Chapter 4
Neurosurgical Management of Spinal Cord Injuries in Athletes

Frank A. De Stefano, William J. Steele III, and Allan D. Levi

Epidemiology

Spinal cord injury (SCI) is a transient or permanent injury that affects sensory, motor, or autonomic function leading to neurological impairment or disability. SCI involving axon damage is mostly irreversible due to the non-regenerating properties of the central nervous system (CNS). Limited neuron growth, absence of neurotrophic factors, the involvement of CNS-related inhibitory factors, and glial scar development contribute to the poor prognosis of such injuries [2]. The United States reports the highest incidence of SCI with an estimated 906 cases per million. SCI is disproportionately more common in males below 30 years of age [3]. An estimated 7% of all new SCIs diagnosed each year are due to athletic activities in the United States [1]. Figure 4.1 demonstrates the percentage of SCI that occurs in each sport in comparison to the total sports-related SCI reported. Due to its higher level of interest, a common misconception exists that injuries of the spinal cord occur at a higher rate in organized sports, such as football, hockey, and rugby. Nonorganized sports, such as skiing and free-diving, have significantly higher rates of these injuries in comparison to organized sports [4]. In this section, we will discuss common injuries of the spine and spinal cord in athletes and their respective management.

F. A. De Stefano
School of Medicine, Kansas City University, Kansas City, MO, USA
e-mail: fdestefano@kansascity.edu

W. J. Steele III · A. D. Levi (✉)
Department of Neurosurgery, University of Miami Miller School of Medicine, Miami, FL, USA
e-mail: wjs98@med.miami.edu; alevi@med.maimi.edu

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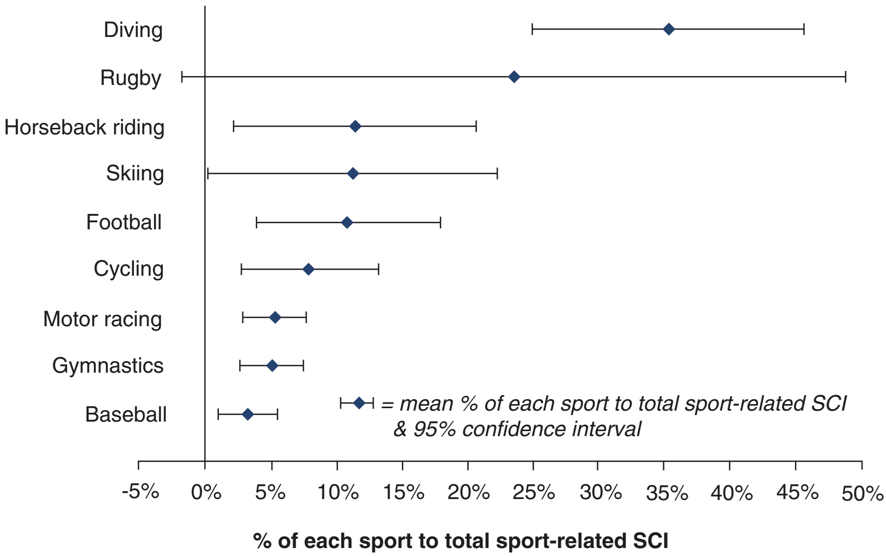

Fig. 4.1 Percentage of SCI as a percentage of all sports-related SCI reported worldwide. (Figured provided courtesy of Taylor and Francis Group [5])

Pathophysiology

Four main types of traumatic forces exist that can result in SCI: impact with persistent compression, impact with transient compression, distraction, and laceration/transection. Impact with persistent compression is most commonly seen in vertebral burst fractures or fractures resulting in dislocation. It is important to note that hyperextension forces typically result in an impact with transient compression. This type of force vector is a common cause of injury in contact sports [6, 7]. SCI occurs most often in the cervical region (53%), followed by thoracic (35%) and lumbosacral areas (11%). Concerning sports-related SCI, the cervical region is disproportionately affected in sports with the highest incidence of SCI [5]. Positioning of the cervical spine during impact is critical in its capability of dissipating axial forces applied at the head during impact. Flexion of the cervical spine during this force of impact is particularly vulnerable to fracture or dislocation, resulting in the most common cause of SCI [8]. The thoracic spine provides the highest structural integrity of the spinal column. High-impact forces are necessary to produce unstable injury. This integrity is, in part, due to support from costotransverse articulations and ligamentous attachments. In the thoracolumbar spine, the relatively narrow spinal canal and transition to more mobile vertebrae place the spinal cord at increased risk of injury with fracture/dislocation.

Two different pathomechanisms, primary and secondary injury, contribute to neurologic recovery and overall prognosis. The primary injury in SCI is a direct result of the mechanical forces applied to the cord during trauma. These forces disrupt vascular supply and directly damage neurons and supporting glia, resulting in cell dysfunction and possible death. The immediate cascade of pathologic events resulting from a primary injury is referred to as secondary injury. Cell dysfunction results in failure to maintain cell membrane integrity and metabolic requirements resulting in edema, inflammation, and apoptotic signaling pathways [9]. The resulting recruitment of inflammatory cells can lead to further permanent damage. It is critical to recognize and treat both pathomechanisms of SCI to improve neurologic recovery and prognostic outcomes.

Initial Evaluation and Management of Sports-Related Spinal Cord Injuries

The rapid, on-field assessment of the athlete suspected of traumatic SCI is strictly performed by qualified athletic staff or first responders. Trauma to multiple organ systems should be considered when evaluating suspected SCI due to the large impact forces needed to produce these injuries. The protocols for initial care in suspected SCI do not diverge from any other trauma scene. It is critical to assess the patient using Advanced Trauma Life Support (ATLS) guidelines, classically known as the ABCD's of trauma support: Airway maintenance, Breathing, Circulation, Disability (Neurologic Evaluation) [10]. Growing evidence suggests that up to 25% of SCI occur after the traumatic event, suggesting the spinal cord is extremely vulnerable to injury during transportation and medical care following suspected SCI [11]. Any patient with suspected SCI or injury that could potentially damage the spinal cord should be immobilized with a focus on moving the patient as minimal as possible. Steps to help with this include the immediate use of a rigid cervical collar, backboard with straps, and the log-roll method when transportation of the patient is necessary (Fig. 4.2) [12].

Fig. 4.2 Proper immobilization for suspected SCI. (Photo: XCollar Co. Ltd., all rights reserved)

In sports that require helmet and shoulder pads, it is advised to keep both pieces of equipment on the player until fracture can be ruled out with radiographic imaging [13]. If removing equipment from the player is necessary, removal of both pieces is recommended. Proper technique to remove equipment is critical to limit motion of the spine and prevent further injury. The chin strap and face mask should be removed first before removing the helmet. During removal of the helmet, manual inline stabilization of the cervical spine is necessary to restrict motion. Padding should be immediately placed under the athlete's head to decrease hyperextension during removal of the shoulder pads. Athletic trainers and medical staff are encouraged to practice equipment removal to better prepare for traumatic SCI during sporting events.

Classification of Spinal Cord Injuries

A full neurologic evaluation of the athlete with suspected SCI is critical in determining the course of acute medical management. Along with this, initial neurologic impairment is highly correlative with the degree of neurologic injury and prognostic outcome for the patient. Many classification tools have been proposed over time taking into consideration the anatomic location of the injury, initial neurologic deficits, and mental status at the time of injury. In 1984, the International Standards for Neurological Classification of Spinal Cord Injury (ISNSCI) produced a classification system for acute SCI to better assess neurological outcomes. The American Spinal Injury Association (ASIA) standard (Table 4.1) is a classification tool used to define neurologic levels of impairment and extent of injury in acute SCI. With its latest revision in 2013, this protocol is recommended in all patients with acute SCI at hospital admission. The ASIA Impairment Score (AIS) determines the level of neurological injury to be the most caudal spinal cord segment with intact motor and sensory function [14].

Table 4.1 American Spinal Injury Association (ASIA) assessment protocol

Grade	Impairment	Details
A	Complete	No sensory or motor function preserved in sacral segment S4–S5
B	Sensory incomplete	Sensory function is preserved below neurological level and includes sacral segments S4–S5. Motor function is not preserved
C	Motor incomplete	Motor function is preserved below the neurological level. Greater than 50% of key muscles below the neurological level have muscle grade < 3
D	Motor incomplete	Motor function is preserved below the neurological level. Greater than 50% of key muscles below the neurological level have muscle grade ≥ 3
E	Normal	Absence of any sensory or motor function deficit

Complete Spinal Cord Injury (AIS A)

Complete SCI results in both sensory and motor function deficits bilaterally below the level of the injury resulting from a complete disruption of the spinal cord pathways at any level. From 1973 to 2013, complete SCI composed 43.1% of all sports-related SCI in the United States [15]. Complete SCI illustrates the most severe level of injury and neurologic deficit. Depending on the neurological level, these patients can present with immediate death, respiratory failure (C3 and higher), autonomic instability, or bowel and bladder incontinence. Neurologic recovery and prognosis from complete SCI remains poor. Patients diagnosed with AIS A injuries have an 8.3% probability of walking independently at 1-year follow-up [16].

Incomplete Spinal Cord Injury (AIS B-D)

Injury resulting in any amount of preserved motor or sensory function below the neurologic level is classified as an incomplete SCI. An important diagnostic criterion differentiating incomplete from complete is the preservation of sensory function in sacral segments S4–S5. Several subtypes of incomplete SCI are described based on the anatomic location of injury: cervicomedullary syndrome, central cord syndrome, Brown–Séquard syndrome, anterior cord syndrome, and posterior cord syndrome. Each subtype of incomplete SCI varies greatly by the inflicting injury, typical neurologic deficit pattern, and prognosis. In clinical practice, patients typically present with mixed subtype presentations.

Early Medical Evaluation and Treatment

Management of patients with acute SCI is necessary in the neurologic intensive care unit (ICU) due to hemodynamic instability, need for continuous neurologic monitoring, and treatment for other injuries. Studies validate that early transfer to the ICU, rapid diagnosis, and management of systemic impairment mitigates further spinal cord damage due to secondary injury [17]. Interview of the patient and informants, physical examination, and vitals should be performed as soon as possible with great caution when moving or examining the patient. Physical examination should include a thorough inspection of the head, axial spine, and extremities. Documentation of any focal neurologic deficits, tenderness, structural abnormalities, or gross injuries is recommended. AIS grading, described earlier, is recommended in all patients with acute SCI within 72 h of admission. It is important to note that AIS grading may be unreliable up to 48 h postinjury due to transient manifestations of spinal shock [14]. Clinical factors that should raise suspicion of SCI include focal tenderness on the spinal column, weakness or numbness of the extremity, bowel or bladder incontinence, loss of consciousness during inciting event, or substance intoxication. It is important to note that 50% of patients with a Glasgow Coma Scale (GCS) less than 8 have been later found to have evidence of cervical spine injury [18]. Unfortunately, guidelines do not exist in the clearing of SCI in unconscious, sedated, or intubated patients and rely solely on radiographic imaging.

Neurogenic shock is a life-threatening sequela due to the disruption of autonomic innervation that maintains hemodynamic stability. Suspicion of neurogenic shock should be raised in injuries of the upper cord, with this form of shock occurring in 19.3% of cervical SCI and 7% of thoracic SCI [19]. It requires immediate recognition and should be distinguished from other causes of shock such as hypovolemic shock due to blood loss. Patients with neurogenic shock present with sudden hypotension, regular or irregular bradycardia, warm extremities, and possible priapism. Medical treatment should focus initially on blood pressure elevation utilizing intravenous fluids as first-line therapy followed by vasopressors for refractory cases [20]. Intravenous phenylephrine and norepinephrine have been described as viable options in the literature, although comparative data investigating outcomes has not been elucidated. Mean arterial pressure greater than 90 mm Hg for a minimum of 7 days post-injury is recommended to allow for adequate perfusion to the spinal cord [21]. Atropine in the treatment of bradycardia is recommended to improve bradycardia.

Respiratory complications are a major factor contributing to high morbidity and mortality in patients with SCI. The C3–C5 nerve roots are responsible for innervation of the diaphragm, the primary inspiratory muscle of the lungs. The diaphragm, along with the intercostal muscles, is the primary driver of inspiration. While expiration is primarily a passive movement, paralysis of the abdominal muscles in SCI can hinder full expiration cycles. Respiratory failure due to cervical SCI requires immediate intervention to establish an airway and support breathing. Flaccid paralysis of the intercostal muscles and diaphragm during spinal shock significantly reduces thoracic cavity volume and inspiratory drive resulting in an estimated 70% of forced vital capacity and 60% of maximal inspiratory force, respectively [22]. Fortunately, rebound spasticity allows for some return to baseline dynamics. Unopposed cholinergic activity resulting from neurogenic shock results in increased mucus production with ineffective clearance due to ciliary muscle paralysis. It is critical to take into consideration the many pathophysiologic factors that contribute to respiratory failure in patients with SCI to prevent hypoxemia and worsening of spinal cord ischemia.

Up to 84% of patients diagnosed with cervical SCI and 65% of patients with thoracic SCI experience respiratory complications post-injury, with atelectasis (36.4%), pneumonia (31.4%), and respiratory failure (22.6%) being the most common [23]. One-third of patients with cervical SCI will require endotracheal intubation with ventilator support. Indications for imminent respiratory failure include a reduction in respiratory vital capacity to less than 1 L, increasing respiratory rate, and a rising arterial PCO_2 [24]. Tracheal intubation techniques are variable in clinical practice and should take into consideration the instability of the spinal cord in patients with SCI. Traditional full extension of the atlanto-occipital and atlanto-axial joints has potential to cause iatrogenic injury to the spinal cord. A systematic review investigating outcomes of different intubation methods concludes that direct laryngoscopy results in increased adverse events and intubation should be performed utilizing a videolaryngoscope or fiberoptic assistance [25]. Ventilator-acquired pneumonia (VAP) is a common cause of mortality in patients requiring prolonged intubation. The risk of developing VAP increases by 1–3% per day of intubation with mortality as high as 43% due to the specific pathogen [26]. It is critical to start empiric antibiotic treatment in patients with new-onset fever, increased secretions, and leukocytosis. It is important to stress that critically-ill patients may have an equivocal presentation with VAP and should be monitored closely. Patients with SCI may require ventilator support for multiple weeks but should be weaned from ventilator support as soon as possible to reduce complication rates. Parameters suggestive of successful weaning include increased forced vital capacity, $FIO_2 < 50\%$, and minute ventilation <10 L [27].

Neurogenic bladder is a common sequela of spinal cord injury. Spinal shock following SCI results in inactivation of the parasympathetic nervous system efferents (S2–S4) with loss of the micturition reflex. Loss of innervation to the bladder results in detrusor muscle hypoactivity and urinary retention. Stasis of the bladder puts the patient at increased risk for renal failure, urinary tract infection (UTI), and urosepsis. Proper bladder management is critical to prevent these complications. Clean intermittent catheterization is recommended for urinary retention using hydrophilic-coated catheters to mitigate the risk of UTI [28]. The use of prophylactic antibiotics to prevent UTI has been debated in the literature. A recent meta-analysis investigating the risks and benefits of prophylactic antibiotics concluded there is insufficient evidence for their use in most patient groups [29].

The use of methylprednisolone sodium succinate (MPSS) in the management of acute phase SCI to prevent or reduce secondary injury is controversial and has been extensively debated. Studies have suggested its inefficacy as a treatment option for acute SCI when taking into consideration the complications that may arise from its use [30]. It is important to note that MPSS is used exclusively off-label as current FDA guidelines lack an indication for its use in the treatment of SCI. 2013 AANS/CNS guidelines do not recommend the use of MPSS in the treatment of acute SCI [31].

Systemic hypothermia is a modality recently proposed in the literature for acute management of cervical SCI with growing research for its use in all SCI. Systemic hypothermia involves cooling methods to reduce the intrathecal cerebrospinal fluid temperature. The use of hypothermia is implemented to reduce the damaging effects of both primary and secondary injuries. Preclinical and clinical data suggest the use of hypothermia playing an effective role in reducing vasogenic edema, excitotoxic metabolites, and decreasing the metabolic demand of the injured tissue. Earlier methods to induce hypothermia included surface cooling utilizing ice packs applied to the groin and axilla, cooling blankets, and lowering the environmental temperature of the patient. Newer methods have proposed intravenous infusion of chilled saline and intravascular heat exchange cooling catheters.

Preclinical data have demonstrated the following parameters produced favorable neurologic outcomes when initiating systemic hypothermia: modest targeted temperatures (32–34 °C), the onset of treatment to injury less than 8 h, treatment lasting 48 h, and gradual rewarming (0.5 °C/6 h) [32]. Levi et al. proposed an endovascular cooling procedure utilizing central venous femoral cooling catheters to achieve modest systemic hypothermia of 33 °C for an average of 47.6 h. Investigation of this method on 14 patients with cervical SCI found that 6 patients improved one AIS grade or greater at 1-year follow-up. Along with this, the study found no significant increase in complication rates in comparison to historical data, suggesting it is relatively safe to consider in patients [33]. A 2010 case report highlighting the use of systemic hypothermia in a professional football player suffering from complete (AIS A) cervical SCI showed rapid neurologic improvement and long-term recovery [34]. A multicenter trial to evaluate the safety and efficacy of systemic hypothermia for the acute treatment of cervical SCI is ongoing.

Imaging

Cervical plain film radiographs are still regarded as acceptable initial imaging when clinical suspicion of SCI is low. However, noncontrast-enhanced computed tomography (CT) has recently become the preferred initial imaging modality in patients with suspected SCI due to its availability, speed, and cost. CT dramatically outperforms plain film in detecting fracture or dislocation with a sensitivity of 100% and 63%, respectively [35]. CT is capable of detecting large soft tissue lesions such as disk herniation and epidural hematomas of considerable size. Unfortunately, CT lacks in delineating soft tissue structures or ligamentous injury in comparison to magnetic resonance imaging (MRI).

MRI is the superior imaging modality in the assessment of the spinal cord and soft tissue in comparison to plain film or CT. Due to the cost and time needed for acquisition, clinicians should have a high suspicion of ligamentous or neural damage before ordering and expect to gain valuable insight with this study. 2013 AANS/CNS guidelines suggest a level III recommendation for the use of MRI in the following scenarios: cervical fracture–dislocation injury that cannot be examined before closed reduction or failed closed reduction, decision-making to discontinue immobilization in awake, symptomatic patients or obtunded patients, diagnosis of atlanto-occipital dislocation or SCI with normal/equivocal findings on CT, evaluation of cord/nerve root compression and ligamentous injury, or predict outcomes in pediatric patients with SCI [36]. Spinal cord injury without radiographic abnormality (SCIWORA) is seen in up to 19% and 14% in children and adults, respectively. It is important to recognize the shortcomings in CT for the detection of SCI. Due to this, patients with focal neurologic deficits and negative or equivocal CT findings should undergo MRI as soon as possible for further work-up [37].

Typical MRI protocol for evaluating SCI includes T1-weighted, T2-weighted, and short tau inversion recovery (STIR)-weighted techniques. The presence of edema, hematoma, herniation, or loss of continuity should raise suspicion for

SCI. Findings supportive of urgent surgical intervention include ligamentous injury resulting in instability of the spinal column and reversible compressive forces such as disk herniation or hematoma. Operations to stabilize the spinal column or decompress the canal may result in immediate resolution of neurologic deficits and should be urgently considered. Sagittal T1-weighted MRI provides sufficient coverage for an overview of anatomical and structural findings of the spinal cord. Spinal cord edema and ligamentous injury are best visualized as hyperintensity foci on T2-weighted MRI with adequate fat suppression or STIR techniques. Evidence of hemorrhage is time-sensitive based on the hemosiderin composition of the hematoma at the time of imaging. Hematoma within 1 week of injury is best visualized on T2-weighted imaging and described as hypointense [35]. Although MRI is the preferred imaging modality in the detection of soft tissue injury and SCI, cases have been reported in the literature of MRI failing to detect these lesions. Diffusion-weighted imaging (DWI) and diffusion tensor imaging (DTI) are newer modalities shown to have higher sensitivity in detecting SCI and possible prognostic information. However, their use is limited in today's clinical practice.

Indication for Closed Reduction with Traction

Cervical facet dislocation is imperative to recognize early in the management of SCI and typically results from flexion–distraction forces. Failure of the posterior ligamentous structures and fracture of the vertebral articular processes are common radiographic findings in cervical facet dislocation. Both unilateral and bilateral cervical facet dislocation commonly result in complete and incomplete SCI. There is an ongoing debate regarding the method (open vs. closed) and the timing of reduction attempts in the current literature. However, closed reduction with traction is safe and effective for realignment of the spinal canal due to cervical fracture, dislocation, and subluxation [38]. Closed reduction can be successfully performed using Gardner-Wells tongs or halo ring. It is important to note that evidence of skull fracture or patients with altered mental status is an absolute contraindication for closed reduction. Weight recommendations for traction after reduction should take into consideration the severity of the dislocation, manufacturer recommendations, and the likelihood of subsequent open reduction interventions. It is also imperative that closed reduction be performed strictly at institutions capable of performing emergent surgery in case of patient deterioration or new-onset neurological deficits.

Surgical Considerations for Acute SCI

Surgical intervention may be a necessary treatment option for acute SCI to decompress the spinal cord, stabilize the spinal column, and reduce dislocations or fractures. A primary goal of surgical intervention is restoration of spinal canal anatomy by removal of bone, hematoma, or foreign bodies that may impinge the spinal cord.

Evidence-based guidelines for surgical management of acute SCI still are not fully established due to the multifactorial approach needed in patients with suspected SCI. Surgery should be considered on a case-by-case basis taking into account the patient's neurologic status, anatomic location of pathology, imaging findings, and other comorbidities. Optimal timing from injury to decompression and this timing's effect on prognostic outcomes remain elusive. A systematic review by Fehlings et al. found class II evidence supporting surgical decompression within 24 h of injury as safe and effective for the treatment of SCI. It was also found that urgent surgical intervention is recommended in all patients with SCI and neurologic deterioration or with cervical SCI and evidence of bilateral locked facets [39]. For other cases, it is important for the surgeon to have a clear benefit in pursuing surgery. Surgical considerations unique to the anatomic location of injury are discussed below.

It is practical to subdivide the cervical spine into upper (occiput-C2) and lower (C3-C7) when considering surgical intervention due to anatomic variation, degree of freedom, and intrinsic stability. The upper cervical spine allows high freedom of motion due to the lack of osseous restriction with stability achieved primarily through ligamentous support. The atlanto-occipital joint allows for up to 50% of flexion and extension in the cervical spine with stability achieved primarily by the anterior and posterior atlanto-occipital membranes. The atlantoaxial joint allows for up to 60% of cervical rotation with stability achieved through the transverse atlantal ligament. Injuries of the upper cervical spine rarely manifest with SCI due to the relatively large spinal canal space. Disruption of these ligaments can result in severe instability refractory to non-operative immobilization. Osseous architecture and ligamentous structure both contribute significantly to the stability of the lower cervical spine. The spinal canal narrows caudally resulting in a greater risk of spinal cord impingement with compressive or translational force. Due to the anatomical design, lower cervical spine injuries present with neurologic injury at far greater rates than the upper cervical spine.

Injuries resulting in occipitocervical dislocation present with severe instability and rapid fatality in some circumstances. Along with the neurologic injury, injury to the vertebral artery should be considered and investigated. Non-operative stabilization techniques in this region should not be considered due to the level of instability resulting from ligament disruption. A posterior approach for stabilization and fusion is recommended utilizing an occipitocervical arthrodesis with rigid internal fixation. The transverse atlantal ligament provides the most stability for the C1–C2 region. Forces result in disruption of the transverse atlantal ligament commonly present with fracture of the C1 or C2 vertebrae. The decision model for surgical treatment with this injury diverges on the location of disruption based on radiographic evidence. Type 1 injuries are described as purely ligamentous injury located at the midportion (IA) or laterally at the periosteal insertion (IB). Due to this, non-operative immobilization is not sufficient and stabilization via C1–C2 posterior arthrodesis is recommended. Type II injuries involve ligamentous injury along with evidence of comminuted fracture (IIA) or avulsion fracture (IIB) at the C1 lateral tubercle. Regarding type II injury, one study demonstrated a 75% healing rate using non-operative immobilization techniques using halo orthosis [40]. Nonoperative stabilization is a viable option that should be initially considered in patients with type II injuries.

Injuries of the lower cervical spine and their management are defined by the causative forces inflicted on the area. Forces seen most include compressive flexion, compressive extension, and distractive flexion. Compressive flexion injuries occur due to a combination of axial and flexile load applied through the head. Radiographic evidence suggesting subluxation, posterior ligament disruption, injury to the anterior column of the vertebral body, or facet injury suggests instability. Alignment in the sagittal plane is key in determining the surgical approach. The presence of alignment allows for an anterior approach with discectomy +/− corpectomy and fusion. In cases with malalignment or evidence of posterior facet damage, a posterior approach may be recommended. Distractive flexion injuries routinely present with serious neurologic deterioration and almost always require immediate surgical intervention. Such forces cause bilateral or unilateral facet dislocation with or without the presence of rotational forces. The severity of injury results from the failure of posterior ligamentous structures. Initial management of distractive flexion injuries is to restore alignment using closed reduction with traction. An anterior approach for decompression and stabilization is recommended if the proper alignment was attained following reduction attempts. In cases of failed alignment, a posterior approach may be necessary. Distractive extension injuries primarily occur due to disruption of the anterior longitudinal ligament, allowing for a widening of the anterior disk space resulting in a central cord syndrome. Patients without significant cervical stenosis tend to recover spontaneously, and surgical intervention is not required if stability is maintained. Evidence of instability should be treated surgically and focuses on restoring the anterior tension band through reconstruction and plating techniques.

The thoracolumbar junction (T10–L2) is a unique transition zone of the spinal column that is particularly vulnerable to SCI, occurring in 50% of all SCI [41]. Determination of complete or incomplete SCI is recommended initially. Surgical efficacy with complete SCI is minimal regarding future neurologic recovery and should generally be reserved to restore alignment or palliation [42]. In contrast, patients with incomplete SCI were found to have greater neurologic recovery when undergoing surgical decompression and stabilization [43]. Many classification systems have been proposed in the literature to categorize fractures of the thoracic and lumbar spine, although a single system is not universally accepted. Denis et al. constructed a system to classify thoracolumbar injuries by dividing the spine into three anatomical regions: anterior column (anterior longitudinal ligament and anterior two-thirds of the vertebral body), middle column (posterior longitudinal ligament, posterior one-third of the vertebral body, posterior vertebral wall), and posterior column (all ligaments and osseous structures posterior to the posterior longitudinal ligament). Surgical indication guidelines based on evidence of injury to these areas have been proposed and include injury to all three columns: 50% reduction in vertebral body height with evidence of posterior column ligamentous injury, any fracture–dislocation injury, and any indication of incomplete SCI [44, 45].

Table 4.2 Thoracolumbar Injury Classification and Severity (TLICS) score [46]

Injury parameter	Point value
Injury morphology	
Compression	1
Burst	2
Translation or rotation	3
Distraction	4
Posterior ligamentous complex integrity	
Intact	0
Injury suspected or indeterminate	2
Injured	3
Neurologic status	
Intact	0
Nerve root involvement	2
Spinal cord or conus medullaris injury	
Incomplete	3
Complete	2
Cauda Equina Syndrome	3
Score: 0–3 = Nonoperative, 4 = Surgeon choice, >4 = Operative candidate	

The thoracolumbar injury classification and severity (TLICS) score is an assessment tool proposed in 2005 by Vaccaro et al. to assist with the determination of surgical necessity in patients with thoracolumbar spinal injuries [46]. The TLICS score calculation takes into consideration clinical and radiologic features of the injury using three parameters: radiographic injury morphology, the integrity of the posterior ligamentous complex, and neurologic status. Table 4.2 provides the dependent values of the TLICS score and the associated decision model based on the total calculated score. A systematic review in 2016 evaluating the TLICS score in clinical practice concluded the assessment tool as safe with high concordance and validity [47]. The study did caution inconsistencies regarding the surgical treatment of stable burst fractures. Possibilities to suggest weakness in the TLICS score are due to lack of consideration in factors such as loss of vertebral height, segmental kyphosis, and canal compromise [48]. Although not validated, these findings are widely reported in the literature as important indications for surgery in this specific injury.

Considerations for Long-Term Hospitalization

During the hospital stay, complications may arise due to prolonged immobilization. Deep venous thrombosis (DVT), and potential pulmonary embolism (PE), is a common, serious issue in patients recovering from acute SCI. DVT was reported in greater than 50% of patients with acute SCI. Five percent of these patients experienced fatal pulmonary embolism. DVT prophylaxis with low-molecular-weight heparin is recommended in all patients with acute SCI for 8–12 weeks post-injury [49]. Joint contractures and stiffness are the most common complications during the acute treatment phase of SCI. Passive exercises in paraplegic and tetraplegic patients are recommended to prevent muscle atrophy, contractures, and pain [50]. Sandbags and pillows can be useful in proper positioning of joints, or, in severe cases, plaster splints and rigid orthotics. Decubitus ulcers commonly occur on the sacrum, trochanter, and ischium due to prolonged immobilization. Steps to avoid this should include position changes not exceeding every 2 h with proper hygienic attention to the at-risk area [51].

Secondary Complications Following Spinal Cord Injury

Post-traumatic deformities of the spine are common manifestations following SCI. Posttraumatic syringomyelia (PTS) is the development of fluid-filled cavities within the spinal cord following SCI. While PTS is radiographically present in up to 30% of cases, less than 10% present with clinical manifestations [52]. Timing of presentation varies widely. Some factors associated with early-onset PTS were advanced age, injuries at the cervical and upper thoracic levels, complete SCI, and patients who underwent surgical stabilization. These factors suggest that the early onset of PTS is in part due to the degree of cervical stenosis at injury as well as the severity of the injury [53]. Surgical intervention for PTS is reserved for patients with radiographic evidence of syrinx progression, neurologic deterioration, or increasing pain. Non-surgical treatment options include off-label pharmacotherapy targeting neuropathic pain including anticonvulsants, tricyclic antidepressants, and narcotic analgesics. Surgical options for the treatment of PTS reported in the literature include spinal decompression, syringostomy, and syringosubarachnoid shunting. Surgical guidelines for the treatment of PTS have not been established [53]. Treatment methods for PTS should be based on the individual's pathoanatomy, syrinx progression, and neurologic status at presentation.

Post-traumatic kyphotic deformity of the cervical spine is a common manifestation following traumatic SCI but can occur iatrogenically due to surgical intervention for the treatment of SCI. Progression of cervical kyphosis places the head in constant flexion leading to significant strain on the cervical musculature. Persistent head flexion can adversely affect vision, swallowing, and breathing. Maintaining forward head posture requires constant muscle contraction and significant force load on the cervical intervertebral discs [54]. Indications for surgical intervention in cervical kyphosis include neurologic deterioration and deformity progression. Evidence from the literature suggests that kyphosis progression of greater than 5 degrees in radiographic sagittal imaging is sufficient for surgical reconstruction [55, 56]. Strategies of surgical intervention remain controversial in the literature. Three main approaches for the treatment of cervical kyphosis are widely used: anterior, posterior, and combined. The main indications regarding the posterior surgical approach include the presence of flexible kyphosis. Anterior and combined methods differ in the degree of deformity correction and post-operative complications. A 2011 literature review found the combined method to produce a greater degree of correction but with higher rates of postoperative complications. The anterior approach alone produced less degrees of cervical lordosis correction but was associated with lower post-operative complication rates [57]. More evidence is needed to fully elucidate the efficacy of these procedure paradigms.

Acute and Long-Term Neurologic Outcomes

With the continued universal acceptance of the ASIA classification scheme, the scientific community is better able to investigate prognostic outcomes associated with the severity of the injury. Physicians are therefore better capable of discussing realistic expectations with patients on their road to recovery. While neurologic recovery can be assessed with many functional outcomes, the capability of ambulation is most studied. The probability of ambulation at 1 year post injury markedly decreases with the severity of injury, with AIS grades A and D found to be 8.3% and 97.3% ambulatory at 1 year, respectively. It is important to note the greatest variability of ambulation recovery occurs in patients with injury grades AIS B and C. Also, the conversion of AIS grades during recovery was poorly correlated to the ability to walk at a 6-month and 1-year follow-up [58]. A 2019 meta-analysis investigating neurologic outcomes of traumatic SCI found the AIS conversation rates of AIS grades A through D to be 19.3%, 73.8%, 87.3%, and 46.5%, respectively. The study also found the level of injury to be a significant predictor of neurologic recovery. Recovery rates based on anatomic location followed this descending order: lumbar, cervical and thoracolumbar, thoracic [59]. These findings demonstrate that recovery of neurologic function strongly depends on the severity of the injury, injury location, and mechanism of injury. Unfortunately, current medical therapies seem to play a lesser role in the prognostic outcomes of SCI in comparison to the inciting injury.

Conclusion

Trauma resulting in injury to the spine and spinal cord is a significant issue in many contact and noncontact sports. Spinal cord injury (SCI) is a medical emergency leading to neurological impairment and disability. Proper neurosurgical care is critical in the acute management of these injuries to reduce or prevent long-term disability.

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