Introductory Article

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A Clinical Practice Guideline for the Management of Acute Spinal Cord Injury: Introduction, Rationale, and Scope

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Abstract

Acute spinal cord injury (SCI) is a traumatic event that results in disturbances to normal sensory, motor, or autonomic function and ultimately affects a patient's physical, psychological, and social well-being. The management of patients with SCI has drastically evolved over the past century as a result of increasing knowledge on injury mechanisms, disease pathophysiology, and the role of surgery. There still, however, remain controversial areas surrounding available management strategies for the treatment of SCI, including the use of corticosteroids such as methylprednisolone sodium succinate, the optimal timing of surgical intervention, the type and timing of anticoagulation prophylaxis, the role of magnetic resonance imaging, and the type and timing of rehabilitation. This lack of consensus has prevented the standardization of care across treatment centers and among the various disciplines that encounter patients with SCI. The objective of this guideline is to form evidence-based recommendations for these areas of controversy and outline how to best manage patients with SCI. The ultimate goal of these guidelines is to improve outcomes and reduce morbidity in patients with SCI by promoting standardization of care and encouraging clinicians to make evidence-informed decisions.

Keywords

clinical guideline, traumatic spinal cord injury, spinal cord injury, acute spinal cord injury

Introduction and Background Information

Acute spinal cord injury (SCI) is a traumatic event that results in disturbances to normal sensory, motor, or autonomic function and ultimately affects a patient's physical, psychological, and social well-being. Acute SCI consists of a primary phase and a secondary phase.[1] The initial traumatic impact to the spinal cord, in the form of fracture or dislocation, causes microhemorrhages in the white and grey matter, axonal damage, and cellular membrane destruction.[2] Following the primary injury, a cascade of pathophysiological events results in impaired neuronal homeostasis, apoptosis, and tissue destruction. These include (1) edema and the release of coagulation factors and vasoactive amines, (2) ionic imbalance and formation of free radicals, and (3) an increased release of the excitatory neurotransmitter glutamate.[3,4] Acute SCI can significantly impair a patient's quality of life, functional status, and social independence.

The incidence and prevalence of acute SCI have been estimated at both national and regional levels in countries throughout the world. Sekhon and Fehlings reported an annual global incidence of acute SCI of 14 to 40 per million.[5] In a review of the literature, Singh et al summarized the results from several epidemiological studies and concluded that the highest reported national incidence was in New Zealand (49.1 per million) and the lowest in Fiji (10.0 per million) and Spain (8.0 per

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million).[6] Of the states and provinces in North America, the crude annual incidence of SCI was highest in Alaska (83 per million) and Mississippi (77 per million) and lowest in Alabama (29.4 per million). There is a high male-to-female ratio of patients suffering from SCI and an age of peak incidence of younger than 30 years. Motor vehicle accidents are the primary cause of SCI, followed by falls in the elderly population.

The management of acute SCI requires significant health care resources and can place substantial financial burden on patients, their families, and the community. These costs are associated with a need for high-level acute care in the short term along with complication management in the long term. According to Krueger et al, the estimated lifetime economic burden associated with SCI in Canada is between CAD$1.47 million for incomplete paraplegia and $3.03 million for a patient with complete tetraplegia.[7] Furthermore, the total annual estimated economic burden of SCI in Canada is $2.67 billion ($1.57 billion in direct costs and $1.10 billion in indirect costs). Given the effects of SCI at both individual and societal levels, there is a pressing need to identify effective methods to manage these injuries and reduce the extent of future disability.

Rationale and General Scope

SCI is a devastating injury that significantly impairs a patient's quality of life, functional status, and social independence. The management of patients with SCI has drastically evolved over the past century as a result of increasing knowledge on injury mechanisms, disease pathophysiology, and the role of surgery. There still, however, remain controversial areas surrounding certain management strategies for the treatment of SCI, including the use of corticosteroids such as methylprednisolone sodium succinate (MPSS), the optimal timing of surgical intervention, the type and timing of anticoagulation prophylaxis, the role of magnetic resonance imaging (MRI), and the type and timing of rehabilitation. This lack of consensus has prevented the standardization of care across treatment centers and across the various disciplines that encounter patients with SCI.

This guideline is divided into five sections. The following sections describe the key knowledge gaps, previous published guidelines, and rationale for each topic.

Timing of Surgical Decompression

The first section of this guideline aims to define the optimal timing of surgical decompression by comparing outcomes and safety between patients decompressed early ($\leq$24 hours of injury) versus late (>24 hours of injury). Preclinical evidence has suggested that persistent compression of the spinal cord after the primary injury represents a reversible form of secondary injury, which, if ameliorated in an expeditious fashion, may lead to reduced neural tissue injury and improved outcomes.[8-10] In the early acute phase of SCI, occurring from minutes to hours, pathophysiological changes include vasogenic edema, microvessel vasospasm, thrombosis, ion imbalance, loss of sodium gradient, release of neurotoxic opioids, inflammation, lipid peroxidation, glutamatergic excitoxicity, cytotoxic edema, and formation of free radicals.[2] From days to weeks postinjury, also known as the subacute phase, mechanisms of cellular injury include microglial stimulation, macrophage activation, and apoptosis. In a review by Fehlings et al, the results of several experimental studies were summarized to determine the impact of early decompression on outcomes.[10] Based on 4 studies, early decompression improved neurological recovery and evoked potentials in dogs and rats. Furthermore, in a meta-analysis by Batchelor et al, compressive pressure significantly influenced neurobehavioral outcomes, with higher pressures generally associated with smaller effect sizes.[11]

Across clinical studies, several different time thresholds have been used to define "early" versus "late" surgical decompression; the heterogeneity of definitions has prevented the formation of strong conclusions surrounding the optimal timing of surgical intervention. The Spinal Trauma Study Group identified the first 24 hours as the most promising time window during which decompression may afford neuroprotection.[12] Unfortunately to date, no surgical guideline exists that rigorously explores the merits of early versus late surgical decompression for SCI, relative to the 24-hour threshold. Previous guidelines on the topic of surgical timing indicated that there was class II evidence to support (1) that early surgery (<72 hours) can be performed safely in patients with SCI if they have hemodynamic optimization, (2) a recommendation for urgent reduction in bilateral locked facets in patients with incomplete tetraplegia, and (3) a recommendation for urgent decompression in patients with SCI with neurologic deterioration.[10]

Perhaps the most controversial area with respect to timing of surgery is when to decompress patients with acute central cord syndrome without instability. The first studies published on this topic advised against surgery in these patients as spontaneous improvement could occur, and because decompression of a "fragile" spinal cord could result in neurological worsening.[13] More recent literature has suggested that surgery may be valuable in these patients as it can address the underlying degenerative pathology, stabilize the spine if necessary, reduce secondary injury cascades, decrease the risk of future catastrophic events, and accelerate neurological recovery.[14] The timing of intervention, however, remains controversial, and it is often debated whether these patients should be treated similarly to those with acute SCI. The overall objective of this guideline is to address these knowledge gaps and advise surgeons on the timing of intervention in patients with acute SCI and central cord syndrome.

The Use of Methylprednisolone Sodium Succinate

The second section of this guideline aims to define the efficacy and safety of MPSS in patients with acute SCI. MPSS is a corticosteroid that has been used across a wide spectrum of disease due to its potent anti-inflammatory actions. Early preclinical studies demonstrated that glucocorticoids can have profound beneficial effects on the injured spinal cord;

specifically, MPSS can prevent the loss of spinal cord neurofilament proteins, facilitate neuronal excitability and impulse conduction, improve blood flow, enhance Na^+K^+-ATPase activity, and preserve the cord structure by decreasing lipid peroxidation and preventing ischemia-induced tissue damage.[15-17]

Several randomized controlled trials have investigated the potential efficacy and safety of MPSS in patients with acute SCI and comprise the largest therapeutic studies completed in the history of SCI research.[18-21] In particular, the National Acute Spinal Cord Injury Study (NASCIS II) by Bracken et al[19] supported a small but clinically important improvement in neurological function for patients who received a 24-hour infusion of this drug within 8 hours of injury. Unfortunately, this article has been the target of intense criticism, with concerns including the reliance on subgroup analysis, the small reported effect size for neurologic improvement, and the potential for harmful and serious adverse events.

In a guideline published in 2002, an expert panel from the American Association of Neurological Surgeons (AANS)/Congress of Neurological Surgeons (CNS) agreed that there was insufficient evidence to support treatment standards and guidelines for the use of MPSS in the context of SCI.[22] Nonetheless, MPSS for either 24 or 48 hours was recommended as an option for the treatment of these patients; the use of MPSS, however, should be undertaken with the knowledge that the evidence suggesting harmful side effects is more consistent than any suggestion of clinical benefit. In 2013, the AANS/CNS proposed different recommendations for the use of MPSS despite a similar evidence base.[23] Specifically, this group developed a level I recommendation against this treatment based on the following reasons: (1) the drug is not Food and Drug Administration approved for this application, (2) there is no class I or II evidence supporting the clinical benefit of MPSS, and (3) class I, II, and III evidence exist that high-dose steroids are associated with harmful side effects, including death. These conflicting recommendations, as well as ongoing debate within the clinical community, leaves the attending physician in a precarious position when faced with the decision to administer this treatment in the acute care setting.

Consequently, this guideline aimed to bridge the gap between the 2002 and 2013 AANS/CNS guidelines and resolve existing controversy in the literature surrounding the use of MPSS. Based on the current body of literature, the guideline development group agreed it was necessary to distinguish between the following groups: (1) a 24- versus a 48-hour administration of MPSS and (2) administration of MPSS within versus after 8 hours of injury. As a result, any discrepancies between these recommendations and those proposed in 2002 or 2013 are likely a result of these group comparisons.

The Type and Timing of Anticoagulation Prophylaxis

The third section of this guideline aims to outline the appropriate type and timing of anticoagulation strategies to prevent venous thromboembolic events (VTE) in patients with acute SCI. Patients with SCI are at an increased risk of deep venous thrombosis (DVT) due to neurologic dysfunction, immobilization, intimal injury, and hypercoagulability.[24] Furthermore, these patients experience extensive tissue damage, are often treated surgically, and may be at a risk of hemorrhage or bleeding around neural tissues. DVTs may propagate and embolize to the pulmonary system where they may obstruct the pulmonary arteries, leading to a number of life-threatening physiologic changes, including impaired gas exchange, cardiovascular compromise, and right-sided heart failure.[24]

The prevention of DVT and pulmonary embolism through the use of anticoagulation is critical in this high-risk population. Unfortunately, prophylactic treatment in these patients is also associated with significant risks, including symptomatic hematoma formation, enlargement of a spinal cord contusion, worsening of neurologic deficits, bleeding, and mortality. Guidelines on this topic must carefully consider both the risks and benefits of each prophylactic strategy, as well as costs, preferences of key stakeholders, and acceptability.

Two previous guidelines have been developed for the prevention and treatment of VTE. First, a guideline developed by the Paralyzed Veterans of America recommended (1) the early use of mechanical compression devices; (2) the use of low-molecular-weight heparin plus intermittent pneumatic compression once primary hemostasis is evident; (3) to not administer anticoagulation in patients with intracranial bleeding, perispinal hematoma, and hemothorax until bleeding is stabilized; and (4) vena cava filters in patients with active bleeding that is anticipated to persist for more than 72 hours.[25] Second, a guideline created by the AANS/CNS proposed the following 8 recommendations (3 level I, 4 level II, and 1 level III) for the prevention of thromboembolic disease: (1) prophylactic treatment in SCI patients with severe motor deficits; (2) the use of low-molecular-weight heparins, rotating beds, or a combination of modalities; (3) the use of low-dose heparin in combination with pneumatic compression stockings or electrical stimulation; (4) early administration of VTE prophylaxis; and (5) a 3-month duration of treatment. In addition, this guideline recommended against the use of low-dose heparin therapy or oral anticoagulation alone and the routine use of vena cava filters.[26,27]

Although the existing guidelines on anticoagulation strategies are rather extensive, there is still controversy as to the optimal type and timing of prophylaxis. This current guideline aims to update and solidify these statements, incorporate the most recent evidence, and follow new and suggested methodological standards for developing recommendations.

The Role of Baseline Magnetic Resonance Imaging in Clinical Decision Making and Prognostication

The fourth section of this guideline aims to outline the role of baseline MRI in clinical decision making and outcome prediction. Imaging of the spine is an essential part of the initial management of acute SCI; plain X-rays or computed tomography form the basis of standard trauma protocols and can

identify most fractures and ligamentous injuries.[28] These imaging modalities, however, cannot visualize the spinal cord or the surrounding soft tissues to the same degree as MRI.[29] The potential benefits of MRI in the setting of acute SCI are that this type of imaging can identify ongoing spinal cord compression; depict soft tissue structures that are responsible for compression, including disc herniation, epidural hematoma, intramedullary hematoma, and preexisting canal stenosis; detect ligamentous instability at the level of injury or at other spinal levels; and identify vertebral artery injury. Furthermore, certain MRI features may correspond to the degree of tissue injury and can help predict neurological, functional, and safety outcomes. In contrast, potential risks and disadvantages of MRI include that it (1) requires a patient to be supine for up to 30 minutes, (2) may be risky in trauma patients with respiratory difficulties or hemodynamic instability, (3) requires substantial resources to ensure 24-hour availability, and (4) may delay surgical intervention.

Several previous efforts have been made to develop guidelines for the role of MRI in patients with acute SCI, including the 2002 and 2013 AANS/CNS guidelines and a systematic review by Bozzo et al.[28-30] Unfortunately, these guidelines do not provide clear evidence-based recommendations on whether MRI should be performed prior to surgical decompression and whether MRI features can predict neurological and functional outcomes following surgery. The 2002 AANS/CNS guidelines suggested the use of MRI as an option (1) to help clear the cervical spine and discontinue immobilization in awake symptomatic patients and obtunded patients; (2) for patients with cervical fracture-dislocation injury that cannot be examined prior to closed reduction, and in patients that fail closed reduction; (3) in adult patients to help diagnose atlanto-occipital dislocation and provide prognostic information in SCI without radiographic abnormality; and (4) in pediatric patients with SCI to exclude cord or nerve root compression, evaluate ligamentous injury, and predict outcomes.[30] The 2013 AANS/CNS guidelines modified the terminology from "option" to a level III recommendation for each specific clinical scenario.[28]

In a systematic review of the literature, Bozzo et al aimed to better establish the role of MRI in acute SCI.[29] This review generated 3 recommendations: (1) a weak recommendation that MRI be done in all patients with acute SCI, when feasible, to direct management; (2) a strong recommendation that MRI be done in the acute period following a SCI for prognostication; and (3) a strong recommendation that the sagittal T2 MRI sequence be included in all MRI protocols to predict neurological outcomes. Unfortunately, the evidence to support the role of MRI in clinical decision making was largely indirect; specifically, MRI may help diagnose certain clinical entities that, if present, may influence management decisions, such as ongoing cord compression, disc herniation, and ligamentous injury.

The Type and Timing of Rehabilitation

The fifth and final section of this guideline aims to outline the appropriate timing and strategies of rehabilitation following acute SCI. Rehabilitation commences once a patient is stable and focuses on preventing secondary complications and optimizing function through the use of compensatory techniques. The overall objectives of rehabilitation include (1) to improve a patient's independence in activities of daily living, such as bathing, eating, dressing, grooming, and wheelchair use; (2) to help a patient accept a new lifestyle with respect to sexual and recreational activities and housing options; and (3) to aid a patient's reintegration into society.

The rehabilitation of individuals with SCI can be divided into 3 phases: acute, subacute, and chronic.[31,32] During the acute and subacute phases of treatment, rehabilitation strategies focus on preventing secondary complications, promoting neurorecovery and maximizing function. In the chronic phase, compensatory or assistive approaches are often used, whereas in the acute and subacute phases, there is a greater emphasis on techniques that address underlying impairments. Rehabilitation is critical for patients confronted with a life-altering event such as a SCI as these individuals are eager and willing to work toward improving function. Furthermore, patient transition to a rehabilitation unit maintains patient flow and resource availability for newly injured individuals.

The optimal management strategies for patients with acute SCI are difficult to define due to the challenges associated with rehabilitation research; these include a lack of standardization of interventions, therapeutic doses and outcome measures, heterogeneous populations, superimposed spontaneous recovery, and problems with group assignment.[33] Furthermore, rehabilitation often combines multiple treatments that are prescribed by multiple health care professionals.

Despite these challenges, the Paralyzed Veterans Association developed several guidelines that focus on various components of rehabilitation, including pressure ulcer prevention and treatment, preservation of upper limb function, respiratory management, sexuality and reproductive health, and bladder management.[34-38] For the guideline on pressure ulcer prevention, recommendations were made for risk and risk assessment; prevention strategies across the continuum of care; assessment and reassessment following onset of complication; nonsurgical and surgical treatments; modification of treatment plans; complications of surgery; pressure redistribution; and support surfaces. In terms of preserving upper limb function, the recommendations focused on ergonomics; equipment selection, training, and environmental adaptations; exercise; management of acute and subacute upper limb injuries and pain; and treatment of chronic musculoskeletal pain to maintain function. Recommendations for respiratory management provided guidance on the initial assessment of acute SCI; prevention and treatment of atelectasis and pneumonia; medications; mechanical ventilation; surfactant and positive end expiratory pressure; complications of short-term and long-term ventilation; weaning from the ventilator; electrophrenic respiration; sleep-disordered breathing; dysphagia and aspiration; psychosocial assessment and treatment; education program development; and discharge planning. In terms of sexuality and reproductive health, the guidelines focused on patient

education; maintenance of sexual well-being; physical and practical considerations; the effect of injury on sexual function, responsiveness, and expression; treatment of dysfunction; effects on infertility; and relationship issues. Finally, recommendations for bladder management provided guidance on intermittent catheterization; crede and valsalva; indwelling catheterization; reflex voiding; alpha-blockers; botulinum toxin injection; urethral stents; transurethral sphincterotomy; electrical stimulation and posterior sacral rhizotomy; bladder augmentation; continent urinary diversion; and cutaneous ileovesicostomy.

These documents by the Paralyzed Veterans Association guide clinicians on how to manage various components of a patient's health in a rehabilitation setting. These guidelines, however, do not provide an overview of the optimal type and timing of rehabilitation strategies in patients with acute SCI.

Overall Objective

The main objective of this guideline is to outline how to best manage patients with acute SCI. This guideline will promote standardization of care and assist clinicians with decision making by providing evidence-based recommendations for controversial areas of patient management. Specific objectives of this guideline include to outline the optimal timing of surgical decompression, the use of MPSS, the type and timing of anticoagulation, the role of MRI for surgical decision making and prognostication, and the type and timing of rehabilitation.

Specific Scope and Aspects of Care

This guideline is to be applied in both the acute and rehabilitation phases of acute SCI in adult ($\geq$14 years old) patients with postresuscitation American Spinal Injury Association (ASIA) grades A to D. Recommendations related to timing of surgical decompression, the use of MPSS and anticoagulation, and the role of MRI will specifically apply to patients with blunt injuries, while recommendations related to type and timing of rehabilitation will focus on patients with either blunt or penetrating trauma.

Specific conditions that are *not covered* in this guideline include the following:

- SCI in pediatric patients (ie, those under 14 years of age)
- Chronic SCI, defined as persistence of paralysis for $\geq$12 months following injury
- Patients without neurological deficit following trauma
- Cord compression due to tumor, hematoma, infection, or degenerative disease
- Inflammatory diseases or multiple sclerosis
- Patients with injuries to the cauda equina

The following specific treatments and aspects of care are addressed in this guideline:

- Timing of surgical decompression in patients with SCI
- Efficacy and safety of MPSS in patients with SCI
- Efficacy, safety, and timing of anticoagulation prophylaxis in patients with SCI
- Role of baseline MRI in surgical decision making and prediction of neurologic, functional, and safety outcomes in patients with SCI
- Type and timing of rehabilitation following SCI

Specific treatments or aspects of care that are *not addressed* in this guideline include the following:

- Use of steroids or agents other than MPSS
- Specific methods for decompression or stabilization of the spine
- Role of computed tomography or radiographic procedures
- Neural prosthetics, cell therapy, spinal cord stimulators
- Speech/language, pharmacological, and respiration/breathing therapy
- Use of electrophysiological testing or monitoring

Relevant Definitions for All Sections

- *Acute spinal cord injury* is defined as sudden onset damage or trauma to the spinal cord resulting in loss of tissue integrity, which can lead to impaired function, reduced mobility or sensory dysfunction.
- *Incomplete spinal cord injury* is defined as sensory and/or motor sparing in the sacral segments S4-5
- *Complete spinal cord injury* is defined as no sensory or motor sparing in the sacral segments S4-5
- *Central cord syndrome* is defined as an incomplete SCI injury to the cervical central region of the cord which presents with greater neurological impairment in the upper extremities than the lower extremities.[39] Central cord syndrome is usually caused by a hyperextension cervical injury in people with previous degenerative pathology. In this guideline, we focused on central cord syndrome without instability.
- *Tetraplegia* occurs in cord injuries from C1 to T1
- *Paraplegia* occurs in cord injuries from T2 to T12
- *Penetrating injuries to the spinal cord* (for some recommendations) are defined as actual penetration of the spinal cord tissue such as a gunshot or stab wound.
- *Brown Sequard syndrome* is defined as an incomplete SCI and is most commonly caused by penetrating trauma.
- *Blunt injury* is defined as an insult causing SCI that does not penetrate the cord.
- *Early surgery* is defined as surgical decompression $\leq$24 hours of injury, whereas *late surgery* is defined as surgical decompression >24 hours of injury.
- *Frankel grade* is a 5-grade classification system that assesses spinal cord function. *Grade A: complete neurological injury*—no motor or sensory function detected below level of lesion; *Grade B: preserved sensation only*—no motor function detected below level of

lesion, some sensory function below level of lesion preserved; *Grade C: preserved motor, nonfunctional*—some voluntary motor function preserved below level of lesion but too weak to serve any useful purpose, sensation may or may not be preserved; *Grade D: preserved motor, functional*—functionally useful voluntary motor function below level of injury is preserved; *Grade E: normal motor function*—normal motor and sensory function below level of lesion, abnormal reflexes may persist.

- *ASIA Impairment Scale* is a 5-grade classification system that assesses spinal cord function.[40] *Grade A: complete*—no sensory or motor function is preserved in the sacral segments S4-5; *Grade B: sensory incomplete*—sensory but not motor function is preserved below the neurological level and includes the sacral segments, no motor function is preserved more than 3 levels below the motor level on either side of the body; *Grade C: motor incomplete*—motor function is preserved below the neurological level and more than half of key muscle functions below the neurological level of injury have a muscle grade less than 3; *Grade D: motor incomplete*—motor function is preserved below the neurological level and at least half of key muscle functions below the neurological level of injury have a muscle grade $\geq$3; *Grade E: normal*—sensation and motor function are graded as normal in all segments.
- *International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI) Motor Score* combines the *Upper Extremity Motor Score (UEMS)* with the *Lower Extremity Motor Score (LEMS)* to yield a total score out of 100 (indicates normal).[40] The function of the following muscles is graded from 0 to 5: elbow flexors (C5), wrist extensors (C6), elbow extensors (C7), finger flexors (C8), finger abductors (T1), hip flexors (L2), knee extensors (L3), ankle dorsiflexors (L4), long toe extensors (L5), and ankle plantar flexors (S1). A score of 0 = total paralysis; 1 = palpable or visible contraction; 2 = active movement, full range of motion with gravity eliminated; 3 = active movement, full range of motion against gravity; 4 = active movement, full range of motion against gravity and moderate resistance in a muscle specific position; 5 = active movement, full range of motion against gravity and full resistance in a functional muscle position expected from an otherwise unimpaired person. Both sides of the body are tested: upper extremity right (maximum = 25), upper extremity left (maximum = 25), lower extremity right (maximum = 25), lower extremity left (maximum = 25).
- *ISNCSCI Sensory Score* combines *Light Touch Scores* with *Pin Prick Scores* to yield a total score out of 224 (indicates normal).[40] The sensation of the dermatomes C2-S4/5 is evaluated on both the right and left sides of the body. A score of 0 = absent, 1 = altered, and 2 = normal. Both light touch and pin prick are evaluated (light touch right, maximum = 56; light touch left, maximum = 56; pin prick right, maximum = 56; pin prick left, maximum = 56).
- *Functional Independence Measure (FIM)* is an 18-item, clinician-administered scale that evaluates a patient's independence in eating, grooming, bathing, dressing upper extremity, dressing lower extremity, post-elimination hygiene, bowel management, bladder management, transfers to bed, chair, or wheelchair, transfers to tub or shower, transfers to toilet, walking or wheelchair propulsion, stair climbing (all included in *FIM Motor Subscore*), comprehension, expression, social interaction, problem solving, and memory (all included in *FIM social-cognitive subscale*).[41] The total FIM score ranges from 18 (total dependence) to 126 (total independence); motor scores range from 13 (total dependence) to 91 (total independence); and cognitive scores range from 5 (total dependence) to 35 (total independence)
- *Spinal Cord Independence Measure (SCIM)* is a 19-item, clinician-administered disability assessment tool that evaluates a patient's ability to perform basic activities of daily living.[42] The SCIM evaluates 3 key domains: self-care (6 items related to feeding, bathing, dressing, and grooming), respiration and sphincter management (4 items related to respiration, bladder management, bowel management, use of toilet), and mobility (9 items related to tasks in the room and toilet, tasks indoors and outdoors). The total score is out of 100, with a lower score indicating greater disability.
- The *Minimum Clinically Important Difference* is the smallest change in a treatment outcome that a patient or clinician would define as meaningful.[43-45]
- A *complication* is a treatment-related adverse event.
- *Methylprednisolone sodium succinate* is a corticosteroid prescribed to relieve inflammation.
- *Deep venous thrombosis* occurs when a blood clot or thrombus forms in a deep vein, usually in the lower limbs.
- *Pulmonary embolism* occurs when a blood clot or thrombus occludes an artery in the lungs.
- *Maximum spinal cord compression* measures the spinal cord diameter at the most compressed segment on a midsagittal MRI against the mean diameter of noncompressed segments from above and below.[46]
- *Maximum canal compromise* measures the spinal canal diameter at the most stenotic segment against the mean diameter of non-stenotic segments from above and below.[46]
- *Cord swelling* is defined as an increase in spinal cord diameter.[47]
- *Body weight–supported treadmill training* is a technique that partially suspends a patient in a harness in order to reduce weight bearing and provide postural support for walking. In some instances, therapists are required to manually move a patient through his or her walk cycle.
- *Functional electrical therapy* is a treatment that uses the application of small electrical charges to improve mobility.

Table 1. Evidence Summary From the Systematic Reviews Used to Develop Our Recommendations.

Title	Key Clinical Questions	Main Results
Timing of decompression in patients with acute spinal cord injury: a systematic review	• What is the efficacy and effectiveness of early decompression (≤24 hours) compared with late decompression (>24 hours) or conservative therapy based on clinically important change in neurological status? • Does timing of decompression influence other functional outcomes or administrative outcomes? • What is the safety profile of early decompression (≤24 hours) compared with late decompression (>24 hours) or conservative therapy? • What is the evidence that early decompression (≤24 hours) has differential efficacy or safety in subpopulations? • What is the cost-effectiveness of the treatment options above?	*Low evidence*: In patients with cervical SCI, patients decompressed early were more likely to exhibit clinically significant improvement in neurologic status (≥2 grade improvement on AIS) than those decompressed late. There was no significant difference in the odds of achieving a ≥1 grade improvement on AIS between groups. *Low evidence:* In patients with thoracolumbar SCI, more patients in the early decompression group experienced a ≥2 grade improvement on AIS than in the late decompression group; however, this relationship did not reach statistical significance. There was no difference in the frequency of patients who achieved a ≥1 grade improvement on AIS between the early and late surgical groups. *Low evidence:* In patients with thoracolumbar SCI, there was no significant difference in length of stay between the early and late decompression groups.
Efficacy and safety of methylprednisolone sodium succinate in acute spinal cord injury: a systematic review	• What is the efficacy and effectiveness of MPSS compared with no pharmacologic treatment? • What is the safety profile of MPSS compared with no pharmacologic treatment? • What is the evidence that MPSS has differential efficacy or safety in subpopulations?	*Moderate evidence*: MPSS administered according to the dose and duration of the NASCIS II protocol confers no benefit compared with no treatment or placebo in motor recovery, pinprick, or light touch when initiated at indiscriminate time periods following acute SCI. *Moderate evidence*: There is a small benefit in motor recovery when MPSS is administered within 8 hours of injury compared with no treatment. *Moderate evidence:* There is no difference between treatment groups in the pooled risk of death, wound infection, GI hemorrhage, sepsis, pulmonary embolism, urinary tract infection, pneumonia, or decubiti.
Efficacy, safety, and timing of anticoagulant thromboprophylaxis for the prevention of venous thromboembolism in patients with acute spinal cord injury: a systematic review	• What is the effectiveness and safety of anticoagulant thromboprophylaxis compared to no prophylaxis, placebo, or another anticoagulant strategy for preventing DVT and PE after acute SCI? • What is the comparative effectiveness and safety of mechanical strategies alone or in combination with other prophylactic strategies for preventing DVT and PE after acute SCI? • What is the comparative effectiveness and safety of prophylactic IVC filter insertion alone or in combination with other prophylactic strategies for preventing DVT and PE after acute SCI? • What is the optimal timing to initiate and/or discontinue anticoagulant, mechanical and/or prophylactic IVC filter following acute SCI? • What is the cost-effectiveness of the above treatment options?	*Moderate evidence*: Patients administered with fixed low-dose heparin have a lower risk of bleeding than those who received an adjusted dose. *Low evidence*: The risk of DVT is higher in patients who received no prophylaxis compared to those who received LMWH. *Low evidence*: There is no difference in the risk of DVT in patients treated with either UFH or placebo/no prophylaxis. *Low evidence:* There is no difference in the risk of DVT, PE, bleeding, or mortality between patients treated with enoxaparin versus dalteparin, or LMWH (tinzaparin or dalteparin) versus UFH. *Low evidence*: The risk of DVT is higher in patients who received fixed low-dose heparin compared to those treated with adjusted-dose heparin. *Low evidence:* There is no difference in the risks of DVT or bleeding between patients receiving IPC alone versus IPC plus aspirin and dipyridamole. *Low evidence:* Patients who received a combination of UFH and electric calf stimulation have a lower risk of DVT than patients treated with UFH alone. There is no difference in the risk of DVT in patients who received LMWH alone compared to those treated with UFH plus IPC. Patients administered with LMWH alone have a lower risk of PE than patients

(continued)

Table 1. (continued)

Title	Key Clinical Questions	Main Results
		who received UFH plus IPC. There is also no difference in the risks of VTE, major and minor bleeding, and mortality between patients who received LMWH and those treated with UFH plus IPC. *Low evidence:* The risk of DVT is significantly lower in patients receiving prophylaxis within 72 hours than those treated after 72 hours of injury.
Role of baseline magnetic resonance imaging in surgical decision-making and prediction of neurologic, functional and safety outcomes in patients with acute spinal cord injury: a systematic review	• How does the acquisition of a baseline MRI influence management strategy(ies) compared with no MRI (or other comparator), and consequently, what changes does it effect in neurologic, functional, patient-reported, and safety outcomes? • Do spinal cord lesion characteristics, pattern, and length identified on baseline MRI predict neurologic, functional, patient-reported, and safety outcomes? • Do spinal cord characteristics identified on diffusion tensor imaging predict neurologic, functional, patient-reported, and safety outcomes? • Is there evidence to suggest that baseline MRI is cost-effective in patients with acute SCI?	*Moderate evidence*: A longer intramedullary hemorrhage is predictive of decreased neurologic recovery. There is no association between lower MSCC, longer SCI lesion length or cord edema, and worse neurological recovery. *Low evidence:* Smaller spinal canal diameter at MSCC is associated with decreased neurologic recovery. MCC is predictive of worse FIM scores.
Type and timing of rehabilitation following acute and subacute spinal cord injury: a systematic review	• Does the time interval between injury and commencing rehabilitation affect outcome? • What is the comparative effectiveness of different rehabilitation strategies, including different intensities and durations of treatment? • Are there patient or injury characteristics that impact the efficacy of rehabilitation? • What is the cost-effectiveness of various rehabilitation strategies?	*Low evidence:* There was no difference between BWSTT and conventional rehabilitation with respect to the FIM-L Score, LEMS Score, the distance walked in 6 minutes, or gait velocity over 15.2 meters. *Low evidence*: Functional electrical therapy may result in slightly better FIM Motor, FIM Self-Care, and SCIM Self-Care subscores compared with conventional occupational therapy. *Low evidence:* There were no clinically important differences in outcomes between training unsupported sitting and standard in-patient rehabilitation.

Abbreviations: SCI, spinal cord injury; AIS, ASIA Impairment Scale; GI, gastrointestinal; MPSS, methylprednisolone sodium succinate; IVC, inferior vena cava; DVT, deep venous thrombosis; PE, pulmonary embolism; LMWH, low-molecular-weight heparin; UFH, unfractionated heparin; VTE, venous thromboembolic events; IPC, intermittent pneumatic compression; MRI, magnetic resonance imaging; MSCC, maximal spinal cord compression; MCC, maximal canal compromise; FIM, functional independence measure; BWSTT, body weight–supported treadmill training; FIM-L, FIM-Locomotor; LEMS, Lower Extremity Motor Score; SCIM, Spinal Cord Independence Measure.

Summary of Contents

Five systematic reviews were conducted to summarize the current body of evidence. Table 1 summarizes the key clinical questions and main results from these reviews. A summary of our recommendations is provided below.

Timing of Surgical Decompression

We suggest that early surgery (≤24 hours after injury) be considered as a treatment option in adult patients with traumatic central cord syndrome. (Grade: Weak Recommendation; Low Evidence)

We suggest that early surgery be offered as an option for adult acute SCI patients regardless of level. (Grade: Weak Recommendation; Low Evidence)

Methylprednisolone Sodium Succinate

We suggest not offering a 24-hour infusion of high-dose MPSS to adult patients who present after 8 hours with acute SCI. (Grade: Weak Recommendation; Moderate Evidence)

We suggest a 24-hour infusion of high-dose MPSS be offered to adult patients within 8 hours of acute SCI as a treatment option. (Grade: Weak Recommendation; Moderate Evidence)

We suggest not offering a 48-hour infusion of high-dose MPSS to adult patients with acute SCI. (Grade: Weak Recommendation; No included studies)

Anticoagulation

We suggest that anticoagulant thromboprophylaxis be offered routinely to reduce the risk of thromboembolic events in the acute period after SCI. (Grade: Weak Recommendation; Low Evidence)

We suggest that anticoagulant thromboprophylaxis, consisting of either subcutaneous low-molecular weight heparin or fixed, low-dose unfractionated heparin, be offered to reduce the risk of thromboembolic events in the acute period after SCI. Given the potential for increased bleeding events with the use of adjusted-dose unfractionated heparin, we suggest against this treatment option. (Grade: Weak Recommendation; Low Evidence)

We suggest commencing anticoagulant thromboprophylaxis within the first 72 hours after injury, if possible, in order to minimize the risk of venous thromboembolic complications during the period of acute hospitalization. (Grade: Weak Recommendation; Low Evidence)

The Role of MRI

We suggest that MRI be performed in adult patients with acute SCI prior to surgical intervention, when feasible, to facilitate improved clinical decision-making. (Grade: Weak Recommendation; Very Low Evidence)

We suggest that MRI should be performed in adult patients in the acute period following SCI, before or after surgical intervention, to improve prediction of neurologic outcome. (Grade: Weak Recommendation; Low Evidence)

Type and Timing of Rehabilitation

We suggest rehabilitation be offered to patients with acute SCI when they are medically stable and can tolerate required rehabilitation intensity. (Grade: Weak Recommendation; No included studies)

We suggest offering body weight–supported treadmill training as an option for ambulation training in addition to conventional overground walking, dependent on resource availability, context, and local expertise. (Grade: Weak Recommendation; Low Evidence)

We suggest that individuals with acute and subacute cervical SCI be offered functional electrical therapy as an option to improve hand and upper extremity function. (Grade: Weak Recommendation; Low Evidence)

Based on the absence of any clear benefit, we suggest not offering additional training in unsupported sitting beyond what is currently incorporated in standard rehabilitation. (Grade: Weak Recommendation; Low Evidence)

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References

1. Witiw CD, Fehlings MG. Acute spinal cord injury. *J Spinal Disord Tech*. 2015;28:202-210. doi:10.1097/BSD.0000000000000287.
2. Wilson J, Fehlings M. Emerging approaches to the surgical management of acute traumatic spinal cord injury. *Neurotherapeutics*. 2011;8:197-194.
3. Schwartz G, Fehlings MG. Secondary injury mechanisms of spinal cord trauma: a novel therapeutic approach for the management of secondary pathophysiology with the sodium channel blocker riluzole. *Prog Brain Res*. 2002;137:177-190.
4. Tator CH, Fehlings MG. Review of the secondary injury theory of acute spinal cord trauma with emphasis on vascular mechanisms. *J Neurosurg*. 1991;75:15-26. doi:10.3171/jns.1991.75.1.0015.
5. Sekhon LH, Fehlings MG. Epidemiology, demographics, and pathophysiology of acute spinal cord injury. *Spine (Phila Pa 1976)*. 2001;26(24 suppl):S2-S12.
6. Singh A, Tetreault L, Kalsi-Ryan S, Nouri A, Fehlings MG. Global prevalence and incidence of traumatic spinal cord

injury. *Clin Epidemiol*. 2014;6:309-331. doi:10.2147/CLEP.S68889.
7. Krueger H, Noonan VK, Trenaman LM, Joshi P, Rivers CS. The economic burden of traumatic spinal cord injury in Canada. *Chronic Dis Inj Can*. 2013;33:113-122.
8. Guha A, Tator C, Endrenyi L. Decompression of the spinal cord improves recovery after acute experimental spinal cord compression injury. *Paraplegia*. 1987;25:324-339.
9. Dimar J, Glassman S, Raque G, Zhang YP, Shields CB. The influence of spinal canal narrowing and timing of decompression on neurologic recovery after spinal cord contusion in a rat model. *Spine (Phila Pa 1976)*. 1999;24:1623-1633.
10. Fehlings MG, Perrin RG. The timing of surgical intervention in the treatment of spinal cord injury: a systematic review of recent clinical evidence. *Spine (Phila Pa 1976)*. 2006;31(11 suppl):S28-S35.
11. Batchelor PE, Wills TE, Skeers P, et al. Meta-analysis of preclinical studies of early decompression in acute spinal cord injury: a battle of time and pressure. *PLoS One*. 2013;8:e72659. doi:10.1371/journal.pone.0072659.
12. Fehlings MG, Vaccaro A, Wilson JR, et al. Early versus delayed decompression for traumatic cervical spinal cord injury: results of the Surgical Timing in Acute Spinal Cord Injury Study (STASCIS). *PLoS One*. 2012;7:e32037. doi:10.31371/journal.pone.0032037.
13. Schneider RC, Cherry G, Pantek H. The syndrome of acute central cervical spinal cord injury; with special reference to the mechanisms involved in hyperextension injuries of cervical spine. *J Neurosurg*. 1954;11:546-577. doi:10.3171/jns.1954.11.6.0546.
14. Anderson KK, Tetreault L, Shamji MF, et al. Optimal timing of surgical decompression for acute traumatic central cord syndrome: a systematic review of the literature. *Neurosurgery*. 2015;77(suppl 4):S15-S32 doi:10.1227/NEU.0000000000000946.
15. Hall ED, Braughler JM. Glucocorticoid mechanisms in acute spinal cord injury: a review and therapeutic rationale. *Surg Neurol*. 1982;18:320-327.
16. Hall ED, Braughler JM. Effects of intravenous methylprednisolone on spinal cord lipid peroxidation and $Na^{++}K^{+}$)-ATPase activity. Dose-response analysis during 1st hour after contusion injury in the cat. *J Neurosurg*. 1982;57:247-253. doi:10.3171/jns.1982.57.2.0247.
17. Braughler JM, Hall ED. Effects of multi-dose methylprednisolone sodium succinate administration on injured cat spinal cord neurofilament degradation and energy metabolism. *J Neurosurg*. 1984;61:290-295. doi:10.3171/jns.1984.61.2.0290.
18. Bracken MB, Shepard MJ, Collins WF Jr, et al. Methylprednisolone or naloxone treatment after acute spinal cord injury: 1-year follow-up data. Results of the second National Acute Spinal Cord Injury Study. *J Neurosurg*. 1992;76:23-31. doi:10.3171/jns.1992.76.1.0023.
19. Bracken MB, Shepard MJ, Collins WF, et al. A randomized, controlled trial of methylprednisolone or naloxone in the treatment of acute spinal-cord injury. Results of the Second National Acute Spinal Cord Injury Study. *N Engl J Med*. 1990;322:1405-1411. doi:10.1056/NEJM199005173222001.
20. Pointillart V, Petitjean ME, Wiart L, et al. Pharmacological therapy of spinal cord injury during the acute phase. *Spinal Cord*. 2000;38:71-76.
21. Matsumoto T, Tamaki T, Kawakami M, Yoshida M, Ando M, Yamada H. Early complications of high-dose methylprednisolone sodium succinate treatment in the follow-up of acute cervical spinal cord injury. *Spine (Phila Pa 1976)*. 2001;26:426-430.
22. Pharmacological therapy after acute cervical spinal cord injury. *Neurosurgery*. 2002;50(3 suppl):S63-S72.
23. Hurlbert RJ, Hadley MN, Walters BC, et al. Pharmacological therapy for acute spinal cord injury. *Neurosurgery*. 2013;72(suppl 2):93-105. doi:10.1227/NEU.0b013e31827765c6.
24. Teasell RW, Hsieh JT, Aubut JA, et al. Venous thromboembolism after spinal cord injury. *Arch Phys Med Rehabil*. 2009;90:232-245. doi:10.1016/j.apmr.2008.09.557.
25. Consortium for Spinal Cord Medicine. Prevention of venous thromboembolism in individuals with spinal cord injury: clinical practice guideline for health care providers, 3rd ed. *Top Spinal Cord Inj Rehabil*. 2016;22:209-240.
26. Dhall SS, Hadley MN, Aarabi B, et al. Deep venous thrombosis and thromboembolism in patients with cervical spinal cord injuries. *Neurosurgery*. 2013;72(suppl 2):244-254. doi:10.1227/NEU.0b013e31827728c0.
27. Deep venous thrombosis and thromboembolism in patients with cervical spinal cord injuries. *Neurosurgery*. 2002;50(3 suppl):S73-S80.
28. Ryken TC, Hadley MN, Walters BC, et al. Radiographic assessment. *Neurosurgery*. 2013;72(suppl 2):54-72. doi:10.1227/NEU.0b013e318276edee.
29. Bozzo A, Marcoux J, Radhakrishna M, et al. The role of magnetic resonance imaging in the management of acute spinal cord injury. *J Neurotrauma*. 2011;28:1401-1411. doi:10.1089/neu.2009.1236.
30. Hadley MN, Walters BC, Grabb PA, et al. Guidelines for the Management of Acute Cervical Spine and Spinal Cord Injuries (Section on Disorders of the Spine and Peripheral Nerves of the American Association of Neurological Surgeons and the Congress of Neurological Surgeons). http://www.aans.org/Education%20and%20Meetings/～/media/Files/Education%20and%20Meetingf/Clinical%20Guidelines/TraumaGuidelines.ashx. Accessed April 7, 2017.
31. Burns AS, Marino RJ, Flanders AE, Flett H. Clinical diagnosis and prognosis following spinal cord injury. *Handb Clin Neurol*. 2012;109:47-62. doi:10.1016/B978-0-444-52137-8.00003-6.
32. Fawcett JW, Curt A, Steeves JD, et al. Guidelines for the conduct of clinical trials for spinal cord injury as developed by the ICCP panel: spontaneous recovery after spinal cord injury and statistical power needed for therapeutic clinical trials. *Spinal Cord*. 2007;45:190-205. doi:10.1038/sj.sc.3102007.
33. Dobkin BH. Confounders in rehabilitation trials of task-oriented training: lessons from the designs of the EXCITE and SCILT multicenter trials. *Neurorehabil Neural Repair*. 2007;21:3-13. doi:10.1177/1545968306297329.
34. Consortium for Spinal Cord Medicine, Paralyzed Veterans Association. *Pressure Ulcer Prevention and Treatment Following Spinal Cord Injury*. http://www.pva.org/media/pdf/CPG_Pressure%20Ulcer.pdf. Published 2014. Accessed April 7, 2017.

35. Consortium for Spinal Cord Medicine, Paralyzed Veterans Association. *Preservation of Upper Limb Function Following Spinal Cord Injury*. http://www.rstce.pitt.edu/RSTCE_Resources/RSTCE_Res_Doc/CPG_Limb_Injury.pdf. Published 2005. Accessed April 7, 2017.
36. Consortium for Spinal Cord Medicine, Paralyzed Veterans Association. *Bladder Management for Adults with Spinal Cord Injury*. http://www.pva.org/media/pdf/CPG_Pressure%20Ulcer.pdf. Published 2006. Accessed April 7, 2017.
37. Consortium for Spinal Cord Medicine, Paralyzed Veterans Association. *Sexuality and Reproductive Health in Adults with Spinal Cord Injury*. http://www.pva.org/media/pdf/CPG_Pressure%20Ulcer.pdf. Published 2010. Accessed April 7, 2017.
38. Consortium for Spinal Cord Medicine, Paralyzed Veterans Association. *Respiratory Management Following Spinal Cord Injury*. http://www.learnicu.org/Docs/Guidelines/CSPMRespiratoryManagement.pdf. Published 2005. Accessed April 7, 2017.
39. Harrop JS, Sharan A, Ratliff J. Central cord injury: pathophysiology, management, and outcomes. *Spine J*. 2006;6(6 suppl): 198S-206S. doi:10.1016/j.spinee.2006.04.006.
40. American Spinal Injury Association. *International Standards for Neurological Classification of Spinal Cord Injury*. Richmond, VA: American Spinal Injury Association; 2015.
41. Granger C, Hamilton B, Keith RA, Zielezny M, Sherwin FS. Advances in functional assessment for medical rehabilitation. *Top Geriatr Rehabil*. 1986;1:59-74.
42. Catz A, Itzkovich M, Agranov E, Ring H, Tamir A. SCIM: spinal cord independence measure: a new disability scale for patients with spinal cord lesions. *Spinal Cord*. 1997;35:850-856.
43. Parker SL, Mendenhall SK, Shau D, et al. Determination of minimum clinically important difference in pain, disability, and quality of life after extension of fusion for adjacent-segment disease. *J Neurosurg Spine*. 2012;16:61-67. doi:10.3171/2011.8.SPINE1194.
44. Parker SL, Mendenhall SK, Shau DN, et al. Minimum clinically important difference in pain, disability, and quality of life after neural decompression and fusion for same-level recurrent lumbar stenosis: understanding clinical versus statistical significance. *J Neurosurg Spine*. 2012;16:471-478. doi:10.3171/2012.1.SPINE11842.
45. Copay AG, Glassman SD, Subach BR, Berven S, Schuler TC, Carreon LY. Minimum clinically important difference in lumbar spine surgery patients: a choice of methods using the Oswestry Disability Index, Medical Outcomes Study questionnaire Short Form 36, and pain scales. *Spine J*. 2008;8:968-974. doi:10.1016/j.spinee.2007.11.006.
46. Fehlings MG, Rao SC, Tator CH, et al. The optimal radiologic method for assessing spinal canal compromise and cord compression in patients with cervical spinal cord injury. Part II: Results of a multicenter study. *Spine (Phila Pa 1976)*. 1999;24:605-613.
47. Selden NR, Quint DJ, Patel N, et al. Emergency magnetic resonance imaging of cervical spinal cord injuries: clinical correlation and prognosis. *Neurosurgery*. 1999;44:785-792.