

Review Article



Surgical Timing After Spinal Cord Injury: A Narrative Review of Current Evidence and Perspectives

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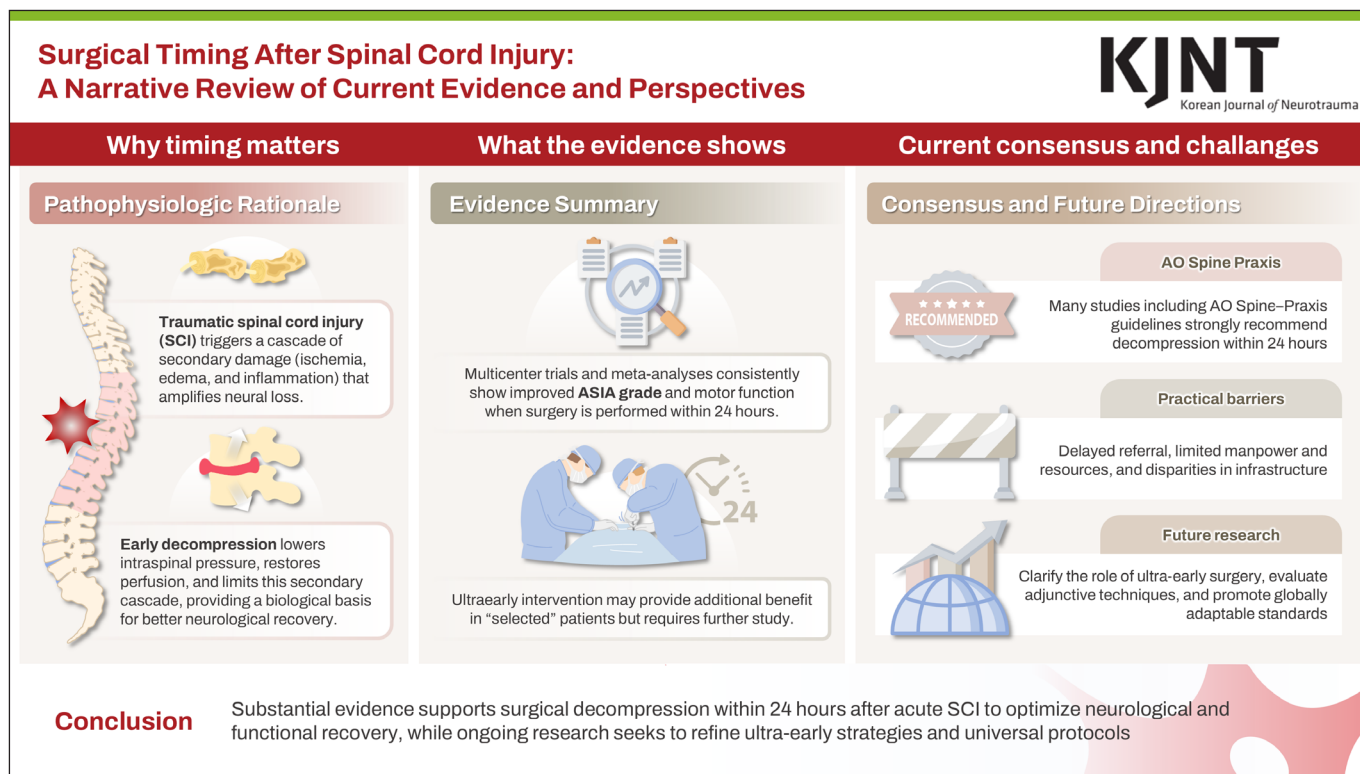
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ABSTRACT

Traumatic spinal cord injury (SCI) causes severe neurological and functional disability with major socioeconomic impact. The primary trauma initiates ischemia, excitotoxicity, and inflammation, leading to progressive neuronal loss and glial scarring. Early surgical decompression is a key strategy to limit secondary injury and promote recovery, though optimal timing remains debated. Preclinical data consistently favor early intervention, while clinical studies define “early” variably (<8–72 hours). Evidence from multicenter trials and meta-analyses indicates that decompression within 24 hours offers nearly a threefold higher chance of ≥2-grade improvement on the ASIA Impairment Scale, along with better motor recovery, functional independence, and fewer complications. Ultra-early (<8–12 hours) decompression may provide additional benefit in select cases, but supporting data remain limited. The strongest effects are seen in cervical and incomplete injuries, with less consistent results in thoracic and polytrauma cases. Emerging adjuncts such as expansile duraplasty and intraoperative ultrasound may further optimize outcomes. The AO Spine–Praxis guidelines strongly recommend decompression within 24 hours, though global disparities in resources persist. Overall, evidence supports early—preferably within 24 hours—decompression to enhance recovery after acute SCI, with future studies needed to refine timing and standardize protocols worldwide.

Keywords: Spinal cord injuries; Surgery; Decompression; Time factors; Recovery of function

GRAPHICAL ABSTRACT

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Conflict of Interest

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Informed Consent

This type of study does not require informed consent.

Ethics Approval

This research did not require ethical approval as it does not involve human subjects, their data, or biological samples.

INTRODUCTION

Traumatic Spinal cord injury (SCI) is one of the leading causes of disability worldwide.²⁸⁾ The physical, psychological, and economic burden of these injuries is grossly debilitating and associated with reduced life expectancy of the victim.¹⁰⁾ This could be devastating, not only for the patient and their families, but also for the whole community. Despite the severity, the global trends of SCI continue to increase. A recent review by Lu et al.²⁷⁾ of the last 20 years of global injury data reported that the overall incidence of spinal cord injuries has been about 23.77 per million population. The estimated rate of SCI is also reported to rise from 250,000 to 500,000 individuals per year.²³⁾ The cervical spine is most commonly affected, followed by the thoracic level. Studies show the incidence in males is significantly higher than in the female population, and the mechanisms of these injuries vary in different age groups. In the younger population, road traffic accidents contribute a significant burden of SCI, whereas in the elderly population, SCI often follows a trivial fall. Other common mechanisms include falls from heights, recreational and sports activities, and occupational accidents.

Those patients with SCI and neurological deterioration tend to have a longer duration of recovery, involving spine care, other systemic management, and rehabilitation. Neurological improvement in the form of regaining sensorimotor, bowel, and bladder function is of paramount importance in these patients. Of the various management options available in the literature, surgical treatment remains the standard of care in patients with ongoing neural compression, neurological deficit, and spinal instability. Studies have shown the advantages of early surgical intervention in SCI, and extensive research has been performed regarding the timing of surgery and its influence on neurological recovery. However, in many hospitals and

facilities with limited infrastructure, emergency spine surgery can be practically challenging due to various factors, such as delayed patient arrival, the nonavailability of operating personnel, a trained anesthetic team, or well-equipped intensive care support. Hence, it is essential to underscore the concept of appropriate timing of surgical decompression in these patients.

In this manuscript, we aim to summarize the current evidence available in the literature regarding surgical decompression in SCI and perspectives on surgical timing following acute SCI. We also emphasize the need for a global consensus on timing thresholds for early decompression and their effect on surgical outcomes.

PATHOPHYSIOLOGIC BASIS OF EARLY DECOMPRESSION

It is well known that a significant injury to the spinal cord could result in the abolition of motor, sensory, and autonomic pathways, causing functional disability. The injury mechanisms contributing to this could be categorized as primary and secondary types. ‘Primary injury’ results from the mechanical damage to the spinal cord at the time of trauma. This can be due to a fractured spinal column, dislocations, and retropulsion of bony fragments, causing injury to the neural elements with associated vascular insult to the spinal cord. Other mechanisms include acute distraction or shearing of the spinal cord due to acceleration-deceleration of the victim, and transection from penetrating injuries. These primary mechanisms trigger a further cascade of events, resulting in secondary SCI. This is a molecular-level biochemical and metabolic disarray, resulting in the accumulation of reactive oxygen species, free radicals, intracellular glutamate, calcium, and altered neuronal excitotoxicity. Secondary injury predisposes and accelerates inflammation, edema, and ischemic changes to the cord, leading to axonal degeneration, apoptosis, remodeling, and ultimately glial scarring. Over the years, various therapeutic strategies have gained the attention of researchers to attenuate this secondary damage to the spinal cord. Molecules such as anti-oxidative agents, anti-apoptotic agents, channel blockers, membrane stabilizing agents, and neurotransmitters have been extensively studied, although their beneficial effects in acute SCI settings remain less proven.^{8,13,31} Similarly, regenerative options such as the application of stem cells in patients with SCI are in their infancy, and most are preclinical, with no clear universally accepted consensus.³⁴

Surgical decompression of the injured spinal cord is a practical and effective option for reducing secondary damage and improving the chances of neurological recovery. Preclinical and experimental studies have demonstrated that the duration of neural compression is a key factor in determining the degree of neurological recovery.⁴ Most of these are animal studies that strongly suggest “early decompression” of the spinal cord in acute traumatic scenarios. Early decompression helps minimize the calcium-mediated cytotoxicity and free-radical-mediated lipid peroxidation, thereby reducing secondary damage to the spinal cord.^{15,20} However, based on the results of these animal studies, it is difficult to identify a critical safe window for decompression in clinical settings.

DEFINING ‘EARLY DECOMPRESSION’: EVOLUTION OF TIME THRESHOLDS

The concept of ‘early decompression’ of the injured spinal cord dates back several decades, when Burrell et al.⁷ postulated that acute decompression of the spinal neurons would prevent

irreversible damage to the spinal cord. Since then, numerous studies have been published, and extensive research has been conducted to validate the optimal timing of surgical decompression. The adage 'Time is Spine' concerning surgical decompression of the injured spinal cord has been globally accepted by spine surgeons. But the precise timing of decompression to maximize the benefits of neurological recovery remains uncertain. Prof. Burrell initially felt that less than 48 hours was a significant time frame for decompression based on his autopsy studies of patients with SCI. However, further studies emphasized the need for medical optimization of the patient before surgery, as results showed a higher mortality rate for patients undergoing early surgery compared to those undergoing late surgery.³⁸⁾

With significant advancements and enhanced safety in spine care, surgeons advocated that early surgery would be possible for SCI patients, without considerable mortality during the postoperative period. However, the literature is highly variable in the definition of 'early decompression.' Studies suggest a time frame ranging from 8 hours to 4 days as early decompression, and this has resulted in difficulty in interpreting the neurological outcomes from these clinical studies.¹⁷⁾ Vaccaro et al.³⁷⁾ in their prospective randomized clinical trial, compared the neurological outcomes in 2 categories of patients with cervical SCI: those undergoing surgical decompression <72 hours (early) and >72 hours (late). Their results showed no significant differences in improvement in the postoperative intensive care stay or American Spinal Injury Association (ASIA) scores between the 2 groups, raising concerns about the appropriate timing for early surgery. On the other hand, results of the Austrian Spinal Cord Injury study showed no additional benefit in the neurological recovery of patients with very-early (<5 hours) decompression in cervical SCI compared to the early (5–24 hours) decompression.²⁹⁾ Biglari et al.⁶⁾ even investigated the advantages of surgical decompression within 4 hours of SCI and found no significant benefits with early decompression.

Several studies were then published, and extended the cutoffs for the time frame to 8 hours post-injury. Wutte et al.⁴²⁾ in their retrospective analysis, observed the advantages of early decompression (<8 hours) in the recovery of bladder function in patients with thoracic SCI at one-year follow-up. Also, a prospective study by Jug et al.²²⁾ reported a superior improvement in ASIA scores (45% of patients) in traumatic cervical SCI patients undergoing decompression within 8 hours compared to 10% improvement in the 8 to 24-hour group. In a recent meta-analysis, Yu et al.⁴⁴⁾ compared the neurological and clinical outcomes in SCI patients undergoing ultra-early (<8 or 12 hours), early (<24 hours), or delayed surgery (>24 hours). The authors observed that early and ultra-early surgery can shorten hospital stay, minimize complications, and improve neurological outcomes in selected cases. Similarly, the time-dependent efficiency of early surgical decompression in SCI patients was reported by Li et al.²⁶⁾ The authors observed more obvious advantages in motor function with longer follow-up (1 year) than in the early postoperative period. Youssef et al.⁴³⁾ also in their study noted significant benefits of early decompression (<24 hours) at the final follow-up at 1 year and not at the 6 months, further emphasizing the need for reporting the neurological results after an optimal follow-up period.

CLINICAL EVIDENCE: MAJOR TRIALS AND META-ANALYSES

Several multi-centre prospective trials have been conducted in various clinical settings to validate the effect of early surgical decompression. Fehlings and his colleagues¹⁶⁾

performed a prospective clinical trial involving multiple centres comparing the efficacy of early (<24 hours) vs. delayed (>24 hours) decompression in patients with cervical SCI. It is one of the largest prospective studies in patients with cervical spine injuries to date, involving 313 (182: early surgery, 131: delayed surgery) patients. Their results showed that 19.8% of patients undergoing early surgery experienced a ≥ 2 -grade improvement in the ASIA Impairment Scale (AIS) compared to 8.8% in the late decompression group. Multiple regression analysis showed the odds of at least a 2-grade AIS improvement were 2.8 times higher in those undergoing early surgery as compared to the other group. However, subsequently, several researchers identified statistical errors in the study, as further analysis of the datasets yielded variable results.^{3,39)} In another Prospective, Observational European Multi-center cohort study, the researchers analysed 294 patients with traumatic SCI.²¹⁾ The authors observed that they did not find any significant difference in the Lower Extremity Motor Score between the early and late decompression groups at 1-year follow-up. They concluded that the baseline differences in the study population, confounders, and irregular follow-up duration would have biased the results of previous studies. However, a recent quantitative meta-analysis by Fehlings et al.¹¹⁾ on early (≤ 24 hours) vs. late decompression (>24 hours) groups observed a moderate strength of evidence favouring the early decompression group, after matching the baseline factors and potential confounders.

Functional independence following SCI is more critical than only neurological outcomes, as it strongly influences the quality of life of these patients. Grassner et al.¹⁸⁾ in their clinical study, analysed the functional recovery in cervical spinal cord-injured patients using the Spinal Cord Independence Measure. The authors observed a significant AIS conversion rate, motor improvement translating to superior functional recovery in patients undergoing early decompression (<8 hours). Also, Wichmann et al.⁴⁰⁾ in their prospective study of 143 SCI patients, noted a decreased functional independence in patients undergoing delayed surgical decompression (>24 hours) at 1-year follow-up. In their multivariate regression analysis, they also concluded that incomplete motor injuries had a better recovery than complete injuries.

SUBGROUP ANALYSIS: COMPLETE VS. INCOMPLETE INJURIES AND ANATOMICAL CONSIDERATIONS

Most studies in the literature have analysed a mixed cohort of patients with complete and incomplete spinal cord injuries and the timing of surgical decompression. A subgroup analysis of complete and incomplete SCI yields variable results across different studies. A meta-analysis by Ter Wengel et al.³⁵⁾ showed similar rates of improvement regardless of timing in the incomplete SCI group. In contrast, Haldrup et al.¹⁹⁾ in their study, observed significant benefits of early decompression (<24 hours) (50% improvement) compared to delayed decompression (>24 hours) (10% improvement) at one-year follow-up in the incomplete SCI group. Similarly, in a meta-analysis by La Rosa et al.,²⁴⁾ the authors observed that the percentage of patients with incomplete neurological deficits who improved after early decompression was 89.7%, advocating for early decompression in such patients. Central cord syndrome (CCS) is also a common form of incomplete SCI, and studies have shown that early decompression is associated with superior upper limb motor recovery, particularly in patients with moderate deficits (AIS C), although the benefit in less severe cases (AIS D) is unclear. A recent meta-analysis by Sattari et al.³³⁾ also demonstrated the superiority of early decompression (<24 hours) in acute traumatic CCS, as evidenced by improved motor scores and reduced complication rates.

In addition, the level of SCI (cervical, thoracic, or lumbar) significantly affects neurological outcomes and recovery following surgical decompression. Early decompression (<24 hours) is most strongly associated with improved neurological recovery in cervical injuries, where the odds of meaningful AIS grade improvement are substantially higher compared to delayed surgery.³⁰⁾ For thoracic and thoracolumbar injuries, the evidence is less robust. Meta-analysis indicates that early decompression may increase the likelihood of AIS grade improvement, but the statistical significance is inconsistent due to the smaller effect size, compared to cervical injuries.^{5,36)} Similarly, in patients with polytrauma, the optimal timing of spinal decompression in SCI is not clearly established in the literature. Hence, there must be standardized protocols according to clinical needs, after intracranial, hemodynamic, and respiratory stabilization in further studies.

The effect of age on neurological recovery in traumatic SCI has also been an area of research. In general, studies show a better improvement in the ASIA grades in the younger age group.¹⁾ However, the neurological recovery in the elderly population and patients with high comorbidities is less explored. No long-term prospective or multicenter trials have been performed specifically in this patient population to compare early and delayed surgical decompression.

CLINICAL CONSENSUS AND PRACTICE PATTERNS: REAL-WORLD IMPLEMENTATION

In addition to evidence from clinical trials and meta-analyses, the importance of surgical timing has been reflected in surveys of real-world practice. In an international survey of more than 900 active spine surgeons, Fehlings et al.¹⁴⁾ reported that over 80% of respondents favored decompression within 24 hours for patients with incomplete injuries (ASIA B or C). This finding highlights a strong consensus among practicing surgeons that early decompression is not only supported by clinical research but is also widely accepted in everyday decision-making.

It is equally important to recognize that the benefits of early decompression are not uniform across all patient groups. Data suggest that patients with incomplete SCI (ASIA B/C) derive the most consistent neurological and functional improvements with surgery within 24 hours.^{11,16,19,24)} By contrast, patients with ASIA D deficits or those with CCS demonstrate less clear benefit, with some studies reporting no significant difference in outcome regardless of surgical timing.^{33,39)} These nuances should temper the “Time is Spine” paradigm and emphasize the importance of individualized decision-making.

Surgical timing must also be considered in the broader framework of acute neurointensive care. Optimal outcomes depend not only on timely decompression but also on careful hemodynamic management to maintain spinal cord perfusion, prevention of venous thromboembolism, and early respiratory support in cervical injuries.^{25,41)} Early surgery complements but does not replace these critical aspects of care, underscoring the need for multidisciplinary coordination in the acute phase.

Finally, the concept of “early” surgery has evolved over time. Initial recommendations emphasized decompression within 48 hours, but subsequent studies, including the STASCIS trial, established the 24-hour threshold as the most widely adopted benchmark.¹⁶⁾

More recent work has explored the role of ultra-early surgery (<6–8 hours), with promising but not yet definitive results.^{5,22,42,44)} Taken together, this historical progression illustrates the steady shift toward earlier intervention as surgical safety, critical care infrastructure, and global awareness have advanced.

EVOLVING CONCEPTS AND FUTURE DIRECTIONS

Most of the current literature has shown favourable neurological outcomes following early surgical decompression. Although the time window for ‘early’ is different across various studies, the current AO Spine-Praxis guidelines for clinical practice suggest a strong recommendation of early decompression within the initial 24 hours of SCI.¹²⁾ This is based on analyses of various systematic reviews and reports from the Guideline Development Group (GDG).¹²⁾ The authors have also highlighted the need to assess the efficacy of ‘ultra early (<8–12 hours) decompression’ in future studies. One of the limitations in reporting outcomes for such patients is the difficulty in performing and interpreting neurological assessments during the ultra-early phase of SCI. Thus, the researchers have urged the use of alternative objective tools for assessing acute SCI.

In addition to the timing of spinal cord decompression, emphasis has also been on the completeness and adequacy of decompression. Studies have shown that in a selected group of patients, laminectomy and decompression of the contused spinal cord would not be sufficient to improve the intraspinal pressure, needing additional procedures like expansile duraplasty to improve the spinal cord perfusion pressure.³²⁾ Azad et al.²⁾ in their systematic review, demonstrated that in addition to surgical decompression, expansile duraplasty of the decompressed segment led to clinically improved patient outcomes in these patients. The role of intraoperative ultrasound (IOUS) to evaluate the completeness of decompression has also recently gained interest among surgeons. Chryssikos et al.⁹⁾ in their study of 51 patients with traumatic cervical SCI, demonstrated the utility of IOUS, showing that about 10% patients needed additional laminectomy after assessment using IOUS. Despite these improvements in spinal cord-related research, the practical challenges of managing SCI patients in various clinical settings, including those in high-, middle-, and low-income countries, persist and could significantly impact the overall outcomes. This includes discrepancies in the medical infrastructure, accessibility to appropriate spine care, and healthcare services. Thus, the surgical treatment of SCI patients demands a global consensus in minimizing these differences and setting standards for timing thresholds for spinal cord decompression in improving the overall neurological outcomes.

CONCLUSION

There is substantial and compelling evidence to suggest a significant sensorimotor recovery following early decompression in acute SCI. Although the literature varies in defining the timing of decompression, the overall trend in most studies is favourable for decompression within 24 hours of injury. However, there is still considerable scope for research regarding the timing of surgery in injuries to specific anatomical regions, patient categories, and the combined effect of procedures like expansile duraplasty. It is also crucial to translate the knowledge into evidence-based, practical guidelines that can be globally adapted to enhance the quality of life for individuals with SCI.

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