Anatomy of Nerve Tissue

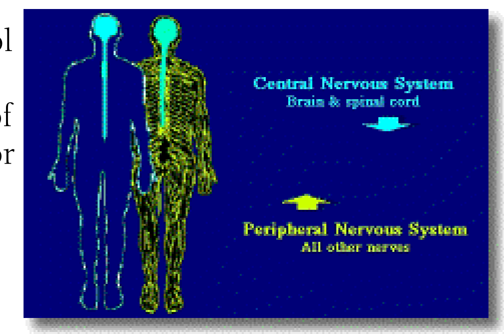
It is important for you as a spinal cord injured person to know as much as possible about your injury. This knowledge will help you better understand the changes in the way your body works.

A damaged spinal cord is the most complex injury a person can receive and yet survive. Describing the structure and function of the spinal cord is also rather complex and, at times, difficult. To make this task easier, this chapter is divided into three main sections: anatomy, physiology, and pathology. We'll explain the most important terms and show them on diagrams.

Anatomy

The basic building blocks of the body are called tissues. The body is made up of four different types of tissues: nerve tissue, connective tissue, muscle, and epithelium. Let's look at each of these more closely.

I. Nerve tissue

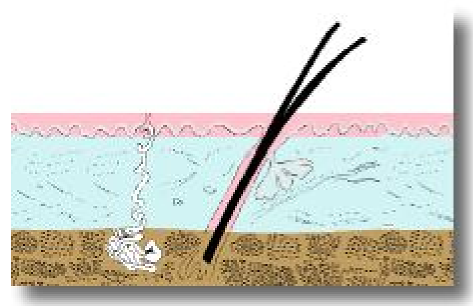


Nerve tissue carries information to and from the brain to control how the body works. There are two major divisions of nerve tissue: the central nervous system (called the CNS) composed of the brain and spinal cord, and the peripheral nervous system (or PNS) composed of the nerves and nerve endings in the rest of the body.

The CNS functions much like a computer. It receives messages from many areas of the body and sends out commands in response. Information and messages are processed in some parts of the brain consciously (thinking), and in other parts of the brain and in the spinal cord unconsciously (reflex response).

The PNS does not process information, but only transmits messages back and forth between the CNS and the rest of the body.

II. Connective tissue



Connective tissue is made up mainly of bone and cartilage and forms the largest portion of the skeletal system. Its function is to provide a strong framework for the body.

Bone is composed mainly of collagen fibers and a substance packed between the cells into which calcium is deposited . Calcium gives bone its hardness and stiffness.

Cartilage, like bone, also provides a framework for the body. It, too, is composed of collagen and a substance between the cells, but does not have calcium. It is more flexible than bone (like dense rubber) and forms the gliding surfaces of joints and the discs of the spine.

Fibrous tissue is a connective tissue made of collagen without the surrounding substance. This flexible material connects muscles to bones (tendons) and connects bones to bones (ligaments).

Yet another kind of connective tissue is adipose tissue (commonly called fat). Adipose tissue stores fat which provides energy to the body when food intake is low. Fat also acts as a cushion. Under the skin it provides padding over bones; and around the spinal cord, it acts as a shock absorber.

III. Muscle

Muscle is a special kind of tissue which is able to contract and move the bones of the skeleton. Skeletal muscles only move when told to do so by the CNS.

IV. Epithelium

This type of tissue includes skin and the linings of the stomach, the intestines, the bladder, and other hollow organs

Diagnostic Imaging

Pictures that show the internal structures of the living body are called diagnostic images. There are four common forms of diagnostic imaging used in the management of individuals with spinal cord injuries: x-rays, MRIs, ultrasound, and radionuclide scanning. Each technique has its own unique advantages and disadvantages.

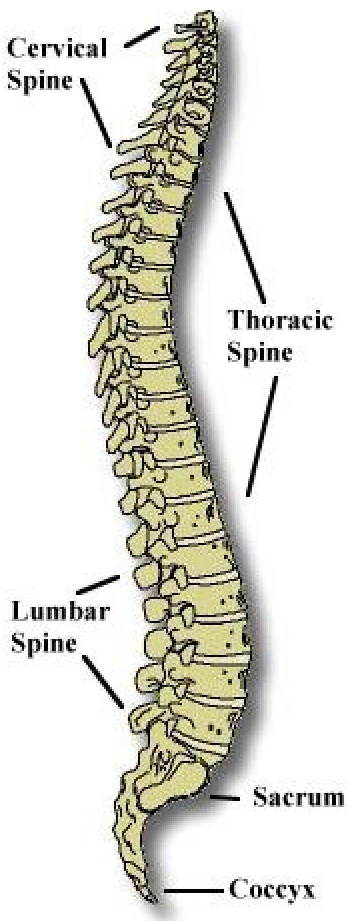
A standard x-ray or radiograph is a shadow picture that is formed on a photographic film by sending x-rays, a form of radiation, through the body. The x-rays are blocked to different degrees by the tissues of the body thus causing variations in the darkness of the x-ray film, and in the process producing a picture. Tissues that contain mineral (bone and teeth) block more x-rays than tissues made up largely of water (muscles, nerves, blood vessels, and many internal organs). Fatty tissues block fewer x-rays, and air spaces within the body block the least. X-rays are excellent for imaging the bones but cannot distinguish between one water density tissue and another.

Some water density structures can be better visualized by x-rays by the injection of a special medicine called a contrast material into the veins or a fluid space. Contrast material removed from the blood by the kidneys and excreted in the urine, for example, can outline kidneys, ureters, and bladder (a study called an intravenous pyelogram, or IVP). Injected into the cerebral spinal fluid, another contrast material can outline the spinal cord (a myelogram).

Computed tomography, or CT scanning, uses a computer and x-rays to provide cross-sectional images of the body. Like standard x-rays, the images obtained depend on the densities of the various tissues. Here again, injected contrast materials can help outline structures that might otherwise blend with their surrounding tissues.

Magnetic resonance imaging (MRI) obtains images of the body using powerful magnetic fields, radio waves, and computer analysis. Unlike x-rays, the images depend not on tissue densities but on the distribution of chemicals - mostly water molecules - within the body. With MRI we can visualize certain structures, such as brain and spinal cord, that are invisible to standard x-ray techniques. Ultrasonography uses sound waves to produce pictures based on differences in soft tissue densities. This technique is particularly helpful for outlining the kidneys and the urinary bladder.

Radionuclide scanning is performed through the injection into the bloodstream of chemicals attached to radioactive isotopes. Different chemicals will be attracted to different tissues in the body, so by choosing the proper substance, the radiologist can target specific body organs. The concentration of radioisotope in an organ can be seen with a device called a gamma camera producing a picture that outlines the organ and provides information on the organ's function. The levels of radiation exposure in such a test is low, little different than that provided by standard x-rays.



Anatomy of the Spine

The spine is the central support of the body. It provides a framework to support the trunk and rigid protection for the spinal cord. Portions of the spine surround the spinal cord providing bony protection for the spinal cord just as the skull protects the brain with a bony shell.

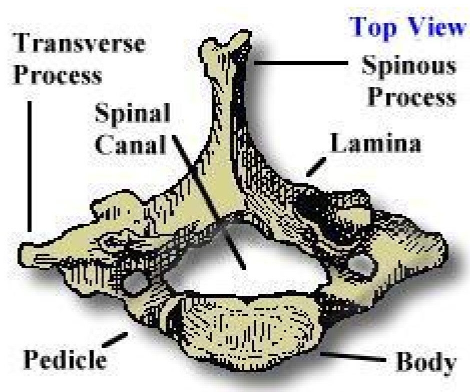
The spine is made up of 24 segments called vertebrae. These bones are stacked on top of one another.

There are seven vertebrae in the neck called cervical vertebrae. These are often referred to as C1 through C7 (top to bottom). The skull sits atop C1.

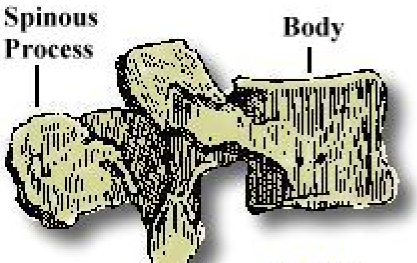
The 12 vertebrae in the region of the chest are called thoracic vertebrae. From top to bottom, these are referred to as T1 through T12. Two ribs are connected to each thoracic vertebra, one on either side. All the ribs and thoracic vertebrae together form the thoracic cage which surrounds and protects the heart and lungs.

The abdominal portion of the spine is formed by five lumbar vertebrae, referred to as L1 through L5. These vertebrae are much larger than those of the thoracic spine, which in turn are larger and stronger than the cervical vertebrae. The vertebrae increase in size from top to bottom to accommodate the increasing body weight.

Except for C1 and C2, all the vertebrae are similar in structure. A typical vertebrae is shown here. Each vertebrae has a drum shaped front section called the body. The purpose of the body is to support weight. Toward the back of the vertebrae, a bony arch (the lamina) surrounds a space called the spinal canal. The spinal cord and nerve roots are located in the spinal canal. Bony projections from the arch, called processes, serve as points of attachment for ligaments and muscles. The rear-most projection of each vertebrae is called the spinous process and is the only part of the vertebrae that can be felt through the skin (the ridge down the middle of your back).



The manner in which the vertebrae are stacked is shown above. Between vertebral bodies are small fibrocartilage cushions called discs. These act, in part, as shock absorbers. Strong ligaments bind the vertebrae together. Although the ligaments will stretch to permit limited movement, they are rigid enough to maintain alignment of the spinal canal as it passes through each vertebrae. The vertebrae, discs, and ligaments are able to maintain the correct alignment and consequently protect the spinal cord against all but the most violent injury.



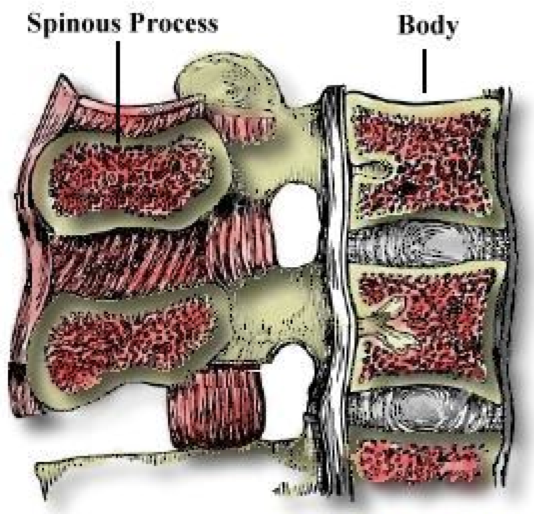
Side View

Between each adjoining vertebrae on each side of the spinal canal are openings called foramina. The foramina are openings for the nerve roots to pass out of the spinal canal and for blood vessels to pass into the canal.

The L5 vertebrae rests on the sacrum, a large bone made up of several smaller vertebrae-like bones which have fused together. The sacrum forms a base for the spine and the back part of the pelvis.

Spinal cord anatomy and physiology

The spinal cord extends down from the base of the brain through a hole in the bottom of the skull. The cord continues down the spinal canal approximately to the level of L1 (figure 4). Nerve roots leave the spinal cord through the foramina along the entire length of the spinal column beginning at the space between the skull and C1.



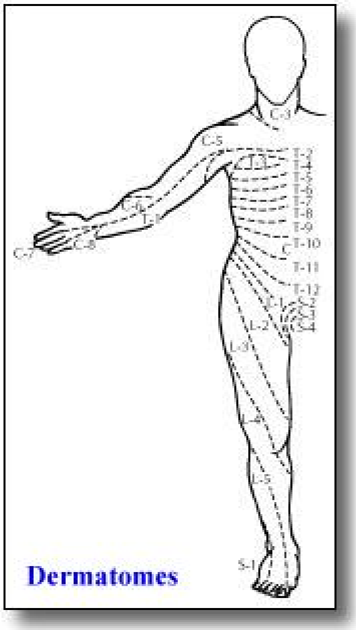
Cross section of spine

There are eight pairs of cervical nerve roots, twelve pairs of thoracic, five pairs of lumbar, and five pairs of sacral nerve roots. The cervical nerve roots are named for the vertebrae directly below the root as it exits from the spinal canal. An exception to this rule is the C8 nerve root which passes between C7 and T1. The thoracic and lumbar nerve roots derive their names from the vertebrae above the exit points. Sacral roots are named in order from top to bottom as they pass from the spinal canal through holes in the sacrum.

The spinal cord is considerably shorter than the spinal canal itself. The nerve roots angle downward increasingly from top to bottom from where they exit to the spinal cord to where they exit from the canal. The spinal canal below the level of L1 contains no spinal cord, only nerve roots. Bundled together the nerve roots resemble the strands of a horse's tail and are referred to collectively as the cauda equina (Latin term meaning horse's tail).

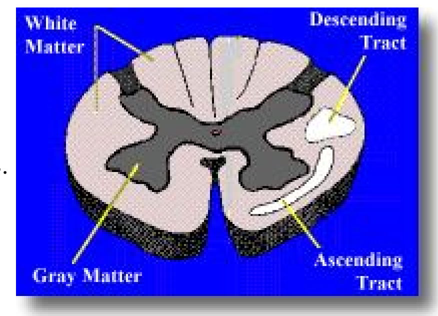
Outside the spinal canal, the nerve roots form into peripheral nerves (part of the peripheral nervous system, or PNS). These nerves carry motor commands from the brain and spinal cord to the individual muscles in the body. Sensory information is carried back along these nerves to the central nervous system (CNS). A great deal of other information controlling body function, but of which we are unaware (it is done automatically), is carried by the spinal cord and the attached network of peripheral nerves.

The skin of the body can be mapped out into separate areas called dermatomes. Each dermatome is supplied by a separate nerve root. By testing for sensation (feeling) in a specific dermatome, it is possible to find out whether that dermatome's nerve root is connected to the conscious portion of the brain.



Motor function carried by the nerve roots can be similarly tested. It is well known which nerve roots provide control to which muscles. In this manner, nerve root function is easily tested.

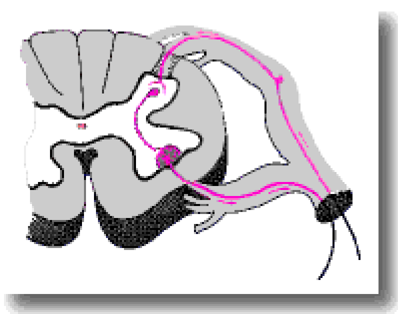
The spinal cord regulates some important unconscious (or automatic) body functions, including bowel and bladder control, and normal sexual organ function. These controls are governed by the lowest part of the cord, called the conus medullaris, and are transmitted by the sacral nerve roots.



Here's what the internal anatomy of the spinal cord looks like. The cord is composed of an outer layer of white matter and a central area of gray matter. In the white matter are major fiber tracts. These bundles of nerves carry messages up (sensory information) and down (motor commands) the spinal cord, to and from the brain. There are many more fiber tracts than are shown, many involving control of unconscious functions.

Connections between nerve cells are located in the gray matter. These connections, like the circuit boards in computers, process information received and send out commands in response. Trillions of nerve fibers are involved, the complexity in the spinal cord alone is far greater than any man-made computer yet conceived.

The information processing that takes place in the spinal cord and which occurs without conscious awareness is called a reflex response. The knee-jerk reflex is an example of the simplest type of reflex response. In striking the tendon of the knee with a reflex hammer, the doctor stretches the extensor muscle. A sensor within the muscle is stimulated, generating a signal which is sent along a peripheral nerve to the L4 nerve root. Here it goes into the gray matter of the lumbar spinal cord and connects with motor nerve cell. The motor nerve cell is stimulated, causing it to send a signal along its nerve fiber to the L4 nerve root. The signal is passed along the peripheral nerve to the extensor muscle, which is stimulated to contract, causing the knee to "kick." This entire sequence occurs without any involvement of the brain. The command to kick the knee has been given before the hammer blow has been consciously felt by the patient.



The knee jerk reflex is an example of a muscle stretch reflex. This type of reflex helps us maintain the position of our arms and legs and permits an able-bodied person to stand without consciously concentrating on the act of standing.

Most other reflexes in the spinal cord are far more complex in that they involve the participation of many more than two nerve cells. Many functions are served by reflex response, especially for the unconscious control of body function, such as blood pressure and body temperature. While an able-bodied individual can prevent his bladder or bowel from emptying when he does not wish it to, the actual emptying process in both cases is largely by reflex and is automatic. The brain often participates in reflex activities of the spinal cord. If an able-bodied person touches a hot stove, the pain causes the muscles to jerk the hand away. This action is caused by a spinal cord reflex. Another branch of the spinal nerve fiber goes up the spinal cord within the spinothalamic tract and carries the pain sensation to the conscious awareness of the brain. In controlling blood pressure, reflexes occur within the spinal cord. Messages are also sent to the brain, although they are not consciously sensed. The processing of such information is unconscious and is, as in the cord, a reflex response.

Pathology

The spinal cord is very well protected. If it is to be damaged, the ligaments or bones of the spine must be injured first. Either the alignment of the spinal canal must be disrupted, or a piece of bone or other material must enter the spinal canal to strike the cord.

The spinal cord is extremely delicate. A blow sufficient to permanently destroy a portion of the spinal cord might not even be perceived as painful if delivered to an arm or leg. The spinal cord does not need to be completely torn or cut across to permanently lose function; a simple bruise can cause the spinal cord to swell. The swelling, in turn, causes the formation of dense scar tissue through which no nerve function may pass.

A spinal cord may be very lightly bruised, however, and go on to recover some or possibly even all of its functions. An important indicator of possible outcome in the first few hours after an injury is whether the spinal cord injury is complete or incomplete. A complete injury is one in which there is no voluntary (as compared to reflex) muscle function or consciously felt sensation below the level of injury. Any preserved motor function or sensory information that passes the level of injury indicates that the injury is incomplete. A person with an incomplete injury may occasionally (but not always) show some recovery. A person with a complete injury almost never recovers significant useful function below the level of the injury.

When a spinal cord is injured, function is disturbed at the level of the injury, but not necessarily elsewhere in the cord. For example, after an injury of the cervical cord, we can identify four levels of nerve function.

Where the actual injury has occurred, all function is lost. The muscles controlled by the nerve roots rising from the injured segment stop functioning and sensory information sent to that portion of the cord is not processed.

The spinal cord below the level of injury loses all contact with the brain and conscious awareness but continues to function automatically (reflex response). In fact, reflexes may become more active than normal. the stretch reflex usually becomes excessively active, resulting in spasticity. Spasticity is the involuntary, often vigorous but purposeless contraction of muscles. While spasticity may interfere with function, other reflexes may be helpful. For example, the bladder reflexes can restore a portion of bladder control.

The third area of nerve function in a complete injury is the portion of the spinal cord well above the injury. This portion retains its connections with the brain and continues to function as it did before the injury for both voluntary muscle control and perceived sensations.

The fourth area, the spinal cord just above the injured segment, may not have been injured itself, but its nerve roots will have been injured because they angle downward after leaving the cord. Cut off from the peripheral nervous system by loss of nerve root function, this portion of the cord is initially functionless. Nerve roots are tougher than spinal cord and more likely to recover from injury. Often the portion of the spinal cord just above the injury recovers function in the months following the accident. Thus, a patient with a complete spinal cord injury may experience an improvement in function by one nerve root level. This type of recovery is called "root return".

When the lower tip of the spinal cord (the conus medullaris) is injured completely, reflex activity is not preserved below the injury because there is no cord below this point. A conus injury will knock out bladder and bowel reflexes and sacral sensation, but often the person is still able to walk since the leg muscles are controlled by higher spinal cord centers.

Since the spinal cord ends a L1, spinal injuries below L1 will not injure the cord. If nerve injury occurs in low lumbar fractures and dislocations, the injury affects the cauda equina. The outlook for recovery in cauda equina is always unknown. This is because the cauda is composed of nerve roots which, compared to the spinal cord, are very tough and can often recover from injury.

When spontaneous recovery occurs to nerve roots, or to an incompletely injured spinal cord, it may require as long as 18 months. After 18 months, there is very little chance for spontaneous return.

Treatment

The treatment of spinal cord injuries is too complex to discuss here in detail, but certain principles of injury management can be stated:

1. When a fracture or dislocation of the spine is unstable, spinal stability must be established. No injury is so bad that it cannot be made worse. An unstable fracture may cause further injury to nerve tissue and may also cause disabling pain. Spinal stability may be achieved internally (through surgery) or externally (braces, halo vests, or casts). The option chosen depends upon the injury.

2. If the injury is incomplete or if important nerve roots are involved and imaging studies show that there is pressure on the spinal cord or nerve root, an operation to decompress the spinal cord or nerve root may be indicated.

3. If the spinal cord injury is complete, operations to relieve pressure are more likely to make function worse than to lead to recovery. An operation for stabilization may still be indicated but not a procedure for decompression.

Levels of Spinal Cord Injury

For each subsequent level it is appropriate to assume that the muscles and the functions of the levels above are present.

C1-3

Functional muscles (partial innervation):
• sternocleidomastoid • upper trapezius • C3 - 1/3 of diaphragm
Movement produced
• neck movement • shoulder shrug • weak abdominal breathing if C3

C4

Functional muscles:
• 2/3 of diaphragm • levator scapulae
Movement produced:
• stronger neck movement • shoulder shrug • abdominal breathing

Goals:
• Independent propulsion and maneuvering of electric wheelchair on different types of terrain using chin or "sip and puff" controls. • Independent weight shift in electric wheelchair using chin or "sip and puff controls. • Independent use of mouth stick for written, typed, and telephone communication; operate tape recorder, push-button T, light switches, elevator; turn pages; recreational activities. • Independent use of environmental control unit to operate telephone, TV, radio, alarm clock, page turner, and electric appliances.

C5

Functional muscle:
• all of diaphragm • rhomboids • serratus anterior • deltoid • rotator cuff

- pectoralis major (clavicular portion)
- biceps
- brachioradialis

Movement produced:

- movement of arm at shoulder
- elbow flexion

Goals:

- Independent propulsion and maneuvering of electric wheelchair on different types of terrain using joy stick and universal cuff.
- Independent weight shift in wheelchair to relieve pressure.
- Able to instruct and assist others in pivot transfers.
- Independent light personal hygiene: teeth, hair, shaving or make-up using adaptive devices; wash hands and face with mitt with difficulty.
- Independent feeding with adaptive utensils and adaptive cup.
- Independent communication: written, typed, telephone, tape recorder with adaptive devices.
- May be independent in upper extremity dressing; independent with velcro closures.
- Possible driving with highly adapted van with lift.

C6

Functional muscles:

- pectoralis major (sternal portion)
- latissimus dorsi
- pronator teres
- extensor carpi radialis

Movement produced:

- stronger shoulder movement
- stronger elbow flexion
- wrist extension

Goals:

- Independent propulsion and maneuvering of standard wheelchair (equipped with rubber or plastic rims or quad pegs) with or without friction cuffs on different types of terrain.
- Independent pressure relief in wheelchair through weight shift of sitting push-up.
- Independent bed mobility: turn self in bed, come to sitting position, self positioning with or without bed rails, arm loops, or trapeze.
- Independent in same level transfer: bed, toilet, shower chair, car (C6- use sliding board and C7- load/unload wheelchair to and from car).
- Independent light personal hygiene, feeding, communication without adaptive devices.

- Independent showering in wheel-in shower or tub seat.
- Independent bowel and bladder care, intermittent cath, external cath.
- Independent upper extremity dressing/undressing; closures (buttons, zippers with devices): lower extremity dressing/undressing with devices.
- Independent homemaking and light housekeeping; meal preparation C6 - light meals: TV dinners, sandwiches, cook-in-bags: C7 - cooking with adaptive equipment).
- Independent driving with hand controls - recommended van with lift.

C7

Functional muscles:

- extensor carpi ulnaris
- flexor carpi radialis
- triceps
- long finger extensors

Movement produced:

- stronger wrist extension
- wrist flexion
- finger extension
- elbow extension

Goals:

- Similar to those for C6

C8

Functional muscles:

- stronger triceps
- stronger flexor carpi ulnaris
- stronger long finger extensors
- common finger flexors

Movement produced:

- stronger elbow, wrist, and finger extension
- finger flexion

Goals:

- Independent propulsion and maneuvering of standard wheelchair on different types of terrain.
- Independent in "wheelie" and negotiating 2 inch door sill, independent in negotiating a 4 inch curb.
- Independent in pressure relief in wheelchair.

- Independent same level transfers without adaptive equipment; variable ability to transfer wheelchair to and from floor and tub.
- Independent activities of daily living including heavy housekeeping.
- Independent driving with hand controls-recommendation of car or van depending on the individuals ability.

T1 - T12

Functional muscles:
• intrinsic hand muscles

T1-T12: intercostal muscles of respiration

Movement produced:
• side movement of fingers • opposition of the thumb

T1 -> T12 - progressively stronger respiration

Goals:

- Similar to those for C8
- Lumbar and sacral levels
- Injuries to the lower spinal cord and to the cauda equina are often mixed. Functional abilities will vary and goals must be individualized.
- Walking, even with braces and crutches, requires knee extension (L3 & L4) to be practical.
- Voluntary control of bladder and bowel function requires at least partially intact sacral nerve roots.

Research and the Future

We can ask individuals who have sustained spinal cord injuries to adapt to their disabilities so that they may continue living productive and, hopefully, enjoyable lives. We do not ask that they accept the injury. Medical science has not yet found a cure for spinal cord injury, but someday it will.

Throughout the world there is considerable research being directed at this topic. Current research is aimed at three different aspects of the problem.

I. Initial treatment

The spinal cord reacts to an injury by swelling. This swelling is followed by the formation of dense scar tissue which effectively blocks nerve repair. Significant advances have been made in developing techniques and medications that minimize the swelling and reduce the scar formation. All of those techniques and medications that are safe and proven are currently in use in every major trauma center in the United States.

The limitations of these initial treatments are that they are only effective if applied in the first few hours following the injury and none, as yet, are curative. To a small degree, we can reduce the severity of the injury and then only if the injury to the spinal cord is incomplete to begin with.

II. Rehabilitation research

This is the area where the greatest gains have been made. Throughout medical history a spinal cord injury uniformly resulted in death within 6 months. The medical advances that followed World War II changed that grim outlook. Now we can expect a properly rehabilitated individual with a spinal cord injury to live a nearly normal life span. We have learned to prevent the loss of kidney function and pressure sores, and we are developing techniques to provide cardiovascular conditioning exercise for many individuals. We have also discovered techniques to discover and develop minimal function in isolated muscles that have only partial nerve supply.

This area of research still presents many challenges. Chief among them is confronting the effects of aging on individuals with poor spinal cord function. As discoveries are made they will be made available to those who might benefit.

III. The Cure

This is the ultimate goal. The problem is complex and there are many obstacles to finding a cure, but in time the answer will be found. Before that cure is found there is much background information we must first understand concerning how nerves are made and how they react to injury.

We understand that scar formation after cord injury is a major problem. Nerve fibers cannot regenerate across scar tissue. How do we remove the scar tissue once it has formed?

The human body at birth contains all the nerve cells it will ever have. When a nerve cell dies we cannot currently replace it. We compensate by substituting other nerves or by learning rehabilitative coping strategies. The information is present within our DNA for generating new nerve cells. How do we access that information? If we learn how to generate new nerve cells, how do we direct them to make the proper connections in order to function? The magnitude of the problem seems enormous. There are over a trillion nerve cells in the human spinal cord (one million times one million) and each of those nerve cells will have between 2,000 and 20,000 connections with other nerve cells.

On the other hand we need only look back on the advances of medical science in this century and note the ever increasing rate of discovery to take heart. The answer will eventually be found and it is not unreasonable for each of us to hope to see that answer.

There are many sources to obtain additional and up-to-date information concerning spinal cord injury research. You can join organizations devoted to the subject and subscribe to their publications. If you own a computer and a modem you will find the internet full of information. You can ask members of your spinal cord injury team. Even if you do not actively seek this information you will not be left out. Rest assured, when discoveries are made they will not be kept secret.