therefore deserves priority on the research and policy agenda commensurate with its potential impact.

An important development not yet fully integrated into guideline recommendations is the use of MRI-based biomarkers — particularly intramedullary lesion length on T2-weighted imaging — to refine surgical urgency at the individual patient level. The stratification proposed by Kamal et al. (2023) — distinguishing patients with IMLL of 30 mm or less (favourable prognosis regardless of timing), 31–60 mm (most sensitive to timing), and greater than 61 mm (universally poor prognosis) — offers a clinically practical framework for prioritising operative speed in the subgroup most likely to benefit. This imaging-guided approach to individualised timing represents a natural evolution beyond the current binary threshold paradigm and warrants prospective validation in adequately powered multicentre cohorts.

This review has several important limitations, which are ultimately limitations of the underlying evidence base. First, no adequately powered, prospective randomised controlled trial comparing early versus delayed decompression in the general tSCI population has been completed. The STASCIS study — the most influential in this field — was non-randomised and subject to substantial baseline imbalance. The OSCIS trial (Chikuda et al., 2021), the only published RCT, was restricted to a narrow subpopulation. This fundamental absence of Class I evidence means that all guideline recommendations are graded conditional or Level III at best. Second, the heterogeneity of timing definitions across studies limits direct comparison: "early" surgery variously refers to decompression within eight, 12, 24, or even 72 hours, and the choice of threshold is frequently determined by institutional logistics rather than biological rationale. Third, the dominant outcome measure across the literature — AIS grade improvement — is a coarse measure that does not capture patient-centred priorities including pain, bladder function, autonomic dysreflexia, and quality of life. Future trials must incorporate patient-reported outcomes alongside clinician-assessed neurological measures.

The research agenda in surgical timing for tSCI is substantial. The most important priority is the completion of adequately powered, prospective, multi-site randomised controlled trials with stratification by injury level and completeness, and pre-specified primary outcomes extending beyond AIS grade. The DISCUS trial and the OPTiCS trial — both in various stages of development at the time of this review — represent attempts to fill this gap. Secondary priorities include prospective validation of MRI-based biomarkers as predictors of timing-response; head-to-head comparison of ultra-early versus standard early decompression in complete cervical injuries; investigation of optimal timing in the elderly; and evaluation of system-level interventions designed to reduce surgical delay at the population level.

Conclusions

The evidence reviewed in this narrative synthesis supports a clear and clinically actionable principal conclusion: early surgical decompression within 24 hours of acute traumatic spinal cord injury is associated with improved neurological outcomes and fewer complications compared with delayed surgery, and this benefit is not offset by increased operative risk. This conclusion holds most robustly for cervical injuries across the spectrum of completeness and is endorsed by the 2024 AO Spine/Praxis guidelines — which extended this recommendation across all injury levels — as well as by the 2013 AANS/CNS guideline for cervical injuries; the AANS and CNS have, however, declined to endorse the stronger 2024 AO Spine/Praxis recommendation, maintaining that available evidence does not meet the threshold required by their evidence classification framework (Hadley & Walters, 2013; American Association of Neurological Surgeons & Congress of Neurological Surgeons, 2024). For thoracic and thoracolumbar injuries, the evidence is more heterogeneous, but favours early intervention in incomplete injuries, particularly those with distraction or translational injury morphology.

Emerging evidence challenges several long-held assumptions. Complete cervical injuries, once considered least likely to benefit from surgical speed, now appear to be the subgroup in which timing matters most, with the greatest neurological gains concentrated in an ultra-early window within 12 hours. The biology of secondary injury — the continuously expanding ischaemic penumbra and the measurable rate of intramedullary lesion growth — underpins a "time is spine" imperative that is increasingly supported by high-quality clinical data.

Critically, the principal barriers to timely surgery are systemic rather than patient-derived, and are therefore amenable to intervention through healthcare organisation, protocol design, and resource allocation. Eliminating transfer delays, establishing dedicated spinal emergency pathways, and extending operative access across the full 24-hour period are achievable system-level changes with the potential to translate guideline recommendations into population-level neurological benefit.

The priority research agenda includes adequately powered randomised trials with stratification by injury level and completeness, validation of MRI biomarkers to guide individualised timing, and prospective evaluation of system-level interventions to reduce surgical delay. Until this evidence matures, the clinical and ethical imperative remains clear: for every patient with acute traumatic spinal cord injury, the shortest achievable interval between injury and adequate surgical decompression is the goal.

Conflicts of Interest. The author declares no conflicts of interest.

Ethical Approval. This article is a narrative review of previously published literature. No original data were collected, no patients were enrolled, and no ethical approval was required.

Data Availability Statement. No new data were generated or analysed for this review. All sources are cited in the reference list and are available in publicly accessible databases.

Funding. This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

REFERENCES

1. Badhiwala, J. H., Wilson, J. R., Witiw, C. D., et al. (2021). The influence of timing of surgical decompression for acute spinal cord injury: A pooled analysis of individual patient data. *The Lancet Neurology, 20*(2), 117–126. https://doi.org/10.1016/S1474-4422(20)30406-3
2. Qiu, Y., Chen, Y., Xie, Y., et al. (2021). Comparative analysis of the efficacy of early and late surgical intervention for acute spinal cord injury: A systematic review and meta-analysis based on 16 studies. *International Journal of Surgery, 94*, Article 106098. https://doi.org/10.1016/j.ijsu.2021.106098
3. Bickenbach, J., Officer, A., Shakespeare, T., & von Groote, P. (Eds.). (2013). *International perspectives on spinal cord injury*. World Health Organization.
4. GBD 2019 Diseases and Injuries Collaborators. (2020). Global burden of 369 diseases and injuries in 204 countries and territories, 1990–2019. *The Lancet, 396*(10258), 1204–1222. https://doi.org/10.1016/S0140-6736(20)30925-9
5. Khorasanizadeh, M., Yousefifard, M., Eskian, M., et al. (2019). Neurological recovery following traumatic spinal cord injury: A systematic review and meta-analysis. *Journal of Neurosurgery: Spine, 30*(5), 683–699. https://doi.org/10.3171/2018.10.SPINE18802
6. Devivo, M. J. (2012). Epidemiology of traumatic spinal cord injury: Trends and future implications. *Spinal Cord, 50*(5), 365–372. https://doi.org/10.1038/sc.2011.178
7. Jain, N. B., Ayers, G. D., Peterson, E. N., et al. (2015). Traumatic spinal cord injuries in the United States, 1993–2012. *JAMA, 313*(22), 2236–2243. https://doi.org/10.1001/jama.2015.6250
8. National Spinal Cord Injury Statistical Center. (2023). *Spinal cord injury facts and figures at a glance*. University of Alabama at Birmingham.
9. Ahuja, C. S., Wilson, J. R., Nori, S., et al. (2017). Traumatic spinal cord injury. *Nature Reviews Disease Primers, 3*, Article 17018. https://doi.org/10.1038/nrdp.2017.18
10. Fehlings, M. G., Vaccaro, A., Wilson, J. R., 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), Article e32037. https://doi.org/10.1371/journal.pone.0032037
11. Tator, C. H., & Fehlings, M. G. (1991). Review of the secondary injury theory of acute spinal cord trauma with emphasis on vascular mechanisms. *Journal of Neurosurgery, 75*(1), 15–26. https://doi.org/10.3171/jns.1991.75.1.0015
12. Le, E., Aarabi, B., Hersh, D. S., et al. (2015). Predictors of intramedullary lesion expansion rate on MR images of patients with subaxial spinal cord injury. *Journal of Neurosurgery: Spine, 22*(6), 611–621. https://doi.org/10.3171/2014.11.SPINE14523
13. Jug, M., Kejzar, N., Cimerman, M., & Bajrovic, F. F. (2015). Neurological recovery after traumatic cervical spinal cord injury is superior if surgical decompression and instrumented fusion are performed within 8 h versus 8 to 24 h after injury: A prospective cohort study. *Journal of Neurotrauma, 32*(18), 1385–1392. https://doi.org/10.1089/neu.2014.3767
14. Adegeest, C. Y., Stolwijk, M. B., Groenland, C. N. L., et al. (2023). Timing of surgery for acute traumatic spinal cord injury: A narrative review. *Current Opinion in Critical Care, 29*(6), 617–623. https://doi.org/10.1097/MCC.0000000000001094
15. Carlson, G. D., Minato, Y., Gorden, C., et al. (1997). Early time-dependent decompression for spinal cord injury: Vascular mechanisms of recovery. *Journal of Neurotrauma, 14*(12), 951–962. https://doi.org/10.1089/neu.1997.14.951
16. Dimar, J. R., Glassman, S. D., Raque, G. H., et al. (1999). The influence of spinal canal narrowing and timing of decompression on neurologic recovery after spinal cord contusion in a rat model. *Spine, 24*(16), 1623–1633. https://doi.org/10.1097/00007632-199908150-00002
17. Vaccaro, A. R., Daugherty, R. J., Sheehan, T. P., et al. (1997). Neurologic outcome of early versus late surgery for cervical spinal cord injury. *Spine, 22*(22), 2609–2613. https://doi.org/10.1097/00007632-199711150-00005
18. Papadopoulos, S. M., Selden, N. R., Quint, D. J., et al. (2002). Immediate spinal cord decompression for cervical spinal cord injury: Feasibility and outcome. *Journal of Trauma, 52*(2), 323–332. https://doi.org/10.1097/00005373-200202000-00022

19. Wilson, J. R., Tetreault, L. A., Kwon, B. K., et al. (2017). Timing of decompression in patients with acute spinal cord injury: A systematic review. *Global Spine Journal, 7*(3 Suppl), 95S–115S. https://doi.org/10.1177/2192568217701716
20. Hadley, M. N., & Walters, B. C. (2013). Introduction to the guidelines for the management of acute cervical spine and spinal cord injuries. *Neurosurgery, 72*(Suppl 2), 5–16. https://doi.org/10.1227/NEU.0b013e3182773549
21. ter Wengel, P. V., De Witt Hamer, P. C., Pauptit, J. C., et al. (2019). Early surgical decompression improves neurological outcome after complete traumatic cervical spinal cord injury: A meta-analysis. *Journal of Neurotrauma, 36*(6), 835–844. https://doi.org/10.1089/neu.2018.5961
22. Hosman, A. J. F., Barbagallo, G., & van Middendorp, J. J., on behalf of the SCI-POEM Study Group. (2023). Neurological recovery after early versus delayed surgical decompression for acute traumatic spinal cord injury: A prospective, observational, European multicentre (SCI-POEM) cohort study. *The Bone & Joint Journal, 105-B*(4), 400–411. https://doi.org/10.1302/0301-620X.105B4.BJJ-2022-0917.R1
23. ter Wengel, P. V., De Witt Hamer, P. C., Daams, J. G., et al. (2019). Published outcomes after early versus late surgical decompression in traumatic spinal cord injury: A systematic review and meta-analysis. *Journal of Neurotrauma, 36*(15), 2223–2234. https://doi.org/10.1089/neu.2018.6071
24. Vasquez-Paredes, G., Zavaleta-Corvera, C., & Caballero-Alvarado, J. (2025). Early versus delayed surgical decompression in spinal cord injury: A systematic review and meta-analysis. *Asian Journal of Neurosurgery, 20*, 199–210. https://doi.org/10.1055/s-0044-1801373
25. Song, Y., Zhu, K. L., Zhou, C. P., et al. (2025). Association between surgical timing and neurological recovery after traumatic spinal cord injury. *European Journal of Medical Research, 30*, Article 1168. https://doi.org/10.1186/s40001-025-02388-y
26. Shetty, S., Ahmed, R., Mukherjee, A., et al. (2025). Effect of early surgical intervention on neurological outcomes in acute spinal cord injury: A systematic review and meta-analysis. *Cureus, 17*(11), Article e97164. https://doi.org/10.7759/cureus.97164
27. Sattari, S. A., Antar, A., Theodore, J. N., et al. (2024). Early versus late surgical decompression for patients with acute traumatic central cord syndrome: A systematic review and meta-analysis. *The Spine Journal, 24*(3), 435–445. https://doi.org/10.1016/j.spinee.2023.10.019
28. Lenehan, B., Fisher, C. G., Vaccaro, A., et al. (2010). The urgency of surgical decompression in acute central cord injuries with spondylosis and without instability. *Spine, 35*(21 Suppl), S180–S186. https://doi.org/10.1097/BRS.0b013e3181f32a44
29. Chikuda, H., Koyama, Y., Matsubayashi, Y., et al. (2021). Effect of early vs delayed surgical treatment on motor recovery in incomplete cervical spinal cord injury with preexisting cervical stenosis: A randomized clinical trial. *JAMA Network Open, 4*(11), Article e2133604. https://doi.org/10.1001/jamanetworkopen.2021.33604
30. Kamal, R., Verma, H., Narasimhaiah, S., & Chopra, S. (2023). 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. *Journal of Neurological Surgery Part A: Central European Neurosurgery, 84*, 144–156. https://doi.org/10.1055/s-0042-1744396
31. Gupta, D. K., Vaghani, G., Siddiqui, S., et al. (2015). Early versus delayed decompression in acute subaxial cervical spinal cord injury: A prospective outcome study. *Asian Journal of Neurosurgery, 10*(3), 158–165. https://doi.org/10.4103/1793-5482.161157
32. Kafle, P., Chaudhary, P. K., Thapa, J., & Sharma, M. R. (2022). Neurological outcome of early versus late surgery following cervical spinal cord injury. *Kathmandu University Medical Journal, 20*(77), 74–81.
33. Du, J. P., Fan, Y., Zhang, J. N., et al. (2019). Early versus delayed decompression for traumatic cervical spinal cord injury: Application of the AOSpine subaxial cervical spinal injury classification system to guide surgical timing. *European Spine Journal, 28*, 1855–1863. https://doi.org/10.1007/s00586-019-05912-z
34. Mayol, M., Saavedra, F. M., Alcedo, R., et al. (2019). Time of surgery in the outcome of cervical spinal cord injury: The University of Puerto Rico experience. *Puerto Rico Health Sciences Journal, 38*(2), 109–112.
35. ter Wengel, P. V., Martin, E., De Witt Hamer, P. C., et al. (2019). The impact of early (<24 h) surgical decompression on neurological recovery in thoracic spinal cord injury: A meta-analysis. *Journal of Neurotrauma, 36*, 2279–2292. https://doi.org/10.1089/neu.2018.6245
36. Dvorak, M. F., Noonan, V. K., Fallah, N., et al. (2015). The influence of time from injury to surgery on motor recovery and length of hospital stay in acute traumatic spinal cord injury: An observational Canadian cohort study. *Journal of Neurotrauma, 32*(9), 645–654. https://doi.org/10.1089/neu.2014.3632
37. Rahimi-Movaghar, V., Niakan, A., Haghnegahdar, A., et al. (2014). Early versus late surgical decompression for traumatic thoracic/thoracolumbar (T1-L1) spinal cord injured patients: Primary results of a randomized controlled trial at one year follow-up. *Neurosciences, 19*(3), 183–191.
38. Cengiz, S. L., Kalkan, E., Bayir, A., et al. (2008). Timing of thoracolumbar spine stabilization in trauma patients: Impact on neurological outcome and clinical course. *Archives of Orthopaedic and Trauma Surgery, 128*(9), 959–966. https://doi.org/10.1007/s00402-007-0445-z

39. Du, J. P., Fan, Y., Liu, J. J., et al. (2018). Decompression for traumatic thoracic/thoracolumbar incomplete spinal cord injury: Application of AO Spine injury classification system to identify the timing of operation. *World Neurosurgery, 116*, e867–e873. https://doi.org/10.1016/j.wneu.2018.05.124
40. Wutte, C., Becker, J., Klein, B., et al. (2020). Early decompression (<8 hours) improves functional bladder outcome and mobility after traumatic thoracic spinal cord injury. *World Neurosurgery, 134*, e847–e854. https://doi.org/10.1016/j.wneu.2019.11.023
41. Nasi, D., Dobran, M., Di Rienzo, A., et al. (2019). The beneficial effect of ultra-early versus early surgical treatment on neurological outcome in cervical spinal cord injury. *Acta Neurochirurgica, 161*(12), 2457–2464. https://doi.org/10.1007/s00701-019-04064-z
42. van Middendorp, J. J., Hosman, A. J., & Doi, S. A. (2013). The effects of the timing of spinal surgery after traumatic spinal cord injury: A systematic review and meta-analysis. *Journal of Neurotrauma, 30*(22), 1781–1794. https://doi.org/10.1089/neu.2013.2932
43. Aarabi, B., Akhtar-Danesh, N., Simard, J. M., et al. (2021). Efficacy of early (≤24 hours), late (25–72 hours), and delayed (>72 hours) surgery with MRI-confirmed decompression in AIS grades C and D acute traumatic central cord syndrome. *Journal of Neurotrauma, 38*, 2073–2083. https://doi.org/10.1089/neu.2020.7451
44. Kopp, M. A., Lubstorf, T., Blex, C., et al. (2022). Association of age with the timing of acute spine surgery: Effects on neurological outcome after traumatic spinal cord injury. *European Spine Journal, 31*, 56–69. https://doi.org/10.1007/s00586-021-06993-5
45. Segi, N., Nakashima, H., Ito, S., et al. (2025). Early versus delayed surgery for elderly traumatic cervical spinal injury: A nationwide multicenter study in Japan. *Global Spine Journal, 15*(2), 1143–1154. https://doi.org/10.1177/21925682231213048
46. Nori, S., Watanabe, K., Takeda, K., et al. (2024). Influence of the timing of surgery for cervical spinal cord injury without bone injury in the elderly: A retrospective multicenter study. *Journal of Orthopaedic Science, 29*(2), 480–485. https://doi.org/10.1016/j.jos.2023.01.004
47. Yousefifard, M., Askari, N., Hosseini, M., et al. (2022). Ultra-early (<12 hours) versus early (12–24 hours) surgical decompression for treatment of traumatic spinal cord injuries: A systematic review and meta-analysis. *Neurochirurgie, 68*(3), 273–282. https://doi.org/10.1016/j.neuchi.2021.10.009
48. Bhimani, A. D., Carr, M. T., Al-sharshai, Z., et al. (2023). Ultra-early (≤8 hours) surgery for thoracolumbar spinal cord injuries: A systematic review and meta-analysis. *North American Spine Society Journal, 16*, Article 100285. https://doi.org/10.1016/j.xnsj.2023.100285
49. Yu, X., Wang, L., Kang, L., et al. (2025). Impact of ultra-early, early and delayed decompression on neurological and clinical outcomes in spinal cord injury: A systematic review and meta-analysis. *Journal of Spinal Cord Medicine, 48*(5), 763–772. https://doi.org/10.1080/10790268.2024.2363529
50. Aarabi, B., Akhtar-Danesh, N., Chryssikos, T., et al. (2020). Efficacy of ultra-early (<12 h), early (12–24 h), and late (>24–138.5 h) surgery with magnetic resonance imaging-confirmed decompression in AIS grades A, B, and C cervical spinal cord injury. *Journal of Neurotrauma, 37*, 448–457. https://doi.org/10.1089/neu.2019.6606
51. Burke, J. F., Yue, J. K., Winkler, E. A., et al. (2019). Ultra-early (<12 hours) surgery correlates with higher rate of American Spinal Injury Association Impairment Scale conversion after cervical spinal cord injury. *Neurosurgery, 85*(2), 199–203. https://doi.org/10.1093/neuros/nyy537
52. Biglari, B., Child, C., Yildirim, T. M., et al. (2016). Does surgical treatment within four hours after trauma have an influence on neurological remission in patients with acute spinal cord injury? *Therapeutics and Clinical Risk Management, 12*, 1339–1346. https://doi.org/10.2147/TCRM.S111005
53. Bock, T., Sturm, J. W., Deininger-Czermak, E., et al. (2021). Optimal timing of surgery in acute traumatic spinal cord injury: A prospective observational study. *Journal of Clinical Medicine, 10*(22), Article 5273. https://doi.org/10.3390/jcm10225273
54. Carr, M. T., Jagtiani, P., Bhimani, A. D., et al. (2024). Optimal timing in cervical spinal cord injury: A comprehensive meta-analysis of ultra-early surgical intervention within five hours. *Cureus, 16*(6), Article e62015. https://doi.org/10.7759/cureus.62015
55. Thompson, C., Mutch, J., Parent, S., & Mac-Thiong, J. M. (2018). Determinants of the time to surgical decompression in patients with traumatic spinal cord injury: A population-based study. *Journal of Neurotrauma, 35*(14), 1620–1626. https://doi.org/10.1089/neu.2017.5472
56. Dakson, A., Brandman, D., Thibault-Halman, G., & Christie, S. D. (2017). Optimisation of the mean arterial pressure and timing of surgical decompression in traumatic spinal cord injury: A retrospective study. *Spinal Cord, 55*(11), 1024–1028. https://doi.org/10.1038/sc.2017.52
57. Guly, H. R., Bouamra, O., & Lecky, F. E. (2008). The incidence of neurogenic shock in patients with isolated spinal cord injury in the emergency department. *Resuscitation, 76*(1), 57–62. https://doi.org/10.1016/j.resuscitation.2007.06.012
58. Adegeest, C. Y., ter Wengel, P. V., & Peul, W. C. (2023). Traumatic spinal cord injury: Acute phase treatment in critical care. *Current Opinion in Critical Care, 29*(6), 659–665. https://doi.org/10.1097/MCC.0000000000001093

59. Sewell, M. D., Vachhani, K., Alrawi, A., & Williams, R. (2018). Results of early and late surgical decompression and stabilization for acute traumatic cervical spinal cord injury in patients with concomitant chest injuries. *World Neurosurgery, 118*, e161–e165. https://doi.org/10.1016/j.wneu.2018.06.167
60. Fehlings, M. G., Tetreault, L. A., Hachem, L., 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. *Global Spine Journal, 14*(3 Suppl), 174S–186S. https://doi.org/10.1177/21925682231181883
61. Qadir, I., Riew, K. D., Alam, S. R., et al. (2020). Timing of surgery in thoracolumbar spine injury: Impact on neurological outcome. *Global Spine Journal, 10*(7), 826–831. https://doi.org/10.1177/2192568219870998
62. Goulet, J., Richard-Denis, A., & Mac-Thiong, J. M. (2020). The use of classification and regression tree analysis to identify the optimal surgical timing for improving neurological outcomes following motor-complete thoracolumbar traumatic spinal cord injury. *Spinal Cord, 58*, 682–688. https://doi.org/10.1038/s41393-019-0405-x
63. Mouchaty, H., Conti, P., Conti, R., et al. (2006). Assessment of three year experience of a strategy for patient selection and timing of operation in the management of acute thoracic and lumbar spine fractures: A prospective study. *Acta Neurochirurgica, 148*, 1181–1187. https://doi.org/10.1007/s00701-006-0818-4
64. Lubelski, D., Voin, V., Ladner, T., et al. (2017). Timing of surgery in thoracic and lumbar spine trauma: Relationship to long-term neurologic and functional outcome. *Clinical Spine Surgery, 30*(8), E1072–E1076. https://doi.org/10.1097/BSD.0000000000000411
65. American Association of Neurological Surgeons & Congress of Neurological Surgeons. (2024). *Neurosurgery position statement on AO Spine/PRAXIS acute spinal cord injury guidelines*. https://www.aans.org/advocacy/articles/neurosurgery-position-statement-on-ao-spine-praxis-acute-spinal-cord-injury-guidelines/
66. Wilson, J. R., Tetreault, L. A., Dobrianskyj, F., et al. (2014). Identifying the window of opportunity for surgical intervention in complete (AIS grade A) cervical spinal cord injured patients: A propensity score matched analysis from a prospective multi-centre cohort study. *PLoS ONE, 9*(8), Article e104159. https://doi.org/10.1371/journal.pone.0104159