Meeting the Emergent Challenge of Spinal Cord Injury

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Confident evaluation and treatment of spinal cord injury is a necessity in the ED, and prevention of further injury is paramount. Patient stabilization and proper use of imaging facilitate management.

Spinal cord injury can be one of the most devastating injuries seen in the emergency department. The age at which spinal cord injury occurs most frequently is 19 years, with half of all injuries occurring in persons ages 16 to 30 years.[1] Significant morbidity and mortality are associated with these injuries, and the evidence is split on exactly which acute interventions can improve outcomes. This article reviews the anatomy of the spinal cord as well as the pathophysiology of spinal cord injury. It also discusses the research that has been published on key issues in the management of acute spinal cord injury, including endotracheal intubation, imaging of the spine, and steroid therapy.

EPIDEMIOLOGY

The National Spinal Cord Injury Statistical Center (NSCISC) maintains the world's largest spinal cord injury database. According to a recent publication from the NSCISC,[2] the incidence of spinal cord injury is 40 new cases per million population in the United States. While spinal cord injury tends to affect younger adults, the age of those affected ranges from younger than 1 year to 98 years, resulting in a mean age at time of injury of 33.9 years.[1] Men are affected more commonly than women, at a ratio of 4 to 1. Up to 3.5% of spinal cord injuries occur in patients younger than 15.[1] The life expectancy of patients with long-term spinal cord injury depends on several variables, including race/ethnicity, age, injury severity, ventilator dependence, and time since injury. Other factors, such as the presence of pressure ulcers and depression, have been shown recently to contribute to a decrease in life expectancy.[3] A patient between ages 25 and 34 years at the time of a spinal cord injury can expect to live an additional 38 years.[4] Leading causes of death include heart disease, pneumonia, and sepsis.

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ANATOMY

Each segment of the spine has inherent anatomic strengths and weaknesses that affect injury patterns. The human spine (Figure 1) is composed of 33 verte-

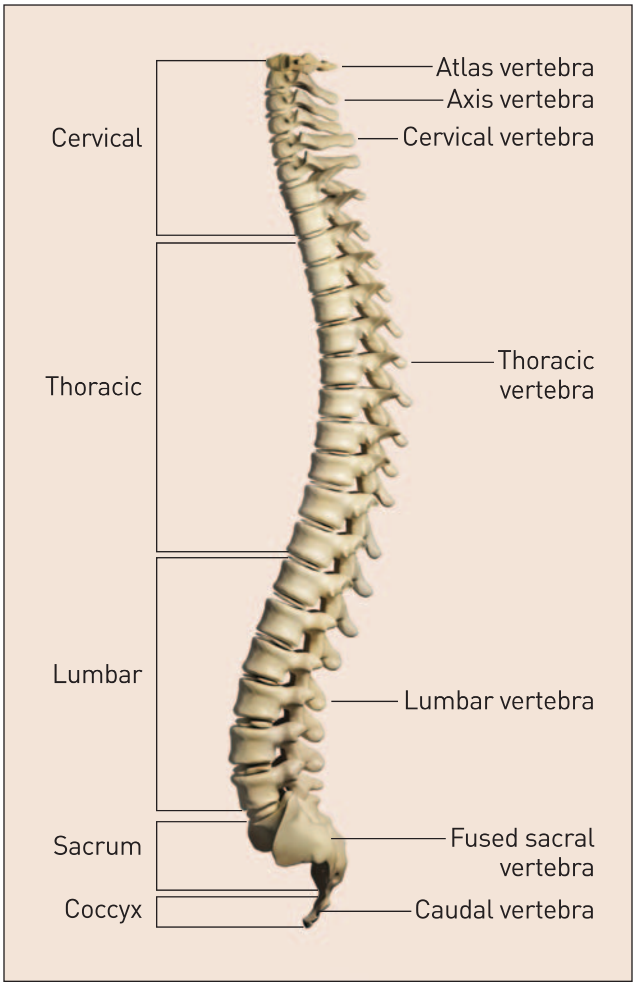

FIGURE 1. Anatomy of the spine

brae: seven cervical; 12 thoracic; five lumbar; five sacral, which are usually fused into one; and four coccygeal, which are usually fused into one (Figures 2-4). Each cervical, thoracic, and lumbar vertebra is separated by intervertebral disks, and the vertebra and disks are held together by ligaments. The spinal column is further divided into three columns. The anterior column consists of the anterior longitudinal ligament and the anterior part of the vertebral body and annulus fibrosus. The middle column includes the posterior wall of the vertebral body, posterior annulus fibrosus, and posterior longitudinal ligament. Finally, the posterior (or dorsal) column includes the bony complex of the posterior vertebral arch and posterior ligamentous complex.[5] Sympathetic nerves exit the cord between C7 and L1. Parasympathetic nerves exit at S2 through S4. Superior parasympathetic nerves exit with cranial nerves above the level of the spinal cord. Traditionally, injuries to nerves below L1 are not considered true spinal cord injuries because the nerve roots at this level include segmental spinal nerves and the cauda equina; however, injury to this area can cause neurologic injury requiring immediate surgical intervention.

The thoracic spine is the most rigid segment of the spinal column, due to its articulation with the rib cage. As a result, it takes a larger force to cause an unstable injury to the thoracic spine as compared to other sections of the spine. Conversely, the spinal canal in the thoracic region is narrower, which increases the risk of injury to the spinal cord. At T11 through L2 there exists a transitional zone involving the fixed thoracic spine and the more mobile lumbar spine. This section of the spinal cord is most vulnerable to injuries, as it often sustains the greatest amount of stress during motion, and the lumbar vertebrae are more mobile than the thoracic vertebrae. The sacral spine articulates with the pelvis, and isolated spinal injuries in this section are rare. Most injuries to the sacral spine occur with concurrent fracture of the pelvis. A fracture of the coccyx is most readily diagnosed by severe tenderness on rectal exam and is not associated with neurologic findings.[6]

In addition to the bony structures of the spine, the spinal cord itself is divided into various tracts that traverse the cord and carry specific sensory messages to and from the brain. It is important that the physician have an understanding of these tracts in order to perform a proper physical exam, as an incomplete spinal cord injury can affect certain tracts while leaving others intact. This leads to variable sensory or motor deficits, depending on the tract(s) involved. In contrast, complete spinal cord injuries generally result in complete sensory and motor loss below the level of the injury.[7] This is discussed in the following section.

PATHOPHYSIOLOGY OF INJURY

Primary injury to the cord results from mechanical disruption and transection of the neural components of the cord. While penetrating trauma can cause this type of injury, it is most commonly caused by fracture or dislocation of the spine. Nontraumatic elements (such as metastatic disease) or extradural pathology (such as hematoma or abscess) also can cause acute cord compression. *Spinal cord injury without radiologic abnormality* (SCIWORA) is a term coined in 1982 by Pang and Wilberger that is often used to describe longitudinal distraction of the cord with or without a flexion/extension injury. The term is somewhat outdated in that it relates primarily to radiographic or CT evidence of injury, whereas MRI can be used to visualize cord contusion, disk rupture, hematoma, and hematomyelia, all of which can cause primary or secondary injury.[8-10]

Secondary cord lesions can result from vascular compromise or from direct injury to the spinal cord, and disrupted blood flow to the cord can cause compromise equivalent to primary mechanisms of injury. The anterior spinal artery supplies the anterior two-thirds of the cord, including the corticospinal, lateral spinothalamic, and autonomic intermediate pathways. The posterior spinal arteries supply the posterior one-third of the spinal cord (dorsal columns). Both spinal arteries arise from the vertebral arteries in the neck, and then descend from the base of the skull. Collateral flow is available via the radicular arteries from the thoracic and abdominal aorta. However, due to variations in the development of certain blood vessels, thoracic levels T1, T5, T8, and T9 tend to have less collateral circulation and as a result are particularly vulnerable to hypoperfusion and ischemic injury.[11,12]

Spinal cord injuries are classified as complete or incomplete. *Complete injuries* are marked by total loss of function below the level of injury, and there is no spontaneous return of function after such injuries. With *incomplete injuries*, some neurologic function is preserved, and function may return to some degree. Spinal cord injuries evolve over time, and therefore it is extremely important to recognize injuries, document findings precisely on neurologic exam, and stabilize any situation that can lead to further injury. Because the pathophysiologic mechanism of injury evolution depends on blood flow, free radical formation, and vasogenic edema, it is crucial to maintain oxygenation, perfusion, and acid-base balance. Without proper management, incomplete lesions can evolve into complete lesions and can even ascend one or two levels above the initial site of injury.[13]

The most common injury patterns seen in an in-

FIGURE 2. Fifth cervical vertebra

FIGURE 3. Fifth thoracic vertebra

FIGURE 4. First lumbar vertebra

Practical Management Considerations

When should radiographs of the thoracic and lumbar spine be ordered? When is CT indicated? If CT of the abdomen/pelvis or chest is performed, can reconstructions of the CT be used to evaluate the spine to avoid additional imaging?

No clear guidelines on these matters exist, and patients who are awake, alert, and cooperative with no signs or symptoms do not need any imaging. CT of the chest/abdomen/pelvis is more sensitive than plain radiography in the detection of thoracolumbar spine fractures (100% vs 73%).[1] Reformatting of the thoracolumbar spine is an option in some centers.

What is the initial imaging study of choice for the cervical spine? When should MRI be used after CT with normal findings?

Most major trauma centers use CT to evaluate for injury to the cervical spine. CT scans often can be obtained faster than an adequate series of plain radiographs, especially when they are obtained at the same time as CT of the head and abdomen/pelvis, and are significantly more sensitive than plain radiographs in the detection of fractures. One retrospective review of trauma patients found that up to 67% of cervical spine fractures and 45% of subluxations were missed when plain radiography was used.[2] Subsequent studies found a sensitivity of 98.5% for CT compared with 43% for plain radiographs in detecting cervical spine fractures.[3] Another study reported a missed-injury rate of 4.13% in patients who had adequate screening plain radiographs.[4] In a prospective study of 1,505 patients with blunt cervical spine trauma, CT was found to be 100% sensitive in detecting clinically significant injuries, while radiography was 46% sensitive in detecting clinically significant injuries in high-risk patients, 37% sensitive for moderate-risk patients, and 25% sensitive for low-risk patients.[5]

While the superiority in sensitivity of CT over that of plain radiography for the detection of fractures in the cervical spine has been substantiated in the medical literature, the question of when it is acceptable to use plain radiographs alone for the evaluation of the cervical spine for trauma is less clear. Disadvantages of using CT of the cervical spine for all traumatic injuries include the significant cost and radiation exposure, particularly to the thyroid gland. Blackmore et al evaluated the cost-effectiveness of using CT of the cervical spine to evaluate for injury and concluded that for high- and moderate-risk patients, CT should be the primary method for screening for injury. Use of CT in low-risk patients as an initial modality is not cost-effective.[6]

MRI is useful to evaluate for ligamentous injury or a

complete spinal cord injury are anterior cord syndrome, posterior cord syndrome, central cord syndrome, cauda equina syndrome, and Brown-Séquard syndrome. In *anterior cord syndrome*, patients have loss of motor function as well as loss of pain and temperature sensation, with preserved proprioception below the injury. *Posterior cord syndrome* results in complete motor paralysis and loss of proprioception below the level of the injury, while pain, temperature, and touch sensation remain intact. Patients who sustain an injury to the central part of the spinal cord can have *central cord syndrome*, which is manifested by motor weakness that is greater in the arms than the legs and variable loss of sensation and reflexes. Patients with *cauda equina syndrome* demonstrate lower extremity weakness, saddle anesthesia, and loss of bowel and bladder control. Damage to a lateral half of the spinal cord can cause *Brown-Séquard syndrome*, resulting in ipsilateral loss of motor control and proprioception and contralateral loss of pain and temperature sensation below the level of the lesion.[7]

Because the phrenic nerve controls respiratory musculature, and this nerve is composed of nerve roots that exit between C3 and C5, higher cervical injuries carry very high risk for airway and breathing compromise. It should also be noted that edema from lower cervical injuries can rise to the level of C3-C5, thus compromising the phrenic nerve.[5]

AVOIDING INJURY DURING ENDOTRACHEAL INTUBATION

Performing endotracheal intubation while maintaining in-line stabilization can be quite difficult, since placing the patient in the optimal "sniffing" position would manipulate the cervical spine. The jaw thrust and chin lift motions are preferred but can also cause a shift of spinal cord lesion such as in central cord syndrome. Persistent pain or neurologic deficits with normal CT findings should prompt an MRI. In some trauma centers, MRI is obtained after a normal CT result in patients who are difficult to evaluate due to obtundation or intubation.[7]

What treatments should be employed for spinal cord injury? When should a neurosurgeon be called? When would a patient need to be discharged in some form of cervical collar or back brace?

Neurosurgical consultation is indicated for any patient with an unstable fracture or neurologic deficits. This consultation should include any recommendations regarding cervical collars or back braces.

Studies concentrating on patient outcomes after emergent surgical decompression are largely from the 1960s and 1970s, with several from the 1990s. None are prospectively controlled or randomized.

Spinal decompression is recommended early in the course of progressive neurologic deterioration, facet dislocation, bilateral locked facets, spinal nerve impingement with progressive radiculopathy, and cauda equina syndrome, but there are no defined standards regarding decompression and stabilization in spinal cord injury otherwise. There is an ongoing prospective trial, the Surgical Treatment for Acute Spinal Cord Injury Study, whose researchers hope to shed light on this issue. In the only prospective, randomized, controlled study to examine the subject, Vaccaro et al noted no significant difference between early or late surgery.[8]

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up to 5 mm, even with a properly placed hard cervical collar.[14] Manual stabilization by another member of the team, however, has been shown to reduce motion,[14] and it is therefore appropriate to remove the cervical collar during intubation. At the Shock Trauma Center in Baltimore, among 3,000 patients who were orotracheally intubated with a modified rapid-sequence induction method using manual in-line stabilization, 1% were found to have spinal injury and none deteriorated neurologically afterward.[15]

SPINE-RELATED ISSUES IN MAJOR TRAUMA

In a multiply injured patient with unstable vital signs, hemorrhage is the most likely cause of hypotension or shock, and a search should be made to identify the source of bleeding. The most common sites for blood loss include the chest, pelvis, abdomen, and long bone (femur). Physical exam may identify bleeding at the femur or pelvis; radiography is also useful for chest and pelvic fractures. Ultrasonography (bedside FAST, or Focused Assessment with Sonography for Trauma) can identify bleeding in the chest and abdomen. Diagnostic peritoneal lavage may be employed to identify intra-abdominal bleeding, and CT is commonly used to look at the abdomen, retroperitoneum, and pelvis. Neurogenic shock can cause hypotension, but this is seen only if the injury is located above T6. Furthermore, neurogenic shock can be concomitant with hemorrhagic shock. This presents a troubling scenario in which the neurologic injury prevents tachycardia, which is often a telltale sign of hemorrhagic shock. Therefore, even with hypotension and neurologic injury, the patient must be examined carefully for sources of bleeding before hypotension can be attributed to neurogenic shock alone.

As previously discussed, secondary injury to the spinal cord can result from hypoperfusion. The American

Table. The NEXUS Criteria

Blunt trauma patients who meet all of the following criteria do not require radiography:

- No posterior midline tenderness of the cervical spine
- Normal level of alertness
- No evidence of intoxication
- No focal neurologic deficit
- No distracting painful injury present

Adapted from Hoffman et al.[17]

College of Surgeons guidelines recommend maintaining a mean arterial pressure of 65 to 70 mm Hg in patients with spinal cord injury.[16] If bradycardia is significant enough to cause hemodynamic instability and it is not related to a preterminal event due to blood loss, small doses of atropine can be given. Research has shown that a systolic blood pressure greater than 90 mm Hg is most beneficial in allowing adequate oxygenation and perfusion to the spinal cord.[16]

After the primary survey, a detailed neurologic exam should be part of the secondary survey to determine what type of neurologic injury may be present. In addition to the incomplete cord syndromes discussed earlier, *conus medullaris syndrome* must be considered. This syndrome is marked by sacral cord injury with or without involvement of the lumbar nerves. Patients experience variable motor and sensory loss in the lower extremities but often have areflexia of the lower limbs, bladder, and bowel. The digital rectal exam is important in evaluating for this syndrome.[11] Patients may also suffer from spinal cord concussion, a transient neurologic deficit localized to the spinal cord, which fully resolves without structural damage.

IMAGING THE CERVICAL SPINE

Most multiply injured trauma patients will undergo CT to evaluate for head and neck injury as well as to search for significant injuries and sources of occult hemorrhage, including the retroperitoneum. Small fractures of the spine can be more easily appreciated on CT than on plain films. Not all patients with neck pain need imaging, however (see "Practical Management Considerations", pages 14-15).

The National Emergency X-Radiography Utilization Study (NEXUS) criteria[17] and Canadian C-Spine Rule[18] were developed to more appropriately manage these patients without the risk of unnecessary radiation.

The NEXUS Criteria and Canadian C-Spine Rule

The NEXUS criteria (Table)[17] and Canadian C-spine Rule (Figure 5)[18] are decision rules developed to guide the use of cervical spine radiography in trauma patients. The purpose of the rules was to establish criteria that could be used to identify those stable trauma patients who are at low risk and do not require further radiologic imaging of the neck. According to the NEXUS criteria, radiologic studies are not warranted and the cervical spine can be reliably cleared clinically if the patient is alert and oriented, denies neck pain, does not show signs of intoxication, does not have midline cervical spine tenderness, and does not have a distracting injury.[17]

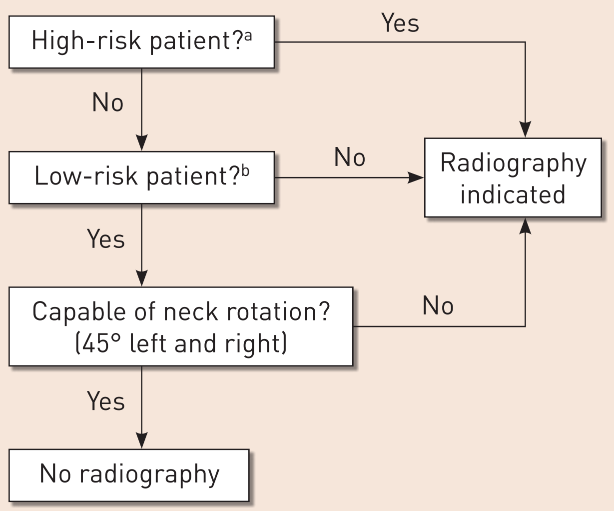
The Canadian C-Spine Rule[18] was developed based on high-risk factors that mandate radiography and low-risk factors that, if present, rule out the need for radiography. These rules apply only to trauma patients who are stable and alert (with a Glasgow Coma Score of 15). High-risk factors include age 65 years or older, injury associated with a dangerous mechanism, and paresthesias in the lower extremities. Low risk is indicated if the patient is able to sit up on his or her own in the emergency department, is ambulatory at any time, was involved in a simple motor vehicle collision, or does not have midline cervical spine tenderness.[18] Those at low risk can be assessed for range of motion, including ability to rotate the neck 45° to the left and the right. If these tasks can be accomplished, no radiography is necessary.

The Canadian C-Spine Rule has been shown to have 100% sensitivity and 42.5% specificity for identifying clinically significant cervical spine injury (defined as any fracture, dislocation, or ligamentous instability demonstrated by diagnostic imaging).[18] The authors of the rule propose that following these criteria may reduce cervical spine radiography utilization to 58%, a relative reduction of 15.5%. Such reductions are important, as past studies have documented inefficiencies in the use of cervical spine radiography. In a study involving 6,855 alert and stable-appearing trauma patients who presented with potential cervical spine injury to eight Canadian hospitals, Stiell et al[19] found cervical spine imaging rates between 37% and 72% across the participating hospitals. Only 1.5% of those radiographs were positive for occult injury. These high radiography ordering rates reflect, in part, the relatively low predictive accuracy of clinical judgment alone in identifying cervical spine injury. In a 2003 study, Bandiera et al[20] compared physician judgment for predicting clinically important cervical spine injury to the detection of such injuries using structured decision rules, namely the Canadian C-Spine Rule. The authors concluded that the predictive accuracy of physician judgment was merely "fair" and that its sensitivity for detecting injury was suboptimal. Those conclusions, combined with the potential for catastrophic outcomes if an injury is missed, result in overuse of imaging in trauma patients. Since studies of the Canadian C-Spine Rule have shown 100% sensitivity for detecting clinically important cervical spine injury, the authors suggest that employing these criteria can help the physician to feel more comfortable about not ordering imaging in those deemed low risk for injury. They prefer the Canadian C-spine Rule to the NEXUS criteria because the low specificity of NEXUS (12.9%) may fail to decrease ordering rates among physicians.[20]

When radiographs of the cervical spine are required, three views are necessary: the anteroposterior, lateral, and odontoid views. Visualization of C7 on T1 is imperative, and the films must be examined for bony injury as well as for predental and prevertebral space swelling, as this may be a clue to occult injury. When plain radiographs are negative but the patient has persistent point tenderness, CT is warranted. True neurologic compromise, including bowel or bladder incontinence, decreased tone on digital rectal exam, or complete paralysis requires emergent MRI to assess the degree of damage.

Recently, Schoenfeld et al[21] raised the question of whether CT alone is truly the best imaging test for evaluating patients at high risk for spinal cord injury. The authors noted that the incidence of missed cervical spine injuries with cervical CT is as high as 20%.

FIGURE 5. The Canadian C-Spine Rule



[a]Patient is considered to be at high risk if any of the following criteria applies:
- Age ≥ 65 years
- Dangerous mechanism (fall from ≥ 1 m or 5 stairs; axial load to head; high-speed motor vehicle crash [> 100 km/h], rollover, ejection; motorized recreational vehicle; or bicycle collision)
- Paresthesias in extremities

[b]Patient is considered to be at low risk if any of the following criteria applies:
- Minor rear-end vehicle crash (excludes being pushed into oncoming traffic, hit by truck/bus, hit by vehicle moving at high speed)
- Delayed onset of neck pain (not present immediately)
- Sitting position in the ED
- Ambulatory at any point
- No midline cervical spine tenderness

Adapted from Stiell et al.[18]

They performed a meta-analysis of studies involving patients who underwent both CT and subsequent MRI and found that 12% of the 1,550 trauma patients with negative cervical spine CT scans had abnormalities on MRI. In 6% of these patients, the MRI findings changed management, including prolonged use of the cervical collar or surgical stabilization of the injury. In this meta-analysis, MRI had a sensitivity of 100% and a specificity of 94% for detecting occult injury to the cervical spine. The practicality of these results remains to be seen. While the negative predictive value of MRI is 100%, the cost of obtaining an MRI in each trauma patient would be extreme. In addition, there is no established "gold standard" against which the authors can compare their results.[21]

FAST TRACK

Patients who demonstrate neurologic deficits, altered mental status, or signs of spinal cord injury (weakness, paresthesias) should undergo MRI.

If a patient meets the NEXUS or Canadian C-spine criteria, then no images are needed. When imaging of the cervical spine is indicated, CT should be used as the initial imaging modality in all patients except those with very low risk of injury, as the sensitivity of CT is significantly higher than that of radiographs for detecting injury. Patients with neurologic deficits, altered mental status, or signs of spinal cord injury (weakness, paresthesias) should undergo MRI to evaluate for injury to the spinal cord.

TREATMENT WITH STEROIDS

Which therapies should be used in the management of spinal cord injury remains a hotly debated topic. Oxygen and blood pressure support are widely accepted, but use of methylprednisolone has been contested. The National Acute Spinal Cord Injury Study (NASCIS) Group conducted three trials examining dosing, timing, and duration of steroid treatment. The first of these trials, published in 1984 and 1985, found no difference in clinical improvement with high- versus low-dose steroids.[22,23] The second trial found that patients had statistically significant improvement in motor and sensory function at 6 months when given high-dose methylprednisolone within 8 hours of their injury.[24,25] At the 1-year mark, however, steroid recipients had improvement only in motor function. A recent small study by Ito et al[26] was conducted to reexamine the conclusions of the second NASCIS study. It was found that steroid recipients did not have better neurologic outcomes than nonrecipients, and they did have higher rates of infection.[26] Finally, the third NASCIS trial found slightly better motor scores at 6 weeks and at 6 months among patients who received steroids for 48 hours versus 24 hours, without any difference in sensory scores.[27] In all of the trials, however, rates of sepsis and death due to respiratory complications were statistically greater in the groups that received steroids at higher doses and for longer periods of time.[27]

Several literature reviews have been conducted in an attempt to find evidence for or against steroid use. In a Cochrane review of randomized trials of steroid use in acute spinal cord injury,[28] Bracken reported that the findings from the NASCIS I and NASCIS II studies were supported by results from a Japanese study,[29] but not those from a French study.[30] Bracken emphasized the "urgent need for more randomized trials" but concluded that high-dose methylprednisolone given within 8 hours post injury was the sole agent to show benefit in a phase 3 randomized trial.[28]

Hurlbert[31] conducted a literature review with the conclusion that other studies attempting to address the benefit of methylprednisolone have not been able to reach the power of the NASCIS studies, and some have been closed early due to poor outcomes endangering the patients. Hugenholtz et al[32] also reviewed 64 citations and concluded that there is not sufficient evidence to use steroids within 8 hours, nor, if they are initiated, is there sufficient evidence to continue their infusion beyond 23 hours. As a final note on the subject, Hurlbert and Moulton[33] surveyed neurologic and orthopedic surgeons and found that more than 70% of respondents used steroids to treat spinal injury because their peers were doing so, and only 17% used them based on efficacy. At this time there is no clear evidence to support steroid use as a recommendation, but it remains an option for physicians involved in the care of spinal cord injury. Some neurosurgeons continue to use steroids despite the lack of evidence of their efficacy.

CONCLUSION

Significantly more research is needed in the field of spinal cord injury until the debate regarding steroid use is put to rest. Strides have been made in long-term treatment of spinal cord injury, including GM-1 ganglioside therapy and stem cell transplant. In the acute setting, the most important aspects of managing spinal cord injury continue to be recognition of high-risk mechanisms, comprehensive evaluation of the patient, stabilizing any suspected injury, and support of perfusion and oxygenation. **EM**

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