PSYCHOLOGY HONOURS
Semester / Year : Semester II / Part I (CBCS)
Name of the Teacher : *Dr.Pooja Chatterjee*
Name of the Topic : *Nervous System : Brain , Spinal Cord & ANS : Structure, Function & Diagram*

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Overview

The brain is an amazing three-pound organ that controls all functions of the body, interprets information from the outside world, and embodies the essence of the mind and soul. Intelligence, creativity, emotion, and memory are a few of the many things governed by the brain. Protected within the skull, the brain is composed of the cerebrum, cerebellum, and brainstem.

The brain receives information through our five senses: sight, smell, touch, taste, and hearing - often many at one time. It assembles the messages in a way that has meaning for us, and can store that information in our memory. The brain controls our thoughts, memory and speech, movement of the arms and legs, and the function of many organs within our body.

The central nervous system (CNS) is composed of the brain and spinal cord. The peripheral nervous system (PNS) is composed of spinal nerves that branch from the spinal cord and cranial nerves that branch from the brain.

Brain

The brain is composed of the cerebrum, cerebellum, and brainstem (Fig. 1).

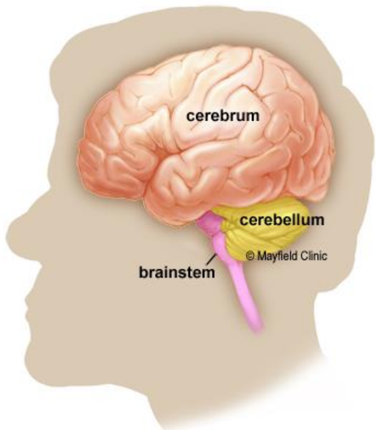


Figure 1. The brain has three main parts: the cerebrum, cerebellum and brainstem.

Cerebrum: is the largest part of the brain and is composed of right and left hemispheres. It performs higher functions like interpreting touch, vision and hearing, as well as speech, reasoning, emotions, learning, and fine control of movement.

Cerebellum: is located under the cerebrum. Its function is to coordinate muscle movements, maintain posture, and balance.

Brainstem: acts as a relay center connecting the cerebrum and cerebellum to the spinal cord. It performs many automatic functions such as breathing, heart rate, body temperature, wake and sleep cycles, digestion, sneezing, coughing, vomiting, and swallowing.

Right brain – left brain

The cerebrum is divided into two halves: the right and left hemispheres (Fig. 2) They are joined by a bundle of fibers called the corpus callosum that transmits messages from one side to the other. Each hemisphere controls the opposite side of the body. If a stroke occurs on the right side of the brain, your left arm or leg may be weak or paralyzed.

Not all functions of the hemispheres are shared. In general, the left hemisphere controls speech, comprehension, arithmetic, and writing. The right hemisphere controls creativity, spatial ability, artistic, and musical skills. The left hemisphere is dominant in hand use and language in about 92% of people.

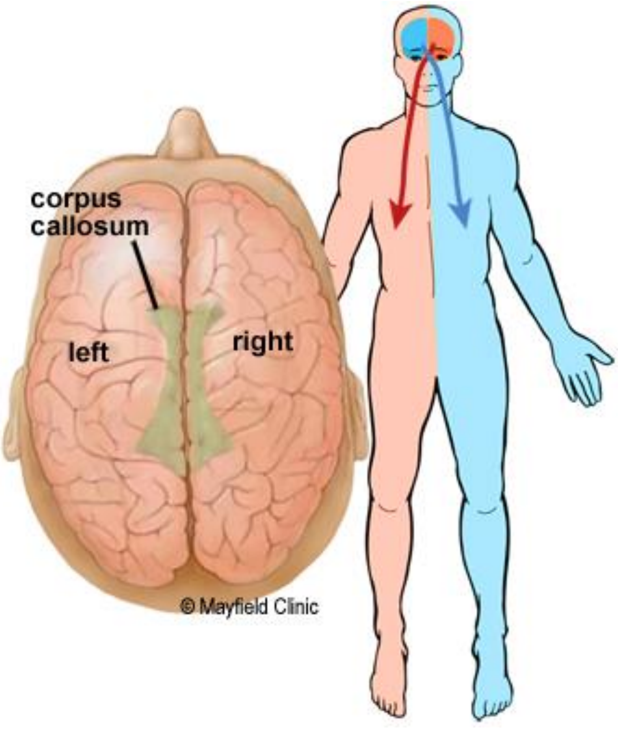


Figure 2. The cerebrum is divided into left and right hemispheres. The two sides are connected by the nerve fibers corpus callosum.

Lobes of the brain

The cerebral hemispheres have distinct fissures, which divide the brain into lobes. Each hemisphere has 4 lobes: frontal, temporal, parietal, and occipital (Fig. 3). Each lobe may be divided, once again, into areas that serve very specific functions. It's important to understand that each lobe of the brain does not function alone. There are very complex relationships between the lobes of the brain and between the right and left hemispheres.

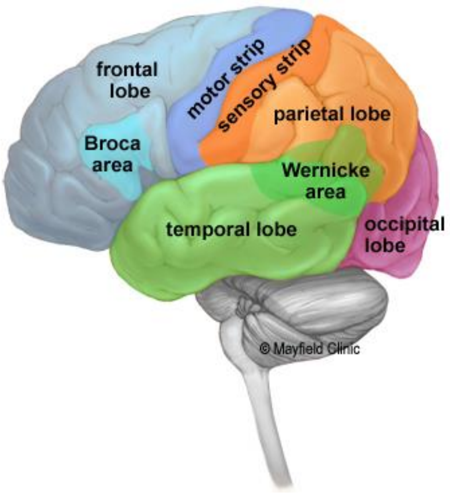


Figure 3. The cerebrum is divided into four lobes: frontal, parietal, occipital and temporal.

Frontal lobe

- Personality, behavior, emotions
- Judgment, planning, problem solving
- Speech: speaking and writing (Broca's area)
- Body movement (motor strip)
- Intelligence, concentration, self awareness

Parietal lobe

- Interprets language, words
- Sense of touch, pain, temperature (sensory strip)
- Interprets signals from vision, hearing, motor, sensory and memory
- Spatial and visual perception

Occipital lobe

- Interprets vision (color, light, movement)

Temporal lobe

- Understanding language (Wernicke's area)
- Memory
- Hearing
- Sequencing and organization

Language

In general, the left hemisphere of the brain is responsible for language and speech and is called the "dominant" hemisphere. The right hemisphere plays a large part in interpreting visual information and spatial processing. In about one third of people who are left-handed, speech function may be located on the right side of the brain. Left-handed people may need special testing to determine if their speech center is on the left or right side prior to any surgery in that area.

Aphasia is a disturbance of language affecting speech production, comprehension, reading or writing, due to brain injury – most commonly from stroke or trauma. The type of aphasia depends on the brain area damaged.

Broca's area: lies in the left frontal lobe (Fig 3). If this area is damaged, one may have difficulty moving the tongue or facial muscles to produce the sounds of speech. The person can still read and understand spoken language but has difficulty in speaking and writing (i.e. forming letters and words, doesn't write within lines) – called Broca's aphasia.

Wernicke's area: lies in the left temporal lobe (Fig 3). Damage to this area causes Wernicke's aphasia. The individual may speak in long sentences that have no meaning, add unnecessary words, and even create new words. They can make speech sounds, however they have difficulty understanding speech and are therefore unaware of their mistakes.

Cortex

The surface of the cerebrum is called the cortex. It has a folded appearance with hills and valleys. The cortex contains 16 billion neurons (the cerebellum has 70 billion = 86 billion total) that are arranged in specific layers. The nerve cell bodies color the cortex grey-brown giving it its name – gray matter (Fig. 4). Beneath the cortex are long nerve fibers (axons) that connect brain areas to each other — called white matter.

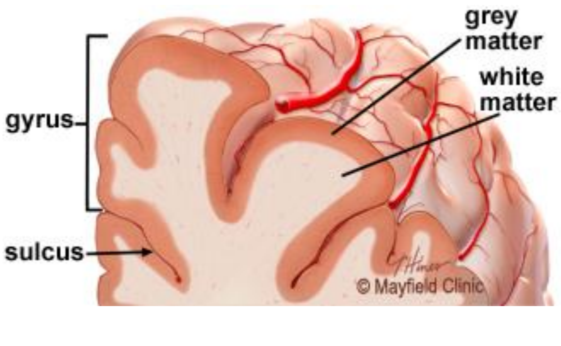


Figure 4. The cortex contains neurons (grey matter), which are interconnected to other brain areas by axons (white matter). The cortex has a folded appearance. A fold is called a gyrus and the valley between is a sulcus.

The folding of the cortex increases the brain’s surface area allowing more neurons to fit inside the skull and enabling higher functions. Each fold is called a gyrus, and each groove between folds is called a sulcus. There are names for the folds and grooves that help define specific brain regions.

Deep structures

Pathways called white matter tracts connect areas of the cortex to each other. Messages can travel from one gyrus to another, from one lobe to another, from one side of the brain to the other, and to structures deep in the brain (Fig. 5).

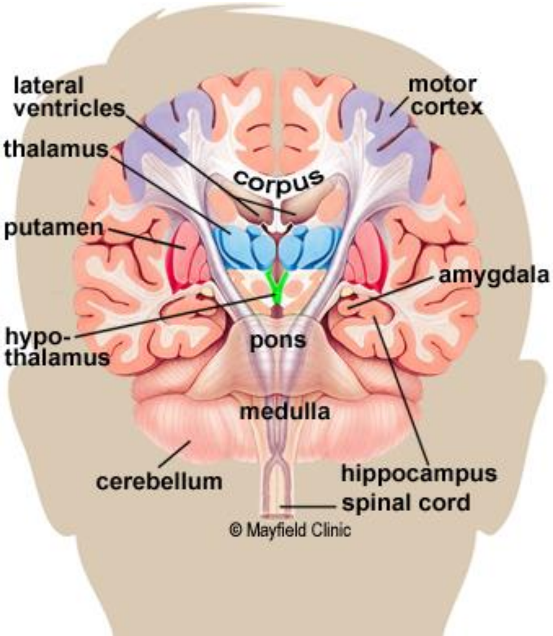


Figure 5. Coronal cross-section showing the basal ganglia.

Hypothalamus: is located in the floor of the third ventricle and is the master control of the autonomic system. It plays a role in controlling behaviors such as hunger, thirst, sleep, and sexual response. It also regulates body temperature, blood pressure, emotions, and secretion of hormones.

Pituitary gland: lies in a small pocket of bone at the skull base called the sella turcica. The pituitary gland is connected to the hypothalamus of the brain by the pituitary stalk. Known as the “master gland,” it controls other endocrine glands in the body. It secretes hormones that control sexual development, promote bone and muscle growth, and respond to stress.

Pineal gland: is located behind the third ventricle. It helps regulate the body’s internal clock and circadian rhythms by secreting melatonin. It has some role in sexual development.

Thalamus: serves as a relay station for almost all information that comes and goes to the cortex. It plays a role in pain sensation, attention, alertness and memory.

Basal ganglia: includes the caudate, putamen and globus pallidus. These nuclei work with the cerebellum to coordinate fine motions, such as fingertip movements.

Limbic system: is the center of our emotions, learning, and memory. Included in this system are the cingulate gyri, hypothalamus, amygdala (emotional reactions) and hippocampus (memory).

Memory

Memory is a complex process that includes three phases: encoding (deciding what information is important), storing, and recalling. Different areas of the brain are involved in different types of memory (Fig. 6). Your brain has to pay attention and rehearse in order for an event to move from short-term to long-term memory – called encoding.

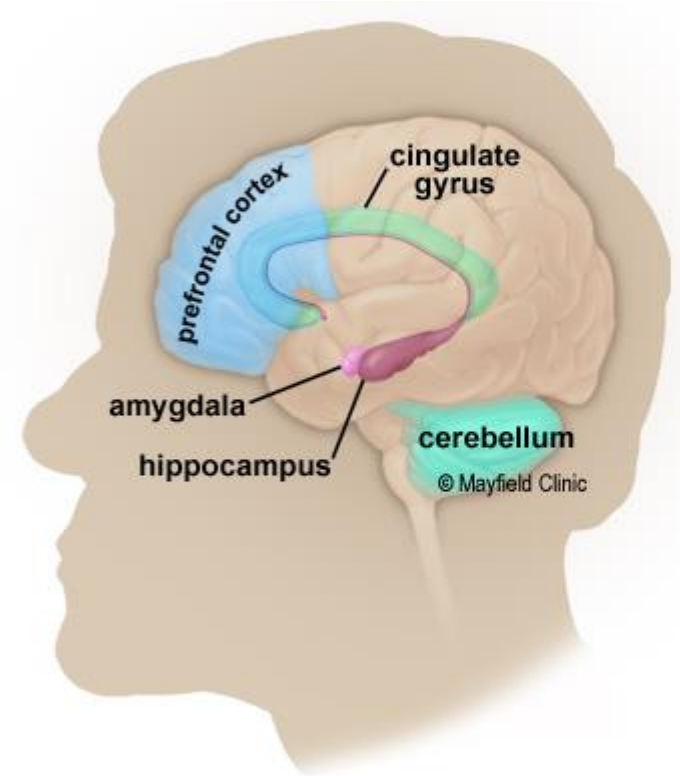


Figure 6. Structures of the limbic system involved in memory formation. The prefrontal cortex holds recent events briefly in short-term memory. The hippocampus is responsible for encoding long-term memory.

- Short-term memory, also called working memory, occurs in the prefrontal cortex. It stores information for about one minute and its capacity is limited to about 7 items. For example, it enables you to dial a phone number someone just told you. It also intervenes during reading, to memorize the sentence you have just read, so that the next one makes sense.

- Long-term memory is processed in the hippocampus of the temporal lobe and is activated when you want to memorize something for a longer time. This memory has unlimited content and duration capacity. It contains personal memories as well as facts and figures.

- Skill memory is processed in the cerebellum, which relays information to the basal ganglia. It stores automatic learned memories like tying a shoe, playing an instrument, or riding a bike.

Ventricles and cerebrospinal fluid

The brain has hollow fluid-filled cavities called ventricles (Fig. 7). Inside the ventricles is a ribbon-like structure called the choroid plexus that makes clear colorless cerebrospinal fluid (CSF). CSF flows within and around the brain and spinal cord to help cushion it from injury. This circulating fluid is constantly being absorbed and replenished.

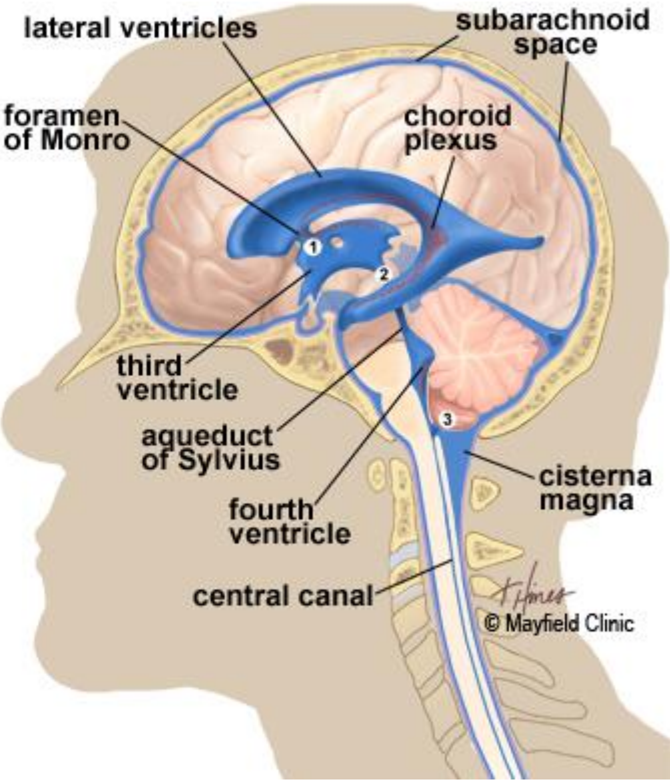


Figure 7. CSF is produced inside the ventricles deep within the brain. CSF fluid circulates inside the brain and spinal cord and then outside to the subarachnoid space. Common sites of obstruction: 1) foramen of Monro, 2) aqueduct of Sylvius, and 3) obex.

There are two ventricles deep within the cerebral hemispheres called the lateral ventricles. They both connect with the third ventricle through a separate opening called the foramen of Monro. The third ventricle connects with the fourth ventricle through a long narrow tube called the aqueduct of Sylvius. From the fourth ventricle, CSF flows into the subarachnoid space where it bathes and cushions the brain. CSF is recycled (or absorbed) by special structures in the superior sagittal sinus called arachnoid villi.

A balance is maintained between the amount of CSF that is absorbed and the amount that is produced. A disruption or blockage in the system can cause a build up of CSF, which can cause enlargement of the ventricles (hydrocephalus) or cause a collection of fluid in the spinal cord (syringomyelia).

Skull

The purpose of the bony skull is to protect the brain from injury. The skull is formed from 8 bones that fuse together along suture lines. These bones include the frontal, parietal (2), temporal (2), sphenoid, occipital and ethmoid (Fig. 8). The face is formed from 14 paired bones including the maxilla, zygoma, nasal, palatine, lacrimal, inferior nasal conchae, mandible, and vomer.

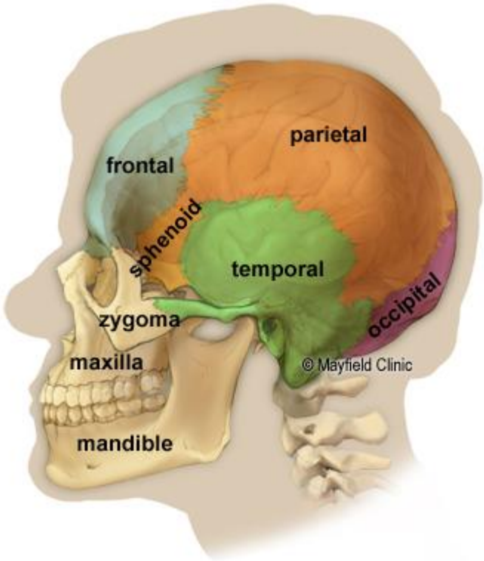


Figure 8. The brain is protected inside the skull. The skull is formed from eight bones.

Inside the skull are three distinct areas: anterior fossa, middle fossa, and posterior fossa (Fig. 9). Doctors sometimes refer to a tumor’s location by these terms, e.g., middle fossa meningioma.

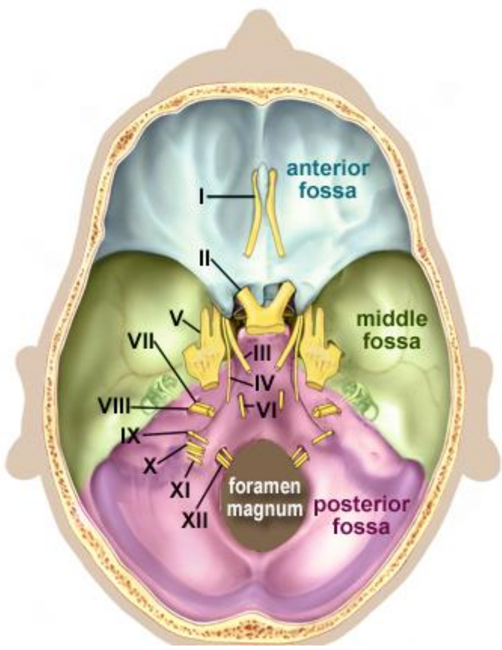


Figure 9. A view of the cranial nerves at the base of the skull with the brain removed. Cranial nerves originate from the brainstem, exit the skull through holes called foramina, and travel to the parts of the body they innervate. The brainstem exits the skull through the foramen magnum. The base of the skull is divided into 3 regions: anterior, middle and posterior fossae.

Similar to cables coming out the back of a computer, all the arteries, veins and nerves exit the base of the skull through holes, called foramina. The big hole in the middle (foramen magnum) is where the spinal cord exits.

Cranial nerves

The brain communicates with the body through the spinal cord and twelve pairs of cranial nerves (Fig. 9). Ten of the twelve pairs of cranial nerves that control hearing, eye movement, facial sensations, taste, swallowing and movement of the face, neck, shoulder and tongue muscles originate in the brainstem. The cranial nerves for smell and vision originate in the cerebrum.

The Roman numeral, name, and main function of the twelve cranial nerves:

Number	***Name***	***Function***
I	**olfactory**	**smell**
II	**optic**	**sight**
III	**oculomotor**	**moves eye, pupil**
IV	**trochlear**	**moves eye**
V	**trigeminal**	**face sensation**
VI	**abducens**	**moves eye**
VII	**facial**	**moves face, salivate**
VIII	**vestibulocochlear**	**hearing, balance**
IX	**glossopharyngeal**	**taste, swallow**

X	**vagus**	**heart rate, digestion**
XI	**accessory**	**moves head**
XII	**hypoglossal**	**moves tongue**

<u>Meninges</u>

The brain and spinal cord are covered and protected by three layers of tissue called meninges. From the outermost layer inward they are: the dura mater, arachnoid mater, and pia mater.

Dura mater: is a strong, thick membrane that closely lines the inside of the skull; its two layers, the periosteal and meningeal dura, are fused and separate only to form venous sinuses. The dura creates little folds or compartments. There are two special dural folds, the falx and the tentorium. The falx separates the right and left hemispheres of the brain and the tentorium separates the cerebrum from the cerebellum.

Arachnoid mater: is a thin, web-like membrane that covers the entire brain. The arachnoid is made of elastic tissue. The space between the dura and arachnoid membranes is called the subdural space.

Pia mater: hugs the surface of the brain following its folds and grooves. The pia mater has many blood vessels that reach deep into the brain. The space between the arachnoid and pia is called the subarachnoid space. It is here where the cerebrospinal fluid bathes and cushions the brain.

Blood supply

Blood is carried to the brain by two paired arteries, the internal carotid arteries and the vertebral arteries (Fig. 10). The internal carotid arteries supply most of the cerebrum.

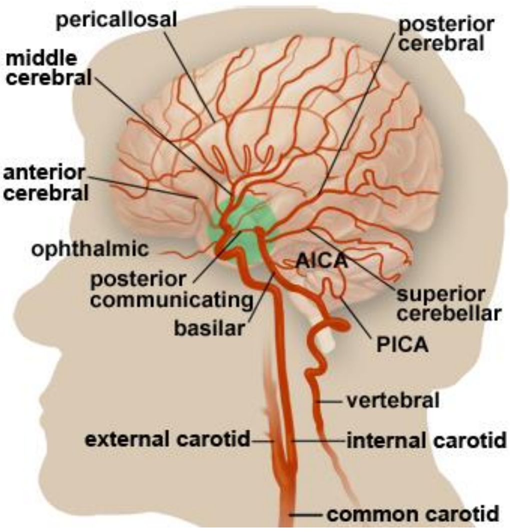


Figure 10. The common carotid artery courses up the neck and divides into the internal and external carotid arteries. The brain's anterior circulation is fed by the internal carotid arteries (ICA) and the posterior circulation is fed by the vertebral arteries (VA). The two systems connect at the Circle of Willis (green circle). The vertebral arteries supply the cerebellum, brainstem, and the underside of the cerebrum. After passing through the skull, the right and left vertebral arteries join together to form the basilar artery. The basilar artery and the internal carotid arteries "communicate" with each other at the base of the brain called the Circle of Willis (Fig. 11). The communication between the internal carotid and vertebral-basilar systems is an important safety feature of the brain. If one of the major vessels becomes blocked, it is possible for collateral blood flow to come across the Circle of Willis and prevent brain damage.

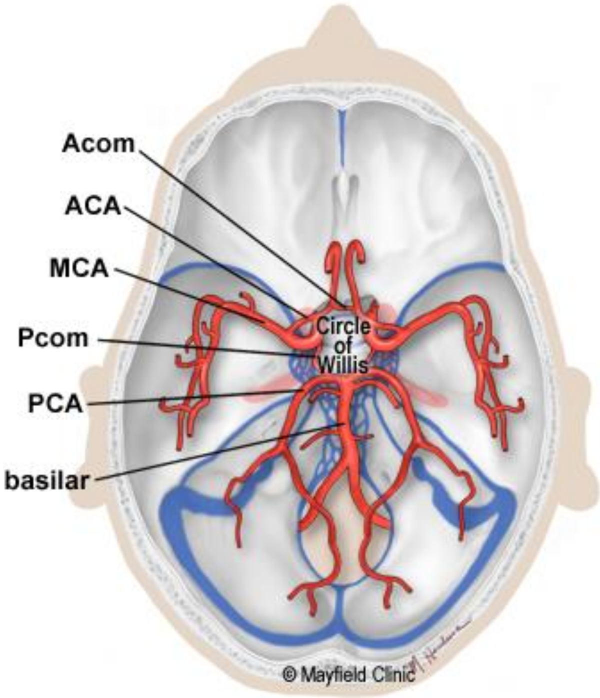


Figure 11. Top view of the Circle of Willis. The internal carotid and vertebral-basilar systems are joined by the anterior communicating (Acom) and posterior communicating (Pcom) arteries.

The venous circulation of the brain is very different from that of the rest of the body. Usually arteries and veins run together as they supply and drain specific areas of the body. So one would think there would be a pair of vertebral veins and internal carotid veins. However, this is not the case in the brain. The major vein collectors are integrated into the dura to form venous sinuses — not to be confused with the air sinuses in the face and nasal region. The venous sinuses collect the blood from the brain and pass it to the internal jugular veins. The superior and inferior sagittal sinuses drain the cerebrum, the cavernous sinuses drains the anterior skull base. All sinuses eventually drain to the sigmoid sinuses, which exit the skull and form the jugular veins. These two jugular veins are essentially the only drainage of the brain.

Cells of the brain

The brain is made up of two types of cells: nerve cells (neurons) and glia cells.

Nerve cells

There are many sizes and shapes of neurons, but all consist of a cell body, dendrites and an axon. The neuron conveys information through electrical and chemical signals. Try to picture electrical wiring in your home. An electrical circuit is made up of numerous wires connected in such a way that when a light switch is turned on, a light bulb will beam. A neuron that is excited will transmit its energy to neurons within its vicinity.

Neurons transmit their energy, or "talk", to each other across a tiny gap called a synapse (Fig. 12). A neuron has many arms called dendrites, which act like antennae picking up messages from other nerve cells. These messages are passed to the cell body, which determines if the message should be passed along. Important messages are passed to the end of the axon where sacs containing neurotransmitters open into the synapse. The neurotransmitter molecules cross the synapse and fit into special receptors on the receiving nerve cell, which stimulates that cell to pass on the message.

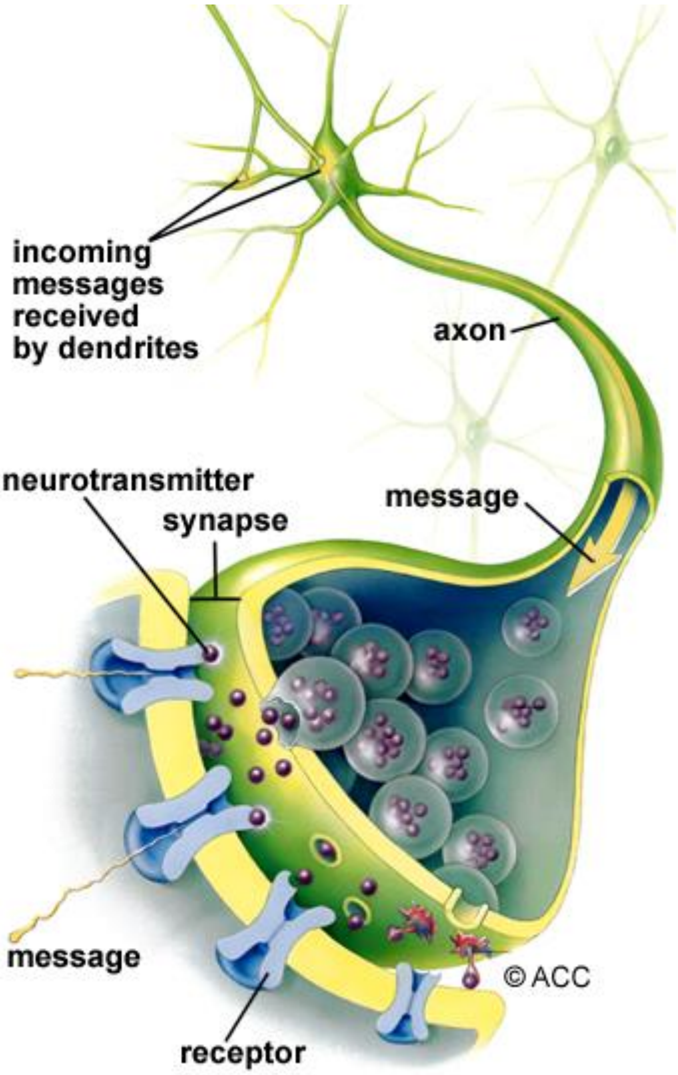


Figure 12. Nerve cells consist of a cell body, dendrites and axon. Neurons communicate with each other by exchanging neurotransmitters across a tiny gap called a synapse.

Glia cells

Glia (Greek word meaning glue) are the cells of the brain that provide neurons with nourishment, protection, and structural support. There are about 10 to 50 times more glia than nerve cells and are the most common type of cells involved in brain tumors.

- Astroglia or astrocytes are the caretakers — they regulate the blood brain barrier, allowing nutrients and molecules to interact with neurons. They control homeostasis, neuronal defense and repair, scar formation, and also affect electrical impulses.

- Oligodendroglia cells create a fatty substance called myelin that insulates axons – allowing electrical messages to travel faster.

- Ependymal cells line the ventricles and secrete cerebrospinal fluid (CSF).

- Microglia are the brain's immune cells, protecting it from invaders and cleaning up debris. They also prune synapses.

Spinal Cord

The spinal cord is the most important structure between the body and the brain. The spinal cord extends from the foramen magnum where it is continuous with the medulla to the level of the first or second lumbar vertebrae. It is a vital link between the brain and the body, and from the body to the brain. The spinal cord is 40 to 50 cm long and 1 cm to 1.5 cm in diameter. Two consecutive rows of nerve roots emerge on each of its sides. These nerve roots join distally to form 31 pairs of **spinal nerves**. The spinal cord is a cylindrical structure of nervous tissue composed of white and gray matter, is uniformly organized and is divided into four regions: cervical (C), thoracic (T), lumbar (L) and sacral (S), (Figure 3.1), each of which is comprised of several segments. The spinal nerve contains motor and sensory nerve fibers to and from all parts of the body. Each spinal cord segment innervates a dermatome (see below and Figure 3.5).

General Features

1. Similar cross-sectional structures at all spinal cord levels (Figure 3.1).

2. It carries sensory information (sensations) from the body and some from the head to the central nervous system (CNS) via afferent fibers, and it performs the initial processing of this information.
3. Motor neurons in the ventral horn project their axons into the periphery to innervate skeletal and smooth muscles that mediate voluntary and involuntary reflexes.
4. It contains neurons whose descending axons mediate autonomic control for most of the visceral functions.
5. It is of great clinical importance because it is a major site of traumatic injury and the locus for many disease processes.

Although the spinal cord constitutes only about 2% of the central nervous system (CNS), its functions are vital. *Knowledge of spinal cord functional anatomy makes it possible to diagnose the nature and location of cord damage and many cord diseases.*

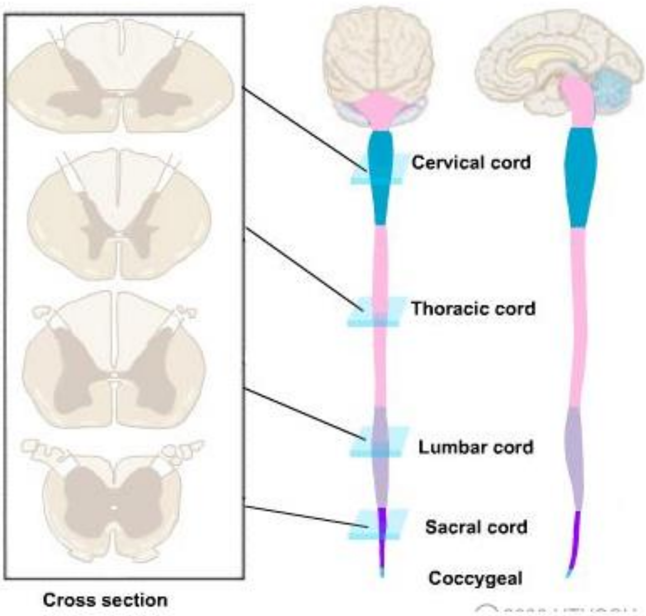


Figure 3.1
Schematic dorsal and lateral view of the spinal cord and four cross sections from cervical, thoracic, lumbar and sacral levels, respectively.

■ Segmental and Longitudinal Organization

The spinal cord is divided into four different regions: the cervical, thoracic, lumbar and sacral regions (Figure 3.1). The different cord regions can be visually distinguished from one another. Two enlargements of the spinal cord can be visualized: The cervical enlargement, which extends between C3 to T1; and the lumbar enlargements which extends between L1 to S2 (Figure 3.1).

The cord is segmentally organized. There are 31 segments, defined by 31 pairs of nerves exiting the cord. These nerves are divided into 8 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 1 coccygeal nerve (Figure 3.2). Dorsal and ventral roots enter and leave the vertebral column respectively through intervertebral foramen at the vertebral segments corresponding to the spinal segment.

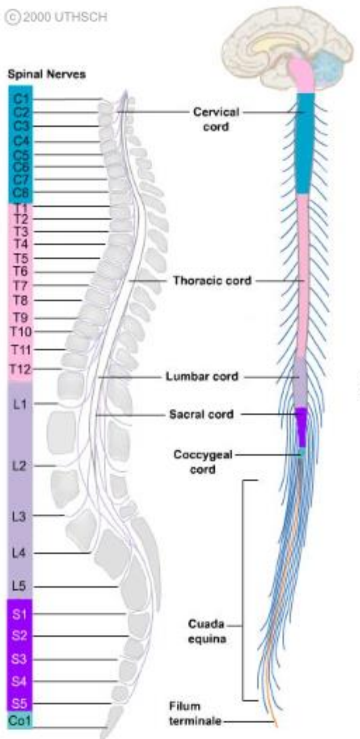
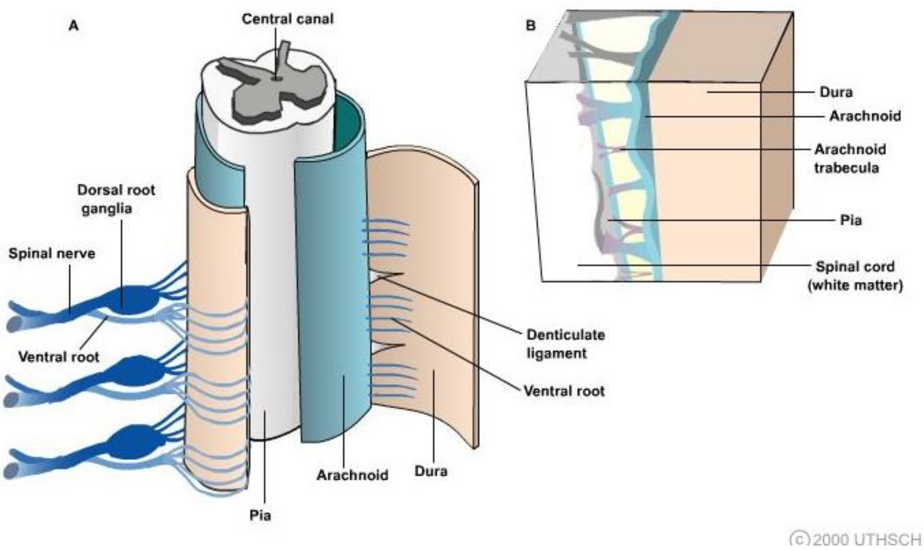


Figure 3.2
Drawing of the 8, 12, 5, 5 and 1 cervical, thoracic, lumbar, sacral and coccygeal spinal nerves and their exit from the vertebrate, respectively.

The cord is sheathed in the same three meninges as is the brain: the pia, arachnoid and dura. The dura is the tough outer sheath, the arachnoid lies beneath it, and the pia closely adheres to the surface of the cord (Figure 3.3). The spinal cord is attached to the dura by a series of lateral denticulate ligaments emanating from the pial folds.



During the initial third month of embryonic development, the spinal cord extends the entire length of the vertebral canal and both grow at about the same rate. As development continues, the body and the vertebral column continue to grow at a much greater rate than the spinal cord proper. This results in displacement of the lower parts of the spinal cord with relation to the vertebrae column. The outcome of this uneven growth is that the adult spinal cord extends to the level of the first or second lumbar vertebrae, and the nerves grow to exit through the same intervertebral foramina as they did during embryonic development. This growth of the nerve roots occurring within the vertebral canal, results in the lumbar, sacral, and coccygeal roots extending to their appropriate vertebral levels (Figure 3.2).

All spinal nerves, except the first, exit below their corresponding vertebrae. In the cervical segments, there are 7 cervical vertebrae and 8 cervical nerves (Figure 3.2). C1-C7 nerves exit above their vertebrae whereas the C8 nerve exits below the C7 vertebra. It leaves between the C7 vertebra and the first thoracic vertebra. Therefore, each subsequent nerve leaves the cord below the corresponding vertebra. In the thoracic and upper lumbar regions, the difference between the vertebrae and cord level is three segments. Therefore, the root filaments of spinal cord segments have to travel longer distances to reach the corresponding intervertebral foramen from which the spinal nerves emerge. The lumbosacral roots are known as the cauda equina (Figure 3.2).

Each spinal nerve is composed of nerve fibers that are related to the region of the muscles and skin that develops from one body somite (segment). A spinal segment is defined by dorsal roots entering and ventral roots exiting the cord, (i.e., a spinal cord section that gives rise to one spinal nerve is considered as a segment.) (Figure 3.4).

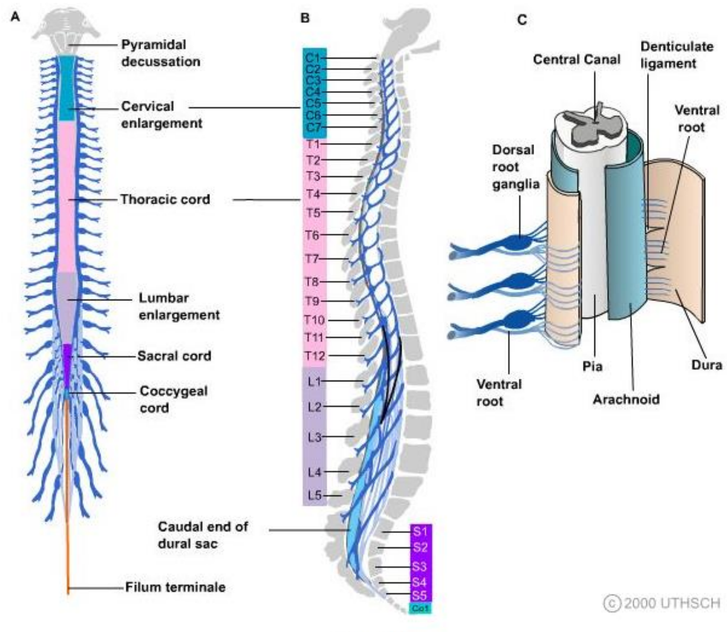


Figure 3.4

A **dermatome** is an area of skin supplied by peripheral nerve fibers originating from a single dorsal root ganglion. If a nerve is cut, one loses sensation from that dermatome. Because each segment of the cord innervates a different region of the body, dermatomes can be precisely mapped on the body surface, and loss of sensation in a dermatome can indicate the exact level of spinal cord damage in clinical assessment of injury (Figure 3.5). It is important to consider that there is some overlap between neighbouring dermatomes. Because sensory information from the body is relayed to the CNS through the dorsal roots, the axons originating from dorsal root ganglion cells are classified as primary sensory afferents, and the dorsal root's neurons are the first order (1°) sensory neuron. Most axons in the ventral roots arise from motor neurons in the ventral horn of the spinal cord and innervate skeletal muscle. Others arise from the lateral horn and synapse on autonomic ganglia that innervate visceral organs. The ventral root axons join with the peripheral processes of the dorsal root ganglion cells to form mixed afferent and efferent spinal nerves, which merge to form peripheral nerves. Knowledge of the segmental innervation of the cutaneous area and the muscles is essential to diagnose the site of an injury.

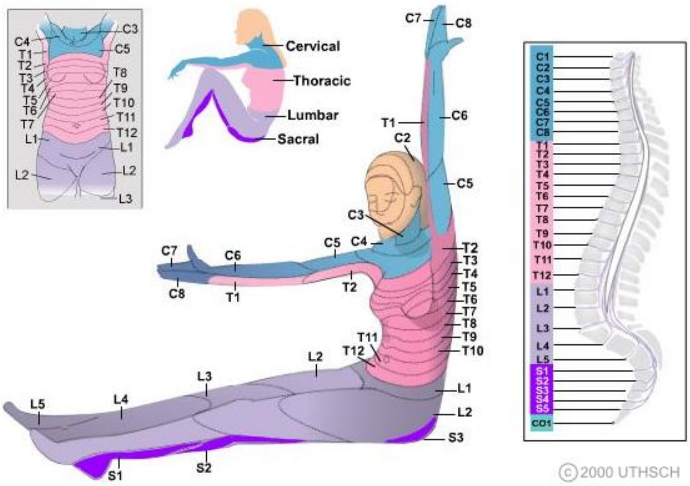


Figure 3.5

Internal Structure of the Spinal Cord

A transverse section of the adult spinal cord shows white matter in the periphery, gray matter inside, and a tiny central canal filled with CSF at its center. Surrounding the canal is a single layer of cells, the ependymal layer. Surrounding the ependymal layer is the gray matter – a region containing cell bodies – shaped like the letter “H” or a “butterfly”. The two “wings” of the butterfly are connected across the midline by the dorsal gray commissure and below the white commissure (Figure 3.6). The shape and size of the gray matter varies according to spinal cord level. At the lower levels, the ratio between gray matter and white matter is greater than in higher levels, mainly because lower levels contain less ascending and descending nerve fibers. (Figure 3.1 and Figure 3.6).

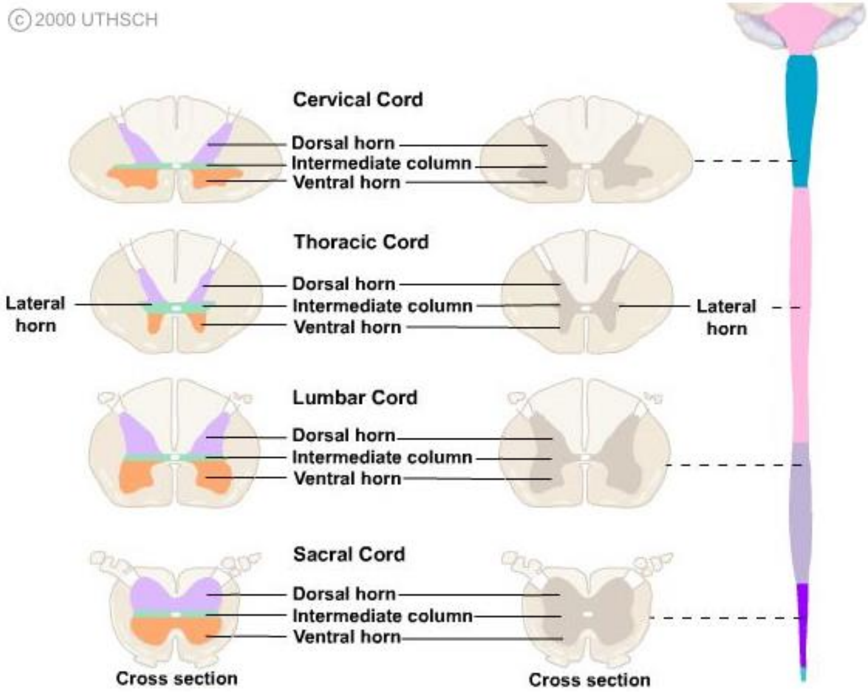


Figure 3.6

The gray matter mainly contains the cell bodies of neurons and glia and is divided into four main columns: dorsal horn, intermediate column, lateral horn and ventral horn column. (Figure 3.6).

The dorsal horn is found at all spinal cord levels and is comprised of sensory nuclei that receive and process incoming somatosensory information. From there, ascending projections emerge to transmit the sensory information to the midbrain and diencephalon. The intermediate column and the lateral horn comprise autonomic neurons innervating visceral and pelvic organs. The ventral horn comprises motor neurons that innervate skeletal muscle.

At all the levels of the spinal cord, nerve cells in the gray substance are multipolar, varying much in their morphology. Many of them are Golgi type I and Golgi type II nerve cells. The axons of Golgi type I are long and pass out of the gray matter into the ventral spinal roots or the fiber tracts of the white matter. The axons and dendrites of the Golgi type II cells are largely confined to the neighboring neurons in the gray matter.

A more recent classification of neurons within the gray matter is based on function. These cells are located at all levels of the spinal cord and are grouped into three main categories: root cells, column or tract cells and propriospinal cells.

The root cells are situated in the ventral and lateral gray horns and vary greatly in size. The most prominent features of the root cells are large multipolar elements exceeding 25 µm of their somata. The root cells contribute their axons to the ventral roots of the spinal nerves and are grouped into two major divisions: 1) somatic efferent root neurons, which innervate the skeletal musculature; and 2) the visceral efferent root neurons, also called preganglionic autonomic axons, which send their axons to various autonomic ganglia.

The **column** or **tract cells** and their processes are located mainly in the dorsal gray horn and are confined entirely within the CNS. The axons of the column cells form longitudinal ascending tracts that ascend in the white columns and terminate upon neurons located rostrally in the brain stem, cerebellum or diencephalon. Some column cells send their axons up and down the cord to terminate in gray matter close to their origin and are known as intersegmental association column cells. Other column cell axons terminate within the segment in which they originate and are called intrasegmental association column cells. Still other column cells send their axons across the midline to terminate in gray matter close to their origin and are called commissure association column cells.

The **propriospinal cells** are spinal interneurons whose axons do not leave the spinal cord proper. Propriospinal cells account for about 90% of spinal neurons. Some of these fibers also are found around the margin of the gray matter of the cord and are collectively called the fasciculus proprius or the propriospinal or the archispinothalamic tract.

Spinal Cord Nuclei and Laminae

Spinal neurons are organized into nuclei and laminae.

■ **Nuclei**

The prominent nuclear groups of cell columns within the spinal cord from dorsal to ventral are the marginal zone, substantia gelatinosa, nucleus proprius, dorsal nucleus of Clarke, intermediolateral nucleus and the lower motor neuron nuclei.

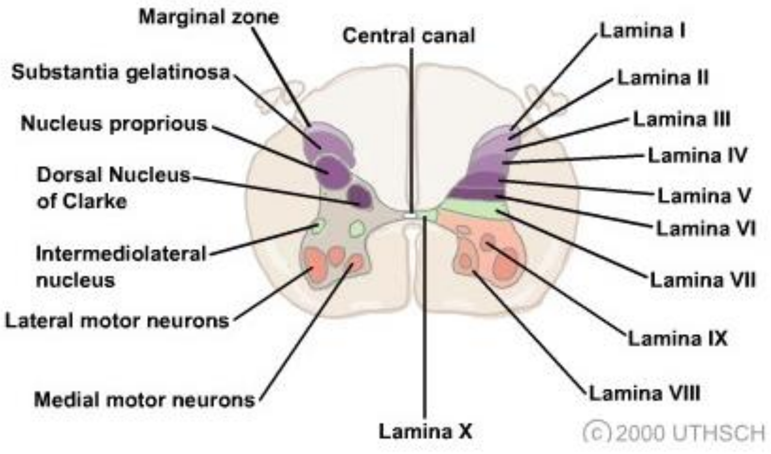


Figure 3.7
Spinal cord nuclei and laminae.

Marginal zone nucleus or posterior marginalis, is found at all spinal cord levels as a thin layer of column/tract cells (column cells) that caps the tip of the dorsal horn. The axons of its neurons contribute to the lateral spinothalamic tract which relays pain and temperature information to the diencephalon (Figure 3.7).

Substantia gelatinosa is found at all levels of the spinal cord. Located in the dorsal cap-like portion of the head of the dorsal horn, it relays pain, temperature and mechanical (light touch) information and consists mainly of column cells (intersegmental column cells). These column cells synapse in cell at Rexed layers IV to VII, whose axons contribute to the ventral (anterior) and lateral spinal thalamic tracts. *The homologous substantia gelatinosa in the medulla is the* ***spinal trigeminal nucleus****.*

Nucleus proprius is located below the substantia gelatinosa in the head and neck of the dorsal horn. This cell group, sometimes called the chief sensory nucleus, is associated with mechanical and temperature sensations. It is a poorly defined cell column which extends through all segments of the spinal cord and its neurons contribute to ventral and lateral spinal thalamic tracts, as well as to spinal cerebellar tracts. The axons originating in nucleus proprius project to the thalamus via the spinothalamic tract and to the cerebellum via the ventral spinocerebellar tract (VSCT).

Dorsal nucleus of Clarke is a cell column located in the mid-portion of the base form of the dorsal horn. The axons from these cells pass uncrossed to the lateral funiculus and form the dorsal (posterior) spinocerebellar tract (DSCT), which subserve unconscious proprioception from muscle spindles and Golgi tendon organs to the cerebellum, and some of them innervate spinal interneurons. The dorsal nucleus of Clarke is found only in segments C8 to L3 of the spinal cord and is most prominent in lower thoracic and upper lumbar segments. *The homologous dorsal nucleus of Clarke in the medulla is the accessory cuneate nucleus, which is the origin of the cuneocerebellar tract (CCT).*

Intermediolateral nucleus is located in the intermediate zone between the dorsal and the ventral horns in the spinal cord levels. Extending from C8 to L3, it receives viscerosensory information and contains preganglionic sympathetic neurons, which form the lateral horn. A large proportion of its cells are root cells which send axons into the ventral spinal roots via the white rami to reach the sympathetic tract as preganglionic fibers. Similarly, cell columns in the intermediolateral nucleus located at the S2 to S4 levels contains preganglionic parasympathetic neurons (Figure 3.7).

Lower motor neuron nuclei are located in the ventral horn of the spinal cord. They contain predominantly motor nuclei consisting of α, β and γ motor neurons and are found at all levels of the spinal cord--they are root cells. The a motor neurons are the final common pathway of the motor system, and they innervate the visceral and skeletal muscles.

Rexed Laminae

The distribution of cells and fibers within the gray matter of the spinal cord exhibits a pattern of lamination. The cellular pattern of each lamina is composed of various sizes or shapes of neurons (cytoarchitecture) which led Rexed to propose a new classification based on 10 layers (laminae). This classification is useful since it is related more accurately to function than the previous classification scheme which was based on major nuclear groups (Figure 3.7).

Laminae I to IV, in general, are concerned with exteroceptive sensation and comprise the dorsal horn, whereas laminae V and VI are concerned primarily with proprioceptive sensations. Lamina VII is equivalent to the intermediate zone and acts as a relay between muscle spindle to midbrain and cerebellum, and laminae VIII-IX comprise the ventral horn and contain mainly motor neurons. The axons of these neurons innervate mainly skeletal muscle. Lamina X surrounds the central canal and contains neuroglia.

Rexed lamina I – Consists of a thin layer of cells that cap the tip of the dorsal horn with small dendrites and a complex array of nonmyelinated axons. Cells in lamina I respond mainly to noxious and thermal stimuli. Lamina I cell axons join the contralateral spinothalamic tract; this layer corresponds to nucleus posteromarginalis.

Rexed lamina II – Composed of tightly packed interneurons. This layer corresponds to the substantia gelatinosa and responds to noxious stimuli while others respond to non-noxious stimuli. The majority of neurons in Rexed lamina II axons receive information from sensory dorsal root ganglion cells as well as descending dorsolateral fasciculus (DLF) fibers. They send axons to Rexed laminae III and IV (fasciculus proprius). High concentrations of substance P and opiate receptors have been identified in Rexed lamina II. The lamina is believed to be important for the modulation of sensory input, with the effect of determining which pattern of incoming information will produce sensations that will be interpreted by the brain as being painful.

Rexed lamina III – Composed of variable cell size, axons of these neurons bifurcate several times and form a dense plexus. Cells in this layer receive axodendritic synapses from Aβ fibers entering dorsal root fibers. It contains dendrites of cells from laminae IV, V and VI. Most of the neurons in lamina III function as propriospinal/interneuron cells.

Rexed lamina IV – The thickest of the first four laminae. Cells in this layer receive Aß axons which carry predominantly non-noxious information. In addition, dendrites of neurons in lamina IV radiate to lamina II, and respond to stimuli such as light touch. The ill-defined nucleus proprius is located in the head of this layer. Some of the cells project to the thalamus via the contralateral and ipsilateral spinothalamic tract.

Rexed lamina V – Composed neurons with their dendrites in lamina II. The neurons in this lamina receive monosynaptic information from Aß, Ad and C axons which also carry nociceptive information from visceral organs. This lamina covers a broad zone extending across the neck of the dorsal horn and is divided into medial and lateral parts. Many of the Rexed lamina V cells project to the brain stem and the thalamus via the contralateral and ipsilateral spinothalamic tract. Moreover, descending corticospinal and rubrospinal fibers synapse upon its cells.

Rexed lamina VI – Is a broad layer which is best developed in the cervical and lumbar enlargements. Lamina VI divides also into medial and lateral parts. Group Ia afferent axons from muscle spindles terminate in the medial part at the C8 to L3 segmental levels and are the source of the ipsilateral spinocerebellar pathways. Many of the small neurons are interneurons participating in spinal reflexes, while descending brainstem pathways project to the lateral zone of Rexed layer VI.

Rexed lamina VII – This lamina occupies a large heterogeneous region. This region is also known as the zona intermedia (or intermediolateral nucleus). Its shape and boundaries vary along the length of the cord. Lamina VII neurons receive information from Rexed lamina II to VI as well as visceral afferent fibers, and they serve as an intermediary relay in transmission of visceral motor neurons impulses. The dorsal nucleus of Clarke forms a prominent round oval cell column from C8 to L3. The large cells give rise to uncrossed nerve fibers of the dorsal spinocerebellar tract (DSCT). Cells in laminae V to VII, which do not form a discrete nucleus, give rise to uncrossed fibers that form the ventral spinocerebellar tract (VSCT). Cells in the lateral horn of the cord in segments T1 and L3 give rise to preganglionic sympathetic fibers to innervate postganglionic cells located in the sympathetic ganglia outside the cord. Lateral horn neurons at segments S2 to S4 give rise to preganglionic neurons of the sacral parasympathetic fibers to innervate postganglionic cells located in peripheral ganglia.

Rexed lamina VIII – Includes an area at the base of the ventral horn, but its shape differs at various cord levels. In the cord enlargements, the lamina occupies only the medial part of the ventral horn, where descending vestibulospinal and reticulospinal fibers terminate. The neurons of lamina VIII modulate motor activity, most probably via g motor neurons which innervate the intrafusal muscle fibers.

Rexed lamina IX – Composed of several distinct groups of large a motor neurons and small γ and β motor neurons embedded within this layer. Its size and shape differ at various cord levels. In the cord enlargements the number of α motor neurons increase and they form numerous groups. The α motor neurons are large and multipolar cells and give rise to ventral root fibers to supply extrafusal skeletal muscle fibers, while the small γ motor neurons give rise to the intrafusal muscle fibers. The α motor neurons are somatotopically organized.

Rexed lamina X – Neurons in Rexed lamina X surround the central canal and occupy the commissural lateral area of the gray commissure, which also contains decussating axons.

In summary, laminae I-IV are concerned with exteroceptive sensations, whereas laminae V and VI are concerned primarily with proprioceptive sensation and act as a relay between the periphery to the midbrain and the cerebellum. Laminae VIII and IX form the final motor pathway to initiate and modulate motor activity via α, β and γ motor neurons, which innervate striated muscle. All visceral motor neurons are located in lamina VII and innervate neurons in autonomic ganglia.

White Matter

Surrounding the gray matter is white matter containing myelinated and unmyelinated nerve fibers. These fibers conduct information up (ascending) or down (descending) the cord. The white matter is divided into the dorsal (or posterior) column (or funiculus), lateral column and ventral (or anterior) column (Figure 3.8). The anterior white commissure resides in the center of the spinal cord, and it contains crossing nerve fibers that belong to the spinothalamic tracts, spinocerebellar tracts, and anterior corticospinal tracts. Three general nerve fiber types can be distinguished in the spinal cord white matter: 1) long ascending nerve fibers originally from the column cells, which make synaptic connections to neurons in various brainstem nuclei, cerebellum and dorsal thalamus, 2) long descending nerve fibers originating from the cerebral cortex and various brainstem nuclei to synapse within the different Rexed layers in the spinal cord gray matter, and 3) shorter nerve fibers interconnecting various spinal cord levels such as the fibers responsible for the coordination of flexor reflexes. Ascending tracts are found in all columns whereas descending tracts are found only in the lateral and the anterior columns.

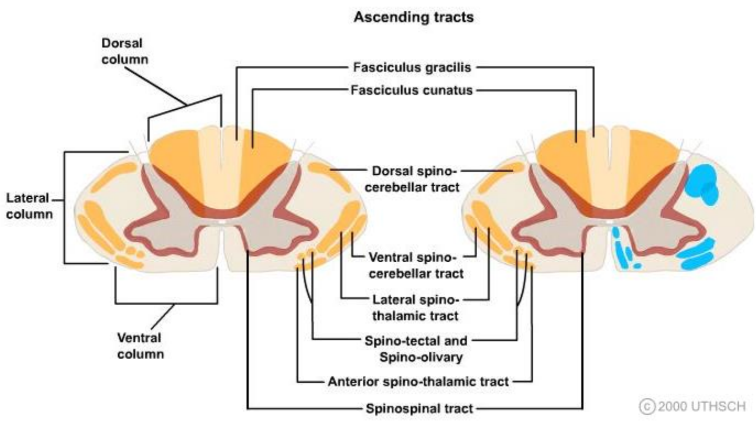


Figure 3.8

Four different terms are often used to describe bundles of axons such as those found in the white matter: funiculus, fasciculus, tract, and pathway. Funiculus is a morphological term to describe a large group of nerve fibers which are located in a given area (e.g., posterior funiculus). Within a funiculus, groups of fibers from diverse origins, which share common features, are sometimes arranged in smaller bundles of axons called fasciculus, (e.g., fasciculus proprius [Figure 3.8]). Fasciculus is primarily a morphological term whereas tracts and pathways are also terms applied to nerve fiber bundles which have a functional connotation. A tract is a group of nerve fibers which usually has the same origin, destination, and course and also has similar functions. The tract name is derived from their origin and their termination (i.e., corticospinal tract - a tract that originates in the cortex and terminates in the spinal cord; lateral spinothalamic tract - a tract originated in the lateral spinal cord and ends in the thalamus). A pathway usually refers to the entire neuronal circuit responsible for a specific function, and it includes all the nuclei and tracts which are associated with that function. For example, the spinothalamic pathway includes the cell bodies of origin (in the dorsal root ganglia), their axons as they project through the dorsal roots, synapses in the spinal cord, and projections of second and third order neurons across the white commissure, which ascend to the thalamus in the spinothalamic tracts.

■ Spinal Cord Tracts

The spinal cord white matter contains ascending and descending tracts.

Ascending tracts (Figure 3.8). The nerve fibers comprise the ascending tract emerge from the first order (1°) neuron located in the dorsal root ganglion (DRG). The ascending tracts transmit sensory information from the sensory receptors to higher levels of the CNS. The ascending gracile and cuneate fasciculi occupying the dorsal column, and sometimes are named the dorsal funiculus. These fibers carry information related to tactile, two point discrimination of simultaneously applied pressure, vibration, position, and movement sense and conscious proprioception. In the lateral column (funiculus), the neospinothalamic tract (or lateral spinothalamic tract) is located more anteriorly and laterally, and carries pain, temperature and crude touch information from somatic and visceral structures. Nearby laterally, the dorsal and ventral spinocerebellar tracts carry unconscious proprioception information from muscles and joints of the lower extremity to the cerebellum. In the ventral column (funiculus) there are four prominent tracts: 1) the paleospinothalamic tract (or anterior spinothalamic tract) is located which carry pain, temperature, and information associated with touch to the brain stem nuclei and to the diencephalon, 2) the spinoolivary tract carries information from Golgi tendon organs to the cerebellum, 3) the spinoreticular tract, and 4) the spinotectal tract. Intersegmental nerve fibers traveling for several segments (2 to 4) and are located as a thin layer around the gray matter is known as fasciculus proprius, spinospinal or archispinothalamic tract. It carries pain information to the brain stem and diencephalon.

Descending tracts (Figure 3.9). The descending tracts originate from different cortical areas and from brain stem nuclei. The descending pathway carry information associated with maintenance of motor activities such as posture, balance, muscle tone, and visceral and somatic reflex activity. These include the lateral corticospinal tract and the rubrospinal tracts located in the lateral column (funiculus). These tracts carry information associated with voluntary movement. Other tracts such as the reticulospinal vestibulospinal and the anterior corticospinal tract mediate balance and postural movements (Figure 3.9). Lissauer's tract, which is wedged between the dorsal horn and the surface of the spinal cord carry the descending fibers of the dorsolateral funiculus (DFL), which regulate incoming pain sensation at the spinal level, and intersegmental fibers..

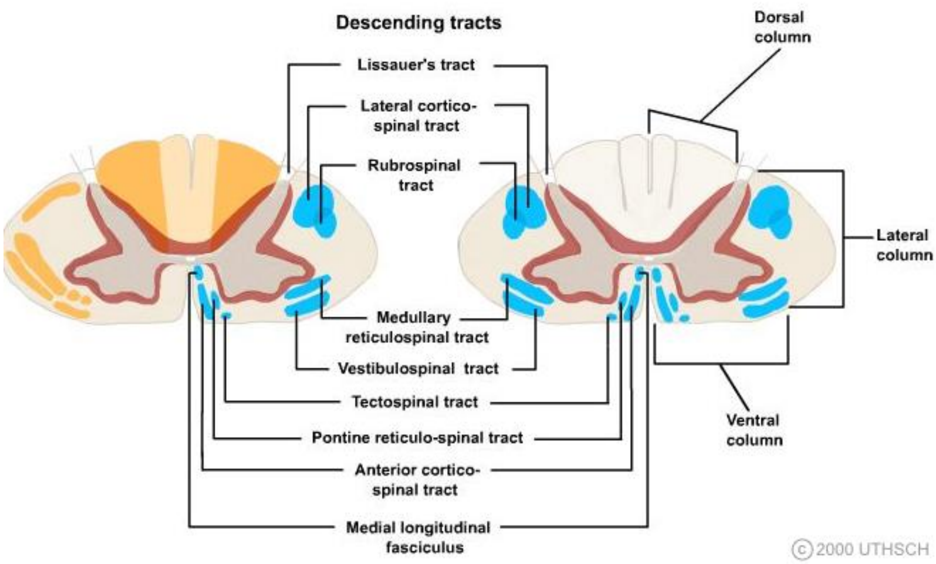


Figure 3.9
The main descending spinal cord tracts.

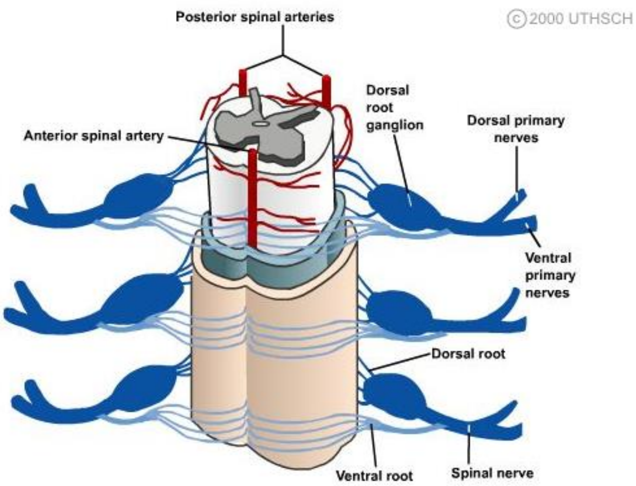


Figure 3.10
Spinal cord section with its ventral and dorsal root fibers and ganglion.

Dorsal Root

Information from the skin, skeletal muscle and joints is relayed to the spinal cord by sensory cells located in the dorsal root ganglia. The dorsal root fibers are the axons originated from the primary sensory dorsal root ganglion cells. Each ascending dorsal root axon, before reaching the spinal cord, bifurcates into ascending and descending branches entering several segments below and above their own segment. The ascending dorsal root fibers and the descending ventral root fibers from and to discrete body areas form a spinal nerve (Figure 3.10). There are 31 paired spinal nerves. The dorsal root fibers segregate into lateral and medial divisions. The lateral division contains most of the unmyelinated and small myelinated axons carrying pain and temperature information to be terminated in the Rexed laminae I, II, and IV of the gray matter. The medial division of dorsal root fibers consists mainly of myelinated axons conducting sensory fibers from skin, muscles and joints; it enters the dorsal/posterior column/funiculus and ascend in the dorsal column to be terminated in the ipsilateral nucleus gracilis or nucleus cuneatus at the medulla oblongata region, i.e., the axons of the first-order (1°) sensory neurons synapse in the medulla oblongata on the second order (2°) neurons (in nucleus gracilis or nucleus cuneatus). In entering the spinal cord, all fibers send collaterals to different Rexed lamina.

Axons entering the cord in the sacral region are found in the dorsal column near the midline and comprise the fasciculus gracilis, whereas axons that enter at higher levels are added in lateral positions and comprise the fasciculus cuneatus (Figure 3.11). ***This orderly representation is termed "somatotopic representation".***

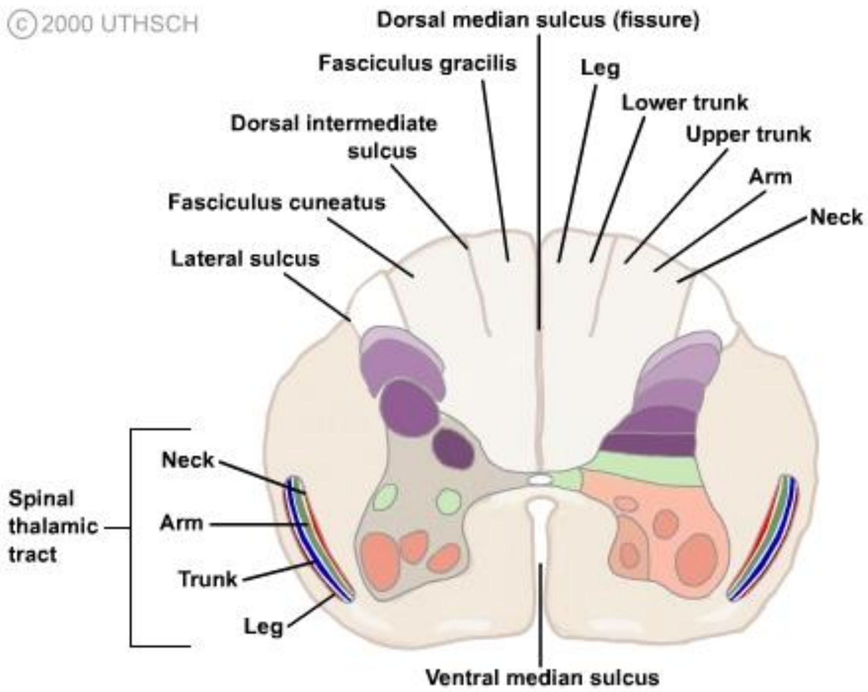


Figure 3.11

Ventral Root

Ventral root fibers are the axons of motor and visceral efferent fibers and emerge from poorly defined ventral lateral sulcus as ventral rootlets. The ventral rootlets from discrete spinal cord section unite and form the ventral root, which contain motor nerve axons from motor and visceral motor neurons. The α motor nerve axons innervate the extrafusal muscle fibers while the small γ motor neuron axons innervate the intrafusal muscle fibers located within the muscle spindles. The visceral neurons send preganglionic fibers to innervate the visceral organs. All these fibers join the dorsal root fibers distal to the dorsal root ganglion to form the spinal nerve (Figure 3.10).

[redacted] Spinal Nerve Roots

The spinal nerve roots are formed by the union of dorsal and ventral roots within the intervertebral foramen, resulting in a mixed nerve joined together and forming the spinal nerve (Figure 3.10). Spinal nerve rami include the dorsal primary nerves (ramus), which innervates the skin and muscles of the back, and the ventral primary nerves (ramus), which innervates the ventral lateral muscles and skin of the trunk, extremities and visceral organs. The ventral and dorsal roots also provide the anchorage and fixation of the spinal cord to the vertebral cauda.

[redacted] Blood Supply of the Spinal Cord

The arterial blood supply to the spinal cord in the upper cervical regions is derived from two branches of the vertebral arteries, the anterior spinal artery and the posterior spinal arteries (Figure 3.12). At the level of medulla, the paired anterior spinal arteries join to form a single artery that lies in the anterior median fissure of the spinal cord. The posterior spinal arteries are paired and form an anastomotic chain over the posterior aspect of the spinal cord. A plexus of small arteries, the arterial vasocorona, on the surface of the cord constitutes an anastomotic connection between the anterior and posterior spinal arteries. This arrangement provides uninterrupted blood supplies along the entire length of the spinal cord.

At spinal cord regions below upper cervical levels, the anterior and posterior spinal arteries narrow and form an anastomotic network with radicular arteries. The radicular arteries are branches of the cervical, trunk, intercostal & iliac arteries. The radicular arteries supply most of the lower levels of the spinal cord. There are approximately 6 to 8 pairs of radicular arteries supplying the anterior and posterior spinal cord (Figure 3.12).

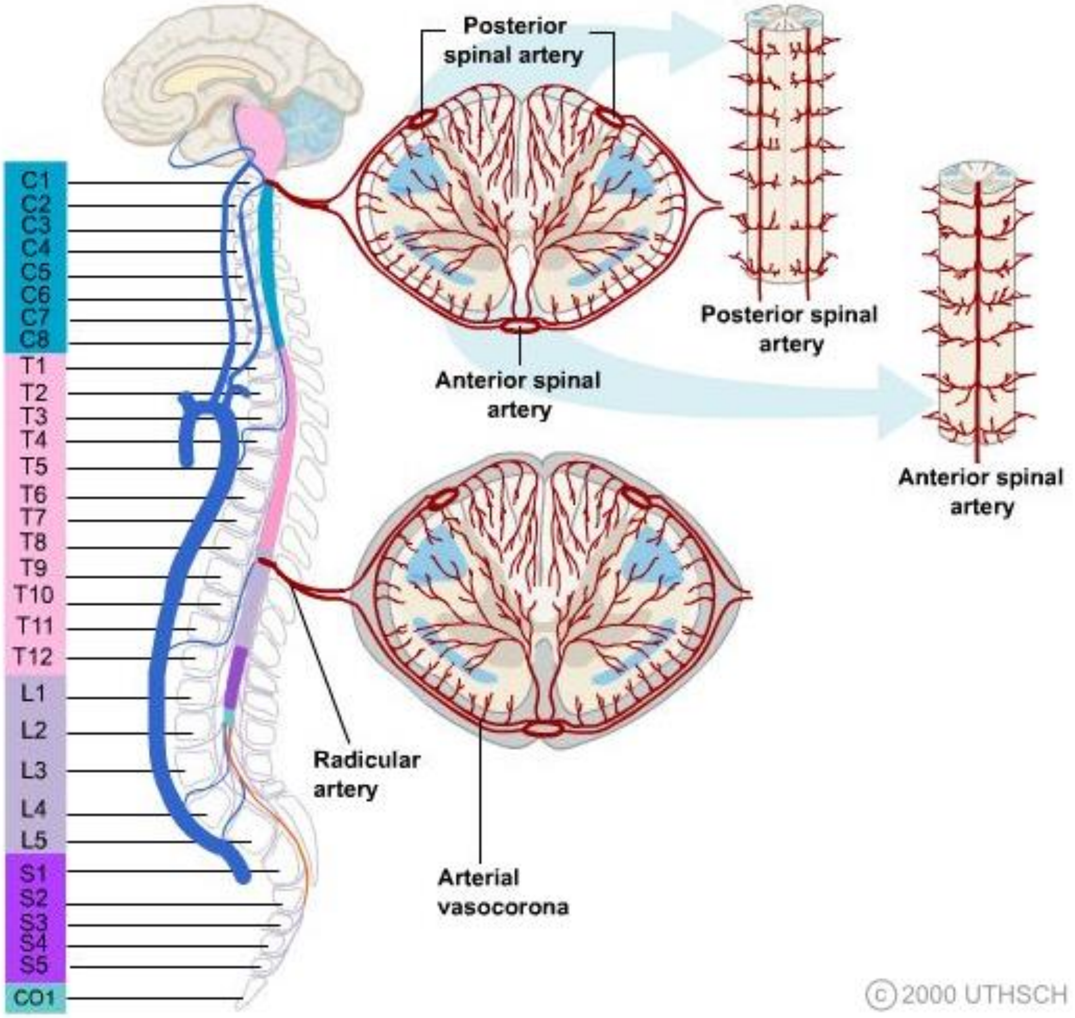


Figure 3.12
The spinal cord arterial circulation.

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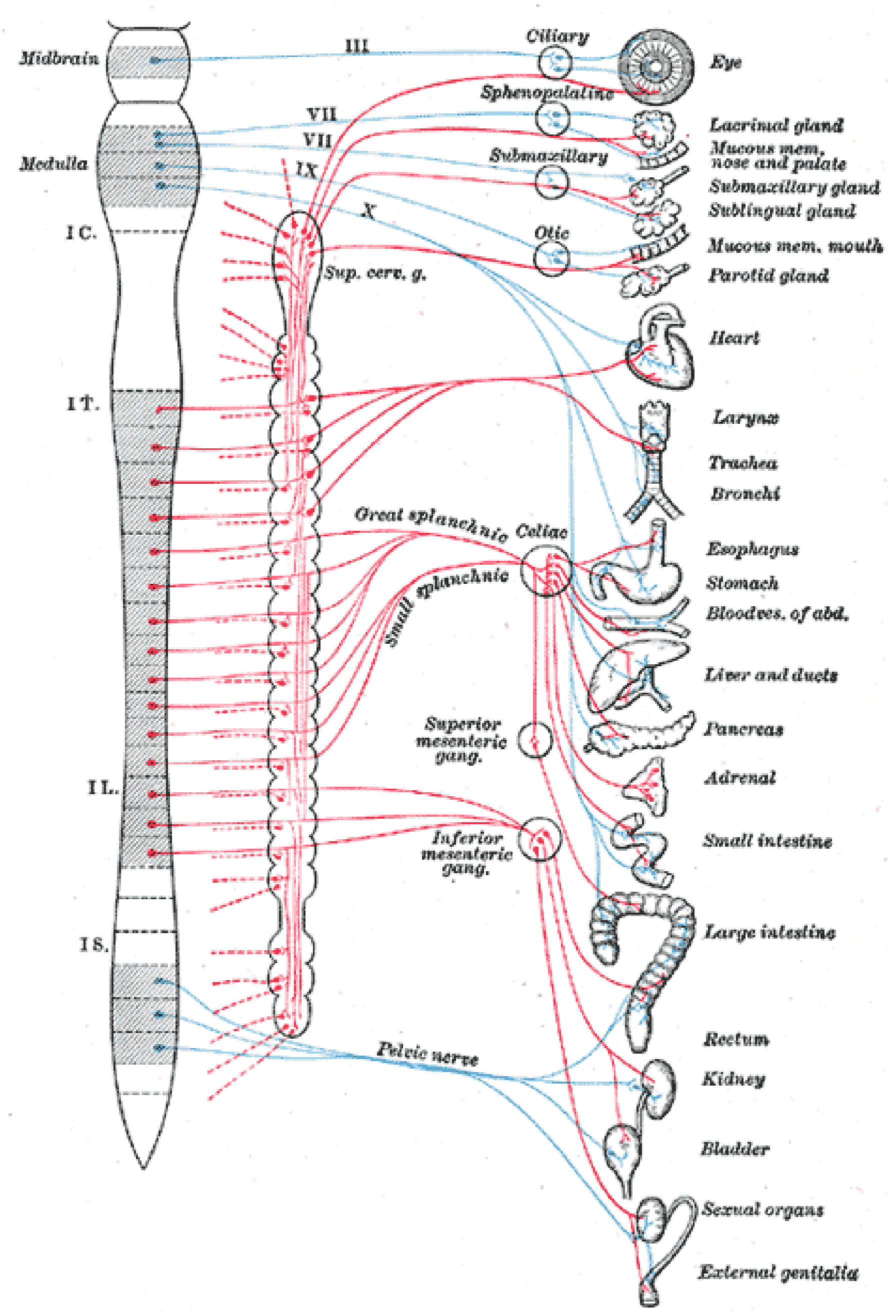
Autonomic Nervous System :A Short Note

The autonomic nervous system (ANS) is classically divided into two subsystems: the parasympathetic nervous system (PSNS) and sympathetic nervous system (SNS). The enteric nervous system is sometimes considered part of the autonomic nervous system, and sometimes considered an independent system.



The subdivisions of the autonomic nervous system: In the autonomic nervous system, preganglionic neurons connect the CNS to the ganglion.

Sympathetic and parasympathetic divisions typically function in opposition to each other. This opposition is often viewed as complementary in nature rather than antagonistic. For an analogy, one may think of the sympathetic division as the accelerator and the parasympathetic division as the brake.

The sympathetic division typically functions in actions requiring quick responses. The parasympathetic division functions with actions that do not require immediate reaction. Many think of sympathetic as fight or flight and parasympathetic as rest and digest or feed and breed.

However, many instances of sympathetic and parasympathetic activity cannot be ascribed to fight or rest situations. For example, standing up from a reclining or sitting position would entail an unsustainable drop in blood pressure if not for a compensatory increase in the arterial sympathetic tonus.

Another example is the constant, second-to-second modulation of heart rate by sympathetic and parasympathetic influences as a function of the respiratory cycles. More generally, these two systems should be seen as permanently modulating vital functions, in usually antagonistic fashion, to achieve homeostasis.

Some functions of the SNS include diverting blood flow away from the gastrointestinal (GI) tract and skin via vasoconstriction, enhancing blood flow to skeletal muscles and the lungs, dilating the bronchioles of the lung to allow for greater oxygen exchange, and increasing heart rate.

The PSNS typically functions in contrast to the SNS by dilating the blood vessels leading to the GI tract, causing constriction of the pupil and contraction of the ciliary muscle to the lens to enable closer vision, and stimulating salivary gland secretion, in keeping with the rest and digest functions.

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