Management of Acute Spinal Cord Injury in the Neurocritical Care Unit

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KEYWORDS

• Spinal cord injury • Neurogenic shock • Mechanical ventilation • Thromboembolism

KEY POINTS

- Traumatic spinal cord injury (SCI) is frequently accompanied by multiple injuries and widespread derangements requiring aggressive monitoring and management in the intensive care unit.
- Neuroprotective therapies are designed to minimize further neurologic deterioration. Several pharmacologic agents and hypothermia are currently under investigation.
- Cardiovascular complications including hypotension and arrhythmias are not uncommon, and represent an important source of morbidity following acute SCI.
- SCI may lead to absent or inefficient respiratory mechanics, atelectasis, pneumonia, and pulmonary dysfunction requiring intubation and mechanical ventilation.
- Prophylaxis and surveillance of deep venous thrombosis is paramount in individuals with SCI, and should be instituted within 72 hours of injury.

INTRODUCTION

Acute spinal cord injury (SCI) is often devastating, and imposes significant emotional and economic costs to the individual and society. The morbidity and sequelae are severe and frequently fatal. Mortality at the time of injury is 48% to 79%, with another 4.4% to 16% of deaths occurring before hospital discharge. Traumatic SCI occurs with an annual incidence of approximately 15 to 40 cases per million in the United States. Estimates of prevalence are 236,000 to 327,000.[1–3] SCI disproportionately affects young adults. The mean age at injury is 41 years, although two-thirds of individuals are younger than 30. Motor vehicle accidents account for 40% to 50% of SCI followed by falls (20%), violence (14%), and recreational and work-related activities.[4,5] The epidemiology and mechanism of SCI have important implications on preventive measures, the type of injury sustained, and subsequent management in the critical care unit.

Evaluation and management of acute SCI is complicated by broad pathophysiologic derangements that require timely identification and intervention. Respiratory insufficiency or other pulmonary dysfunction, systemic hypotension, cardiac arrhythmias, and delayed neurologic decline are well-described phenomena following SCI. Additional systemic injuries are commonplace, with 20% to 57% of those with SCI having other significant injuries typically involving the head or chest. Isolated SCIs are reported to occur in only 20% of individuals.[6] The management of these

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patients in the intensive care unit is frequently directed by treatment of concurrent injuries. The majority of traumatic SCIs (55%) involve the cervical spine.[7] The last 3 decades have witnessed an increase in the proportion of cervical spine injuries. Specifically this has been injury to C1 to C4, nearly tripling the number of individuals requiring intubation and ventilator dependence from 1.4% in 1970 to 4.6% in 2004.[3] During this same period there has been a concomitant decrease in the number of complete SCIs from more than 60% to 45%.[8] This decline is multifactorial and reflects improvements in prehospital resuscitation and retrieval, immobilization, and motor vehicle restraint and safety devices. Advances in monitoring and medical management also hold an important role in limiting secondary injury from hypoxia or hypotension. Several studies have demonstrated improved morbidity and mortality with monitoring and aggressive management of SCI in the critical care setting.[9] The median length of hospital admission following SCI is 67 days, with 11 of those days spent in the acute care setting at a cost of $95,203.[10] This review discusses the potential complications and medical management of acute SCI in the neurocritical care unit.

MANAGEMENT OF NEUROLOGIC INJURY

Treatment of acute SCI in the intensive care unit focuses on prevention of secondary injury and neuroprotection. Following an initial insult or trauma producing spinal cord compression, contusion, laceration, or shear, a cascade of pathologic events develops. These abnormalities include loss of normal blood flow in the spine, ischemia, vasospasm, thrombosis, hemorrhage, impaired autoregulation of the microcirculation, and systemic hypotension from neurogenic shock; electrolyte disturbances; neurotransmitter accumulation and excitotoxicity; lipid peroxidation; arachidonic acid production and inflammation; free radical production; edema; apoptosis; and necrosis.[2,11,12] Delayed neurologic deterioration is well described, with a reported incidence of 1.8% to 10%, and may be seen from hours to days following the onset of injury.[13] Intensive monitoring and rapid correction of hypotension or hypoxia is essential (see later discussion). Pharmacologic strategies to blunt secondary injury have also been used, perhaps the most well described being methylprednisolone.

Glucocorticoids offer neuroprotection by increasing cell membrane integrity, augmenting spinal cord perfusion, inhibiting endogenous endorphin release, and decreasing inflammation and free radical production, as well as by limiting vasogenic edema through stabilization of the blood–spinal cord barrier. The largest clinical trials investigating the efficacy of methylprednisolone are the 3 multicenter randomized NASCIS (National Acute Spinal Cord Injury Study) trials. The first of these studies (NASCIS I) compared motor and sensory scores in individuals with SCI following administration of either a 100-mg or 1000-mg bolus of methylprednisolone followed by a daily dose for 10 days. There was no placebo, and comparison of the outcomes at 6 weeks and 6 months showed no difference.[14] With the NASCIS II study, the dose of methylprednisolone was increased and individuals with SCI were randomized to 3 different treatments: (1) methylprednisolone (30 mg/kg bolus followed by 5.4 mg/kg/h for 23 hours); (2) the opioid antagonist naloxone (5.4 mg/kg bolus followed by 4.0 mg/kg/h for 23 hours); and (3) placebo. Through post hoc analysis the investigators reported improved motor and sensory scores at 6 months if methylprednisolone was administered within 8 hours of injury. This benefit was observed for both complete and incomplete injuries, but was not present in patients receiving steroids more than 8 hours following injury, naloxone, or placebo.[15,16] A third trial (NASCIS III) randomized patients to receive methylprednisolone for 24 or 48 hours or the antioxidant tirilizad mesylate for 48 hours after a bolus of methylprednisolone. Tirilizad mesylate impairs lipid peroxidation but does not contain the steroid moiety to interact with and activate glucocorticoid receptors, and is thus thought to avoid the adverse effects of methylprednisolone. Neurologic outcomes were similar for all treatment groups if initiated within 3 hours of injury. When comparing individuals treated between 3 and 8 hours following injury, motor scores and functional measures were improved at 6 weeks and 6 months in participants treated with methylprednisolone for 48 hours. The neurologic outcomes were equivocal for subjects who received 24 hours of methylprednisolone and 48 hours of tirilizad mesylate. No difference in functional outcome scores was seen in the 3 groups at 1 year.[17,18]

Several limitations to the NASCIS trials exist. The studies excluded pediatric SCI, penetrating injury, or cauda equina injuries, and do not specifically address these entities. Administration of methylprednisolone was associated with increased incidence of pulmonary embolism and pneumonia, wound infection, sepsis, and gastrointestinal complications in NASCIS II and III. Other reports have also noted increased length of admission and altered immune function.[12,19] Several methodological flaws have also been identified, including a post hoc versus prospectively defined time course (ie,

8 hours), inclusion of patients with minimal deficits and lesions below T12, use of right-sided motor scores only, lack of functional measures, and no standardization with respect to surgical or medical treatment.[12,20] For these reasons, the use of methylprednisolone in SCI is controversial. The Cochrane database offers the NASCIS experience as a recommendation for the use of methylprednisolone within 8 hours of injury.[21] Guidelines published by the American Association of Neurological Surgeons (AANS) and the Congress of Neurological Surgeons (CNS) recently modified the recommendations against the use of methylprednisolone in the management of spinal cord injury.[22]

Other pharmacologic agents have also been studied in the setting of acute SCI.[20] In laboratory studies, GM-1 ganglioside has been associated with increased neural plasticity following injury, diminished excitotoxicity, and reduced apoptosis. A prospective study randomizing 37 individuals with SCI to placebo or GM-1 ganglioside demonstrated improved Frankel and ASIA (American Spinal Injury Association) scores at 1-year follow-up in participants who received 100 mg of GM-1 for 30 days.[23] This study served as the impetus for a large multicenter randomized trial examining the effects of low-dose GM-1, high-dose GM-1, and placebo. All subjects received methylprednisolone as described in the NASCIS II study. In this large study of 797 patients, there was no significant difference in neurologic outcome between the treatment groups, limiting the use of GM-1.[24] Opioid antagonists such as naloxone, glutamate antagonists, nimodipine, other anti-inflammatories, and erythropoietin have all garnered interest following optimistic findings in laboratory models.

In addition to pharmacologic methods of neuroprotection, there is increasing interest in therapeutic hypothermia. In laboratory models, moderate hypothermia has led to alterations in apoptosis as well as reduced mitochondrial dysfunction, metabolic demand, cell membrane injury, and inflammation. In rodents, prompt cooling following induced SCI offered improved motor outcomes, and the use of hypothermia is reported to decrease SCI following aortic cross-clamping.[25] Fourteen patients with complete SCI underwent moderate hypothermia (33°C) for 48 hours in a study by Levi and colleagues[26] in 2009. At median follow-up of 12 months, 6 individuals (43%) had neurologic improvement.[27] The most frequent complications were pulmonary (pneumonia or atelectasis), but occurred at a rate similar to that of controls. Another study had similar results following endovascular cooling in 35 individuals with complete cervical SCI. The duration of hypothermic therapy was 48 hours, and 15 (43%) had improvement based on the International Standards for Neurological Classification of Spinal Cord Injury scale.[28] Following completion of phase I trials, large multicenter studies are currently being conducted (see clinicaltrials.gov).

CARDIOVASCULAR COMPLICATIONS

Severe SCI is frequently associated with hemodynamic instability. Disruption of sympathetic fibers through injury to the cervical or high-thoracic (>T6) spinal cord produces hypotension and cardiac arrhythmias. Fifty percent to 90% of individuals with acute cervical SCI require aggressive fluid resuscitation or initiation of vasopressors to maintain a mean arterial pressure greater than 80 mm Hg.[29] Typically the degree of cardiac instability is related to the severity of the SCI. At autopsy, individuals with cervical SCI developing significant hypotension, arrhythmia, or autonomic dysreflexia had increased degeneration compared with those without cardiac instability.[30] In addition, these individuals had fewer preserved axons within the lateral funiculus. Descending sympathetic fibers originating in the hypothalamus or brainstem are located within the intermediolateral and dorsolateral aspects of the lateral funiculus.[31] Injury leads to loss of sympathetic outflow and unopposed parasympathetic tone with decreased cardiac contractility, heart rate, and vasoconstrictor tone.

The hypotension and neurogenic shock following acute SCI is a distributive process resulting from loss of vasoconstrictor tone in peripheral arterioles and pooling of blood within the peripheral vasculature. Initial attempts at correction should include volume resuscitation with intravenous fluids. Administration of fluids transiently increases venous return. However, with disruption of sympathetic innervation to the heart and predominance of parasympathetic tone, cardiac output remains low because of impaired cardiac contractility and decreased heart rate. If after 1 to 2 L of intravenous fluids the blood pressure has not improved, vasopressor therapy may be indicated. Vasoactive agents with α-adrenergic and β-adrenergic effects, such as dopamine and norepinephrine, increase vasoconstrictor tone and chronotropic support to the heart. Vasopressors with exclusive α-adrenergic function have no chronotropic effect and are of limited use in neurogenic shock. Furthermore, phenylephrine frequently produces a reflex bradycardia. Throughout these interventions frequent monitoring of blood pressure, heart rate, urine output, and resolution of acidosis are vital. Echocardiography offers the ability to efficiently assess cardiac output and filling. In select situations, invasive monitoring with a pulmonary

artery catheter assists in treatment by measuring cardiac output and peripheral vascular resistance, although this has largely been replaced by the echocardiogram.[32]

In a study by Levi and colleagues,[33] 82% of individuals with incomplete cervical SCI required vasopressor therapy for an average of 5.7 days following injury to maintain a mean arterial pressure (MAP) of greater than 90 mm Hg. Another study correlated level and severity of spinal injury with the need for vasopressors: complete cervical SCI 90%, incomplete cervical SCI 52%, complete thoracic SCI 33%, and incomplete thoracic 25%.[34] Management of hypotension following SCI is commonplace in the neurocritical care unit. Throughout the resuscitation efforts it is important to continually reassess and ensure that other events such as hemorrhage, tension pneumothorax, or cardiac tamponade are not etiologic.

Although avoidance of systemic hypotension and adequate tissue perfusion are well accepted, blood pressure targets are not as clearly defined. In addition, it is difficult to accurately assess spinal cord perfusion. There are several uncontrolled studies describing improved neurologic outcomes with a MAP greater than 85 to 90 mm Hg. Vale and colleagues[34] used a MAP of 85 mm Hg to direct aggressive fluid resuscitation and vasopressors for 7 days following injury. The small series reported improved outcomes, but the MAP in this study was selected arbitrarily. The AANS/CNS guidelines recommend maintenance of a MAP of between 85 and 90 mm Hg for the first 7 days as an option for treatment.[22]

Loss of sympathetic innervation with unopposed vagal tone produces frequent and often severe cardiac arrhythmias such as bradycardia and, less often, supraventricular tachycardia or ventricular tachycardia. Estimates of cardiac arrest following cervical SCI are as high as 15%. The arrhythmias typically develop within 3 to 5 days following injury and become less pronounced at day 14. The severity of cardiac instability is influenced by the degree of spinal injury as well as other factors such as hypoxia, endotracheal suctioning, and physical stimulation. Treatment includes continuous monitoring and, when symptomatic bradycardia develops, oxygen, atropine, inotropes, and aminophylline. These pharmacologic measures are usually effective, but if bradycardia persists patients may require a cardiac pacemaker. The number of individuals with cervical SCI requiring cardiac pacing ranges from 9% to 17%.[35]

Orthostatic hypotension and autonomic dysreflexia are known to occur following SCI. Typically these are seen in the subacute or chronic phase of injury,[36] but may complicate admission to the neurocritical care unit. Orthostatic hypotension is defined as a decrease in systolic blood pressure of greater than 20 mm Hg or diastolic blood pressure greater than 10 mm Hg when transitioning from a supine to upright position. The prevalence of orthostatic hypotension is approximately 80% and 50% for quadriplegics and paraplegics, respectively.[37] Nearly 50% of individuals with cervical SCI will experience symptoms of orthostatic hypotension, and require treatment. This orthostasis results from venous pooling of blood resulting from the loss of vasoconstrictor tone and arterial baroreceptors caudal to the injury level, an ineffective increase in heart rate from unopposed vagal tone, and loss of muscular tone in the lower extremities, impairing venous return to the heart. Treatment measures include volume expansion through fluids, increased salt intake, or fludrocortisone; pressure devices such as abdominal binders; devices supplying electrical stimulation to and contraction of the lower extremity musculature; midodrine, a potent α-agonist; or ephedrine. The most well-described pharmacologic agents are fludrocortisone and midodrine.[38]

Individuals with severe SCI rostral to T6 are subject to autonomic dysreflexia. During these periods noxious or seemingly benign stimulation below the level of injury, such as bowel or bladder distention, leads to rapid and dramatic elevation in blood pressure and heart rate. By definition this is characterized by an elevation in blood pressure greater than 20%, tachycardia, or bradycardia, and is associated with other symptoms of overactive autonomic stimulation such as piloerection, diaphoresis, or flushing. Dysreflexia is seen in up to 90% of individuals with complete tetraplegia but in less than 30% of those with incomplete tetraplegia. Autonomic dysreflexia is typically a chronic complication following SCI. In a study of 58 patients with cervical SCI, however, approximately 3% of subjects exhibited dysreflexic episodes acutely. Prompt recognition and treatment is important in avoiding complications of hypertensive crisis such as intracranial or retinal hemorrhages, seizure, or death.[38,39]

Treatment of autonomic dysreflexia begins with identification of the offending stimulus. A distended bladder or bowel should be relieved and all other noxious stimuli removed. Pharmacologic interventions designed to shorten the disturbance include nitrates, prostaglandin E_2, hydralazine, labetalol, or captopril. Prevention of dysreflexic episodes involves avoidance of noxious stimuli. In addition, the use of prazosin or terazosin is described in the literature.[40–42] Nifedipine had once been used for this purpose but has since been abandoned following reports of deaths associated with this medication.

RESPIRATORY INSUFFICIENCY AND PULMONARY DYSFUNCTION

SCI has profound effects on the mechanics of ventilation and respiratory physiology. Inspiration occurs through contraction of the diaphragm and internal intercostal muscles, leading to expansion of the chest cavity. At strenuous levels of respiration, the accessory muscles defined by the pectoralis major, scalene, and sternocleidomastoid are recruited. Expiration is largely a passive process, but is augmented by contraction of the abdominal wall. The diaphragm is innervated by the C3-C5 segments forming the phrenic nerve. Innervation of the accessory muscles is variable, involving several spinal segments: thoracic nerves (intercostal), C1-C2 (sternocleidomastoid), and C4-C8 (scalene). SCI above the C3 level leads to loss of diaphragmatic function and immediate respiratory insufficiency. Typically the injury is fatal unless mechanical ventilation is initiated. Although function of the diaphragm is spared with injury below the C3 level, ventilation remains significantly compromised. Acutely following injury there is flaccid paralysis of the accessory muscles innervated by the lower cervical and thoracic segments. The accessory muscles normally stabilize the chest wall, and in their absence contraction of the diaphragm causes the chest wall to contract rather than expand, with paradoxic motion and decreased volumes.[32] The loss of ventilatory function is profound, with a decrease in maximal inspiratory force of 70%.[43,44]

The mechanics of the diaphragm are similarly affected by paralysis of the abdominal musculature. Integrated action of the intact intercostal and abdominal musculature functions as a fulcrum against which the diaphragm contracts. Loss of this mechanical advantage leads to increased diaphragmatic work. In addition, with flaccid paralysis of the abdominal muscles, the abdominal contents and viscera are displaced inferiorly away from the diaphragm. The diaphragm subsequently flattens, diminishing the radius of curvature and placing the diaphragm at a mechanical disadvantage. This effect is further exaggerated when a quadriplegic patient is positioned in the upright position; paradoxically, ventilation is improved when supine. Similarly, the loss of abdominal-wall contraction during expiration decreases the maximal expiratory force, leading to a decreased ability to cough and clear secretions. With resolution of spinal shock, the intercostal muscles develop a spastic paralysis and the chest wall regains its rigidity, no longer collapsing with inspiration. This process leads to improved ventilation. At 5 months following injury, the forced vital capacity and maximal inspiratory force approach 60% of preinjury levels.[32,43,44]

Other factors contributing to respiratory insufficiency and pulmonary dysfunction following SCI include loss of compliance and bronchial hyperresponsiveness. Spastic paresis of the intercostal muscles stiffens the thoracic cage, decreasing compliance. In addition, persistent low lung volumes and altered surfactant have been reported to contribute to reduced lung compliance in cervical SCI.[45,46] Increased bronchial responsiveness and reversible airflow limitation have also been reported in individuals with quadriplegia. This finding reflects unopposed vagal or cholinergic tone to the bronchioles mediating bronchoconstriction, and is reversed with anticholinergic agents. The loss of postganglionic sympathetic innervation and impaired smooth muscle relaxation from low lung volumes has a minor effect.[47]

Intubation and Mechanical Ventilation

The inefficient and compromised ventilation that occurs following SCI is initially tolerated and is compensated by an increase in respiratory rate. Arterial blood gas is often within normal limits, or notable only for mild hypoxia. The rapid and shallow breathing is difficult to maintain, owing to increased work. The proportion of each breath participating in gas exchange decreases because of the fixed dead space of the trachea and bronchi. Low lung volumes promote atelectasis, further contributing to respiratory insufficiency and fatigue. Approximately one-third of patients with injuries to the cervical spine require intubation within the first 24 hours of injury.[48] Ninety percent of those developing respiratory failure do so within the first 3 days. Frequent monitoring for signs of impending respiratory insufficiency are crucial in the acute period following SCI. The decision of when to intubate is often difficult, but should be considered with increasing respiratory rate, rising partial pressure of CO_2, and progressive decline in vital capacity.

Ideally intubation is performed under a controlled setting rather than in an emergent situation. Two large series have demonstrated the safety of endotracheal intubation in cervical SCI with manual in-line traction.[32,49,50] Paralytics facilitate control of the airway during intubation. Although succinylcholine is ideal in most instances because of its rapid onset and short half-life, it should be avoided in SCI after more than 4 days because of the risk of potentially life-threatening hyperkalemia.[32]

Over the following weeks there is progressive improvement in pulmonary function. With resolution of spinal cord inflammation and spinal shock,

there is a functional descent in the level of neurologic injury and transition from flaccid to spastic paralysis of the intercostal muscles, restoring support to the chest wall in individuals with injury below C4. Respiratory failure is more common in complete than in incomplete injuries, and the duration of mechanical ventilation varies based on the level of injury. The average number of days on mechanical ventilation is 65 for C1-C4 injuries, 22 for C4-C8 injuries, and 12 for thoracic injuries. Typically ventilator support is not weaned until about 12 days following injury. The appropriate timing is variable, but indicators that weaning may be tolerated include an increase in the forced vital capacity, inspired oxygen content of less than 50%, and minute ventilation less than 10 L. Pressure support modes of ventilation allow for a progressive decrease in the amount of mechanical support. T-piece trials and continuous positive airway pressure are other effective methods of weaning.[32]

Tracheostomy

The timing of tracheostomy is variable, but typically will be considered after 14 days of mechanical ventilation. There are several advantages to tracheostomy, and it often facilitates transfer to lower levels of care. A tracheostomy is less irritating to the posterior pharyngeal mucosa than an endotracheal tube, and is generally better tolerated and more comfortable to the patient. For individuals with a marginal respiratory status, tracheostomy has less dead space ventilation and offers the ability to alternate between mechanical and spontaneous ventilation for periods of time. There is limited evidence from the trauma literature that tracheostomy is associated with lower rates of pneumonia.[51,52] When an anterior stabilization has been performed, the tracheostomy site is often near the incision, necessitating that the tracheostomy be delayed to allow for adequate tissue healing.

Pneumonia

Following SCI several respiratory disturbances contribute to the development of pneumonia, the most significant of which is mechanical ventilation. The incidence of ventilator-associated pneumonia increases by 1% to 3% per day of mechanical ventilation, and represents an important cause of morbidity and mortality (27%) in SCI.[53] If diagnosed within 4 days of intubation, the most common pathogens are *Streptococcus pneumonia* or *Haemophilus influenzae*, whereas gram-negative bacilli and *Staphylococcus aureus* dominate at later time points, affecting antibiotic selection. Prompt diagnosis and initiation of treatment is important. Guidelines assembled by the American College of Chest Physicians to aid in the diagnosis of nosocomial pneumonia include: (1) temperature higher than 38°C or lower than 36°C; (2) leukocytosis or leukopenia; (3) purulent secretions; (4) hypoxemia. Alternatively, if chest radiographs or imaging exhibit an infiltrate or air bronchograms, the selection of antibiotics is based on culture data from tracheal aspirates, either quantitative or qualitative.[54] After initiating broad-spectrum antimicrobials, the antibiotic therapy should be tailored to the offending pathogens once identified. If infection from *Pseudomonas* is suspected, aggressive treatment with 2 agents, a β-lactam and aminoglycoside, should be administered. The mortality from *Pseudomonas* pneumonia is reported to be as high as 47%.[32]

THROMBOEMBOLIC COMPLICATIONS

The incidence of venous thromboembolism following SCI is as high as 81%, with the most significant risk occurring between 72 hours and 2 weeks following injury.[38,55,56] A meta-analysis reviewing the factors associated with venous thromboembolism in trauma patients demonstrated that the risk was increased 2-fold in patients with spine fractures and 3-fold in those with injury to the cord.[57] Initiation of thromboprophylaxis following injury is essential, as is efficient diagnosis if venous thromboembolism is suspected. The options for prophylaxis are mechanical devices such as external pneumatic compression devices or stockings, and the anticoagulants unfractionated heparin, low molecular weight heparin, and warfarin. Mechanical compression devices are low risk and widely used, but alone are not sufficient. Anticoagulation is effective, with a well-documented decrease in the incidence of thromboembolism associated with its use. A potential disadvantage, however, is the increased risk of hemorrhage, particularly in the setting of intracranial or spinal hematoma. The incidence of venous thromboembolism is relatively low within the first 72 hours of SCI, and the current consensus is to start prophylactic anticoagulation within 72 hours of injury for a duration of 8 weeks. Standard mini-dose heparin administered twice daily is not sufficient in patients with SCI, and the first-line recommendation is to use low molecular weight heparin.[58,59] An inferior vena cava filter should be considered if thromboprophylaxis has failed, if anticoagulation is contraindicated because of active hemorrhage, or if a patient with a high cervical injury has a tenuous cardiopulmonary reserve.[59]

Multiple methods exist for the diagnosis of venous thrombosis or pulmonary embolism. The use of compression B-mode ultrasonography is efficient and safe, largely replacing the use of contrast venography. Similarly, the pulmonary angiogram remains the standard for the diagnosis of a pulmonary embolism, but its use has been restricted owing to concerns for complications and cost. Less invasive techniques to evaluate for a pulmonary embolism are ventilation-perfusion (V/Q) scans and spiral computed tomography (CT). Spiral CT now dominates as the diagnostic test of choice for clots in the segmental and subsegmental pulmonary artery branches.[32] The reported sensitivity and specificity are 94% and 96%, respectively; in patients with suspected pulmonary embolism randomized to a spiral CT or V/Q scan, the diagnosis was made more frequently in those undergoing CT.[60] Finally, the hemodynamic strain often associated with a large pulmonary embolism may be appreciated on a transthoracic echocardiogram.

If not contraindicated, treatment with parenteral anticoagulation such as warfarin should be initiated immediately following diagnosis of a deep venous thrombosis (DVT) or pulmonary embolism. In the setting of a DVT, therapeutic anticoagulation for 6 weeks to 6 months helps reduce the risk of recurrent DVT, post-thrombotic syndrome, and pulmonary embolism. When a patient is found to have a pulmonary embolism, it is recommended that therapeutic unfractionated heparin or low molecular weight heparin be administered for 5 days and an International Normalized Ratio of 2 to 3 is achieved for 2 consecutive days on warfarin. The duration of anticoagulation is typically 6 months.[38]

REFERENCES

1. van den Berg ME, Castellote JM, de Pedro-Cuesta J, et al. Survival after spinal cord injury: a systematic review. J Neurotrauma 2010;27(8): 1517–28.
2. Sekhon LH, Fehlings MG. Epidemiology, demographics, and pathophysiology of acute spinal cord injury. Spine 2001;26(Suppl 24):S2–12.
3. Devivo MJ. Epidemiology of traumatic spinal cord injury: trends and future implications. Spinal Cord 2012;50(5):365–72.
4. Vitale MG, Goss JM, Matsumoto H, et al. Epidemiology of pediatric spinal cord injury in the United States: years 1997 and 2000. J Pediatr Orthop 2006;26(6):745–9.
5. Jackson AB, Dijkers M, Devivo MJ, et al. A demographic profile of new traumatic spinal cord injuries: change and stability over 30 years. Arch Phys Med Rehabil 2004;85(11):1740–8.
6. Burney RE, Maio RF, Maynard F, et al. Incidence, characteristics, and outcome of spinal cord injury at trauma centers in North America. Arch Surg 1993;128(5):596–9.
7. Hasler RM, Exadaktylos AK, Bouamra O, et al. Epidemiology and predictors of cervical spine injury in adult major trauma patients: a multicenter cohort study. J Trauma Acute Care Surg 2012; 72(4):975–81.
8. Tator CH, Duncan EG, Edmonds VE, et al. Changes in epidemiology of acute spinal cord injury from 1947 to 1981. Surg Neurol 1993;40(3):207–15.
9. Management of acute spinal cord injuries in an intensive care unit or other monitored setting. Neurosurgery 2002;50(Suppl 3):S51–7.
10. National Spinal Cord Injury Statistical Center, Birmingham, AL. Annual report for the model spinal cord injury care systems, Birmingham, October, 2011. (Citation is from the 2011 Annual statistical report of the National Spinal Cord Injury Statisical Center).
11. McDonald JW, Sadowsky C. Spinal-cord injury. Lancet 2002;359(9304):417–25.
12. Pharmacological therapy after acute cervical spinal cord injury. Neurosurgery 2002;50(Suppl 3):S63–72.
13. Harrop JS, Sharan AD, Vaccaro AR, et al. The cause of neurologic deterioration after acute cervical spinal cord injury. Spine 2001;26(4):340–6.
14. Bracken MB, Collins WF, Freeman DF, et al. Efficacy of methylprednisolone in acute spinal cord injury. JAMA 1984;251(1):45–52.
15. 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(20):1405–11.
16. 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(1):23–31.
17. Bracken MB, Shepard MJ, Holford TR, et al. Administration of methylprednisolone for 24 or 48 hours or tirilazad mesylate for 48 hours in the treatment of acute spinal cord injury. Results of the Third National Acute Spinal Cord Injury Randomized Controlled Trial. National Acute Spinal Cord Injury Study. JAMA 1997;277(20):1597–604.
18. Bracken MB, Shepard MJ, Holford TR, et al. Methylprednisolone or tirilazad mesylate administration after acute spinal cord injury: 1-year follow up. Results of the third National Acute Spinal Cord Injury randomized controlled trial. J Neurosurg 1998; 89(5):699–706.
19. Galandiuk S, Raque G, Appel S, et al. The two-edged sword of large-dose steroids for spinal

cord trauma. Ann Surg 1993;218(4):419–25 [discussion: 419–25].
20. Kwon BK, Tetzlaff W, Grauer JN, et al. Pathophysiology and pharmacologic treatment of acute spinal cord injury. Spine J 2004;4(4):451–64.
21. Bracken MB. Steroids for acute spinal cord injury. Cochrane Database Syst Rev 2012;(1):CD001046.
22. Hurlbert RH, Hadley MN, et al. Guidelines for the management of acute cervical spine and spinal cord injuries. Clin Neurosurg 2013;72: 93–105.
23. Geisler FH, Dorsey FC, Coleman WP. Recovery of motor function after spinal-cord injury—a randomized, placebo-controlled trial with GM-1 ganglioside. N Engl J Med 1991;324(26):1829–38.
24. Geisler FH, Coleman WP, Grieco G, et al. The Sygen multicenter acute spinal cord injury study. Spine 2001;26(Suppl 24):S87–98.
25. Castillo-Abrego G. Hypothermia in spinal cord injury. Crit Care 2012;16(Suppl 2):A12.
26. Levi AD, Green BA, Wang MY, et al. Clinical application of modest hypothermia after spinal cord injury. J Neurotrauma 2009;26(3):407–15.
27. Levi AD, Casella G, Green BA, et al. Clinical outcomes using modest intravascular hypothermia after acute cervical spinal cord injury. Neurosurgery 2010;66(4):670–7.
28. Dididze M, Green BA, Dalton Dietrich W, et al. Systemic hypothermia in acute cervical spinal cord injury: a case-controlled study. Spinal Cord 2012; 50(12):1–6.
29. Zahra M, Samdani A, Piggott K, et al. Acute changes in systemic hemodynamics and serum vasopressin after complete cervical spinal cord injury in piglets. Neurocrit Care 2010;13(1):132–40.
30. Furlan JC, Fehlings MG, Shannon P, et al. Descending vasomotor pathways in humans: correlation between axonal preservation and cardiovascular dysfunction after spinal cord injury. J Neurotrauma 2003;20(12):1351–63.
31. Nathan PW, Smith MC. The location of descending fibres to sympathetic preganglionic vasomotor and sudomotor neurons in man. J Neurol Neurosurg Psychiatr 1987;50(10):1253–62.
32. Ball PA. Critical care of spinal cord injury. Spine 2001;26(Suppl 24):S27–30.
33. Levi L, Wolf A, Belzberg H. Hemodynamic parameters in patients with acute cervical cord trauma: description, intervention, and prediction of outcome. Neurosurgery 1993;33(6):1007–16 [discussion: 1016–7].
34. Vale FL, Burns J, Jackson AB, et al. Combined medical and surgical treatment after acute spinal cord injury: results of a prospective pilot study to assess the merits of aggressive medical resuscitation and blood pressure management. J Neurosurg 1997;87(2):239–46.
35. Rangappa P, Jeyadoss J, Flabouris A, et al. Cardiac pacing in patients with a cervical spinal cord injury. Spinal Cord 2010;48(12):867–71.
36. Helkowski WM, Ditunno JF Jr, Boninger M. Autonomic dysreflexia: incidence in persons with neurologically complete and incomplete tetraplegia. J Spinal Cord Med 2003;26(3):244–7.
37. Illman A, Stiller K, Williams M. The prevalence of orthostatic hypotension during physiotherapy treatment in patients with an acute spinal cord injury. Spinal Cord 2000;38(12):741–7.
38. Furlan JC, Fehlings MG. Cardiovascular complications after acute spinal cord injury: pathophysiology, diagnosis, and management. Neurosurg Focus 2008;25(5):E13.
39. Krassioukov AV, Furlan JC, Fehlings MG. Autonomic dysreflexia in acute spinal cord injury: an under-recognized clinical entity. J Neurotrauma 2003;20(8):707–16.
40. Karlsson AK. Autonomic dysreflexia. Spinal Cord 1999;37(6):383–91.
41. Chancellor MB, Erhard MJ, Hirsch IH, et al. Prospective evaluation of terazosin for the treatment of autonomic dysreflexia. J Urol 1994; 151(1):111–3.
42. Vaidyanathan S, Soni BM, Sett P, et al. Pathophysiology of autonomic dysreflexia: long-term treatment with terazosin in adult and paediatric spinal cord injury patients manifesting recurrent dysreflexic episodes. Spinal Cord 1998;36(11): 761–70.
43. Ledsome JR, Sharp JM. Pulmonary function in acute cervical cord injury. Am Rev Respir Dis 1981;124(1):41–4.
44. McMichan JC, Michel L, Westbrook PR. Pulmonary dysfunction following traumatic quadriplegia. Recognition, prevention, and treatment. JAMA 1980;243(6):528–31.
45. Scanlon PD, Loring SH, Pichurko BM, et al. Respiratory mechanics in acute quadriplegia. Lung and chest wall compliance and dimensional changes during respiratory maneuvers. Am Rev Respir Dis 1989;139(3):615–20.
46. Brown R, DiMarco AF, Hoit JD, et al. Respiratory dysfunction and management in spinal cord injury. Respir Care 2006;51(8):853–68 [discussion: 869–70].
47. Almenoff PL, Alexander LR, Spungen AM, et al. Bronchodilatory effects of ipratropium bromide in patients with tetraplegia. Paraplegia 1995;33(5): 274–7.
48. Gardner BP, Watt JW, Krishnan KR. The artificial ventilation of acute spinal cord damaged patients: a retrospective study of forty-four patients. Paraplegia 1986;24(4):208–20.
49. Grande CM, Barton CR, Stene JK. Appropriate techniques for airway management of emergency

patients with suspected spinal cord injury. Anesth Analg 1988;67(7):714–5.
50. Shatney CH, Brunner RD, Nguyen TQ. The safety of orotracheal intubation in patients with unstable cervical spine fracture or high spinal cord injury. Am J Surg 1995;170(6):676–9 [discussion: 679–80].
51. Rodriguez JL, Steinberg SM, Luchetti FA, et al. Early tracheostomy for primary airway management in the surgical critical care setting. Surgery 1990;108(4):655–9.
52. Kane TD, Rodriguez JL, Luchette FA. Early versus late tracheostomy in the trauma patient. Respir Care Clin N Am 1997;3(1):1–20.
53. Fagon JY, Chastre J, Hance AJ, et al. Nosocomial pneumonia in ventilated patients: a cohort study evaluating attributable mortality and hospital stay. Am J Med 1993;94(3):281–8.
54. Grossman RF, Fein A. Evidence-based assessment of diagnostic tests for ventilator-associated pneumonia. Executive summary. Chest 2000;117(4 Suppl 2):177S–81S.
55. Furlan JC, Fehlings MG. Role of screening tests for deep venous thrombosis in asymptomatic adults with acute spinal cord injury: an evidence-based analysis. Spine 2007;32(17):1908–16.
56. Geerts WH, Code KI, Jay RM, et al. A prospective study of venous thromboembolism after major trauma. N Engl J Med 1994;331(24):1601–6.
57. Green D, Rossi EC, Yao JS, et al. Deep vein thrombosis in spinal cord injury: effect of prophylaxis with calf compression, aspirin, and dipyridamole. Paraplegia 1982;20(4):227–34.
58. Merli GJ, Herbison GJ, Ditunno JF, et al. Deep vein thrombosis: prophylaxis in acute spinal cord injured patients. Arch Phys Med Rehabil 1988; 69(9):661–4.
59. Deep venous thrombosis and thromboembolism in patients with cervical spinal cord injuries. Neurosurgery 2002;50(Suppl 3):S73–80.
60. van Rossum AB, Pattynama PM, Ton ER, et al. Pulmonary embolism: validation of spiral CT angiography in 149 patients. Radiology 1996;201(2): 467–70.