Government of Western Australia
Department of Health

The Anatomy and Physiology of Spinal Cord Injury

A Resource for Health Service Providers

WA State Spinal Injury Unit

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This document has been developed to provide health service providers with a sound understanding of the anatomy and physiology of Spinal Cord Injury (SCI) and the tools used to measure the functional impact of SCI.

Key points

- The spinal cord transmits neural messages to and from the brain to control many voluntary and involuntary functions.
- SCI can occur following a traumatic injury, or as the result of a non-traumatic illness or disease (e.g.: Spinal tumours, infection or blood supply interruption).
- Paraplegia is the impairment of motor and sensory function of the lower limbs and trunk.
- Tetraplegia (also termed Quadriplegia) is when impairment of motor and sensory function occurs in all four limbs.
- A Complete SCI indicates that there is no sensory or motor function in the lowest sacral segment of the spinal cord (S4/5).
- An Incomplete SCI indicates that there is some preservation of motor and/or sensory function below the level of the injury that includes the lowest sacral segment (S4/5). The degree of completeness of a SCI is classified using the ASIA Impairment Scale (AIS).
- The Spinal Cord ends at approximately the level of T12/L1 and beyond that the nerve bundle branches out to become the Cauda Equina. The level of the SCI in relation to the ending of the spinal cord has important implications for other body systems
- SCI has an impact on many body systems and functions, including:
    - Autonomic Nervous System
    - Bladder and bowel function
    - Circulatory and Cardiovascular Systems
    - Musculoskeletal function
    - Respiratory function
    - Sexual function
    - Skin integrity
- The functional impact of a SCI depends on both the level and the severity of your spinal cord damage. The American Spinal Injury Association (ASIA) assessment is the International Standard for the Neurological Classification of Spinal Cord Injury.
- Vertebral level of injury is often different to neurological level of injury. Neurological level of injury is determined by the lowest spinal segment with normal neurological function as per ASIA.

Aetiology of Spinal Cord Injury

Spinal cord injury (SCI) can be caused by

- traumatic injury e.g.: fractures, ligament or inter-vertebral disc injuries or
- non-traumatic injury e.g.: disease, infection, degeneration, tumours or blood supply interruption.

The Australian Institute of Health and Welfare report on the national statistics for SCI using data obtained from case registrations sent to the Australian Spinal Cord Injury Registry at Flinders University in South Australia. The most recent published data is from 2007-2008 there was a total of 362 cases of SCI reported; 285 (79%) were traumatic and 77 (21%) were non-traumatic. Traumatic SCI remains significantly more common in males (84%). 30% of traumatic SCI occurred in individuals aged between 15-24 years, with an average age of injury of 42 years. Non-traumatic SCI was also more common in males (57%) and occurred at an average age of 56 years [1].

The national incidence rate for Spinal Cord Injury in Australia from 2007-2008 was 15.1 per million of the population. Western Australia was significantly higher than this with an incidence rate of 25.1 cases per million of the population[1].

In Western Australia, there are an estimated 1,100 people living with a SCI, with an average of 40 new cases of SCI per year, based on data obtained from 2000-2008 admission data for the State Spinal Injuries Unit. Based on this data, the three most common traumatic mechanisms of injury were Motor Vehicle Accident, Fall and Motor Bike Accident. The table below outlines data for acute SCI admissions and chronic SCI re-admissions to the State Spinal Injuries Unit in Western Australia in 2012: [2]

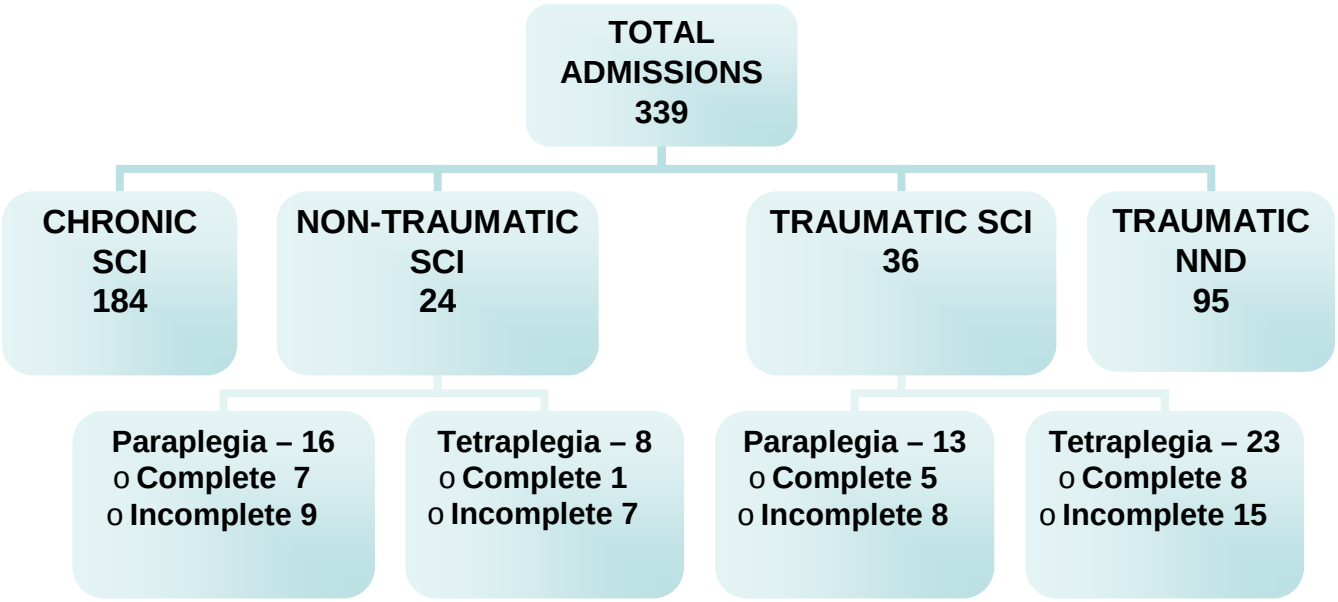


Figure 1: Western Australia State Spinal Injuries Unit admission data for 2012 [2]

Anatomy of the Vertebral Column and Spinal Cord

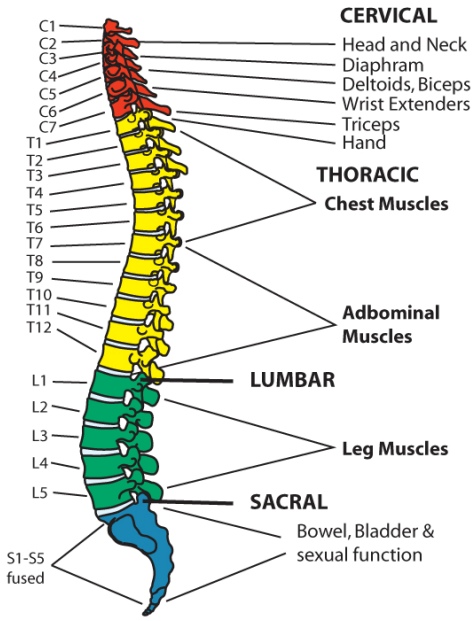


Diagram 1: Anatomy of the Vertebral Column

The vertebral column is comprised of 33 vertebrae (7 cervical, 12 thoracic, 5 lumbar, 5 fused sacral, 4 fused coccygeal), intervertebral discs and supporting muscles and ligaments. The spinal cord lies within the spinal canal, it is protected by the vertebral column and surrounding cerebrospinal fluid.

It is possible to have an injury to the vertebral column without sustaining an injury of the spinal cord. This is referred to as “no neurological deficit”. Similarly, you can sustain an injury to the spinal cord without having an injury to your vertebral column.

The spinal cord is part of the central nervous system. It is the main pathway that transmits messages between the peripheral nervous system and the brain. The spinal cord regulates many voluntary and involuntary functions which will be outlined in this section.

The spinal cord is essentially a bundle of nerve fibres and pathways (spinal tracts) that extends from the brainstem to the lower back. Peripheral nerves enter and exit the spinal cord as pairs on both sides of the vertebral column through the neural foramina between each vertebrae. At each of the 31 spinal segments, sensory (afferent) information enters the spinal cord and motor (efferent) information exits the spinal cord via paired spinal nerves. There are 8 cervical, 12 thoracic, 5 lumbar and 6 sacral nerves.

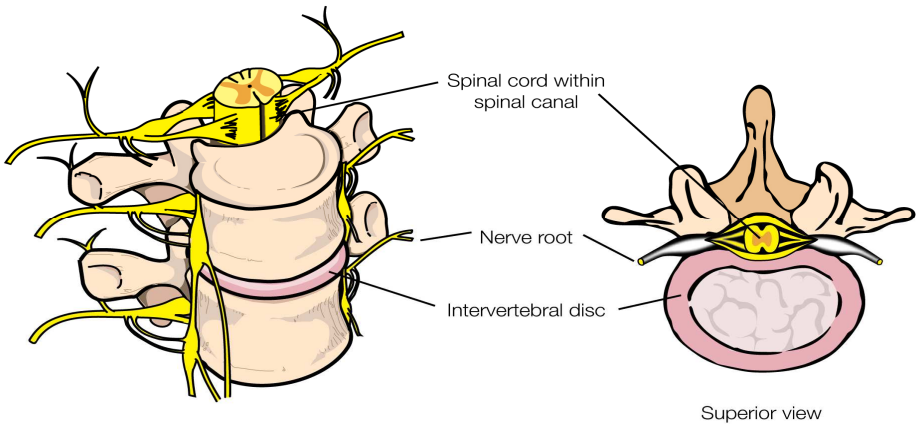


Diagram 2: Anatomy of the Spinal Cord and Spinal Nerves

The spinal cord ends at approximately the level of T12/L1 vertebrae and beyond that the nerve bundle branches out to become the Cauda Equina.

Autonomic Nervous System

The autonomic nervous system comprises the parasympathetic and sympathetic nervous systems. These systems oppose each other in their actions and act automatically to regulate many bodily functions. Most organs of the body are supplied by both the parasympathetic and the sympathetic nervous systems.

The parasympathetic nervous system acts via cranial nerves in the brainstem, and sacral spinal nerves. The cranial nerves innervate the bodies vital organs, including the heart and lungs, therefore after a SCI these systems will continue to function. The sympathetic nervous system acts via neurons in the grey matter of the spinal cord in the thoraco-lumbar regions. The effect that activation of the parasympathetic and sympathetic nervous systems have on different body systems are outlined in Table 1. Note that the role of the autonomic nervous system is not discussed in relation to Autonomic Dysreflexia, Bladder, Bowel or Sexual Function as this will be covered in the corresponding sections.

Body Function	Parasympathetic	Sympathetic	Effect of SCI
Cardiovascular	Vagus Nerve (Cranial Nerve X) controls Heart Rate It acts to slow the Heart Rate	Cause vasoconstriction in upper and lower body resulting in increased blood pressure • T1-T5 regulates the upper body blood vessels • T5-L2 regulates the lower body blood vessels	Passive vasodilation occurs due to lack of sympathetic innervation resulting in hypotension
Respiratory	Controls smooth muscles of the airways, with excitation reducing airway diameter (bronchoconstriction). Also controls secretion production	T1-T6 act to increase airway diameter via bronchodilation	Loss of sympathetic innervation results in increased bronchoconstriction secretion production

Sweat Glands	Nil	T1-T5 regulates upper body sweat glands T5-L2 regulates lower body sweat glands	Loss of sympathetic innervation results in an absence of sweating below the level of the injury
Temperature Regulation	Nil	When body temperature lowers the following occur as regulated by the hypothalamus via sympathetic mechanisms to increase temperature[3] • Piloerection • Shivering • Vasoconstriction	Due to loss of communication between the hypothalamus and the Sympathetic nervous system following SCI, the body is unable to increase temperature by piloerection, shivering and vasoconstriction increasing likelihood of hypothermia.[3] More common in injuries above T6[3]

Table 1.

The most well-known effect of a SCI is a loss (partial or complete) of movement and sensation below the level of the injury. However, spinal cord damage will also result in changes in the functioning of many other body systems which are summarised below.

- Autonomic Nervous System
  - Altered temperature regulation, loss of ability to sweat and shiver below the level of the injury.
  - Autonomic Dysreflexia is a medical emergency that can occur in individuals with a SCI above the level of T6. See Autonomic Dysreflexia Section
- Neurogenic bladder dysfunction. See Neurogenic Bladder Section
- Neurogenic bowel dysfunction. See Neurogenic Bowel Section
- Cardiovascular System
  - The cardiovascular system is affected by the reduction or loss of sympathetic nervous system responses below the level of the injury [2]
  - Neurogenic Shock is a complication of SCI due to the interruption of sympathetic output of the autonomic nervous system. Cardiovascular implications may include Bradycardia, arteriolar dilation, reduced venous return and subsequent systemic hypotension [5]
  - Increasing risk of deep vein thrombosis (DVT) due to venous stasis and impaired circulation [4,4]
  - Ongoing impairment in Blood Pressure regulation with an incidence of 74% of individuals with SCI having a BP response indicative of postural Hypotension [6]
  - Altered cardiovascular response to physical exercise [7]
- Musculoskeletal System
  - Changes in neural muscle tone, including muscle spasm and spasticity. See Spasticity Section
  - Increased strain on joints, particularly shoulders, increasing risk of overuse injuries

    - Reduction in bone density leading to increased risk of osteoporosis and fractures
- Respiratory Function. See Respiratory Section
- Sexual Function
    - Varies depending on neurological level and completeness of injury
    - In females SCI impact on lubrication during stimulation and orgasm. Fertility remains unaffected
    - In males SCI impacts reflex and psychogenic erectile function and ejaculatory function. Fertility may be reduced however individuals are able to have children.
- Skin Integrity
    - Increased risk of skin breakdown and pressure areas due to impaired circulation, sensation and mobility. See Skin Section

Most body parts and organs can repair themselves after damage, but the spinal cord cannot. Although attempts to regenerate function after spinal cord damage is currently being researched worldwide, there is not yet a cure.

Neurological classification of Spinal Cord Injury

The impact of a SCI depends on the neurological level and the severity of the damage to the spinal cord. It is this neurological level which determines the expected level of functional independence for the individual, and it is this level which should be used in the diagnosis of a SCI as well as in education to the individual and their family/friends.

The **neurological level of injury** is defined as the lowest (most caudal) spinal segment with normal motor and sensory function. Therefore, below this level, motor and/or sensory function is reduced or absent. The neurological level of injury may differ from the orthopaedic level of injury (level of damage to the vertebral column). In terms of determining functional expectations and prognosis following a SCI, it is important to differentiate between these.

Paraplegia is the impairment of motor and sensory function in the lower limbs. Paraplegia relates to a spinal cord injury at or below the level of T1. **Tetraplegia** (also known as quadriplegia) is the impairment of motor and sensory function in all four limbs. Tetraplegia results from a SCI at or above the level of C7.

A **complete** spinal cord injury means that there is a total blockage of signals from the brain to the lowest sacral segment (S4/5) i.e. No sensation or motor function at S4/5. An **incomplete** spinal cord injury means there is some preservation of nerves from the brain to the lowest sacral segment of the spinal cord (S4/5) i.e.: some preservation of sensory and/or motor function at S4/5. The amount of movement and feeling that is preserved below the level of the injury in an incomplete SCI is different for each person as it depends on the severity of damage to the spinal cord.

The American Spinal Injury Association (ASIA) assessment is the International Standard for the Neurological Classification of Spinal Cord Injury. The ASIA assessment is conducted by trained Spinal Physicians, Allied Health and Senior Nurses in Western Australia.

The ASIA assessment consists of:

- Motor Examination of 5 key muscle groups for the upper and lower limbs, scored from 0-5 using manual muscle testing.
- Sensory Examination that assesses light touch and pin prick sensation in each dermatome from C2 – S4/5, scored from 0-2 (absent, impaired or normal).
- Digital Rectal Examination that evaluates the presence / absence of deep anal sensation and voluntary anal contraction. This indicates the preservation, or absence, of sensory and motor function at the lowest sacral segment (S4/5) and is important in classifying the completeness of the SCI.

** Refer to the 'Useful Resources' section at the end of this document for PDF links to the ASIA website (including ASIA Examination Form, e-learning, Motor and Sensory Examination Guides*).

The **ASIA IMPAIRMENT SCALE (AIS)** classifies the completeness of the SCI. There are 5 classifications which are summarised below:

- AIS A (Complete)
- AIS B (Sensory Incomplete)
- AIS C (Motor Incomplete – weak)
- AIS D (Motor Incomplete – stronger)
- AIS E (Initial motor and sensory deficit has returned to normal).

As a general guide, the more incomplete the SCI, particularly in the early stages following injury, the better the prognosis for potential neurological recovery. Refer to the links above for further definitions related to ASIA Impairment Scale classifications.

The **Zone of Partial Preservation (ZPP)** is used to identify the lowest spinal level whereby some motor or sensory function is preserved following a complete SCI. The ZPP captures the extent of residual neurological function that can be present after a complete SCI, as this residual function has an impact on functional expectations following injury. This is not relevant for incomplete SCI as the ZPP will always be the lowest sacral segment (S4/5).

The ASIA assessment also classifies 6 **syndromes** of distinct patterns of neurological impairment for Incomplete SCI. This terminology is often used clinically and is summarised below [8]:

1. Central Cord Syndrome - characterised by greater bilateral weakness of the upper limbs compared to the lower limbs, and is almost exclusively related to cervical SCI.
2. Brown-Sequard Syndrome – occurs as a result of injury to one side of the spinal cord, whilst the other half is preserved. Clinical presentation is that of voluntary motor weakness and proprioceptive impairment on the ipsilateral side of the body, with contralateral impairment of pain and temperature sensation. This occurs due to the separation of sensory pathways within the spinal cord responsible for the transmission of pain-temperature and proprioceptive messages.
3. Anterior Cord Syndrome – characterised by a SCI that affects the anterior two thirds of the cord, whilst the posterior columns are preserved. Clinical presentation is that of motor and pin-prick sensation impairment, with relative preservation of light touch, proprioception and deep-pressure sensation.
4. Posterior Cord Syndrome – characterised by a lesion of the dorsal columns resulting in impairment of proprioceptive and light touch sensation, whilst motor

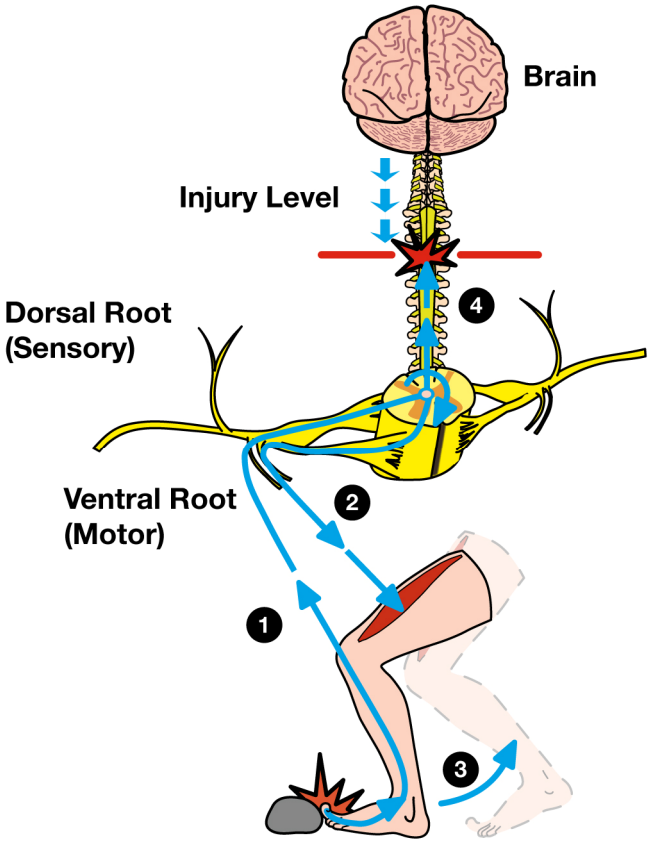
function and other sensory pathways (pin-prick, temperature) are relatively preserved.

5. Conus Medullaris – characterised by a mixed presentation of reflexive activity of the sacral spinal segments with injuries that occur at the level where the spinal cord ends (e.g. may have intact or absent bulbocarnosus reflex).
6. Cauda Equina Syndrome – Occurs with an injury below the level where the spinal cord ends, therefore resulting in flaccid reflexes due to a LMN injury.

Upper Motor Neuron versus Lower Motor Neuron injury.

A SCI above the level where the spinal cord ends (~T12/L1) will result in an **Upper Motor Neuron (UMN)** injury. Following an UMN injury, reflexive activity below the level of the injury is preserved and is usually heightened (hyper-reflexic). A SCI that occurs at or below the end of the spinal cord, ie within the Cauda Equina, is an injury to the peripheral nerves and is therefore classified as a **Lower Motor Neuron (LMN)** Injury. Following a LMN injury, reflexive activity below the level of the injury is absent (hypo-reflexic or flaccid).

Reflexes are a rapid, automatic reaction to a stimulus that occur in everybody, often acting as a protective mechanism. There are many types of normal reflexes that occur in the body, these include protective reflexes to potential harmful stimuli. After a SCI, individuals may still experience reflexive activity below the level of their lesion however this is dependant upon the level of injury. The difference between the reflexes of a person with a SCI, to those without, is that the voluntary control (ability to 'override') these reflexes are affected by the spinal cord lesion.



The reflex arc with spinal cord injury above T12/L1

Diagram 3: Spinal Reflex Arc following UMN Lesion of the Spinal Cord

Initially after spinal cord damage there is a period of **Spinal Shock** where reflexes below the level of the injury (including bulbocavernosus) are absent. These reflexes can return anytime from 2 weeks to 3 months, usually around 1 to 6 weeks. Until your reflexes return there is a 'flaccid' effect. This period of spinal shock has an impact on the function of many body systems (including bladder and bowel) that require medical management and monitoring.

The **Bulbocavernosus reflex ('bulbo')** is the reflex activity of the sacral nerves S2-S4/5. After a spinal cord injury, this reflex will initially be flaccid (spinal shock), it will return if the individual has an UMN injury, however will remain absent in a LMN injury.

This reflex is assessed by trained nursing and medical staff. The test involves inserting a gloved finger into the rectum, followed by stimulation by either squeezing the glands of the penis or clitoris, or firmly pulling (briefly) on an indwelling catheter. If this reflex is intact anal sphincter will reflexively tighten around the examiners finger. The result of this assessment will be documented as being Positive (present) or Negative (absent).

The presence or absence of the bulbocavernosus reflex determines the most effective means of bowel management for that individual at that stage of their SCI. It is important not to confuse the presence or absence of this reflexive (involuntary) activity with that of voluntary anal contraction (of the external anal sphincter). In other words, reflexive activity is not an indicator of the completeness of a SCI.

Presentation of those with an UMN lesion

- Reflexes present
- Involuntary muscle spasm present below neurological level of injury
- Reflex erections
- Overactive bladder
- Suppositories useful in bowel management
- Positive **Bulbocavernosus reflex**

Presentation of those with a LMN lesion

- Flaccid paralysis
- Muscle wastage to lower limbs
- Absence of reflexes, including reflex erection, any bladder activity and rectal contraction
- Require manual evacuation for bowels
- Negative **Bulbocavernosus reflex**

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Useful resources

The American Spinal Injury Association:

- http://www.asia-spinalinjury.org/elearning/elearning.php - e-learning packages related to the International Standards for the Neurological Classification of Spinal Cord Injury.
- http://www.asia-spinalinjury.org/elearning/motor_exam.php - Motor Examination Guide
- http://www.asia-spinalinjury.org/elearning/sensory_exam.php - Sensory Examination Guide
- http://www.asia-spinalinjury.org/elearning/ISNCSCI.php - International Standards for the Neurological Classification of Spinal Cord Injury assessment form

The Rick Hansen Institute have developed an online algorithm which classifies and interprets the ASIA Assessment

- http://www.isncscialgorithm.com

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