COURSE DESCRIPTION:
This course provides an introduction to the anatomy and physiology of the spinal cord and spinal nerves. Because the control of muscles is affected primarily by the nervous system, this course describes certain aspects of the nervous system as it relates to muscles and to the practice of massage.

COURSE OBJECTIVES:
This course focuses on aspects of the nervous system as it relates to muscles and thus to the practice of massage therapy. When you finish this course you will be able to:

• Understand, through knowledge of nerve physiology, how massage therapy affects the functioning of the nervous system and its control of muscles.
• List six general effects of massage therapy on nervous tissue.
• Describe the processes of communication and repair in the CNS and PNS.
• List the areas in the body supported by plexuses and intercostals nerves.
• Describe the results of injuries to the brachial plexus and four other types of injuries common to nerves.
• Describe two ways the spinal cord promotes homeostasis.
• Describe the roles of muscle spindles and tendon organs.
• List three common sites of injury to the spinal cord and effects of transections.
OVERVIEW OF THE NERVOUS SYSTEM

Nervous tissue is one of the four main tissue types. It acts together with the endocrine system to regulate homeostasis in the body. The nervous system has many similarities with the endocrine system, and they control the activities of the body to keep it within optimal limits. However, the nervous system is extremely fast-acting, but shorter lived in action than the endocrine (hormonal) system. Think of how quickly you reflexively move when you accidentally put your hand on a hot stove or step on a tack.

The nervous system uses a series of electrochemical signals to receive information from the receptors of the body in the peripheral nervous system (PNS) regions and sends them to the central nervous system (CNS), the brain and spinal cord, to coordinate our actions. A new message is then sent to an effector organ or muscle to take action. This whole process of sending information from receptor to coordinator to reactor takes only a fraction of a second. That would not sound so amazing, if not for the fact that this is happening at millions of places in the body at once.

Nervous tissue monitors every body activity, including breathing, digestion and the beating of your heart. You do not even need to actively think about these things since they are done for you automatically (or autonomically) without your conscious thought. Certain of the manual therapies may utilize routine sensory, motor and reflex tests to assess the role of the nervous system in maintaining homeostasis.

Even in this age of technology and computers, no computer built today can rival the complexity of the human nervous system. The nervous system is a network of billions of interconnected nerve cells (neurons) that receive stimuli, coordinate this sensory information and cause the body to respond appropriately. The individual neurons transmit messages by means of a complicated electrochemical process. With a mass of only 3 percent of the total body weight, the nervous system is one of the smallest yet most complex of the 11 body systems. The two main subdivisions of the nervous system are the central nervous system (CNS), which consists of the brain and spinal cord, and the peripheral nervous system (PNS), which includes all nervous tissue outside the CNS.

The nervous system is also responsible for our perceptions, behaviors and memories, as well as initiating all voluntary movements. Because the nervous system is quite complex, it’s commonly considered in several chapters of a typical textbook. We will consider the organization of the nervous system, the structure and functions of the spinal cord and spinal nerves, as well as certain applications to the manual therapies.

STRUCTURES OF THE NERVOUS SYSTEM

The spinal cord connects to the brain, contains about 100 million neurons and is encircled by the bones of the vertebral column. Emerging from the spinal cord are 31 pairs of spinal nerves, each serving a specific region on the right or left side of the body. A nerve is a bundle of hundreds to thousands of axons, plus associated connective tissue and blood vessels that lie outside the brain and spinal cord. Nerves follow a defined path and serve specific regions of the body. Ganglia (swelling or knot; singular is ganglion) contain cell bodies of neurons, located outside the brain and spinal cord, and are closely associated with cranial and spinal nerves.

The walls of organs of the gastrointestinal tract contain extensive networks of neurons—called enteric plexuses—that help regulate the digestive system. Sensory receptors are dendrites of sensory neurons (such as sensory receptors in the skin) or separate, specialized cells that monitor changes in the internal or external environment (such as photoreceptors in the retina of the eye).

The branch of medical science that deals with the normal functioning and disorders of the nervous system is neurology. A neurologist is a physician who specializes in the diagnosis and treatment of disorders of the nervous system.

FUNCTIONS OF THE NERVOUS SYSTEM

Individual neurons carry incoming signals, or communicate with an array of neurons, or carry signals to effectors that produce an action. The nervous system thus carries out a complex assortment of tasks, such as sensing smells, producing speech, remembering past events, providing signals that control body movements and regulating the operation of internal organs. These diverse activities are grouped into three basic functions: sensory, integrative and motor.

Sensory function. The sensory receptors detect many different types of stimuli, both within your body, such as an increase in blood temperature, and outside your body, such as a touch on your arm. Sensory or afferent neurons carry this sensory information into the brain and spinal cord through cranial and spinal nerves.

Integrative function. The nervous system integrates (processes) sensory information by analyzing and
storing some of it and making decisions for appropriate responses. An important integrative function is perception, the conscious awareness of sensory stimuli. Perception occurs in the brain. Many of the neurons that participate in integration are interneurons (association neurons), whose axons extend for only a short distance and contact nearby neurons in the brain or spinal cord. Interneurons comprise the vast majority of neurons in the body.

**Motor function.** Once a sensory stimulus is received, the nervous system may elicit an appropriate motor response, such as muscular contraction or glandular secretion. The neurons that serve this function are motor (efferent) neurons. Motor neurons carry information from the brain toward the spinal cord, or out of the brain and spinal cord to effectors (muscles and glands) through cranial and spinal nerves. Stimulation of the effectors by motor neurons causes muscles to contract and glands to secrete.

**ORGANIZATION OF THE NERVOUS SYSTEM**

The CNS integrates and correlates many different kinds of incoming sensory information, as well as being the source of thoughts, emotions and memories. Most nerve impulses that stimulate muscles to contract and glands to secrete originate in the CNS. Structural components of the PNS are cranial nerves and their branches, spinal nerves and their branches, ganglia and sensory receptors. The PNS is further subdivided into a somatic nervous system (SNS), an autonomic nervous system (ANS), and an enteric nervous system (ENS).

The somatic nervous system consists of 1) sensory neurons that convey information from somatic receptors in the head, body wall, viscera, and limbs and from receptors for the special senses of vision, hearing, taste, and smell to the CNS, and 2) motor neurons that conduct impulses from the CNS to skeletal muscles only. Because these motor responses can be consciously controlled, the action of this part of the PNS is voluntary.

The ANS consists of motor neurons that conduct nerve impulses from the CNS to smooth muscle, cardiac muscle, and glands. Because its motor responses are not normally under conscious control, the action of the ANS is involuntary.

The ANS consists of two divisions, sympathetic and parasympathetic. With a few exceptions, effectors are innervated by both divisions, and the two divisions usually have opposing actions. For example, sympathetic neurons speed the heartbeat, and parasympathetic neurons slow it down. In general, the sympathetic division helps support exercise and/or emergency actions, so-called fight-or-flight responses, and the parasympathetic division takes care of “rest and digest” activities.

The enteric system is the brain of the gut, and its operation is involuntary. Its neurons extend most of the length of the gastrointestinal (GI) tract. Sensory neurons of the enteric nervous system monitor chemical changes within the GI tract and the stretching of its walls. Enteric motor neurons govern contraction of GI tract smooth muscle, secretions of the GI tract organs, such as acid secretion by the stomach, and activity of GI tract endocrine cells.

**PHYSIOLOGICAL EFFECTS OF APPROPRIATE MASSAGE ON NERVOUS TISSUE**

Specific massage techniques are not the focus of this course, but most comments apply to all nervous tissue. The following description is not
complete, but includes many of the widely accepted physiological effects of appropriate massage on nervous tissue:
* Depending on the techniques utilized, massage can be either stimulative or sedative to nervous tissue, as well as other tissues associated with it, like muscles, for example.
* Massage releases or reduces emotional stress.
* General massage tends to quiet the sympathetic division of the autonomic nervous system, that portion of the nervous system that responds to fight-or-flight situations.
* Massage enhances the development and growth of nervous tissue, especially in newborn children.
* Massage affects exteroceptors, interoceptors, and proprioceptors which, through reflexes, affect a large number of internal organs.
* Massage increases the production and release of a number of neurotransmitters and other substances from nervous tissue that facilitate homeostasis.

**REGENERATION AND REPAIR OF NERVOUS TISSUE**
Throughout your life, your nervous system is capable of changing based on experienced—called plasticity. At the level of individual neurons, the changes that can occur include the sprouting of new dendrites, synthesis of new proteins and changes in synaptic contacts with other neurons. Undoubtedly, both chemical and electrical signals drive the changes that occur. Despite plasticity, however, mammalian neurons have very limited powers of regeneration, or the capability to replicate or repair themselves. In the PNS, damage to dendrites and myelinated axons may be repaired if the cell body remains intact, and if the Schwann cells that produce myelination remain active. In the CNS, little or no repair of damage to neurons occurs. Even when the cell body remains intact, a severed axon in the CNS cannot be repaired or regrown.

**NEUROGENESIS IN THE CNS**
Neurogenesis—the birth of new neurons from undifferentiated stem cells—occurs regularly in some animals. For example, new neurons appear and disappear every year in some songbirds.

Until relatively recently, the dogma in humans and other primates was “no new neurons” in the adult brain. Then, in 1992, Canadian researchers published their unexpected finding that epidermal growth factor (EGF) stimulated cells taken from the brains of adult mice to proliferate into both neurons and astrocytes. Previously, EGF was known to trigger mitosis in a variety of non-neuronal cells, and to promote wound healing and tissue regeneration. In 1998, scientists discovered that significant numbers of new neurons do arise in the adult human hippocampus, an area of the brain that is crucial for learning.

The nearly complete lack of neurogenesis in other regions of the brain and spinal cord seems to result from two factors: inhibitory influences from neuroglia—particularly oligodendrocytes—and absence of growth-stimulating cues that were present during fetal development. Axons in the CNS are myelinated by oligodendrocytes that do not form neurolemmas (sheaths of Schwann). In addition, CNS myelin is one of the factors inhibiting regeneration of myelinated axons in the peripheral nervous system may be repaired if the cell body remains intact and if the Schwann cells remain active.
neurons. Perhaps this same mechanism stops axonal growth once a target region has been reached during development.

Also, after axonal damage, nearby astrocytes proliferate rapidly, forming a type of scar tissue that acts as a physical barrier to regeneration. Thus, injury of the brain or spinal cord usually is permanent. Ongoing research seeks ways to improve the environment for existing spinal cord axons to bridge the injury gap. Scientists also are trying to find ways to stimulate dormant stem cells to replace neurons lost through damage or disease, and to develop tissue-cultured neurons that can be used for transplantation purposes.

**DAMAGE AND REPAIR IN THE PNS**

Axons and dendrites that are associated with a neurolemma may undergo repair if 1) the cell body is intact, 2) the Schwann cells (neurolemmocytes) are functional, and 3) scar tissue formation does not occur too rapidly. Most nerves in the PNS consist of processes that are covered with a neurolemma.

As occurs with most other systems in the body, varying degrees of damage may occur in a nerve of the PNS. The mildest form of damage that produces clinical deficits is called neurapraxia, meaning there is a loss of nerve conduction, but the axon does not degenerate and recovery is complete.

More severe damage results in degeneration of the axon distal to the site of the lesion and is called axonotmesis. In this instance, the connective tissue coverings are left intact and Wallerian degeneration of axons occurs. The most severe damage to a nerve, wherein the associated connective tissues are also damaged, is called neurotmesis. With this condition, recovery of nerve function is highly unlikely.

A person who experiences neurapraxia or axonotmesis of a nerve in an upper limb has a good chance of regaining nerve function.

A person who experiences neurapraxia or axonotmesis of a nerve in an upper limb, for example, has a good chance of regaining nerve function. When there is damage to an axon, changes usually occur both in the cell body of the affected neuron and in the portion of the axon distal to the site of injury. Changes may also occur in the portion of the axon proximal to the site of injury.

About 24 to 48 hours after injury to a process of a normal peripheral neuron, the Nissl bodies break up into fine granular masses. This alteration is called chromatolysis. By the third to fifth day, the part of the axon distal to the damaged region becomes slightly swollen and breaks up into fragments. The myelin sheath also deteriorates. Even though the axon and myelin sheath degenerate, the neurolemma remains. Degeneration of the distal portion of the axon and myelin sheath is called Wallerian degeneration.

Following chromatolysis, signs of recovery in the cell body become evident. Macrophages phagocytize the debris. Synthesis of RNA and protein accelerates, which favors rebuilding or regeneration of the axon. The Schwann cells on either side of the injured site multiply by mitosis, grow toward each other, and may form a regeneration tube across the injured area. This tube guides growth of a new axon from the proximal area across the injured area into the distal area previously occupied by the original axon. However, new axons cannot grow if the gap at the site of injury is too large, or if the gap becomes filled with collagen fibers.

During the first few days following damage, buds of regenerating axons begin to invade the tube formed by the Schwann cells. Axons from the proximal area grow at a rate of about 1.5 mm (0.06 in.) per day across the area of damage, find their way into the distal regeneration tubes, and grow toward the distally located receptors and effectors. Thus, some sensory and motor connections are reestablished and some functions restored. In time, the Schwann cells form a new myelin sheath.

**REPAIR OF DAMAGED NERVES**

Some neurons travel from the lower spinal cord to the great toe. The overall growth rate of 1.5 mm per day is approximately 2 inches per month. Assuming that trauma of a patient occurred in a peripheral nerve, but near the spinal cord, it could take more than two years for the repair of damaged nerves, as evidenced by the return of sensation and function of the great toe.

In another scenario, if a nerve (a bundle of neurons, some of which are sensory and others motor) is completely severed, elastic fibers around the nerve cause the two ends to be retracted. When this occurs, the two ends must be connected surgically. Although a surgeon will attempt to align the two cut ends by aligning the blood vessels that are servicing the outside of the nerve, it’s rare that the alignment of neu-
rions is exactly correct.
As long as the nerve cell bodies are intact and scar tissue does not block the process, the neurons will regenerate and axonal growth into neurolemmal tunnels (regeneration tubes) will take place. The axons may, however, grow through different tunnels. Assuming that regeneration is complete, the brain may send messages down the “wrong” motor neurons, and therefore the actions of the person may be inappropriate.

Similarly, sensory neurons growing through different neurolemmal tunnels will result in inaccurate perceptions in the brain. Physical therapy and other modalities may be required to retrain the brain so that the appropriate actions and perceptions will occur. As described previously, manual therapy can be of value to the patient by maximizing the flow of nutrients into the areas of healing (regeneration).

The Spinal Cord and Spinal Nerves

Early anatomists made a distinction between the brain and spinal cord. Today we know that the brain and spinal cord are really just one large, interconnected group of nervous tissues known as the central nervous system (CNS). Since the nervous system is so complex, it’s more convenient to study the individual parts rather than the whole.

However, it is important to think of the nervous system as one complex mass of interconnected neurons. Function or dysfunction of any part may affect many seemingly independent neuronal structures.

The spinal cord contains a series of “pathways” that relay sensory information along fibers to the processing centers and then react by sending information along different fibers for motor function. The spinal cord allows us to make quick responses, such as pulling the foot away quickly when we step on a sharp tack. We lift our foot before we have a chance to think.

This action is an example of a spinal cord reflex—a quick, automatic response to certain kinds of stimuli that involves neurons only in the spinal nerves and spinal cord. Reflexes are simply preprogrammed reactions to strong stimuli such as pain, touch, temperature or pressure. An example is when a physician strikes near your elbow with a reflex hammer and an extensor reflex pathway causes your upper limb to straighten.

The spinal cord is continuous with the medulla oblongata of the brain. Both portions of the CNS contain gray and white matter for specialized processing of information. Two types of connective tissue coverings—bony vertebrae and tough, connective tissue meninges, plus a cushion of cerebrospinal fluid (produced in the brain)—surround and protect the delicate nervous tissue of the spinal cord.

External Anatomy of the Spinal Cord
The spinal cord, although roughly cylindrical, is flattened slightly in its anterior–posterior dimension. In adults, it extends from the medulla oblongata of the brain, to the inferior border of the first lumbar vertebra (L1) or the superior border of the second lumbar vertebra (L2). In newborn infants, the spinal cord extends to the third or fourth lumbar vertebra.

During early childhood, both the spinal cord and the vertebral column grow longer as part of overall body growth. Elongation of the spinal cord stops around age 4 or 5, but growth of the vertebral column continues. Thus, the spinal cord does not extend the entire length of the adult vertebral column. The length of the adult spinal cord ranges from 42–45 cm (16–18 in.). Its diameter is about 2 cm (0.75 in.) in the mid-thoracic region, somewhat larger in the lower cervical and mid-lumbar regions, and smallest at the inferior tip.

When the spinal cord is viewed externally, two conspicuous enlargements can be seen. The superior enlargement, the cervical enlargement, extends from the fourth cervical vertebra (C4) to the first thoracic vertebra (T1). Nerves to and from the upper limbs arise from the cervical enlargement. The inferior enlargement, called the lumbar enlargement, extends from the ninth to the 12th thoracic vertebra (T9–T12). Nerves to and from the lower limbs arise from the lumbar enlargement.

Inferior to the lumbar enlargement, the spinal cord terminates as a tapering, conical structure called the conus medullaris, which ends at the level of the intervertebral disc between the first and second lumbar vertebrae in adults. Arising from the conus medullaris is the filum terminale (terminal filament), an extension of the pia mater that extends inferiorly and anchors the spinal cord to the coccyx.

Because the spinal cord is shorter than the vertebral column, nerves that arise from the lumbar, sacral and coccygeal regions of the spinal cord do not leave the vertebral column at the same level they exit the cord. The roots of these spinal nerves angle inferiorly in the vertebral cavity from the end of the spinal cord like wisps of hair. Appropriately, the roots of these nerves are collectively named the cauda equina, meaning “horse’s tail.”

Internal Anatomy of the Spinal Cord
Two grooves penetrate the white matter of the spinal cord and divide it into right and left sides. The anterior median fissure is a deep, wide
A groove on the anterior (ventral) side. The **posterior median sulcus** is a shallower, narrow groove on the posterior (dorsal) side. The gray matter of the spinal cord is shaped like the letter H or a butterfly and is surrounded by white matter. The gray matter consists of dendrites and cell bodies of neurons, unmyelinated axons and neuroglia. The white matter consists primarily of bundles of myelinated axons of neurons.

The **gray commissure** forms the crossbar of the H. In the center of the gray commissure is a small space called the **central canal** that extends the entire length of the spinal cord and is filled with cerebrospinal fluid. At its superior end, the central canal is continuous with the fourth ventricle (a space that contains cerebrospinal fluid) in the medulla oblongata of the brain. Anterior to the gray commissure is the **anterior (ventral) white commissure**, which connects the white matter of the right and left sides of the spinal cord.

In the gray matter of the spinal cord and brain, clusters of neuronal cell bodies form functional groups called nuclei. Sensory nuclei receive input from sensory receptors via sensory neurons, and motor nuclei provide output to effector tissues via motor neurons.

The gray matter on each side of the spinal cord is subdivided into regions called **horns**.

- **Anterior (ventral) gray horns** contain somatic motor nuclei, which provide nerve impulses for contraction of skeletal muscles.
- **Posterior (dorsal) gray horns** contain somatic and autonomic sensory nuclei. Between the anterior and posterior gray horns are the **lateral gray horns**, which are present only in the thoracic, upper lumbar and sacral segments of the spinal cord. The lateral horns contain autonomic motor nuclei that regulate the activity of smooth muscle, cardiac muscle and glands.

The white matter, like the gray matter, is organized into regions. The anterior and posterior gray horns divide the white matter on each side into three broad areas called columns: (1) anterior (ventral) white columns, (2) posterior (dorsal) white columns, and (3) lateral white columns. Each column, in turn, contains distinct bundles of axons having a common origin or destination and carrying similar information.

These bundles, which may extend long distances up or down the spinal cord, are called tracts. Tracts are bundles of axons in the CNS (you’ll recall that nerves are bundles of axons in the PNS). Sensory (ascending) tracts consist of axons that conduct nerve impulses toward the brain. Tracts consisting of axons that carry nerve impulses from the brain are called motor (descending) tracts. Sensory and motor tracts of the spinal cord are continuous with sensory and motor tracts in the brain.
Motor output from the spinal cord to skeletal muscles involves somatic motor neurons of the ventral gray horn. Many somatic motor neurons are regulated by the brain.

The internal organization of the spinal cord allows sensory input and motor output to be processed by the spinal cord in the following way: Sensory receptors detect a sensory stimulus.

Sensory neurons convey this sensory input in the form of nerve impulses along their axons, which extend from sensory receptors into the spinal nerve and then into the dorsal root. From the dorsal root, axons of sensory neurons may proceed along three possible paths.

Axons of sensory neurons may extend into the white matter of the spinal cord and ascend to the brain as part of a sensory tract.

Axons of sensory neurons may enter the dorsal gray horn and synapse with interneurons whose axons extend into the white matter of the spinal cord and then ascend to the brain as part of a sensory tract.

Axons of sensory neurons may enter the dorsal gray horn and synapse with interneurons that in turn synapse with somatic motor neurons of the ventral gray horn. Many somatic motor neurons are regulated by the brain. Axons from higher brain centers form motor tracts that descend from the brain into the white matter of the spinal cord. There, they synapse with the somatic motor neurons either directly or indirectly by first synapsing with interneurons that in turn synapse with somatic motor neurons.

When activated, somatic motor neurons convey motor output in the form of nerve impulses along their axons, which sequentially pass through the ventral gray horn and ventral root to enter the spinal nerve. From the spinal nerve, axons of somatic motor neurons extend to skeletal muscles of the body.

Motor output from the spinal cord to cardiac muscle, smooth muscle, and glands involves autonomic motor neurons of the lateral gray horn. When activated, autonomic motor neurons convey motor output in the form of nerve impulses along their axons, which sequentially pass through the lateral gray horn, ventral gray horn and ventral root to enter the spinal nerve.

From the spinal nerve, axons of autonomic motor neurons from the spinal cord synapse with another group of autonomic motor neurons located in the PNS. The axons of this second group of autonomic motor neurons in turn synapse with cardiac muscle, smooth muscle and glands.

Spinal nerves, part of the PNS, are the paths of communication between the spinal cord and the nerves supplying specific regions of the body. Spinal cord organization appears to be segmented because the 31 pairs of spinal nerves emerge at regular intervals from intervertebral foramina.

Indeed, each pair of spinal nerves is said to arise from a spinal segment. Within the spinal cord, there is no obvious segmentation. But, for convenience, the naming of spinal nerves is based on the segment in which they are located. There are eight pairs of cervical nerves represented as C1–C8, 12 pairs of thoracic nerves (T1–T12), five pairs of lumbar nerves (L1–L5), five pairs of sacral nerves (S1–S5) and one pair of coccygeal nerves (C01)—for a total of 31 pairs.

The first cervical pair emerges between the atlas (first cervical vertebra) and the occipital bone. All other spinal nerves emerge from the vertebral column through the intervertebral foramina between adjoining vertebrae. Not all spinal cord segments are aligned with their corresponding vertebrae. Recall that the spinal cord ends near the level of the superior border of the second lumbar vertebra, and that the roots of the lumbar, sacral and coccygeal nerves descend at an angle to reach their respective foramina before emerging from the vertebral column. This arrangement constitutes the cauda equina.

Two bundles of axons—called roots—connect each spinal nerve to a segment of the cord by a series of small rootlets. The posterior (dorsal) root and rootlets contain only sensory axons, which conduct nerve impulses from sensory receptors in the skin, muscles and internal organs into the central nervous system. Each posterior root has a swelling, the posterior (dorsal) root ganglion, which contains the cell bodies of
sensory neurons. The anterior (ventral) root and rootlets contain axons of motor neurons, which conduct nerve impulses from the CNS to effectors (muscles and glands). The dorsal and ventral roots unite to form a spinal nerve at the intervertebral foramen. Because the dorsal root contains sensory axons and the ventral root contains motor axons, a spinal nerve is classified as a mixed nerve.

**Spinal Nerve Root Damage**
As you have just learned, spinal nerve roots exit from the vertebral canal through intervertebral foramina. The most common cause of spinal nerve root damage is a herniated intervertebral disc. Damage to vertebrae as a result of osteoporosis, osteoarthritis, cancer or trauma can also damage spinal nerve roots.

Symptoms of spinal nerve root damage include pain, muscle weakness and loss of feeling. Rest, manual therapy, pain medications and epidural injections are the most widely used conservative treatments. It is recommended that six to 12 weeks of conservative therapy be attempted first. If the pain continues, is intense, or is impairing normal functioning, surgery is often the next step.

**CONNECTIVE TISSUE COVERINGS OF SPINAL NERVES**
Each spinal nerve and cranial nerve consists of many individual axons and contains layers of protective connective tissue coverings. Individual axons within a nerve, whether myelinated or unmyelinated, are wrapped in **endoneurium**, the innermost layer. Groups of axons with their endoneurium are arranged in bundles called **fascicles**, each of which is wrapped in **perineurium**, the middle layer. The outermost covering over the entire nerve is the **epineurium**.

The dura mater of the spinal meninges fuses with the epineurium as the nerve passes through the intervertebral foramen. Note the presence of many blood vessels, which nourish nerves, within all three layers of connective tissue. The connective tissue coverings of skeletal muscles—endomysium, perimysium and epimysium—are similar in organization to those of nerves.

**DISTRIBUTION OF SPINAL NERVES**
Branches. A short distance after passing through its intervertebral foramen, a spinal nerve divides into several branches. These branches are known as rami. The posterior (dorsal) ramus (singular form) serves the deep muscles and skin of the dorsal surface of the trunk. The anterior (ventral) ramus serves the muscles and structures of the upper and lower limbs, as well as the skin of the lateral and ventral surfaces of the trunk.
In addition to posterior and anterior rami, spinal nerves also give off a meningeal branch. This branch re-enters the vertebral cavity through the intervertebral foramen, and supplies the vertebrae, vertebral ligaments, blood vessels of the spinal cord and meninges. Other branches of a spinal nerve are the rami communicantes, components of the autonomic nervous system.

**Plexuses.** Axons from the anterior rami of spinal nerves, except for thoracic nerves T2–T12, do not innervate the body structures directly. Instead, they form networks on both the left and right sides of the body by joining with various numbers of axons from anterior rami of adjacent nerves. Such a network of axons is called a plexus (the plural form may be plexuses or plexi).

The principal plexuses are the cervical, brachial, lumbar and sacral. A smaller coccygeal plexus is also present. Emerging from the plexuses are nerves bearing names that are often descriptive of the general regions they serve or the course they take. Each of the nerves, in turn, may have several branches named for the specific structures they innervate.

The anterior rami of spinal nerves T2–T12 are called intercostal nerves.

**Cervical Plexus.** The cervical plexus is formed by the roots (ventral rami) of the first four cervical nerves (C1–C4), with contributions from C5. There is one on each side of the neck alongside the first four cervical vertebrae.

The cervical plexus supplies the skin and muscles of the head, neck, and superior part of the shoulders and chest. The phrenic nerve arises from the cervical plexus and supplies motor fibers to the diaphragm. Branches of the cervical plexus also run parallel to two cranial nerves, the accessory (XI) nerve and hypoglossal (XII) nerve.

Complete transection of the spinal cord above the origin of the phrenic nerves (C3, C4 and C5) causes respiratory arrest. Breathing stops because the phrenic nerves no longer send nerve impulses to the diaphragm.

**Intercostal Nerves.** The anterior rami of spinal nerves T2–T12 are not part of the plexus and are known as intercostal (thoracic) nerves. These nerves directly connect to the structures they supply in the intercostal spaces. After leaving its intervertebral foramen, the anterior ramus of nerve T2 innervates the intercostal muscles of the second intercostal space and supplies the skin of the axilla and posteromedial aspect of the arm.

Nerves T3–T6 extend along the costal grooves of the ribs and then to the intercostal muscles and skin of the anterior and lateral chest wall. Nerves T7–T12 supply the intercostal muscles and abdominal muscles, and the overlying skin. The posterior rami of the intercostal nerves supply the deep back muscles and skin of the posterior aspect of the thorax.

**Brachial Plexus.** The roots (ventral rami) of spinal nerves C5–C8 and T1 form the brachial plexus, which extends inferiorly and laterally on either side of the last four cervical and first thoracic vertebrae, passing between the anterior and middle scalene muscles and above the first rib posterior to the clavicle. The plexus goes deep to the pectoralis minor muscle and then enters the axilla.

Since the brachial plexus is so complex, an explanation of its various parts is helpful. As with the cer-
vical and other plexuses, the roots are the ventral rami of the spinal nerves. The roots of several spinal nerves unite to form trunks in the inferior part of the neck. These are the superior, middle, and inferior trunks.

Posterior to the clavicles, the trunks divide into divisions, called the anterior and posterior divisions. In the axillae, the divisions unite to form cords called the lateral, medial, and posterior cords. The cords are named for their relationship to the axillary artery, a large artery that supplies blood to the upper limb.

The principal nerves of the brachial plexus branch from the cords. The brachial plexus provides the entire nerve supply of the shoulders and upper limbs. Five important nerves arise from the brachial plexus: 1) axillary supplies the deltoid and teres minor muscles, 2) musculocutaneous supplies the flexors of the arm, 3) radial supplies the muscles on the posterior aspect of the arm and forearm, 4) median supplies most of the muscles of the anterior forearm and some of the muscles of the hand, and 5) ulnar supplies the anteromedial muscles of the forearm and most of the muscles of the hand.

**Thoracic Outlet Syndrome**
Compression of the brachial plexus on one or more of its nerves is sometimes known as thoracic outlet syndrome. The subclavian artery and subclavian vein may also be compressed. The compression may result from spasm of the scalene or pectoralis minor muscles, the presence of a cervical rib (an embryological anomaly), or misaligned ribs.

The patient may experience pain, numbness, weakness or tingling in the upper limb, across the upper thoracic area and over the scapula on the affected side. The symptoms of thoracic outlet syndrome are exaggerated during physical or emotional stress because the added stress increases the contraction of the involved muscles.

**INJURIES TO NERVES EMERGING FROM THE BRACHIAL PLEXUS**
Injury to the roots of the brachial plexus (C5–C6) may result from forceful pulling away of the head from the shoulder, as might occur from a heavy fall on the shoulder or excessive stretching of an infant’s neck during childbirth.

The presentation of this injury is characterized by an upper limb where the shoulder is adducted, the arm is medially rotated, the elbow is extended, the forearm is pronated and the wrist is flexed. This condition is called Erb-Duchenne palsy or waiter’s tip position. There is loss of sensation along the lateral side of the arm.

**Radial (and axillary) nerve injury** can be caused by improperly administered intramuscular injections into the deltoid muscle. The radial nerve may also be injured when a cast is applied too tightly around the midhumerus.

Radial nerve injury is indicated by wrist drop, as well as the inability to extend the wrist and fingers. Sensory loss is minimal due to the overlap of sensory innervation by adjacent nerves.

**Median nerve injury** may result in median nerve palsy, which is indicated by numbness, tingling, and pain in the palm and fingers. There is also an inability to pronate the
forearm and flex the proximal interphalangeal joints of all digits, and the distal interphalangeal joints of the second and third digits.

In addition, wrist flexion and thumb movements are weak, and are accompanied by adduction of the thumb due to a loss of function of the muscles of the thenar eminence.

**Carpal tunnel pain** is caused by compression of the median nerve. The carpal tunnel is a narrow passageway formed anteriorly by the flexor retinaculum and posteriorly by the carpal bones. Through this tunnel pass the median nerve, the most superficial structure, and the long flexor tendons for the digits. Structures within the carpal tunnel, especially the median nerve, are vulnerable to compression, and the resulting condition is known as carpal tunnel syndrome.

The person may experience numbness, tingling, or pain of the wrist and hand. Compression within the tunnel usually results from inflamed and thickened tendon sheaths of flexor tendons, fluid retention, excessive exercise, infection, trauma, and/or repetitive activities that involve flexion of the wrist such as keyboarding, cutting hair and playing a piano.

Treatment may be progressive if the problem worsens. Initial treatment may include aspirin or ibuprofen (both are anti-inflammatory drugs), and may progress to an injection of cortisone into the carpal tunnel. Persons might be asked to keep the wrist straight to minimize movement of the inflamed tendon sheaths, and some type of splint or brace may be prescribed.

Continued pain may necessitate surgery to cut (release) the transverse carpal ligament and relieve the compression of the nerve. It should be noted that “carpal tunnel pain” can also be caused by compression of the median nerve in two areas of the shoulder. When this occurs, carpal tunnel surgery will not alleviate the pain. Furthermore, scar tissue formed after the surgery may exacerbate the problem.

Compression of the median nerve can also occur between the anterior and middle scalenes or deep to the pectoralis minor. Pain in the wrist or hand is perceived by the patient and is identical to the pain of true carpal tunnel syndrome. Massage of the scalenes and pectoralis minor can usually lengthen those muscles, and thereby reduce impingement on the median nerve. By lengthening these muscles, a manual therapist can usually determine within minutes whether the pain of the wrist and hand may be a function of compression of the median nerve in the neck or axilla, or compression of the median nerve within the carpal tunnel.

**Ulnar nerve injury** may result in ulnar nerve palsy (claw hand), which is indicated by an inability to abduct or adduct the fingers, atrophy of the interosseus muscles of the hand, hyperextension of the metacarpophalangeal joints, and flexion of the interphalangeal joints—a condition called claw hand. People with the condition might also experience a loss of sensation over the little finger and the medial half of the ring finger.

**Long thoracic nerve injury** results in paralysis of the serratus anterior muscle. The medial border of the scapula protrudes, giving it the appearance of a wing. When the arm is raised, the vertebral border and inferior angle of the scapula pull away from the thoracic wall and protrude outward, causing the medial border of the scapula to protrude. Because the scapula looks like a wing, this condition is called winged scapula.

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**THE LUMBAR PLEXUS SUPPLIES THE ANTEROLATERAL ABDOMINAL WALL, EXTERNAL GENITALS AND PART OF THE LOWER LIMBS.**
The arm cannot be abducted beyond the horizontal position.

**Lumbar Plexus.** The roots (ventral rami) of spinal nerves L1–L4 form the lumbar plexus. Unlike the brachial plexus, there is no intricate intermingling of fibers in the lumbar plexus. On either side of the first four lumbar vertebrae, the lumbar plexus passes obliquely outward, posterior to the psoas major muscle and anterior to the quadratus lumborum muscle. It then gives rise to its peripheral nerves. The lumbar plexus supplies the anterolateral abdominal wall, external genitals and part of the lower limbs.

**Sacral Plexus.** The roots (ventral rami) of spinal nerves L4–L5 and S1–S4 form the sacral plexus. This plexus is situated largely anterior to the sacrum. The sacral plexus supplies the buttocks, perineum and lower limbs. The largest nerve in the body—the sciatic nerve—arises from the sacral plexus.

**Coccygeal Plexus.** The roots (ventral rami) of spinal nerves S4–S5 and the coccygeal nerves form a small coccygeal plexus, which supplies a small area of skin in the coccygeal region.

**Spinal Tap**

In a spinal tap (lumbar puncture), a local anesthetic is given, and a long needle is inserted into the subarachnoid space. During this procedure, the patient lies on their side with the vertebral column flexed, like when in the fetal position.

Flexion of the vertebral column increases the distance between the spinous processes of the vertebrae, which allows easy access to the subarachnoid space. The spinal cord ends around the second lumbar vertebra (L2). The spinal meninges, however, extend to the second sacral vertebra (S2).

Between vertebrae L2 and S2, the spinal meninges are present—but the spinal cord is absent. Consequently, a spinal tap is normally performed in adults between vertebrae L3 and L4 or L4 and L5 because this region provides safe access to the subarachnoid space without the risk of damaging the spinal cord. (A line drawn across the highest points of the iliac crests, called the supracristal line, passes through the spinous process of the fourth lumbar vertebra.)

A spinal tap is used to withdraw cerebrospinal fluid (CSF) for diagnostic purposes, as well as to introduce antibiotics, contrast media for myelography, or anesthetics. Other uses include administering chemotherapy, measuring CSF pressure, and/or evaluating the effects of treatment for diseases such as meningitis.

**Dermatomes.** The skin over the entire body is supplied by somatic sensory neurons that carry nerve impulses from the skin into the spinal cord and brain. Each spinal nerve, except for C1, contains sensory neurons that serve a specific, predictable segment of the body.

One of the cranial nerves—the trigeminal (V) nerve—serves most of the skin of the face and scalp. The area of the skin that provides sensory input to the CNS via one pair of spinal nerves or the trigeminal (V) nerve is called a dermatome. The nerve supply in adjacent dermatomes overlaps somewhat.

Knowing which spinal cord segments supply each dermatome makes it possible to locate damaged regions of the spinal cord. If the skin in a particular region is stimulated but the sensation is not perceived, the nerves supplying that derma-
tome are probably damaged. In regions where the overlap is considerable, little loss of sensation may result if only one of the nerves supplying the dermatome is damaged.

Information about the innervation patterns of spinal nerves can also be used therapeutically. Cutting posterior roots or infusing local anesthetics can block pain either permanently or transiently. Because dermatomes overlap, deliberate production of a region of complete anesthesia may require that at least three adjacent spinal nerves be cut or blocked by an anesthetic drug.

**Shingles.** This acute infection of the peripheral nervous system is caused by herpes zoster, the virus that also causes chicken pox. After a person recovers from chicken pox, the virus retreats to a posterior root ganglion. If the virus is reactivated, the immune system usually prevents it from spreading.

From time to time, however, the reactivated virus overcomes a weakened immune system, leaves the ganglion, and travels down sensory neurons of the skin by fast axonal transport. The result is pain, discoloration of the skin and a characteristic line of skin blisters. The line of blisters marks the distribution (dermatome) of the particular cutaneous sensory nerve belonging to the infected posterior root ganglion.

**Sciatic Nerve Injury.** The most common form of back pain is caused by compression or irritation of the sciatic nerve, the longest nerve in the human body. It is actually two nerves—tibial and common fibular—bound together by a common sheath of connective tissue. This nerve splits into its two divisions, usually at the knee.

Sciatic nerve injury results in sciatica, pain that may extend from the buttock down the posterior and lateral aspect of the leg and the lateral aspect of the foot. The sciatic nerve may be injured because of a herniated (slipped) disc, dislocated hip, osteoarthritis of the lumbar-sacral spine, pathological shortening of the lateral rotator muscles of the thigh (especially piriformis), pressure from the uterus during pregnancy, inflammation, irritation or an improperly administered gluteal intramuscular injection. In addition, sitting on a wallet or other object for a long period of time can also compress the nerve and induce pain.

In many sciatic nerve injuries, the common fibular portion is the most affected, frequently from fractures of the fibula or by pressure from casts or splints over the thigh or leg. Damage to the common fibular nerve causes the foot to be plantar flexed, a condition called foot drop, and inverted, a condition called equinovarus.

There is also loss of function along the anterolateral aspects of the leg and dorsum of the foot and toes. Injury to the tibial portion of the sciatic nerve results in dorsiflexion of the foot plus eversion, a condition called calcaneovalgus. Loss of sensation on the sole also occurs. Treatments for sciatica are similar to those outlined earlier for a herniated (slipped) disc—rest, pain medications, exercises, ice or heat and massage. The topics of nerve injuries and the effects on muscles cannot be well differentiated.

A very common cause of sciatic pain is spasm of the piriformis muscle. Remember that spasm of a
The spinal cord has two principal functions in maintaining homeostasis: nerve impulse propagation and integration of information.

From the neck, trunk, limbs and posterior aspect of the head, somatic sensory impulses propagate along spinal nerves into the spinal cord.

**Second-order neurons** conduct impulses from the brain stem and spinal cord to the thalamus. Axons of second-order neurons decussate (cross over to the opposite side) in the brain stem or spinal cord before ascending to the thalamus. Thus, all somatic sensory information from one side of the body reaches the thalamus on the opposite side.

**Third-order neurons** conduct impulses from the thalamus to the primary somatosensory area of the cortex on the same side.

Somatic sensory impulses ascend to the cerebral cortex via two main pathways: 1) the posterior column–medial lemniscus pathway, and 2) the anterolateral spinothalamic pathways.

Nerve impulses for touch, pressure, vibration and conscious proprioception (awareness of the positions of body parts) from the limbs, trunk, neck and posterior head ascend to the cerebral cortex along the posterior column–medial lemniscus pathway. The name of the pathway comes from the names of two white-matter tracts that convey the impulses: the posterior column of the spinal cord and the medial lemniscus of the brain stem.

Nerve impulses for pain, temperature, itch and tickle from the limbs, trunk, neck and posterior head ascend to the cerebral cortex along cranial nerves.
the anterolateral or spinthalamic pathway. This pathway begins in two spinal cord tracts—the lateral and anterior spinthalamic tracts.

The spinothalamocerebellar tracts are the major routes that proprioceptive impulses take to reach the cerebellum. Although they are not consciously perceived, sensory impulses conveyed to the cerebellum along these pathways are critical for posture, balance and coordination of movements.

The sensory systems keep the CNS informed of changes in the external and internal environments. The sensory information is integrated by interneurons in the spinal cord and brain. Responses to the integrative decisions (muscular contractions of all three types of muscles and glandular secretions) are brought about by motor activities.

Neurons in the brain and spinal cord coordinate all voluntary and involuntary movements. All somatic motor pathways involve at least two motor neurons. The cell bodies of upper motor neurons are in the higher integration centers of the CNS. The axons of lower motor neurons extend out of the brain stem to stimulate skeletal muscles in the head, and out of the spinal cord to stimulate skeletal muscles in the limbs and trunk.

The cerebral cortex—the outer part of the brain—plays a major role in controlling precise voluntary muscular movements. Other brain regions provide important integration for regulation of automatic movements, such as arm swinging during walking.

Motor output to skeletal muscles travels down the spinal cord in two types of descending pathways: direct and indirect. The direct motor pathways in the spinal cord include the lateral corticospinal and anterior corticospinal tracts. They convey nerve impulses that originate in the cerebral cortex and are destined to cause precise, voluntary movements of skeletal muscles.

Indirect motor pathways located in the spinal cord include the rubrospinal, reticulospinal, tectospinal, and vestibulospinal tracts. They convey nerve impulses from the brain stem and other parts of the brain to govern automatic movements and help coordinate body movements with visual stimuli. Indirect pathways also maintain skeletal muscle tone, maintain contraction of postural muscles, and play a major role in equilibrium by regulating muscle tone in response to movements of the head.

**WORKING WITH PATIENTS WITH PARALYSIS**

Damage or disease of lower motor neurons produces flaccid paralysis of muscles on the same (ipsilateral) side of the body: The muscles lack voluntary control and reflexes, muscle tone is decreased or lost, and the muscle remains flaccid (limp). Injury or disease of upper motor neurons causes spastic paralysis of muscles on the opposite (contralateral) side of the body. In this condition, muscle tone is increased, reflexes are exaggerated and pathological reflexes appear.

Manual therapists should be aware that patients with spinal cord injury confined to wheelchairs have varying degrees of spastic paralysis. Patients with moderate spasticity are usually prescribed medications that reduce the severity. Patients with severe spasticity commonly have their lower limbs strapped to the wheelchair so that the uncontrolled movements of the limbs don’t cause bruising, fracture or other trauma.

When a patient is on your table, only the slightest environmental stimulus may cause uncontrolled spastic movements. Application of hot or cold lubricants, effleurage, pettrisage and other techniques—as well as warm or cool temperature of the room—are a few stimuli that will induce spastic movements. If you are dressing the patient after treatment, tying the shoe laces too tightly is another example of a stimulus that will be problematic for the patient with severe spasticity.

**Muscle Spindles.** Muscle spindles are the proprioceptors in skeletal muscles that monitor changes in the length of skeletal muscles and participate in stretch reflexes. By adjusting how vigorously a muscle spindle responds to stretching of a skeletal muscle, the brain sets an overall level of muscle tone—the small degree of contraction that is present while the muscle is at rest.

Each muscle spindle consists of several slowly adapting sensory nerve endings that wrap around three to 10 specialized muscle fibers, called intrafusal fibers. A connective tissue capsule encloses the sensory nerve endings and intrafusal fibers, anchoring the spindle to the endomysium and perimysium.

Muscle spindles are interspersed among most skeletal muscle fibers and aligned parallel to them. In muscles that produce finely controlled movements, such as those of the fingers or eyes, muscle spindles are plentiful. Muscles involved in coarser but more forceful movements, like the quadriceps femoris and hamstring muscles of the thigh, have fewer muscle spindles. The only skeletal muscles that lack spindles are the tiny muscles of the middle ear.

The main function of muscle spindles is to measure muscle length—how much a muscle is being stretched. Either sudden or prolonged stretching of the central
areas of the intrafusal muscle fibers stimulates the sensory nerve endings. The resulting nerve impulses propagate into the CNS. Information from muscle spindles arrives quickly at the somatic sensory areas of the cerebral cortex, which allows conscious perception of limb positions and movements. At the same time, impulses from muscle spindles pass to the cerebellum, where the input is used to coordinate muscle contractions.

In addition to their sensory nerve endings near the middle of intrafusal fibers, muscle spindles contain motor neurons called gamma motor neurons. These motor neurons terminate near both ends of the intrafusal fibers and adjust the tension in a muscle spindle to variations in the length of the muscle organ.

For example, when a muscle shortens, gamma motor neurons stimulate the ends of the intrafusal fibers to contract slightly. This keeps the intrafusal fibers taut, and maintains the sensitivity of the muscle spindle to stretching of the muscle. As the frequency of impulses in its gamma motor neuron increases, a muscle spindle becomes more sensitive to stretching of its mid-region. Surrounding muscle spindles are ordinary skeletal muscle fibers, called extrafusal muscle fibers, which are supplied by large-diameter A fibers called alpha motor neurons. The cell bodies of both gamma and alpha motor neurons are located in the anterior gray horn of the spinal cord (or in the brain stem for muscles in the head). During the stretch reflex, impulses in muscle spindle sensory axons propagate into the spinal cord and brain stem and activate alpha motor neurons that connect to extrafusal muscle fibers in the same muscle. In this way, activation of its muscle spindles causes contraction of a skeletal muscle, which relieves the stretching.

**Tendon Organs.** Tendon organs are located at the junction of a tendon and a muscle. By initiating tendon reflexes, tendon organs protect tendons and their associated muscles from damage due to excessive tension.

A contracting muscle exerts a force that pulls the points of attachment of the muscle at either end toward each other. This force is the muscle tension. Each tendon organ consists of a thin capsule of connective tissue that encloses a few tendon fascicles (bundles of collagen fibers). Penetrating the capsule are one or more sensory nerve endings that entwine among and around the collagen fibers of the tendon. When tension is applied to a muscle,
the tendon organs generate nerve impulses that propagate into the CNS, providing information about changes in muscle tension. Tendon reflexes decrease muscle tension by causing muscle relaxation.

Reflexes and Reflex Arcs. The second way the spinal cord promotes homeostasis is by serving as an integrating center for some reflexes. A reflex is a fast, automatic, unplanned sequence of actions that occurs in response to a particular stimulus. Some reflexes are inborn, such as pulling your hand away from a hot surface before you even feel that it is hot. Other reflexes are learned or acquired. For instance, you learn many reflexes while acquiring driving expertise. Slamming on the brakes in an emergency is one example.

When integration takes place in the spinal cord gray matter, the reflex is a spinal reflex. An example is the familiar patellar reflex (knee jerk). If integration occurs in the brain stem rather than the spinal cord, the reflex is called a cranial reflex. An example is the tracking movements of your eyes as you read this sentence. You are probably most aware of somatic reflexes, which involve contraction of skeletal muscles. Equally important, however, are the autonomic (visceral) reflexes, which generally are not consciously perceived. They involve responses of smooth muscle, cardiac muscle and glands. Body functions—such as heart rate, digestion, urination and defecation—are controlled by the autonomic nervous system through autonomic reflexes.

Nerve impulses propagating into, through and out of the CNS follow specific pathways, depending on the kind of information, its origin and its destination. The pathway followed by nerve impulses that produce a reflex is a reflex arc (reflex circuit). A reflex arc includes the following five functional components:

1. Sensory receptor. The distal end of a sensory neuron (dendrite) or an associated sensory structure serves as a sensory receptor. It responds to a specific stimulus—a change in the internal or external environment—by producing a graded potential called a generator (or receptor) potential. If a generator potential reaches the threshold level of depolarization, it will trigger one or more nerve impulses in the sensory neuron.

2. Sensory neuron. The nerve impulses propagate from the sensory receptor along the axon of the sensory neuron to the axon terminals, which are located in the gray matter of the spinal cord or brain stem.

3. Integrating center. One or more regions of gray matter within the CNS act as an integrating center. In the simplest type of reflex, the integrating center is a single synapse between a sensory neuron and a motor neuron. A reflex pathway having only one synapse in the CNS is termed a monosynaptic reflex arc. More often, the integrating center consists of one or more interneurons, which may relay impulses to other interneurons as well as to a motor neuron. A polysynaptic reflex arc involves more than two types of neurons and more than one CNS synapse.

4. Motor neuron. Impulses triggered by the integrating center propagate out of the CNS along a motor neuron to the part of the body that will respond.

5. Effector. The part of the body that responds to the motor nerve
impulse, such as a muscle or gland, is the effector. Its action is called a reflex. If the effector is skeletal muscle, the reflex is a somatic reflex. If the effector is smooth muscle, cardiac muscle or a gland, the reflex is an autonomic (visceral) reflex.

TRAUMATIC INJURIES OF THE SPINAL CORD

Most spinal cord injuries are due to trauma that results from incidents such as automobile accidents, falls, contact sports, diving or acts of violence. The effects of the injury depend on the extent of direct trauma to the spinal cord or compression of the cord by fractured or displaced vertebrae or blood clots. Although any segment of the spinal cord may be involved, most common sites of injury are in the cervical, lower thoracic and upper lumbar regions.

Depending on the location and extent of spinal cord damage, paralysis may occur. Monoplegia is paralysis of one limb only, and diplegia is paralysis of both upper limbs or both lower limbs. Paraplegia is paralysis of both lower limbs, and hemiplegia is paralysis of the upper limb, trunk and lower limb on one side of the body. Quadriplegia is paralysis of all four limbs.

Complete transection of the spinal cord means that the cord is severed from one side to the other, thus cutting all sensory and motor tracts—resulting in a loss of all sensations and voluntary movement below the level of the transection. A person will have permanent loss of all sensations in dermatomes below the injury because ascending nerve impulses cannot propagate past the transection to reach the brain.

At the same time, voluntary muscle contractions will be lost below the transection because nerve impulses descending from the brain also cannot pass. The extent of paralysis of skeletal muscles depends on the level of injury.

The following list outlines which muscle functions may be retained at progressively lower levels of spinal cord transection.

- C1–C3: No function maintained from the neck down; ventilator needed for breathing.
- C4–C5: Diaphragm, which allows breathing.
- C6–C7: Some arm and chest muscles, which allows feeding, some dressing and propelling wheelchair.
- T1–T3: Intact arm function.
- T4–T9: Control of trunk above the umbilicus.
- T10–L1: Most thigh muscles, which allows walking with long leg braces.
- L1–L2: Most leg muscles, which allows walking with short leg braces.

Hemisection is a partial transection of the cord on either the right or left side. Following complete transection, and to varying degrees after hemisection, spinal shock occurs. Spinal shock is an immediate response to spinal cord injury characterized by temporary areflexia, or loss of reflex function. The areflexia occurs in parts of the body served by spinal nerves below the level of the injury. Signs of acute spinal shock include slow heart rate, low blood pressure, flaccid paralysis of skeletal muscles, loss of somatic sensations and urinary bladder dysfunction. Spinal shock may begin within one hour after injury, and may last from several minutes to several months, after which reflex activity gradually returns.

In many cases of traumatic injury of the spinal cord, the patient may have an improved outcome if an anti-inflammatory corticosteroid drug called methylprednisolone is given within eight hours of the injury. This is because the degree of neurological deficit is greatest immediately following traumatic injury as a result of edema (collection of fluid within tissues) as the immune system responds to injury.

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