REVIEW

OPEN

Time is spine: critical updates for the intensivist

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Purpose of review

The concept of 'time is spine' emphasizes early or ultra-early surgical decompression within 24 or 12 h, respectively, after spinal cord injury (SCI) to maximize recovery. This review updates the latest findings on the timing of surgical decompression and hemodynamic management in acute SCI, focusing on neurological outcomes and complications.

Recent findings

While early decompression may improve neurological outcomes, factors like injury severity, comorbidities, and system resources affect surgical timing. Recent studies question the benefits of ultra-early decompression, finding no significant improvement at 12 months, suggesting earlier analyses may have overstated its benefits. Current recommendations include tailoring decompression timing to individual cases, considering patient-specific and systemic factors. New techniques like spinal cord pressure monitoring, intraoperative ultrasound, and advanced imaging are advancing targeted intervention and hemodynamic management in SCI.

Summary

The timing of spinal decompression and hemodynamic management may impact neurological function, however, because of the deficiencies of current studies, individualized, patient-tailored decision-making is critical. A multidisciplinary approach that considers injury severity and patient characteristics is essential for optimal management. Further research is required to refine the timing of surgical intervention and explore additional factors influencing recovery.

Keywords

early decompression, neurological outcomes, spinal cord injury, surgery timing, ultra-early intervention

INTRODUCTION

The 'Time is Spine' principle, drawing parallels with the 'Time is Brain' adage in stroke management, highlights the critical importance of prompt intervention in spinal cord injury (SCI) [1–4]. Timely action is paramount to mitigating secondary injury processes such as ischemia, inflammation, and apoptosis, which can exacerbate the primary mechanical trauma [5]. For intensivists and other care providers, targeted rapid intervention is key to improving patient outcomes, as delays in treatment may result in irreversible damage and long-term disability.

THE ROLE OF THE INTENSIVIST IN SPINAL CORD INJURY MANAGEMENT

Intensivists represent one of the first lines of healthcare practitioners to assess SCI patients, and their early actions can significantly influence recovery outcomes. The intensivist's role often involves:

(1) Maintenance of spinal stabilization: Immediate stabilization of the airway, breathing, and circulation, along with spinal stabilization, is crucial to prevent further mechanical damage [6,7] and reduce the risk of exacerbating spinal injuries during patient transport and positioning.
(2) Neurological assessment: Standardized tools such as the International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI) published by the American Spinal Injury Association are used to assess the severity of the injury and monitor for any changes in the patient's neurological status [8,9]. Regular

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KEY POINTS

- The 'Time is Spine' principle emphasizes the urgency of early intervention in spinal cord injuries to prevent secondary damage like ischemia and inflammation.
- It is currently unclear whether timing of surgery for all spinal cord injury (SCI) impacts neurological outcomes and decisions regarding the timing of surgical management should consider the specific injury characteristics and additional patient-specific factors. Earlier intervention may decrease major complications and acute hospital length of stay.
- Maintaining optimal spinal cord perfusion through vigilant hemodynamic management is critical, but evidence on specific mean arterial pressure targets and vasopressor use is still weak.
- Intrathecal pressure, intraspinal pressure, MRI/CT myelogram, and intraoperative ultrasound are now being developed to improve assessments of spinal cord perfusion pressure and cord compression. Durotomy with duraplasty is also being assessed as an additional intervention for spinal cord decompression.
- Intensivists play a crucial role in SCI management by ensuring spinal stabilization, monitoring neurological function, maintaining hemodynamic stability, and coordinating multidisciplinary care.

assessments are critical for tracking progress and determining surgical or other interventional needs.

(3) Hemodynamic management: Hypotension is common in SCI due to neurogenic shock or hypovolemia and can worsen secondary injury by reducing spinal cord perfusion. Ensuring adequate optimal spinal cord perfusion through vigilant hemodynamic management is ideal to prevent further ischemic injury to the spinal cord [10–12].

(4) Respiratory management: Supporting respiratory function, especially in cervical SCIs, which may impair ventilation. Early mechanical ventilation, especially in injuries above the C3 level, and proactive pulmonary care can reduce the risk of complications like pneumonia [13–16].

(5) Multidisciplinary coordination: The intensivist plays an integral role in coordinating multidisciplinary are with neurosurgeons, orthopedic surgeons, and trauma teams. This collaboration is critical for determining the timing of decompression surgery and ensuring that all aspects of the patient's care are integrated for the best possible outcome.

TIMING OF SURGICAL DECOMPRESSION: WHY 'TIME IS SPINE' MATTERS

Neurological recovery after SCI depends on the severity of the injury and recovery can be impacted by the timing of intervention. Surgical decompression and stabilization are aimed at relieving spinal cord compression, restoring spinal alignment, and minimizing additional secondary injury mechanisms such as ischemia and inflammation. While it is still unclear if earlier intervention with spinal decompression results in improved neurological recovery, earlier spinal decompression and stabilization may facilitate earlier patient mobilization and, thereby, decrease complications and critical care unit stays [13,17–21].

EARLY VERSUS ULTRA-EARLY DECOMPRESSION

Early decompression, defined by decompression performed within 24 h, has been advocated for improving neurological outcomes [1,17,18,21,22]. The *Surgical Timing in Acute Spinal Cord Injury Study (STASCIS)* found that decompression prior to 24 h after traumatic spinal cord injury was associated with improved neurologic outcomes compared to decompression after 24 h [4,21,23]. However, because of the study methodology, the question of whether early decompression improved neurological outcome is still not definitively answered [24].

Some studies suggest that ultra-early decompression (within 12 h) may offer additional benefits [25]. The traumatic Spinal Cord Injury Prospective, Observational European Multicentre (SCI-POEM) study attempted to improve upon the study methodology with propensity score adjustment to mitigate population heterogeneity and studied ultra-early ($\leq$12 h) surgical decompression. They found no statistically significant or clinically meaningful neurological improvements with ultra-early surgical decompression following acute SCI at 12 months, suggesting that previous unadjusted analyses may have overestimated its benefits due to baseline imbalances and high follow-up loss [26]. A recent guideline recommendation has recommended that patients with an acute SCI, regardless of level, undergo surgery within 24 h after injury when medically feasible [27▪▪], However, the American Association of Neurological Surgeons/Congress of Neurological Surgeons subsequently published a position statement highlighting that the best current evidence regarding the timing of surgery is constrained by heterogenous patient populations, inconsistent treatment protocols, and variable outcome measures [28▪]. As these deficiencies limit the ability to draw conclusions regarding the timing of surgical intervention that will have a meaningful impact on the patient's neurological outcome, they have concluded that there is no prospective class I evidence that supports a recommendation for the timing of surgical intervention. Their position is that decisions regarding the timing of surgical management must take into account both the particular characteristics of the injury and additional patient-specific factors that may influence outcomes [28▪].

LATE DECOMPRESSION

Historically, decompression surgery performed beyond 24 h was standard in cases where patients presented with polytrauma or other complicating factors [20]. However, late decompression has been associated with worse neurological outcomes, including prolonged critical care unit stays and increased complication rates [17,18,21]. Although some patients, particularly those with polytrauma, may still require delayed interventions due to the complexity of their injuries, the general trend in SCI care has been moving towards earlier surgical intervention to allow earlier mobilization of patients and decrease complications associated with prolonged bedrest. However, recent systematic reviews found low evidence that early decompression may decrease acute hospital length of stay or decrease major complications. Indeed, there was also no difference in rates of mortality, sepsis/systemic infection or neurological deterioration with respect to timing of surgery [27▪▪].

LIMITATIONS OF ULTRA-EARLY AND EARLY DECOMPRESSION

Several factors suggest that early or ultra-early decompression may have limited utility in the management of SCI. These factors can be patient-specific, injury-specific, or related to broader healthcare system capabilities. Factors such as those listed below may impact the evaluation of the potential benefits on the timing of surgical intervention:

(1) Severity of initial injury: The extent of the primary mechanical damage to the spinal cord can be a determinant of outcome [29]. In cases of complete transection or severe contusion with extensive neurological deficit, the potential for recovery may be limited regardless of the timing of decompression.
(2) Presence of polytrauma: Patients with multiple injuries may not be stable enough for immediate surgery [20]. The need to prioritize life-saving interventions over decompressive surgery can necessitate the delay of surgical intervention.
(3) Preexisting comorbidities: Patients with significant comorbidities may not tolerate early surgery well, and the risks associated with anesthesia and the surgical procedure itself may outweigh the potential benefits of early decompression [30].
(4) Presence of confounding factors: Patients may present with confounding factors such as intoxication from drugs or alcohol, limiting the initial exam and potentially overestimating the benefits of early surgery [31].
(5) Spinal cord edema: Extensive spinal cord swelling can make early surgical intervention of only osseous decompression insufficient. In these cases, a more extensive decompression and/or durotomy with duraplasty may be required [32].
(6) Spinal shock: The presence of spinal shock, characterized by a temporary loss of spinal reflex activity below the level of injury, can make it difficult to accurately assess the degree of SCI and the potential benefits of early decompression [33].
(7) Availability of surgical expertise and resources: The lack of immediate access to a specialized spine surgery team and the necessary infrastructure can preclude ultra-early or early decompression.
(8) Quality of evidence: There is no prospective class I evidence that supports a recommendation for the timing of surgical intervention [28▪,34].
(9) Molecular and genetic factors: Emerging research suggests that individual molecular and genetic factors may influence the response to injury and recovery potential, potentially impacting the utility of early decompression [5,35].
(10) Logistical and systemic delays: Delays in diagnosis, transfer to a specialized center, obtaining necessary imaging studies or obtaining expert personnel can impact the timing of decompression beyond the early or ultra-early window.
(11) Economic and social considerations: Financial constraints, lack of insurance coverage, or social circumstances may delay the timing of surgery.

In summary, while early and ultra-early decompression have been associated with improved outcomes in some studies, individual patient factors, injury characteristics, and systemic issues must be carefully considered when determining the optimal timing for surgical intervention in SCI.

BENEFITS OF EARLY DECOMPRESSION

Conversely, several factors suggest that early or ultra-early decompression may be beneficial for patients with SCI. These factors are based on the understanding of SCI pathophysiology and the potential for improved outcomes with timely intervention:

(1) Mechanism of injury: In cases where SCI is primarily due to ongoing compression from bone fragments, herniated discs, or hematoma, early or ultra-early decompression can relieve mechanical pressure and may limit secondary injury.
(2) Incomplete SCI: Patients with incomplete SCI, where some sensory or motor function is preserved below the level of injury, may benefit more from early decompression for recovery of function and prevention of further deterioration
(3) Rapidly worsening neurological status: If a patient's neurological status is deteriorating quickly, early decompression may halt or reverse this decline [1–4].
(4) Spinal cord edema without severe compression: If imaging suggests that spinal cord edema is present without severe compression, decompression may prevent further ischemic damage by improving vascular perfusion [13,36].
(5) Availability of surgical expertise and infrastructure: Access to a specialized neurosurgical team and the necessary infrastructure for immediate surgery can facilitate early decompression and potentially improve outcomes.
(6) Evidence of ongoing compression on imaging: MRI, CT myelogram or intraoperative ultrasound showing evidence of ongoing spinal cord compression would provide a rationale for interventions to alleviate pressure.
(7) Younger age and good health: Younger patients and those in good health may have a better capacity for recovery and tolerate early surgical intervention more effectively.
(8) Absence of major comorbidities: Patients without significant comorbidities are less likely to experience complications from early surgery and may benefit from early decompression [30].
(9) Patient and family preferences: Informed patients or their families who understand the potential benefits and risks may opt for early intervention.
(10) Systemic inflammatory response: Early decompression may mitigate the systemic inflammatory response that can exacerbate secondary injury [4,5].
(11) Preservation of spinal cord perfusion: Early decompression can help preserve spinal cord blood flow, which is critical for the delivery of oxygen and nutrients, as well as the removal of waste products [12,23,37,38].
(12) Reduction in hospital stay and healthcare costs: Early decompression with spinal stabilization may be associated with shorter hospital stays and reduced healthcare costs due to faster recovery and fewer complications [39].
(13) Potential for neural plasticity: Early intervention may capitalize on the spinal cord's plasticity, enhancing the potential for neural circuit reorganization and recovery [40,41].
(14) Alignment and stabilization: Early decompression with spinal stabilization can prevent further mechanical injury and facilitate earlier rehabilitation.

It is important to note that while these factors suggest potential benefits of early or ultra-early decompression, the decision to proceed with surgery must be individualized. The overall clinical context and the patient's specific circumstances should guide the timing of decompression, with collaboration among neurosurgeons, intensivists, and rehabilitation specialists aimed at optimizing patient outcomes.

HEMODYNAMIC MANAGEMENT OF ACUTE SPINAL CORD INJURY

Hemodynamic and cardiovascular management in spinal cord injury

Maintaining spinal cord perfusion is crucial in the early management of SCI, as reduced blood flow can exacerbate tissue damage and worsen outcomes. SCI patients, especially those with high thoracic and cervical injuries, are prone to cardiovascular complications such as neurogenic shock, bradycardia, and hypotension.

Optimizing hemodynamic management

Mean arterial pressure (MAP) measurements have been used as a surrogate marker of spinal cord perfusion, however, again, the evidence is weak with respect to whether maintenance of a MAP target impacts neurologic recovery. Optimizing spinal cord perfusion through vigilant hemodynamic management could prevent further ischemic injury to the spinal cord as hypotension, common in SCI due to neurogenic shock or hypovolemia, can worsen secondary injury. However, maintaining MAP targets can result in arrhythmias and myocardial injuries from vasopressor use, and worsen intraparenchymal hemorrhage (IPH) within the spinal cord and spinal cord IPH has been associated with poorer neurological outcomes [42]. Because of the low-quality evidence and uncertainty between MAP and neurologic recovery, recommendations regarding mean arterial pressure targets are weak [43▪]. There is a weak suggestion to augment MAP to at least 75–80 mmHg, but not actively augment beyond an upper limit of 90–95 mmHg. There is also a weak recommendation to augment MAP for a duration of 3–7 days. There are no recommendations regarding choice of vasopressor because of the lack of available evidence.

UTILITY OF MONITORING FOR TARGETING SPINAL CORD PERFUSION

Analogous to traumatic brain injury measurement of intracranial pressure (ICP) to help target cerebral perfusion pressure, there has been interest in assessing spinal cord perfusion pressure (SCPP) which would be the difference between MAP and either intrathecal pressure (ITP) or intraspinal pressure (ISP). ITP has been assessed with lumbar intrathecal catheters and ISP with intradural pressure probes placed at the anatomical site of injury [44].

The measurement of ITP and ISP have shed light on the previous 'black box' of spinal cord injury where the concept of bony or osseous decompression may no longer be sufficient to decompress the spinal cord [32]. Werndle *et al.* found that laminectomy may increase intraspinal pressure and was potentially detrimental in that it allowed skin compression to be transmitted to the injured spinal cord [44]. To avoid transmission of external forces to the injured spinal cord, they proposed that the patient be nursed on the side or prone on a ring-shaped pillow supporting the remaining bony structures.

Other interventions include using imaging techniques to assess whether the spinal cord is swollen to the point where it is compressed by the dura. Magnetic resonance imaging has been shown to identify patients where the intrinsic swelling of the cord filled to occupy the intrathecal space [45]. CT myelography can also be used and while it may help in cases where instrumentation obscures the MRI, it is more invasive. Intraoperative ultrasound is another modality that has been utilized to ensure sufficient cord decompression after spinal cord injury during surgery [46].

If sufficient cord compression is identified even after bony decompression, modalities to further decompress the spinal cord include durotomy with duraplasty and this is currently being investigated in cervical SCI patients with a randomized controlled trial known as DISCUS (Duroplasty for Injured Cervical Spinal Cord with Uncontrolled Swelling) [47]. The intradural decompression is believed to enhance cord perfusion, decrease cord ischemia and reduce inflammation.

While hemodynamic management based on SCPP may impact neurologic function, there is currently a 'dearth of available evidence' regarding what SCPP targets should be used [43▪].

CHALLENGES IN IMPLEMENTING 'TIME IS SPINE'

Implementing the 'time is spine' concept is not without challenges [1–4]. Managing polytrauma, systemic inflammation, and logistical hurdles are ongoing issues. Intensivists play a crucial role in expediting diagnosis, hemodynamic stabilization, and surgical coordination to meet the 24-h window.

CONCLUSION: THE PATH FORWARD IN SPINAL CORD INJURY CARE

The principle of early or ultra-early decompression, supported by the 'time is spine' concept, shows promise in improving neurological outcomes for SCI patients [1–4]. However, because of insufficient evidence, the decision regarding the timing of surgery must be tailored to each patient, considering the severity of the injury, comorbidities, and the resources available. Optimizing hemodynamic management may also further improve spinal cord injury patient care and neurological recovery. Intensivists play a pivotal role in managing the critical initial stages of SCI, focusing on hemodynamic stability, respiratory care, and the coordination of multidisciplinary teams. Moving forward, there is a need for more rigorous, randomized studies and individualized approaches in managing spinal cord injuries, including the integration of neuroprotective strategies alongside surgical intervention.

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Conflicts of interest

There are no conflicts of interest.

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