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TRAUMATIC SPINE INJURY

Emergency Neurological Life Support: Traumatic Spine Injury

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Abstract

Traumatic spine injuries (TSIs) are associated with significant short- and long-term neurological sequelae that may lead to high morbidity and mortality. Early critical care stabilization and interventions may mitigate some of the secondary sequelae of TSI. Key tenets of the rapid physical and medical stabilization are reviewed as well as recent data that suggest that early surgical decompression may have a role in improving the neurological outcome. The role of the intensivist/neurointensivist in the early identification of spine cord injury (SCI) and stabilization of the patient for definitive surgical intervention is emphasized. The prevention of the long-term complications of SCI is also reviewed.

Keywords: Spinal cord injury (SCI), Traumatic spine injury (TSI), Neurogenic shock, NEXUS, Canadian C-spine rules

Introduction

It is estimated that the annual incidence of traumatic spinal injury (TSI) in the USA is approximately 40 injuries per million adults. Estimates place the number of new cases per year to be between 12,000 and 17,500 [1]. The number of patients in the USA living with the long-term sequelae is about 285,000, but estimates range from 247,000 to 358,000. [2, 3] Mechanisms of spinal cord injuries are in order of frequency:

- Motor vehicle collisions (42%)
- Falls (27%)
- Violence-related acts (15%)
- Sports injuries (8%)
- Other causes (9%) [2, 3]

In over 50% of patients, injuries to the spine are isolated [4], while nearly 25% have concomitant brain, chest, and/or major extremity injuries [5]. The multi-trauma patient with concurrent spine injury poses a particular challenge because of the increased opportunities for secondary insults to the spine. For example, injuries to the chest, abdomen, or extremities may lead to hypoxia and hypotension which may adversely affect the injured spine. Thus, the critical care management of these patients in their first hours after presentation is important to stabilize the patient particularly if there is a plan for surgical intervention on the spine [6].

Though classically thought to be an injury of young males, recent epidemiological studies of patients with TSI depict a bimodal distribution. The first peak occurs in adolescents and young adults, as expected, however, the second peak occurs in the elderly population (age > 65 years) [7]. The patterns of injury are different in this latter group and will be discussed in more detail later [8].

The life expectancy for a patient who sustains a TSI is significantly lower than for the general population [1, 2]. There has been some improvement with advances in medical care and rehabilitation, but the average life expectancy continues to remain lower than expected and is profoundly affected by the degree and level of the injury [1, 3]. Average lifetime costs (in 2017 dollars) for a patient with TSI range from approximately $1,153,000 for a 50-year-old with an incomplete injury at any level, to $4,891,000 for a 25-year-old patient with high tetraplegia [1].

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Injuries to the spine tend to occur at areas of maximal mobility. Cervical injuries account for over 50% of traumatic TSIs and are associated with a much higher short- and long-term morbidity than injuries affecting the cord at the thoracic or lumbar level [9–11]. The most frequent injuries are incomplete tetraplegia (31%), followed by complete paraplegia (25%), complete tetraplegia (20%), and incomplete paraplegia (19%) [12].

Diagnosis

Traditional teaching to evaluate a blunt trauma victim is that medical personnel must assume the patient has a spinal column injury until proven otherwise. Recently, a number of organizations have suggested a change in the term "spinal immobilization" to "spinal motion restriction" and have suggested that spinal motion restriction, including the use of cervical collars and backboards, should not be used in patients at low risk of spinal column injury [13–15]. The change in terminology was proposed with realization that it is very challenging to accomplish true spinal immobilization, without any movement of the spine during the nursing and medical evaluation of a patient that sustained trauma. Spinal motion restriction reflects the true approach to patients with suspected TSI. Spinal motion restriction should be considered for patients with plausible blunt mechanism of injury and any of the following:

- Altered level of consciousness or clinical intoxication
- Focal midline spine/bony pain and/or tenderness
- Focal neurologic signs and/or symptoms (e.g., numbness and/or motor weakness)
- Anatomic deformity or step-off of the spine
- Distracting non-spine traumatic injury (i.e., concomitant orthopedic or intra-abdominal injuries, etc.)

While not typically considered for spinal motion restriction, some patients with penetrating trauma and/or active cardiac arrest may have spine or spinal cord injuries. Priorities may be different at this point, and concern is appropriately focused on airway, breathing and circulation issues to stabilize the patient. However, concern may be highest for gunshot wounds directed at the neck, middle of the back, or central chest [16, 17].

In a patient with any of the above risk factors, the spinal column should be restricted until an unstable injury can be excluded. In the prehospital setting, patients with risk factors for TSI are typically fitted with a cervical collar to provide cervical spinal column movement restriction, and patients are subsequently transferred to the hospital using spinal protection techniques. Different types of collars provide different amounts of restriction of movement [18]. Spinal protection techniques may include the use of a cervical collar and/or backboard to assist with transfer or transportation. Patients should be maintained in a supine position, using log-roll technique to assist with movement when necessary. If necessary, the head of bed may be elevated utilizing reverse Trendelenburg positioning via lowering the feet of the patient, or placing material under a backboard—but keeping the patient in a strict supine position. If the patient is intoxicated and uncooperative with medical evaluation, chemical sedation or physical restraints may be indicated to assure proper protection of the spinal column and, more importantly, the spinal cord. It is important to assess patient comfort and prevent pressure-related injuries, particularly in unresponsive patients while they are being transported from the scene to the ER or during inter-hospital transfers on long backboards. Older adults with cognitive impairment, noted to be a growing population of trauma victims, present unique challenges as chemical sedation can be problematic.

Once in the emergency department (ED), the immediate evaluation of a patient with a suspected cervical spinal injury is no different from any other trauma patient. The ABCs—airway, breathing, and circulation—take utmost priority. Generally, the diagnosis and treatment of the majority of spine injuries can be deferred to address other life-threatening injuries, such as hemorrhage or traumatic brain injury, as long as spinal protection is maintained. Clinicians should perform their primary survey, assessing the patient's ABCs and disability. Lastly the physician should fully expose the patient looking for signs of injury [19].

During the disability portion of the primary survey, clinicians should quickly perform a basic neurologic assessment. In trauma patients, this can be abbreviated to the patient's Glasgow Coma Scale (GCS), pupil size and reactivity, and ability to move all four extremities. If the patient is intubated before these three items can be assessed, it becomes more difficult to assess prognosis.

After the primary survey is conducted to assess for potential life-threatening injuries, the secondary survey should be completed. The secondary survey entails a complete head-to-toe evaluation, including a more thorough history of present illness (if possible to obtain). In the suspected spinal injury patient, the entire spinal column and paravertebral musculature should be examined for deformity and palpated in a search for areas of focal tenderness. Vertebral fractures or subluxations may cause step-offs appreciated via palpation of the spinal column or areas of focal tenderness along the midline of the back/neck. The presence of priapism in male patients, or loss of bowel and/or bladder control in any patient, should always prompt further investigation of TSI. As during the primary survey, spinal precautions should be maintained while evaluating the patient. When assessing the cervical spine, it may be safer for the front portion of the rigid cervical collar to remain on the patient, keeping the head and neck stabilized while a clinician slips their hand behind the neck to assess the spinal column [6, 14].

If transported on a backboard, the patient should be removed as soon as possible, ideally at the conclusion of the primary or secondary survey. Leaving a patient on the backboard can quickly lead to complications and additional pain. Pressure ulcers or deep tissue injuries can develop when the pressure applied to the skin is greater than the diastolic blood pressure. Studies have shown that skin breakdown can occur in as quickly as within the first hour [20–22]. Tissue injury is more likely in elderly patients, obese patients, those who are on harder surfaces, and those who have suffered hypotension. Additionally, in other studies, a lower Glasgow Coma Score, ICP monitoring, pain from the immobilization device, and a higher injury score have also been found to be risk factors for pressure ulcers [21, 22]. Pressure ulcers and deep tissues injuries have been associated with higher mortality rates, the need for costly medical treatments, and longer hospital stays. In addition to injuries related to the backboard, increased pain complaints from lying on a hard board can result in unnecessary imaging, along with elevated cost and additional radiation exposure risk [21, 22].

Who to Image

To avoid unnecessary radiation exposure, patients with low or moderate pre-test probability of cervical spinal injury should undergo evaluation with a clinical decision rule before imaging. Both the NEXUS criteria [23] and the Canadian C-Spine Rules (CCR) [24, 25] are widely used within clinical practice in the evaluation of patients with suspected cervical spine injuries.

National Emergency X-Radiography Utilization Study (NEXUS) Low-Risk Criteria (NLC)

In the NEXUS study, a clinical clearance protocol consisting of five criteria was validated with 100% sensitivity for the exclusion of cervical spinal injury [23]. The first criterion requires the practitioner to identify signs of intoxication in the patient. In the original study, this included the detection of the smell of alcohol on a patient. The second criterion requires the practitioner to assess for the presence of focal neurologic deficits. The third criterion is the identification of painful distracting injuries. A distracting injury has no specific definition in the NEXUS study, but examples in the study that prevented clinical clearance were:

- Long bone fractures
- Large lacerations
- De-gloving or crush injuries
- Large burn(s)
- Visceral injuries needing surgical consultation
- Any injuries producing acute functional impairment [26]

With the fourth criterion, the practitioner should assess whether the patient has a normal level of alertness. Specifically, there should be no delay or inappropriate response to external stimuli by the patient. Lastly, to assess the fifth criterion—presence of posterior midline tenderness to palpation—the physician should unhook the strap of the cervical collar and, with the anterior collar still in place, push on each vertebra, monitoring the patient for a response to pain. Using the NEXUS criteria, if no painful response is elicited, and the patient has met all prior criteria, the C-collar can be removed and C-spine imaging is not required.

Canadian C-Spine Rules (CCR)

The CCR does not preclude clinical clearance solely due to posterior neck tenderness [15]. It includes both high-risk and low-risk criteria that allow clearance in patients 18–65 years old (see http://www.mdcalc.com/canadian-c-spine-rule/). Although it is more complicated, the greater specificity of the CCR may allow additional patients to be cleared when compared to the NEXUS criteria [24, 25]. The presence of posterior neck tenderness may be one of the deciding points for which rule to choose. If the patient has posterior tenderness, NEXUS will not be usable, but the patient may still avoid imaging with the CCR.

In the CCR, the final stage of clearance is to have the patient rotate his or her head 45° to the left and right. The inability of the patient to perform this maneuver is an indication for further imaging. In further follow-up studies of the CCR, it has been shown to consistently demonstrate excellent sensitivity and negative prediction [27]. Though this stage was not a reported part of the NEXUS criteria, it is still recommended as an appropriate final step in clearance. During this portion of the evaluation, the clinician should remember that minimal pain during active range of motion may be experienced by the patient. However, if the action proves too painful to complete, ligamentous injury is a possibility and the C-collar should be left in place and advanced imaging pursued [24, 25].

Imaging

Historically, a 3-view cervical spine radiograph series was the standard initial evaluation for cervical spine injury [28, 29]. However, if imaging is deemed necessary by the clinician, The Eastern Association for the Surgery of Trauma (EAST) [30] and the American College of Radiology have recommended that computed tomography (CT) with multi-planar reconstruction should be the initial imaging modality [31, 32]. Implementation of evidence-based interventions (i.e., teaching sessions, posters, computerized decision support) has been shown to be effective in decreasing unnecessary C-spine imaging in the ED [33]. Patients with radiographic evidence of cervical spine injury should be screened for vertebral artery injury with either CT or MR angiography of the head and neck particularly if there are indications of vertebral foramina involvement. Recent studies have proposed that patients with a severe mechanism involving the neck should be screened for possible carotid and vertebral artery injuries [34, 35]. This is clearly an area where recommendations are being studied and are evolving.

If imaging is negative (radiograph or CT scan), the clinician should re-attempt to clinically clear the patient from the collar. If the patient continues to have persistent midline tenderness at the time of collar clearance, the collar should be left in place. If there is not any significant midline tenderness, the patient should be asked to range left and right 45° as mentioned above. If the patient is unable to range, the collar should be replaced. At this point, institutional protocol should dictate further imaging, consultation, or discharge in a cervical collar combined with appropriate region-specific follow-up (primary care physician, trauma surgeon, neurological surgeon, spine surgeon, etc.).

Clinical judgment must be used for the clearance of possible thoracolumbar (TL) spinal column injuries, as there are currently no validated guidelines. Focal tenderness over the TL spine, neurologic deficit, and high-energy mechanism are risk factors that have been identified to be associated with TL spinal column injuries [32]. Because of the increased rigidity of the cervical and thoracic spine in patients with ankylosing spondylitis (AS) and diffuse idiopathic skeletal hyperostosis (DISH), patients with these entities are at increased risks of having fractures. After a fracture, they have associated spinal cord injury (SCI) in 19–97.3% of the cases. It is important to have a high index of suspicion in these patients [36, 37].

Additionally, in patients with one vertebral column fracture, the presence of a second non-adjoining fracture has been estimated to have an incidence of up to 15%. As a result, when one vertebral fracture has been identified, it is recommended that the entire spinal column undergoes imaging to assess for concomitant fracture [38].

Motor and Sensory Examinations

If any neurological abnormalities are discovered during initial screening, a detailed neurologic examination of motor and sensory function at all spinal levels should be performed and the patient should be maintained with spinal motion restriction.

The neurological examination in any patient with suspected TSI should focus on the motor and sensory examinations, as well as rectal tone and perineal sensation findings. If the patient has abnormality in any of these areas, the lesion should be localized to the highest spinal level where dysfunction is noted. As a general guide, some of the commonly referred motor and sensory levels are:

Motor

- C4—deltoid
- C5—biceps
- C6—wrist extensors
- C7—triceps
- T1—finger abduction
- L2—hip flexors
- L3—knee extension
- L4—ankle dorsiflexion
- S1—plantar flexion

Sensory

- C4—deltoid
- T4—nipple
- T10—umbilicus

The levels above refer to the respective myotomes and dermatomes for these regions of dysfunction. A rectal examination is of utmost importance in any patient with a suspected TSI, as decreased or absent rectal tone may be the only sign of a TSI and helps differentiate complete from incomplete lesions, which is of vital importance in prognostication for recovery of function.

American Spinal Injury Association (ASIA) Scale

The full examination recommended by the American Spinal Injury Association (ASIA) (http://www.asia-spinalinjury.org) includes a detailed motor and sensory examination. It is the preferred evaluation tool as recommended by the American Association of Neurological Surgeons (AANS) and the Congress of Neurological Surgeons (CNS) [39].

ASIA also defines a five-element scale, the ASIA Impairment Scale (AIS), that is prognostic of neurologic recovery [3, 39–42]:

A. Complete—No motor or sensory function in the lowest sacral segment.
B. Incomplete—Sensory but not motor function is preserved in the lowest sacral segment.

C. Incomplete—Less than 1/2 of the key muscles below the neurological spinal level have grade 3 or better strength.
D. Incomplete—At least 1/2 of the key muscles below the neurological level have grade 3 or better strength.
E. Normal—Sensory and motor functions are normal.

Complete injuries, defined by absence of sensory or motor function below a spinal level, have a worse prognosis for functional recovery. One caveat is that in the setting of significant spinal shock, absence of sensation or function may be a manifestation of the spinal shock itself as opposed to the primary injury. Once the spinal shock resolves, incomplete injuries may become unmasked [43]. Incomplete injuries have a much better prognosis for functional recovery.

Syndromes

A number of discrete neurologic syndromes have also been described. The regional anatomy and the location of the insult to the spine dictate the neurologic findings. These are reviewed and the pertinent anatomy depicted and described in the publication of Diaz and Morales, 2016 [44]. If present, these syndromes help indicate the extent and nature of the injury:

- *Anterior Cord Syndrome (ACS)*—Described as a loss of pain, temperature, and motor function with preservation of light touch. It is caused by injury to the anterior spinal cord, commonly from contusion or occlusion of the anterior spinal artery. ACS is associated with axial compression causing burst fractures of the spinal column with fragment retropulsion [44].
- *Central Cord Syndrome (CCS)*—Described as a loss of cervical motor function with relative sparing of lower extremity strength. This is most often due to hyperextension injury, commonly seen in elderly patients with cervical stenosis or a posteriorly protruding calcified disk or osteophyte [45, 46]. It is usually not associated with a fracture, but with a "pinching" of the spinal cord between the posterior ligamentum flavum and the osteophytes that results in cord contusion or ischemia within the central part of the cord [47, 48]. The upper extremities are more profoundly affected than the lower extremities, and distal weakness is more profound than proximal weakness. This is because of the topography of the corticospinal tracts where the fibers for the hands/fingers are more centrally placed. The amount of damage to the laterally located corticospinal tracts is variable and determines the amount of lower extremity weakness [44]. CCS is the most common acute incomplete SCI. [48] An acute herniated disk may also result in a CCS. Figure 1 is an example of a patient that had the acute onset of CCS after an injury that resulted in a posteriorly protruding herniated cervical disk. Figure 2 is an example of a patient with multilevel cervical stenosis that is long-standing. The narrowing of the spinal canal and impingement on the spinal cord is noted. A mild fall can readily result in CCS with transient compression (usually with hyperextension) of the spinal cord that can result in significant symptomatology.

Fig. 1 MRI depicting an acute cervical herniated disc at C4-5. This leads to focal stenosis and signs and symptoms of a central cord syndrome after the patient had a fall

- *Brown-Séquard Syndrome*—Described as a hemiplegia with loss of ipsilateral light touch and contralateral pain/temperature sensation. This is due to traumatic hemisection of the cord. It is most frequently seen with penetrating cord injury, often from missiles or knife wounds, or a lateral mass fracture of the spine. It may also result from acute bleeding or an acute disk that is herniated laterally [49–51].
- *Posterior Cord Syndrome*—The symptoms include loss of proprioception, vibration, and touch sensation below the level of the injury. This can occur with posteriorly directed penetrating trauma that leads to damage of the posterior spinal artery [44].

Management

Initial Management in Confirmed or Suspected TSI

Once a fracture has been diagnosed, the patient should be maintained with spinal motion restriction during all treatments. As opposed to patients with spinal column

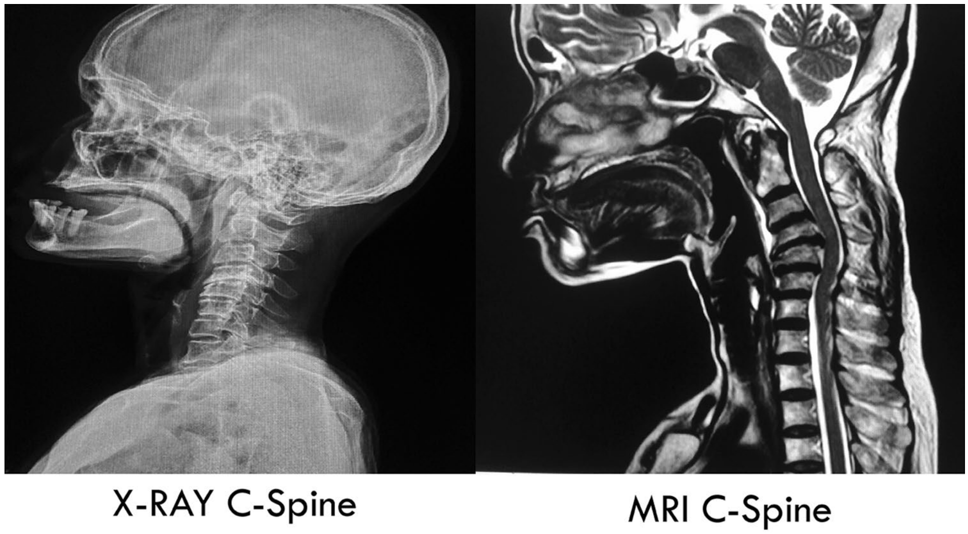

Fig. 2 Cervical spine stenosis with focal narrowing for central cord

injuries without deficit or patients with TL injuries, patients with cervical TSIs often have life-threatening issues that are a direct consequence of their spine injury. These issues require emergent attention and take priority in the acute management of these patients.

Airway

Patients with cervical TSI can be at exceptionally high risk of airway compromise due to a number of factors. Airway and soft tissue edema or hematomas from direct neck trauma and local bleeding can contribute to airway compromise. In patients with high cervical TSI (C3–C5), loss of diaphragmatic innervation, as well as loss of chest and abdominal wall strength, contributes significantly to a patient's inability to maintain adequate oxygenation and ventilation. Patients with high (above C3) complete TSI will almost invariably suffer a respiratory arrest within minutes of initial injury and, if not intubated by prehospital providers, typically present in cardiac arrest.

As a general recommendation, all patients with a complete cervical TSI above C5 should be intubated as soon as possible [52, 53].

Patients with incomplete or lower injuries will have a high degree of variability in their ability to maintain adequate oxygenation and ventilation. General parameters for urgent intubation include:

- Obvious respiratory distress
- Dyspnea
- Complaint of inability to "catch my breath"
- Inability to hold breath for 12 s [24]
  - (Have patient count as high as they can. Less than 20 is concerning for respiratory compromise)
- Vital capacity < 10 mL/kg or decreasing vital capacity
- Appearance of "belly breathing" or "quad breathing"
  - abdomen protrudes out sharply with inspiration
- pCO2 greater than 20 mmHg above baseline

When in doubt, it is better to electively intubate a patient with a cervical TSI than to wait until it must be performed emergently. Patients will typically develop worsening of their primary injury shortly after admission due to cord edema and progressive loss of muscle strength; therefore, vigilance in monitoring these patients for worsening of respiratory status is essential [6, 52]. Providers should consider monitoring stable appearing patients with end-tidal CO_2 for an objective measurement of their ventilatory adequacy. Table 1 provides some absolute and relative indications for urgent intubation in patients with an acute cervical TSI.

Generally, patients with cervical TSI who require non-urgent intubation should be intubated by an experienced provider using an awake fiberoptic approach or an in-line stabilization technique. This will minimize movement of the cervical spine and the risk of exacerbation of SCI in the setting of ligamentous or fracture instability. It will also allow for a neurological examination following intubation to document any changes. Patients who require urgent or emergent intubation should be intubated using rapid sequence intubation (RSI) [54]. Providers should strongly consider video laryngoscopy and/or airway adjuncts that help minimize cervical spine mobility, while

Table 1 Indications for intubation in patients with traumatic cervical spine injury

Absolute indications	
Complete SCI above C5 level	
Respiratory distress	
Hypoxemia despite adequate attempts at oxygenation	
Severe respiratory acidosis	
Relative indications	
Complaint of shortness of breath	
Development of "quad breathing" Paradoxical abdominal work of breathing	
Vital capacity (VC) of < 10 ml/kg or decreasing VC	
Consideration should be given	
Need to "travel" remote from ED (MRI, transfer to another facility)	

optimizing visualization of the vocal cords. The cervical collar should be removed with in-line stabilization carefully maintained, and extreme care must be taken to avoid hyper-extending the neck to minimize the risk of worsening the injury.

No particular RSI medication regimen is recommended, but it should be considered that many of these patients may already be vasodilated from loss of sympathetic tone. Therefore, medications that further diminish the catecholamine surge may result in exacerbation of hypotension and bradycardia [55–57]. Tracheal or laryngeal manipulation can also stimulate a bradycardic response in these patients, as can any degree of hypoxia [58]. Atropine and bolus dose phenylephrine should always be immediately available when manipulating the airway of a patient with an acute cervical TSI. Though traditionally avoided in patients with TSI due to the risk of hyperkalemia from depolarization [59], succinylcholine is safe to use in the first 48 h after injury, prior to up-regulation of acetylcholine receptors [60].

Breathing

Patients with cervical TSI are at high risk of inadequate oxygenation and ventilation due to a combination of factors [52]. High cervical TSIs result in loss of diaphragmatic function and can cause apnea. The chest wall and abdominal musculature that are so vital for effective ventilation are often severely compromised, even in patients with incomplete injuries. This results in hypoventilation and a significant inability to generate an effective cough to clear secretions. Aspiration, retention of secretions, and the development of atelectasis contribute to further respiratory decompensation. Providers should consider using end-tidal CO_2 monitoring while determining the need for intubation [54].

Concomitant injuries such as pulmonary contusions and pneumothoraces are often found in the polytrauma patient. Up to 65% of patients with cervical TSI will have evidence of respiratory dysfunction on admission to the intensive care unit (ICU) [61]. Supplemental oxygen should be supplied to all patients with cervical TSI to maintain an arterial saturation > 92%, as hypoxemia is extremely detrimental to patients with neurological injury. Appropriate pre-oxygenation should be employed prior to intubation. Hypoxemia can cause severe bradycardia in patients with high cervical TSIs due to unopposed vagal stimulation [58, 59]. Non-invasive methods of ventilation should be used with caution in this patient population, as the inability to cough and clear secretions may lead to an increased risk of aspiration.

Circulation

Patients with TSI above the T6 level are at high risk of the development of neurogenic shock [52]. The patient suffers an interruption of the sympathetic chain, resulting in unopposed vagal tone. This leads to a distributive shock with hypotension and bradycardia, though variable heart rates have also been described [62]. Bradycardia is a characteristic finding of neurogenic shock and may help to differentiate from other forms of shock. Care should be taken to avoid assuming that a patient has neurogenic shock because of a lack of tachycardia. Young healthy patients, elderly patients, and patients on pre-injury beta-blockers will often not manifest tachycardia in the setting of hemorrhage.

Patients with neurogenic shock are generally hypotensive with warm, dry skin, as opposed to patients with hypovolemic shock from hemorrhage. This is due to the loss of sympathetic tone, resulting in an inability to redirect blood flow from the periphery to the core circulation. However, in the patient with multiple injuries, other causes of hypotension, such as hemorrhagic shock or tension pneumothorax, can be present. These causes must be identified and immediately addressed [6].

As a general rule, the higher and more complete the injury, the more severe and refractory the neurogenic shock [63]. These signs can be expected to last from 1 to 3 weeks. Patients may develop manifestations of neurogenic shock within hours to days following injury due to progressive edema and ischemia of the spinal cord, resulting in ascension of their injury [64, 65]. Of note, the term "spinal shock" is not related to hemodynamics, but rather refers to the loss of spinal reflexes below the level of injury [65–67].

First-line treatment of neurogenic shock is always fluid resuscitation to ensure euvolemia [60]. The loss of sympathetic tone leads to vasodilation and the need for an increase in the circulating blood volume. Once euvolemia is established, second-line therapy includes vasopressors and/or inotropes [68] (Also see the *ENLS Pharmacotherapy* manuscript). There is currently no established recommended single agent, though potential agents include:

- *Norepinephrine*—Has both alpha and some beta-1 activity, thereby improving both peripheral vasoconstriction and inotropy, contributing to both blood pressure and bradycardia, and is most likely the preferred agent.
- *Phenylephrine*—A pure alpha-1 agonist that is very commonly used and easily titrated. Phenylephrine lacks beta activity, does not treat bradycardia, and may actually worsen the heart rate through reflexive mechanisms [60]. This is best used in patients with lesions below T6 in whom bradycardia is less of a concern.
- *Dopamine*—Also frequently used, but high doses (> 10 mcg/kg/min) are needed to obtain the beta effect. It does have significant alpha effects at lower doses. If lower doses are used, it may lead to inadvertent diuresis, exacerbating relative hypovolemia. Dopamine is associated with increased arrhythmic events in all patients, and increased mortality in patients with cardiogenic shock [69]
- *Epinephrine*—An alpha and beta-1,2 agonist that causes vasoconstriction and increased cardiac output. The high doses that may be required can lead to inadvertent mucosal ischemia. In most centers, epinephrine is rarely used or needed.
- *Dobutamine*—Can be useful, as it is a pure beta agonist and inotrope that can affect bradycardia, and may be helpful for treatment of hypotension if the loss of sympathetic tone causes cardiac dysfunction. Caution should be taken in patients who are not adequately volume loaded, as it may cause hypotension.

All inotropes and vasopressors may be administered through a peripheral IV in an emergency until definitive central access is established [6, 70].

The AANS and the CNS Guidelines for the Management of Acute Cervical Spine and Spinal Cord Injuries recommend maintenance of mean arterial blood pressure (MAP) at 85–90 mmHg for the first 7 days following acute TSI to improve spinal cord perfusion [71]. This is based on uncontrolled studies that demonstrated benefit in patients who were maintained with a MAP of 85 for 7 days following injury [43, 72]. Providers should maintain caution when inducing elevated blood pressure in patients with concomitant injuries, especially traumatic brain injuries [6, 73]. An overall risk/benefit analysis should be applied to each individual patient prior to reflexively starting or protocolizing an elevated MAP goal in a patient with a TSI.

Immobilization of Confirmed Injuries

Confirmed cervical spinal column fractures should be kept stabilized in a cervical collar with "log-roll" precautions off the backboard as discussed above until definitive management can be arranged. The initial goal of treatment should be to prevent further injury caused by spine motion with resultant worsening of neurologic outcome. An additional goal would be to minimize skin breakdown while maintaining spinal stabilization.

Studies have demonstrated that Philadelphia™ collars and Miami J™ collars are more effective than standard emergency medical services (EMS) collars in reducing cervical spinal column range of motion [18]. Miami J™ collars have also been shown to apply the least amount of pressure to the facial tissues of the patient compared to other cervical immobilizing collars [18]. Miami J™ collars are indicated for stable cervical spinal column injuries from C2 to C5. A thoracic extension can be added if immobilization is needed for a stable injury from C6 to T2. It should be noted that there is not a cervical collar that will prevent a determined or delirious patient from moving his or her head, potentially worsening injury. Agitated patients may require aggressive pain control and sedation to minimize mobility of the cervical spine.

Patients with spinal column injuries have historically been moved only with "log-roll" precautions once in the hospital, and this remains the standard of care in many centers. However, the method has been called into question by some practitioners given that significant movement of the spinal column can still occur. The High Arm In Endangered Spine (HAINES) method has been recommended by some clinicians given that it may minimize movement of the spine compared to the traditional log-roll method [15, 23]. With the patient lying supine, the knees are bent, and one arm is abducted to 180 degrees with the other arm across the patient's chest. With a clinician providing in-line stabilization while on the side of the patient with the arm across the chest, the patient can be gently rolled to his or her side, and a transfer device can be placed underneath the patient [74].

Definitive Treatment

The mainstay of treatment for TSIs is decompression of the spinal cord to minimize additional injury from cord compression by surgical stabilization of unstable ligamentous and bony injury. Traditionally, there has been a bias that patients with a complete (ASIA A) injury did not improve with early surgery. There were arguments that early surgical interventions on the injured cord actually worsened the neurological outcome because of spinal cord edema and systemic hypotension. However, several recent studies with early surgery (within 8–24 h of injury) have demonstrated improvement in neurologic outcome. The rationale for early surgery is to decrease injury from the compression and to improve the surrounding environment. This could speed and enhance the recovery [75, 76]. Bourassa-Moreau et al. found that patients with complete cervical spine injuries demonstrated more benefit from early surgery that those with complete TL injuries. They hypothesized that the forces needed to inflict a TL complete spinal injury were greater than in the cervical spine, thus the decreased recovery [77].

After the completion of the surgery, it is important to minimize the effect of secondary complications, such as venous thromboembolic disease, pressure ulcers, respiratory failure, and infections. Early consideration should be given to placement of indwelling urinary catheters, both to monitor volume status and prevent urinary retention [6, 52]. Once an indwelling urinary catheter is removed, the care team should initially perform frequent bladder urine volume assessments, and straight catheter for urine greater than 400 cc to prevent bladder distension and overflow incontinence [78]. Additionally, stress ulcer prophylaxis should be initiated early following injury, due to an increased risk of gastrointestinal bleeding in patients with cervical TSI [79–81]. There are few therapeutic options for the injured spine itself. Though there has been extensive research in the field, no neuroprotective therapy has been definitively proven effective in improving outcome following traumatic SCI [3, 60].

Steroids

The use of steroids following TSI was based on experimental work in animal models that suggested methylprednisolone (MP) has neuroprotective effects through an anti-inflammatory mechanism [82, 83]. This led to the National Acute Spinal Cord Injury Studies (NASCIS) trials. NASCIS II concluded there was efficacy of high-dose MP in patients who had received the drug within 8 h after injury [84, 85]. This was based on patient's experiencing neurologic improvement in 1–2 sensory levels from their original injury. As a result, this regimen quickly became the standard of care. However, there has been extensive debate and discussion about the validity of the results, as well as an inability to confirm the results in additional trials [85–89]. Moreover, extensive concerns have been raised about increased complications, such as pneumonia and gastrointestinal bleeding in patients treated with steroids following acute cervical TSI [90, 91].

Based on these circumstances, the most recent version of the AANS and the CNS' Guidelines for the Management of Acute Cervical Spine and Spinal Cord Injuries state: "Administration of MP for the treatment of acute 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. Other than the problematic NASCIS trial, there is no Class I or Class II medical evidence supporting the clinical benefit of MP in the treatment of acute TSI. 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." [72] An additional 15 medical societies have also stated that steroids should not be considered the standard of care after SCI.

Algorithm Section

The updated ENLS traumatic SCI algorithm is shown in Fig. 3. Given the necessary attention to airway, breathing and circulation, as well as spinal motion restriction, the detailed steps of the algorithm have been best described in the management section of this manuscript. A patient with a suspected SCI should be maintained in strict spinal motion restriction throughout their evaluation. Immediate attention to adequate airway protection, ventilation/oxygenation support, and shock prevention and treatment are paramount to the management of these patients. A thorough trauma secondary survey to evaluate for concomitant traumatic injuries is essential. Finally, clearance from spinal motion restriction as soon as medically feasible is recommended to allow for early mobility, as well as removal of unnecessary lines, indwelling tubes and devices (Tables 2, 3).

Unique Pediatric Considerations

TSI that occurs in children and adolescents who are still developing represents a different challenge than TSI in adults. An important distinction in children is that injury mechanisms and patterns of injury vary by age. In infants and young children, TSI is an appreciable portion of injury in inflicted, non-accidental trauma (iNAT), and may contribute to morbidity and mortality [92, 93]. Mechanisms of injury to the brain and spine from abusive etiologies involve a complex interplay between biomechanical forces and development stage. The infant's large head, in combination with weak neck muscles and shallow angles of the facet joints in the spine, leads to acceleration/deceleration rotational forces on the brain and neck from shaking alone, or in combination with, direct impact [94]. In children with iNAT, neurologic deficits on examination can often be mild despite evidence of significant brain and SCI on imaging. Greater than 60% of children with iNAT have evidence of spinal subdural

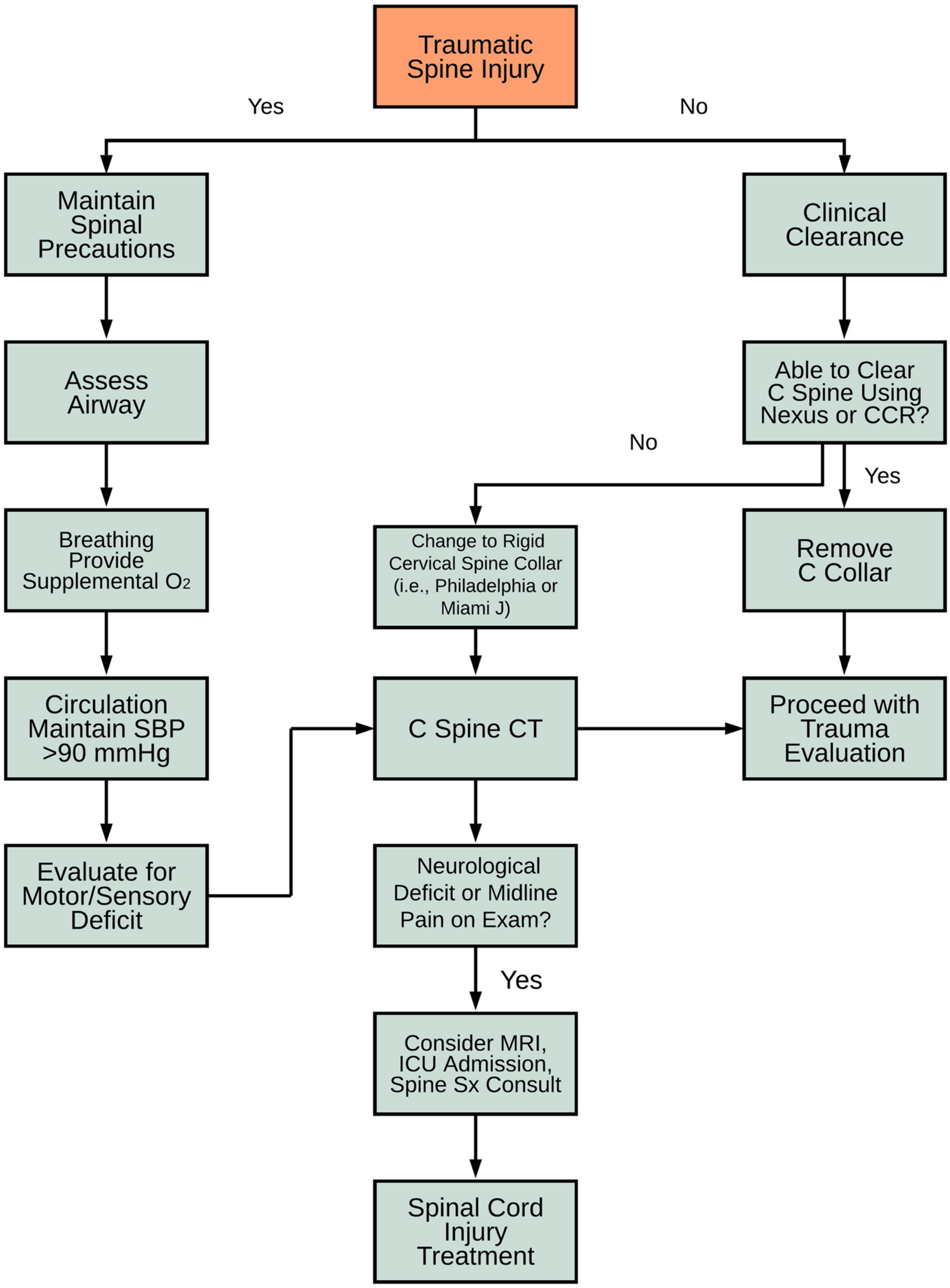

Fig. 3 ENLS traumatic spinal cord injury protocol

hematoma (SDH) on imaging compared to 1% of children with accidental traumatic brain injury, so this finding is highly suggestive of an abusive etiology [95].

Unique differences in anatomy (large head size and highly flexible spine) also predispose pediatric trauma patients to SCI without radiologic abnormality (SCIWORA). SCIWORA occurs in up to one-quarter of all pediatric SCIs, with a peak incidence in children under age 8 years [96]. Cervical spine injury commonly occurs from hyperextension mechanism that results in deformation of the spinal cord without fracture, leading to contusion or ischemia from temporary occlusion of the vertebral arteries, followed by return of the spine to its original position [97]. This condition should always be considered in children with neurologic changes, concern for TSI, or with an unreliable examination, in the absence

Table 2 Traumatic Spine Injury checklist for the first hour

Checklist
☐ Spinal motion restriction with cervical collar, and maintain spine precautions with "flat/bed rest" until seen by spine specialist
☐ Keep SBP > 90 mmHg with IV fluids and vasoactive medications as needed
☐ Administer supplemental O_2 if SpO_2 < 92%
☐ Consider early intubation for failure of ventilation per Table 1
☐ Rule out other causes of hypotension such as hemorrhage, pneumothorax, cardiac dysfunction Do not assume neurogenic shock

Table 3 Traumatic Spine Injury communication regarding assessment and transfer/referral

Communication
☐ Age
☐ Mechanism of injury
☐ Vital signs
☐ Basic neurologic examination including any sensory deficit, motor deficit, "level" of deficit, and rectal tone and sensation
☐ Additional traumatic injuries
☐ Interventions and medications administered including IV fluids and blood products administered and any vasoactive infusions with dose
☐ CT scan including location of fractures, displacement of fragments, dislocation and/or MRI scan including spinal cord signal change and ligamentous injury noted

of abnormalities on plain films or CT scan imaging [98]. Spine magnetic resonance imaging (MRI) is the most accurate imaging study for SCIWORA because of its superior ability to diagnose cord edema, hematomas and ligamentous injuries.

Motor vehicle collisions are the leading cause of TSI in children, followed by falls particularly in children younger than age 8 years, and sports-related injuries in adolescence [99]. Firearm injuries and other forms of violence in adolescents may also result in SCI. The vertebral column is more flexible in children 9 years old and younger, making the spinal cord more susceptible to injury, including an increased risk of atlantoaxial dislocation [94, 100–102]. Some genetic conditions in children (e.g., Trisomy 21, Klippel-Feil syndrome, skeletal dysplasias, and mucopolysaccharidoses) are associated with atlantoaxial instability due to odontoid hypoplasia or ligamentous laxity, which increases the risk of TSI. Children with underlying genetic diseases may have multiple pathologies that affect spine function.

There is no validated prediction rule for cervical spine imaging in children. Historical and physical examination findings that warrant imaging should include [103]:

- Altered mental status or GCS < 14
- Focal neurologic deficit
- Neck pain
- Torticollis
- Significant torso and other distracting injuries (e.g., visceral, orthopedic)
- Condition predisposing to SCI
- High-risk mechanism, including suspected or known child abuse

If the initial radiographs are inconclusive, spine motion should be restricted until SCI is reliably excluded with CT or MRI. Given concerns of radiation exposure, expert consensus advises that CT should be used sparingly in children. In children with TSI whose mechanism involves high-energy thoracic trauma, injury to the carotid or vertebral arteries should be considered. Angiography should be pursued in children with unexplained coma, ischemic changes on brain imaging, or clinical signs of stroke. Skull base fractures or several facial trauma is additional risk factors.

As is the case in adult TSI, there are no established neuroprotective treatments for pediatric SCI. Once the spinal trauma has been diagnosed, children should be treated like adults with spinal motion restriction. Children can be more challenging to maintain in a restricted position, and patient selection is important. Special attention to positioning is important, as the large head size pre-disposes young children to flexion of the neck. Careful selection of an appropriate-sized neck collar is also important to prevent skin lesions, inadvertent neck movement, or obstruction of the child's cerebral venous circulation. Clinicians should approach pediatric patients with the same algorithm as adult patients, with priority given to the airway, breathing and circulation, and avoidance of second insults that may aggravate the initial injury (i.e., hypoxia and hypotension). In children, blood loss sufficient to cause hypotension is generally not due to bleeding in the cranium, except in small infants in whom subgaleal hematomas can be life-threatening. Hypotension in children is defined as systolic blood pressure (SBP) below the 5th percentile for age or by clinical signs of shock. The 5th percentile for age of SBP can be estimated by: 70 mmHg + [2 × age in years]. While the optimal blood pressure range for children with SCI has not been established, SBP greater than the 5th percentile for age should be maintained, with similar considerations as with adults with concomitant brain injury. If necessary, an intravenous bolus of 20 mL/kg 0.9% sodium chloride solution should be administered as soon as vascular access is obtained. Subsequent doses of fluid should be guided by serial assessment of blood pressure, perfusion and hematocrit. Lack of compensatory tachycardia also occurs in children and is a useful way to differentiate neurogenic shock from hypovolemia. The initial approach includes surgical decompression in selective cases. The role of operative treatment, such as decompression and fusion, should be determined by a multidisciplinary team of pediatric specialists in trauma surgery, emergency medicine, neurosurgery, neurology, orthopedic surgery and critical care medicine. The main systemic complications of TSI in children include respiratory failure, hemodynamic instability, autonomic dysreflexia, pain, venous thromboembolism, psychological distress, neurogenic bladder and bowel, hypercalcemia and skin pressure ulcers. Early stabilization even in cases of complete SCI may be beneficial to facilitate early mobilization and maintain spinal alignment.

TSI in children can be complex and heterogeneous. Because of the need for multidisciplinary care of pediatric trauma patients, consideration for early transfer to a specialized pediatric center should be made early after initial systemic stabilization [104].

Prehospital Considerations

The evidence base for safe extrication techniques and the benefits of spinal immobilization in the prehospital setting is limited and largely dated [105]. Overall, systematic reviews have not confirmed the benefits of immobilization; therefore, a shift to the concept of spinal motion limitation is reasonable although clearly this is an area where more evidence is needed. In addition, it is unclear how much harm has been induced in recent years through strict adherence to immobilization through airway aspiration and soft tissue pressure injuries. Interestingly, standard extrication techniques emphasizing a lack of patient movement may induce more spinal disruption than directed self-extrication, but more prospective research on patients with acute injury is needed [106]. As noted above, patients may have concomitant injuries, comorbidities, and intoxicants. The prehospital providers must emphasize the safe and careful movement of these patients to definitive care. In short, the emphasis of care in the prehospital setting should emphasize protecting and when necessary securing the airway, ensuring adequate ventilation and maintaining adequate perfusion pressure. The emergence of airway adjuncts in the field, such as the iGel LMA, may allow for prehospital providers to temporize with interventions that put less strain on the neck than standard endotracheal intubation. As in the hospital, the emphasis should be on limitation of movement, and protection from secondary injury as opposed to the prior paradigm of strict "immobilization."

Nursing Considerations

It is anticipated that the patient will arrive via EMS or via triage with acute injury and will receive rapid imaging protocols to attempt to clear the patient from spinal precautions, yet some patients may now be medically cleared per updated guidelines. For those that remain on spinal precautions, frequent neurological, respiratory, bowel, bladder and skin integrity assessments must be maintained to identify and prevent advancement of spinal injury or secondary concerns. A systematic sensory/motor assessment should be completed to monitor the level of injury [107]. A dual registered nurses' handoff should be completed to ensure consistency of neurological assessment from one shift to another and during handoff between care locations (emergency department, surgery, post-operative care, intensive care, etc.) [108].

For cervical spinal involvement, central cord injury, or any spinal injury with concurrent traumatic brain involvement, a standardized bedside swallow evaluation such as the "Standardized Swallowing Assessment" should be completed prior to anything given per mouth. For failed swallow evaluations, the physician or representative should be made aware and the patient made NPO, until further testing can be completed by a speech language pathologist [107, 109].

In addition to the physical well-being of the patient during this traumatic insult, consideration must be made for any family accompanying the patient and the need to keep them informed of condition of the patient, particularly as it may be changing over time [110].

Special Considerations in the Elderly

Most statistics indicate that with an aging population, there are an increasing number of ground level falls. In most series, about 40–50% of these patients suffer brain or spine injuries. As discussed previously, a fall with a hyperextension injury is a common mechanism for central cord injuries. In fact, central cord injury is the most frequent incomplete SCI [44, 47, 48]. Another common cervical spine injury that occurs in the elderly from a ground level fall is a Type II Odontoid or Dens fracture. The osteoporotic neck of the odontoid process pre-disposes this region to fracturing. Also because it is in a "watershed" vascular territory, healing is problematic [8]. Different surgical techniques have evolved over the last two decades to treat these fractures. Anterior approaches have complications with swallowing and aspiration. Posterior procedures have issues with the placement of screws very close to the vertebral arteries [8, 111, 112]. Many have advocated long-term treatment in a rigid collar with a more sedentary existence. Because most of these occur with ground level falls, and because there is a good deal of space at the C1–2 region, these fractures may be missed as the patients may not have neurological deficits. Their only symptom may be neck pain. This is deceptive as inappropriate movement of the fracture site may lead to impingement on the brainstem [113]. Proper limitation of spinal mobility starts with a rigid collar [8, 114]

Clinical Pearls

- The economic impact of a spinal cord injury is tremendous. Improvement in neurological outcome by the avoidance of secondary insults may have significant social and emotional benefits for the patient in the long term
- There are classic neurological examinations that are expected with specific spinal cord syndromes such as central cord, anterior cord, posterior cord, and Brown–Sequard. Recognition of these and their natural histories are important in the planning of therapies and treatment paradigms
- Newer studies have demonstrated that there is improved neurological outcome with early surgical decompression and stabilization (8–24 h) after the injury. This seems to be applicable in the cervical spine than the thoracolumbar spine
- Pediatric considerations: the anatomy of the pediatric patient is different than adults. The larger head relative to the spine and body lead to occipital-atlanto dislocations which may have devastating consequences. Recognition of this possibility is important in the initial stabilization and immobilization of these patients after an injury
- The ASIA grading scale for spinal cord injury is important in allowing one to follow the progression or improvement of patients with spinal cord injury. The initial evaluation is particularly important as prognosis and interventions may be planned based on the ASIA score. This scale is used in many clinical trials for spinal cord injury and is used to assess the potential effects of the agents tested

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* Important papers
** Landmark papers

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