Key Concepts in the Perioperative Management of Spinal Cord Injuries

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KEY POINTS

- Initial management of acute spinal cord trauma is key to reducing secondary injury and morbidity.
- Understanding the location and type of injury helps guide immediate and subsequent management.
- Haemodynamic management to avoid hypotension and maintain spinal cord perfusion is critical.
- Airway management can be complicated by mechanical injuries or the need for neck stabilisation.

INTRODUCTION

Traumatic spinal cord injuries (SCIs) can be devastating, not only to the individual but also to the wider society. SCIs were responsible for loss of an estimated 9.5 million disability-adjusted life-years globally, between 1990 and 2016.[1] In the United Kingdom there are 16 cases of SCI per million people, every year. This is in comparison to 54 cases/million in the United States and 25 cases/million in lower- to middle-income countries.[2,3] Despite what may appear to be relatively low numbers, the associated significant long-term disability means each injury a significant society and personal impact. Although the average age at time of injury has risen from 29 years in the 1970s to 43 years today, this still equates to a significant loss of years of good health, productivity, and extensive expense for ongoing care.[4] Outcomes following injury can vary broadly between patients, from a complete recovery, to the need for long-term mechanical ventilation. The degree and type of disabilities are often correlated with age, comorbidities, and the level or severity of spinal cord injury. Outcomes are not fixed at the time of injury though, with initial treatment and interventions known to significantly impact the extent of a patient's recovery and outcome.

In both high-income countries and lower- to middle-income countries, the most common causes of SCI are road traffic collisions (∼40%), followed by falls (∼35%-40%). Other causes vary geographically. In the United Kingdom, these include sporting injuries, whereas violent injuries and collapsed tunnels from illegal mining feature highly in some parts of lower- to middle-income countries.[3]

Anaesthetists encounter these patients in a variety of settings: prehospital, the emergency department, the operating theatre, and critical care. Patients with SCIs may also present to non-specialist centres, which commonly have limited expertise or access to essential equipment for managing the complex needs of these injuries. In the period immediately following injury, principles of advanced trauma and life support need to be adhered to, but also a focus on rapid immobilisation of the spine and optimisation of the patient's haemodynamics to maintain spinal cord perfusion is also necessary. Patients often require transfer to a trauma centre experienced in managing SCIs, and specialist rehabilitation centres for ongoing care. Access to these specialist spinal units has been shown to decrease mortality, decrease length of stay, and improve overall health, functional, and social outcomes.[5,6] Expeditious clinical management is heavily dependent on good organisational coordination: identifying

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patients for timely referral, while communicating with retrieval systems to ensure these patients reach appropriate services swiftly and safely.

The damage from an SCI can be divided into 2 stages: the initial, or primary, injury and the secondary injury.

- Primary injury is the damage from the initial mechanical trauma to the spinal cord resulting from direct cord compression, haemorrhage, traction forces, or penetrating trauma.
- Secondary injury occurs when the primary injury results in local and spreading changes at a cellular level over the subsequent hours, days, and weeks.

The mechanism of trauma can often predict the associated injuries and guide immediate interventions until further diagnostic tests can be conducted. The mechanisms of trauma most commonly associated with SCI include vertebral subluxation, hyperextension (common in road traffic collisions), axial loading (falls on top of the head), and retropulsion injuries. Importantly though, SCIs are not always associated with a vertebral fracture.[7]

Secondary SCI stems from a cascade of changes involving altered cellular permeability, interruption of the microvascular blood supply (either by vasospasm or thrombosis), and an influx of inflammatory cells, cytokines, and vasoactive peptides.[8] These changes all lead to increasing cord oedema, which can expand across multiple spinal segments, further exacerbating the initial spinal cord damage. Subsequently, secondary damage can actually exceed that caused by the primary injury. Even small extensions in the level of a SCI can lead to a devastating increase in disability. While a midcervical injury can result in significant motor dysfunction, extension to higher cervical levels could lead to respiratory compromise and dependence on mechanical ventilation. As some areas of the spinal cord are more vulnerable, initial management to optimise spinal cord perfusion and oxygenation is a key component in reducing secondary injuries.

SPINAL ANATOMY

Familiarity with spinal cord anatomy helps correlate how specific traumas translate into primary or secondary injuries. The bony spine (vertebral column) is comprised of 24 vertebrae, the sacrum, and connective ligaments. The spinal column and cord are contained within the vertebrae and are divided in to 4 distinct regions: cervical, thoracic, lumbar, and sacral. The thoracic spine is normally kyphotic and relatively fixed, whereas the cervical and lumbar regions are normally more mobile. The spine is more susceptible to injury at junctions between these mobile and less mobile areas, and therefore injuries appear more commonly at these levels. The diameter of the canal varies along its length, with its narrowest point in the thoracic spine. Thus, thoracic injuries leave less space for spinal cord oedema or impingement when the canal is compromised.

The spinal cord contains several neuronal tracts: sensory pathways (spinothalamic) ascending from the periphery to the brain, and descending motor pathways (cortico-spinal) from the brain to the periphery. The autonomic fibres within these tracts control various physiologic functions of the cardiac, gastrointestinal, and other organ systems. The location and severity of an SCI can thus commonly be diagnosed by the specific pattern of signs and symptoms observed.[9]

Blood supply to the posterior third of the spinal cord is via a pair of posterior spinal arteries, while the ventral two thirds of the cord is supplied by a single anterior spinal artery. This artery is particularly sensitive to disruption by retropulsion injuries. Several radicular arteries from the aorta supplement the anterior spinal artery blood supply, these are most numerous in the cervical region and least in the thoracic region. The artery of Adamkiewicz is the main thoraco-lumbar radicular and supplies the cord from T8 to the conus. The thoracic areas dependant on this single artery are therefore more vulnerable to ischaemia when it is compromised.

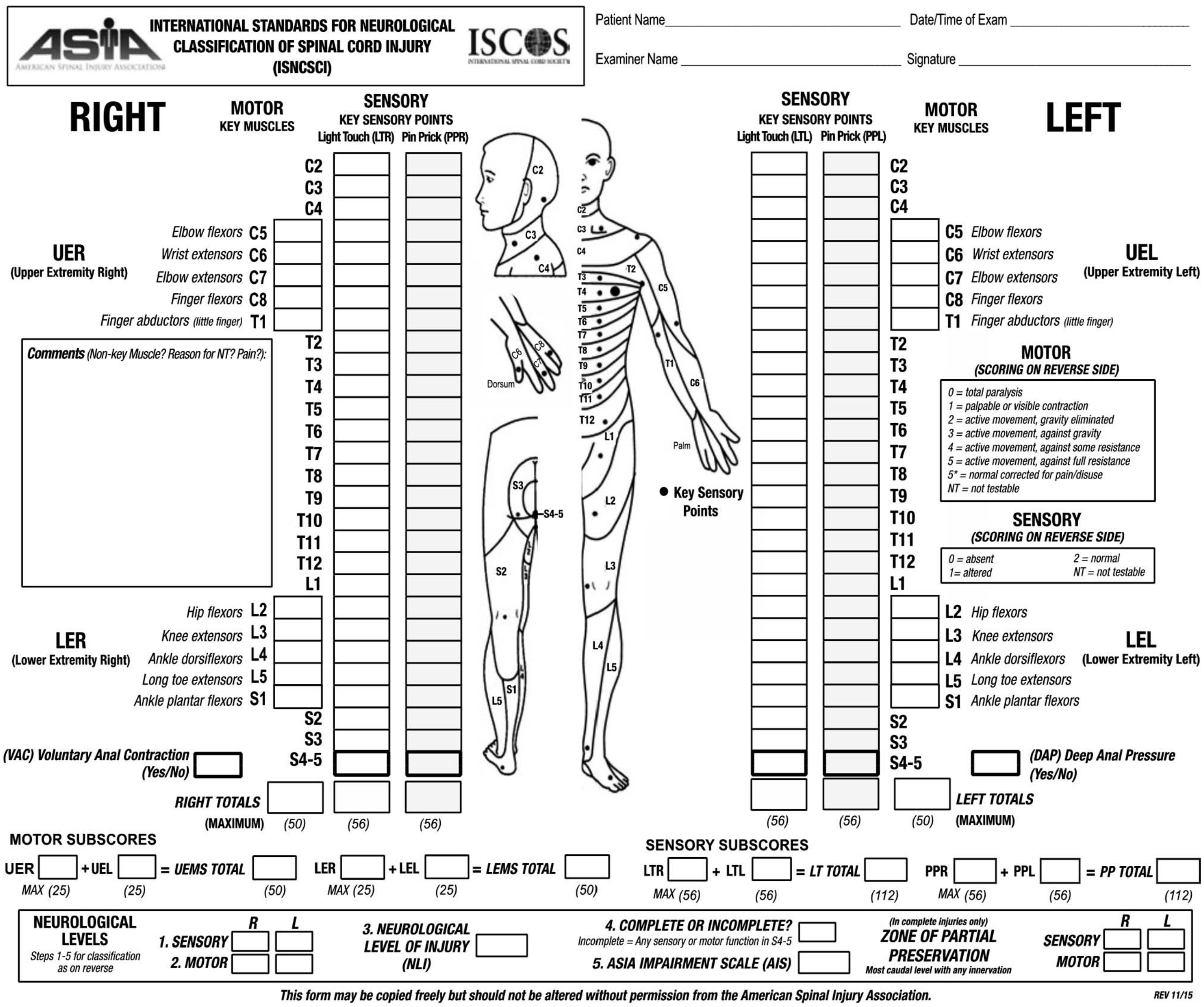
CLASSIFICATION OF SCIs

In general, the higher the level of a SCI, the more severe the subsequent degree of disability. Low thoracic and lumbar injuries are often associated with lower limb dysfunction, whereas cervical and high thoracic injuries result in additional upper limb dysfunction, as well as the potential for respiratory or autonomic dysfunction.

There are agreed-upon international standards for the neurological classification of spinal cord injuries, published by the American Spinal Injury Association (ASIA) (Figures 1 and 2). This classification requires a clinical examination in an awake and cooperative patient, which can limit its application in more severe cases of trauma. The level of neurological injury is classified by the lowest spinal level with normal remaining motor and sensory function remaining.[10] The ASIA score at 72 hours postinjury is currently the most sensitive predictor of a patient's long-term prognosis.

Complete Versus Incomplete Injuries

Broadly speaking, SCIs can be divided into complete and incomplete injuries. Complete injuries are characterised by a loss of motor and sensory function in the anal and perineal region, representing the lowest sacral segments (S4 and S5) of the spinal



INTERNATIONAL STANDARDS FOR NEUROLOGICAL CLASSIFICATION OF SPINAL CORD INJURY (ISNCSCI)

Patient Name ______ Date/Time of Exam ______
Examiner Name ______ Signature ______

RIGHT — MOTOR KEY MUSCLES — SENSORY KEY SENSORY POINTS Light Touch (LTR) Pin Prick (PPR)

SENSORY KEY SENSORY POINTS Light Touch (LTL) Pin Prick (PPL) — MOTOR KEY MUSCLES — LEFT

C2, C3, C4

UER (Upper Extremity Right) / UEL (Upper Extremity Left)
C5 Elbow flexors
C6 Wrist extensors
C7 Elbow extensors
C8 Finger flexors
T1 Finger abductors (little finger)

Comments (Non-key Muscle? Reason for NT? Pain?):

T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, L1

MOTOR (SCORING ON REVERSE SIDE)
0 = total paralysis
1 = palpable or visible contraction
2 = active movement, gravity eliminated
3 = active movement, against gravity
4 = active movement, against some resistance
5 = active movement, against full resistance
5* = normal corrected for pain/disuse
NT = not testable

SENSORY (SCORING ON REVERSE SIDE)
0 = absent 2 = normal
1= altered NT = not testable

● Key Sensory Points

LER (Lower Extremity Right) / LEL (Lower Extremity Left)
L2 Hip flexors
L3 Knee extensors
L4 Ankle dorsiflexors
L5 Long toe extensors
S1 Ankle plantar flexors

S2, S3, S4-5

(VAC) Voluntary Anal Contraction (Yes/No)
(DAP) Deep Anal Pressure (Yes/No)

RIGHT TOTALS (MAXIMUM) (50) (56) (56)
LEFT TOTALS (MAXIMUM) (56) (56) (50)

MOTOR SUBSCORES
UER + UEL = UEMS TOTAL — MAX (25) (25) (50)
LER + LEL = LEMS TOTAL — MAX (25) (25) (50)

SENSORY SUBSCORES
LTR + LTL = LT TOTAL — MAX (56) (56) (112)
PPR + PPL = PP TOTAL — MAX (56) (56) (112)

NEUROLOGICAL LEVELS (Steps 1-5 for classification as on reverse) — R L — 1. SENSORY 2. MOTOR
3. NEUROLOGICAL LEVEL OF INJURY (NLI)
4. COMPLETE OR INCOMPLETE? Incomplete = Any sensory or motor function in S4-5
5. ASIA IMPAIRMENT SCALE (AIS)
(In complete injuries only) ZONE OF PARTIAL PRESERVATION Most caudal level with any innervation — R L — SENSORY MOTOR

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Figure 1. International standards for spinal cord injury scoring card.

cord. Incomplete injuries involve some degree of preserved neurological function, and are subsequently described by their residual functions.

Some well-described syndromes of incomplete spinal cord injuries include the following:

- *Anterior spinal artery syndrome* involves injury to the anterior two thirds of the spinal cord, with loss of bilateral motor function, pain, and temperature sensation below the level of injury, but preserved proprioception and light touch.
- *Brown-Séquard syndrome* is characterized by lateral damage to the cord, with ipsilateral loss of motor function, proprioception, light touch, and contralateral loss of pain and temperature below the level of injury.
- *Central cord syndrome* is secondary to haemorrhage, ischemia, or oedema of the central grey matter, commonly in the cervical region. It involves a disproportionately greater impairment of motor function in the upper versus lower extremities, with bladder dysfunction and a variable sensory loss below the level of injury.
- *Posterior cord syndrome* involves injury to the posterior third of the spinal cord, resulting in loss of light touch and proprioception only.

ANAESTHETIC MANAGEMENT OF TRAUMATIC SCIs

Initial treatment of patients with an acute traumatic SCI is ultimately focused on managing immediate threats and minimising secondary injury.

Muscle Function Grading

0 = total paralysis
1 = palpable or visible contraction
2 = active movement, full range of motion (ROM) with gravity eliminated
3 = active movement, full ROM against gravity
4 = active movement, full ROM against gravity and moderate resistance in a muscle specific position
5 = (normal) active movement, full ROM against gravity and full resistance in a functional muscle position expected from an otherwise unimpaired person
5* = (normal) active movement, full ROM against gravity and sufficient resistance to be considered normal if identified inhibiting factors (i.e. pain, disuse) were not present
NT = not testable (i.e. due to immobilization, severe pain such that the patient cannot be graded, amputation of limb, or contracture of > 50% of the normal ROM)

Sensory Grading

0 = Absent
1 = Altered, either decreased/impaired sensation or hypersensitivity
2 = Normal
NT = Not testable

When to Test Non-Key Muscles:

In a patient with an apparent AIS B classification, non-key muscle functions more than 3 levels below the motor level on each side should be tested to most accurately classify the injury (differentiate between AIS B and C).

Movement	Root level
Shoulder: Flexion, extension, abduction, adduction, internal and external rotation **Elbow:** Supination	C5
Elbow: Pronation **Wrist:** Flexion	C6
Finger: Flexion at proximal joint, extension. **Thumb:** Flexion, extension and abduction in plane of thumb	C7
Finger: Flexion at MCP joint **Thumb:** Opposition, adduction and abduction perpendicular to palm	C8
Finger: Abduction of the index finger	T1
Hip: Adduction	L2
Hip: External rotation	L3
Hip: Extension, abduction, internal rotation **Knee:** Flexion **Ankle:** Inversion and eversion **Toe:** MP and IP extension	L4
Hallux and Toe: DIP and PIP flexion and abduction	L5
Hallux: Adduction	S1

ASIA Impairment Scale (AIS)

A = Complete. No sensory or motor function is preserved in the sacral segments S4-5.

B = Sensory Incomplete. Sensory but not motor function is preserved below the neurological level and includes the sacral segments S4-5 (light touch or pin prick at S4-5 or deep anal pressure) AND no motor function is preserved more than three levels below the motor level on either side of the body.

C = Motor Incomplete. Motor function is preserved at the most caudal sacral segments for voluntary anal contraction (VAC) OR the patient meets the criteria for sensory incomplete status (sensory function preserved at the most caudal sacral segments (S4-S5) by LT, PP or DAP), and has some sparing of motor function more than three levels below the ipsilateral motor level on either side of the body.
(This includes key or non-key muscle functions to determine motor incomplete status.) For AIS C – less than half of key muscle functions below the single NLI have a muscle grade ≥ 3.

D = Motor Incomplete. Motor incomplete status as defined above, with at least half (half or more) of key muscle functions below the single NLI having a muscle grade ≥ 3.

E = Normal. If sensation and motor function as tested with the ISNCSCI are graded as normal in all segments, and the patient had prior deficits, then the AIS grade is E. Someone without an initial SCI does not receive an AIS grade.

Using ND: To document the sensory, motor and NLI levels, the ASIA Impairment Scale grade, and/or the zone of partial preservation (ZPP) when they are unable to be determined based on the examination results.

AMERICAN SPINAL INJURY ASSOCIATION

INTERNATIONAL STANDARDS FOR NEUROLOGICAL CLASSIFICATION OF SPINAL CORD INJURY

ISCOS

Steps in Classification

The following order is recommended for determining the classification of individuals with SCI.

1. Determine sensory levels for right and left sides.
The sensory level is the most caudal, intact dermatome for both pin prick and light touch sensation.

2. Determine motor levels for right and left sides.
Defined by the lowest key muscle function that has a grade of at least 3 (on supine testing), providing the key muscle functions represented by segments above that level are judged to be intact (graded as a 5).
Note: in regions where there is no myotome to test, the motor level is presumed to be the same as the sensory level, if testable motor function above that level is also normal.

3. Determine the neurological level of injury (NLI)
This refers to the most caudal segment of the cord with intact sensation and antigravity (3 or more) muscle function strength, provided that there is normal (intact) sensory and motor function rostrally respectively.
The NLI is the most cephalad of the sensory and motor levels determined in steps 1 and 2.

4. Determine whether the injury is Complete or Incomplete.
(i.e. absence or presence of sacral sparing)
*If voluntary anal contraction = **No** AND all S4-5 sensory scores = **0** AND deep anal pressure = **No,** then injury is **Complete.***
*Otherwise, injury is **Incomplete.***

5. Determine ASIA Impairment Scale (AIS) Grade:

Is injury Complete? **If YES, AIS=A** and can record ZPP (lowest dermatome or myotome on each side with some preservation)

NO ↓

Is injury Motor Complete? **If YES, AIS=B**

NO ↓ (No=voluntary anal contraction OR motor function more than three levels below the motor level on a given side, if the patient has sensory incomplete classification)

Are at least half (half or more) of the key muscles below the neurological level of injury graded 3 or better?

NO ↓ **AIS=C** **YES** ↓ **AIS=D**

If sensation and motor function is normal in all segments, AIS=E
Note: AIS E is used in follow-up testing when an individual with a documented SCI has recovered normal function. If at initial testing no deficits are found, the individual is neurologically intact; the ASIA Impairment Scale does not apply.

Figure 2. International standards for spinal cord injury scoring tool guide.

Patients with traumatic SCI often present in the context of a polytrauma and should always be approached systematically, with resuscitation and assessment occurring simultaneously. Imaging is an essential resource (via a whole-body computed tomography scan), but shouldn't precede completion of the primary survey. If unavailable, a trauma series of x-rays, including the cervical spine, are an alternative option. Imaging helps identify bony spinal injuries, but (as discussed previously) not all SCIs are associated with vertebral fractures. Neurological assessment is therefore essential, ideally prior to any anaesthetic intervention.

The cervical spine cannot be clinically cleared whilst other distracting injuries are present or in obtunded or uncooperative patients. A cervical collar should therefore remain in place until an appropriate assessment can be performed and imaging reviewed by a competent authority (ideally a spinal surgeon).

Airway/Breathing

Traumatic SCI patients present unique challenges for the induction of anaesthesia and intubation. The need to minimise further injury by maintaining in-line neck stabilisation can hinder normal manipulation for intubation. Additionally, common haemodynamic swings during induction and intubation can potentiate secondary injuries to the spinal cord.

Spinal cord perfusion and oxygenation is imperative, yet hypoventilation is commonly encountered in this patient population. This is attributable to a variety of causes: rib fractures, traumatic brain injury, pain, pneumo- or haemothoraces, or neurologic disruption to the muscles of ventilation. In addition to standard indications for intubation, patients with upper or midcervical injuries are at increased risk of respiratory deterioration, with up to 80% requiring intubation during their care.[7] The potential for mechanical airway obstruction due to enlarging a haematoma around the cervical spine following injury can also necessitate early endotracheal intubation. Therefore, vigilance, with a low threshold for early intubation, is important to protect their airway and maintain ventilation/oxygenation.[11]

Circulation

Autonomic dysfunction due to disruption of spinal sympathetic fibres may lead to hypotension and bradycardia; referred to as 'neurogenic shock'. This arises from unopposed vagal parasympathetic tone and a combination of vasodilatation with interruption in the cardio-accelerator fibres from the upper thoracic spine. Hypotension should be aggressively treated, as poor spinal cord perfusion can exacerbate cord ischemia and the extent of injury. A target mean arterial pressure of 85 to 90 mm Hg should be maintained for the initial 5 to 7 days postinjury, facilitated by the use of invasive arterial monitoring.

Resolution of neurogenic shock usually develops 4 to 6 weeks postinjury, but may present as early as 4 days. Clinically, the return of deep tendon reflexes often heralds the resolution of susceptibility to neurogenic shock. This is not to be confused with 'spinal shock', which isn't really shock as such, but instead refers to a flaccid areflexia that may occur after SCI.

In patients with higher levels of SCI, care should also be taken when performing vagally stimulating procedures, such as laryngoscopy and tracheal suctioning. If unopposed by sympathetic action, vagal stimulation from these procedures can yield severe bradycardia or even asystole. Pretreatment with anticholinergics, such as glycopyrrolate or atropine, are options which should be considered.

Other Considerations

- Positioning: Surgery for spinal injuries can be long, are often in the prone position, and involve a variety of customised tables and supports, the nuances of which are beyond the scope of this tutorial. The importance of familiarity with the ergonomics and human factors in these operations cannot be overstated.
- Nutritional support and glycaemic control: Traumatic SCI is known to cause a hypermetabolic state and risks rapid nitrogen depletion. Good nutrition is vital to aid wound healing, weaning of mechanical ventilation, and ongoing recovery and rehabilitation. Both hyper- or hypoglycaemia may worsen outcomes and should be addressed.
- Pressure sore prevention: These are a major cause of morbidity and mortality, especially in resource-poor environments. Regular repositioning of the patient by appropriately trained staff is essential for preventing pressure sores.
- Venous Thromboembolism (VTE) prophylaxis: Patients will be immobile and hypercoagulable post injury, with a high risk of deep vein thrombosis or pulmonary embolus. Mechanical thromboprophylaxis should be used as soon as possible and (when deemed safe by the surgical team), pharmacologic thromboprophylaxis (such as heparin or enoxaparin) should be utilised.
- Gastric prophylaxis: Stress ulceration is common in trauma patients. Prophylaxis with a proton pump inhibitor (such as pantoprazole) should be considered.
- Bladder and bowel dysfunction: These are common due to autonomic dysfunction. Urinary catheterisation should be initiated, with laxatives prescribed to minimise constipation.
- Thermoregulation: Vasodilation below the spinal cord lesion predisposes to hypothermia, while a compromised ability to sweat impairs heat dissipation, hence monitoring and maintenance of body temperature is vital.

ONGOING CARE

Patients with SCI require ongoing treatment and rehabilitation. After acute management, transfer to specialised SCI centre for continued management and rehabilitation is commonly necessitated. These patients often re-present to hospital for further interventions, many of which may require anaesthesia.

Autonomic dysreflexia is a physiologic derangement commonly found in injuries above the T6 level. This is an inappropriate autonomic response to stimuli below the level of injury, resulting in episodes of malignant hypertension, characterised by headache, flushing, pallor, and sweating above the level of the lesion. Autonomic dysreflexia can be triggered by even minor stimuli, such as bladder distention, constipation, or pressure sores.[12]

It is important to appropriately manage this condition as a matter of urgency. Removing the stimulus will often improve the situation, as will sitting the patient up if possible. Pharmacological agents, such as sublingual glyceryl trinitrate (GTN) or a short-acting vasodilator may be beneficial for acute management.

In areas where access to ongoing support and rehabilitation is limited, survival rates have improved, but mortality is still high, particularly amongst populations in lower- to middle-income countries. The most common complications in management encountered amongst patients after SCIs include urinary tract infections, pressure sores, pneumonia, and associated sepsis.[13] Simple steps, such as access to wheelchairs, catheters, and repositioning to reduce pressure sores is invaluable; however the associated cost and availability of these resources can be a limiting factor. In the United Kingdom, the estimated average lifetime cost of caring for a person with a spinal cord injury is presently £1.12 million.[2] The extensive resources required to support patients with SCIs highlights the importance of minimising secondary injury via meticulous care during the acute phase of injury.

SUMMARY

SCIs can present in a multitude of traumatic injuries. Their management needs to balance a combination of goals to minimise progression of the injury, administer essential treatments, and consider transfer of care to a specialised centre. While experienced centres will have protocols for triaging and managing spinal cord injuries, all practitioners should be aware of the potential airway difficulties and autonomic dysfunctions that these patients may present with, as well as the importance of maintaining adequate spinal cord perfusion and spinal stabilisation to prevent further injury.

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