Spinal cord injury

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Abstract

With an annual incidence of 13 per million, around 40,000 people in the UK live with spinal cord injury (SCI). The extent of morbidity and mortality and thus quality of life, is highly dependent on meticulous management from the first point of contact with medical services. Treatment is focussed on reducing the risk of further cord injury and prevention of secondary (penumbral) damage through avoidable complications. As key members of trauma, theatre, intensive care and pain teams, anaesthetists and intensivists play a crucial role in influencing patient outcome.

Keywords Injury; primary; secondary; spine; trauma

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Learning objectives

After reading this article you should be able to:
- define primary and secondary spinal cord injury
- outline the initial management of patients with spinal cord injury
- consider appropriate imaging to identify spinal injury

Epidemiology and aetiology

Trauma is the leading cause of death in western societies in the age range 5—44 years.

In a recently published analysis of the European Trauma Audit and Research Network (TARN) database,[1] spinal injuries following major trauma were found to be present in 13% of cases, with 1.8% suffering cord injury. It also revealed a male bias (64.9%) and a median age of 44.5 years. About 45% of those with spinal injuries will also have other significant injuries.

Of all spinal cord injuries, 40% resulted from road traffic collisions, 30% from falls of more than 2 m, and 16% from falls of less than 2 m. Violence and sporting injuries comprised just over 4% of the total.

Anatomy

Knowledge of the basic anatomy of the spine and spinal cord is essential. It enables the clinician to detect injury, assess level and therefore institute and predict appropriate management.

In the adult, the spinal cord extends from the medulla oblongata to the conus at L1/2 where it continues on as the cauda equina. It is covered by three layers of meninges (pia, arachnoid, dura) and protected by seven cervical, 12 thoracic and five lumbar bony vertebrae. The cervical and thoracolumbar segments are most vulnerable to injury due to their greater mobility.

The spinal cord itself is highly complex and acts as a bi-directional information conduit between the brain and body. It consists of many white matter ascending and descending tracts, three of which are regularly used by clinicians to assess cord integrity:
- Ascending (sensory)
  - Posterior columns (cuneate and gracilis); fine touch, vibration and position sense
  - Anterolateral spinothalamic tract; pain and temperature
- Descending (motor control)
  - Posterolateral corticospinal tract.

Blood is supplied to the cord via one anterior and two posterior spinal arteries, which are branches of the vertebral and posterior inferior cerebellar arteries respectively. There are also important contributions from radicular arteries en route, especially in the thoracic region. The anterior artery supplies the anterior two-thirds of the cord with the posterior arteries supplying the posterior third.

Mechanisms of injury and pathophysiology

Injury can be divided into primary and secondary.

Primary injury is concerned with direct damage to the cord or supporting vasculature caused by the initial trauma. This can be caused by a number of mechanical forces:
- *Distraction* — occurring when the bony spine is hyperextended, as in rapid acceleration and deceleration injuries.
- *Compression* — resulting from axial loading, compromising the spinal cord because of encroachment of vertebral body fragments or intravertebral discs.
- *Penetrating trauma* can directly damage the spinal cord or vessels.

There is very little that can be done to reverse primary cord injury. Immediate management is focused on preventing secondary injury.

Secondary injury occurs within minutes of the primary insult. Damage to neural cells and blood vessels cause a spiralling cascade of injury which includes: haemorrhage, disruption of cell metabolism and apoptosis, electrolyte shifts and release of free radicals and inflammatory messengers. These lead to increased cord oedema, ischaemia and loss of autoregulation. Oedema will not be localized to the site of primary injury, but continue to spread bi-directionally along the cord for up to 72 hours, increasing the neurological compromise.

Systemic insults such as hypoperfusion, hypoxia, hyperthermia and catecholamine release can significantly increase the

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extent of penumbral damage. Initial management of spinal cord injury (SCI) is focused on the prevention of such insults.

Classification of injury

Classification of injury is important as it enables the clinician to not only prognosticate but also plan appropriate management for the patient.

The most consistent predictor of long-term morbidity and mortality is severity of neurology as measured by completeness and level of injury.

An injury can be defined as complete or incomplete.

- *Complete (cord transection)* – complete absence of motor and sensory function below the level of the injury.
- *Incomplete* – partial preservation of neurological function more than one level below the injury. This has a better prognosis for recovery. Up to 80% with incomplete paraplegia will stand by 12 months, 50% will walk out of hospital within 12 months and neurological recovery can be seen up to 2 years post-injury. Incomplete lesions can result in syndromes or patterns of injury.
- *Anterior cord syndrome* – infarction of the anterior two-thirds of the cord due to an interruption in blood flow through the anterior spinal artery. This results in loss of motor function and pain/temperature sensation below the level of the injury. Proprioception and fine touch sensation are preserved.
- *Brown-Séquard syndrome* – caused by lateral hemisection of the cord and characterized by loss of motor function, fine touch, proprioception on the ipsilateral side and loss of pain and temperature sensation on the contralateral side.
- *Cauda equina syndrome* – damage to the cauda equina causes loss of sensation in the saddle area and disturbance of bowel and bladder function.
- *Central cord syndrome* – this is the most common pattern of incomplete SCI. It is characterized by disproportionate upper limb weakness compared to lower limb, variable sensory loss below the level of injury and bowel and bladder dysfunction.
- *Posterior cord syndrome* – caused by an interruption to blood supply to the posterior cord. It is characterized by the sole loss of proprioception and vibration sense only. It is very rare.

The American Spinal Injury Association (ASIA) has developed a standardized neurological impairment scale for SCI that combines severity of deficits with completeness of injury to produce five classes (A–E) that correlate with outcome.[2]

Level of injury

Injury level is defined as: the 'most caudal segment of the spinal cord with normal bilateral motor strength (power >3/5) and sensory (light touch and pain) function'.

For the anaesthetist and intensivist this is important to determine as the higher a SCI above T8, the more likely the patient is going to require ventilatory support. SCI above C3 will likely need immediate and long-term ventilation, 80% of SCI between C3-5 will require ventilation within 48 hours.

Initial management

An ABC approach as outlined by the Advanced Trauma Life Support (ATLS) course of the American College of Surgeons should be adopted with all patients. Mechanisms of injury associated with SCI can also result in other life-threatening traumatic injuries. Situations can be challenging due to the high anxiety of patient and responder in trauma.

Airway (with spine protection)

As far as possible the C spine should be protected in a well-fitting, hard collar and immobilized with blocks and tape. This may be challenging in the combative patient and thus sedation or general anaesthesia may be indicated to facilitate spinal protection.

Airway maintenance is often difficult due to the need to maintain spinal immobilization in combination with the possibility of airway and facial trauma, foreign bodies, swelling, vomitus.

Endotracheal intubation may be indicated for a number of reasons including:

- Threatened airway
  - Swelling, burns, haematoma, airway or maxillofacial trauma, Glasgow Coma Scale (GCS) score less than 9 (or deteriorating)
- Respiratory failure
- Traumatic brain injury
  - GCS score less than 9
  - Combative
  - Control of raised ICP.

The choice of technique for securing an airway in trauma varies and is largely dependent on the clinical situation and clinician experience, no individual technique is thought to be superior. Oxygenation is the priority in preventing secondary cord damage and thus clinicians should use a familiar technique. Difficult airway equipment including intubating fibrescope should be available, but may be challenging to use in the acute situation due to blood, secretions, swelling and equipment unfamiliarity. There is no evidence of improved neurologic outcomes in patients with SCI who have been intubated with the assistance of a fibreoptic bronchoscope.[3]

RSI with manual in-line stabilization (MILS) and gentle laryngoscopy is commonly used.

Effect on laryngoscopy of different cervical spine immobilization techniques has been investigated. The MILS technique improved the laryngoscopic view (Cormack and Lehane) by at least one grade in 66% of patients when compared to Collar, tape and sandbags.[4]

Endotracheal intubation should be confirmed as soon as possible with capnography.

Choice of muscle relaxation for intubation must be carefully considered. Depolarizing muscle relaxants are contraindicated in patients more than 72 hours post-SCI due to the potential to precipitate life-threatening hyperkalaemia.

Breathing

Pulmonary complications are the leading cause of death and morbidity in SCI patients. Respiratory failure is an independent predictor of 3-month mortality.

SCI is rarely the sole cause of ventilatory compromise or failure of oxygenation in the acute trauma patient. A high index of suspicion for other diagnoses should be maintained throughout the acute period. Respiration can be affected directly or indirectly.

Direct

- Chest trauma (rib fractures, pulmonary contusions, haemo or pneumothorax).

Indirect

- Traumatic brain injury (TBI) – airway compromise, respiratory centre involvement, neurogenic pulmonary oedema.
- Acute lung injury (ALI) from release of systemic inflammatory mediators.
- Aspiration pneumonia/pneumonitis.

SCI above the level of T8 may require assisted ventilation. The diaphragm is supplied by C3-5 segments of the cord. Injury above C3 results in apnoea and is usually fatal unless assisted ventilation is instituted immediately. Many patients with injuries below C5 have normal diaphragmatic function but proceed to respiratory failure in the early stages of acute spinal cord injury. The reasons for this are a combination of underlying associated pulmonary injury, loss of abdominal muscle tone and absent intercostal muscle function. The initially flaccid intercostal muscles cause the chest wall to be drawn in and contract rather than expand during inspiration, which results in a 70% reduction in forced vital capacity (FVC). Respiratory wean is later aided by the spasticity that develops in these intercostal muscles, reducing indrawing and maximal inspiratory force can eventually return to almost 60% of pre-injury levels.

Weaning from mechanical ventilation is often slow and requires meticulous attention to fluid management, nutrition, early lung-protective ventilation and measures to reduce ventilatory assisted pneumonia. An early tracheostomy is often desirable, but its impact on operative cervical fixation must be considered. The contractility of the diaphragm is maximal in the supine position. Patients with cervical cord lesions, who have lost intercostal function and are dependent on diaphragmatic breathing, wean optimally when managed supine.

On examination of the respiratory system with a C-spine injury, one is likely to see changes in ventilatory control, abnormal breathing patterns and respiratory mechanics or 'see-saw' breathing. This is occurs as a result of expansion of upper rib cage while the flaccid diaphragm ascends into the thoracic cavity, generating a paradoxical inward movement of the abdomen during inspiration. Patients with injuries above T8 may also exhibit a poor cough leading to sputum retention and lobar collapse or pneumonia.

Circulation

Cardiovascular instability frequently complicates SCI.

- *Hypovolaemic shock* – it is important to remember that haemorrhage should be the initial concern when managing a hypotensive trauma patient. Other common causes of shock in trauma patients should also be considered; tension pneumothorax, pericardial tamponade, direct myocardial injury and sepsis.
- *Neurogenic shock* – this can occur with any injury to the spinal cord, especially with upper thoracic or cervical injuries. There is a loss of the sympathetic contribution to vascular tone causing arteriolar dilatation and venous pooling. In addition, injuries above T5 can disrupt cardiac sympathetic innervation resulting in unopposed vagal tone causing bradycardia and reduction in cardiac contractility. Bradycardias will usually respond to antimuscarinics and chronotropes, pacing is rarely indicated.

Hypotension secondary to neurogenic shock is usually resistant to fluid boluses. Minimally invasive cardiac output monitoring techniques such as PiCCO, LiDCO or oesophageal Doppler techniques can assist in guiding fluid resuscitation and vasopressor support.

Neurogenic shock can last from 24 hours to weeks after the primary injury. Autonomic hyper-reflexia occurs in 85% of patients with complete injuries above T5. It is the result of excessive sympathetic response to stimulation below the level of injury, in the absence of the normal inhibition of the descending cords. Relatively trivial problems, such as constipation or urinary retention, can trigger this potentially devastating condition, and close cardiovascular monitoring needs to be maintained even in the post-acute recovery stage.

Spinal imaging

All trauma patients with spinal pain, obvious deformity, neurological deficit or a mechanism consistent with a risk of spinal injury should be imaged. Patients with a low GCS score or distracting injury should be treated with a high index of suspicion.

CT has largely replaced plain radiographs as the imaging of choice, especially in trauma centres. Clearance of the cervical spine using a single lateral film is known to miss more than 15% of unstable injuries, with the addition of CT the incidence drops to 0.1–0.5%. This must be balanced against risks of CT: expensive, increased radiation exposure to patient, unsuitable for very unstable patients.

If plain radiographs are used, there are a few key essential points to consider:

- Antero-posterior, lateral and odontoid views should be taken.
- Ensure the C7-T1 intervertebral space is visualized. Views of this can be improved with a 'swimmers view'.
- Radiographs should be assessed for vertebral alignment, bony structure, intervertebral space and soft tissue thickening.

MRI is the modality of choice for assessing acute cord injury. It also detects ligamentous and other non-bony injury that can be missed by other imaging modalities.

About 15% of adults with SCI have no radiological injury. For this reason, patients should have a full neurological assessment once they are no longer obtunded or have distracting injury.

Spinal surgery

Removal of bone, disc, and ligament fragments to decompress the swollen cord is one option; however, early surgery remains controversial. Early internal stabilization surgery has substantial pragmatic advantages in the rehabilitation phase compared with external (halo) stabilization devices. However, early fixation can worsen neurological function and indwelling metalwork can become infected. A recent trial has suggested that early fixation is associated with a shorter hospital stay, but no differences in mortality, intensive care stay or number of ventilator days were demonstrated.

Spinal clearance

Spinal clearance should be achieved as soon as possible whilst ensuring patient safety. Maintenance of spinal precautions for long periods has multiple complications:

- *Airway* — poor oral hygiene, difficult intubation and delayed tracheostomy.
- *Breathing* — increased risk of ventilator-associated pneumonia, limited physiotherapy options.
- *Circulation* — difficult central venous line placement, increased risk of thromboembolism.
- *Neurological* — risk of increased intracranial pressure.
- *Gut* — gastrostasis, reflux and aspiration, delayed enteral nutrition.
- *Skin* — pressure sores.
- *Staffing* — large impact due to log rolling, therefore increased risk of cross-infection and reduced vigilance on the unit.

These risks have to be balanced against the risk of causing cord injury in a patient with an unstable spinal injury.

In a patient with a GCS score of 15, no distracting injuries or neurological deficit and minimal analgesic requirements, the spine can be cleared clinically by an experienced clinician. If these conditions are not met or if examination reveals concern, three-view radiographs should be taken with a low threshold for CT if these are abnormal or inadequate. Ventilated patients never meet the criteria for clinical clearance, therefore patients should always be imaged, usually by CT. The current policy in the author's institution is for CT of all 'at-risk' spines in intubated patients. This should then be cleared only after detailed review by a musculoskeletal radiology consultant.

Spinal surgery

Surgery should be considered where there is ongoing direct pressure to the cord, and stabilization should be considered urgently in any patients with neurological deterioration. Although early surgery has not been shown to improve injury level, it has been shown to reduce ventilator days and length of stay.

Other important therapies to consider

- *Steroids* — The US standard was the administration of high-dose methylprednisolone within the first 8 hours after injury. The evidence for this treatment was based primarily on the second National Acute Spinal Cord Injury Study trial in which patients were randomized to methylprednisolone, naloxone or placebo within 12 hours of injury. The results suggested improved motor function at 1-year follow-up. Analysis of these results showed that benefit was demonstrated in a non-predetermined subgroup (treated within 8 hours) and that the associated neurological improvement was relatively small. A recent Cochrane review of steroid treatment for acute spinal cord injury has not supported its routine use and steroids have been removed from the guidelines of ATLS. Treatment with high-dose methylprednisolone is associated with complications, including an increased frequency of gastric bleeding and wound infection.
- *Thromboprophylaxis* — patients with spinal injuries are at increased risk of venous thrombosis with an incidence in untreated patients of around 39–100% compared to 9–32% in untreated medical or surgical patients. There is currently no clear benefit of one prophylactic regimen over another.

Radiological spine clearance in the unconscious

- High-resolution CT scan of whole cervical spine down to T4 (T1–T4 often poorly imaged by plain radiology) with 1.5–2.0-mm slices and sagittal reconstructions
- Thoracolumbar anteroposterior and lateral plain radiographs
- Reconstruction of thoracolumbar spine views if incidental thoracic or abdominal CT performed
- Review of images by senior radiologist
- Consideration of MRI if there is a radiological or focal neurological abnormality

Box 1

Outcomes

Anaesthetists and intensivists play a vital role in the prevention of secondary injury in the patient with acute SCI. A good knowledge of basic spinal cord anatomy and physiology, mechanisms of injury and key points in acute management is a crucial step in reducing the mortality and morbidity and maximizing functional outcomes.

Of those who survive the first 24 hours, 85% are alive 10 years later. Those with permanent cord injury will not only be vulnerable to a wide range of long-term physical complications but also psychosocial difficulties, the magnitude of which should not be underestimated. Sadly, suicide remains a common cause of death in patients with SCI.

A suggested protocol for radiological spine clearance in the unconscious patient is shown in Box 1. ◆

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FURTHER READING

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