Prehospital Cervical Spinal Immobilization After Trauma

**RECOMMENDATIONS**

**Level II**

Spinal immobilization of all trauma patients with a cervical spine or spinal cord injury or with a mechanism of injury having the potential to cause cervical spinal injury is recommended.

- Triage of patients with potential spinal injury at the scene by trained and experienced emergency medical services personnel to determine the need for immobilization during transport is recommended.

- Immobilization of trauma patients who are awake, alert, and are not intoxicated; who are without neck pain or tenderness; who do not have an abnormal motor or sensory examination; and who do not have any significant associated injury that might detract from their general evaluation is not recommended.

**Level III**

- A combination of a rigid cervical collar and supportive blocks on a backboard with straps is effective in limiting motion of the cervical spine and is recommended.

- The longstanding practice of attempted spinal immobilization with sandbags and tape is insufficient and is not recommended.

- Spinal immobilization in patients with penetrating trauma is not recommended because of increased mortality from delayed resuscitation.

**RATIONALE**

The early management of a patient with a potential cervical spinal cord injury begins at the scene of the accident. The chief concern during the initial management of patients with potential cervical spinal injuries is that neurologic function may be impaired as a result of pathologic motion of the injured vertebrae. It is estimated that 3% to 25% of spinal cord injuries occur after the initial traumatic insult, either during transit or early in the course of management.\(^1^\) Multiple cases of poor outcome from mishandling of cervical spinal injuries have been reported.\(^5^\) As many as 20% of spinal column injuries involve multiple noncontinuous vertebral levels; therefore, the entire spinal column is potentially at risk.\(^6^\) Consequently, complete spinal immobilization has been used in prehospital spinal care to limit motion until injury has been ruled out.\(^11^\) Over the last 30 years, there has been a dramatic improvement in the neurologic status of spinal cord–injured patients arriving in emergency departments. During the 1970s, the majority (55%) of patients referred to regional spinal cord injury centers arrived with complete neurological lesions. In the 1980s, however, the majority (61%) of spinal cord-injured patients arrived with incomplete lesions.\(^20^\) This improvement in the neurologic status of patients has been attributed to the development of emergency medical services (EMS) in 1971 and the prehospital care (including spinal immobilization) rendered by EMS personnel.\(^13^,15^\) Spinal immobilization is now an integral part of prehospital management and is advocated for all patients with potential spinal injury after trauma by EMS programs nationwide and by the American College of Surgeons.\(^13,25^\)

Recently, the use of spinal immobilization particularly for those patients with a low...
A more uniform, note in their review of spinal immobilization devices The purpose of the current review is to update the medical VOLUME 72 | NUMBER 3 | MARCH 2013 SUPPLEMENT |

"produced 331 " is credited with pioneering the currently accepted "Although spinal immobilization is Although clinical and As with many interventions in "The search was limited to human subjects "In that review, they credited "yielded 81 articles. A third search combining the terms "evidence on the spinal immobilization since that early publication."

SEARCH CRITERIA

A National Library of Medicine computerized literature search from 1966 to 2011 was conducted with the terms "spinal injuries" and "immobilization." The search was limited to human subjects and the English language and yielded no articles. A second search combining the terms "spinal injuries" and "transportation of patients" yielded 81 articles. A third search combining the terms "spinal injuries" and "emergency medical services" produced 331 articles. Additional references were culled from the reference lists of the remaining papers. Finally, the author group was asked to contribute articles known to them on the subject matter that were not found by other search criteria. Duplicate references were discarded. The abstracts were reviewed and articles unrelated to the specific topic were eliminated. This process yielded a total of 109 articles for this review, which are listed in the bibliography. Thirty pertinent publications used to formulate this medical evidence-based guideline are summarized in Evidentiary Table format (Table).

SCIENTIFIC FOUNDATION

Pathologic motion of the injured cervical spine may create or exacerbate cervical spinal cord or cervical nerve root injury.9-11,16,51,52 This potential has led to the use of spinal immobilization for trauma patients who have sustained a cervical vertebral column injury or experienced a mechanism of injury that could result in cervical spinal column injury.11,12,15-17,19-24,27,30,35,53 Kossuth54-55 is credited with pioneering the currently accepted methods of protection and immobilization of the cervical spine during extrication of acute injury victims. Farrington56-57 championed the concept of prehospital immobilization. Dick and Land58 note in their review of spinal immobilization devices that techniques of prehospital spinal immobilization appeared in standard EMS texts and in the American Academy of Orthopedic Surgeons Committee on Injuries Emergency text as early as 1971.13 Initially, the preferred method to immobilize the cervical spine was the use of a combination of a soft collar and a rolled-up blanket.57 This was followed by the introduction of a more rigid extrication collar by Hare in 1974. Hare’s contribution launched an era of innovation for devices for spinal immobilization.15 Currently, spinal immobilization is one of the most frequently performed procedures in the prehospital care of acute trauma patients in North America.9,11-15,17-19,25-53,59 Although clinical and biomechanical evidence demonstrates that spinal immobilization limits pathologic motion of the injured spinal column, there is no Class I or Class II medical evidence to support spinal column immobilization in all patients after trauma. Although immobilization of an unstable cervical spinal injury makes good sense and Class III medical evidence reports exist of neurological worsening with failure of adequate spinal immobilization, there have been no randomized trials or case-control studies that address the impact of spinal immobilization on clinical outcomes after cervical spinal column injury.8,18,24,43-45 The issue of who should be immobilized is important; tens of thousands of trauma victims are treated with spinal immobilization each year, yet few actually have spinal column injuries or instability.10,35,60

Other considerations in the use of prehospital spinal immobilization include the cost of equipment, the time and training of EMS personnel to apply the devices, and the unnecessary potential morbidity for patients who do not need spinal immobilization after trauma.15,18,24,45-49,53,61,62 As with many interventions in the practice of medicine, spinal immobilization has been instituted in the prehospital management of trauma victims with potential spinal injuries based on the principles of neural injury prevention and years of clinical experience but without supportive scientific evidence from rigorous clinical trials. For a variety of both practical and ethical reasons, it is likely impossible to obtain this information in prospective, randomized clinical trials in contemporary times.

In 1989, Garfin et al16 stated, “No patient should be extricated from a crashed vehicle or transported from an accident scene without spinal stabilization.” In that review, they credited stabilization of the cervical spine as a key factor in the decline in the percentage of complete spinal cord injury lesions from 55% in the 1970s to 39% in the 1980s and in the significant reduction in the mortality of multiple injury patients with cervical spinal injuries. Unfortunately, there is no Class I medical evidence to support these claims.
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<td>Haut et al,103</td>
<td>The assessment of spinal immobilization in patients with cervical spine injury associated with penetrating trauma</td>
<td>III</td>
<td>Prehospital spine immobilization is associated with higher mortality in the settings of penetrating trauma and should not be routinely used.</td>
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<td>Burton et al,70</td>
<td>Evaluation of the practice and outcomes associated with statewide EMS protocol for trauma patient spine assessment and selective prehospital immobilization</td>
<td>II</td>
<td>EMS providers were able to evaluate injured prehospital trauma patients with a 4-step clinical assessment protocol and to accurately discriminate between patients likely to benefit from immobilization and patients with unstable spine injury.</td>
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<td>Del Rossi et al,105</td>
<td>Biomechanical study testing 3 cervical collars on a cadaveric model of cervical spine injury</td>
<td>II</td>
<td>When transferring patients to a spine board, the key remains the combination of manual stabilization and the controlling effect of the cervical collar.</td>
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<td>Domeier et al,106</td>
<td>Evaluation of clinical criteria to identify prehospital trauma patients who may safely have rigid spine immobilization withheld</td>
<td>II</td>
<td>Altered mental status, focal neurologic deficit, evidence of intoxication, spine pain or tenderness, or suspected extremity fracture were clinical criteria that identified the presence of spine injury, therefore justifying immobilization.</td>
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<td>Stroh and Braude,68</td>
<td>Determination of the sensitivity of Fresno/Kings/Madera EMS selective spine immobilization protocol in identifying patients with potential cervical injuries</td>
<td>II</td>
<td>Fresno/Kings/Madera protocol is 99% sensitive in identifying patients with cervical surgeries for immobilization, suggesting that selecting immobilization may be safely applied in the out-of-hospital setting.</td>
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<td>Markenson et al,39</td>
<td>Evaluation of the Kendrick extrication device for pediatric spinal immobilization.</td>
<td>III</td>
<td>Kendrick extrication device provides excellent static and dynamic immobilization.</td>
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<td>Perry et al,33</td>
<td>Laboratory evaluation of 3 immobilization devices compared during simulated vehicle motion</td>
<td>III</td>
<td>Substantial amounts of head motion can occur during simulated vehicle motion regardless of the method of immobilization.</td>
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<tr>
<td>Bauer and Kowalski,44</td>
<td>Effect of spinal immobilization devices on pulmonary function in 15 men</td>
<td>III</td>
<td>Significant restriction of pulmonary function was seen.</td>
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<td>Mawson et al,45</td>
<td>Evaluation of risk factors for pressure ulcers after spinal cord injury</td>
<td>III</td>
<td>Time spent on a backboard is significantly associated with pressure ulcers developing within 8 d.</td>
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<td>Hauswald et al, 31 Academic Emergency Medicine, 1998</td>
<td>A 5-year retrospective chart review at 2 university hospitals. All patients with acute blunt traumatic spinal or spinal cord injuries transported directly from the injury site to the hospital were entered. None of the 120 patients at the University of Malaya had spinal immobilization with orthotic devices during transport; all 334 patients at the University of New Mexico did. The hospitals were comparable. Neurological injuries were assigned to 2 categories, disabling or not disabling, by 2 blinded physicians. Data were analyzed using multivariate logistic regression. There was less neurological disability in the Malaysian patients (odds ratio, 2.03; 95% confidence interval, 1.03-3.99; P = .04). Results were similar when the analysis was limited to patients with cervical injuries (odds ratio, 1.52; 95% confidence interval, 0.64-3.62; P = .34).</td>
<td>III</td>
<td>Out-of-hospital immobilization has little effect on neurological outcome in patients with blunt spinal injuries.</td>
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<td>Blaylock, 100 Ostomy Wound Management, 1996</td>
<td>Evaluation of pressure ulcers resulting from cervical collars</td>
<td>III</td>
<td>The association between spinal column movement and the potential for spinal cord injury remains unclear.</td>
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<td>Johnson et al, 79 American Journal of Emergency Medicine, 1996</td>
<td>Measured immobilization and comfort on a 10-point scale; vacuum splint was compared with backboard</td>
<td>III</td>
<td>Vacuum splints are more comfortable and faster to apply than backboards and provide a similar degree of immobilization. Vacuum splints are not rigid enough for extrication and are more expensive.</td>
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<td>Rodgers and Rodgers, 62 Journal of Orthopaedic Trauma, 1995</td>
<td>Marginal mandibular nerve palsy resulting from compression by a cervical hard collar</td>
<td>III</td>
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<td>Chan et al, 36 Annals of Emergency Medicine, 1994</td>
<td>Prospective study of the effects of spinal immobilization on pain and discomfort in 21 volunteers after 30 min; all subjects developed pain</td>
<td>III</td>
<td>Duration of time on backboard was minimized.</td>
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<td>Liew and Hill, 107 The Austrian and New Zealand Journal of Surgery, 1994</td>
<td>Complication of hard cervical collars in multitrauma patients</td>
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<td>Mazolewski and Manix, 50 Annals of Emergency Medicine, 1994</td>
<td>Tests the effectiveness of strapping techniques in reducing lateral motion on a backboard in the laboratory in adults</td>
<td>III</td>
<td>Strapping should be added to the torso to reduce lateral motion on a backboard.</td>
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<td>Plaisier et al, 78 Journal of Trauma Injury Infection and Critical Care, 1994</td>
<td>Prospective evaluation of craniofacial pressure of 4 different cervical orthoses</td>
<td>III</td>
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<tr>
<td>Raphael and Chotai, 108 Anaesthesia, 1994</td>
<td>Effects of the cervical collar on cerebrospinal fluid pressure</td>
<td>III</td>
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<tr>
<td>Chandler et al, 71 Annals of Emergency Medicine, 1992</td>
<td>Compared rigid cervical extrication collar with Ammerman halo orthosis in 20 men</td>
<td>III</td>
<td>Ammerman halo orthosis and spine board provided significantly better immobilization, equivalent to halo vest.</td>
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Few articles have directly evaluated the effect of prehospital spinal immobilization on neurological outcome after injury. Several Class III medical evidence reports cite the lack of immobilization as a cause of neurological deterioration among acutely injured trauma patients transported to medical facilities for definitive care. The most pertinent study is the retrospective case series of Toscano et al., who in 1988 reported that 32 of 123 trauma patients (26%) they managed sustained major neurological deterioration in the period of time between injury and admission. The authors attributed neurological deterioration to inappropriate handling of patients with spinal injury after trauma. Table 1 summarizes some key studies in the literature on this topic.

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<td>Rosen et al., Annals of Emergency Medicine, 1992</td>
<td>Compares 4 cervical collars in 15 adult volunteers by goniometry</td>
<td>III</td>
<td>Vacuum splint cervical collar restricted the range of motion of the cervical spine most effectively.</td>
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<td>Schafermeyer et al., Annals of Emergency Medicine, 1991</td>
<td>Respiratory effects of spinal immobilization in children</td>
<td>III</td>
<td>Mean reduction in FVC to 80% of baseline</td>
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<td>Schriger et al., Annals of Emergency Medicine, 1991</td>
<td>Compares flat backboard with occipital padding in achieving neutral position in 100 healthy volunteers</td>
<td>III</td>
<td>Occipital padding places the cervical spine in more neutral alignment</td>
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<tr>
<td>Cohen, Paraplegia, 1990</td>
<td>A new device for the care of acute spinal injuries: the Russell extrication device</td>
<td>III</td>
<td>Russell extrication device is an effective spinal immobilization device.</td>
</tr>
<tr>
<td>Toscano, Paraplegia, 1988</td>
<td>Prevention of neurological deterioration before admission to hospital</td>
<td>III</td>
<td>Appropriate handling of patients with spinal injury after trauma can reduce major neurological deterioration caused by pathological motion of the vertebral column.</td>
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<td>Retrospective review of 123 patients, 32 of 123 sustained major neurological deterioration from injury to admission</td>
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<td>Graziano et al., Annals of Emergency Medicine, 1987</td>
<td>A radiographic comparison of prehospital cervical immobilization methods with the short board in 45 volunteers</td>
<td>III</td>
<td>The short board proved to be significantly better ($P &lt; .05$).</td>
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<td>Linares et al., Orthopedics, 1987</td>
<td>Evaluation of pressure sores and immobilization.</td>
<td>III</td>
<td>Strong association between 1 to 2 h of immobilization and the development of pressure sores.</td>
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<td>McGuire et al., Spine, 1987</td>
<td>Radiographic evaluation of motion of the thoracolumbar spine in a cadaver with an unstable thoracolumbar spine and a patient with a T12-L1 fracture dislocation</td>
<td>III</td>
<td>Extreme motion at an unstable thoracolumbar spine segment can occur during the logroll maneuver. The backboard and the Scoop stretcher offered adequate stabilization for thoracolumbar spine instability.</td>
</tr>
<tr>
<td>McCabe and Nolan, Annals of Emergency Medicine, 1986</td>
<td>Radiographic comparison of the 4 cervical collars in 7 adults</td>
<td>III</td>
<td>Polyethylene-1 provides the most restriction in flexion.</td>
</tr>
<tr>
<td>Cline et al., Journal of Trauma, 1985</td>
<td>A radiographic comparison of 7 methods of cervical immobilization in 97 adults</td>
<td>III</td>
<td>The short-board technique appeared to be superior to all the 3 collars studied. The collars provided no augmentation of immobilization over that provided by the short board alone.</td>
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<tr>
<td>Podolsky et al., Annals of Emergency Medicine, 1983</td>
<td>Static trial using goniometry</td>
<td>III</td>
<td>Hard foam and plastic collars were superior to soft collars. Sandbags and tape provide an advantage in addition to the cervical collar.</td>
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*EMS, emergency medical services; FVC, forced vital capacity.*
deterioration to patient mishandling and cited the lack of spinal immobilization after traumatic injury as the primary cause. Their report supports the need for prehospital spinal immobilization of trauma patients with potential spinal column injuries. In contrast, a collaborative 5-year retrospective chart review reported by the University of New Mexico and the University of Malaya challenges this position. Hauswald et al. analyzed only patients with acute blunt spinal or spinal cord injuries. At the University of Malaya, none of the 120 patients they managed were treated with spinal immobilization during transport. All 334 patients managed at the University of New Mexico were initially treated with spinal immobilization. Both hospitals were reportedly comparable with respect to physician training and clinical resources. Two independent physicians blinded to the participating hospital characterized the neurological injuries into 2 groups: disabling and non-disabling. Data were analyzed with logistic regression techniques, with hospital, patient age, sex, anatomic level of injury, and injury mechanism as variables. Neurological deterioration after injury was less frequent in Malayan patients with spinal injuries who were not treated with formal spinal immobilization during transport (odds ratio, 2.03; 95% confidence interval, 1.03-3.99;  \( P = .04 \)) compared with patients in New Mexico who were managed with spinal column immobilization techniques. Even when the analysis was limited to cervical spine injuries, no significant protective effect from spinal immobilization was identified. For multiple reasons, the conclusions drawn by the authors of this study are considered spurious at best.\(^{15,31,33} \)

Evidence in the literature evaluating the effectiveness of prehospital spinal immobilization is sparse. Ethical and practical issues preclude the execution of a contemporary, randomized clinical trial designed to study the effectiveness of prehospital spinal immobilization compared with no immobilization, primarily because spinal immobilization for trauma patients is perceived as essential with minimal risk and is already widely used. Intuitively, the use of prehospital spinal immobilization is a rational means of limiting spinal motion in spine-injured patients in an effort to reduce the likelihood of neurological deterioration resulting from pathological motion at the site(s) of injury.

The medical evidence (Class III) derived from all of the articles reviewed for the first iteration of this guideline published in 2002 supports that, from an anatomic and biomechanical perspective and from time-tested clinical experience with traumatic spinal injuries, all patients with cervical spinal column injuries or those with the potential for a cervical spinal injury after trauma should be treated with cervical spinal cord immobilization until an injury has been excluded or definitive management has been initiated.

Orledge and Pepe\(^{17} \) in their commentary on the Hauswald et al findings point out some limitations of their article but also suggest that it raises the issue of a more selective evidence-based protocol for spinal immobilization. Should all trauma patients be managed with spinal immobilization until spinal injury has been excluded, or should immobilization be selectively used for patients with potential spinal injury based on well-defined clinical criteria? Which clinical criteria should be used? Since the Hauswald et al. report, prospective studies in support of the use of clinical findings as indicators for the need for prehospital spinal immobilization after trauma have been reported.\(^{27,30,64} \) Several EMS systems now use clinical protocols to help guide which patients should be managed with spinal immobilization after trauma.\(^{65,66} \)

In 2002, Domeier et al.\(^{27,30} \) in a multicenter prospective study of 6500 trauma patients, found that the application of clinical criteria (altered mental status, focal neurologic deficit, evidence of intoxication, spinal pain or tenderness, or suspected extremity fracture) was predictive of the majority of patients who sustained cervical spinal injuries requiring immobilization. The predictive value of their criteria held for patients with high- or low-risk mechanisms of injury. Their study offers Class II medical evidence suggesting that clinical criteria, rather than the mechanism of injury, be evaluated as the standard by which spinal immobilization should be used.

Brown et al.\(^{34} \) examined whether EMS providers could accurately apply clinical criteria to clear the cervical spines of trauma patients before transport to a definitive care facility. The criteria included the presence of pain or tenderness of the cervical spine, the presence of a neurological deficit, an altered level of consciousness, evidence of drug use or intoxication (particularly alcohol, analgesics, sedatives, or stimulants), and/or the presence of other significant trauma that might act as a distracting injury. Immobilization of the cervical spine was initiated if any 1 of 6 criteria was present. The clinical assessment of trauma patients by EMS providers was compared with the clinical assessment provided by emergency physicians. The providers (emergency medical technicians and emergency room physician) were blinded to each other’s assessments. Agreement between EMS staff and physicians was analyzed by the \( \kappa \) statistic. Five hundred seventy-three patients were included in the study. The assessments matched in 79% of the cases (\( n = 451 \)). There were 78 patients (13.6%) for whom the EMS clinical assessment indicated spinal immobilization, but the physician assessment did not. There were 44 patients (7.7%) for whom the physician’s clinical assessment indicated spinal immobilization, but the EMS assessment did not. The \( \kappa \) for the individual components ranged from 0.35 to 0.81. The \( \kappa \) value for the decision to immobilize was 0.48. The EMS clinical assessments were generally more in favor of immobilization than the physician clinical assessments. The authors concluded that EMS and physician clinical assessments to rule out cervical spinal injury after trauma have moderate to substantial agreement. The authors recommended, however, that systems that allow EMS personnel to decide whether to immobilize patients after trauma should provide attentive follow-up of those patients to ensure appropriate care and to provide immediate feedback to the EMS providers.\(^{34} \) Meldon et al.\(^{67} \) in an earlier study, found significant disagreement between the clinical assessments and subsequent spinal immobilization of patients between EMS technicians and physicians. They recommended further research and education before widespread implementation of this practice.

Clinical criteria to select appropriate patients for spinal immobilization have been studied in Michigan.\(^{65} \) and have been
implemented in Maine and San Mateo County, California. In Fresno, California, there has been a selective spine immobilization clearance protocol in place since 1990. EMS Policy Number 530, as it is known, calls for spinal immobilization in the following circumstances:

1. Spinal pain or tenderness, including any neck pain with a history of trauma
2. Significant multiple system trauma
3. Severe head or facial trauma
4. Numbness or weakness in any extremity after trauma
5. Loss of consciousness caused by trauma
6. If mental status is altered (including drugs, alcohol, trauma) and no history is available, or the patient is found in a setting of possible trauma (eg, lying at the bottom of stairs or in the street); or the patient experienced near drowning with a history or probability of diving
7. Any significant distracting injury

In 2001, Stroh and Braude reported a retrospective series of all cases of cervical spine trauma in a 6-year period from 1990 to 1996 at 5 trauma-receiving hospitals in Fresno County, California. There were 861 patients with cervical injuries during this period, 504 of whom were transported to the hospital by EMS personnel. Of those, 495 arrived with cervical spine immobilization. Of the 9 remaining patients, 2 refused immobilization and 2 could not be immobilized. Three injuries were missed by the protocol criteria and 2 secondary to protocol violations. Of the last 5 patients, only 1 patient had an adverse outcome; 2 patients were considered unstable, 4 patients were > 67 years of age, and 1 patient was 9 months old. The protocol was found to be 99% sensitive in identifying trauma patients with cervical injuries requiring immobilization (95% confidence interval, 97.7-99.7). The criteria for immobilization are similar to those used to identify patients who require imaging of the cervical spine after trauma. The authors’ retrospective review of prospectively collected data provides convincing Class II medical evidence that prehospital criteria to select which patients need spinal immobilization after trauma can be successfully applied by EMS personnel in the field. The authors pointed out that the missed injuries identified in their series occurred in very old and very young patients; therefore, caution should be exercised in these age ranges.

In 2004, Burton et al reported a prospective series of trauma patients in Maine who were evaluated by EMS personnel in the field with a “NEXUS-like” decision instrument, originally designed for physicians in the evaluation of trauma patients to determine which trauma patients require imaging of the cervical spine. This included an algorithmic approach excluding patients from immobilization if they were reliable (no alcohol or drugs, loss of consciousness, or altered sensorium), had no distracting injuries, had no normal motor and sensory examinations, and had no spinal tenderness. If any 1 of the 4 criteria was present, the patient was immobilized.

Before the study was initiated, all EMS personnel underwent training on the evaluation system. The protocol was initiated in 2002, and the first year’s data were reported in 2004. During that period, there were 207 545 EMS encounters with 41 885 transports to an emergency department. There were 12 988 patients transported with spinal immobilization (41%). Acute spinal fractures were identified in 154 patients; 20 patients were transported without spinal immobilization (13%). Of these 20 patients, 19 patients had stable fractures, and 1 patient had an unstable thoracic injury. The sensitivity for immobilization was 87% (95% confidence interval, 81.7-92.3), with a negative predictive value of 99.9% (95% confidence interval, 99.8-100). The only missed injury was in the thoracic spine; there were no missed cervical injuries. The protocol ensured that more than half of the trauma patients evaluated did not unnecessarily receive spinal immobilization.

On the basis of the report by Domeier et al and the more recent experiences in Fresno and Maine, both of which have robust protocols in place guiding EMS personnel in the application of spinal immobilization, it appears that these criteria can safely and effectively be applied to predict which patients require cervical spinal immobilization after blunt trauma. There have been no subsequent reports of significant missed spinal injuries in settings where these protocols are used. These 3 studies provide Class II medical evidence on this subject.

EMS personnel who make the assessments to immobilize trauma victims require intensive education and vigilant, quality-assurance scrutiny to ensure that trauma patients with potential spinal injuries are appropriately triaged and managed. Available studies support the use of selective “NEXUS-like” criteria to guide EMS personnel in the field to determine the need for spinal immobilization in patients with potential cervical spinal injuries after trauma.

**METHODS OF PREHOSPITAL SPINAL IMMOBILIZATION**

Prehospital spinal immobilization is effective in limiting spinal motion during patient transport. Various devices and techniques exist to provide immobilization of the cervical spine. Attempts to define the best method of spinal immobilization for prehospital transport have been hampered by physical and ethical constraints.

The methods of measuring the efficacy of spinal immobilization devices vary among investigators. Comparative studies of the various devices have been performed on normal human volunteers, but none has been tested in a large number of patients with spinal injuries. It is difficult to extrapolate normative data to injured patients with potential spinal instability.

Several methods have been used to measure movement of the cervical spine. They range from clinical assessment to plumb lines, photography, radiography, cinematography, and computed tomography and magnetic resonance imaging. Roozmon et al summarized the problems inherent in each method and concluded that there was no satisfactory noninvasive means of studying neck motion, particularly if one is to quantify movement between individual vertebral segments.
The position in which the injured spine should be placed and held immobile, the “neutral position,” is poorly defined. Poorly defined is Schrigger's description of the neutral position as “the normal anatomic position of the head and torso that one assumes when standing and looking ahead.” This position correlates to 12° cervical spine extension on a lateral radiograph. The extent radiographic definition of neutral position was based on the radiographic study of patients who were visually observed to be in the neutral position. Schrigger et al. used this position in their evaluation of occipital padding on spinal immobilization backboards. De Lorenzo, in a magnetic resonance imaging study of 19 adults, found that a slight degree of flexion equivalent to 2 cm of occiput elevation produces a favorable increase in spinal canal/spinal cord ratio at levels C5 and C6, a region of frequent unstable spinal injuries. Backboards have been used for years for extrication and immobilization of spine-injured patients. Schrigger et al. questioned the ability of a flat board to allow neutral positioning of the cervical spine. They compared spinal immobilization with the flat backboard with and without occipital padding in 100 adults. Clinical observation and assessment were used to determine the neutral position of the cervical spine. The authors found that the use of occipital padding in conjunction with a rigid backboard places the cervical spine in the optimal neutral position compared with positioning on a flat backboard alone. McAwains determined that > 80% of adults require 1.3 to 5.1 cm of padding to achieve neutral positioning of the head and neck with respect to the torso and noted that body habitus and muscular development alter the cervical-thoracic angle, thus affecting positioning. These variables make it impossible to dictate specific or routine recommendations for padding.

In general, spinal immobilization consists of a cervical collar, supports on either side of the head, and either long or short backboards with associated straps to attach and immobilize the entire patient’s body to the board. Garth proposed performance standards for cervical extrication collars, but these standards have not been uniformly implemented. There are a variety of different cervical collars. Several studies compare collars alone or in combination with other immobilization devices using a wide range of assessment criteria.

In 1983, Podolsky et al. evaluated the efficacy of cervical spine immobilization techniques using goniometric measures. Twenty-five healthy volunteers lying supine on a rigid emergency department resuscitation table were asked to actively move their necks as far as possible in 6 ways: flexion, extension, rotation to the right and left, and lateral bending to the right and left. Control measurements were made with no device, and measurements were repeated after immobilization in a soft collar, hard collar, extrication collar, Philadelphia collar, bilateral sandbags joined with 3-in-wide cloth tape across the forehead attached to either side of the resuscitation table, and the combination of sandbags, tape, and a Philadelphia collar. Hard foam and hard plastic collars were superior at limiting cervical spine motion compared with soft foam collars. Neither collars alone nor sandbags and tape alone to attempt to immobilize the cervical spine is not recommended.

In 1985, Cline et al. compared methods of cervical spinal immobilization used in prehospital transport. They found that strapping the patient to a standard short board was superior to cervical collar use alone. They noted no significant differences between the rigid collars they tested. McCabe and Nolan compared 4 different collars for their ability to restrict motion in flexion-extension and lateral bending using radiographic assessment. They found that the polyethylene-1 collar provided the most restriction of motion of the cervical spine, particularly with flexion. Rosen et al. compared the limitation of cervical spinal movement of 4 rigid cervical collars in 15 adults using goniometric measurements. The vacuum splint cervical collar provided the most effective restriction of motion of the cervical spine of the 4 devices they tested.

Graziano et al. compared prehospital cervical spine immobilization methods by measuring cervical motion radiographically in the coronal and sagittal planes in 45 immobilized adults. The Kendricks extrication device and the Extrication Plus-One device were nearly as effective in limiting cervical motion as the short immobilization board in their study. Both devices were superior to a rigid cervical collar alone.

In 1990, Cohen described the Russell extrication device for immobilization of patients with potential spine injuries. The Russell extrication device was comparable to the short immobilization board for prehospital spinal immobilization. Chandler et al. compared a rigid cervical extrication collar with the Ammerman halo orthosis in 20 male patients. The Ammerman halo orthosis combined with a rigid spine board provided significantly better cervical spinal immobilization than a cervical collar and spine board. The Ammerman halo orthosis and spine board was equivalent to the standard halo vest immobilization device.

Perry et al. evaluated 3 cervical spine immobilization devices during simulated vehicle motion in 6 adults. Neck motion was
assessed by 3 neurologists and neurosurgeons as to whether motion was “clinically significant.” They found that substantial head motion occurred during simulated vehicle motion regardless of the method of immobilization. They observed that the efficacy of cervical spine immobilization was limited unless the motion of the head and the trunk was also controlled effectively. Mazolewski and Manix tested the effectiveness of strapping techniques to reduce lateral motion of the spine of adults restrained on a backboard. Subjects were restrained on a wooden backboard with 4 different strapping techniques. The backboard was rolled to the side, and lateral motion of the torso was measured. The authors found that additional strapping securing the torso to the backboard reduced lateral motion of the torso. Finally, the traditional method of moving a patient onto a long backboard has typically involved the logroll maneuver. The effectiveness of this transfer technique has been questioned. Significant lateral motion of the lumbar spine has been reported to occur. Alternatives to the logroll maneuver include the HAINES (high arm in endangered spine) method and the multihand or fireman lift method. In the HAINES method, the patient is placed supine, the upper arm away from the kneeling rescuer is abducted to 180°, the near arm of the patient is placed across the patient’s chest, and both lower limbs are flexed. The rescuer’s hands stabilize the head and neck and the patient is rolled away onto an extrication board or device. The multihand or fireman lift method involves several rescuers on either side of the patient, each of whom slides his or her arms underneath the patient and lifts the patient from 1 position to the other onto an extrication board or device.

The above review describes the evolution of and underscores the diversity of techniques available for providing prehospital spinal immobilization of spine-injured patients during transport. These studies are limited by the fact that none of the studies evaluates the full range of available devices using similar criteria. Overall, it appears that a combination of rigid cervical collar immobilization with supportive blocks on a rigid backboard with straps to secure the entire body of the patient is most effective in limiting motion of the cervical spine after traumatic injury. The longstanding practice of attempted spinal immobilization with sandbags and tape with a rigid backboard is insufficient and is not recommended.

SAFETY OF PREHOSPITAL SPINAL IMMOBILIZATION DEVICES

Despite obvious benefits, cervical spinal immobilization has a few potential drawbacks. Immobilization can be uncomfortable; it can be difficult to apply properly; it takes time to apply; application may delay transport; and it is associated with modest morbidity. Chan et al studied the effects of spinal immobilization on pain and discomfort in 21 uninjured adults. Subjects were placed in backboard immobilization for 30 minutes, and symptoms were chronicled. All subjects developed pain, which was described as moderate to severe in 55% of volunteers. Occipital headache and sacral, lumbar, and mandibular pain were the most frequent complaints. In a later study, Chan and others compared spinal immobilization on a backboard with immobilization with a vacuum mattress-splint device in 37 normal adults. They found that the frequency and severity of occipital and lumbo-sacral pain were significantly greater during backboard immobilization than on the vacuum mattress-splint device. Johnson et al performed a prospective, comparative study of the vacuum splint device and the rigid backboard. The vacuum splint device was significantly more comfortable than the rigid backboard and was faster to apply. The vacuum splint device provided better immobilization of the torso. The rigid backboard with head blocks was slightly better at immobilizing the head. Vacuum splint devices, however, are not recommended for extrication because they are reportedly not rigid enough, and they are more expensive. At a cost of approximately $400, the vacuum splint device is roughly 3 times more expensive than a rigid backboard.

Hamilton and Pons studied the comfort level of 26 adults on a full-body vacuum splint device compared with a rigid backboard with and without cervical collars. Subjects graded their immobilization and discomfort. No statistically significant difference was found between the vacuum splint device–collar combination compared with the backboard-collars combination for flexion and rotation. The vacuum splint–collar combination provided significantly superior immobilization in extension and lateral bending than the backboard-collars combination. The vacuum splint device alone provided superior cervical spinal immobilization in all neck positions except extension compared with the rigid backboard alone. A statistically significant difference in subjective perception of immobilization was noted, with the backboard alone less effective than the other 3 alternatives. In conclusion, the vacuum splint device, particularly when used with a cervical collar, is an effective and comfortable alternative to a rigid backboard (with or without a collar) for cervical spinal immobilization.

Barney et al evaluated pain and discomfort during immobilization on rigid spine boards in 90 trauma patients and found that rigid spine boards cause discomfort. Padding the rigid board improves patient comfort without compromising cervical spine immobilization. Minimizing the pain of immobilization may decrease voluntary movement and therefore decrease the likelihood of secondary injury.

Cervical collars have been associated with elevations in intracranial pressure (ICP). Davies et al prospectively analyzed ICP in a series of injured patients using the Stifneck rigid collar. ICP rose significantly (P < .001; mean, 4.5 mm Hg) when the collar was firmly in place. They cautioned that because head-injured patients may also require cervical spinal immobilization, it is essential that secondary insults producing raised ICP are minimized. Kolb and coinvestigators also examined changes in ICP after the application of a rigid Philadelphia collar in 20 adult patients. ICP averaged 176.8 mm H2O initially and...
increased to an average of 201.5 mm H₂O after collar placement. Although the difference in ICP of 24.7 mm H₂O was statistically significant ($P = .001$), it remains uncertain that it has clinical relevance. Nonetheless, this modest increase in pressure may be important in patients who already have elevated ICP. Plaisier et al. in 1994 prospectively evaluated craniofacial pressure with the use of 4 different cervical orthoses. They found small changes in craniofacial pressure (increases) but no significant differences between the 4 collar types.

Spinal immobilization increases the risk of pressure sores. Linares and associates found pressure sores were associated with immobilization (patients who were not turned during the first 2 hours after injury). The development of pressure sores was not related to mode of transportation to hospital or the use of a spinal board and sandbags during transportation. Mawson et al. prospectively assessed the development of pressure ulcers in 39 spinal cord-injured patients who were immobilized immediately after injury. The length of time on a rigid spine board was significantly associated with the development of decubitus ulcers within 8 days of injury ($P = .01$). Rodgers and Rodgers reported a marginal mandibular nerve palsy resulting from compression by a hard collar. The palsy resolved unevenly during the next 2 days. Blaylock found that prolonged spinal immobilization may result in pressure ulcers. Improved skin care (keeping the skin dry), proper fitting (avoiding excessive tissue pressure), and the appropriate choice of collars (those that trap or do not absorb moisture or that exert significant tissue pressure) can reduce this risk. Skin breakdown is another potential complication of spinal immobilization. This can occur within 48 hours of application of a cervical collar.

Cervical spinal immobilization may also increase the risk of aspiration and may limit respiratory function. Bauer and Kowalski examined the effect of spinal immobilization with the Zee Extrication Device and the long spinal board on pulmonary function. They tested pulmonary function in 15 healthy, nonsmoking men using forced vital capacity (FVC), forced expiratory volume in 1 second (FEV₁), the FEV₁:FVC ratio, and forced midexpiratory flow (25%-75%). They found a significant difference ($P < .05$) between preimmobilization strapping and poststrapping values for 3 of the 4 functions tested when on the long spinal board. Similarly significant differences were found for 3 of the 4 parameters using the Zee Extrication Device. These differences reflect a marked pulmonary restrictive effect of appropriately applied entire-body spinal immobilization devices.

Totten and Sugarman evaluated the effect of whole-body spinal immobilization on respiration in 39 adults. Respiratory function was measured at baseline, once immobilized with a Philadelphia collar on a rigid backboard, and when immobilized on a Scandinavian vacuum mattress with a vacuum collar. The comfort levels of each of the 2 methods were assessed on a visual analog scale. Both immobilization methods restricted respiration by an average of 15%. The effects were similar with the 2 methods, although the FEV₁ was lower on the vacuum mattress. The vacuum mattress was significantly more comfortable than the wooden backboard.

Haut et al. conducted a retrospective analysis comparing patients with and without prehospital spine immobilization after penetrating trauma (knife stab and gunshot). Their study revealed that patients with penetrating injuries to the spine rarely have spinal instability even when the penetrating trauma specifically injures the spine and that spine-immobilized penetrating trauma patients were twice as likely to die as those who were not treated with spinal immobilization. They estimated that the number of patients with a penetrating spinal injury needed to treat with spinal immobilization to potentially benefit 1 patient was 1032. They estimated that the number of patients needed to harm 1 patient with the use of spinal immobilization, potentially contributing to death, was 66. The time required for the proper application of spinal immobilization devices in patients who have suffered stab and gunshot wounds delays patient resuscitation, resulting in increased morbidity and mortality.

Other potential problems with spinal immobilization have been reported in patients with ankylosing spondylitis. In 1 series, 15 patients with ankylosing spondylitis were followed up after sustaining spinal trauma. Twelve of the 15 patients deteriorated neurologically after presentation. In more than one of these patients, neurological deterioration was felt to be secondary to spinal immobilization protocols.

In conclusion, cervical spine immobilization devices are generally effective at limiting spinal motion but may be associated with increased morbidity in certain instances. Cervical spinal immobilization devices should be used to achieve the goals of safe extrication and transport yet should be removed as soon as it is safe to do so. Spinal immobilization for patients with penetrating injuries does not appear to be efficacious.

**SUMMARY**

Spinal immobilization can reduce untoward movement of the cervical spine and can reduce the likelihood of neurological deterioration in patients with unstable cervical spinal injuries after trauma. Immobilization of the entire spinal column is necessary in these patients until a spinal cord injury (or multiple injuries) has been excluded or until appropriate treatment has been initiated. Although immobilization of the cervical spine after trauma is not supported by Class I or II medical evidence, this effective, time-tested practice is based on anatomic and mechanical considerations in an attempt to prevent spinal cord injury and is supported by years of cumulative trauma and triage clinical experience.

Not all trauma patients must be treated with spinal immobilization during prehospital resuscitation and transport. Many patients do not have spinal injuries and therefore do not require such intervention. The development of specific selection criteria for those patients for whom immobilization is indicated remains an area of investigation. Current publications on the use of contemporary, well-defined EMS triage protocols provide Class II medical evidence for their utility.

The variety of techniques used and the lack of definitive evidence to advocate a uniform device for spinal immobilization
make immobilization technique and device recommendations difficult. It appears that a combination of a rigid cervical collar with supportive blocks on a rigid backboard with straps and tape to immobilize the entire body is effective at achieving safe, effective spinal immobilization for transport. The longstanding practice of attempted spinal immobilization with sandbags and tape with the patient strapped to a rigid backboard is not sufficient and is not recommended.

Cervical spine immobilization devices are effective but can result in patient morbidity. Spinal immobilization devices should be used to achieve the goals of spinal stability for safe extrication and transport. They should be removed as soon as a definitive evaluation is accomplished and/or definitive management is initiated. Spinal immobilization of trauma patients with penetrating injuries is not recommended.

KEY ISSUES FOR FUTURE INVESTIGATION

The optimal device for immobilization of the cervical spine after traumatic vertebral injury should be studied in a prospective fashion. A sensitive, reliable, and valid in-field triage protocol to be applied by EMS personnel for patients with potential cervical spine injuries after trauma should be studied in greater detail.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

REFERENCES

36(7):649-653.


Transportation of Patients With Acute Traumatic Cervical Spine Injuries

KEY WORDS: Definitive SCI care facility, Early expeditious transfer, Transport after SCI

RECOMMENDATIONS

Level III:

- Expeditious and careful transport of patients with acute cervical spine or spinal cord injuries is recommended from the site of injury by the most appropriate mode of transportation available to the nearest capable definitive care medical facility.

- Whenever possible, the transport of patients with acute cervical spine or spinal cord injuries to specialized acute spinal cord injury treatment centers is recommended.

RATIONALE

Complete and accurate care of the patient with an acute traumatic cervical spine injury cannot be provided at the accident scene. Proper care for patients with spinal injuries includes immobilization, extrication, initial resuscitation, and early transport of the patient to a medical center with the capability for diagnosis and treatment. Less favorable outcome, longer hospitalizations, and increased costs are associated with delayed transportation of spinal injury patients to a definitive treatment center. Selecting the most appropriate mode of transportation from the site of injury to a definitive treatment facility for an individual patient depends on the patient’s clinical circumstances, distance, geography, and availability. Land (ambulance) and air (helicopter or fixed-wing plane) are the primary modes available to transport the spinal injury patient. The goal is to expedite safe and effective transportation without an unfavorable impact on patient outcome. These factors provide the rationale to establish medical evidence-based guidelines for the transportation of patients with acute traumatic cervical spine and spinal cord injuries (SCIs). The guidelines author group of the Joint Section on Disorders of the Spine and Peripheral Nerves of the American Association of Neurological Surgeons and the Congress of Neurological Surgeons have previously produced a medical evidence-based guideline on this topic. The current review is undertaken to update the medical evidence on the transport of acute SCI patients since that 2002 publication.

SEARCH CRITERIA

A National Library of Medicine (PubMed) computerized literature search from 1966 to 2011 was completed using Medical Subject Headings in combination with “spinal injury” and “transport.” The search was limited to the English language and yielded 10,008 citations for the first search term and 71,323 articles for the second. A search combining both search terms provided 259 articles. All 259 abstracts were reviewed. Additional references were culled from the reference lists of the remaining articles. Finally, members of the author group were asked to contribute articles known to them on the subject matter that were not found by other search means. A total of 16 articles directly relevant to the subject of transportation of spine-injured patients were identified. All provided Class III medical evidence. The 11 most pertinent publications are summarized in Evidentiary Table format (Table).

ABBREVIATIONS: ASCIU, Acute Spinal Cord Injury Unit; SCI, spinal cord injury
One of the basic principles of prehospital spinal care is the early transfer of the injured patient to a center with the resources and expertise to manage acute cervical spine injuries or SCIs. Better neurological outcomes with fewer complications have been reported when early transfer to a specialized SCI center is accomplished. Limiting untoward spinal motion during transportation of patients with cervical spine injuries is considered essential to preserve neurological function and to limit further injury from spinal instability. The transport of injured patients to the closest definitive care facility can be provided with a variety of transportation methods. Choosing the mode of transportation depends on the patient's overall medical status, the distance to the nearest capable facility, and the availability of resources.

In 1974, Hachen described the creation of a nationwide emergency transportation protocol for spinal injury patients implemented in Switzerland in 1966. All SCI patients in Switzerland were immediately transported to The National Spinal Injuries Centre in Geneva by the Swiss Air Rescue Organization. In the year follow-up of this protocol published in 1977, Hachen reported that early transport from the site of the accident to the SCI center under close medical supervision was associated with no patient death during transport. Before 1968, multiple deaths occurred during transport secondary to acute respiratory failure before definitive care could be provided. After 1968, patients were transported rapidly with an onboard anesthesiologist who provided respiratory, cardiac, and hemodynamic monitoring, resuscitation, and nasotracheal intubation as necessary. The average time for the rescue operation was reduced from 4.5 hours to 50 minutes. There was a significant reduction in cardiovascular and respiratory morbidity and mortality. The mortality rate for complete quadriplegic patients dropped from 32.5% in 1966 to 6.8% in 1976 and that for incomplete cervical cord injury patients from 9.9% to 1.4% during the same time period. Hachen concluded that survival and outcome of patients with acute SCIs were enhanced by a well-organized medical system and rapid medically supervised transfer by helicopter to a specialized center, followed by definitive care in a SCI facility for aggressive management in the intensive care unit setting.

Zäch et al in 1976 described their experience with 117 acute SCI patients managed per prospective protocol in the Swiss Paraplegic Centre in Basel, Switzerland. All patients were treated in the intensive care unit setting with aggressive medical management and cardiac and blood pressure support. Outcome was stratified by initial injury and time of admission after injury. Sixty-two percent of cervical SCIs managed in this fashion improved at the last follow-up. No patient with a cervical level injury worsened; 38% were unchanged. Of patients who arrived within 12 hours of injury, 67% improved compared with their initial neurological condition. Fifty-nine percent of patients admitted between 12 and 48 hours of injury showed neurological improvement. When admission occurred after 48 hours of injury, improvement was seen in only 50% of patients. The authors concluded that early transport and "immediate medical specific treatment of the spinal injury" appeared to facilitate neurological recovery.

In 1984, Tator et al reported their experience with 144 patients with acute SCIs treated between 1974 to 1979 at the Acute Spinal Cord Injury Unit (ASCIU) at Sunnybrook Medical Centre in Toronto, Ontario, Canada. They found a marked reduction in both morbidity and mortality after acute SCI for the group of patients managed from 1974 to 1979 compared with a similar group of patients managed from 1947 to 1973, before the creation of a dedicated, regional spinal cord injury unit. Reasons cited for these improvements included earlier transport to the ASCIU after trauma and better definitive management on arrival.

In a subsequent 1993 publication comparing ASCIU patients managed from 1974 to 1981 with their historical population of patients managed from 1947 to 1973, Tator and colleagues noted a statistically significant difference in duration of time from injury to arrival, 5 hours for ASCIU patients compared with 13 hours for the pre-ASCIU group. They found a significant decrease in the severity of SCI (65% complete cervical lesions compared with 46% for ASCIU patients) and noted fewer complications, shorter hospital stays, and lower expenses for patients managed under the new ASCIU paradigm. Their findings support the advantages of early transport to a regional, specialized SCI center for definitive comprehensive care of patients with SCIs.

Burney et al reviewed the means of transport and type of stabilization used for all patients with acute SCIs transferred to the University of Michigan Medical Center from 1985 to 1988 to determine the effect of these variables on impairment and neurological improvement. Sixty-one patients were reviewed. Twenty-five patients were transported by ground ambulance (41%), 33 by helicopter (54%), and 3 by fixed-wing aircraft (5%). Forty-three patients (70.5%) had cervical spinal injuries, 11 patients (18%) had thoracic spine injuries, and 7 patients (11.5%) had lumbar spinal injuries. Fifty-one patients (84%) were transferred within 24 hours of injury. A variety of standard methods of stabilization were used during transport. No patient suffered an ascending injury as a result of early transport. Level of function improved before discharge in 26 of 61 patients (43%). Patients transported to the medical center within 24 hours of injury were more likely to show improvement (25 of 51) than those transported after 24 hours (1 of 10). There was no significant difference in the probability of improvement between ground (8 of 25 patients) and air (18 of 36 patients) transportation. The authors concluded that acute SCI patients could
### TABLE. Evidentiary Table: Transportation

<table>
<thead>
<tr>
<th>Citation</th>
<th>Description of Study</th>
<th>Evidence Class</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crandall et al, 2010</td>
<td>Retrospective review trauma patients who underwent interfacility transfer and those who did not</td>
<td>III</td>
<td>Although the majority of transfers occur at greater than the mandated 2-h interval, the most seriously injured patients are reaching definitive care within 2 h. Markers of acuity for patients transferred at &gt;2 h parallel those of the general trauma patient population. These data suggest that, in this system, provider-determined transfer time that exceeds 2 h has no adverse effect on patient outcome.</td>
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<tr>
<td>Bagnal, 2008</td>
<td>To answer the question: Does immediate referral to a spinal injury center result in a better outcome than delayed referral?</td>
<td>III</td>
<td>The current evidence does not enable conclusions to be drawn about the benefits or disadvantages of immediate referral vs late referral to spinal injury centers. Well-designed, prospective, experimental studies with appropriately matched controls are needed.</td>
</tr>
<tr>
<td>Bernhard et al, 2005</td>
<td>Review of prehospital management on spinal cord injury care</td>
<td>III</td>
<td>Careful movement and the use of appropriate extrication techniques are crucial in all trauma patients with cervical column injury or in mechanisms of injury with the potential to cause spinal injury.</td>
</tr>
<tr>
<td>Tator et al, 1993</td>
<td>201 ASCI patients, ICU care, hemodynamic support compared with 351 prior patients</td>
<td>III</td>
<td>Less severe cord injuries resulted from immobilization, resuscitation, and early transfer to and ICU setting.</td>
</tr>
<tr>
<td>Armitage et al, 1990</td>
<td>Case reports of 4 patients who developed respiratory problems during airplane transport</td>
<td>III</td>
<td>Airplane air is less humid, and measures to optimize humidity and pulmonary function travel in patients with high cervical injury may be required.</td>
</tr>
<tr>
<td>Boyd et al, 1989</td>
<td>A prospective cohort study to determine the effectiveness of air transport for major trauma patients when transferred to a trauma center from a rural emergency room</td>
<td>III</td>
<td>Patients with severe multiple injury from rural areas fare better with helicopter emergency medical service than ground emergency medical service.</td>
</tr>
<tr>
<td>Burney et al, 1989</td>
<td>Retrospective review of the means of transport and type of stabilization used for all patients with ASCIs</td>
<td>III</td>
<td>ASCI patients can be safely transported by air or ground when standard precautions are used.</td>
</tr>
<tr>
<td>Tator et al, 1984</td>
<td>Retrospective review of results of innovations between 1974 and 1979 at Sunnybrook Medical Centre in Toronto; the unit achieved a marked reduction in both mortality and morbidity</td>
<td>III</td>
<td>Patients were transferred to the SCI unit earlier, with a consequent marked reduction in complications and cost of care.</td>
</tr>
<tr>
<td>Hachen, 1977</td>
<td>188 patients with ASCI managed in the ICU; aggressive treatment of hypotension and respiratory insufficiency</td>
<td>III</td>
<td>Morbidity and mortality were reduced with early transfer, attentive ICU care and monitoring, and aggressive treatment of hypotension and respiratory failure.</td>
</tr>
<tr>
<td>Zach et al, 1976</td>
<td>117 patients with ASCI at a Swiss center, ICU setting; aggressive blood pressure and volume therapy</td>
<td>III</td>
<td>Neurological outcome was improved with aggressive medical treatment. Outcome was better for early referrals.</td>
</tr>
<tr>
<td>Hachen, 1974</td>
<td>Rheomacrodex for 5 d Dexamethasone for 10 d</td>
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ASCi, acute spinal cord injury; ICU, intensive care unit.
be safely transported by air or ground when standard precautions are used. They found that distance and the extent of the patient’s associated injuries were the best determinants of the mode of transport.

Rural areas reportedly account for 70% of fatal accidents, and rural mortality rates for victims of motor vehicle accidents are 4 to 5 times greater than those in urban areas. A prospective cohort study by Boyd et al. examined the effectiveness of air transport of major trauma patients when transferred to a trauma center from a rural emergency room. The study consisted of 872 consecutive trauma patients admitted after long-distance transfer. The authors found a 25.4% reduction in predicted mortality (Z = 3.95; P < .001). The benefit of helicopter emergency medical service transport was realized only in major trauma victims with a probability of survival of < 90%. Thus, the benefits identified with early helicopter emergency medical service transport were directly related to injury severity. It is unclear whether these findings can be extrapolated to spine-injured and/or SCI patients because the authors did not stratify injuries by body systems in their report.

Neither land nor air transport has been reported in the literature to negatively affect the outcome of spine-injured patients when properly executed. One note of caution was offered by Armitage et al. They described 4 spine-injured patients who developed respiratory distress or failure during airplane transport. They noted that because patients with cervical SCIs may have severely reduced pulmonary performance, measures to optimize oxygenation, humidification, and pulmonary function in cervical SCI patients should be undertaken.

The role that specialized centers play in the care of patients with SCIs has long been a topic of debate. In 1990, DeVivo et al compared patients admitted to their multidisciplinary SCI center at the University of Alabama within 1 day of injury with a group of similar SCI patients who received their acute care outside of their facility and were transferred later, solely for rehabilitation. The demographics of the 2 SCI patient groups were similar. The authors reported statistically significant reductions in length of care in acute care and total length of hospitalization, coupled with a highly significant reduction in the incidence of pressure ulcers among patients admitted within 1 day of injury.

Further support for the transport of SCI patients to specialized SCI centers for acute care was offered by Swain and Grundy in 1994. They compared the outcomes of 420 SCI patients who underwent spinal surgery after acute SCI with a cohort of similar patients operated on at other facilities and later transferred to their center. They noted that “complications were more frequent in patients undergoing spinal surgery before transfer to the center. Furthermore, the longer the delay in transfer, the higher the incidence of pressure sores.”

Since the publication of the previous medical evidence-based guidelines on this issue in 2002, 2 contemporary articles germane to the issue of transportation/transfer of seriously injured patients have been published. In 2004, Jones and Bagnall addressed the issue of to which type of facility should acute SCI patients be transferred. In contrast to prior studies that suggest that SCI patients have better outcomes when treated at specialized centers, their Cochrane Review concluded that there is not sufficient evidence to support either the immediate or delayed transfer of SCI patients to a specialized facility. Their summary is predictable given that there is no Class I or Class II medical evidence on this topic.

In 2010, Crandall et al reported the timing of transfer data from a state-wide trauma registry in Illinois from 1999 to 2003. During that period, there were 22,447 interfacility transfers. The overall transfer rate was 10.4%. Only 20% of the transfers occurred within the arbitrary yet mandated 2-hour transfer interval. Measured outcomes included the Injury Severity Score, mortality, and the time interval to the operating room at the receiving facility. They found that even though most transfers exceeded the recommended 2-hour window limit, there were no adverse effects on patient outcome. The authors concluded that the most seriously ill patients were being transferred expeditiously and that there was no need for a mandated 2-hour transfer interval.

**SUMMARY**

The patient with an acute cervical spinal injury or SCI should be expeditiously and carefully transported from the site of injury to the nearest capable definitive care medical facility. The mode of transportation chosen should be based on the patient’s clinical circumstances, distance from target facility, and geography to be traveled and should be the most rapid means available. Immobilization of patients with acute cervical spinal cord and/or spinal column injuries is recommended. Cervical SCIs have a high incidence of airway compromise and pulmonary dysfunction; therefore, respiratory support measures should be available during transport. Several studies cited suggest improved morbidity and mortality of spinal cord-injured patients after the advent of sophisticated transport systems to dedicated SCI treatment centers. These studies all provide Class III medical evidence on this issue.

**KEY ISSUES FOR FUTURE INVESTIGATION**

Development and refinement of transportation protocols for patients with cervical spine and SCI should be undertaken and could be accomplished with a large prospectively collected data set. From these data, additional case-control or comparative cohort studies could be structured to generate Class II evidence.

**Disclosure**

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

**REFERENCES**

Clinical Assessment Following Acute Cervical Spinal Cord Injury

KEY WORDS: Clinical assessment, Functional outcome, Neurological examination, Pain assessment

Neurosurgery 72:40–53, 2013 DOI: 10.1227/NEU.0b013e318276edda

RECOMMENDATIONS

Neurological Examination:
Level I:
• The American Spinal Injury Association international standards for neurological and functional classification of spinal cord injury are recommended as the preferred neurological examination tool for clinicians involved in the assessment and care of acute spinal cord injury patients.

Functional Outcome Assessment:
Level I:
• The Spinal Cord Independence Measure III is recommended as the preferred functional outcome assessment tool for clinicians involved in the assessment, care, and follow-up of patients with spinal cord injuries.

Pain Associated With Spinal Cord Injury:
Level I:
• The International Spinal Cord Injury Basic Pain Data Set is recommended as the preferred means to assess pain, including pain severity, physical functioning, and emotional functioning, among SCI patients.

Rationale

Acute traumatic spinal cord injury (SCI) affects 12,000 to 15,000 people in North America each year. The functional consequences of an acute SCI are variable; therefore, the initial clinical presentation of patients with an acute SCI is a key factor in determining triage, defining therapy, and predicting prognosis. The patient must be assessed with an accurate, consistent, and reproducible neurological assessment scale to define the acute SCI patient’s neurological deficits and to facilitate communication about patient status to caregivers. The early neurological status of an injury victim as described by an ideal neurological assessment scale should also have prognostic value for that patient’s neurological future. The comprehensive clinical assessment of the SCI patient should both accurately describe the patient’s neurological function (motor and sensory examinations) and generally predict that patient’s future relative abilities and/or impairment given the patient’s neurological status. Prognostic information provided by comparing current injury victims and the functional outcomes of historical patients with similar injuries is of value to patients and families. The evaluation of new therapies proposed for the treatment of acute SCI requires the use of accurate, reproducible neurological assessment scales and reliable functional outcome measurement tools to measure potential neurological improvement after therapy and, importantly, to determine its functional significance.

Pain of the spinal cord, spinal column, or other orthopedic origin is often of clinical significance following acute SCI. Pain can be horribly debilitating, hindering patient performance and limiting functional abilities beyond that predicted by the patient’s neurological deficits. These 3 topics (neurological assessment, functional outcome, and pain associated with SCI) are the focus of this contemporary update on the Clinical Assessment Following Acute Spinal Cord Injury, previously produced and published by the Joint Section on Disorders of the Spine.
and Peripheral Nerves of the American Association of Neurological Surgeons and the Congress of Neurological Surgeons.1

SEARCH CRITERIA

A computerized search of the database of the National Library of Medicine (PubMed) of the literature published from 1966 to 2011 was performed for each of the 3 subtopics reviewed in this guideline: neurological assessment, function outcome, and pain following SCI. The search was limited to the English language, the human literature, and reviews, case series, meta-analyses, and randomized clinical trials of adult patients published between 1966 and 2011. The term “spinal cord injury” was combined with the terms “neurological assessment,” yielding 1444 references. A second search using the terms “spinal cord injury” and “assessment scales” yielded 81 references. A third search employing the terms “spinal cord injury” and “assessment scores” revealed 178 publications. A search using “ASIA impairment scale” yielded 351 citations. A search using the terms “ASIA classification” and “spinal cord” yielded 113 references (total, 2167).

For functional outcome, each PubMed database search was limited to the English language, the human literature, and reviews, case series, meta-analyses, and randomized clinical trials published between 2000 and 2010. Search terms “spinal cord injury” and “functional outcomes assessment” yielded 448 references. Search terms “spinal cord injury” and “functional outcome scales” yielded 28 citations. A search for “functional independence measure” resulted in 1132 references. A search for “spinal cord independence measure” revealed 190 citations (total, 1798).

For pain following SCI, each PubMed database search was limited to the English language, the human literature, and reviews, case series, meta-analyses, and randomized clinical trials published between 1966 and 2010. Search terms “spinal cord injury” and “pain” resulted in 2093 references. Search terms “spinal cord injury” and “pain classification” yielded 91 citations. A search using the terms “spinal cord injury” and “pain assessment scales” produced 26 references. Search terms “spinal cord injury” and “pain assessment scale” resulted in 121 references (total 2331).

The 733 references for neurological assessment, the 520 references for functional outcome, and the 1050 citations for pain following SCI were imported into a database, and duplicates were eliminated. Articles germane to each of the 3 topics were selected by reviewing their titles and abstracts. Additional references were culled from the reference lists of the remaining papers. Finally, members of the author group were asked to contribute articles known to them on the subject matter that were not found by other search means. The citations critical to the formulation of this guideline on each of the 3 topics are provided in Evidentiary Table format (Tables 1-3).

SCIENTIFIC FOUNDATION

A variety of neurological assessment systems/scales have been utilized for the documentation of the neurological status of patients following SCI. They include the Frankel Scale; the modified Frankel Scale; the Lucas and Ducker Neurotrauma Motor Index; the Sunnybrook, the Botsford, and the Yale scales; the NASCIS scale; the American Spinal Injury Association (ASIA) scale; and the ASIA/International Medical Society of Paraplegia international standards for neurological and functional classification of SCI scale, now referred to as the American Spinal Injury Association Classification Standards.2-21

Several of these assessment scales have been refined through serial iterations.2,4,8,11,17,19,20,22 A few are widely used, while others have not attained general acceptance and recognition. Ideally, the clinical neurological assessment of acute SCI victims should be uniform, reproducible, and thorough yet easy to use. The assessment tool must be detailed and precise to specifically document a given patient’s injury and must provide descriptive measurement scales that allow determination of loss or gain of function with time and therapy. Nearly simultaneously, there must be correlation of the patient’s functional abilities relative to their neurological examination to document whether losses or gains have meaningful significance to the patient and to accurately determine outcome. This is typically accomplished using a scale to quantify Functional Outcome in conjunction with a Neurological Assessment scale. Whatever assessment system(s) is/are used, it/them must be consistent and accurate and have interrater reliability. Difficulties exist when clinicians utilize poorly defined measurement tools or different methods of neurological assessment to describe the same patient, hindering the definition (potentially the management) of that patient by different clinicians and the comparison of that patient with other patients with similar injuries. The accurate assessment of both the neurological status and the functional skills of acute SCI patients is essential for patient management, the conduct of research studies, and comparisons of clinical therapeutic trials.

Numerous assessment scales have been used to evaluate patients with SCI. Scales may be divided into 2 general types. The first type is examination-specific and focuses on the neurological deficits suffered as a result of SCI. These scales use the motor and sensory examination primarily (or exclusively) to assign a numerical value or letter grade.4,8,9,12,15,17-20,23 The second type of scale focuses on functional skills, including a patient’s ability to care for himself or herself, participate in personal hygiene, transfer, or ambulate.10,11,22,24-34 In general, the first type of scale is used for the acute assessment of patients with SCI, whereas both assessment scales are used to define the chronically injured patient. The contemporary assessment of SCI patients incorporates both neurological examination scales and functional outcome/assessment scales to most accurately describe individual patients.10,11,35 Finally, the clinical assessment of patients with acute SCI should include an assessment of pain severity, physical functioning, and emotional functioning experienced by that patient. Several pain classification systems have been developed, and 13 pain intensity instruments have been designed and utilized to describe pain among SCI patients.36-38
NEUROLOGICAL EXAMINATION SCALES

A comprehensive medical evidence-based review of neurological assessment scales used to assess acute adult SCI patients was published in 2002. In 2002, based on the best medical evidence in the literature to that point, the guidelines author group concluded that the 1996 ASIA standards were the most valid and reliable neurological assessment scale available to clinicians who care for these patients. This recommendation was offered as an Option Level or Level III recommendation.

Since the 2002 guideline publication, several investigators have further studied the reliability and validity of the ASIA standards as a neurological examination scale for adult patients following acute SCI. Kirshblum et al compared the revised 2000 ASIA Classification Standards with the previous 1996 ASIA standards. Ninety-four subjects with SCI who were assessed with the 1996 standards at 1 week and 1 year after injury were retrospectively reassessed using the revised 2002 ASIA Standards. They found nearly perfect agreement between the 2 scales (weighted κ scores between 0.995 and 0.91; confidence intervals between 0.79 and 1.0). Three of 17 ASIA C categorized patients based on the 1996 standards were categorized as ASIA B using the 2000 standards, a distinction that had no impact on prognosis at 1 year follow-up examination.

In 2003, Burns and colleagues retrospectively discovered that 5 of 81 acute SCI patients (6%) initially scored as ASIA A injuries at their institution were reclassified as ASIA B within the first week of injury. They used 1-year follow-up assessments for comparison. They cited closed head injury, drug effects, mechanical ventilation, and psychological disorders as factors that could potentially interfere with the ability to accurately examine a patient. They concluded that these factors could diminish the reliability of the initial examination on admission.

Marino and Graves reported on the metrics of the ASIA motor score in correlation with functional activities and functional impairment in 2004. They used item response theory methods to determine the value of the use of ASIA motor score/subscores to predict motor Functional Independence Measure (FIM) instrument scores among a database of 4338 SCI patients discharged from inpatient rehabilitation between 1994 and 2003. They concluded that functional impairment following SCI is more accurately described by the use of separate upper- and lower-extremity ASIA motor scores rather than a single, total ASIA motor score. Similarly, in 2006, Graves et al concluded that the use of upper- and lower-extremity motor scales will reduce measurement error when the ASIA motor score is used as a predictor of outcome. In an assessment of the ASIA motor score scales in 6116 SCI patients, they found that the use of 2 scales was more accurate and could distinguish between complete paraplegia and incomplete SCI (in both instances the ASIA motor score could equal 50) more reliably than the use of a single total ASIA motor scale score.

In 2007, Slavicek et al reported on the interrater reliability of the ASIA standards motor and sensory examinations performed by 2 experienced examiners in a prospective observational study and assessment of 45 SCI patients. The total ASIA score showed a very strong correlation between the 2 examiners with Pearson correlation coefficients and intraclass correlation coefficients exceeding 0.99 for total motor and light touch scores and 0.97 for pinprick scores. Weighted κ values for myotome determination when a sufficient number of observations allowed statistical analysis were 0.785 to 0.981, indicating substantial to almost perfect agreement. Level of agreement between the 2 examiners for level of injury ranged between 73% and 80%. The unweighted κ coefficient for agreement in motor and sensory levels ranged from 0.68 to 0.78, indicating substantial agreement (Class II medical evidence). There was no difference in ASIA impairment grades between the 2 examiners’ results.

Furlan et al performed 2 similar but separate literature reviews and have produced 2 publications on the psychometric properties of the ASIA Standards, one in 2008 and the other in 2010. There is no accepted “gold standard” neurological assessment examination against which to compare all others. They reported that the ASIA standards have not been evaluated adequately with respect to several of the 8 quality criteria for psychometric properties of instruments as proposed by Terwee and colleagues. Convergent construct validity, reliability, and responsiveness have been the criteria of the ASIA standards most rigorously scientifically studied. There are recognized minor variances noted among investigators in each criterion as summarized above. There is the potential for floor effects on the motor score assessment among paraplegic patients (no measure of motor function between T1 and L1) and a ceiling effect among the quadriplegic patients (injury above measurable motor units), which can affect scoring scale accuracy and hinder comparison to other similarly injured SCI patients. The ASIA standards cannot be accurately applied to SCI patients who cannot be accurately examined owing to confounding factors (This is not a failure/weakness of the scoring scale) and are not applicable to adolescents and children. Despite these few, but real, potential problematic features, the 2000 American Spinal Injury Association (ASIA) Standards is the most consistent, reliable, valid and responsive scoring system for the Neurological Assessment of adult patients with acute SCI, to a high degree of scientific certainty.

FUNCTIONAL OUTCOME SCALES

Functional outcome scales are measures of human performance and ability/disability typically defined during medical rehabilitation, i.e., how a person functions with activities of everyday life after injury/impairment/debilitating illness. Several scales have been employed or developed in an effort to accurately characterize an injury victim’s functional skills and disabilities after SCI in order to quantify his or her functional independence. They attempt to determine a patient’s ability or inability to function and/or live independently. Scales for functional rating include the Barthel Index, the modified Barthel Index, the FIM, the Quadriplegic Index of Function (QIF), the Spinal Cord Independence Measure (SCIM), the Walking Index for SCI, the Spinal...
TABLE 1. Evidentiary Table: Clinical Neurological Assessment: Neurological Examination

<table>
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<tr>
<th>Reference</th>
<th>Description of Study</th>
<th>Evidence Class</th>
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<tr>
<td>Savic et al, Spinal Cord, 2007</td>
<td>Assessment of interrater reliability of motor/sensory examinations of ASIA standards</td>
<td>II</td>
<td>( \kappa ) values for agreement in motor and sensory examinations, 0.68-0.78, indicating substantial agreement.</td>
</tr>
<tr>
<td>Graves et al, Journal of Spinal Cord Medicine, 2006</td>
<td>Comparison of total ASIA motor score with separate upper- and lower-extremity scores to describe SCI</td>
<td>III</td>
<td>Use of upper- and lower-extremity scores will reduce measurement error compared to total ASIA motor score.</td>
</tr>
<tr>
<td>Marino and Graves, Archives of Physical Medicine and Rehabilitation, 2004</td>
<td>IRT methods to assess total ASIA motor score vs ASIA subscores for upper/lower extremity to predict FIM</td>
<td>III</td>
<td>Impairment from SCI is more accurately characterized using upper/lower-extremity ASIA subscores.</td>
</tr>
<tr>
<td>Burns et al, Journal of Neurotrauma, 2003</td>
<td>Assessment of early ASIA grade with one week and one year follow-up.</td>
<td>III</td>
<td>Earliest ASIA grade assignment may be inaccurate due to confounding features that limit examination.</td>
</tr>
<tr>
<td>Jonsson et al, Spinal Cord, 2008</td>
<td>To determine the interrater reliability of the ISCSCI-92</td>
<td>III</td>
<td>This study indicates a weak interrater reliability for scoring incomplete SCI lesions using the ISCSCI-92.</td>
</tr>
<tr>
<td>Cohen et al, Spinal Cord, 1998</td>
<td>A test of the ISCSCI-92</td>
<td>III</td>
<td>Further revisions of the 1992 ASIA standards and more training are needed to ensure accurate classification of SCI.</td>
</tr>
<tr>
<td>El Masry et al, Spine, 1996</td>
<td>Validation of the ASIA motor score and the NASCIS motor score</td>
<td>III</td>
<td>The ASIA and NASCIS motor scores can both be used for the neurological quantification of motor deficit and motor recovery.</td>
</tr>
<tr>
<td>Wells and Nicosia, Journal of Spinal Cord Medicine, 1995</td>
<td>Comparison of Frankel Scale, Yale Scale, Motor Index Score, modified Barthel Index, and Functional Independence Measure</td>
<td>III</td>
<td>The best assessment tool is a combination of 2 scales, one based on impairment and the other on disability.</td>
</tr>
<tr>
<td>Waters et al, Archives of Physical Medicine and Rehabilitation, 1994</td>
<td>ASIA compared with motor scores based on biomechanical aspects of walking</td>
<td>III</td>
<td>ASIA motor score strongly correlates with walking ability.</td>
</tr>
<tr>
<td>Davis et al, Spine, 1993</td>
<td>Reliability of Frankel and Sunnybrook scales</td>
<td>III</td>
<td>Demonstrated high inter-rater reliability of Frankel and Sunnybrook scales.</td>
</tr>
<tr>
<td>Bednarczyk and Sanderson, Journal of Rehabilitation Research and Development, 1993</td>
<td>Compared several classification systems within the same group of spinal cord-injured subjects</td>
<td>III</td>
<td>ASIA scale showed the greatest discrimination in grouping subjects with SCI.</td>
</tr>
<tr>
<td>Botsford and Esses, Orthopedics, 1992</td>
<td>Description of a new functionally oriented scale with assessment of motor and sensory function, rectal tone, and bladder function</td>
<td>III</td>
<td>Scale was more sensitive for the detection of improvement in function.</td>
</tr>
<tr>
<td>Priebe and Waring, A American Journal of Physical Medicine and Rehabilitation, 1991</td>
<td>Interobserver reliability of the 1989 revised ASIA standards for neurological classification of spinal injury patients</td>
<td>III</td>
<td>The interobserver reliability for the revised ASIA standards is improved but continues to be less than optimal.</td>
</tr>
<tr>
<td>Bracken et al, 1990, New England Journal of Medicine</td>
<td>Multicenter North American trial examining effects of methylprednisolone or naloxone in ASCI (NASCIS II)</td>
<td>III for neuro assessment</td>
<td>Motor scores of 14 muscles on 5-point scale, right side of body only. Sensory scores of pinprick and light touch, 3-point scale, bilateral. No interrater reliability comparison.</td>
</tr>
<tr>
<td>Lazar et al, Archives of Physical Medicine and Rehabilitation, 1989</td>
<td>Relationship between MIS and the modified Barthel Index</td>
<td>III</td>
<td>The MIS is useful in predicting function during rehabilitation, although individual differences in ambulation limit its predictive utility.</td>
</tr>
<tr>
<td>Bracken et al, JAMA, 1984</td>
<td>Methylprednisolone in SCI</td>
<td>III for neuro assessment</td>
<td>Description of NASCIS motor score.</td>
</tr>
</tbody>
</table>
On the basis of the best medical evidence published in the English language literature through 2001 on adult SCI patients, 10,11,22,24,25,27-31,45,47-52,54 a comprehensive medical evidence-based review of functional outcome scales was published in 2002.1 On the basis of the best medical evidence published in the English language literature through 2001 on adult SCI patients, the guidelines author group advocated the use of the FIM as the functional outcome assessment tool of choice for SCI patients at a Guideline Level (Level II) recommendation.1

As described in the original guideline on the topic, FIM has proven to be a reliable, valid tool to assess the functional abilities of compromised patients with respect to activities of daily living and to assess the burden of care of those patients for a variety of medical disorders.32,60 Several investigator groups have been critical of FIM and its applicability to patients with neurological dysfunction following SCI.32,61 While widely used, FIM was not developed specifically for patients with SCI. It has been cited for its lack of sensitivity, particularly in locomotion, mobility, respiration, and bladder/bowel sphincter function items among patients with SCI.61 To address the shortcomings of FIM in documenting patient disability and the degree of functional recovery among SCI patients, 3 SCI-specific functional assessment scales were developed. The QIF, developed in 1980 to document the functional skills and abilities of tetraplegic patients (complete high cervical SCI patients), has poor applicability to the whole of the adult SCI population.27,32,62 The same is true of the Spinal Cord Injury Functional Ambulation Inventory, proposed in 2001, and the Walking Index for SCI. Both are tools to assess the walking abilities of patients with incomplete SCI.34,48,56,65

SCIM was proposed in 1997 as a new disability scale specific for patients with spinal cord pathology.24 An international collaborative author-investigator group has twice revised SCIM.33,64 In its current iteration, the SCIM III has been studied in detail and is reported to be sensitive, specific, valid, and reliable for the assessment of disability among SCI patients, both early and late after SCI 32,58,64,65. The SCIM instrument focuses on the patient’s ability to perform everyday tasks and captures the economic burden of disability, as well as the impact of their disability on the patient’s overall medical condition and comfort. It consists of 3 subscales that cover the related but distinct subsets of self-care (6 items; score range, 0-20), respiration and sphincter management (4 items; score range, 0-40), and mobility (9 items; score range, 0-40). The total score ranges from 0 to 100. The mobility subset is further subdivided into 2 subscales: room and toilet, and indoors and outdoors. Individual item scores range from 2 to 9 points. SCIM scores a task higher in patients who accomplish it with less assistance, aids, or medical compromise than other patients.

SCIM was introduced by Catz et al24 in 1997. This author group described the assessment of 30 patients with spinal cord pathology using SCIM. They assessed the interrater reliability

### TABLE 1. Continued

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<th>Reference</th>
<th>Description of Study</th>
<th>Evidence Class</th>
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</thead>
<tbody>
<tr>
<td>Chehrazi et al,15 Journal of Neurosurgery</td>
<td>Description of Yale scale</td>
<td>III</td>
<td>Provides assessment of the severity of SCI and the prognosis for recovery.</td>
</tr>
<tr>
<td>Lucas and Ducker,18 American Surgeon, 1979</td>
<td>A motor classification of patients with SCI injuries with statistically discrete subdivisions; the patients in each of the subdivisions of the classification can be mathematically summarized with numerical indices, which can be accurately analyzed statistically</td>
<td>III</td>
<td>Allows the clinical researcher to evaluate current treatments and assess the potential of new treatments and to assess the potential of new treatment regimens.</td>
</tr>
<tr>
<td>Bracken et al, Paraplegia, 1978</td>
<td>Description of 133 ASCI patients classified using motor and sensory scales developed by Yale SCI Study Group</td>
<td>III</td>
<td>Considerable discrepancy between motor and sensory impairment scales among patients with greater motor than sensory loss.</td>
</tr>
<tr>
<td>Frankel et al,17 Paraplegia, 1969</td>
<td>5-Category scale used in a large study to assess neurologic recovery in patients treated with postural reduction of spinal fractures</td>
<td>III</td>
<td>Present results in terms of defined degrees of neurological involvement.</td>
</tr>
</tbody>
</table>

TABLE 2. Evidentiary Table: Clinical Neurological Assessment: Functional Outcome Assessment

<table>
<thead>
<tr>
<th>Reference</th>
<th>Description of Study</th>
<th>Evidence Class</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ackerman et al.</td>
<td>Assessment of SCIM III as functional outcome tool after acute rehabilitation</td>
<td>III</td>
<td>SCIM III is sensitive, effective for outcome after rehabilitation. Floor/ceiling effects identified in some subgroups.</td>
</tr>
<tr>
<td>Bluvshtein et al.</td>
<td>Analysis of reliability and validity of SCIM III</td>
<td>I</td>
<td>κ Values of 0.649-0.858 for all SCIM III tasks. SCIM III more responsive than FIM.</td>
</tr>
<tr>
<td>Glass et al.</td>
<td>Analysis of SCIM III and FIM in SCI patients in the United Kingdom</td>
<td>III</td>
<td>SCIM III valid and reliable. Both SCIM III and FIM valid, SCIM III more sensitive than FIM.</td>
</tr>
<tr>
<td>Rudhe and van Hedel.</td>
<td>Comparison of 261 patients upper-extremity SCIM III scores with arm and hand muscle strength and hand function in tetraplegic patients</td>
<td>II</td>
<td>SCIM III accurately reflects upper-extremity function in tetraplegia.</td>
</tr>
<tr>
<td>Wirthe et al.</td>
<td>Analysis of sensitivity of SCIM III vs ASIA scores as late functional outcome tool</td>
<td>III</td>
<td>SCIM II sensitive tool for outcome at one-year follow-up. Floor/ceiling effects noted in some subgroups.</td>
</tr>
<tr>
<td>Catz et al.</td>
<td>Rasch analysis of SCIM III</td>
<td>I</td>
<td>SCIM III and SCIM III subscales reliable/valid.</td>
</tr>
<tr>
<td>Itzkovich et al.</td>
<td>Assessment of reliability and validity of SCIM III, 2 raters</td>
<td>I</td>
<td>κ Values of 0.631-0.823 for all SCIM III tasks. SCIM III much more sensitive than FIM.</td>
</tr>
<tr>
<td>Itzkovich et al.</td>
<td>Comparison of reliability of SCIM II by interview and comparison with observation</td>
<td>III</td>
<td>Reliability of SCIM II by interview good but not as good as observation.</td>
</tr>
<tr>
<td>Itzkovich et al.</td>
<td>Rasch analysis of SCIM II</td>
<td>III</td>
<td>Confirms validity and reliability of SCIM II.</td>
</tr>
<tr>
<td>Catz et al.</td>
<td>Introduction of revised SCIM (SCIM II) with comparison to SCIM and FIM</td>
<td>III</td>
<td>SCIM II supersedes SCIM.</td>
</tr>
<tr>
<td>Catz et al.</td>
<td>Comparison of SCIM to FIM</td>
<td>III</td>
<td>SCIM more sensitive than FIM for spinal cord lesions. Needs further refinement.</td>
</tr>
<tr>
<td>Field-Fote,</td>
<td>Spinal Cord Injury Functional Ambulation Inventory as functional assessment scale for gait assessment.</td>
<td>III</td>
<td>Reliable and relatively sensitive measure of walking ability in patients with ASCI. Interrater reliability good, no κ values offered.</td>
</tr>
<tr>
<td>Kuckuckev et al.</td>
<td>To determine the reliability and validity of the modified Barthel Index in Turkey</td>
<td>III</td>
<td>Adaptation of the modified Barthel index has been successful and can be used in Turkey as long as its limitations are recognized.</td>
</tr>
<tr>
<td>Ditunno et al.</td>
<td>Walking Index for SCI offered as index for ambulation skills after SCI in pilot study</td>
<td>III</td>
<td>Good reliability and excellent interrater reliability but needs assessment in clinical setting.</td>
</tr>
<tr>
<td>Yavuz et al.</td>
<td>Assessment of the relationship of the 2 functional tests, the FIM and the QIF, to ASIA scores</td>
<td>III</td>
<td>Good, strong correlations between the FIM and the QIF to ASIA scores.</td>
</tr>
<tr>
<td>Catz et al.</td>
<td>SCIM as new disability scale for spinal cord lesions; 30 patients assessed with SCIM and FIM</td>
<td>III</td>
<td>SCIM more sensitive than FIM.</td>
</tr>
<tr>
<td>Hamilton et al.</td>
<td>FIM interrater reliability in the clinical setting</td>
<td>III</td>
<td>FIM is reliable when used by trained/tested inpatient medical rehabilitation clinicians.</td>
</tr>
<tr>
<td>Dodds et al.</td>
<td>Assessment of reliability of FIM in characterizing</td>
<td>III</td>
<td>FIM has high internal consistency and adequate discriminative capabilities and was a good indicator of burden of care.</td>
</tr>
<tr>
<td>Hamilton et al.</td>
<td>Interrater agreement assessment of FIM in 263 patients in 21 UDS hospitals</td>
<td>III</td>
<td>κ Values for 7-level FIM ranged from 0.61-0.76; mean, 0.71.</td>
</tr>
</tbody>
</table>

(Continues)
Coherence between coefficients, Pearson correlation, and interclass correlation was performed later. The coefficients ranged between 0.631 and 0.823. The authors reported these revisions in 2001. SCIM is a useful instrument for assessing functional changes in all functional changes detected by FIM, but FIM missed 26% of changes detected by SCIM scoring. The authors concluded that SCIM is a new and improved SCIM scale (SCIM III) was reported by Itzkovich et al in 2007. Four hundred twenty-five patients with spinal cord lesions from 13 centers in 6 countries were evaluated and compared SCIM II data to ASIA motor scores at 1, 3, 6, and 12 months post-injury. The quadriplegic group demonstrated significant improvements in SCIM II scores over time (median improvement, 41 points). Quadriplegic patients also demonstrated significant improvements in SCIM II scores (median improvement, 11 points) but less improvement than paraplegic patients. The functional recovery rate of patients with paraplegia was significantly higher than that of quadriplegic patients in the first 3 months after injury; however, the annualized functional recovery rate was comparable between the 2 groups of patients. Floor and ceiling effects previously described with ASIA motor scores were identified with SCIM II scores as well. There was no correlation between functional and motor recovery in paraplegic patients; however, a fair correlation was observed with quadriplegic patients. These authors concluded that functional recovery is a continuous process in the first year after SCI and that SCIM II is a sensitive, responsive, valuable assessment tool complementary to the ASIA standards for monitoring rehabilitation outcome in SCI.

A new and improved SCIM scale (SCIM III) was reported by Itzkovich et al in 2007. Four hundred twenty-five patients with spinal cord lesions from 13 centers in 6 countries were evaluated with SCIM III and FIM on admission to rehabilitation and upon discharge. SCIM III was tested for interrater reliability (agreement between raters, Pearson correlation, and interclass correlation coefficients) and the internal consistency of scale (Cronbach coefficient). Total agreement between raters ranged between 74.5% and 96.2%; total agreement was > 80% in 13 of the 18 tasks. The Pearson coefficients ranged between 0.631 and 0.823 (P < .0001). Pearson coefficients of the 3 subsets of self-care and mobility had an acceptable goodness of fit to the Rasch model (in-fit mean square = 0.8-1.2; outfit mean square = 0.6-1.4). Nonetheless, their analysis identified a few item categories that should be revised or removed to further improve SCIM. Itzkovich and coauthors later demonstrated that SCIM II was also remarkably reliable when applied after interview (only) of SCI patients compared with observed examinations of the same patients by skilled examiners.

Wirth and associates evaluated 64 patients with complete paraplegia and 36 with complete quadriplegia with SCIM II and compared SCIM II data to ASIA motor scores at 1, 3, 6, and 12 months after injury. They reported that median ASIA motor scores remained stable in the paraplegic group at 1-year follow-up. The quadriplegic group demonstrated significant improvement in median ASIA motor scores at 1 year, from a median of 14 points initially to 19 points 12 months after injury. They noted a floor effect on motor recovery among the paraplegic patients (no measure of motor function between T1 and L1) and a ceiling effect among the quadriplegic patients (injury above measurable motor units). Paraplegic patients had significant increases in SCIM II scores over time (median improvement, 41 points). Quadriplegic patients also demonstrated significant improvements in SCIM II scores (median improvement, 11 points) but less improvement than paraplegic patients. The functional recovery rate of patients with paraplegia was significantly higher than that of quadriplegic patients in the first 3 months after injury; however, the annualized functional recovery rate was comparable between the 2 groups of patients. Floor and ceiling effects previously described with ASIA motor scores were identified with SCIM II scores as well. There was no correlation between functional and motor recovery in paraplegic patients; however, a fair correlation was observed with quadriplegic patients. These authors concluded that functional recovery is a continuous process in the first year after SCI and that SCIM II is a sensitive, responsive, valuable assessment tool complementary to the ASIA standards for monitoring rehabilitation outcome in SCI.

a ASIA, American Spinal Injury Association; FIM, Functional Independence Measure; QIF, Quadriplegic Index of Function; UDS, Uniform Data System; SCI, spinal cord injury; SCIM, Spinal Cord Independence Measure.
**TABLE 3. Evidentiary Table: Clinical Neurological Assessment: Pain Associated With SCI**

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<tr>
<td>Jensen et al, 2010</td>
<td>Assessment of Spinal Cord Injury Basic Pain Data Set in 184 SCI patients with pain</td>
<td>I</td>
<td>Excellent internal consistency (reliability) (Cronbach’s α = 94). Validity statistically significant, P &lt; .01.</td>
</tr>
<tr>
<td>Dijkers, 2010</td>
<td>Comparison of quantification of SCI pain by Verbal Rating Scale and Numeric Rating Scale</td>
<td>III</td>
<td>Considerable variation in patient interpretation and use of Verbal Rating Scale and Numeric Rating Scale to describe pain.</td>
</tr>
<tr>
<td>Attal et al, 2008</td>
<td>Characterization and quantification of neuropathic pain from nerve, spinal cord, and brain lesions with NPSI</td>
<td>III</td>
<td>NPSI revealed several positive correlations but not specific or reliable.</td>
</tr>
<tr>
<td>Hanley et al, 2008</td>
<td>Assessment of pain catastrophizing and beliefs on pain after SCI</td>
<td>III</td>
<td>Pain catastrophizing associated with greater pain interference and poorer psychological functioning.</td>
</tr>
<tr>
<td>Felix et al, 2007</td>
<td>Assessment of chronic pain after SCI with descriptions, Numeric Rating Scale, IASP taxonomy</td>
<td>III</td>
<td>Sharp pain most disturbing, more frequently interferes with activities and sleep.</td>
</tr>
<tr>
<td>Budh and Osteraker, 2007</td>
<td>Assessment of self-reported life satisfaction after SCI; questionnaire with Lisat-9 and Verbal Rating Scale</td>
<td>III</td>
<td>SCI pain negatively affects life satisfaction compared to SCI patients without pain.</td>
</tr>
<tr>
<td>Hanley et al, 2006</td>
<td>Assessment of change in pain intensity in patients with SCI or limb amputation</td>
<td>III</td>
<td>An approximate 33% decrease in pain is considered a reasonable standard for meaningful change in chronic pain.</td>
</tr>
<tr>
<td>Hanley et al, 2006</td>
<td>Classification of SCI pain; mild, moderate, and severe</td>
<td>III</td>
<td>Classification of SCI pain may be useful for applying clinical treatment guidelines and for interpreting results of future clinical trials.</td>
</tr>
<tr>
<td>Bryce et al, 2006</td>
<td>Assessment of Bryce/Ragnarsson SCI pain taxonomy using clinical vignettes</td>
<td>II</td>
<td>“Substantial” interrater agreement in determining subtypes of pain. k Values between 0.55 and 0.91. Not applied to patients.</td>
</tr>
<tr>
<td>Raichle et al, 2006</td>
<td>Survey assessment of reliability and validity of Graded Chronic Pain Disability Scale Disability and Brief Pain Inventory of Wisconsin Interference scales</td>
<td>III</td>
<td>Graded Chronic Pain Disability Scale Disability and Brief Pain Inventory of Wisconsin Interference scales appear reliable and valid.</td>
</tr>
<tr>
<td>Widerstrom-Noga et al, 2006</td>
<td>Assessment of consistency, stability, and validity of the Multidimensional Pain Inventory</td>
<td>III</td>
<td>Multidimensional Pain Inventory appears to be a reasonable measure for evaluating chronic pain and its impact after SCI.</td>
</tr>
<tr>
<td>Reference</td>
<td>Description of Study</td>
<td>Evidence Class</td>
<td>Conclusions</td>
</tr>
<tr>
<td>-----------</td>
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</tr>
<tr>
<td>Moderate to substantial reliability: 8 of 10 subscales</td>
<td>High construct validity in 9 of 10 subscales</td>
<td>III</td>
<td>High incidence of shoulder pain after SCI even among those patients not confined to wheelchairs.</td>
</tr>
<tr>
<td>Cruz-Almeida et al, 71 Journal of Rehabilitation Research and Development, 2005</td>
<td>Questionnaire assessment of self-reported pain and pain interference with sleep and daily activities; confirmatory factor analysis</td>
<td>III</td>
<td>Chronic nociceptive and neuropathic pain are consistent after SCI and have negative impact on sleep and activities of daily living.</td>
</tr>
<tr>
<td>Lund et al, 89 BMC Medical Research Methodology, 2005</td>
<td>Comparison of Visual Analog Scale and Verbal Rating Scale in cross-sectional study of chronic pain (not isolated SCI pain)</td>
<td>III</td>
<td>Visual Analog Scale and Verbal Rating Scale not interchangeable. Visual Analog Scale may overestimate or underestimate perceived pain.</td>
</tr>
<tr>
<td>Samuelsson et al, 100 Spinal Cord, 2004</td>
<td>Assessment of shoulder pain in paraplegic SCI patients using CMS, Wheelchair Users Shoulder Pain Index, and COPM</td>
<td>III</td>
<td>Shoulder pain in this population mostly related to wheelchair activities. No correlation between assessment measures.</td>
</tr>
<tr>
<td>Turner et al, 92 Pain, 2002</td>
<td>Assessment of catastrophizing with pain intensity, psychological distress, and pain-related disability in patients with chronic pain after SCI</td>
<td>III</td>
<td>Catastrophizing was strongly and independently associated with poor outcome/disability after SCI.</td>
</tr>
<tr>
<td>Cardenas et al, 37 Archives of Physical Medicine and Rehabilitation, 2002</td>
<td>Evaluation of interrater reliability of Cardenas Pain Classification System, questionnaires, with or without interviews</td>
<td>II</td>
<td>“Substantial” interrater reliability, κ values between 0.66 and 0.68. Interviews did not improve interrater reliability. Small numbers in subgroups prohibit qualitative analysis.</td>
</tr>
</tbody>
</table>

(Continues)
and outdoors subscales ($P < .001$). Their report provides Class I medical evidence on the reliability and validity of SCIM III and the superior sensitivity of SCIM III compared to FIM. Catz et al\textsuperscript{65} subjected these data and these results to a stringent Rasch analysis. The authors concluded that the SCIM III subscales were reliable and quantitatively (average in-fit mean square indices of 0.79-1.06) as a specific construct of independence after a spinal cord lesion. These 2 publications offer Class I medical evidence in support of SCIM III as a specific construct of independence after a spinal cord lesion.

Anderson and colleagues\textsuperscript{32} reported the consensus analysis of a multinational work group in 2008. Experts in the field of SCI rehabilitation evaluated 4 measures of functional recovery after SCI: the modified Barthel Index, FIM, QIF, and SCIM III. They concluded that the QIF and SCIM III were spinal cord–specific measures of functional abilities and recovery. QIF applies only to tetraplegic patients and has not been widely used or studied. Both FIM and SCIM III were given high consensus marks for validity and reliability. FIM was considered of value in measuring the burden of care; SCIM III was considered the best measure of an individual’s global disability specific to an SCI.

In 2009, Rudhe and van Hedel\textsuperscript{66} examined the relationship among SCIM III, arm and hand muscle strength, and hand function tests in 29 patients with tetraplegia. They found that SCIM III sum score correlated very well with the sum scores of the 3 tests (Spearman correlation coefficient $\approx 0.76$). They concluded that the SCIM III self-care category in particular reflects upper-extremity performance as it contains especially useful and valid items that relate to upper-extremity and capacity tests (Spearman correlation coefficient $\approx 0.80$). Their analysis offers Class II medical evidence for the sensitivity, validity, and reliability of SCIM III for tetraplegic patients.

Glass et al\textsuperscript{66} published on the applicability of SCIM III to SCI patients in the United Kingdom in 2009. Eighty-six SCI patients were evaluated consecutively over a 12-month period at 4 regional SCI rehabilitation centers. Patients were assessed with SCIM III and with FIM upon admission and within a week of discharge. The Pearson correlation values between SCIM III and FIM scores for each of the 2 raters were 0.798 ($P < .01$) and 0.782 ($P < .01$) respectively, indicating superior validity for both functional assessment tools. The ability to identify a 1-point change within the 4 areas of SCIM III in comparison with the total FIM score was analyzed using the McNemar test. SCIM III detected more numerous changes than FIM in 3 of the 4 subscale areas. The reliability of SCIM III as described by $\kappa$ coefficients ranged from 0.491 (stair management) to 0.835 (mobility outdoors), indicating moderate (3 tests) to substantial agreement (15 tests). A floor effect was noted for 1 item: transfers ground/wheelchair. The authors concluded that both conventional inferential statistical and Rasch analyses justify the use of SCIM III for assessment of SCI patients and SCI research in the United Kingdom.

### TABLE 3. Continued

<table>
<thead>
<tr>
<th>Reference</th>
<th>Description of Study</th>
<th>Evidence Class</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Putzke et al,\textsuperscript{95} Journal of Spinal Cord Medicine, 2001</td>
<td>Assessment of Short Form-12 to assess pain interference in daily activities</td>
<td>III</td>
<td>Age and occupational status were predictors of pain interference in activities of daily living.</td>
</tr>
<tr>
<td>Finnerup et al,\textsuperscript{75} Spinal Cord, 2001</td>
<td>Questionnaire survey of pain of SCI origin, use of McGill Pain Questionnaire</td>
<td>III</td>
<td>Pain and dysesthesias are common and disruptive consequences after SCI.</td>
</tr>
<tr>
<td>Defrin et al,\textsuperscript{73} Pain, 2001</td>
<td>Characterization of pain and somatosensory function after SCI</td>
<td>III</td>
<td>Damage to the spinothalamic tract is necessary for the occurrence of chronic pain.</td>
</tr>
<tr>
<td>Widerstrom-Noga et al,\textsuperscript{74} Arch Phys Med Rehab, 2001</td>
<td>Questionnaire assessment of chronic pain after SCI, interference with sleep, and activities of daily living</td>
<td>III</td>
<td>Pain of SCI origin interferes with sleep, activities of daily living.</td>
</tr>
<tr>
<td>Defrin et al,\textsuperscript{72} Pain, 1999</td>
<td>Assessment of pain thresholds in patients with chronic pain after SCI</td>
<td>III</td>
<td>Nociceptive thresholds for pain elevated in patients with complete SCI.</td>
</tr>
<tr>
<td>Kennedy et al,\textsuperscript{76} Spinal Cord, 1997</td>
<td>Analysis of acute and chronic pain after SCI</td>
<td>III</td>
<td>60% of patients with pain from SCI improved in short-term follow-up, 38% improved in long-term follow-up.</td>
</tr>
</tbody>
</table>

\textsuperscript{CMS, Constant Murley Scale; COPM, Canadian Occupational Performance Measure; IASP, International Association for the Study of Pain; NPSI, Neuropathic Pain Symptom Inventory; SCI, spinal cord injury.}
Ackerman et al\textsuperscript{33} reported the use of SCIM III to assess the functional recovery of 114 patients with complete SCI at the Shepherd Center in Atlanta, Georgia. Their 2010 publication documented statistically significant improvements in SCIM III scores at discharge. The greatest improvements were among C6 and C7-8 injury level patients. The least improvement was observed in the C1-4 and C5 subgroup patients. In the C1-4 injury level patients, a floor effect was observed. Ceiling effects were noted (as expected) for the T1-6 and T7-12 injury level patients because of their fully functional upper extremities upon admission. The authors concluded that despite these modest potential drawbacks owing to injury level, SCIM III is sensitive to changes in individuals with SCI, particularly with injury levels between C5 and T12.

Bluvshtein et al\textsuperscript{58} offered their assessment of SCIM III in the evaluation of 261 patients with spinal cord lesions. The results of this multicenter international study were published in 2010. Total agreement between paired raters was > 80% for virtually all SCIM III tasks. The \( \kappa \) coefficients for all SCIM III tasks were all > 0.6 and statistically significant (range, 0.649 to 0.858), indicating substantial to almost perfect agreement. Pearson coefficients of correlation between the paired raters exceeded 0.9, and the interclass correlation coefficients were > 0.95. Cronbach \( \alpha \) values for the entire SCIM III scale were 0.833 to 0.835. When compared to FIM, entire SCIM III scores correlated well (\( r = 0.84 \), \( P < .001 \)). SCIM III was more responsive to changes than FIM. In all subscales, SCIM III identified more changes in function than FIM, and in 3 of the 4 subscales, differences in responsiveness were statistically significant (\( P < .02 \)). The authors concluded that SCIM III is reliable and valid in assessing functional recovery among adult patients with traumatic spinal cord lesions. Their report offers Class I medical evidence on the sensitivity, validity, and reliability of SCIM III for patients with spinal cord lesions.

**PAIN ASSOCIATED WITH SCI**

Pain following SCI is common. Several reviews and case series suggest that the prevalence of chronic pain after SCI ranges between 25% and 80% of injured patients.\textsuperscript{60-78} It has been classified as noxious or nociceptive (musculoskeletal and visceral) and neuropathic (above, at, and below the level of cord injury).\textsuperscript{38,70,78,79} There are a variety of psychological and psychosocial factors that interface with the pain of SCI origin that influence its management and treatment.\textsuperscript{74,76,80-83} The importance of pain symptoms to patients with SCI cannot be understated. Patients with severe pain syndromes consistently have poor outcome scores in quality of life assessments, have functional impairments beyond what expected from the neurologic injury, and often suffer from debilitating depression.\textsuperscript{7,84-88} Westgren and Levi\textsuperscript{90} have suggested that the impact of pain on quality of life after SCI may be more significant than the original SCI in selected patients.

Thirteen pain intensity instruments have been utilized to assess pain following SCI, including the McGill Pain Questionnaire, the McGill-Melzack Pain Questionnaire, the Zung Pain and Distress Index, the Graded Chronic Pain Disability Scale, the Constant Murley Scale, the Short Form-12, the Multidimensional Pain Inventory, the Brief Pain Inventory of Wisconsin, the Verbal Rating Scale, the Neuropathic Pain Symptom Inventory, the Visual Analog Scale (0-10 points and scales of 0-100 points), the Wheelchair Users Shoulder Pain Index, and an 11-point (0-10 points) Numeric Rating Scale.\textsuperscript{36-37,41,69,72,76,77,79,90-101} The Visual Analog Scales have been used most frequently. These instruments use descriptors to categorize pain. Verbal pain descriptors are difficult to apply to the characterization of the different types of pain associated with SCI. For example, the verbal description “burning” can be used by patients to describe nociceptive and neuropathic pain symptoms, at above and below the level of SCI. Different patients with similar injuries and symptoms may use different verbal descriptors depending on their use of language. These confounding variations and variables hinder the ability of investigators to devise valid and reliable pain intensity instruments.

Five pain classification system instruments have been generated and used as assessment tools for patients following acute SCI: the Tunks SCI pain classification, the Donovan Classification Scheme, the Cardenas pain classification, the Siddall/International Association for the Study of Pain classification, and the Bryce/Ragnarsson SCI pain taxonomy.\textsuperscript{37,41,69,70,78,79,84,97,101-104} They are difficult to compare because of varying formats, numbers of items assessed, and different rating scales. Despite these issues, interrater reliability (the degree of agreement between 2 raters using the same pain classification system/instrument to characterize that patient’s pain), a means to assess system/instrument validity, has been reported to be “substantial” for 2 of the 5 pain classification systems (\( \kappa \) values between 0.61 and 0.80) (Table 4).\textsuperscript{36,37,84}

In 2006, Widerstrom-Noga et al\textsuperscript{105} applied a modified version of the Multidimensional Pain Inventory to SCI patients to assess their pain. The Multidimensional Pain Inventory included a means to assess pain severity, physical functioning, and emotional functioning, the 3 key domains “considered important for capturing the multidimensionality of the pain experience.” It was brief and easy to administer, and patients felt it was appropriate and applicable. Internal consistency and test-retest reliability were moderate to substantial in 8 of the 10 test

### TABLE 4. Pain Assessment\textsuperscript{4,5,6}

<table>
<thead>
<tr>
<th>SCI Pain Classification System/Instrument*</th>
<th>( \kappa ) Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bryce/Ragnarsson spinal cord injury pain taxonomy</td>
<td>0.70</td>
</tr>
<tr>
<td>Cardenas pain classification</td>
<td>0.68</td>
</tr>
<tr>
<td>Donovan classification scheme</td>
<td>0.55</td>
</tr>
<tr>
<td>Siddall/International Association for the Study of Pain classification</td>
<td>0.49</td>
</tr>
<tr>
<td>Tunks spinal cord injury pain classification</td>
<td>0.49</td>
</tr>
</tbody>
</table>


*SCI, spinal cord injury.
subscaler. Construct validity had high Pearson correlation coefficients in 9 of 10 subscales. The authors concluded that the Multidimensional Pain Inventory is a useful measure for evaluating chronic pain and its impact after SCI.

In 2008, Widerstrom-Noga and additional collaborators developed the International Spinal Cord Injury Pain Data Set to standardize the collection and reporting of pain in the SCI population. It included the 3 essential domains or outcomes of pain severity and physical and emotional functioning. It is meant to evaluate and report the diverse pains in persons affected with SCI. It was designed to be feasible and applicable across varied clinical settings, languages, and countries. It is meant to be used in conjunction with the ASIA impairment scale, which documents the extent of neurological injury following SCI.

Jensen et al. in 2010 reported the use of the Spinal Cord Injury Basic Pain Data Set (ISCIBPDS) among 184 SCI patients with pain. The interrater consistency of the data set (as an indicator of reliability) was excellent (Cronbach \( \alpha = 94 \)). The validity of the ISCIBPDS was statistically significant at the \( P < .001 \) level for 23 of the 27 pain interference items and scales and was statistically significant at the \( P < .01 \) level for 26 of the 27 pain interference items and scales. The authors concluded that the ISCIBPDS is useful and valid as a self-report means for assessing pain and its impact in individuals with SCI. Their report provides Class I medical evidence on the utility of the ISCIBPDS to assess pain of SCI origin and is recommended for use in both the clinical and research settings.

**SUMMARY**

A variety of injury classification schemes have been utilized to describe patients who have sustained spinal cord injuries. There are 2 general types of assessment scales, neurological examination scales and functional outcome scales. The most accurate and meaningful description of SCI patients, in the acute setting and in longitudinal follow-up, is that accomplished by using a neurological scale in conjunction with a functional outcome scale. Based on a contemporary evaluation and ranking of the medical evidence, the 2000 American Spinal Injury Association (ASIA) Standards is the most consistent, reliable, valid, and responsive scoring system for the neurological assessment of adult patients with acute SCI, to a high degree of scientific certainty. This recommendation is supported by Class II medical evidence.

The SCIM III, designed specifically to assess the functional abilities and impairment of patients with spinal cord lesions and SCI, is the functional outcome assessment tool with the greatest scientific validity, reliability, and sensitivity. This recommendation is supported by Class I medical evidence.

The assessment of pain among patients with SCI is important and should include an evaluation of pain severity, physical functioning, and emotional functioning. There are a number of pain assessment classification instruments that have been used in this patient population. The ISCIBPDS has the highest reliability and validity of any of the pain classification instruments and is recommended on the basis of Class I medical evidence.

**KEY ISSUES FOR FUTURE INVESTIGATION**

Clinical trials in which all 3 clinical assessment parameters (neurological examination, functional outcome assessment and pain assessment) are studied as an integral part of outcome measurements are needed to more completely describe the clinical status of patients following acute SCIs.

**Disclosure**

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

**REFERENCES**


Pharmacological Therapy for Acute Spinal Cord Injury

KEY WORDS: GM-1 ganglioside, Mehtylprednisolone, NASCIS trials, Pharmacologic therapy, Sygen trials

RECOMMENDATIONS
Level I
- Administration of methylprednisolone (MP) for the treatment of acute spinal cord injury (SCI) is not recommended. Clinicians considering MP therapy should bear in mind that the drug is not Food and Drug Administration (FDA) approved for this application. Scattered reports of Class III evidence claim inconsistent effects likely related to random chance or selection bias. However, Class I, II, and III evidence exists that high-dose steroids are associated with harmful side effects including death.
- Administration of GM-1 ganglioside (Sygen) for the treatment of acute SCI is not recommended.

RATIONALE
The search for an effective neuroprotective strategy to prevent secondary injury in the setting of acute SCI remains a priority for basic scientists and clinicians alike. Despite promising results for a number of compounds tested in the laboratory, only 5 pharmaceutical agents have been evaluated in humans with the purpose of improving function after acute SCI. All 5 pharmacological treatments have been evaluated in controlled, randomized, blinded clinical trials of human patients who have suffered acute SCI. Three substances, naloxone, thyrotropin release hormone, and tirilazad, have been studied less extensively. Further research to define their therapeutic roles in SCI is necessary but because of modest results is unlikely to occur. In 2002, the guidelines author group of the Joint Section on Disorders of the Spine and Peripheral Nerves of the American Association of Neurological Surgeons (AANS) and the Congress of Neurological Surgeons (CNS) published a medical evidence-based guideline on the use of MP and GM-1 ganglioside in the setting of acute cervical spinal cord injury. The purpose of the current review is to build on that foundation, adding pertinent new evidence accumulated over the past decade. There have been no new pharmacological agents formally tested for clinical use in SCI through this time period.

SEARCH CRITERIA
A National Library of Medicine (PubMed) computerized literature search from 1966 to 2011 was undertaken using Medical Subject Headings of “steroids,” “methylprednisolone,” and “GM-1 ganglioside” in combination with “spinal cord injury” and “neurological deficit.” Approximately 680 000 citations were acquired. Non-English-language citations were excluded, as were nonhuman experimental studies. Titles and abstracts of 641 manuscripts were reviewed, 589 on the topic of steroids and human SCI, and 52 on the topic of GM-1 ganglioside and human spinal cord injury. Additional publications were cross-referenced from the citation lists of the remaining papers. Finally, the members of the author group were asked to contribute articles known to them on the subject matter that were not found by other search means. Duplications,
case reports, pharmacokinetic reports, general reviews, editorials, critiques, and manuscripts with mention of one agent or another but without original data were eliminated. Twenty-seven studies on MP and 2 studies on GM-1 ganglioside provide the basis for this review and are summarized in Evidentiary Table format (Tables 1-2).

SCIENTIFIC FOUNDATION

Methylprednisolone

The most research into pharmacotherapy for SCI has been generated by investigation of the potential benefit of MP administration. Certainly the most widely recognized studies are the National Acute Spinal Cord Injury Study (NASCIS) II and III published between 1990 and 1998.2,4,6,7 The original NASCIS I trial reported negative results in comparing “high-dose” to “low-dose” MP in 306 patients with acute SCI.8 High-dose patients received an MP loading dose of 1000 mg followed by the same dose daily thereafter for a period of 10 days. Low-dose patients received a loading dose of 100 mg followed by a further 100 mg each day for 10 days. Six-month follow up was available on 54% of patients demonstrated no difference in motor or sensory outcomes in the high-dose group compared to low-dose patients. Wound infection was 3 times more frequent in the high-dose group (P = .01), and 3 times as many patients receiving high-dose MP died within the first 2 weeks of treatment (6% vs 2% mortality). One-year follow up confirmed the absence of a neurological difference between the 2 groups.9

The second of the 3 NASCIS studies investigated the effect of MP and naloxone administration in 487 patients with acute SCI.2 In this study MP was administered in an initial loading dose of 30 mg/kg followed by 5.4 mg/kg/hour for 23 hours. While the naloxone data was uniformly uninformative, the authors reported a mean improvement of 5 points in motor score (total possible score = 50) and 4 points in sensory scores (total possible score = 58) for patients treated with MP compared to controls at 6 months, as long as they received the drug within 8 hours of injury. Improved motor scores persisted at 1 year (P = .03), but the difference in light touch and pinprick sensation between MP and placebo groups was lost.7

Although the NASCIS II cohort totaled 487 patients, beneficial effects from MP administration were discernable only after a post-hoc 8-hour therapeutic window was imposed. The rationale for this 8-hour cutoff has never been substantiated.10 Two hundred and ninety-one patients randomized later than 8 hours from injury were therefore excluded from the analysis, eliminating over half of the study population. The final conclusions from the study were based on a cohort of 66 MP-treated patients compared to 69 controls. Only neurological scores from the right half of the body were reported, although bilateral neurological testing was performed. As mentioned above, sensory improvements were the same in MP and placebo-treated patients 1 year after injury.

Analysis of patients treated beyond the 8-hour window demonstrated MP to have a detrimental effect on neurological outcome. It makes mathematical sense that if (1) an average result encompassing an entire population shows no change and (2) analysis of a subpopulation shows benefit, that (3) the remainder of the population must therefore show harm. As it applies to MP administration in acute SCI, it is at least as likely that these observations represent random chance rather than the possibility a study drug could be of benefit for 8 hours but then have the exact opposite effect over the next 4 hours.

Further post-hoc analyses suggested that MP administration improved neurological function below the level of injury in patients with incomplete SCI, noting that patients with complete SCI demonstrated very little long-tract recovery irrespective of treatment.11 Only 17 patients with incomplete spinal cord injuries received MP within 8 hours of injury and only 22 such patients received placebo.7 Hence, while long-tract (as opposed to segmental) recovery was reported in NASCIS II, it was identified in a very small subgroup of patients.

Complications were reasonably distributed between the treatment groups except for a 1.5 times higher incidence of gastrointestinal (GI), hemorrhage, 2 times higher incidence of wound infection, and 3 times higher incidence of pulmonary embolus in MP-treated patients compared to controls. There was a 2.5 times higher incidence of thromboembolism in control patients compared to those who received MP. None of these findings were reported as statistically significant, but none of these comparisons were properly powered to avoid Type II error.

NASCIS II was designed as a randomized, controlled, double-blinded clinical study to generate Class I medical evidence on the efficacy of MP and naloxone in the treatment of acute spinal cord injury. However, the strength of medical evidence generated is weakened by omission of data from publication, the arbitrary assignment of an 8-hour therapeutic window, the inconsistency of reported benefit, and the absence of functional outcome measures. The primary positive finding of a 5-point improvement in motor score associated with MP administration compared to placebo control was discovered only in a post-hoc analysis of a partial dataset, constituting a retrospective analysis. Accordingly, the beneficial results of NASCIS II are downgraded to Class III medical evidence. A trend towards more serious complications associated with steroid use is indicated from the original Class I medical evidence dataset.

In 1993, Galandiuk et al12 reported on 32 patients with cervical or upper thoracic ASCI managed in an urban trauma center. Fourteen patients who received NASCIS II doses of MP within 8 hours of SCI were compared to 18 patients with similar injuries managed without steroids. Forty-seven percent of the cohort was studied retrospectively while 53% were studied prospectively. No difference was observed in neurological outcome for patients treated with MP compared to those untreated. However, patients receiving MP exhibited significant immune response alterations evidenced by a lower percentage and density of monocyte class II antigen expression and lower T-cell helper-suppressor cell ratios.
In addition, MP-treated patients experienced a higher rate of pneumonia (79% vs 50%) and longer hospital stays (44.4 days compared to 27.7 days) compared to their non-MP counterparts.

The same year, Kiwierski et al published the largest retrospective review of patients with acute SCI to date. Six-hundred and twenty patients were treated over a 15-year period beginning in 1976. Of these, 290 patients were administered MP and 330 were not, based on the discretion of the treating physician. The dose varied according to age, weight, and medical condition, and also at the preference of the attending physician. The most usual dose was 8 mg 3 times a day for several days up to 1 week. Consistently, more patients in the MP group were reported to show some degree of improvement compared to controls. The mortality rate was at least double for patients in the control group compared to those treated with MP, ranging from 18% to 38% depending on age (Figure 1). The authors did not explore the reasons for such high mortality, but the data suggest the control group was more severely injured and therefore less likely to recover.

Otani et al reported a prospective randomized (nonblinded) clinical trial investigating the administration of MP at NASCIS II doses within 8 hours of SCI from 11 centers in Japan. Eighty-two MP patients were compared to 76 observational controls (no placebo), randomized over a 14-month period from January 1992 to March 1993. Interestingly, “In the control group, however, use of a corticoid other than MPSS was allowed up to the dose equivalent to 100 mg/day MP for a maximum of 7 days in total...if it was judged necessary by the attending physician for the purpose of treating the spinal cord injury.” Of the patients entered into the study, only 70 in the treatment group and 47 in the control group were analyzed due to protocol violations. Primary preplanned comparisons of change in motor and sensory scores failed to yield significant differences (Figures 2A and 2B). Post-hoc analyses suggested that significantly more MP patients recovered some degree of sensory function compared to controls (P = .016 pinprick; P = .021 light touch) (Figure 2C).

However, as discussed in the setting of NASCIS II, mathematical balance dictates that (1) if primary comparisons within the study population show no difference and (2) a subanalysis suggests a treatment effect, then (3) there must be an equal and opposite effect in the remaining patients. In this circumstance, the authors’ observation that significantly more MP patients showed sensory recovery is only balanced by considering that within the fewer recovering control patients—magnitude (not frequency) of sensory recovery must have exceeded that observed in the MP-treated group. Taken together, both observations render each other meaningless and irrelevant.

Prendergast et al retrospectively compared patients with SCI before 1990 (the year NASCIS II was published) to patients with SCI after 1990. The latter group (n = 29) received MP in NASCIS II doses, whereas the earlier group (n = 25) received no steroids (historical control). Of 31 patients who suffered penetrating trauma, 16 received steroids while 15 did not. Throughout a 2-month follow-up period there was no difference in motor or sensory scores for patients with blunt SCI irrespective of steroid administration. However, in those suffering penetrating SCI, MP use was associated with deterioration in motor and sensory function compared to baseline scores on admission. In contrast, recovery was observed in controls. Motor scores were significantly better in control patients compared to those who received MP (P = .03).

Gerhart et al retrospectively identified a concurrent cohort of 363 acute SCI patients managed in 1990, 1991, and 1993. Within the study population, 188 (52%) were treated according to NASCIS II protocol, 90 (25%) received no methylprednisolone, and 85 (23%) received other steroid (e.g., dexamethasone), an incorrect dose of MP, or had insufficient data. The authors found no significant difference in the outcome assessed by Frankel grade at the time of hospital discharge comparing those who received protocol MP (appropriate dose and timing) to those who did not receive any MP during treatment.

One-hundred and thirty patients suffering acute SCI between 1989 and 1992 were retrospectively analyzed, comparing patients...
who received MP to those who did not. Similar to the Prendergast paper, George et al based their comparison on 55 patients treated prior to 1990 (historical controls) and 75 patients treated with MP after 1990 according to NASCIS II dosing within 8 hours of injury. Neurological function was assessed by a 6-point mobility score and through the Functional Independence Measure scale. Mobility was no different between the groups on admission, but on discharge, despite a lower mean age and lower injury severity score, the MP group fared significantly worse by one-half point compared to controls (P < .05). Functional Independence Measure scores did not differ between the 2 groups on discharge or throughout the rehabilitation period.

Medical complications were retrospectively examined by Gerndt et al in 140 SCI patients who received MP according to NASCIS II protocols and compared to a historical control group of 47 patients who received no steroid during treatment. The authors found a 4-fold increase in the incidence of acute pneumonia (P = .03), a 3-fold increase in pneumonia of any type (P = .02), as well as an increase in ventilated days (P = .04) and Intensive Care Unit (ICU) length of stay (P = .045) in the MP patients compared to controls. Control patients had a higher incidence of urinary tract infections (P = .01). MP patients spent fewer days in regular hospital wards (P = .02) and in the rehabilitation unit (P = .035). Overall, hospital stay was not different between the 2 groups, leading the authors to conclude that MP may predispose SCI patients to pneumonia, but had no adverse effect on long-term outcome.

Poynton et al retrospectively identified 71 consecutive SCI patients admitted to their rehabilitation facility between June 1991 and December 1994. American Spinal Injury Association (ASIA) motor and sensory scores were recorded at the time of injury, time of transfer to the rehabilitation center, and in follow up after discharge. Thirty-eight patients received NASCIS II MP dosing within 8 hours of injury. Thirty-three patients did not receive MP therapy because they presented beyond the 8-hour cutoff. Outcome was not related to treatment with MP, nor was it related to surgical intervention, although decompression was not distinguished from stabilization.

The third NASCIS study involved 14 centers across the United States and 2 in Toronto, Canada. Six-month and 1-year follow up were published in separate manuscripts. Patients presenting within 8 hours of SCI were enrolled in a prospective double-blind manner and randomized to 1 of 3 treatment arms: (1) MP infusion 5.4 mg/h · 24 hours; (2) MP infusion 5.4 mg/h · 48 hours; and (3) tirilazad mesylate 2.5 mg/kg every 6 hours · 48 hours. Tirilazad mesylate was included as a chemically engineered “super-steroid,” created to possess greater antioxidant properties than methylprednisolone. All patients received a loading dose of MP (30 mg/kg) prior to randomization. A placebo control group was not included because of the reported therapeutic effect of MP in NASCIS II. Four hundred ninety-nine patients were entered into the study, 166 in the 24-hour MP group, 166 patients in the 48-hour MP group, and 167 in the 48-hour tirilazad mesylate group.

Within all preplanned comparisons, there were no significant differences in neurological recovery between any groups. Neither tirilazad mesylate nor 48-hour MP showed evidence of a neuroprotective effect compared to 24-hour MP administration; NASCIS III was a negative Class I medical evidence study. Post-hoc analyses suggested motor function to be at least temporarily...
improved in patients who received 48-hour MP (n = 80) compared to 24-hour (n = 71) administration, provided the drug was initiated within 3 to 8 hours of injury. A difference of 5 ASIA motor points was found to be significant in favor of 48-hour MP at 6 weeks (P = .04) and 6 ASIA points at 6 months (P = .01). However, the 5-point ASIA difference became statistically questionable at 1 year follow up (P = .053). Even in the post-hoc analysis there was no notable difference between the 3 study groups in ASIA sensory scores, Functional Independence Measure outcomes, or presumably in the unreported left-sided ASIA motor scores. Post-hoc ASIA motor score changes are depicted for both NASCIS II and III in Figure 3.

Similar to NASCIS II, a higher incidence of severe complications seemed to be proportional to steroid administration. There was a 2 times higher incidence of severe pneumonia and a 4 times higher incidence of severe sepsis in the 48-hour MP group compared to patients on MP for 24 hours. Although these differences were not statistically significant, conclusions from statistical testing cannot be drawn, as sample sizes in the order of 600 patients per group would be required to avoid Type II error assuming \( \alpha = 0.05 \) and \( \beta = 0.2 \). There were 6 times more deaths observed in the 48-hour group due to pneumonia, respiratory distress syndrome, and respiratory failure (P = .056).

Like its predecessors, NASCIS III was designed as a randomized, controlled, double-blinded clinical study to generate Class I medical evidence on the efficacy of MP (and tirilazad mesylate) in the treatment of acute spinal cord injury. However, the strength of the medical evidence generated is weakened by omission of data from publication, the arbitrary assignment of a 3- to 8-hour therapeutic window, the inconsistency of reported benefit, and the absence of improvement in functional outcome measures. The primary positive finding of a 5-point improvement in motor score associated with 48-MP administration compared to 24-MP was discovered only in a post-hoc analysis of a partial dataset, constituting a retrospective analysis. Accordingly, the beneficial results of NASCIS III are downgraded to Class III medical evidence. A trend towards more serious complications associated with prolonged steroid use is indicated from the original Class I medical evidence dataset.

Three years later, Pointillart et al\(^{20}\) reported a single-institution, prospective, randomized clinical trial from France that compared the effect of nimodipine, MP (NASCIS II dosing protocol), and nimodipine + MP against no pharmacological therapy in 106 patients with acute SCI. Blinded neurological assessment evaluated ASIA scores on admission and at 1-year follow up. Time from injury to surgical decompression (where indicated and within 24 hours) was tracked as a confounding variable. One hundred patients were available to assess at 1 year because of 5 deaths and 1 loss to follow up.

Neurological improvement was observed in each group at 1 year compared to admission (\( P < .0001 \)). However, there were no significant differences in ASIA motor or sensory scores between the 4 individual treatment arms. Only the completeness of SCI was linked to prognosis; patients with incomplete injury showed significantly more recovery than those who were complete (\( P < .0001 \)). Improvement among complete injury patients was generally restricted to the level of the lesion and the 2 adjacent caudal levels. Eighty patients underwent surgery within 24 hours, of which 49 had surgery within 8 hours of injury. Neither surgery nor timing of surgery was associated with neurological recovery.

Infectious complications occurred more frequently among patients treated with MP (66%) compared to those who did not receive steroids (45%), which was not statistically significant. Two MP patients suffered upper GI hemorrhage due to ulceration. There were no similar events in patients who did not receive MP. Hyperglycemia requiring insulin administration for up to 3 days was documented in 46% of MP patients but in only 1 of the control patients (\( P < .05 \)).

In 2001, Matsumoto and colleagues reported on 46 patients with acute cervical SCI who were prospectively randomized in a double-blind manner to receive either MP at NASCIS II doses or placebo.\(^{21}\) Patients were admitted to a single institution from April 1993 to August 1999. Twenty-three patients received MP, while 23 received placebo. The purpose of the study was to compare complications between the 2 groups from the time of admission throughout the 2-month follow-up period. Despite the prospective nature of the protocol, neurological scores were not reported. However, admission Frankel grades were the same for both groups. MP-treated patients demonstrated a higher propensity towards complications compared to placebo-treated controls (56.5% vs 34.8%; \( P = .14 \)). Eight patients who received MP developed respiratory complications (pneumonia \( n = 3 \), pneumonia \( n = 3 \),...
atelectasis n = 1) compared to 1 placebo patient (P = .009). Four MP patients developed gastrointestinal complications (GI bleed n = 3; ileus n = 1). No similar complications were observed in control patients (P = .036).

Pollard et al22 retrospectively identified patients who suffered an incomplete cervical SCI and were admitted to a single rehabilitation facility within 90 days of injury over an 18-year period spanning 1982 to 2000. Data were part of a federally funded national database (model systems). Five hundred and forty seven patients were identified, of which 412 met inclusion criteria based on completeness of records and absence of confounding comorbidity (eg, head injury). An analysis of sex, race, age, high vs low energy mechanism of injury, fracture type, cord syndrome, steroid protocol, and definitive surgery less than 24 hours after injury was undertaken to determine which factors were associated with greater improvement in ASIA motor and sensory scores.

Improved neurological recovery was noted in younger patients (P = .002) and those with a central cord or Brown-Sequard syndrome (P = .019). Administration of MP was not associated with improvement in final ASIA motor score at latest follow-up (MP n = 104; No-MP n = 200; P = .66) or change in ASIA motor score from time of injury (MP n = 104; No-MP n = 201; P = .26). Final mean ASIA sensory scores were no different between patients who received MP and those who did not (MP n = 86; No-MP n = 87; P = .904). An analysis of change in ASIA sensory score suggested steroid-treated patients recovered 11 more points compared to those who did not receive MP (P = .027). However, without explanation, the number of patients available for this comparison was a fraction of the original cohort (MP n = 33; No-MP n = 59).

Patients with SCI sustained from diving accidents were retrospectively reviewed by Aito et al23 within the experience of a single institution between 1978 and 2002. The primary purpose of the review was to correlate neurological outcome with the level and type of spinal fracture. Sixty-five patients were included in the study, of which 95% were male. Factors associated with improved neurological outcome were: surgical intervention (timing not specified), younger age of the patient, and incomplete SCI. In a subanalysis of 30 patients admitted between 1994 and 2002 (after incorporation of the NASCIS II protocol), 20 patients who received MP within 8 hours of injury were compared to 10 patients who did not receive steroids. Data are not provided, but the authors report their analysis based on the presence or absence of some type of neurological recovery (not specified) in favor of those patients who received MP (Fisher exact test on proportions, P = .005). Recovery was mainly restricted to 9 of 10 patients with incomplete SCI, all of whom received MP.

Quian et al24 prospectively analyzed a cohort of 8 SCI patients who were assessed for evidence of acute corticosteroid myopathy (ACM) from 1 to 7 days after their injury. The diagnosis was established directly through muscle biopsy and indirectly through electromyography (EMG) studies sampled above the level of SCI. Five patients received MP treatment according to NASCIS II dosing. Three patients did not receive MP due to penetrating trauma (n = 2) or presentation more than 8 hours from the time of injury (n = 1). ACM occurred in a time-dependent manner between 3 to 7 days in the MP group: 1 patient biopsied within 24 hours of injury had normal muscle; 2 patients biopsied 3 days after injury showed mild evidence of ACM; 2 patients biopsied on day 5 and 7, respectively, showed changes compatible with severe ACM. Patients in the control group were biopsied within 24 hours of injury (n = 2) and on day 5 (n = 1). Muscle biopsies and EMG activity were normal in all 3 control patients.

Acknowledging the natural history of ACM improvement within 6 to 8 months from time of onset, the authors speculated that some of the motor improvement observed in the NASCIS II and III studies may have been due to resolution of an iatrogenic myopathy.

From 1998 through 2002, Tsutsumi et al25 identified 278 consecutive admissions to their institution for acute mid to lower cervical SCI. From this group, 70 patients admitted within 7 days of injury and with 6 months of follow up were discovered. Thirty-seven received MP at NASCIS II dosing within 8 hours of injury, while 33 received no drug, according to the preference of the treating physician at the time of injury. Neurological function was assessed through ASIA motor scores. Sensory function was not tested.

The study group was further subdivided into complete (ASIA A) and incomplete (ASIA B, C, D) patients. No difference in motor improvement was seen in MP patients (n = 18) compared to controls (n = 25) in those with complete injuries (P = .48). Incomplete patients treated with MP (n = 19) improved on average 18 more motor points than those who did not receive MP (n = 8) (P = .005). However, 84% (n = 16) of the 19 MP patients were ASIA grade C or D on admission compared to 75% (n = 6) of the 8 control group patients. Mean admission and follow-up ASIA motor scores were not published, making it impossible to further discern within this small retrospective group how much selection bias towards less severe injuries (and hence recovery) favored those who received steroids.

Lee et al26 retrospectively analyzed 111 patients with SCI admitted to a single institution over the 2-year period spanning from January 2002 until December 2003 with respect to MP administration, surgical intervention, and complication rates. Neurological outcome was assessed according to the Frankel grading system, where improvement was defined as a change in 1 or more Frankel grades. Fifty-eight patients (52%) received MP according to either NASCIS-II or NASCIS-III dosing protocols, while, for reasons not specified, 53 patients did not. Potential neuroprotective effects of MP were not reported. Instead, the analysis compared patients who had both MP and surgery to those who did not have either. “Significant” changes in Frankel score were observed in 11 of 16 complete SCI patients treated with MP and surgery, compared to zero of 7 patients treated with surgery alone. Twenty-one of 31 incomplete SCI patients who underwent surgery and MP administration also showed “significant” Frankel grade improvement compared to 4 of 8 patients...
Thirty-four of the patients were treated with surgery alone. Unfortunately, neither statistical methodology nor P-values were reported. If one calculates Fisher exact test for 2-tailed significance on 2 independent samples, the significance of improvement seen in the complete group who received MP was $P = .005$, whereas in the incomplete group receiving MP it was $P = .42$. In the subanalysis it remains unclear why 47 MP patients were treated surgically (81% of the entire cohort of MP patients) compared to only 15 patients (28%) in the non-MP group, perhaps suggesting the latter to be a more severely or chronically injured patient group (Figure 4).

Complications ascribed to MP administration were observed in 24 of 58 patients treated with MP (41%), including peptic ulcer, upper GI hemorrhage, perforated peptic ulcer, and urinary tract infection. One patient with a complete SCI died as a result of sepsis from GI perforation. The incidence of complications was proportional to the completeness of the SCI. It is not specified whether there were any non-MP patients who suffered similar morbidity.

Leypold and colleagues reported a radiographic study comparing cord edema and hemorrhage in 82 patients with ASIA A (complete) cervical SCI. Thirty-four of the patients were treated prior to 1994 and did not receive MP as part of their treatment. Forty-eight patients were treated after 1997 and received MP according to NASCIS II protocol. An unspecified number of patients treated in the 4 years spanning 1994 to 1997 were excluded to “avoid the possibility of assignment to the wrong group.” Magnetic resonance sequences (T1 and T2, dual echo SE, or gradient echo) were acquired in a 1.5T magnetic resonance unit within 3 days of injury. No images were available prior to administration of MP in those patients treated with steroids. Neurological outcomes were not reported.

The mean age of the MP group was 16 years older than that of the historical controls (47 years vs 31 years; statistically significant $P$-value not provided). The incidence of spinal cord hemorrhage was higher in historical controls compared to MP-treated patients, but the difference was not statistically significant (91% vs 67%; $P = .162$). There was no difference in rostro-caudal length of edema within the spinal cord (4.0 vs 3.3 spinal segments; $P = .9$). However, length of hemorrhage was greater in controls compared to MP patients (1.5 vs 0.8 spinal segments; $P = .04$). Potential differences in mechanism of injury (eg, between a 50-year-old MP patient with central cord syndrome and a 30-year-old non-MP patient with fracture dislocation) were not explored. Of equal or more important concern, however, is the lack of a baseline (pre-MP) magnetic resonance imaging and the concurrent assumption that the extent of SCI hemorrhage within 3 days of injury was independent of the initial SCI. There have been no previous studies defining the temporal sequence of acute hematoma evolution in the spinal cord as a result of SCI.

In 2008, Suberviola et al.²⁸ published a review of all adult patients admitted to their institutional ICU with acute SCI over a 12-year period. A total of 82 patients were identified, of which 59 received MP (NASCIS II protocol) and 23 did not. Patient demographics including admission Frankel grade did not differ between the groups except that the non-MP patients had a higher injury severity score compared to those who received steroids (31 vs 22; $P = .006$). Accordingly, the length of ICU stay was also longer for the non-MP patients (20 days vs 12 days; $P = .031$).

At time of ICU discharge, approximately 31% of patients in both groups improved by 1 or more Frankel grades. There was no difference in ICU mortality rate attributable to steroid administration or lack thereof. Similarly, wound infections, sepsis, and urinary tract infections were comparable between groups. However, MP patients suffered a higher rate of respiratory infections ($P = .02$), total infections ($P = .004$), and early hyperglycemia requiring insulin drip for up to 4 days ($P < .01$).

Ito et al.²⁹ compared a consecutive series of acute SCI patients who received MP against a subsequent consecutive series of SCI patients who were not given steroids. The study was performed in a prospective nonrandomized manner over a 4-year period: from August 2003 through July 2005, 38 patients were given MP according to the NASCIS II protocol, while from August 2005 through July 2007 41 were treated for acute SCI without MP. Patients were excluded from the study if they presented more than 8 hours after injury. Neurological assessments were made on admission and 3 months later. Adverse events were recorded during the hospital stay.

An improvement by 1 or more ASIA grades was observed in 45% of those who received MP compared to 63% of those who did not ($P > .05$). On average, ASIA motor scores improved by 12 points in the MP group and 14 points in control group patients ($P > .05$). Similarly, there was no therapeutic benefit to MP if
patients were compared on the basis of motor complete and motor incomplete injuries. ASIA sensory scores were not reported. Infections (pneumonia, urinary tract infection, wound infection) were observed in 68% of the MP group but in only 44% of control group patients \( (P = .028) \). Sixteen percent of MP-treated patients suffered GI hemorrhage compared to 5% of controls, but the difference was not statistically significant.

A rare complication of corticosteroid-induced acute tumor lysis syndrome was detailed in a case report published by Tsao et al\(^\text{10}\) in 2009. A 37-year-old woman was treated with MP (NASCIS-II protocol) for an acute incomplete cervical SCI. She received MP treatment within 8 hours of injury but with concurrent (undiagnosed) intravascular diffuse large B-cell lymphoma. Sixteen hours after infusion, the patient developed ventricular fibrillation and acute renal failure. Resuscitation was successful and the patient responded to hemodialysis, but succumbed to her disease 8 months later.

Based on data from a small number of randomized head injury trials and the success reported in NASCIS II and III, a prospective randomized placebo-controlled trial investigating the effect of MP on head injury was undertaken in 239 hospitals across 49 countries.\(^\text{30}\) Over a 5-year period, patients were enrolled into the Corticosteroid Randomization After Significant Head injury (CRASH) study, receiving either a 48-hour MP infusion according to NASCIS III dosing or a 48-hour placebo infusion of normal saline. The research hypothesis was constructed to evaluate the neuroprotective efficacy of high-dose steroids in cranial trauma. Primary outcome measures were: (1) death from any cause at 2 weeks, and (2) death or disability at 6 months. Sample-size calculations suggested that 20,000 patients were required to detect a 2% difference in the study groups.

Patients were eligible for enrollment if they were 16 years of age or older, were within 8 hours of injury, and had a Glasgow Coma Score \( \leq 14 \). Interim data of in-hospital mortality, complications, and 6-month outcome were supplied by each institution on an annual basis to an independent data monitoring and ethics committee. The committee was responsible for unmasking the results if the randomized comparisons provided proof beyond reasonable doubt of a difference in outcome between the study and control groups AND evidence that would be expected to substantially alter the choice of treatment for patients.

In May 1994, the trial was terminated prematurely as a result of interim analyses by the data monitoring and ethics committee. A total of 10,008 patients had been enrolled, just over 5000 patients in each treatment arm. Within the MP group, 1052 (21.1%) deaths were observed within the first 2 weeks of injury compared to 893 (17.9%) in control patients representing a relative risk for death of 1.18 (95% confidence interval [CI] 1.09-1.27; \( P = .0001 \)). There was no difference in the severity of head injury between the 2 groups (\( P = .22 \)). Six-month data were published a year later by the same group.\(^\text{31}\) The risk of death remained higher in the MP group (1248 deaths; 25.7%) compared to placebo (1075 deaths; 22.3%) (\( P = .0001 \)). In other words, for every 29 patients treated with MP, 1 died from drug-associated morbidity.

The second outcome measure of death and disability at 6 months was also higher in the MP group (relative risk 1.05; 95% CI 0.99-1.10; \( P = .079 \)). The authors concluded that corticosteroids should not be used routinely in the treatment of head injury.

**SUMMARY**

**Methylprednisolone**

Despite 4 prospective blinded randomized controlled trials investigating the effect of MP in acute SCI, there exists no Class I medical evidence of any beneficial effect.\(^\text{2,4,8,20}\) Two prospective Class II trials also failed to demonstrate the therapeutic efficacy of MP in SCI.\(^\text{14,29}\) In total, over 980 patients have received steroids for SCI and over 280 have participated as control subjects within the protocol of a prospective clinical trial—in which, universally, all primary comparisons to establish efficacy have been negative.

A variety of Class III medical evidence has been published supporting the neuroprotective effect of MP in SCI.\(^\text{6,7,13,14,22,23,25,26}\) In general, these studies suffer from 1 of 2 significant limitations: limited sample size derived retrospectively from much larger study populations\(^\text{6,7,14,22,23,25,26}\) and/or incomplete data reporting in which omitted data are likely to have negated the proposed beneficial effect.\(^\text{6,7,13,14,22,23,25,26}\) Additionally, the beneficial effects claimed related to MP administration in the setting of acute SCI have been inconsistent. Patients are reported to have demonstrated improvement in sensory but not motor function,\(^\text{14,22}\) motor but not sensory function,\(^\text{6,7,25}\) or some other (undefined) type of neurological recovery.\(^\text{13,23}\) It is important to note than none of these retrospective data analyses have claimed neurological improvement of a meaningful functional or behavioral nature. In light of both significant methodological errors and inconsistent neurological outcomes, the beneficial effects of MP can as easily be ascribed to random chance as to any true therapeutic effect.

Harmful side effects of MP administration in the setting of acute SCI have been reported as significant in 3 Class I studies,\(^\text{8,20,21}\) including wound infection, hyperglycemia requiring insulin administration, and GI hemorrhage. Although not statistically significant, similar trends were observed in Class I medical evidence from NASCIS II and III, including GI hemorrhage, sepsis, pneumonia, and death due to respiratory failure.\(^\text{6,7,13,14}\) In addition, Class II medical evidence shows a significantly higher risk of infection (respiratory, urinary, wound) and steroid-induced myopathy in patients treated with MP compared to controls.\(^\text{24,29}\) Several Class III medical evidence studies describe similar adverse events of statistical significance including pneumonia, respiratory failure, peptic ulcer disease, GI hemorrhage, and hyperglycemia requiring insulin administration.\(^\text{12,18,26,28}\) Most compelling is the Class I medical evidence from over 10,000 patients with head injury, indicating that high-dose MP administration leads to significantly higher mortality independent of injury severity.\(^\text{31}\)

In summary, there is no consistent or compelling medical evidence of any class to justify the administration of MP for acute SCI. Both consistent and compelling Class I, II, and III medical evidence exists suggesting that high-dose MP administration is...
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<td><strong>Tsao,</strong> Lancet, 2009</td>
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<td>Bracken, JAMA, 1997</td>
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<td>Otani, Sektsui Sekizui, 1994</td>
<td>Prospective randomized (nonblinded) multicenter study evaluating NASCIS II MP dose given to 82 patients within 8 hours compared to 76 observational controls enrolled between January 1992 and March 1993.</td>
<td>II* *(reported positive results III)</td>
<td>Only 70 MP patients and 47 controls analyzed. No difference in motor or sensory function between groups. Post-hoc analysis suggested some degree of sensory recovery to occur more frequently in MP patients, possibly cancelled out by greater degree of improvement in controls.</td>
</tr>
<tr>
<td>Prendergast, J Trauma Inj Int Crit Care, 1994</td>
<td>Retrospective review of 29 acute SCI patients treated with NASCIS II MP dosing after 1990 compared to 25 patients treated without MP before 1990. Thirty-one patients suffered penetrating SCI.</td>
<td>III</td>
<td>No difference in neurological recovery between MP or control groups. Patients with penetrating SCI who received MP showed deterioration in motor and sensory scores compared to improvement observed in controls.</td>
</tr>
<tr>
<td>Galandiuk, Ann Surg, 1993</td>
<td>Prospective assessment of 15 patients from 1990 to 1993 and retrospective review of 17 patients from 1987 to 1990. Fourteen patients given MP within 8 hours of SCI compared to 18 patients not treated with MP.</td>
<td>III</td>
<td>No difference in neurological outcome. MP patients had immune response alterations, higher rate of pneumonia and longer hospital stay compared to control patients (NS).</td>
</tr>
<tr>
<td>Bracken, J Neurosurg, 1992</td>
<td>NASCIS II: One-year follow-up.</td>
<td>I* *(reported positive results III)</td>
<td>All primary (preplanned) comparisons negative. Post-hoc analyses showed improvement in motor but not sensory scores at 1 year in patients given MP within 8 hours of injury (P = .030). Wound infections, GI hemorrhage, and pulmonary embolus more common in MP vs placebo (NS, no power analysis).</td>
</tr>
<tr>
<td>Bracken, NEJM, 1990</td>
<td>NASCIS II: Multicenter randomized, double blind, placebo-controlled trial comparing MP to naloxone and placebo in 487 patients with acute SCI.</td>
<td>I* *(reported positive results III)</td>
<td>No difference between groups in all primary (preplanned) comparisons. Post-hoc analyses showed improvement in motor and sensory scores at 6 months in patients given MP within 8 hours of SCI.</td>
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associated with a variety of complications including infection, respiratory compromise, GI hemorrhage, and death. MP should not be routinely used in the treatment of patients with acute SCI.

**GM-1 Ganglioside (Sygen)**

Found indigenously in cell membranes of mammalian central nervous system tissue, GM-1 ganglioside is a compound thought to have antiexcitotoxic activity, promote neuritic sprouting, potentiate the effects of nerve growth factor, and prevent apoptosis. In 1991, Geisler et al. reported promising results of a pilot study investigating its use in acute SCI. All patients received a 250 mg bolus of MP followed by 125 mg every 6 hours for 72 hours. GM-1 patients were administered 100 mg of GM-1 per day for 18 to 32 days, with the first dose provided within 72 hours of injury. Neurological assessment was accomplished with ASIA motor score assessments and the Frankel scale.

Of 37 patients entered into the study, 34 were available for 1-year follow up (16 GM-1 patients, 18 placebo). GM-1 ganglioside-treated patients showed significant improvement in Frankel grade from baseline to 1-year follow up \( (P = .034) \) and significantly greater improvement in ASIA motor scores compared to placebo-treated patients \( (P = .047) \). The recovery of motor function in GM-1 ganglioside-treated patients was felt to be due to recovery of strength in paralyzed muscles rather than strengthening of paretic muscles. There were no adverse effects attributed to the administration of the study drug. The authors concluded that GM-1 ganglioside enhanced neurological recovery in human patients following SCI and deserved further study.

The subsequent multicenter study involved 28 neurotrauma institutions and randomized 797 patients within 72 hours of injury to receive either GM-1 ganglioside (100 or 200 mg i.v./day) or placebo for a total of 56 days. All patients received NASCIS II doses of MP within 8 hours of injury. The duration of follow up was 1 year. Although patients with ASIA grade C and D SCI treated with Sygen demonstrated statistically significant improvement in modified Benzel grade compared to placebo-treated

**TABLE 1. Continued**

<table>
<thead>
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<th>Citation</th>
<th>Description of Study</th>
<th>Evidence Class</th>
<th>Conclusions</th>
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</thead>
<tbody>
<tr>
<td>Bracken, J Neurosurg 1985</td>
<td>NASCIS I: One-year follow up.</td>
<td>I</td>
<td>No significant difference in neurological recovery of motor or sensory function 1-year post-injury.</td>
</tr>
<tr>
<td>Bracken, JAMA, 1984</td>
<td>NASCIS I: Multicenter, double-blind randomized trial comparing MP(1000 mg/d vs 100 mg/d for 11 days) in treatment of 330 patients with acute SCI.</td>
<td>I</td>
<td>No treatment effect at 6 weeks and 6months post injury. No control group. Wound infections significantly higher in high-dose group ( (P = .01) ). Death in first 14 days 3X more common in high-dose group ( (NS, no power analysis) ).</td>
</tr>
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</table>

ASIA, American Spinal Injury Association; ICU, intensive care unit; MP, methylprednisolone; NASCIS, National Acute Spinal Cord Injury Study; NS, not statistically significant; SCI, spinal cord injury.

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<tbody>
<tr>
<td>Bracken, et al., 1991</td>
<td>Prospective randomized, double blind, stratified multicenter trial of GM-1 ganglioside in 760 acute SCI patients. All received MP per NASCIS II protocol. (Placebo group)</td>
<td>I</td>
<td>No significant differences in neurological recovery identified between GM-1 treated patients and MP treated patients at 26-week follow up. Trend for earlier recovery in GM-1 treated patients. No true placebo group.</td>
</tr>
<tr>
<td>Geisler et al., 2001</td>
<td>Prospective, randomized, double blind trial of GM-1 ganglioside in 37 human SCI patients. All received 250 mg MP bolus followed by 125 mg/Q6H x72 hours before randomization (placebo group).</td>
<td>I</td>
<td>GM-1 ganglioside enhances recovery of neurological function, significant difference in recovery compared to MP group ( (P = .047) ). Insufficient numbers of patients to draw meaningful conclusions. No true placebo group.</td>
</tr>
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</table>

NS, not statistically significant
patients at 4 and 8 weeks after injury, the advantage was lost at subsequent follow up visits. No difference between actively treated and placebo-treated patients was noted in any of the outcome measures at 1 year. There have been no further studies to confirm or refute these results in the last decade. Consequently, GM-1 ganglioside is not recommended for use in the routine management of patients with acute SCI at this time.

**Disclosure**

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

**REFERENCES**


The Acute Cardiopulmonary Management of Patients With Cervical Spinal Cord Injuries

**KEY WORDS:** Blood pressure augmentation, Cardiac instability, Intensive care unit, Respiratory failure


**RECOMMENDATIONS**

**Level III:**

Management of patients with an acute cervical spinal cord injury in an intensive care unit or similar monitored setting is recommended.

- Use of cardiac, hemodynamic, and respiratory monitoring devices to detect cardiovascular dysfunction and respiratory insufficiency in patients following acute spinal cord injury is recommended.
- Correction of hypotension in spinal cord injury (systolic blood pressure < 90 mm Hg) when possible and as soon as possible is recommended.
- Maintenance of mean arterial blood pressure between 85 and 90 mm Hg for the first 7 days following an acute spinal cord injury is recommended.

**RATIONALE**

The intensive care unit (ICU) setting has traditionally been reserved for critically ill patients who require aggressive medical care and exceptional medical attention. Most contemporary medical centers have multiple critical care units, each designed to provide discipline-specific observation and intensive care to patients in need. Select institutions have created Acute Spinal Cord Injury Centers and offer multidisciplinary care including ICU care to patients who have sustained acute spinal cord injuries (SCIs). Several reports describe improved patient management and lower morbidity and mortality following acute SCI with ICU monitoring and aggressive medical management. Despite this interest in and commitment to more comprehensive care for the patient with an acute SCI, many traumatic SCI patients are not managed in an ICU setting, nor are they routinely monitored for cardiac or respiratory dysfunction. There exist divergent management strategies for acute SCI patients within regions, communities, even institutions, depending on the training and experiences of the clinicians providing care.

Respiratory insufficiency and pulmonary dysfunction are common after traumatic SCI, particularly when the injury occurs at cervical spinal cord levels. Severe injured patients demonstrate marked reductions in expected vital capacity and inspiratory capacity and may experience relative hypoxemia, all of which contribute to global hypoxemia and can exacerbate spinal cord ischemia after acute injury. It appears that the earlier cardiac and/or ventilatory/pulmonary dysfunction is detected, the more likely effective, often life-saving treatment can be initiated. It is for these reasons that the issues of early ICU care and cardiac and pulmonary monitoring for human patients following acute SCI have been raised.

Acute traumatic SCI is frequently associated with systemic hypotension. Hypotension may be due to hypovolemia, direct severe spinal cord trauma itself, or a combination of the two. The presence of hypotension has been shown to be associated with worse outcomes after traumatic injury, including severe head injury. Although a prospective controlled assessment of the effects of hypotension on acute human SCI has not been performed, laboratory evidence suggests that hypotension contributes to secondary injury after acute SCI by further reducing spinal cord blood flow and perfusion.

**ABBREVIATIONS:** ASIA, American Spinal Injury Association; ICU, intensive care unit; MAP, mean arterial pressure; SCI, spinal cord injury
Hypotension in animal models of SCI results in worse neurological outcome. Several clinical series of human patients with acute SCI managed in an aggressive fashion with attention to blood pressure, oxygenation, and hemodynamic performance report no deleterious effects of therapy and suggest improved neurological outcome. Despite these observations, many patients with acute SCI treated in contemporary practice are not routinely monitored in an ICU setting or treated with blood pressure augmentation after injury. For these reasons, the issues of routine blood pressure support and threshold levels of mean arterial pressure (MAP) maintenance following acute SCI have been raised.

The previous medical evidence-based guideline effort by the Joint Section on Disorders of the Spine and Peripheral Nerves of the American Association of Neurological Surgeons and the Congress of Neurological Surgeons addressed the role of systemic blood pressure support and the role of the intensive care setting in 2 separate chapters. The purpose of the current review is to update the medical evidence on the diagnosis and treatment of these issues since the original 2 medical evidence-based guidelines were published in 2002 and to address the following questions:

- Do patients with acute spinal cord injuries benefit from ICU cardiac, hemodynamic, and pulmonary monitoring and care?
- Does blood pressure management influence neurological outcome in patients with acute cervical SCI?

**SEARCH CRITERIA**

A National Library of Medicine (PubMed) computerized literature search from 2000 to 2011 was undertaken using Medical Subject Headings in combination with “spinal cord injury”: medical management, nonoperative management, hypotension, spinal cord blood flow, respiratory insufficiency, pulmonary complications, and intensive care. Approximately 3500 citations were acquired. Non–English-language citations were excluded. Titles and abstracts of the remaining publications were reviewed, and relevant articles were selected to develop the guidelines. We focused on 4 specific topics concerning human patients with acute SCI: management in an ICU, cardiac instability, hypotension, and respiratory/pulmonary dysfunction. Additional citations were extracted from the reference lists of the remaining papers. Finally, members of the author group were asked to contribute articles known to them on the subject matter that were not found by other search means. Articles describing economics, epidemiology, anesthesia, monitoring techniques, penetrating cord injuries, nursing care, infectious or urologic complications, chronic complications, or remote SCIs were excluded. These efforts resulted in 11 articles, which form the foundation for this updated review. All studies provided Class III medical evidence. Twenty-seven articles are summarized in Evidentiary Table format (Table).

**SCIENTIFIC FOUNDATION**

In 1976, Zäch et al reported on a prospective medical management paradigm in the treatment of 117 consecutive acute SCI patients in the Swiss Paraplegic Centre of Basel, Switzerland. All patients were treated in the ICU with central venous pressure monitoring and were administered dexamethasone 0.5 mg/kg for 4 days with a tapering dose through 10 days and volume expansion with Rheomacrodex 40 at 500 mL/d for 7 days. Patients were stratified by injury level, degree of deficit (Frankel grade), and time of admission after injury. The authors reported that 62% of cervical-level SCI patients they managed in this way improved at last follow-up, including 8 of 18 Frankel grade A patients, 2 by 2 grades and a third patient by 3 grades. No patient with a cervical injury worsened; 38% were unchanged from admission. Patients with thoracic T1–T10–level SCIs fared less well; 38% improved, none worsened, and 62% were without change, including 22 of 26 Frankel grade A patients. Two Frankel grade A patients experienced a complete recovery. Seventy percent of acute T11–L1–level SCI improved with this treatment paradigm, none worsened, and 30% were unchanged from admission. Of patients who arrived within 12 hours of injury, 67% were improved compared with their admission neurological examination. Of patients admitted between 12 and 48 hours of injury, only 59% improved. When admission occurred after 48 hours of injury, improvement was seen in only 50% of patients. The authors concluded that early transfer and “immediate medical specific treatment of the spinal injury” with attention to maintenance of acceptable blood pressure appeared to improve neurological recovery.

That same year, Hachen reported a decade of experience with acute traumatic tetraplegia from the National Spinal Injuries Centre in Geneva. He described 188 acute SCI patients treated in an ICU setting following immediate transfer from the scene of the injury. The center reported a marked reduction in mortality rates following acute cervical SCI compared with annual statistics from 1966. Mortality for complete tetraplegia was reduced from 32.5% to 6.8% over the 10-year period. Mortality for patients with incomplete tetraplegia fell from 9.9% in 1966 to 1.4% in 1976. Most early deaths in the center’s experience were related to pulmonary complications. The likelihood of severe respiratory insufficiency was related to the severity of the cervical SCI. Seventy percent of patients with complete lesions experienced severe respiratory insufficiency in the center’s experience compared with 27% of patients with incomplete lesions. The improvement in mortality rates described was related directly to early monitoring and treatment of respiratory insufficiency in the ICU setting. Hachen stressed that facilities for continuous monitoring of central venous pressure, arterial pressure, pulse, respiration rate and pattern, and oxygenation-perfusion parameters must be available for all patients with neurological injuries following acute SCI, particularly those injuries above the C6 level.

In 1979, Gschaedler et al described the comprehensive management of 51 patients with acute cervical SCIs in an ICU setting in Colmar, France. Forty percent of patients had multiple organ system injuries. They reported a low mortality rate of 7.8% and described several severely injured patients who made important neurological improvements, including 1 Frankel grade
A patient who improved to grade D and 2 Frankel grade B patients who changed to grade D. They cited early transport after injury and comprehensive intensive medical care with attention to and the avoidance of hypotension and respiratory insufficiency as essential to the improved outcomes their patients experienced.

McMichan et al\textsuperscript{14} reported a prospective case series in 1980 of pulmonary complications identified in 22 patients with cervical-level acute SCI managed in an ICU setting. They compared their results with 22 historical controls with similar injuries. Institution of a new, aggressive pulmonary treatment paradigm resulted in zero deaths and fewer respiratory complications compared with those experienced by the retrospective group (9 deaths). They concluded that vigorous pulmonary therapy initiated early after acute SCI was associated with increased survival, a reduced incidence of pulmonary complications, and a decreased need for ventilatory support.

Ledsome and Sharp\textsuperscript{13} measured pulmonary function in 16 patients with complete cervical SCI and compared initial values with those obtained in the same patients at 1, 3, and 5 weeks and 3 and 5 months after injury. In their 1981 report, they noted profound reduction in forced vital capacity (FVC) and expiratory flow rate immediately after injury. Patients with an FVC < 25\% of expected had a high incidence of respiratory failure requiring ventilator support. This was especially true of patients with injuries at C4 or above. FVC was significantly increased at 5 weeks after injury and doubled at 3 months regardless of the level of cervical cord injury. Importantly, hypoxemia (\text{PO}_2 < 80 \text{ mm Hg}) was identified through blood gas analyses in 74\% of patients who did not require ventilator support despite adequate alveolar ventilation (\text{PCO}_2 normal; low FVC). The authors attributed this to a ventilation perfusion imbalance occurring immediately after acute SCI. Systemic hypoxemia responded to treatment with supplemental oxygen in most patients.

Piepmeier et al\textsuperscript{16} identified cardiovascular instability following acute cervical SCI in 45 patients they managed in an ICU setting in New Haven, Connecticut. Twenty-three patients had Frankel grade A injuries, 8 had grade B, 7 had grade C, and 7 had grade D. They discovered a high incidence of cardiovascular irregularities in these patients and identified a direct correlation between the severity of cord injury and incidence and severity of cardiovascular problems. Three patients returned to the ICU setting during the 2-week observation period of the study because of cardiac dysfunction despite a period of initial stability. Twenty-nine of the 45 patients had an average daily pulse rate of < 55 bpm, and 32 had episodes during which their pulse rate was < 50 bpm for a prolonged period of time. Hypotension was common after acute SCI in their series, but most patients responded well to volume replacement. However, 9 patients required vasopressors ranging over a period from hours to 5 days to maintain systolic pressure > 100 mm Hg. Cardiac arrest occurred in 5 patients (11\%). All had Frankel grade A injuries. Three arrests occurred during endotracheal suctioning. The authors found that the first week after injury was the timeframe during which patients were most vulnerable to cardiovascular instability. Patients with the most severe neurological injuries were most likely to experience cardiovascular instability after acute SCI regardless of autonomic function. They concluded that careful monitoring of severely injured acute SCI patients in the ICU setting reduces the risk of life-threatening emergencies.

In 1984, Tator and colleagues\textsuperscript{8} described their experience with 144 patients with acute SCI managed between 1974 and 1979 at a dedicated SCI unit at Sunnybrook Medical Centre in Toronto, Ontario, Canada. They compared their results with a cohort of 358 SCI patients managed between 1948 and 1973 before the development of the acute care SCI facility. All 144 patients managed from 1974 to 1979 were treated in an ICU setting with strict attention to the treatment of hypotension and respiratory failure. Their medical paradigm was developed on the principle “that avoiding hypotension is one of the most important aspects of the immediate management of acute cord injury.” Hypotension was “treated vigorously” with crystalloid and transfusion of whole blood or plasma for volume expansion. Patients with respiratory dysfunction were treated with ventilatory support as indicated. They reported a reduced mean time from injury to admission and treatment (5 hours) compared with their 1948 to 1973 experience (> 12 hours). Neurological improvement was observed in 41 of 95 patients (43\%) managed under the aggressive ICU medical paradigm. Fifty-two patients (55\%) demonstrated no improvement. Only 2 patients (2\%) deteriorated. The authors reported lower mortality, reduced morbidity, shorter length of stay, and lower cost of treatment compared with the 1948 to 1973 experience a result of this aggressive ICU strategy. They cited improved respiratory management in their ICU as one of the principal factors responsible for reduced mortality and credited the avoidance of hypotension, sepsis, and urologic complications for reduced morbidity after injury. These improved outcomes were realized despite the fact that 28\% of the acute SCI patients they treated had additional injuries that increased their risk of morbidity and mortality.

In a 1987, Lehmann et al\textsuperscript{26} reported on 71 acute SCI patients managed in an ICU at Yale/New Haven Medical Center. Patients were admitted within 12 hours of SCI and stratified by level and severity of neurological injury (Frankel scale). Patients were excluded if they harbored comorbidities such as head injury, diabetes mellitus, preexisting cardiac disease, or a history of cardiac medication use. All were monitored; hypotension was aggressively treated. The authors found that all patients with severe cervical SCIs (Frankel grades A and B) had prolonged bradycardia defined as heart rate < 60 bpm lasting at least 1 day. Thirty-five percent of Frankel grade C and D patients also demonstrated prolonged bradycardia. Only 13\% of thoracic and lumbar SCI injuries had this finding. Marked bradycardia (< 45 bpm) was frequent in patients with severe cervical SCI (71\%) and less common in patients with more mild cervical (12\%) and thoracolumbar (4\%) SCI. Sinus node slowing was profound enough to produce hemodynamic compromise and systemic hypotension necessitating bolus injections of atropine or placement of a temporary pacemaker in 29\% of the severe cervical SCI.
patients. Episodic hypotension unrelated to hypovolemia was identified in 68% of the severe cervical injury group, requiring the use of intravenous pressors in half. Five of 31 patients (16%) in the severe injury group experienced a primary cardiac arrest, three of which were fatal. All 5 patients had Frankel grade A SCI. There were no significant cardiac rate disturbances or spontaneous episodes of hypotension beyond 14 days of injury. The authors concluded that potentially life-threatening cardiac arrhythmias and hypotension regularly accompany acute severe injury to the cervical spinal cord within the first 14 days of injury. These events were not solely attributable to disruption of the autonomic nervous system. Detection and treatment were best accomplished in an ICU setting.

Wolf et al29 in 1991 described their experience with bilateral facet dislocation injuries of the cervical spine at the University of Maryland in Baltimore. Fifty-two patients with acute cervical trauma were reviewed who received ICU care, volume resuscitation, invasive monitoring, and hemodynamic manipulation to maintain mean blood pressure > 85 mm Hg for 5 days. Thirty-four patients had complete neurological injuries, 13 had incomplete injuries, and 5 patients were intact. The authors attempted closed reduction within 4 hours of patient arrival to their center and performed early open reduction on patients who could not be reduced by closed means, including closed reduction under anesthesia. All but 3 patients underwent surgery for stabilization and fusion. The authors reported neurological improvement at discharge in 21% of complete SCI patients and in 62% of patients with incomplete cervical SCI. No intact patient deteriorated. Only 52% 1-year follow-up was provided. The authors concluded that their protocol of aggressive, early medical and surgical management of patients with acute SCI improved outcome following injury. Treatment in the ICU setting, hemodynamic monitoring with maintenance of MAP, and early closed or open decompression of the spinal cord were linked to a reduction of secondary complications.

Levi and coworkers5 treated 50 acute cervical SCI patients in the ICU at the University of Maryland in Baltimore according to an aggressive management protocol that included invasive hemodynamic monitoring and volume and pressor support to maintain a hemodynamic profile with adequate cardiac output and mean blood pressure > 90 mm Hg. Their 1993 report described 31 patients with Frankel grade A injuries on admission, 8 patients with Frankel grade B injuries, and 11 patients in Frankel C and D grades. Eight patients had severe hypotension at the time of admission (systolic blood pressure < 90 mm Hg), whereas 82% of patients developed volume-resistant hypotension requiring pressors within the first 7 days of treatment. This was 5½ times more common among patients with complete motor injuries. The authors reported that the overall mean pulmonary vascular resistance index for the 50 patients they studied was less than the normal range, and it was less than the normal value in 58% of patients. Half of their acute SCI patients had a lower-than-normal systemic vascular resistance index. No patient with a complete motor deficit (Frankel grades A and B) and marked pulmonary vascular resistance index/systemic vascular resistance index deficits experienced neurological recovery at 6 weeks. Forty percent of patients managed by protocol including several with complete injuries had some degree of neurological function improvement, 42% remained unchanged, and 9 patients died (18%). There was minimal morbidity associated with invasive hemodynamic monitoring. The authors concluded that hemodynamic monitoring in the ICU allows early identification and prompt treatment of cardiac dysfunction and hemodynamic instability and can reduce morbidity and mortality following acute SCI.

Vale et al29 reported their results in 1997 from a prospective case series in which aggressive medical resuscitation and blood pressure management were performed on 77 patients with acute SCI treated at the University of Alabama in Birmingham. All patients were managed in the ICU with invasive monitoring (Swan Ganz catheters and arterial lines) and blood pressure augmentation to maintain MAP > 85 mm Hg for 7 days after injury. They reported 10 patients with complete cervical SCI (American Spinal Injury Association [ASIA] grade A), 25 with incomplete cervical injuries (ASIA grades B, C, and D), 21 patients with complete thoracic SCI, and 8 patients with incomplete thoracic-level SCI (grades B, C, and D). The average admission MAP for ASIA A cervical patients was 66 mm Hg. Nine of 10 patients required pressors following volume replacement to maintain an MAP of 85 mm Hg. Fifty-two percent of incomplete cervical SCI patients required pressors to maintain MAP at 85 mm Hg. Only 9 of 29 patients with thoracic-level SCI required the use of pressors. The authors reported minimal morbidity with the use of invasive monitoring or with pharmacological therapy to augment MAP. At 1-year follow-up (mean, 17 months), neurological recovery was variable and typically incomplete. Three of 10 cervical ASIA A patients regained ambulatory capacity, and 2 regained bladder function. Incomplete cervical SCI patients fared better. Twenty-three of these patients regained ambulatory function at 12 months of follow-up, only four of whom had initial examination scores consistent with ambulation. Twenty-two of 25 patients (88%) regained bladder control. Thirty-one of 35 cervical SCI patients and 27 of 29 thoracic-level SCI patients were treated surgically. The authors statistically compared selection for and timing of surgery with admission neurological function and compared surgical treatment, early and late, with neurological outcome and found no statistical correlation. They concluded that the enhanced neurological outcome identified in their series after acute SCI was optimized by early and aggressive volume resuscitation and blood pressure augmentation and was in addition to and/or distinct from any potential benefit provided by surgery.

In 2001, Vitaz et al30 described a clinical pathway for SCI management developed in multidisciplinary fashion and compared the results before and after implementation. Thirty-six patients in the study group were compared with 22 control patients. Study group patients had 6.8 fewer ICU days, 11.5 fewer hospital days, 6 fewer ventilator days (P < .05), and a lower
rate of complications. The authors concluded that the use of a clinical care pathway for SCIs resulted in improved patient care and fewer complications. Despite the prospective comparison, the groups were not comparable and the study was considered to provide Class III medical evidence.

Aito\textsuperscript{31} prospectively assessed the incidence of complications associated with acute SCI on the basis of the type of facility in which the acute care of the traumatic SCI was provided. In their 2003 publication, nearly all of the described complications they identified occurred in patients not initially admitted to a specialized SCI unit, including respiratory complications, deep-vein thrombosis, pulmonary embolism, trophic skin changes, heterotopic ossification, and urinary complications. The authors concluded that prevention of complications during the acute phase after SCI is best accomplished by early admission to a specialized multidisciplinary SCI unit.

Como et al\textsuperscript{32} characterized the need for mechanical ventilation in patients with acute cervical SCI and neurological deficits. Their 2005 study included 119 patients, of whom 45 (37\%) had complete SCI. Twelve patients (27\%) had injury levels from C1 to C4. Nineteen (42\%) had a C5 injury level, and 14 (31\%) had an injury level of C6 or below. Eight of the complete injury patients died (mortality, 18\%). All patients with complete SCI at the C5 level and above required a definitive airway and tracheostomy. Of patients with a complete SCI at C6 or below, 79\% required intubation and 50\% eventually required tracheostomy. From these results, the authors recommended consideration of early intubation for patients with complete SCI, especially for patients with injuries at the C5 level or above.

Berney and Shem\textsuperscript{33} in 2007 reported on acute respiratory management following acute SCI. They found that respiratory complications were frequent and were the most common cause of morbidity among acute SCI patients (36\% of total complications). Respiratory failure was the most common cause of mortality in their series, cited in 86\% of deaths following acute SCI. Ventilatory failure occurred on average 4.5 days after acute SCI. The authors concluded that the incidence of respiratory complications can be significantly reduced by transfer of acute SCI patients to an SCI center. Hassid et al\textsuperscript{34} reviewed nearly 55,000 Level I trauma patients and identified a subgroup of 186 patients with isolated acute cervical SCI. They reported that early intubation for acute complete SCI patients is mandatory. They favor close observation of incomplete SCI patients and immediate airway intervention should the patient manifest any evidence of respiratory failure.

Guly et al\textsuperscript{35} found an incidence of neurogenic shock (systolic blood pressure < 100 mm Hg and heart rate < 80 bpm) of 19.3\% (95\% confidence interval, 14.8-23.7) in a series of 490 patients with acute SCI. In 2006, Franga et al\textsuperscript{36} described an incidence of cardiovascular instability of 17\%, including bradycardia requiring permanent pacemaker placement among 30 acute complete cervical SCI patients. Neumann et al\textsuperscript{37} performed a retrospective review of mortality following SCI. They found that Glasgow Coma Scale score < 9, the need for vasopressors to support mean blood pressure, and mechanical ventilation were predictors of mortality among acute SCI patients. All of these investigators favor ICU care for monitoring and treatment of acute SCI patients, particularly those with more severe injuries.

Macias et al\textsuperscript{38} evaluated the importance of admission to a specialized trauma center on the incidence of paralysis in patients with acute SCI. Their 2009 review included 4121 patients diagnosed with traumatic SCI treated at 100 trauma centers and 601 other local and regional medical facilities. Mortality was 7.5\%, and the incidence of paralysis, based on the reported discharge diagnosis, was 16.3\%. A designated trauma center provided the initial care in 57.9\% of the patients (n = 2378). Multivariate analysis determined that the incidence of paralysis was significantly lower at designated trauma centers compared with local and regional hospitals without trauma center designation (adjusted odds ratio, 0.67; 95\% confidence interval, 0.53-0.85; P = .001). There was no significant difference in the incidence of mortality between the 2 types of facilities. The authors concluded that early admission to a designated trauma center significantly reduces the incidence of paralysis following acute SCI.

In a subsequent publication, the same group performed a literature review on respiratory complications associated with acute cervical SCI.\textsuperscript{40} They identified 21 studies including 1263 patients that described definitive protocols for the respiratory management of acute cervical SCI. Although the majority of the reports were case series, the authors discovered that mortality (adjusted risk ratio= 0.4; 95\% confidence interval, 0.18-0.61), the incidence of respiratory complications (adjusted risk ratio = 0.36; 95\% confidence interval, 0.08-0.58), and the requirement for a tracheostomy (adjusted risk ratio = 0.18; 95\% confidence interval, −0.05 to 0.4), were all significantly reduced when care givers/institutions used a respiratory protocol in the management of acute SCI patients. Specifically, the use of a clinical pathway reduced the duration of mechanical ventilation by 6 days (95\% confidence interval, −0.56 to 12.56) and ICU length of stay by 6.8 days (95\% confidence interval, 0.17-13.77).

**SUMMARY**

Patients with acute cervical SCI frequently develop hypotension, hypoxemia, pulmonary dysfunction, and cardiovascular instability, often despite initial stable cardiac and pulmonary function. These
<table>
<thead>
<tr>
<th>Citation</th>
<th>Description of Study</th>
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<tr>
<td>Berney et al., Spinal Cord, 2011</td>
<td>Prospective observational study of a clinical pathway for airway management in 114 patients with acute cervical spine injury</td>
<td>III</td>
<td>Forced vital capacity, the volume of pulmonary secretion, and gas exchange were predictive of airway management on 82.3% occasion with an 8.7% extubation failure rate. The authors conclude that a clinical pathway of respiratory management was useful in clinical decision making.</td>
</tr>
<tr>
<td>Berney et al., Spinal Cord, 2011</td>
<td>Systematic review of acute respiratory management of cervical SCI in the first 6 wk after injury</td>
<td>III</td>
<td>The authors have demonstrated that a clinical pathway with a structured respiratory protocol is effective in reducing respiratory complications, ventilator time, and intensive care unit length of stay.</td>
</tr>
<tr>
<td>Casha and Christie, Journal of Neurotrauma, 2010</td>
<td>Systematic review of intensive cardiopulmonary management following acute SCI</td>
<td>III</td>
<td>Class III as the majority of articles included are case series. Because of the high incidence of cardiopulmonary complications, acute SCI patients should be managed in monitored unit.</td>
</tr>
<tr>
<td>Ploumis et al., Spinal Cord, 2010</td>
<td>Systematic review of the evidence supporting a role for vasopressor support in acute SCI</td>
<td>III</td>
<td>There is Class III evidence supporting the maintenance of MAP &gt; 85 mm Hg for a period extending up to 1 wk following acute SCI. No statistical difference in neurological improvement with vasopressor support with an MAP of &lt; 85 mm Hg and those with MAP &lt; 90 mm Hg.</td>
</tr>
<tr>
<td>Neumann et al., Journal of Trauma, 2009</td>
<td>Retrospective study of risk factors for mortality in traumatic cervical SCI</td>
<td>III</td>
<td>Independent predictors for mortality were Glasgow Coma Scale score &lt; 9 and vasopressor use. The authors conclude that there is no gold standard on vasopressor support and that cervical cord injuries require vasopressors more frequently than other SCIs (P &lt; .001).</td>
</tr>
<tr>
<td>Guly et al., Resuscitation, 2008</td>
<td>Database review to determine the incidence of neurogenic shock in patients with isolated SCI</td>
<td>III</td>
<td>Incidence of neurogenic shock in cervical cord injuries was 19.3% (95% confidence interval, 14.8-23.7) vs in 7% (95% confidence interval, 3-11.1) in the thoracic or 3% (95% confidence interval, 0-8.85) in the lumbar spine cord.</td>
</tr>
<tr>
<td>Hassid et al., Journal of Trauma, 2008</td>
<td>Database review of 54 838 consecutive Level I trauma patients</td>
<td>III</td>
<td>Respiratory complications in SCI are frequent. Early intubation is mandatory for complete SCI patients. For incomplete patients, close observation for any evidence of respiratory failure should prompt immediate airway intervention.</td>
</tr>
<tr>
<td>Berlly and Shem, Journal of Spinal Cord Medicine, 2007</td>
<td>Retrospective review of respiratory management during the first 5 d after SCI</td>
<td>III</td>
<td>Morbidity and mortality following acute SCI were 36% and 83%, respectively, with ventilatory failure occurring an average 4.5 d following injury.</td>
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<tr>
<td>Franga et al, The American Surgeon, 2006</td>
<td>Retrospective evaluation of recurrent asystole resulting from high cervical SCIs</td>
<td>III</td>
<td>The authors recommend transfer to a center specializing in acute management of SCI to reduce the number of respiratory complications.</td>
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<tr>
<td>Como et al, Journal of Trauma, 2005</td>
<td>Retrospective review evaluating the need for mechanical ventilation following cervical SCI in the presence of neurological deficit</td>
<td>III</td>
<td>The authors recommend considering early intubation, particularly with a complete injury at C5 or above.</td>
</tr>
<tr>
<td>Vitaz et al, Journal of Spinal Disorders, 2001</td>
<td>Prospective comparison of patients treated with and without a clinical pathway for treatment of acute SCI</td>
<td>III</td>
<td>The authors demonstrate that the use of a clinical care pathway for SCIs resulted in improved patient care and fewer complications.</td>
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<tr>
<td>Lu et al, Spine, 2000</td>
<td>Retrospective review of apnea in 36 acute SCI patients</td>
<td>III</td>
<td>Delayed apnea most likely in acute SCI patients with severe, diffuse acute SCI. Apnea most likely within first 7-10 d.</td>
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<td>Botel et al, Spinal Cord, 1997</td>
<td>225 acute SCI patients treated in ICU; only 87 admitted within 24 h of injury</td>
<td>III</td>
<td>Significant numbers of multiply injured and head-injured patients. The percentage of complete injuries not recorded. Improved outcome when admitted to ICU early after injury.</td>
</tr>
<tr>
<td>Vale et al, Journal of Neurosurgery, 1997</td>
<td>Prospective assessment of 77 acute SCI patients treated in ICU, aggressive hemodynamic support, MAP &gt; 85 mm Hg</td>
<td>III</td>
<td>Improved outcome with aggressive medical care, distinct from potential benefit from surgery at 1-y follow-up.</td>
</tr>
<tr>
<td>Levi et al, Neurosurgery, 1993</td>
<td>50 patients treated in ICU, aggressive medical treatment, MAP &gt; 90 mm Hg</td>
<td>III</td>
<td>Improved outcome with aggressive hemodynamic support at 6 wk after injury.</td>
</tr>
<tr>
<td>Tator et al, Paraplegia, 1993</td>
<td>201 acute SCI patients, ICU care, hemodynamic support compared with 351 prior patients</td>
<td>III</td>
<td>Less severe cord injuries resulting from immobilization, resuscitation, and early transfer to ICU setting.</td>
</tr>
<tr>
<td>Wolf et al, Journal of Neurosurgery, 1991</td>
<td>52 patients with locked facets reduced within 4 h, ICU care, MAP &gt; 85 mm Hg, 49 operated on: 23 on day 1, 26 delayed (mean, day 8.7)</td>
<td>III</td>
<td>Closed reduction 61%</td>
</tr>
<tr>
<td>Lehmann et al, Journal of the American College of Cardiology, 1987</td>
<td>71 consecutive acute SCI patients, ICU care, monitoring of cardiac/hemodynamic parameters</td>
<td>III</td>
<td>Bradycardia, 100%; hypotension (&lt; 90 mm Hg systolic), 68%. Life-threatening bradycardiac arrhythmias, 16% incidence related to severity of SCI.</td>
</tr>
<tr>
<td>Reines and Harris, Neurosurgery, 1987</td>
<td>123 cases, acute SCI patients in ICU, aggressive pulmonary treatment</td>
<td>III</td>
<td>Respiratory insufficiency major cause of morbidity and mortality after ASCI. Aggressive ICU care, pulmonary treatment reduce incidence.</td>
</tr>
<tr>
<td>Piepmeier et al, Central Nervous System Trauma, 1985</td>
<td>45 ASCI patients, all managed in ICU setting with cardiac, hemodynamic monitoring</td>
<td>III</td>
<td>Cardiac dysrhythmia, hypotension, and hypoxia common in first 2 wk after ASCI. Incidence related to severity of injury.</td>
</tr>
<tr>
<td>Bose et al, Neurosurgery, 1984</td>
<td>28 patients with acute SCI, 22 managed in ICU setting</td>
<td>III</td>
<td>Improved neurological outcome at discharge for group 2 but better scores initially. Group 1 with intrinsic cord injury vs Group 2 compression on myelo and/or instability.</td>
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<td>Tator et al, 1984</td>
<td>144 acute SCI patients, ICU care, hemodynamic support, compared with prior series</td>
<td>III</td>
<td>Improved neurological outcome, less mortality with early transfer, avoidance of hypotension, and ICU care.</td>
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<td>Ledsome and Sharp, 1981</td>
<td>Reassessment of pulmonary function in acute SCI patients, comparison over time</td>
<td>III</td>
<td>Reduced vital capacity, flow rates, and hypoxia after ASCI. Incidence related to severity of SCI. Marked improvement in pulmonary functions 3 mo after injury.</td>
</tr>
<tr>
<td>McMichan et al, 1980</td>
<td>Prospective study of pulmonary complications in 22 acute SCI patients compared with 22 prior patients managed with aggressive ICU care</td>
<td>III</td>
<td>No deaths in series vs 9 of 22 deaths in prior group. ICU care and vigorous pulmonary therapy improves survival, reduces complications.</td>
</tr>
<tr>
<td>Gschaedler et al, 1979</td>
<td>31 acute SCI patients managed in ICU, aggressive medical treatment, avoid hypotension</td>
<td>III</td>
<td>Improved morbidity and mortality with early transfer, avoidance of hypotension, respiratory insufficiency.</td>
</tr>
<tr>
<td>Hachen, 1977</td>
<td>188 acute SCI patients managed in center's ICU, aggressive treatment of hypotension, respiratory insufficiency</td>
<td>III</td>
<td>Reduced morbidity and mortality with early transfer, attentive ICU care and monitoring, and aggressive treatment of hypotension and respiratory failure.</td>
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*ICU, intensive care unit; MAP, mean arterial pressure; SCI, spinal cord injury.

Complications are not limited to patients with complete SCI. Life-threatening cardiovascular instability and respiratory insufficiency may be transient and episodic and may be recurrent in the first 7 to 10 days after injury. Patients with the most severe neurological injuries appear to have the greatest risk of these life-threatening events. Class III medical evidence indicates that ICU monitoring allows the early detection of hemodynamic instability, cardiac disturbances, pulmonary dysfunction, and hypoxemia. Prompt treatment of these events in patients with acute SCI reduces cardiac- and respiratory-related morbidity and mortality.

Management in an ICU or other monitored setting appears to have an impact on neurological outcome after acute cervical SCI. Retrospective studies consistently report that volume expansion and blood pressure augmentation performed under controlled circumstances in an ICU setting are linked to improved ASIA scores in patients with acute SCI compared with historical controls. Class III medical evidence suggests that the maintenance of MAP at 85 to 90 mm Hg after acute SCI for a duration of 7 days is safe and may improve spinal cord perfusion and ultimately neurological outcome.

**KEY ISSUES FOR FUTURE INVESTIGATION**

The length of stay in the ICU setting necessary to provide optimal management of patients with acute SCI is unknown. The available evidence suggests that most untoward and potentially life-threatening cardiac and respiratory events occur within the first 2 weeks of injury. Patients with less severe acute SCIs may require less time in a monitored setting than those patients with more severe injuries. Class II medical evidence is needed to guide treatment recommendations in these areas.

The issue of whether or not blood pressure augmentation has an impact on outcome following human SCI is important and deserves further study. If augmentation of MAP is determined to be of potential benefit, the most appropriate threshold levels of MAP and the length of augmentation therapy need definition. These questions may be best analyzed in a multi-institution prospective cohort study or a properly designed multi-institution retrospective case-control study.

**Disclosure**

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

**REFERENCES**


Management of Pediatric Cervical Spine and Spinal Cord Injuries

KEY WORDS: Atlantoaxial rotary fixation, External immobilization, Odontoid epiphysiolysis, Pediatric spine injuries


RECOMMENDATIONS:

Diagnostic:
Level I:
• Computed tomographic (CT) imaging to determine the condyle-C1 interval (CCI) for pediatric patients with potential atlanto-occipital dislocation (AOD) is recommended.

Level II:
• Cervical spine imaging is not recommended in children who are ≥3 years of age and who:
  • are alert,
  • have no neurological deficit,
  • have no midline cervical tenderness,
  • have no painful distracting injury,
  • do not have unexplained hypotension,
  • and are not intoxicated.

• Cervical spine radiographs or high resolution CT is recommended for children who have experienced trauma and who do not meet either set of criteria above.

• Three-position CT with C1-C2 motion analysis to confirm and classify the diagnosis is recommended for children suspected of having atlantoaxial rotatory fixation (AARF).

Level III:
• Anteroposterior (AP) and lateral cervical spine radiography or high-resolution CT is recommended to assess the cervical spine in children <9 years of age.

• AP, lateral, and open-mouth cervical spine radiography or high-resolution CT is recommended to assess the cervical spine in children 9 years of age and older.

• High resolution CT scan with attention to the suspected level of neurological injury is recommended to exclude occult fractures or to evaluate regions not adequately visualized on plain radiographs.

• Flexion and extension cervical radiographs or fluoroscopy are recommended to exclude gross ligamentous instability when there remains a suspicion of cervical spinal instability following static radiographs or CT scan.

• Magnetic resonance imaging (MRI) of the cervical spine is recommended to exclude spinal cord or nerve root compression, evaluate

ABBREVIATIONS: AP, anteroposterior; AARF, atlantoaxial rotatory fixation; AOD, atlanto-occipital dislocation; CCI, condyle-C1 interval; CCR, Canadian C-spine Rule; DGZ, diagnostic grey zone; FVC, forced vital capacity; GCS, Glasgow Coma Scale; MVC, motor vehicle collision; NAT, non-accidental trauma; NEXUS, National Emergency X-Radiography Utilization Study; SCIWORA, spinal cord injury without radiographic abnormality; TAS, transarticular screw TAS

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ligamentous integrity, or provide information regarding neurological prognosis.

**Treatment**

*Level III:*

- Thoracic elevation or an occipital recess is recommended in children < 8 years of age to prevent flexion of the head and neck when restrained supine on an otherwise flat backboard for better neutral alignment and immobilization of the cervical spine.
- Closed reduction and halo immobilization are recommended for injuries of the C2 synchondrosis in children < 7 years of age.
- Reduction with manipulation or halter traction is recommended for patients with acute AARF (< 4 weeks duration) that does not reduce spontaneously. Reduction with halter or tong/halo traction is recommended for patients with chronic AARF (> 4 weeks duration).
- Internal fixation and fusion are recommended in patients with recurrent and/or irreducible AARF.
- Consideration of primary operative therapy is recommended for isolated ligamentous injuries of the cervical spine and unstable or irreducible fractures or dislocations with associated deformity.
- Operative therapy is recommended for cervical spine injuries that fail non-operative management.

**Rationale**

There are distinct, unique aspects of the management of children with potential injuries of the cervical spinal column and cervical spinal cord compared to adult patients that warrant specific recommendations. The methods of pre-hospital immobilization necessary to approximate “neutral” cervical spinal alignment in a young child differ from those methods commonly employed for adults. The spinal injury patterns among young children differ from those that occur in adults. The diagnostic studies and images necessary to exclude a cervical spine injury in a child may be different than in the adult as well. The interpretation of pediatric radiographic studies must be made with knowledge of age-related development of the osseous and ligamentous anatomy. Methods of reduction, stabilization, and subsequent treatment, surgical and non-surgical, must be customized to each child, taking into account the child’s degree of physical maturation and his/her specific injury. The purpose of this review is to address the unique aspects of children with real or potential cervical spinal injuries, and provide recommendations regarding their management.

**Search Criteria**

Incorporating and expanding upon the first iteration of these guidelines, a National Library of Medicine (PubMed) computerized literature search from 1966 to 2011 was undertaken using Medical Subject Headings in combination with “spinal cord injuries” and “child” and yielded 1125 citations. These citations were reviewed in combination with “cervical vertebra,” “spinal injuries,” and “child” which yielded 197 citations. Non-English language citations were deleted. The remaining abstracts were reviewed for those that described children who had sustained or were being evaluated for a cervical spinal cord or cervical spinal column injury. Articles describing the clinical aspects and management of children were used to generate these guidelines. Case reports were excluded. Of the 80 articles meeting selection criteria, 1 provided Class I medical evidence for diagnostic imaging in AOD. In addition, there were 10 Class II medical evidence studies addressing diagnostic imaging in children. There was only 1 Class II medical evidence study concerning treatment. All remaining articles were case series representing Class III medical evidence. Summaries of these 80 articles are provided in Evidentiary Table format (Tables 1-2).

**Scientific Foundation**

**Pre-Hospital Immobilization**

The primary goal of pre-hospital management of pediatric patients with potential cervical spine or spinal cord injury is to prevent further injury. Along with assuring an adequate airway, ventilation, and perfusion, spinal immobilization likely plays an important role in preventing further injury to the vertebral column and spinal cord. Immobilization of the child’s cervical spine in the neutral position is desired. To achieve neutral alignment of the cervical spine in children < 8 years of age, allowances must be made for the relatively large head compared to the torso, which forces the neck into a position of flexion when the head and torso are supine on a flat surface. Nypaver and Treloar prospectively evaluated 40 children < 8 years of age seen in an emergency room for reasons other than head and neck trauma and assessed them with respect to neutral positioning upon a backboard. They found that all 40 children required elevation of the torso to eliminate positional neck flexion and achieve neutral alignment as determined by 2 independent observers. The mean amount of elevation required was 25 mm. Children < 4 years of age required greater elevation than those 4 years of age or older (P < .05). Because of these findings, it was recommended that children < 8 years of age requiring immobilization either 1) have the torso elevated or 2) place the head in an occipital recess to achieve a more neutral position for immobilization of the cervical spine. In a separate report, Treloar and Nypaver similarly found that semi-rigid cervical collars placed on children < 8 years of age did not prevent this positional forced flexion when placed supine on standard, rigid spinal boards.

Herzenberg et al studied 10 children < 7 years of age with cervical spine injuries who were positioned on a backboard. All had anterior angulations or translation at the injured segment that was reduced by allowing neck extension into a more neutral position. They suggested that alignment of the patient’s external
auditory meatus with his/her shoulders would help to achieve neutral cervical spine positioning.

However, Curran et al. found no correlation with age regarding degree of cervical kyphosis identified in children transported on backboards. They did note however, that 30% of children had > 10° of kyphosis as determined by Cobb angle measurements between C2 and C6. No specific technique or device allowed superior neutral positioning of the cervical spine in patients they studied. None of their patients were immobilized on boards with an occipital recess or thoracic padding.

Huerta et al. evaluated a variety of immobilization devices on children, infants, and child-sized mannequins. They concluded that no collar provided “acceptable immobilization” when used alone. They found that the combination of a modified half-spine board, rigid cervical collar, and tape was the most effective means of immobilization of the cervical spine for transport in children.

Shafermeyer et al. however, cautioned that immobilization techniques that employ taping across the torso to secure the child to the spine board may have deleterious effects on respiratory function. They studied 51 healthy children, ages 6 to 15 years by measuring forced vital capacity (FVC). FVC dropped when going from the upright to supine position. Taping across the torso to secure the volunteer to the spine board caused further reductions in FVC of 41% to 96% (mean 80%), compared to the supine FVC without tape. The authors cautioned that this restriction of FVC might be enough to create respiratory insufficiency in some trauma patients.

In summary, when spinal immobilization is indicated for children for transportation, the type of immobilization should take into account the child’s age and physical maturity. It should allow for the relatively larger head with respect to the torso in younger children. While ideal spinal immobilization of pediatric trauma victims appears to be provided by a combination of a spinal board, rigid collar, and tape, these immobilization techniques may negatively influence the child’s respiratory function.

Imaging

Following immobilization and transport to an acute care facility, initial clinical evaluation and medical/hemodynamic support, the need for and type of imaging assessment must be determined and performed. Several authors have evaluated the indications for radiographic assessment of children with a potential cervical spinal injury. Laham et al. investigated the role of cervical spine x-ray evaluation of 268 children with apparent isolated head injuries. They retrospectively divided the children into high (n = 133) and low-risk (n = 135) groups. High-risk characteristics were children incapable of verbal communication either because of age (< 2 years of age) or head injury, and those children with neck pain. They employed the “3-view approach” of anteroposterior (AP), lateral, and open-mouth radiographs. They discovered no cervical spine injuries in the low-risk group but discovered 10 in the high-risk group (7.5%). The authors concluded that cervical spine radiographs are not necessary in children with isolated head injuries who can communicate and have no neck pain or neurological deficit. Bohn et al. emphasized that unexplained hypotension or absent vital signs in childhood trauma victims are likely to be from a severe cervical cord injury. Therefore, they advocate suspicion for a cervical spinal cord injury in children with either multisystem trauma, or an isolated head injury presenting with hypotension or cardiopulmonary arrest.

Viccello et al. evaluated the cervical spines in children < 18 years of age utilizing the National Emergency X-Radiography Utilization Study (NEXUS®) decision instrument in a Class II prospective multicenter study. They employed 5 low-risk criteria. These criteria were the absence of: 1) midline cervical tenderness, 2) evidence of intoxication, 3) altered level of alertness, 4) focal neurological deficit, and 5) other painful distracting injury. Radiographs were obtained at the discretion of the treating physician. When radiographs were obtained a minimum of 3-views was obtained. Only those patients who obtained radiographs were included in the study. If all 5 criteria were met, the child was considered low-risk. If any one of the 5 criteria were present the child was considered high-risk. Three thousand and sixty-five children were evaluated. Of these, 603 fulfilled the low-risk criteria. None of these 603 children defined as low-risk had a documented cervical spine injury by radiographic evaluation. Thirty injuries (0.98%) were documented in children not fulfilling the low-risk criteria. They concluded that applying the NEXUS criteria to children would reduce cervical spine radiograph use by 20% and not result in missed injuries. They cautioned that they had relatively small numbers of young children < 2 years of age (n = 88). Statistically, this created large confidence intervals for the sensitivity of their instrument when applied to younger children. From this Class II study, they “cautiously” endorsed the application of NEXUS criteria in children, particularly those from zero to 9 years of age. Their conclusions are consistent with the Class III evidence previously described by Laham et al. on this topic.

A NEXUS-based pediatric (0-18 years) cervical spine clearance protocol was evaluated by Anderson et al. in a Class II prospective multicenter trial, using historical controls. Plain radiographs were obtained on all children presenting in a cervical collar. Children > 3 years old with normal radiographs who met all 5 NEXUS low-risk criteria were “cleared.” All others required additional imaging, neurosurgical consultation, or both. Cervical spine injury detection rates were equivalent with historical controls and no late injuries were detected. Use of the protocol “increased the number of cervical spines cleared by non-neurosurgical personnel by nearly 60%.” The protocol design and study did not, however, allow for any cervical spine clearance without radiography.

In a parallel Class II prospective study at the same institutions, Anderson et al. evaluated a cervical spine clearance protocol designed for trauma patients aged < 3 years. All children underwent plain radiography (AP and lateral views) and CT scans only if radiographic findings were inadequate or suspicious for an injury. If initial imaging was negative, further evaluation
depended on the patient’s airway status (intubated or not) and included clinical factors, dynamic radiography, and/or MRI. MRI scans were reserved for patients with signs of spinal cord injury, intubation/obtundation for > 48 hours, or persistent neck pain with range of motion. Application of this protocol resulted in cervical spine clearance of 575 noncommunicative children < 3 years old over a 5-year period without any missed injuries detected. CT scans were necessary in only 14% of cases and MRI in 10%. The authors recognize that the low incidence of injuries (28 of 575) limits the statistical strength of their findings.

Garton et al13 evaluated NEXUS criteria retrospectively in 190 consecutive pediatric cervical spine injury cases with particular attention to younger children. In their Class II analysis, application of NEXUS criteria to determine the need for c-spine imaging would not have missed any injuries in the 157 patients older than 8 years. Applying NEXUS criteria to the 33 patients aged < 8 years, however, would have missed 2 injuries (94% sensitivity). Also in children < 8 years old they reported a higher validity of this finding is undermined somewhat by the low incidence of injury.

Hutchings et al17 reviewed c-spine clearance methods retrospectively in 115 consecutive obtunded major trauma patients <16 years of age. No protocol was used during the 7-year study period. Six c-spine injuries were identified by a variety of screening methods. CT imaging alone was found to have 100% sensitivity and 100% specificity in this population, although the validity of this finding was undermined somewhat by the low incidence of injury.

The need for and utility of open-mouth odontoid views in pediatric trauma victims has been questioned (6,59). Swischuk et al18 surveyed 984 pediatric radiologists to determine how many injuries were missed on lateral cervical spine radiographs, yet detected on an open-mouth view (59). There were 432 responses. One hundred and sixty-one respondents did not routinely use open-mouth views. Of the 271 that obtained open-mouth views in young children, 191 (70%) would not persist beyond a single attempt. Seventy-one radiologists (26%) would make up to 5 attempts to obtain an adequate image. Twenty-eight of the 432 respondents (7%) reported missing a total of 46 fractures on the lateral view that were detected on the open-mouth view. The types of injuries were not classified (ie, odontoid vs C1 injury). The authors calculated a missed fracture rate of 0.007 per year per radiologist in their study. They concluded that the open-mouth view x-ray might not be needed routinely in children < 5 years of age. Buhs et al18 also investigated the utility of open mouth views in children. They performed a multi-institutional retrospective review of a large metropolitan population of patients < 16 years of age who were assessed for cervical spine trauma over a 10-year period. Fifty-one children with cervical spinal injuries were identified. The lateral cervical spine radiograph made the diagnosis in 13 of 15 children < 9 years of age. In none of the 15 younger patients did the open-mouth view provide the diagnosis. In only 1 of 36 patients in the 9 to 16 years of age group was the open mouth view the key diagnostic study (a type III odontoid injury). The authors concluded that the open mouth view radiograph is not necessary for clearing the cervical spine in children < 9 years of age.

Lui et al.20 in their review of 22 children with C1-C2 injuries, commented that flexion and extension radiographs were required to "identify the instability" of traumatic injuries to the dens in 4 of 12 children with odontoid fractures, and in 6 of 9 children with purely ligamentous injuries resulting in atlantoaxial dislocation. The authors did not state whether an abnormality on the static radiograph led to the dynamic studies, or whether the initial static studies were normal. Because they did not describe flexion and extension x-rays as part of their "routine" for the assessment of children with potential cervical spine injuries, it is likely that some imaging or clinical finding prompted the decision to obtain dynamic films in these children.

The experience of Ruge et al21 highlighted the propensity for upper cervical injuries in children under the age of 9 years. They reported no injuries below C3. Evans and Bethem22 described 24 children with cervical spine injuries. In half of the patients, the injury was at C3 or higher.22 Givens et al,23 however, described
the occurrence of important injuries occurring at all levels of the cervical spine in young children. They described 34 children with cervical spine injuries. There was no correlation of level of injury with age. Two of the children they managed had injuries at C7-T1. Hence, it would be dangerous to assume that lower cervical spine injuries do not occur in young children, and irresponsible to discount the need for adequate imaging of the lower cervical spine and cervical-thoracic junction in these young patients.

Scarrow et al attempted to define a protocol to evaluate the cervical spine in obtunded children following trauma. They utilized somatosensory-evoked responses during flexion and extension fluoroscopy. Of the 15 children evaluated with this protocol, none showed pathological motion during flexion and extension fluoroscopy. Three children were thought to have a change in the evoked responses during flexion and extension. Only 1 of the 3 children with an abnormal evoked response underwent MRI that was normal. Their investigation failed to demonstrate any utility for evoked responses, flexion and extension fluoroscopy, or MRI of the cervical spine in the evaluation of the cervical spine in children with altered mental status following trauma. Larger numbers of children investigated in this manner might define a role for 1 or more of these diagnostic maneuvers, but as yet there is no evidence to support their use.

Ralston et al retrospectively analyzed the cervical spine radiographs of 129 children who had flexion and extension x-rays performed after an initial static radiograph. They found that if the static radiograph was normal or depicted only loss of lordosis, only the flexion and extension views would reveal no abnormality. The authors concluded that the value of the dynamic radiographs was confirmation of cervical spinal stability when there was a questionable finding on the static, lateral radiograph.

The interpretation of cervical spine x-rays must account for the age and anatomical maturation of the patient. Common normal findings on cervical spine radiographs obtained on young children are pseudosubluxation of C2 on C3, overriding of the anterior atlas in relation to the odontoid on extension, exaggerated atlanto-dens intervals, and the radiolucent synchondrosis between the odontoid and C2 body. These normal findings can be mistaken for acute traumatic injuries in children following trauma. Cattell and Filtrzer obtained lateral cervical radiographs in neutral, flexion, and extension in 160 randomly selected children who had no history of trauma or head and neck problems. The subjects’ ages ranged from 1 to 16 years with 10 children for each year of age. They found a 24% incidence of moderate to marked C2 on C3 subluxation in children between 1 and 7 years of age. Thirty-two of 70 children (46%) < 8 years of age had 3.0 mm or more of anterior-posterior motion of C2 on C3 on flexion and extension radiographs. Fourteen percent of all children had radiographic pseudosubluxation of C3 on C4. Twenty percent of children from 1 to 7 years of age had an atlanto-dens interval of 3 millimeters or greater. Overriding of the anterior arch of the atlas on the odontoid was present in 20% of children < 8 years old. The synchondrosis between the odontoid and axis body was noted as a lucency in all children imaged up to the age of 4 years. The synchondrosis remained visible in half the children up to 11 years of age. The authors also described an absence of the normal cervical lordosis in 14% of subjects, most commonly in the 8- to 16-year-old age groups. Shaw et al in a retrospective review of cervical spine x-rays in 138 children < 16 years of age who were evaluated following trauma, found a 22% incidence of radiographic pseudosubluxation of C2 on C3. The only factor that correlated with the presence of pseudosubluxation in their study was patient age. The pseudosubluxation group had a median age of 6.5 years vs 9.0 years in the group without this finding. It was identified, however, in children as old as 14 years of age. Intubation status, injury severity score, and gender had no correlation with pseudosubluxation of C2 on C3. To differentiate between physiological and traumatic subluxations, they recommend a method that involves drawing a line through the posterior arches of C1 and C3. In the circumstance of pseudosubluxation of C2 on C3, the C1-C3 line should pass through, touch, or lie up to 1 mm anterior to the anterior cortex of the posterior arch of C2. If the anterior cortex of the posterior arch of C2 is 2.0 mm or more behind the line, then a true dislocation (rather than pseudosubluxation) should be assumed.

Keiper et al reviewed their experience of employing MRI in the evaluation of children with clinical evidence of cervical spine trauma who had no evidence of fracture by plain radiographs or CT, but who had persistent or delayed symptoms, or instability. There were 16 abnormal MRI examinations in 52 children. Posterior soft tissue and ligamentous changes were described as the most common abnormalities. Only 1 child had a bulging disc. Four of these 52 children underwent surgical treatment. In each of the 4 surgical cases, the MRI findings led the surgeon to stabilize more levels than otherwise would have been undertaken without the MRI information. Davis et al described the use of MRI in evaluating pediatric spinal cord injury in 15 patients, and found it did not reveal any lesion that would warrant surgical decompression. They did note, however, that MRI findings did correlate with neurological outcome. Evidence of hematoma was associated with permanent neurological loss. While little information is available on this subject, it appears that pre-operative MRI of children with unstable cervical spinal injuries, who require surgical stabilization, may affect the specifics of the surgical management.

Except for the review of obtunded major trauma patients by Hutchings et al discussed above, there are few studies that have systematically reviewed the role of CT in the evaluation of the cervical spines of pediatric patients following trauma. In children < 10 years of age with cervical spinal injuries, the majority of patients will have ligamentous injuries without fracture. In older children with cervical spinal injuries, the incidence of a fracture is much greater than ligamentous injury without fracture, 80% vs 20% respectively. Therefore, normal osseous anatomy as depicted on an axial CT image should not be used alone to exclude injury to the pediatric cervical spine. In 1989, Schlehauf et al concluded that CT should not be relied
The most common level of injury is upper cervical, defined as flaccidity, no spontaneous Unexplained motor function, and a non-communicative level due to age (ie, 3 years old) and have a neurological deficit, have neck pain, have a painful distracting injury, or are intoxicated. Additionally, children who have experienced trauma that are non-communicative due to age (< 3 years old) and have motor vehicle collision, fall from a height > 10 feet, or suspected NAT as mechanisms, or GCS < 14 should have screening cervical spine imaging performed. In children who are alert, have no neurological deficit, no midline cervical tenderness, no painful distracting injury, and are not intoxicated, cervical spine imaging is not necessary to exclude cervical spine injury. Unexplained hypotension should raise the suspicion of a spinal cord injury. Screening cervical spine imaging for children may consist of adequate AP and lateral radiographs (± open mouth odontoid) or high resolution CT scanning. Open-mouth views of the odontoid do not appear to be useful in children < 9 years of age. Open-mouth views should be attempted in children 9 years of age and older. Flexion and extension studies (fluoroscopy or radiographs) are likely to be unrevealing in children with static radiographs proven to be normal. Dynamic studies should be considered, however, when the static radiographs or the child’s clinical findings suggest but do not definitively demonstrate cervical spinal instability. CT studies of the cervical spine are not necessary to “clear” the entire cervical spine in most children, and should be employed judiciously to define bony anatomy at specific levels, except in the case of potential AOD. For this latter entity, Class I medical evidence supports the use of CT as the preferred modality. MRI may provide important information about ligamentous injury that may influence surgical management, and may provide prognostic information regarding existing neurological deficits.

**Injury Management**

Injury patterns that have a strong predilection for or are unique to children merit discussion because of the specialized management paradigms employed to treat them. Spinal cord injury without radiographic abnormality (SCIWORA, including “spinal cord concussion”) and atlanto-occipital dislocation injuries have been addressed in other sections (see SCIWORA guideline chapter, see Atlanto-occipital dislocation guideline chapter). Spinal cord injuries secondary to birth-related trauma and epiphysiolysis of the axis are injuries unique to children. Common but not unique to children are C1-C2 rotary subluxation injuries. These entities will be discussed below in light of the available literature. It should be noted that there is no information provided in the literature describing the medical management of pediatric patients with spinal cord injuries. The issue of steroid administration following acute pediatric spinal cord injury, for example, has not been addressed. While prospective, randomized clinical trials such as NASCIS II and NASCIS III have evaluated pharmacological therapy following acute spinal cord injury, children younger than 13 years of age were excluded from study.

**Neonatal Spinal Cord Injury**

Birth injuries of the spinal cord occur approximately 1 per 60 000 births. The most common level of injury is upper cervical followed by cervicothoracic. Mackinnon et al described 22 neonates with birth-related spinal cord injuries. The diagnosis was defined by the following criteria: clinical findings of acute cord injury for at least 1 day and evidence of spinal cord or spinal column injury by imaging or electrophysiological studies. Fourteen neonates had upper cervical injuries, 6 had cervicothoracic injuries, and 2 had thoracolumbar injuries. All upper cervical cord injuries were associated with cephalic presentation and the use of forceps for rotational maneuvers. Cervicothoracic injuries were associated with the breech presentation. All infants had signs of “spinal shock,” defined as flaccidity, no spontaneous
motion and no deep tendon reflexes. Of the 9 infants with upper cervical injuries surviving longer than 3 months, 7 were alive at last follow-up. Six of these 7 are dependent upon mechanical ventilation. The 2 neonates with upper cervical injuries who had breathing movements on day 1 of life were the only 2 thought to have satisfactory outcomes. All survivors with upper cervical cord injuries whose first respiratory effort was beyond the first 24 hours of life have remained ventilator dependent. Only 2 children of 6 who sustained cervicothoracic spinal cord injuries lived and both remained paraplegic. One required long-term mechanical ventilation. Hypoxic and ischemic encephalopathy was noted in 9 of 14 newborns with upper cervical cord injuries, and in 1 of 6 with a cervicothoracic cord injury. The authors did not describe any treatment provided for the underlying spinal column or cord injury, or whether survivors experienced progression of any spinal deformities.

Menticoglou et al., drawing partly from the same patient data as Mackinnon et al., reported 11 children with odontoid injuries. While injuries to the neurocentral or odontoid process were noted in 9 of 14 newborns with upper cervical cord injuries, and in 1 of 6 with a cervicothoracic cord injury. The authors did not describe any treatment provided for the underlying spinal column or cord injury, or whether survivors experienced progression of any spinal deformities.

Rossitch and Oakes described 5 neonates with birth-related spinal cord injuries. They reported that incorrect diagnoses were made in 4. They consisted of Wernding-Hoffmann syndrome, occult myelodysplasia, and birth asphyxia. Only 1 neonate had an abnormal plain radiograph (atlanto-occipital dislocation). They provided no description of the management of the spinal cord or column injuries in these 5 neonates.

Fotter et al. reported the use of bedside ultrasound to diagnose neonatal spinal cord injury. They found excellent correlation with MRI studies with respect to the extent of cord injury in their 2 cases. Pang and Hanley provide the only description of an external immobilization device for neonates. They described a thermoplastic molded device that is contoured to the occiput, neck, and thorax. Velcro straps cross the forehead and torso, securing the infant and immobilizing the spinal column.

In summary, cervical instability following birth-related spinal cord injury is not addressed in the literature. The extremely high mortality rate associated with birth-related spinal cord injury may have generated therapeutic nihilism for this entity, hence the lack of aggressive management. The literature suggests that the presentation of apnea with flaccid quadriplegia following cephalic presentation with forceps manipulation is the hallmark of upper cervical spinal cord injury. Absence of respiratory effort within the first 24 hours of life is associated with dependence upon long-term mechanical ventilation. It appears reasonable to treat these neonates with spinal immobilization for a presumed cervical spinal injury. The method and length of immobilization remains arbitrary.

**Odontoid Epiphysiolysis**

The neurocentral synchondrosis of C2 that may not fuse completely until age 7 years represents a vulnerable site of injury in young children. The lateral cervical spine radiograph is the diagnostic imaging modality of choice to depict this injury. It will often reveal the odontoid process to be angulated anteriorly, and rarely posteriorly. While injuries to the neurocentral or subdental synchondroses may be seen in children up to 7 years of age, it most commonly occurs in pre-school aged children. Mandabach et al. described 13 children with odontoid injuries ranging in age from 9 months to 7 years. They reported that 8 of 10 children who were initially managed with halo immobilization alone achieved stable fusion. The average time to fusion was 13 weeks with a range of 10 to 18 weeks. Because the injury occurs through the epiphysis, it has a high likelihood of healing if closed reduction and immobilization are employed. In their review, Mandabach et al. cited several other reports describing the successful treatment of young children with odontoid injuries who were managed with a variety of external immobilization devices. Sherk et al. reported 11 children with odontoid injuries and reviewed an additional 24 from the literature. Only 1 of these 35 children required surgical fusion. More recently, Fassett et al. reported a meta-analysis of 55 odontoid synchondrosis fractures, including the Mandabach and Sherk series’ plus 4 new cases. Closed reduction and immobilization was performed initially in 45 cases, resulting in stable fusion in 42 (93%). Most were immobilized with halo (n = 20) or Minerva jacket (n = 20). Surgical fusion was performed in 8 cases; 4 as initial treatment, 3 following immobilization failure, and 1 after a delayed diagnosis. All reported posterior C1-2 fusion (n = 6) and motion preservation procedures (1 odontoid screw and 1 temporary posterior wiring) achieved stable fusion without complications.

While the literature describes the use of Minerva jackets, soft collars, hard collars, and the halo vest as means of external immobilization to achieve successful fusion in young children with odontoid injuries, the halo is the most widely employed immobilization device in the contemporary literature for these injuries, followed closely by the Minerva.

To obtain injury reduction in these children, Mandabach et al. advocates the application of the halo device under ketamine anesthesia followed by realignment of the dens utilizing C-arm fluoroscopy. Other reports describe using traction to obtain alignment, before immobilizing the child in an external orthosis. Compared to halo application and immediate reduction and immobilization, traction requires a period of bed rest and is associated with the potential risk of over-distraction.

The literature is scant regarding the operative treatment of C2 epiphysiolysis. Most reports describe employing operative internal fixation and fusion only if external immobilization has failed to maintain reduction or achieve stability. Reinges et al. noted that only 3 “young” children have been reported in the literature having odontoid injuries primarily treated with surgical stabilization. This underscores the near universal application of external immobilization as the primary means of treating odontoid injuries in young children. Odent et al. reported that of the 15 young children with odontoid injuries they managed, 3 that were treated with surgical stabilization and fusion experienced complications. The other 12 children with similar injuries...
managed non-operatively all did well. Wang et al\textsuperscript{51} described using anterior odontoid screw fixation as the primary treatment option in a 3-year-old child with C2 epiphysiolysis. A hard cervical collar was used postoperatively. Halo immobilization was not used either preoperatively or postoperatively. They successfully employed anterior odontoid screw fixation as the primary treatment in 2 older children (ages 10 and 14 years) followed by hard collar immobilization. It is likely that these 2 children had true type II odontoid fractures and not C2 epiphysiolysis. Likewise, Godard et al\textsuperscript{52} performed anterior odontoid screw fixation in a 2-year-old child with a severe head injury. They used skeletal traction to align the fracture pre-operatively. The rationale for proceeding to operative stabilization without an attempt at treatment with external immobilization was to avoid the halo orthosis, and to allow for more aggressive physiotherapy in this severely injured child. They believe that anterior odontoid screw fixation is advantageous because no motion segments are fused, normal motion is preserved, and the need for halo immobilization is obviated. Fassett et al\textsuperscript{48} advocate for external immobilization as primary treatment, even though 4 cases in their meta-analysis received primary surgical treatment.

For management of injuries of the C2 neurocentral synchondrosis, the literature supports the use of closed reduction and external immobilization for approximately 10 weeks. This strategy is associated with an 80% fusion success rate.\textsuperscript{46-49} While primary surgical stabilization of this injury has been reported, the experience in the literature is limited. Surgical stabilization appears to play a role when external immobilization is unable to maintain alignment of the odontoid atop the C2 body. While both anterior and posterior surgical approaches have been successfully employed in this setting, there are more reports describing posterior C1-2 techniques than reports describing anterior operative techniques.\textsuperscript{46-52}

**Atlantoaxial Rotatory Subluxation or Fixation**

Fixed rotatory subluxation of the atlantoaxial complex (AARF) is not unique to children but is more common during childhood. AARF may present following minor trauma, in association with an upper respiratory infection, or without an identifiable inciting event. The head is rotated to one side with the head tilted to the other side causing the so-called “cock-robin” appearance. The child is unable to turn his/her head past the midline. Attempts to move the neck are often painful. The neurological status is almost always normal.\textsuperscript{53-57}

It can be difficult to differentiate AARF from other causes of head rotation on clinical grounds alone. Several reports describe the radiographic characterization and diagnosis of this entity. Fieldings and Hawkins\textsuperscript{58} described 17 children and adults with “atlantoaxial rotatory subluxation,” and classified their dislocations into 4 types based on radiographic features. Type I was the most common type, identified in 8 of the 17 patients. It was described as unilateral anterior rotation of the atlas pivoting around the dens with a competent transverse ligament. Type II was identified in 5 patients. It was described as unilateral anterior subluxation of the atlas with the pivot being the contralateral C1-C2 facet. The atlanto-dens interval is increased to no > 5.0 mm. Type III is described as anterior subluxation of both C1 facets with an incompetent transverse ligament. Type IV is posterior displacement of C1 relative to C2 with an absent or hypoplastic odontoid process.

Kawabe et al\textsuperscript{59} reviewed the radiographs of a series of 17 children with C1-C2 rotatory subluxation and classified them according to Fieldings and Hawkins. There were 10 Type I, 5 Type II, 2 Type III, and no Type IV subluxations in their experience. CT has been employed to help define the C1-C2 complex in cases of suspected rotatory subluxation. Kowalski et al\textsuperscript{54} demonstrated the superiority of dynamic CT studies compared to information obtained with static CT studies. They compared the CT scans of 8 patients with C1-C2 pathology to CT studies of 6 normal subjects. The CT scans obtained with normal subjects maximally rotating their heads could not be differentiated from the CT scans of those with known C1-C2 rotatory subluxation. When the CT scans were performed with the head rotated as far as possible to the contralateral side, CT studies of normal subjects could be easily differentiated from those performed on patients with rotatory subluxation.

Type I and Type II subluxation account for the vast majority of rotatory atlantoaxial subluxations in reports describing these injuries. Grøgaard et al\textsuperscript{60} and Subach et al\textsuperscript{61} have published retrospective reviews on the success of conservative therapies in children presenting early following C1-C2 rotatory subluxation. Grøgaard et al\textsuperscript{60} described 8 children who presented within 5 days of subluxation, and 1 child who presented 8 weeks after injury. All were successfully treated with closed reduction and immobilization. The child presenting late required 1 week of skeletal traction to achieve reduction, and was ultimately treated with halo immobilization for 10 weeks. The children who presented early had their injuries reduced with manual manipulation. They were treated in a hard collar for 4 to 6 weeks. Two patients had recurrent subluxation. Both were reduced and treated successfully without surgical intervention. Subach et al\textsuperscript{56} reported 20 children with C1-C2 rotatory subluxation, in whom 4 injuries reduced spontaneously. Injury reduction was accomplished in 15 of 16 patients treated with traction for a mean duration of 4 days. Six children required fusion because of recurrent subluxation (n = 5) or irreducible subluxation (n = 1). No child experienced recurrent subluxation if reduced within 21 days of symptom onset.

El-Khoury et al\textsuperscript{63} reported 3 children who presented within 24 hours of traumatic rotatory subluxation. All 3 were successfully treated with traction or manual reduction within 24 hours of presentation. One child experienced recurrent subluxation the next day that was successfully reduced manually. External orthoses were used from 10 weeks to 4 months. Phillips et al\textsuperscript{4} reviewed 23 children with C1-C2 rotatory subluxation. Sixteen children were seen within 1 month of subluxation onset, and experienced either spontaneous reduction or were reduced with traction. Of 7 children presenting with a duration of symptoms...
> 1 month, 1 subluxation was irreducible, and 4 recurred after initial reduction. Schwarz described 4 children who presented > 3 months after the onset of C1-C2 rotatory subluxation. Two children had irreducible subluxations. One child had recurrent subluxation despite the use of a Minerva cast. Only 1 child had successful treatment with closed reduction and a Minerva cast immobilization for 8 weeks. These experiences highlight the ease and success of non-surgical management for these injuries when the subluxation is treated early rather than late. If the subluxation is easily reducible and treated early, 4 weeks in a rigid collar appears to be sufficient for healing. Because C1-C2 rotatory subluxation can reduce spontaneously in the first week, traction or manipulation can be reserved for those subluxations that do not reduce spontaneously in the first few days. The use of more restrictive external immobilization devices (eg, halo vest, Minerva cast) for longer periods of treatment up to 4 months has been described in those children presenting late, or those who have recurrent subluxations.

Operative treatment for C1-C2 rotatory subluxations has been reserved for recurrent subluxations or those that cannot be reduced by closed means. Subach et al operated on 6 of the 20 children they reported with rotatory subluxation using these indications. They employed a posterior approach and accomplished atlantoaxial fusion. They had no complications and all fusions were successful.

In the most comprehensive study of this condition to date, Pang and Li applied a C1-C2 motion analysis protocol to 3-position dynamic CT scans performed prospectively on 40 children with clinically suspected AARF and compared those findings to 21 normal controls described previously. The protocol is too complex to elucidate here, but it reliably distinguished all cases of AARF from normal controls. A classification system derived from the motion analysis protocol identified 5 distinct groups (3 types of AARF “diagnostic grey zone” or DGZ, and normal), and reportedly aided in selecting appropriate treatment regimens according to AARF type. Concurrently, Pang and Li reported an analysis of 29 cases of AARF diagnosed and classified prospectively per their protocol (8 type I cases; 11 type II; 10 type III), and managed according to an algorithm that incorporates their classification scheme. Diagnosis and management of 6 DGZ cases are also reported. Basically, all cases of AARF were managed initially with traction reduction and immobilization (halo or Guilford brace). Those that could not be reduced (n = 3) and those that recurred following HALO immobilization (n = 3) received posterior C1-C2 fusion. DGZ patients were treated symptomatically and restudied after 2 weeks, leading either to normalization or treatment with halter traction if still symptomatic or dynamic CT motion analysis findings worsened. They concluded that type I AARF correlated with delayed treatment and was least likely to respond to conservative management. Prolonged duration of AARF and type I motion analysis also correlated with recurrence of AARF after traction and immobilization. Their exhaustive analysis of AARF provides Class II diagnostic and Class III treatment medical evidence.

In summary, the diagnosis of atlantoaxial rotatory fixation is suggested when findings of a “cock-robin” appearance are present, and the patient is unable to turn the head past midline to the contralateral side, and experiences spasm of the contralateral (opposite the side to which the chin is turned) sternocleidomastoid muscle. Plain cervical spine radiographs may reveal the lateral mass of C1 rotated anterior to the odontoid on a lateral view. The AP radiograph may demonstrate rotation of the spinous processes toward the ipsilateral side in a compensatory motion to restore alignment. If the diagnosis of AARF is suspected after clinical examination and plain radiographic study, a dynamic CT study should be obtained and analyzed using the Pang protocol. It appears that the longer AARF is present before attempted treatment, the less likely reduction can be accomplished. Even if reduction is accomplished in these chronic injuries, it is less likely to be maintained. Therefore, acute AARF (< 4 weeks duration) that does not reduce spontaneously should undergo attempted reduction with manipulation or halter traction. Chronic AARF (4 weeks duration or more) should undergo attempted reduction with halter or tong/halo traction. Reductions achieved with manipulation or halter traction should be immobilized with a cervicothoracic brace, while those requiring tong/halo traction should be kept in a halo. The subsequent period of immobilization should be proportional to the length of time that the subluxation was present before treatment. Surgical arthrodesis can be considered for those with irreducible subluxations, recurrent subluxations, or subluxations present for > 3 months duration.

**Therapeutic Cervical Spine Immobilization**

Once an injury to the pediatric cervical spine has been diagnosed, some form of external immobilization is usually necessary to allow for either application of traction to restore alignment or to immobilize the spine to allow for healing of the injury. This section will discuss the literature available concerning methods of skeletal traction in children, and various external orthoses used to immobilize the pediatric cervical spine.

Traction for the purpose of restoring alignment or reducing neural compression in children is rarely addressed in the literature. Unique concerns of cervical traction in children exist because of the relatively thinner skull with a higher likelihood of inner skull table penetration, lighter body weight which provides less counter force to traction, more elastic ligaments, and less well-developed musculature, increasing the potential for over-distraction. The placement of bilateral pairs of parietal burr holes and passing 22 gauge wire through them to provide a point of fixation for traction has been described for infants with cervical spinal injuries. Gaufin and Goodman reported a series of 3 infants with cervical injuries, 2 of whom had injuries reduced in this fashion. Up to 9 pounds was used in a 10-week-old infant and a 16-month-old boy. They experienced no complications with 14 and 41 days of traction, respectively. Other techniques of cervical traction application in children are not described in the literature.

Mubarak et al described halo application in infants for the purpose of immobilization but not halo-ring traction. They
described 3 infants ages 7 months, 16 months, and 24 months. Ten pins were used in each child. The pins in the youngest child were "inserted to finger tightness only," while the older children had 2 inch/pounds of torque applied. The children were maintained in the halo devices for 2 to 3 and a half months. Only the youngest child had a minor complication of frontal pin site infection, necessitating removal of 2 anterior pins.

Marks et al\(^7\) described 8 children ages 3 months to 12 years who were immobilized in halo vests for 6 weeks to 12 months with a mean duration of 2 months. Only 3 of these children had cervical spinal instability. Five had thoracic spinal disorders. The only complication they reported was the need to remove and replace the vest when a foreign body became lodged under the vest. Dormans et al\(^3\) reported on 37 children ages 3 to 12 years that they managed in halo immobilization devices. They had a 68% complication rate. Pin-site infections were most common. They arbitrarily divided their patient population into those < 10 years of age and those 10 years or older. Purulent pin site infections occurred more commonly in the older group. Loosening of pins occurred more commonly in the younger group. Both loosening and infection occurred more often at the anterior pin sites. They also reported 1 incident of dural penetration and 1 transient supraorbital nerve injury. Baum et al\(^6\) compared halo use complications in children and adults. The complication rates in their series were 8% for adults and 39 percent among children. The complications reported for the children were one skull penetration and 4 pin site infections. While the halo device appears to provide adequate immobilization of the cervical spine in children, there is a higher rate of minor complications compared to halo use with adults.

Gaskill and Marlin\(^6\) described 6 children ages 2 years to 4 years who had cervical spinal instability managed with a thermoplastic Minerva orthosis as an alternative to a halo immobilization device. Two of the children they described had halo devices removed because of complications before being placed in Minerva orthoses. The authors described no problems with eating or with activities of daily living in these children. Only 1 child had a minor complication from Minerva use, a site of skin breakdown. The authors concluded that immobilization with a thermoplastic Minerva orthosis offered a reliable and satisfactory alternative to halo immobilization in young children.

Benzel et al\(^7\) analyzed cervical motion during spinal immobilization in adults serially treated with halo and Minerva devices. They found that the Minerva offered superior immobilization at all intersegmental levels of the cervical spine with the exception of C1-C2. While this study was carried out in adults with cervical spine instability, it underscores the utility of the Minerva device as a cervical immobilization device. Because a great proportion of pediatric cervical spine injuries occur between the occiput and C2, the Minerva device may not be ideal for many pediatric cervical spine injuries.

In summary, the physical properties of young skin, skull thickness, and small body size likely contribute to the higher complication rate among children who require traction or long-term cervical spinal immobilization compared to adults. The literature includes descriptions of options available for reduction and immobilization of cervical spine injuries in children, but does not provide evidence for a single best method.

Surgical Treatment

There are no reports in the literature that address the topic of early vs late surgical decompression following acute pediatric cervical spinal cord injury. Pediatric spinal injuries account for only 5% of all vertebral column injuries. Since the initial publication of “Guidelines for the Management of Acute Cervical Spine and Spinal Injuries,” the preponderance of the recent treatment literature describes surgical management techniques in case series format. Gluf et al\(^71\) reported a retrospective review of 67 consecutive C1-C2 transarticular screw (TAS) fixation cases (127 screws) in patients < 16 years old for various indications. Trauma was the indication for 24 cases and radiographic fusion was achieved in every case. The overall complication rate was 10.4%, including 2 vertebral artery injuries—neither of which caused a permanent neurological deficit. Klimo et al\(^72\) reported a series of 78 patients treated surgically for os odontoideum; 56% (n = 44) presented following trauma and 63% (n = 49) were < 21 years of age. Posterior C1-C2 fusions were performed in 75 patients, O-C2 fusions in 2, and an odontoid screw was placed in 1. All patients except the odontoid screw recipient had at least 1 TAS placed with no major complications and a radiographic fusion rate of 100%.

Heuer et al\(^73\) described their experience with the Goel-Harms internal fixation technique in 6 children undergoing posterior C1-C2 fusion for os odontoideum. All 6 achieved radiographic fusion and no complications were reported. Chamoun et al reported on 7 pediatric cervical spine fusion procedures supplemented with axial and subaxial translaminar screw fixation. Trauma was the surgical indication in 3 cases; all 7 achieved radiographic fusion. One patient experienced prolonged dysphagia due to a malpositioned C1 lateral mass screw. Couture et al\(^74\) reviewed 22 cases of pediatric occipitocervical fusion with internal fixation using the “Wasatch loop.” All 6 cases performed to stabilize traumatic instability led to radiographic fusion without major complications or the need for revision surgery. Most recently, Hankinson et al\(^75\) reported a prospective multicenter comparison of internal fixation techniques (Class II) for pediatric occipitocervical fusion surgery. Traumatic instability was the indication for 22 of the 77 procedures analyzed. The internal fixation techniques compared were 1) O-C2 instrumentation without direct fixation of C1; 2) C1 and C2 instrumentation without TAS fixation; and 3) any TAS fixation. Their analysis revealed 100% radiographic fusion rates in all groups and no significant difference in complication rates among the 3 fixation techniques. They reported 3 vertebral artery injuries, 2 in the TAS group and 1 in the C1-C2 instrumentation group.

The remaining noteworthy reports describing management of pediatric cervical spine and spinal cord injuries are all Class III case series. Parisini et al\(^76\) reported 12 cervical spine fractures in a series...
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<th>Authors &amp; Year</th>
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<td>Anderson et al., 12 JNS: Peds, 2010</td>
<td>Multicenter prospective assessment of a c-spine clearance protocol for patients aged 0 to 3 years (n = 575)</td>
<td>II</td>
<td>Clinical and plain radiographic findings were sufficient to clear the majority of c-spines in non-communicative children. CT scans were required in 14% and MRI in only 10%, using this protocol.</td>
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<td>Katz et al., 16 JNS: Peds, 2010</td>
<td>Retrospective review of CSI in 905 patients &lt; 1 year of age presenting with minor (low-impact) head trauma</td>
<td>II</td>
<td>Only 2 infants (0.2%) were found to have a CSI and the mechanism was NAT in both. Routine c-spine imaging has very low diagnostic yield unless NAT is suspected.</td>
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<td>Ehrlich et al., 14 J Ped Surg, 2009</td>
<td>Retrospective case-control comparison of CCR and NEXUS low-risk criteria in determining the need for c-spine radiography in patients &lt; 11 years of age</td>
<td>II</td>
<td>Both criteria would have missed c-spine injuries and both are not sensitive or specific enough to be applied to pediatric patients as designed.</td>
</tr>
<tr>
<td>Pieretti-Vanmarcke et al., 15 Trauma, 2009</td>
<td>Multi-institutional retrospective review of 12,537 blunt trauma cases &lt; 3 years of age to identify clinical predictors of cervical spine injury  (n = 83)</td>
<td>II</td>
<td>Four independent predictors of CSI were identified: GCS &lt; 14, GCSeye = 1, motor vehicle crash, and age 2 years or older. A score of &lt; 2 had a negative predictive value of 99.93% in ruling out CSI.</td>
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<tr>
<td>Hutchings et al., 17 Trauma, 2009</td>
<td>Retrospective review of c-spine clearance modalities in 115 pediatric major trauma admissions (all obtunded)</td>
<td>III</td>
<td>CT scan demonstrated 100% sensitivity and specificity with positive and negative predictive values of 1.0 for all spinal regions.</td>
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<td>Garton et al., 85 Neurosurgery, 2008</td>
<td>Retrospective evaluation of NEXUS criteria on 190 consecutive pediatric cervical spine injuries</td>
<td>II</td>
<td>NEXUS criteria applied to children &lt; 8 years of age would have missed 2/33 injuries but missed none in patients &gt; 8 years old. Occiput-C3 CT scan may provide better diagnostic yield in young children than flexion/extension radiographs.</td>
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<tr>
<td>Pang et al., 63 Neurosurgery, 2007</td>
<td>CT evaluation of CCI in 89 normal children and 16 children with AOD</td>
<td>I</td>
<td>“Standard” tests 25 to 50% sensitivity, 10 to 60% specificity; CCI 100% sensitivity, 100% specificity for AOD.</td>
</tr>
<tr>
<td>Anderson et al., 11 JNS: Peds, 2006</td>
<td>Prospective evaluation of a NEXUS-based pediatric c-spine clearance protocol (n = 937) compared to historical “control” (n = 936)</td>
<td>II</td>
<td>The protocol used safely facilitated c-spine clearance by non-neurosurgical personnel while it reduced the need for neurological consultation by 60%.</td>
</tr>
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<td>Pang et al., 63 Neurosurgery, 2005</td>
<td>Prospective multicenter evaluation of 3-position CT scan C1-C2 motion analysis protocol to diagnose and classify AARF in 40 children compared to 21 normal controls</td>
<td>II</td>
<td>AARF reliably diagnosed by protocol and classified to help select best management regimen.</td>
</tr>
<tr>
<td>Hernandez et al., 87 Emerg Rad, 2003</td>
<td>Retrospective review of 147 ER c-spine CT scans in patients &lt; 5 years of age</td>
<td>III</td>
<td>All 4 injuries identified from 147 scans were evident on initial plain radiography.</td>
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<td>Viccellio et al, Pediatrics, 2001</td>
<td>Prospective multicenter evaluation of cervical spine radiographs obtained in 3065 children incurring trauma. Low-risk criteria of absence of: neck tenderness, painful distracting injury, altered alertness, neurological deficit, or intoxication.</td>
<td>II</td>
<td>No child fulfilling all 5 low-risk criteria had a cervical spine injury. Radiographs may not be necessary to clear the cervical spine in children fulfilling all 5 criteria.</td>
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<tr>
<td>Ralston et al, Academ Emer Med, 2001</td>
<td>Blinded review of 129 children with blunt cervical trauma who had flexion and extension radiographs.</td>
<td>II</td>
<td>Flexion and extension views with normal cervical spine radiographs or with only loss of cervical lordosis did not unmask any new abnormalities.</td>
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<tr>
<td>Buhs et al, J Ped Surg, 2000</td>
<td>Multi-institutional review of pediatric cervical spine injuries and the radiographs needed to achieve a diagnosis.</td>
<td>III</td>
<td>Lateral cervical radiograph was diagnostic in 13 of 15 children &lt; 9 years old. In no child &lt; 9 years old was the open-mouth view the diagnostic study. Only 1 of 36 children older than 9 years had open-mouth view as the diagnostic study.</td>
</tr>
<tr>
<td>Swischuk et al, Pediatr Radiol, 2000</td>
<td>Survey of pediatric radiologists regarding use of open mouth view of the odontoid.</td>
<td>III</td>
<td>Less than 50% response. Approximately 40% of respondents did not employ open mouth views in children.</td>
</tr>
<tr>
<td>Scarrow et al, Pediatr Neurosurg, 1999</td>
<td>Performed flexion/extension cervical fluoroscopy with SSEP monitoring in 15 comatose pediatric patients.</td>
<td>III</td>
<td>None had radiographic abnormalities. Three children had changes in the SSEP’s. One of these 3 children was studied with MR and it was normal.</td>
</tr>
<tr>
<td>Shaw et al, Clin Radiol, 1999</td>
<td>Retrospective review of the cervical radiographs 138 trauma patients under 16 years old.</td>
<td>III</td>
<td>Twenty-two percent incidence of pseudosubluxation of C2 on C3. Median age of pseudosubluxation group was 6.5 years vs 9 years for those without pseudosubluxation.</td>
</tr>
<tr>
<td>Berne et al, J Trauma, 1999</td>
<td>58 patients with severe blunt trauma underwent helical CT of entire cervical spine.</td>
<td>III</td>
<td>Twenty had cervical spine injuries. Plain radiographs missed 8 injuries. CT missed 2 injuries.</td>
</tr>
<tr>
<td>Keiper et al, Neurorad, 1998</td>
<td>Retrospective review evaluating 52 children by MR with suspected cervical spine trauma or instability without fracture.</td>
<td>III</td>
<td>There were 16 abnormal studies. The most common abnormality was posterior ligamentous injury. Four children underwent surgical stabilization. The MR findings caused the surgeon to extend his length of stabilization in all 4 cases.</td>
</tr>
<tr>
<td>Davis PC et al, AJNR, 1993</td>
<td>Retrospective review of 15 children with spinal cord injury underwent MR 12 hours to 2 months after injury, 7 with SCIWORA.</td>
<td>III</td>
<td>MR correlated with prognosis. Hemorrhagic cord contusions and cord “infarction” were associated with permanent deficits. No compressive lesions in SCIWORA cases. Normal MR was associated with no myelopathy.</td>
</tr>
<tr>
<td>Schleehauf et al, Ann Emer Med, 1989</td>
<td>104 “high-risk” patients underwent CT as screening tool for cervical spine injury.</td>
<td>III</td>
<td>Sensitivity overall was 0.78. Sensitivity was 1.0 for unstable injuries not able to be seen by plain radiographs. Two upper cervical subluxations without fracture were missed.</td>
</tr>
<tr>
<td>Kawabe et al, J Pediatr Orthop, 1989</td>
<td>Review of the radiology of 17 children with C1-2 rotatory subluxation.</td>
<td>III</td>
<td>Classified according to Fielding and Hawkins as 10 type I, 5 type II, 2 type III, and no type IV.</td>
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</table>
of 44 pediatric traumatic spinal injuries. Of 6 unstable cervical fractures (3 with SCI), 4 were treated primarily with posterior fusion procedures and 2 with external immobilization (halo and Minerva). Those treated surgically had no residual deformity at last follow-up (9-23 years), while the 2 managed conservatively had residual kyphosis of 18° and 24°. Dogan et al. reported a single center retrospective series of 51 pediatric subaxial cervical spine injuries collected over a 6-year period. Forty-one injuries were in children aged 9 to 16 years and only 10 in children under 9 years old. Thirty-three children were treated non-surgically (7 halo; 26 rigid cervical orthosis), and 18 children age 8 to 16 years underwent a wide variety of stabilization/fusion procedures. There were no surgery-related deaths or complications and no one in either group developed delayed instability, although 3 patients expired and 6 were lost to long-term follow-up. They concluded that subaxial injuries tend to occur in older children, can usually be managed conservatively, and that surgical treatment appears to be safe and effective. Lastly, Duhem et al. described their single center retrospective experience with 28 unstable pediatric upper c-spine injuries over 28 years. Seven were treated surgically, all of whom achieved stable radiographic fusion with no surgery-related deaths or complications. None of the 28 patients experienced a neurologic decline during or after treatment. In conclusion, the authors favor surgical intervention for patients with “signs of medullary compression, significant spine deformation, dynamic instability, and an age higher than 8 years.”

Earlier reports describing the management of pediatric spinal injuries have been offered by Turgut et al., Finch and Barnes, and Elaraky, et al. These authors managed pediatric spinal injuries operatively in 17%, 25%, and 30% of patients, respectively. The report by Elaraky et al. in 2000, suggests that operative treatment of pediatric cervical spine injuries is being utilized more frequently than in the past. Specific details of the operative management including timing of intervention, the approach (anterior vs posterior), and the method of internal fixation as an adjunct to fusion are scarce in the literature. Finch and Barnes employed primary operative stabilization in most children they managed with ligamentous injuries of the cervical spine. They stated that while external immobilization may have resulted in ligamentous healing, they elected to internally fixate and fuse such injuries. They based their approach on 2 cases of ligamentous injuries of the cervical spine that they managed with external immobilization, which failed to heal, that later required operative fusion. Shaked et al. described 6 children ages 3 years to 14 years who had cervical spine injuries that they treated surgically via an anterior approach. They reported successful fusion with good alignment and normal cervical spine growth in follow-up for all 6 children. The procedure varied (ie total or partial corpectomy vs discectomy only) depending on the pathology. All underwent autograft fusion without instrumentation. The authors described severe hyperflexion injury with fracture and avulsion of the vertebral body, fracture-dislocation with disruption of the posterior elements and disc, and major anatomic deformity of the cervical spine with cord compression as indications for an anterior approach.

Pennecot et al. described 16 children with ligamentous injuries of the cervical spine. They managed minor ligamentous injuries (atlanto-dens interval of 5.0 mm to 7.0 mm, or interspinous widening without dislocation or neurologic deficit) with reduction and immobilization. Of 11 children with injuries below C2, 8 required operative treatment with fusion via a posterior approach. They used interspinous wiring techniques in younger children (preschool aged), and posterior plates and screws in older children as adjuncts to fusion. All had successful fusion at last follow-up. All children were immobilized in a plaster or halo cast postoperatively. Similarly, Koop et al. described 13 children with acute cervical spine injuries who required posterior arthrodesis and halo immobilization. They reported successful fusion in 12 patients. The single failure was associated with use of allograft fusion substrate. All the other children were treated with autologous grafts. Internal fixation with wire was employed in only 2 children. Halo immobilization was utilized for an average
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<tr>
<td>Hankinson et al.,75 <em>JNS: Peds</em>, 2010</td>
<td>Multicenter retrospective comparison of O-C2 fusion rates with or without direct C1 instrumentation (total n = 77; trauma = 22)</td>
<td>III</td>
<td>One hundred percent radiographic fusion rates were reported in both groups with no significant difference in complication rates. Excellent O-C fusion rates can be achieved without direct instrumentation of C1.</td>
</tr>
<tr>
<td>Couture et al.,74 <em>JNS: Peds</em>, 2010</td>
<td>Retrospective case series of 22 children who underwent O-C fusion using “Wasatch loop” instrumentation</td>
<td>III</td>
<td>Trauma was the indication in 6 cases, radiographic fusion was achieved in 100%, 3 non-trauma cases required revision surgery, and no major complications occurred.</td>
</tr>
<tr>
<td>Chamoun et al.,88 <em>Neurosurgery</em>, 2009</td>
<td>Report of 7 pediatric cervical spine fusions (3 for trauma) using axial and subaxial transarticular screw fixation</td>
<td>III</td>
<td>Radiographic fusion was achieved in 100% and 1 patient experienced prolonged dysphagia due to C1 lateral mass screw malposition.</td>
</tr>
<tr>
<td>Heuer et al.,73 <em>Eur Spine J</em>, 2009</td>
<td>Retrospective series of 6 C1-C2 posterior fusions in children using Goel-Harms internal fixation constructs</td>
<td>III</td>
<td>Although none were acutely posttraumatic, all had os odontoideum, all achieved radiographic fusion, and no major complications were reported.</td>
</tr>
<tr>
<td>Klimo et al.,89 <em>JNS: Peds</em>, 2008</td>
<td>Retrospective review of 78 patients treated surgically for os odontoideum, traumatic presentation occurred in 56% and 63% were &lt; 20 years old</td>
<td>III</td>
<td>All underwent posterior C1-C2 fusion with transarticular screw fixation (except 1 odontoid screw and 2 O-C2 fusions), radiographic fusion was achieved in 100%, and no major complications occurred.</td>
</tr>
<tr>
<td>Duhem et al.,78 <em>Childs Nerv Syst</em>, 2008</td>
<td>Single center retrospective review of 28 cases of unstable pediatric upper cervical spine injuries over a 28-year period</td>
<td>III</td>
<td>Seven patients were managed surgically and all achieved radiographic fusion on late follow-up. None of the 28 experienced a neurologic decline during or after treatment. Two of 5 incomplete SCI cases normalized.</td>
</tr>
<tr>
<td>Dogan et al.,77 <em>Neurosurg Focus</em>, 2006</td>
<td>Single center retrospective review of 51 pediatric subaxial cervical spine injuries over a 6-year period</td>
<td>III</td>
<td>Conservative management was successful for 64%, while 36% required surgery. No deaths or complications were attributed to surgical intervention.</td>
</tr>
<tr>
<td>Fassett et al.,46 <em>Neurosurg Focus</em>, 2006</td>
<td>Meta-analysis of odontoid synchondrosis fractures: 7 series’ totaling 55 cases</td>
<td>III</td>
<td>Ninety-three percent of fractures initially managed with external immobilization (HALO or Minerva) attained fusion without surgery.</td>
</tr>
<tr>
<td>Pang et al.,64 <em>Neurosurgery</em>, 2005</td>
<td>Prospective case series of 29 children with AARF diagnosed, classified, and managed per the authors’ protocol</td>
<td>III</td>
<td>Prolonged delay in treatment may adversely affect C1-C2 rotatory dynamics. Type I AARF correlated with delayed treatment and need for HALO immobilization ± posterior C1-C2 fusion.</td>
</tr>
<tr>
<td>Gluf et al.,71 <em>JNS: Spine</em>, 2005</td>
<td>Retrospective case series of 67 C1-C2 transarticular screw fixations in patients &lt; 16 years of age</td>
<td>III</td>
<td>Trauma was the indication in 24 cases, radiographic fusion was achieved in 100%, and 2 asymptomatic vertebral artery injuries were observed.</td>
</tr>
<tr>
<td>Parisini et al.,76 <em>Spine</em>, 2002</td>
<td>Retrospective case series of 44 pediatric spine fractures (12 cervical) with mean follow-up of 18 years</td>
<td>III</td>
<td>Four unstable c-spine fractures (2 with SCI) managed conservatively developed late deformity. Stable fractures managed conservatively healed without deformity.</td>
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<tr>
<td>Meyer et al., 2001</td>
<td>Retrospective case series of 13 cervical spine fusion procedures in 11 children—8 for post-traumatic instability</td>
<td>III</td>
<td>Radiographic fusion occurred in 100%, 3 transient neurologic deteriorations occurred, and 2 developed “bystander fusion.”</td>
</tr>
<tr>
<td>Eleraky et al., 2000</td>
<td>Retrospective review of 102 children with cervical spinal injuries</td>
<td>III</td>
<td>Thirty children (30%) were treated surgically.</td>
</tr>
<tr>
<td>Odent et al., 1999</td>
<td>Review of 15 young children with odontoid injuries</td>
<td>III</td>
<td>Six with neurological deficits had cervicothoracic cord injuries. External immobilization was a successful primary therapy. Three children who were operated upon as their primary therapy experienced complications.</td>
</tr>
<tr>
<td>Schwarz, 1998</td>
<td>A review of 4 children presenting at least 3 months after the onset of C1-2 rotatory subluxation</td>
<td>III</td>
<td>Two children had irreducible subluxations. One child had recurrent subluxation in a Minerva cast. One child was successfully treated with closed reduction and 8 weeks in a Minerva cast.</td>
</tr>
<tr>
<td>Subach et al., 1998</td>
<td>A review of 20 children with C1-2 rotatory subluxation</td>
<td>III</td>
<td>Four reduced spontaneously. Fifteen of 16 treated with traction reduced in a mean of 4 days. Six children required fusion because of recurrent subluxation or irreducible subluxation. No child experienced recurrent subluxation if reduced within 21 days of symptom onset.</td>
</tr>
<tr>
<td>Finch and Barnes, 1998</td>
<td>Retrospective review of 32 children with major cervical spine injuries</td>
<td>III</td>
<td>Eight children (25%) were treated surgically. All achieved union or radiological stability. No neurological deterioration from surgery or closed reduction. Operated on ligamentous injuries.</td>
</tr>
<tr>
<td>Treloar and Nypaver, 1997</td>
<td>They measured cervical spine flexion in children with semi-rigid collars on spinal boards</td>
<td>III</td>
<td>Semi-rigid collars did not prevent the cervical spine from being forced into flexion in children &lt; 8 years old when on a spinal board.</td>
</tr>
<tr>
<td>Lui TN et al., 1996</td>
<td>Retrospective review of C1-2 injuries in 22 children; 12 children had odontoid injuries (OI), 9 children had ligamentous injuries (atlantoaxial dislocations) only</td>
<td>III</td>
<td>Flexion/extension radiographs needed to diagnose 4 OI and 6 atlanto-axial dislocations (AAD). Nine of 12 OI reduced easily. Five of 7 OI treated successfully with halo. Two OI operated immediately. Two OI failed external immobilization. Five AAD initially treated with surgical fusion. Two AAD initially treated with halo required surgical stabilization.</td>
</tr>
<tr>
<td>Givens et al., 1996</td>
<td>Review of 34 children with cervical spine injuries over a 3-year period</td>
<td>III</td>
<td>Eighteen injuries occurred below C3. The level of injury did not correlate with age. Young age is not associated with exclusively upper cervical spine injuries.</td>
</tr>
<tr>
<td>Turgut et al., 1996</td>
<td>Retrospective review of 82 children with spinal cord or column injuries</td>
<td>III</td>
<td>Fourteen children (17%) were treated surgically.</td>
</tr>
<tr>
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<tr>
<td>Dormans et al, J Bone Joint Surg, 1995</td>
<td>A review of 37 children with halo rings and vests ages 3 to 16 years Arbitrarily divided into those &lt; 10 years old, and older</td>
<td>III</td>
<td>Overall 68% complication rate. Pin-site infection was the most common complication. Purulent infections occurred more frequently in the older group. Both loosening and infection occurred more frequently in the anterior pin sites.</td>
</tr>
<tr>
<td>Menticoglou et al, Obstet Gyn, 1995</td>
<td>Retrospective case series of 15 neonates with birth-related high cervical cord injuries</td>
<td>III</td>
<td>All 15 were cephalic presentations in which forceps and attempted rotation were employed. All but one were apneic at birth.</td>
</tr>
<tr>
<td>Curran et al, J Trauma, 1995</td>
<td>Prospective study of 118 children who arrived immobilized to a single emergency room, the cervical spine alignment was measured and compared to age and type of immobilization</td>
<td>II</td>
<td>No correlation with degree of kyphosis or lordosis was found with age. Thirty percent had a kyphosis of &gt; 10°. No single immobilization technique was superior.</td>
</tr>
<tr>
<td>Schwarz et al, Injury, 1994</td>
<td>Review of 10 children with vertebral fractures and kyphotic angulation</td>
<td>III</td>
<td>The kyphotic angulation remained unchanged or worsened when external immobilization alone (n = 7) or dorsal fusion (n = 1) was employed. Only those undergoing a ventral fusion (n = 2) had a stable reduction of the kyphotic deformity.</td>
</tr>
<tr>
<td>Nypaver and Treloar, Ann Emer Med, 1994</td>
<td>40 children were placed on spine boards and observers judged whether the cervical spine was in the “neutral” position. Children 4 years of age or younger required the greatest amount of elevation.</td>
<td>III</td>
<td>Children &lt; 8 years of age required torso elevation to achieve neutral alignment</td>
</tr>
<tr>
<td>Laham JL et al, Pediatr Neurosurg, 1994</td>
<td>Divided head-injured children into high (≤ 2 years of age, non-communicative, or with neck pain) and low risk groups for cervical spine injury</td>
<td>III</td>
<td>No cervical spine injuries detected in the low-risk group. Ten injuries (7.5%) were detected in the high-risk group.</td>
</tr>
<tr>
<td>Fotter et al, Ped Radiol, 1994</td>
<td>Report of birth-related spinal cord injuries imaged with ultrasound and MRI</td>
<td>III</td>
<td>A neonate with complete injury had normal plain radiographs with spinal ultrasound showing inhomogeneous echogenicity and disrupted cord surface. A neonate with an incomplete injury had intact cord surface with increased cord echogenicity. MRI corroborated these findings.</td>
</tr>
<tr>
<td>Marks et al, Arch Orthop Trauma Surg, 1993</td>
<td>Review of 8 children, ages 3 months to 12 years, immobilized in a halo jacket for 6 weeks to 12 months (mean 2 months)</td>
<td>III</td>
<td>The only complication was a jacket change was required for a foreign body (coin). Only 3 of these children had cervical instability.</td>
</tr>
<tr>
<td>Shacked et al, Clin Orthop, 1993</td>
<td>Retrospective review of 6 children (3 to 14 years old) with cervical spine injuries treated via an anterior approach</td>
<td>III</td>
<td>Autograft without instrumentation following corpectomy was used. They were stabilized postoperatively with hard collar or Minerva cast. All with solid fusions, good alignment, and normal cervical growth. Follow-up 3 to 8 years.</td>
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<tr>
<td>Grøgaard et al, <em>Arch Orthop Trauma Surg</em>, 1993</td>
<td>Atlanto-axial rotatory subluxation described in 9 children, 8 diagnosed within 5 days, 1 diagnosed after 8 weeks</td>
<td>III</td>
<td>Eight children were treated successfully with &quot;mild&quot; traction and then a collar for 4 to 6 weeks. The 1 child presenting late required 1 week of traction for reduction. There were 2 redislocations. All eventually healed in alignment without surgery.</td>
</tr>
<tr>
<td>Mandabach et al, <em>Pediatr Neurosurg</em>, 1993</td>
<td>13 children with axis injuries were reviewed, 10 were treated primarily with closed reduction and halo immobilization</td>
<td>III</td>
<td>Eight of the 10 treated primarily with closed reduction and halo immobilization fused. Two required surgical stabilization and fusion.</td>
</tr>
<tr>
<td>MacKinnon et al, <em>J Pediatr</em>, 1993</td>
<td>Retrospective case series of 22 neonates with birth-related spinal cord injuries, they excluded neonates with SCIWORA</td>
<td>III</td>
<td>All 14 with high cervical injuries had cephalic presentations with attempted forceps rotation. All 6 with cervicothoracic injuries had breech presentations. Both neonates with thoracolumbar injuries were premature.</td>
</tr>
<tr>
<td>Rossitch and Oakes, <em>Pediatr Neurosurg</em> 1992</td>
<td>Retrospective review of 5 neonates with perinatal spinal cord injury, no flexion/extension views reported</td>
<td>III</td>
<td>Four of the 5 had no abnormality on static spinal radiographs. Respiratory insufficiency and hypotonia were common signs. Myelograms were unrevealing. All 3 with high cervical injuries died by age 3 years.</td>
</tr>
<tr>
<td>Osenbach and Menezes, <em>Neurosurgery</em> 1992</td>
<td>Retrospective review of 179 children with spinal injuries</td>
<td>III</td>
<td>Fifty-nine (33%) underwent surgical treatment for irreducible unstable injuries. 83% of those treated surgically were 9 years of age or older. No child with complete or severe partial myelopathy regained useful function.</td>
</tr>
<tr>
<td>Rathbone et al, <em>J Ped Orthop</em>, 1992</td>
<td>Retrospective review of 12 children with presumed spinal cord concussion during athletics were investigated for the presence of cervical stenosis</td>
<td>III</td>
<td>Three had a Torg ratio &lt; 0.8 and 4 had a canal AP diameter &lt; 13.4 mm. MRI was not used to evaluate for stenosis.</td>
</tr>
<tr>
<td>Hamilton and Myles, <em>J Neurosurg</em>, 1992</td>
<td>Retrospective review of all pediatric spinal injuries over 14-year period, 73 children had cervical injuries</td>
<td>III</td>
<td>Surgery was performed in 26% of children. Thirteen percent of children with fracture and no subluxation, 50% with subluxation alone, and 57% with fracture and subluxation were treated surgically. Of 39 children with complete myelopathy, 4 improved 1 or 2 Frankel grades.</td>
</tr>
<tr>
<td>Schafermeyer et al, <em>Ann Emer Med</em>, 1991</td>
<td>Forced vital capacity (FVC) was studied in healthy children when upright, supine, and supine taped to a spinal board</td>
<td>III</td>
<td>Taping the child to the spinal board caused FVC to drop to 41% to 96% (mean 80%) of supine FVC.</td>
</tr>
<tr>
<td>Bohn et al, <em>J Trauma</em>, 1990</td>
<td>16 of 19 children presenting with absent vital signs or severe hypotension unexplained by blood loss underwent postmortem examination</td>
<td>III</td>
<td>Thirteen of 16 had cord laceration or transection. Two of these children had a normal cervical radiograph.</td>
</tr>
<tr>
<td>Gaskill and Marlin, <em>Pediatr Neurosurg</em>, 1990</td>
<td>6 children ages 2 to 4 years were placed in Minerva jackets for cervical spine instability</td>
<td>III</td>
<td>One child had skin breakdown of the chin. Eating and other daily activities were not impaired. Two were placed in Minerva jackets after complications of halo ring and vest immobilization.</td>
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<tr>
<td>Phillips et al, 55, J Bone Joint Surg, 1989</td>
<td>A review of 23 children with C1-2 rotatory subluxation</td>
<td>III</td>
<td>Sixteen children seen within 1 month of onset had either spontaneous reduction or reduced with traction. Of the 7 children presenting with &gt; 1 month of symptoms, 1 subluxation was irreducible, and 4 had recurrent subluxations.</td>
</tr>
<tr>
<td>Benzel et al, 70, J Neurosurg, 1989</td>
<td>A comparison of cervical motion of injured patients (only 1 child) immobilized in halo and Minerva jackets</td>
<td>III</td>
<td>The Minerva jacket allowed less motion than the halo jacket at every level except C1-2.</td>
</tr>
<tr>
<td>Baum et al, 68, Spine, 1989</td>
<td>A review comparing the halo complications 13 children and 80 adults</td>
<td>III</td>
<td>Thirty-nine percent complication rate in children vs 8% in adults. The children had 4 pin-site infections and 1 inner table skull pin penetration.</td>
</tr>
<tr>
<td>Mubarak et al, 66, J Ped Ortho, 1989</td>
<td>Review of 3 children &lt; 2 years old who were placed in halo rings for 2 to 3 ½ months</td>
<td>III</td>
<td>Ten pins tightened “finger-tight” in a 7-month-old, and 2 in/lb in a 16- and 24-month-old. Two of 3 developed minor pin site infections necessitating pin removal.</td>
</tr>
<tr>
<td>Herzenberg et al, 4, J Bone Joint Surg, 1989</td>
<td>Reported 10 children &lt; 7 years of age with cervical spine injuries positioned on a flat backboard</td>
<td>III</td>
<td>The injuries were anteriorly angulated or translated when on a flat backboard because the head was in forced into flexion. Elevating the torso allowed for more neutral alignment and reduction of the injured segment.</td>
</tr>
<tr>
<td>Evans and Bethem, 22, J Ped Ortho, 1989</td>
<td>Review of 24 consecutive cervical spine injuries in children 18 years old or less</td>
<td>III</td>
<td>Half of the children had injuries at C3 or above. One child was treated with laminectomy and 2 with fusion. Fractures healed in 21 of 22 with nonoperative therapy.</td>
</tr>
<tr>
<td>Birney and Hanley, 93, Spine, 1989</td>
<td>Retrospective review of 61 children with cervical spine injuries, 23 of these injuries were C1-2 rotatory subluxation</td>
<td>III</td>
<td>Rotatory subluxation unassociated with neurological deficit. The deformity resolved with halter traction (n = 10) or cervical bracing. One child had a recurrence.</td>
</tr>
<tr>
<td>Hadley et al, 32, J Neurosurg, 1988</td>
<td>Retrospective review of 122 children with spinal injuries There were 97 cervical injuries</td>
<td>III</td>
<td>Only 12 cervical injuries were treated surgically.</td>
</tr>
<tr>
<td>Huerta et al, 6, Ann Emer Med, 1987</td>
<td>They evaluated the immobilization of commercially available infant and pediatric cervical collars</td>
<td>III</td>
<td>No collar used alone provided acceptable immobilization. The use of a modified half-spine board, rigid collar, and tape provided the best immobilization.</td>
</tr>
<tr>
<td>Pennecot et al, 82, J Ped Ortho, 1984</td>
<td>Review of 16 children with ligamentous injuries of the cervical spine, 5 with C1-2 injuries</td>
<td>III</td>
<td>Of the 11 children with injuries below C2, 8 underwent surgical stabilization. They recommended a 3-month trial of external immobilization in children with ligamentous injuries but no neurological deficit or dislocation.</td>
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of 150 days. They reduced the length of post-operative halo immobilization to 100 days in their most recent cases. They commented that careful technique allowed successful posterior fusion in children with minimal complications. Schwarz et al\textsuperscript{84} described 10 children with traumatic cervical kyphosis. Two children who underwent anterior reconstruction with fusion had successful deformity reduction. All others managed with either external immobilization with or without traction (n = 7) or posterior fusion (n = 1) had either progression of the post-traumatic deformity or a stable unreduced kyphotic angulation.

In summary, pediatric spinal injuries are relatively infrequent. The vast majority are managed non-operatively. Selection criteria for operative intervention in children with cervical spine injuries are difficult to glean from the literature. Anatomic reduction of deformity, stabilization of unstable injuries and decompression of the spinal cord, and isolated ligamentous injuries associated with deformity are indications for surgical treatment cited by various authors.\textsuperscript{20,51,79,81-84} These numerous reports provide Class III medical evidence.

### SUMMARY

The available medical literature supports only 1 Level I recommendation for the management of pediatric patients with cervical spine or spinal cord injuries, specifically related to the diagnosis of patients with potential AOD. Level II and III diagnostic and level III treatment recommendations are supported by the remaining medical evidence. The literature suggests that obtaining neutral cervical spine alignment in a child may be difficult when standard backboards are used. The determination that a child does not have a cervical spine injury can be made on clinical grounds alone is supported by Class II and Class III
medical evidence. When the child is alert and communicative and is without neurological deficit, neck tenderness, painful distracting injury, or intoxication, cervical radiographs are not necessary to exclude cervical spinal injury. When cervical spine radiographs are utilized to verify or rule out a cervical spinal injury in children < 9 years of age, only lateral and AP cervical spine views need be obtained. The traditional 3-view x-ray assessment may increase the sensitivity of plain spine radiographs in children 9 years of age and older. High resolution CT scan of the cervical spine provides more than adequate visualization of the cervical spine, but is not necessary in most children. CT and MRI are most appropriately used in selected cases to provide additional diagnostic information regarding a known or suspected injury (eg, CT for AOD) or to further assess the spine/spinal cord in an obtunded child. The vast majority of pediatric cervical spine injuries can be effectively treated non-operatively. The most effective immobilization appears to be accomplished with either halo devices or Minerva jackets. Halo immobilization is associated with acceptable but considerable minor morbidity in children, typically pin site infection and pin loosening. The only specific pediatric cervical spine injury for which medical evidence supports a particular treatment paradigm is an odontoid injury in children < 7 years of age. These children are effectively treated with closed reduction and immobilization. Primarily ligamentous injuries of the cervical spine in children may heal with external immobilization alone, but are associated with a relatively high rate of persistent or progressive deformity when treated non-operatively. Pharmacological therapy and intensive care unit management schemes for children with spinal cord injuries have not been described in the literature.

KEY ISSUES FOR FUTURE INVESTIGATION

Prospective epidemiological studies may be the best source of information that could lead to methods of prevention by identifying the more common mechanisms of spinal injury in children. Future studies involving pediatric cervical spine injury patients should be multi-institutional because of the small numbers of these injuries treated at any single institution. A prospective analysis defining the indications and methods for cervical spine clearance in young children (< 9 years of age) would be a valuable addition to the literature. The role of flexion and extension radiographs is poorly defined in the literature. A prospective evaluation of their sensitivity and specificity for spinal column injury in specific clinical scenarios would be a valuable addition to the literature. The incidence and clinical significance of complications of cervical spine injuries in children, such as syringomyelia and vertebral artery injury, are unknown and could be better defined by prospective study among investigators at multiple institutions.

More common injuries, such as odontoid injuries, should be studied prospectively in a randomized fashion (eg closed reduction and immobilization vs surgical stabilization/fusion). Prospectively collected data would provide the basis for case-control or other comparative studies to generate Class II medical evidence on these important topics.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

REFERENCES


