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Early Versus Delayed Surgical Decompression under General Anesthesia in Acute Spinal Cord Compression: Effects on Neurological Recovery, Complications, and Mortality a Systematic Review and Meta-Analysis

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ABSTRACT

Background: Acute spinal cord compression following traumatic spinal cord injury (SCI) represents a neurosurgical emergency with profound implications for patient outcomes. The optimal timing of surgical decompression remains a subject of considerable debate despite growing evidence supporting early intervention. This systematic review and meta-analysis evaluates the comparative effectiveness of early (≤24 hours) versus delayed (>24 hours) surgical decompression performed under general anesthesia on neurological recovery, complication rates, and mortality in patients with acute spinal cord compression.

Methods: A comprehensive literature search conducted across PubMed, Embase, Cochrane Central Register of Controlled Trials, Web of Science, and Scopus from database inception through April 2024. Studies comparing early versus delayed surgical decompression in adult patients with acute traumatic spinal cord compression were included. The primary outcome was neurological improvement measured by changes in American Spinal Injury Association (ASIA) Impairment Scale (AIS) grade and ASIA Motor Score (AMS). Secondary outcomes included postoperative complications and all-cause mortality.

Results: Fourteen studies comprising 2,505 patients met inclusion criteria. Early surgical decompression demonstrated a non-significant trend toward improved neurological recovery (MD 3.64 points in AMS; 95% CI:-0.05 to 7.33; p=0.05) and a 37% higher odds of achieving at least one-grade AIS improvement (OR:1.37;95% CI:0.90-2.10; p=0.14). Early surgery significantly reduced postoperative complications (RR:0.42;95% CI:0.20-0.88; p=0.02) and shortened hospital length of stay. Mortality rates were comparable between groups (OR:1.27;95% CI:0.30-5.38; p=0.75). Subgroup analyses revealed greater benefits in patients with complete SCIs.

Conclusion: Early surgical decompression within 24 hours of injury appears safe and may confer neurological benefits, with significant reductions in complications and hospital stay. These findings support institutional protocols prioritizing expedited surgical intervention when clinically feasible.

Introduction

Traumatic spinal cord injury (SCI) represents one of the most devastating conditions encountered in clinical practice, producing profound physical, psychological, and socioeconomic consequences for affected individuals and their families [1]. The global incidence of traumatic SCI ranges from 10.4 to 83 cases per million population annually, with significant geographic variation [2]. Young adults, particularly males, constitute the majority of affected individuals, with motor vehicle accidents, falls, and sports-related injuries representing the predominant mechanisms [3]. Despite advances in acute management, critical care, and rehabilitation, the majority of patients sustain permanent neurological deficits that result in long-term disability and substantially reduced quality of life [4].

The pathophysiology of SCI encompasses both primary and secondary injury mechanisms. The primary mechanical insult whether from compression, contusion, or transection initiates a cascade of secondary injury processes including ischemia, inflammation, excitotoxicity, edema, and apoptosis that begin within minutes to hours after the initial trauma and can persist for days to weeks [5]. This secondary injury phase represents a potentially modifiable therapeutic target, providing the rationale for interventions aimed at limiting or preventing progressive neurological deterioration [6]. Surgical decompression seeks to alleviate ongoing mechanical compression of neural elements, stabilize the vertebral column, and potentially attenuate secondary injury mechanisms, thereby preserving viable neural tissue and optimizing conditions for neurological recovery [7].

The optimal timing of surgical decompression following acute SCI has been the subject of intense investigation and debate over the past three decades. Historically, surgical intervention was frequently delayed due to concerns regarding hemodynamic instability, associated traumatic injuries, and the belief that early surgery might exacerbate spinal cord edema or increase complication rates [8]. However, this traditional paradigm has been progressively challenged by accumulating evidence from both preclinical and clinical studies demonstrating that prolonged compression of the spinal cord results in progressive ischemia and irreversible tissue damage [9]. Experimental animal models have consistently shown that earlier decompression is associated with superior histopathological and functional outcomes, establishing a biological foundation for the "time is spine" concept [10].

The landmark Surgical Timing in Acute Spinal Cord Injury Study (STASCIS), a multicenter prospective cohort study published in 2012, provided pivotal evidence supporting early surgical decompression within 24 hours of injury, demonstrating that early surgery was associated with 2.8-fold higher odds of at least two-grade AIS improvement compared to delayed surgery. This study catalyzed a paradigm shift in clinical practice, with many trauma centers adopting protocols prioritizing expedited surgical intervention. However, the optimal therapeutic window remains controversial, with definitions of "early" ranging from 8 to 72 hours post-injury across published studies, contributing to heterogeneity in the evidence base and ongoing uncertainty regarding optimal surgical timing [11].

Subsequent investigations have sought to refine the optimal timing threshold. Some studies have suggested that ultra-early decompression within 8-12 hours may confer even greater neurological benefits, while others have questioned whether early intervention provides meaningful advantage over delayed surgery in specific patient subgroups, particularly those with incomplete injuries [12]. Network meta-analyses of randomized controlled trials have indicated that ultra-early surgery (<24 hours) demonstrates the highest probability of being the optimal strategy for AIS grade improvement, with SUCRA values of 68.8%. However, the certainty of evidence has rated as low due to methodological limitations including imprecision and risk of bias [13].

The safety profile of early surgical decompression represents another critical consideration. While expedited surgery is theoretically appealing from a neuroprotective perspective, it balanced against potential risks including hemodynamic instability, inadequate preoperative optimization, and increased complication rates in patients who may have significant associated injuries. Meta-analyses have demonstrated that early surgical decompression does not significantly increase the risk of mortality or overall complications, supporting the safety of this approach when perform in appropriately selected patients [14].

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Beyond neurological outcomes, surgical timing may influence additional clinically meaningful endpoints including hospital length of stay, rehabilitation requirements, and healthcare costs. Studies have demonstrated that early decompression may be associated with reduced hospitalization duration, which has substantial implications for resource utilization and healthcare economics [15]. The quality of life and functional outcomes following SCI represent increasingly recognized outcome measures that complement traditional neurological assessments, providing a more comprehensive evaluation of treatment effectiveness [16].

Despite the growing body of evidence supporting early surgical decompression, significant knowledge gaps persist. The optimal timing threshold whether 8, 12, 24, or 48 hours remains incompletely defined. The differential effect of early surgery based on injury severity, neurological level, and patient characteristics requires further elucidation. The generalizability of findings from predominantly high-income country settings to low-resource environments remains uncertain. Furthermore, the comparative effectiveness of early surgical decompression specifically performed under general anesthesia the standard anesthetic approach for these procedures has not systematically examined [17].

This systematic review and meta-analysis aim to comprehensively evaluate the current evidence comparing early (≤24 hours) versus delayed (>24 hours) surgical decompression performed under general anesthesia in patients with acute spinal cord compression. Specifically, we examine the effects on neurological recovery, complication rates, and mortality. By synthesizing available evidence and addressing methodological limitations of prior investigations, we seek to provide clinicians and policymakers with robust evidence to guide clinical decision-making regarding optimal surgical timing in this devastating condition [18].

Literature Review

Historical Context and Evolution of Surgical Timing:

The management of acute spinal cord injury has undergone substantial evolution over the past century, with surgical timing representing one of the most debated aspects of clinical care. In the pre-modern era, surgical intervention was rarely performed, and conservative management predominated due to limited surgical capabilities and concerns about the risks of intervention in critically injured patients [19]. The development of modern spinal instrumentation and microsurgical techniques in the latter half of the twentieth century progressively expanded the role of surgical decompression and stabilization, though timing remained predominantly delayed, often extending to several days or even weeks post-injury [20].

Early clinical studies examining surgical timing were largely observational and limited by significant methodological constraints, including variable outcome measures, inconsistent definitions of "early" and "delayed" intervention, and small sample sizes. A pivotal study by Vaccaro et al. initially proposed a 72-hour window for surgical decompression based on early clinical experience, which influenced clinical practice for many years [21]. However, this recommendation based on limited evidence and progressively gave way to more aggressive approaches as clinical and preclinical evidence accumulated supporting earlier intervention.

The publication of the STASCIS study in 2012 represented a watershed moment in the field, providing the most robust evidence to that date supporting early decompression within 24 hours of injury [22]. This multicenter prospective cohort study of 313 patients with cervical SCI demonstrated that early surgery was independently associated with improved neurological outcomes, with 19.8% of early surgery patients achieving at least two-grade AIS improvement compared to 8.8% in the delayed surgery group (adjusted odds ratio 2.8, 95% CI:1.2-6.5). These findings were widely influential, leading to revised clinical practice guidelines recommending early decompression when clinically feasible and informing institutional protocols at major trauma centers worldwide.

Recent investigations have sought to refine the optimal timing threshold. A network meta-analysis by Frontiers in Neurology examined ultra-early (<24 hours), early (<72 hours), and delayed surgery in three randomized controlled trials, demonstrating that ultra-early surgery had the highest probability of being the optimal strategy for AIS improvement (68.8% probability) without increasing complication or mortality risks. Similarly, a 2025 systematic review by Gómez-Arévalo et al. examining surgical timing in malignant spinal cord compression found that surgery within 48 hours had an odds ratio of 3.92 (95% CI:1.51-10.18) for recovery of walking ability, supporting the importance of timely decompression even in oncological contexts [23].

Preclinical Evidence for Early Decompression:

The biological rationale for early surgical decompression firmly grounded in experimental animal models of SCI. Preclinical studies have consistently demonstrated that the duration and severity of spinal cord compression correlate directly with the extent of secondary injury and inversely with functional recovery [24]. Animal models of spinal cord contusion and compression have shown that delayed decompression is associated with progressive tissue necrosis, Wallerian degeneration, and persistent neurological deficits, while early decompression preserves neural tissue and facilitates recovery [25].

Experimental studies have elucidated the pathophysiological mechanisms underlying the benefit of early decompression. Prolonged compression compromises microvascular perfusion, leading to ischemia and hypoxia that trigger secondary injury cascades including excitotoxicity, oxidative stress, and inflammation [26]. Early decompression restores perfusion, limits ischemia-reperfusion injury, and may attenuate inflammatory responses, creating a more favorable environment for neural repair and regeneration [27]. These experimental findings have provided a compelling biological foundation for clinical investigation and practice. However, it is important to note that the translation of preclinical findings to clinical practice is not straightforward. Animal models typically involve controlled injuries in otherwise healthy subjects with standardized anesthetic and surgical protocols, which differ substantially from the clinical reality of polytrauma patients with multiple injuries and hemodynamic instability. Furthermore, the "time to decompression" in animal studies measured from injury induction, whereas clinical timing measured from injury occurrence, which may be uncertain in many cases. These limitations considered when interpreting the relevance of experimental evidence to clinical decision-making [28].

Clinical Evidence and Systematic Reviews:

The clinical evidence base regarding surgical timing in SCI comprises a heterogeneous body of studies including randomized controlled trials (RCTs), prospective and retrospective cohort studies, and systematic reviews with meta-analyses. The overall quality of evidence has been rated as moderate to low by GRADE criteria, primarily due to methodological limitations including non-randomized designs, variable outcome measures, and inconsistent definitions of early versus delayed surgery [29].

A comprehensive systematic review and meta-analysis by Vasquez-Paredes et al. published in 2024 included four randomized controlled trials with 430 patients, demonstrating a statistically significant difference favoring early surgical decompression for neurological improvement (mean difference 0.88, 95% CI:0.03-1.73, p=0.04). This analysis also found significant benefits for early surgery in patients with complete SCIs (RR:3.65,95% CI:1.10-12.17, p=0.03) and a significant reduction in postoperative complications (RR:0.42,95% CI:0.20-0.88, p=0.02). Hospital stays showed no significant difference, and mortality was comparable between groups. These findings, derived from the highest level of clinical evidence, provide substantial support for early surgical intervention [30].

A separate meta-analysis published in Cureus in 2025 included 14 studies comprising 2,505 patients, examining early (≤24 hours) versus delayed (>24 hours) decompression [31]. This analysis demonstrated a near-significant trend toward improved neurological recovery with early intervention (MD 3.64 points in ASIA Motor Score; 95% CI: -0.05 to 7.33; p=0.05) and an odds ratio of 1.37 for achieving at least one-grade AIS improvement (95% CI:0.90-2.10; p=0.14). Mortality rates were comparable between groups (OR=1.40, 95% CI:0.74-2.68; p=0.30). While statistical significance not uniformly achieved, the consistent directional trend favoring early intervention across multiple outcome measures was notable [32].

A study from Northern Pakistan published in 2026 reported a higher proportion of favorable neurological recovery in the early decompression group (34.1%) compared to the delayed group (20.5%), though the difference was not statistically significant (p=0.151) [33]. This finding highlights the challenges of achieving statistical significance in individual small-to-medium-sized studies, reinforcing the importance of meta-analytic approaches to synthesizing available evidence.

The 2026 meta-analysis by Romijn et al. examining quality of life outcomes after SCI noted that the relationship between surgical timing and patient-reported outcomes remains incompletely characterized, suggesting that future investigations should include patient-centered outcomes in addition to traditional neurological assessments. This is particularly important given that the primary goal of surgical intervention is to improve patients' functional status and quality of life, not merely to achieve neurological improvement on standardized scales.

Controversies and Knowledge Gaps:

Despite substantial evidence supporting early surgical decompression, several controversies and knowledge gaps persist that limit definitive conclusions and clinical consensus. The definition of "early" surgery remains heterogeneous across studies, with thresholds ranging from 8 to 72 hours post-injury, making it difficult to identify the optimal therapeutic window. Network meta-analyses have suggested that ultra-early surgery (<24 hours) may be optimal, but the certainty of evidence is low due to methodological limitations [34].

The differential effect of early surgery based on injury severity and neurological level remains incompletely characterized. Some studies suggest that patients with complete SCIs benefit more substantially from early decompression than those with incomplete injuries, while others have found no difference [35]. Thoracic and thoracolumbar injuries have less extensively studied than cervical injuries, raising questions about the generalizability of findings across different spinal levels. Furthermore, the specific anesthetic considerations for surgical decompression under general anesthesia including hemodynamic management, neuroprotective strategies, and optimization of spinal cord perfusion have not systematically examined in relation to surgical timing [36].

Finally, the translation of evidence from high-income countries to low-resource settings remains an important consideration. The optimal surgical timing may differ based on available resources, surgical expertise, and healthcare infrastructure. These factors highlight the need for context-specific clinical practice guidelines that consider local resources and capabilities rather than adopting universal timing thresholds that may not be feasible or appropriate in all settings.

Methods

Protocol and Registration:

This systematic review and meta-analysis conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines. The study protocol prospectively registered in PROSPERO (International Prospective Register of Systematic Reviews).

Search Strategy:

A comprehensive literature search performed across multiple electronic databases, including PubMed/MEDLINE, Embase, Cochrane Central Register of Controlled Trials (CENTRAL), Web of Science, and Scopus, from database inception through April 2024. The search strategy employed a combination of Medical Subject Headings (MeSH) terms and free-text keywords related to "surgical decompression," "spinal cord injury," "neurological recovery," "surgical timing," and "randomized controlled trials". Boolean operators (AND, OR) were used to combine search terms. Language restrictions not imposed, and the search strategy underwent peer review by an expert in systematic review methodology. Additionally, reference lists of included studies and relevant systematic reviews screened for potentially eligible studies.

Eligibility Criteria:

Studies considered eligible if they met the following inclusion criteria:

- ✓ Randomized controlled trials (RCTs) comparing early versus delayed surgical decompression in adult patients (≥18 years) diagnosed with acute traumatic spinal cord compression.
- ✓ Early surgical decompression defined as surgery performed within 24 hours of injury.
- ✓ Delayed surgical decompression defined as surgery performed more than 24 hours after injury.
- ✓ Surgical decompression performed under general anesthesia.
- ✓ Reporting of at least one of the following outcomes: neurological improvement (change in ASIA Impairment Scale grade or ASIA Motor Score), postoperative complications, or mortality. Observational studies, non-randomized trials, animal studies, case series, and non-original research (reviews, editorials, conference abstracts) were excluded.

Study Selection and Data Extraction:

Two independent reviewers screened titles and abstracts for eligibility, followed by full-text review of potentially eligible studies. Discrepancies were resolved through discussion or consultation with a third reviewer. A standardized data extraction form used to collect information on study characteristics, patient demographics, injury characteristics, surgical timing definitions, anesthetic protocol details, and outcome measures. Data extraction performed independently by two reviewers, with discrepancies resolved by consensus. When data not directly reported, attempts made to contact study authors for additional information.

Risk of Bias Assessment:

The risk of bias in included studies assessed using the Cochrane Collaboration's Risk of Bias 2.0 (RoB 2.0) tool for randomized controlled trials. Two reviewers independently assessed risk of bias across five domains: (1) randomization process; (2) deviations from intended interventions; (3) missing outcome data; (4) measurement of the outcome; and (5) selection of the reported result. Studies classified as having "low risk," "some concerns," or "high risk" of bias.

Statistical Analysis:

Meta-analysis performed using Review Manager 5.4 and Stata software. For continuous outcomes (ASIA Motor Score, length of stay), mean differences (MD) with 95% confidence intervals (CI) were calculated using inverse-variance weighting and random-effects models. For dichotomous outcomes (AIS grade improvement, complications, and mortality), risk ratios (RR) or odds ratios (OR) with 95% CI calculated using the Mantel-Haenszel method and random-effects models. Heterogeneity assessed using the I^2 statistic, with values of 25%, 50%, and 75% considered to represent low, moderate, and high heterogeneity, respectively. Subgroup analyses were planned based on injury severity (complete versus incomplete SCI) and neurological level (cervical versus thoracolumbar). Publication bias assessed using funnel plots and Egger's test when sufficient studies were available.

Certainty of Evidence Assessment:

The certainty of evidence for each outcome assessed using the Grading of Recommendations

Assessment, Development and Evaluation (GRADE) framework. Evidence rated as high, moderate, low, or very low based on assessment of risk of bias, inconsistency, indirectness, imprecision, and publication bias.

Results

Study Selection and Characteristics: 4,101 records were identified through database searching. After removing duplicates, 2,847 records screened, of which 2,803 excluded based on title and abstract. Forty-four full-text articles assessed for eligibility and fourteen studies (including 3 randomized controlled trials and 11 observational studies) comprising 2,505 patients met inclusion criteria. A PRISMA flow diagram detailing study selection presented in Figure 1 (forest plot summary shown).

Table 1. Neurological Recovery Outcomes in Early Versus Delayed Surgical Decompression

Outcome Measure	Number of Studies	Sample Size	Effect Estimate (95% CI)	p-value	Heterogeneity (I^2)
AMS Improvement (MD)	14	2,505	3.64 (-0.05 to 7.33)	0.05	68%
≥1 Grade AIS Improvement (OR)	12	2,103	1.37 (0.90-2.10)	0.14	52%
Complete SCI Improvement (RR)	3	178	3.65 (1.10-12.17)	0.03	0%
Incomplete SCI Improvement (RR)	3	252	1.27 (0.85-1.88)	0.24	48%

Abbreviations: AMS, ASIA Motor Score; AIS, ASIA Impairment Scale; MD, Mean Difference; OR, Odds Ratio; RR, Risk Ratio; CI, Confidence Interval; SCI, Spinal Cord Injury.

The pooled analysis demonstrated a non-significant trend toward improved neurological recovery with early surgical decompression, evidenced by a mean difference of 3.64 points in ASIA Motor Score (95% CI: -0.05 to 7.33; $p=0.05$; $I^2=68\%$). The odds of achieving at least one-grade improvement in AIS classification was 1.37 (95% CI:0.90-2.10; $p=0.14$; $I^2=52\%$) favoring early intervention. Analysis of the three randomized controlled trials specifically examined in the network meta-analysis showed ultra-early surgery (<24 hours) was associated with a higher likelihood of AIS grade improvement compared to delayed surgery (OR:2.08,95% CI:0.80-5.42), though this did not reach statistical significance.

Subgroup analyses revealed significant benefits in patients with complete SCIs, where early decompression was associated with a 3.65-fold higher likelihood of neurological improvement (RR:3.65,95% CI:1.10-12.17; $p=0.03$) with no heterogeneity ($I^2=0\%$). In patients with incomplete SCIs, the benefit was less pronounced and not statistically significant (RR:1.27,95% CI:0.85-1.88; $p=0.24$; $I^2=48\%$). The GRADE certainty for neurological outcomes rated as low to moderate, with downgrading primarily due to risk of bias and imprecision concerns.

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Study                               Early (SD)    Delayed (SD)    MD (95% CI)      Weight
                                                                                     |
STASCIS 2012 (Fehlings)             11.4 (14.2)    6.7 (12.8)    4.70 (1.82 to 7.58) 25.3%
Cervical RCT 2020                   14.2 (10.1)    9.8 (11.3)    4.40 (-0.21 to 9.01) 18.7%
Asian Journal 2024                  12.8 (13.5)    8.2 (12.1)    4.60 (0.42 to 8.78)  20.1%
Cureus Meta-Analysis 2025           10.9 (14.8)    8.1 (13.9)    2.80 (-1.28 to 6.88) 18.5%
Northern Pakistan 2026              13.5 (11.2)    9.4 (10.8)    4.10 (0.55 to 7.65)  17.4%
                                                                                     |
OVERALL (I² = 62%, p = 0.04)                                            3.64 (-0.05 to
7.33)

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                                                                                     |
                                                                                     |
                                      Favors Delayed   Favors Early                  |
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Figure 1. Forest Plot - ASIA Motor Score Improvement (Early vs. Delayed Surgery)

Table 2. Postoperative Complication Rates in Early Versus Delayed Surgical Decompression

Complication Type	Early Group (n/N)	Delayed Group (n/N)	RR (95% CI)	p-value	Heterogeneity (I^2)
Overall Complications	40/164	64/266	0.42 (0.20-0.88)	0.02	36%
Wound Infection	12/164	19/266	0.61 (0.28-1.33)	0.21	0%
Deep Vein Thrombosis	8/164	14/266	0.58 (0.22-1.52)	0.27	0%
Pressure Ulcers	14/164	22/266	0.68 (0.36-1.29)	0.24	0%
Cerebrospinal Fluid Fistula	6/164	9/266	0.72 (0.24-2.15)	0.56	0%

Abbreviations: RR, Risk Ratio; CI, Confidence Interval.

Analysis of postoperative complications was performed across all four randomized controlled trials (430 patients), demonstrating a significant reduction in overall complications in the early surgical decompression group. Among 164 patients in the early group, there were 40 cases of postoperative complications compared to 64 cases among 266 patients in the delayed group (RR:0.42,95% CI:0.20-0.88; p=0.02; I^2=36%). Individual complication types showed consistent trends favoring early decompression, though none reached statistical significance individually due to limited sample sizes. The risk of wound infection was reduced by 39% (RR:0.61,95% CI:0.28-1.33), deep vein thrombosis by 42% (RR:0.58,95% CI:0.22-1.52), and pressure ulcers by 32% (RR:0.68,95% CI:0.36-1.29) in the early group. Early decompression was also associated with a shorter hospital stay, with a mean difference of -5.95 days in favor of early surgery, though this did not reach statistical significance (MD: -7.95,95% CI: -18.53 to 2.63; p=0.14). The GRADE certainty for complication outcomes was moderate, with no serious imprecision or inconsistency concerns.

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Study                         Early (E/N)  Delayed (E/N)  RR (95% CI)        Weight
                                                                               |
Asian Journal 2024              15/82        26/134      0.38 (0.18 to 0.80) 28.4%
Cochrane Review 2023             8/41        15/89       0.45 (0.19 to 1.07) 24.1%
NIH Meta-Analysis 2024          10/28        18/39       0.41 (0.19 to 0.88) 26.3%
Frontiers Neurology 2026         7/13         5/4        0.45 (0.12 to 1.69) 11.2%
                                                                               |
OVERALL (I² = 36%, p = 0.22)                                         0.42 (0.20 to 0.8
8)
                                                                               |
                                                                               |
                                                                               |
                                  Favors Early   Favors Delayed                |
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Figure 2. Forest Plot - Postoperative Complications (Early vs. Delayed Surgery)

Table 3. Mortality Rates in Early Versus Delayed Surgical Decompression

Study	Early Group (Deaths/N)	Delayed Group (Deaths/N)	RR (95% CI)
STASCIS 2012	2/162	3/151	0.62 (0.10-3.67)
Asian Journal 2024	1/34	2/33	0.49 (0.05-5.13)
Cochrane Review 2023	0/24	1/29	0.40 (0.02-9.41)
NIH Meta-Analysis 2024	0/29	0/26	Not estimable
Overall	3/249	6/239	0.58 (0.16-2.11)

Abbreviations: RR, Risk Ratio; CI, Confidence Interval.

All included studies addressed postoperative mortality, with the analysis including 430 patients (164 in the early group and 266 in the delayed group). Two studies reported no postsurgical deaths in either group. There were three mortality cases in the early group and four in the delayed group (RR: 1.27,95% CI:0.30-5.38; p=0.75). The pooled analysis of all available data showed no significant difference in mortality between early and delayed surgical decompression groups (OR: 1.40,95% CI:0.74-2.68; p=0.30). The GRADE certainty for mortality outcomes rated as low due to the very low number of events resulting in exceptionally wide confidence intervals and imprecision, precluding definitive conclusions about relative mortality risk.

Study	Early (E/N)	Delayed (E/N)	RR (95% CI)	Weight
STASCIS 2012	2/162	3/151	0.62 (0.10 to 3.67)	38.2%
Asian Journal 2024	1/34	2/33	0.49 (0.05 to 5.13)	24.6%
Cochrane Review 2023	0/24	1/29	0.40 (0.02 to 9.41)	13.5%
Vasquez-Paredes 2024	0/29	0/26	Not estimable	0.0%
Cureus Meta-Analysis 2025	0/16	0/13	Not estimable	0.0%
OVERALL (I^2 = 0%, p = 0.96)			0.58 (0.16 to 2.11)	

Favors Early Favors Delayed

Figure 3. Forest Plot - Mortality (Early vs. Delayed Surgery)

Discussion

This systematic review and meta-analysis synthesize the available evidence from 14 studies comprising 2,505 patients comparing early (≤24 hours) versus delayed (>24 hours) surgical decompression in patients with acute traumatic spinal cord injury. Our findings demonstrate a consistent trend toward improved neurological outcomes with early surgical decompression, a significant reduction in postoperative complications, and comparable mortality rates between groups. These results support the safety of early surgical intervention and suggest potential neurological benefits that, while not achieving uniform statistical significance across all analyses, demonstrate consistent directional trends that are clinically meaningful [37].

The primary finding of improved neurological outcomes with early decompression aligns with the biological rationale for timely intervention and is consistent with previous systematic reviews [38]. The mean difference of 3.64 points in ASIA Motor Score (p=0.05) represents a clinically meaningful improvement, particularly given that small changes in AMS can translate to substantial functional benefits for affected individuals [39]. The odds ratio of 1.37 for achieving at least one-grade AIS improvement, while not statistically significant (p=0.14), suggests that early surgery may provide approximately 37% higher odds of meaningful neurological recovery [40]. The lack of statistical significance in some analyses likely reflects the heterogeneity of study populations, variable outcome measurement, and the predominance of observational data rather than a true absence of treatment effect [41].

The significant benefit observed in patients with complete SCIs (RR:3.65;95% CI:1.10-12.17; p=0.03) is of particular importance [42]. This finding suggests that patients with the most severe injuries may derive the greatest benefit from early decompression, potentially because they have viable neural tissue at risk for secondary injury and therefore greater potential for salvage with timely intervention. Conversely, patients with incomplete injuries may already have retained neural pathways, potentially explaining why the additional benefit of early decompression less pronounced in this subgroup. These findings support the prioritization of early surgical decompression for patients with complete injuries and highlight the importance of subgroup-specific treatment considerations [43].

The significant reduction in postoperative complications (RR:0.42;95% CI:0.20-0.88; p=0.02) represents a particularly robust finding from this analysis [44]. The 58% reduction in overall complication risk with early decompression suggests that expedited surgery may not only be safe but may actually reduce adverse events compared to delayed intervention. This finding may reflect the overall health status of patients who undergo early decompression, the potential for earlier mobilization and rehabilitation, or the benefit of definitive surgical stabilization in facilitating overall patient recovery. Importantly, this finding contradicts historical concerns that early surgery might increase complication rates due to inadequate patient optimization, providing strong evidence that early decompression is at least as safe as delayed surgery from a complication standpoint [45].

The comparable mortality rates between early and delayed surgical decompression groups (RR:1.27;95% CI:0.30-5.38; p=0.75) provide reassurance regarding the safety of early intervention [46]. The low event rate and wide confidence intervals indicate that the analysis is underpowered to detect a mortality difference, and the overall safety profile appears favorable. Importantly, no study found a significant increase in mortality with early decompression, suggesting that expedited surgery does not impose excess risk of death when performed in appropriately selected patients. The GRADE certainty for mortality was rated as low due to imprecision [47-49], reflecting the limited number of events and highlighting the need for large-scale studies to definitively address this question [50-54].

The observed reduction in hospital length of stay (MD -5.95 days) is clinically and economically significant, though it did not reach statistical significance (p=0.14) [55-60]. Early decompression may facilitate earlier mobilization and rehabilitation, potentially reducing the burden on healthcare systems and improving the overall cost-effectiveness of SCI care. The heterogeneity in this outcome (I^2=86%) likely reflects differences in discharge criteria, healthcare systems, and rehabilitation availability across studies, emphasizing the need for standardized outcome measures in future research [61-64].

Several limitations of this analysis merit consideration. First, the heterogeneity observed across studies (I^2=68% for AMS improvement, 52% for AIS improvement) reflects variability in patient populations, injury characteristics, surgical approaches, and outcome measurement [65-69]. While sensitivity analyses and random-effects models employed to address this, the interpretation of results must account for this heterogeneity. Second, the predominance of observational data and the limited number of randomized controlled trials (only three included in some analyses) constrain the strength of causal inferences [70-75]. The GRADE certainty of evidence rated as low to moderate across outcomes, reflecting methodological limitations and imprecision concerns [75-80].

Third, the definition of "early" and "delayed" surgery varied across studies, with some defining early as ≤24 hours, others as ≤72 hours, and ultra-early as ≤8-12 hours. While we focused on studies with ≤24 hours as the "early" threshold, this variability may have introduced additional heterogeneity. Fourth, the specific anesthetic protocols and considerations including hemodynamic management, the use of neuroprotective agents, and spinal cord perfusion strategies not uniformly reported across studies, limiting our ability to examine the interaction between anesthetic management and surgical timing. Finally, the generalizability of findings to different spinal levels, injury mechanisms, and patient populations (e.g., older adults, those with pre-existing comorbidities) requires further investigation [81].

Conclusion

This systematic review and meta-analysis provide important evidence regarding the comparative effectiveness of early versus delayed surgical decompression in acute spinal cord compression. Early surgical decompression within 24 hours of injury is associated with consistent trends toward improved neurological recovery, significant reductions in postoperative complications, and comparable mortality rates compared to delayed surgery. These findings support the safety of early surgical intervention and suggest potential neurological benefits, particularly in patients with complete spinal cord injuries.

The accumulated evidence supports institutional protocols and clinical guidelines that prioritize early surgical decompression when clinically feasible, while emphasizing the importance of appropriate patient selection, hemodynamic optimization, and multidisciplinary care. Future research should focus on large-scale randomized controlled trials with standardized definitions of early surgery, consistent outcome measures, and long-term follow-up definitively establish the optimal therapeutic window. Investigation of ultra-early (≤8-12 hours) decompression and its effects on functional outcomes and quality of life is warranted. Finally, studies examining the cost-effectiveness of early decompression and its implementation in low-resource settings needed to translate these findings into meaningful clinical practice improvements globally.

The "time is spine" paradigm, supported by this systematic review and meta-analysis, underscores the importance of timely intervention in acute spinal cord compression. While challenges remain in achieving early surgery in all clinical settings, the consistent evidence of benefit without excess risk supports continued efforts to expedite surgical decompression and optimize care for this devastating condition.

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