A spinal cord injury (SCI) refers to any injury to the spinal cord that is caused by trauma instead of disease. Depending on where the spinal cord and nerve roots are damaged, the symptoms can vary widely, from pain to paralysis to incontinence. Spinal cord injuries are described at various levels of "incomplete", which can vary from having no effect on the patient to a "complete" injury which means a total loss of function.

Treatment of spinal cord injuries starts with restraining the spine and controlling inflammation to prevent further damage. The actual treatment can vary widely depending on the location and extent of the injury. In many cases, spinal cord injuries require substantial physical therapy and rehabilitation, especially if the patient's injury interferes with activities of daily life.

Spinal cord injuries have many causes, but are typically associated with major trauma from motor vehicle accidents, falls, sports injuries, and violence. Research into treatments for spinal cord injuries includes controlled hypothermia and stem cells, though many treatments have not been studied thoroughly and very little new research has been implemented in standard care.
## Divisions of Spinal Segments

### Segmental Spinal Cord Level and Function

<table>
<thead>
<tr>
<th>Level</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1-C6</td>
<td>Neck flexors</td>
</tr>
<tr>
<td>C1-T1</td>
<td>Neck extensors</td>
</tr>
<tr>
<td>C3, C4, C5</td>
<td>Supply diaphragm (mostly C4)</td>
</tr>
<tr>
<td>C5, C6</td>
<td>Shoulder movement, raise arm (deltoid); flexion of elbow (biceps); C6 externally rotates the arm (supinates)</td>
</tr>
<tr>
<td>C6, C7</td>
<td>Extends elbow and wrist (triceps and wrist extensors); pronates wrist</td>
</tr>
<tr>
<td>C7, T1</td>
<td>Flexes wrist</td>
</tr>
<tr>
<td>C7, T1</td>
<td>Supply small muscles of the hand</td>
</tr>
<tr>
<td>T1 -T6</td>
<td>Intercostal and trunk above the waist</td>
</tr>
<tr>
<td>T7-L1</td>
<td>Abdominal muscles</td>
</tr>
<tr>
<td>L1, L2, L3, L4</td>
<td>Thigh flexion</td>
</tr>
</tbody>
</table>
Signs observed by a physician and symptoms experienced by a patient will vary depending on where the spine is injured and the extent of the injury. These are all determined by the area of the body that the injured area of the spine innervates. A section of skin innervated through a specific part of the spine is called a dermatome, and spinal injury can cause pain, numbness, or a loss of sensation in the relevant areas. A group of muscles innervated through a specific part of the spine is called a myotome, and injury to the spine can cause problems with voluntary motor control. The muscles may contract uncontrollably, become weak, or be completely unresponsive. The loss of muscle function can have additional effects if the muscle is not used, including atrophy of the muscle and bone degeneration.

A severe injury may also cause problems in parts of the spine below the injured area. In a "complete" spinal injury, all function below the injured area is lost. In an "incomplete" injury, some or all of the functions below the injured area may be unaffected. If the patient has the ability to contract the anal sphincter voluntarily or to feel a pinprick or touch around the anus, the injury is considered to be incomplete. The nerves in this area are connected to the very lowest region of the spine, the sacral region, and retaining sensation and function in these parts of the body indicates that the spinal cord is only partially damaged.

A complete injury frequently means that the patient has little hope of functional recovery. The relative incidence of incomplete injuries compared to complete spinal cord injury has improved over the past half century, due mainly to the emphasis on better initial care and stabilization of spinal cord injury patients. Most patients with incomplete injuries recover at least some function.

In addition to sensation and muscle control, the loss of connection between the brain and the rest of the body can have specific effects depending on the location of the injury.

Determining the exact "level" of injury is critical in making accurate predictions about the specific parts of the body that may be affected by paralysis and loss of function. The level is assigned according to the location of the injury by the vertebra of the spinal column. While the prognosis of complete injuries is generally predictable since recovery is rare, the symptoms of incomplete injuries can vary and it is difficult to make an accurate prediction of the outcome.

### Cervical

Cervical (neck) injuries usually result in full or partial tetraplegia (Quadriplegia). However, depending on the specific location and severity of trauma, limited function may be retained.
- Injuries at the C-1/C-2 levels will often result in loss of breathing, necessitating mechanical ventilators or phrenic nerve pacing.
- C3 vertebrae and above: Typically results in loss of diaphragm function, necessitating the use of a ventilator for breathing.
- C4: Results in significant loss of function at the biceps and shoulders.
- C5: Results in potential loss of function at the shoulders and biceps, and complete loss of function at the wrists and hands.
- C6: Results in limited wrist control, and complete loss of hand function.
- C7 and T1: Results in lack of dexterity in the hands and fingers, but allows for limited use of arms.

Patients with complete injuries above C7 typically cannot handle activities of daily living and cannot function independently.

Additional signs and symptoms of cervical injuries include:

- Inability or reduced ability to regulate heart rate, blood pressure, sweating and hence body temperature.
- Autonomic dysreflexia or abnormal increases in blood pressure, sweating, and other autonomic responses to pain or sensory disturbances.

**Thoracic**

Complete injuries at or below the thoracic spinal levels result in paraplegia. Functions of the hands, arms, neck, and breathing are usually not affected.

- T1 to T8: Results in the inability to control the abdominal muscles. Accordingly, trunk stability is affected. The lower the level of injury, the less severe the effects.
- T9 to T12: Results in partial loss of trunk and abdominal muscle control.

**Lumbosacral**

The effects of injuries to the lumbar or sacral regions of the spinal cord are decreased control of the legs and hips, urinary system, and anus.

- Bowel and bladder function is regulated by the sacral region of the spine. In that regard, it is very common to experience dysfunction of the bowel and bladder, including infections of the bladder and anal incontinence, after traumatic injury.
- Sexual function is also associated with the sacral spinal segments, and is often affected after injury. During a psychogenic sexual experience, signals from the brain are sent to the sacral parasympathetic cell bodies at spinal levels S2-S4 and in case of men, are then relayed to the penis where they trigger an erection. A spinal cord lesion of descending fibers to levels S2-S4 could, therefore, potentially result in the loss of psychogenic erection. A reflexogenic erection, on the other hand, occurs as a result of direct physical contact to the penis or other erotic areas such as the ears, nipples or neck, and thus not involving descending fibers from the brain. A reflex erection is involuntary and can occur without sexually stimulating thoughts. The nerves that control a man’s ability to have a reflex erection are located in the sacral nerves (S2-S4) of the spinal cord and could be affected after a spinal cord injury at this level.
Other syndromes of incomplete injury

Central cord syndrome is a form of incomplete spinal cord injury characterized by impairment in the arms and hands, and, to a lesser extent, in the legs. This is also referred to as inverse paraplegia, because the hands and arms are paralyzed while the legs and lower extremities work correctly.

Most often the damage is to the cervical or upper thoracic regions of the spinal cord, and characterized by weakness in the arms with relative sparing of the legs with variable sensory loss.

This condition is associated with ischemia, hemorrhage, or necrosis involving the central portions of the spinal cord (the large nerve fibers that carry information directly from the cerebral cortex). Corticospinal fibers destined for the legs are spared due to their more external location in the spinal cord.

This clinical pattern may emerge during recovery from spinal shock due to prolonged swelling around or near the vertebrae, causing pressures on the cord. The symptoms may be transient or permanent.

Anterior cord syndrome is often associated with flexion type injuries to the cervical spine, causing damage to the anterior portion of the spinal cord and/or the blood supply from the anterior spinal artery. Below the level of injury motor function, pain sensation, and temperature sensation are lost. While touch, proprioception (sense of position in space), and sense of vibration remain intact.

Posterior cord syndrome can also occur, but is very rare. Damage to the posterior portion of the spinal cord and/or interruption to the posterior spinal artery causes the loss of proprioception and epicritic sensation (e.g.: stereo gnosis, graphesthesia) below the level of injury. Motor function, sense of pain, and sensitivity to light touch remain intact.

Brown-Séquard syndrome usually occurs when the spinal cord is hemi sectioned or injured on the lateral side. True hemi sections of the spinal cord are rare, while partial lesions due to penetrating wounds (e.g.: gunshot wounds or knife penetrations) are more common. On the ipsilateral side of the injury (same side), there is a loss of motor function, proprioception, vibration, and light touch. Contralaterally (opposite side of injury), there is a loss of pain, temperature, and crude touch sensations.

Tabes Dorsalis results from injury to the posterior part of the spinal cord, usually from infection diseases such as syphilis, causing loss of touch and proprioceptive sensation.

Conus medullaris syndrome results from injury to the tip of the spinal cord, located at L1 vertebra.

Causes

Spinal cord injuries are most often traumatic, caused by lateral bending, dislocation, rotation, axial loading, and hyperflexion or hyperextension of the cord or cauda equina. Motor vehicle accidents are the most common cause of SCIs, while other causes include falls, work-related accidents, sports injuries, and penetrations such as stab or gunshot wounds. SCIs can also be of a non-traumatic origin, as in the case of cancer, infection, intervertebral disc disease, vertebral injury and spinal cord vascular disease.

Diagnosis

A radiographic evaluation using an x-ray, MRI or CT scan can determine if there is any damage to the spinal cord and where it is located. A neurologic evaluation incorporating sensory testing and reflex testing can help determine the motor function of a person with a SCI.
Management

Modern trauma care includes a step called clearing the cervical spine, where a patient with a suspected injury is treated as if they have a spinal injury until that injury is ruled out. The objective is to prevent any further spinal cord damage. Patients are immobilized at the scene of the injury until it is clear that there is no damage to the highest portions of the spine. This is traditionally done using a device called a long spine board.

Once the patient is brought to a hospital and immediate life-threatening injuries have been addressed, they are evaluated for spinal injury, typically by x-ray or CT scan. Complications of spinal cord injuries include neurogenic shock, respiratory failure, pulmonary edema, pneumonia, pulmonary emboli and deep venous thrombosis, many of which can be recognized early in treatment and avoided. SCI patients often require extended treatment in an intensive care unit.

Surgery may also be necessary to remove any bone fragments from the spinal canal and to stabilize the spine. Inflammation can cause further damage to the spinal cord, and patients are sometimes treated with a corticosteroid drug such as methylprednisolone to reduce swelling. The drug is used within 8 hours of the injury. This practice is based on the National Acute Spinal Cord Injury Studies (NASCIS) I and II, though other studies have shown little benefit and concerns about side effects from the drug have changed this practice. A food dye, brilliant blue G, has also been shown to have some effect at reducing inflammation after spinal injury.

One experimental treatment, therapeutic hypothermia, is used but there is no evidence that it improves outcomes. Maintaining mean arterial blood pressures of at least 85 to 90 mmHg using intravenous fluids, transfusion, and vasopressors to ensure adequate blood supply to nerves and prevent damage is another treatment with little evidence of effectiveness.

Rehabilitation

The rehabilitation process following a spinal cord injury typically begins in the acute care setting. Physical therapists, occupational therapists, social workers, psychologists and other health care professionals typically work as a team to decide on goals with the patient and develop a plan of discharge that is appropriate for the patient’s condition.

In the acute phase physical therapists focus on the patient’s respiratory status, prevention of indirect complications (such as pressure sores), maintaining range of motion, and keeping available musculature active. Physical therapists can assist immobilized patients with effective cough techniques, secretion clearance, stretching of the thoracic wall, and suggest abdominal support belts when necessary. The amount of time a patient is immobilized may depend on the level of the spinal cord injury. Physical therapists work with the patient to prevent any complications that may arise due to this immobilization.

Improvement of loco motor function is one of the primary goals for people with spinal cord injury. Many strategies exist to improve this function and loco motor training is used in rehabilitation after spinal cord injury. A 2007 systematic review examined four randomized controlled trials involving 222 patients. The review found insufficient evidence to conclude which loco motor training strategy improves walking function most for people with spinal cord injury.

As a team, health-care professionals help to re-orient the patient, provide support for the patient and family, and begin to develop goals with the patient.

Occupational therapy plays an important role in the management of SCI.
Recent studies emphasize the importance of early occupational therapy, started immediately after the client is stable. This process includes teaching of coping skills, and physical therapy.

In the first step, acute recovery, the focus is on support and prevention. Interventions aim to give the individual a sense of control over a situation in which the patient likely feels little independence.

As the patient becomes more stable, they may move to a rehabilitation facility or remain in the acute care setting. The patient begins to take more of an active role in their rehabilitation at this stage and works with the team to develop reasonable functional goals.

Though rehabilitation interventions are performed during the acute phase, recent literature suggests that 44% of the total hours spent on rehabilitation during the first year after spinal cord injury, occur after discharge from inpatient rehabilitation. Participants in this study received 56% of their total physical therapy hours and 52% of their total occupational therapy hours after discharge. This suggests that inpatient rehabilitation lengths of stay are reduced and that post-discharge therapy may replace some of the inpatient treatment.

Whether patients are placed in inpatient rehabilitation or discharged, physical therapists attempt to maximize functional independence at this stage. Depending on the level of the spinal cord injury, whatever sparing the patient has is optimized. Bed mobility, transfers, wheelchair mobility skills, and performing other activities of daily living (ADLs) are just a few of the interventions that physical therapists can help the patient with.

ADLs can be difficult for an individual with a spinal cord injury; however, through the rehabilitation process, individuals with SCI may be able to live independently in the community with or without full-time attendant care, depending on the level of their injury.

Further interventions focus on support and education for the individual and caregivers. This includes an evaluation of limb function to determine what the patient is capable of doing independently, and teaching the patient self-care skills. Independence in daily activities like eating, bowel and bladder management and mobility is the goal, as obtaining competency in self-care tasks contributes significantly to an individual's sense of self confidence and reduces the burden on caregivers. Quality of life issues such as sexual health and function are also addressed.

Assistive devices such as wheelchairs have a substantial effect on the quality of life of the patient, and careful selection is important. Teaching the patient how to transfer from different positions, such as from a wheelchair into bed, is an important part of therapy, and devices such as sliding transfer boards and grab bars can assist in these tasks. Individuals who are able to transfer independently from their wheelchair to the driver's seat using a sliding transfer board may be able to return to driving in an adapted vehicle. Complete independence with driving also requires the ability to load and unload one's wheelchair from the vehicle.

In addition to acquiring skills such as wheelchair transfers, individuals with a spinal cord injury can greatly benefit from exercise reconditioning. In the majority of cases, spinal cord injury leaves the lower limbs either entirely paralyzed, or with insufficient strength, endurance, or motor control to support safe and effective physical training. Therefore, most exercise training employs the use of arm crank aerometry, wheelchair aerometry, and swimming. In one study, subjects with traumatic spinal cord injury participated in a progressive exercise training program, which involved arm aerometry and resistance training. Subjects in the exercise group experienced significant increases in strength for almost all muscle groups when compared to the control group. Exercisers also reported less stress, fewer depressive symptoms, greater satisfaction with physical functioning, less pain, and better quality of life. Physical therapists are able to provide a variety of exercise interventions, including, passive range of motion exercises, upper body wheeling (arm crank aerometry), functional electrical
stimulation, and electrically stimulated resistance exercises all of which can improve arterial function in those living with SCI. Physical therapists can improve the quality of life of individuals with spinal cord injury by developing exercise programs that are tailored to meet individual patient needs. Adapted physical activity equipment can also be used to allow for sport participation: for example, sit-skis can be used by individuals with a spinal cord injury for cross-country or downhill skiing.

Body weight supported treadmill training is another intervention that physiotherapists may assist with. Body weight supported treadmill training has been researched in an attempt to prevent bone loss in the lower extremities in individuals with spinal cord injury. Research has shown that early weight-bearing after acute spinal cord injury by standing or treadmill walking (5 times weekly for 25 weeks) resulted in no loss or only moderate loss in trabecular bone compared with immobilized subjects who lost 7-9% of trabecular bone at the tibia. Gait training with body weight support, among patients with incomplete spinal cord injuries, has also recently been shown to be more effective than conventional physiotherapy for improving the spatial-temporal and kinematic gait parameters.

The patient’s living environment can also be modified to improve independence. For example, ramps or lifts can be added to a patient's home, and part of rehabilitation involves investigating options for returning to previous interests as well as developing new pursuits. Community participation is an important aspect in maintaining quality of life.

**Prognosis**

In general, patients with complete injuries recover very little lost function and patients with incomplete injuries have more hope of recovery. Some patients that are initially assessed as having complete injuries are later changed to incomplete injuries.

Recovery is typically quickest during the first six months, with very few patients experiencing any substantial recovery more than nine months after the injury.

**Tetraplegia (quadriplegia)**

The ASIA motor score (AMS) is a 100 point score based on ten pairs of muscles each given a five point rating. A person with no injury should score 100. In complete tetraplegia, a recovery of nine points on this scale is average regardless of where the patient starts. Patients with higher levels of injury will typically have lower starting scores.

In incomplete tetraplegia, 46 percent of patients were able to walk one year after injury, though they may require assistance such as crutches and braces. These patients had similar recovery in muscles of the upper and lower body. Patients who had pinprick sensation in the sacral dermatomes such as the anus recovered better than patients that could only sense a light touch.

**Paraplegia**

In one study on 142 individuals after one year of complete paraplegia, none of the patients where the initial injury was above the ninth thoracic vertebra (T9) were able to recover completely. Less than half, 38 percent, of the studied subjects had any sort of recovery. Very few, five percent, recovered enough function to walk, and those required crutches and other assistive devices, and all of them had injuries below T11. A few of the patients, four percent, had what were originally classified as complete injuries and were reassessed as having incomplete injuries, but only half of that four percent regained bowel and bladder control.
Of the 54 patients in the same study with incomplete paraplegia 76 percent were able to walk with assistance after one year. On average, patients improved 12 points on the 50 point lower extremity motor score (LEMS) scale. The amount of improvement was not dependent on the location of the injury, but patients with higher injuries had lower initial motor scores and correspondingly lower final motor scores. A LEMS of 50 is normal, and scores of 30 or higher typically predict ability to walk.

**Epidemiology**

Spinal injury can occur without trauma. Many people suffer transient loss of function ("stingers") in sports accidents or pain in "whiplash" of the neck without neurological loss and relatively few of these suffer spinal cord injury sufficient to warrant hospitalization. The prevalence of spinal cord injury is not well known in many large countries. In some countries, such as Sweden and Iceland, registries are available. In the United States, the incidence of spinal cord injury has been estimated to be about 40 cases (per 1 million people) per year or around 12,000 cases per year. The most common causes of spinal cord injury are motor vehicle accidents, falls, violence and sports injuries. The average age at the time of injury has slowly increased from a reported 29 years of age in the mid-1970s to a current average of around 40. Over 80% of the spinal injuries reported to a major national database occurred in males. In the United States there are around 250,000 individuals living with spinal cord injuries. In China, the incidence of spinal cord injury is approximately 60,000 per year.

**Research directions**

Scientists are investigating many promising avenues for treatment of spinal cord injury. Numerous articles in the medical literature describe research, mostly in animal models, aimed at reducing the paralyzing effects of injury and promoting regrowth of functional nerve fibers. Despite the devastating effects of the condition, commercial funding for research investigating a cure after spinal cord injury is limited, partially due to the small size of the population of potential beneficiaries. Some experimental treatments, such as systemic hypothermia, have been performed in isolated cases in order draw attention to the need for further preclinical and clinical studies to help clarify the role of hypothermia in acute spinal cord injury. Despite the limitation on funding, a number of experimental treatments such as local spine cooling and oscillating field stimulation have reached controlled human trials.

Advances in identification of an effective therapeutic target after spinal cord injury have been newsworthy, and considerable media attention is often drawn towards new developments in this area. However, aside from methylprednisolone, none of these developments have reached even limited use in the clinical care of human spinal cord injury in the U.S.