Neuroanatomy and Spinal Anatomy

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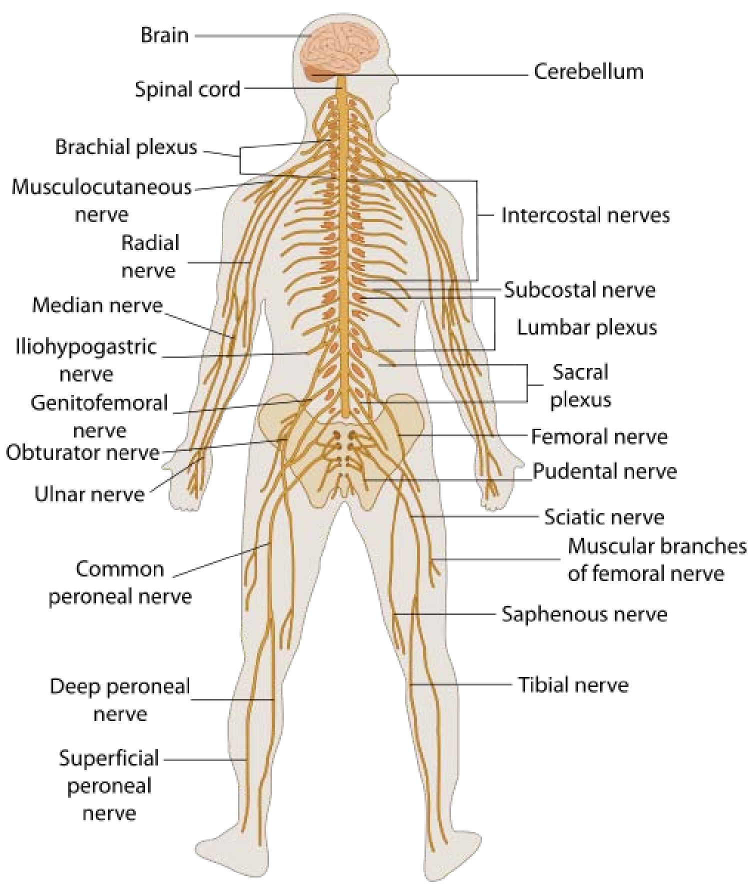

The Human Nervous System.

Latin	*systema nervosum*

The **nervous system** is an organ system containing a network of specialized cells called neurons that coordinate the actions of an animal and transmit signals between different parts of its body. In most animals the nervous system consists of two parts, central and peripheral. The central nervous system of vertebrates (such as humans) contains the brain, spinal cord, and retina. The peripheral nervous system consists of sensory neurons, clusters of neurons called ganglia, and nerves connecting them to each other and to the central nervous system. These regions are all interconnected by means of complex neural pathways. The enteric nervous system, a subsystem of the peripheral nervous system, has the capacity, even when severed from the rest of the nervous system through its primary connection by the vagus nerve, to function independently in controlling the gastrointestinal system.

Neurons send signals to other cells as electrochemical waves travelling along thin fibers called axons, which cause chemicals called neurotransmitters to be released at junctions called synapses. A cell that receives a synaptic signal may be excited, inhibited, or otherwise modulated. Sensory neurons are activated by physical stimuli impinging on them, and send signals that inform the central nervous system of the state of the body and the external environment. Motor neurons, situated either in the central nervous system or in peripheral ganglia, connect the nervous system to muscles or other effector organs. Central neurons, which in vertebrates greatly outnumber the other types, make all of their input and output connections with other neurons. The interactions of all these types of neurons form neural circuits that generate an organism's perception of the world and determine its behavior. Along with neurons, the nervous system contains other specialized cells called glial cells (or simply glia), which provide structural and metabolic support.

Nervous systems are found in most multicellular animals, but vary greatly in complexity. Sponges have no nervous system, although they have homologs of many genes that play crucial roles in nervous system function, and are capable of several whole-body responses, including a primitive form of locomotion. Placozoans and mesozoans—other simple animals that are not classified as part of the subkingdom Eumetazoa—also have no nervous system. In Radiata (radially symmetric animals such as jellyfish) the nervous system consists of a simple nerve net. Bilateria, which include the great majority of vertebrates and invertebrates, all have a nervous system containing a brain, one central cord (or two running in parallel), and peripheral nerves. The size of the bilaterian nervous system ranges from a few hundred cells in the simplest worms, to on the order of 100 billion cells in humans. Neuroscience is the study of the nervous system.

Structure

The nervous system derives its name from nerves, which are cylindrical bundles of tissue that emanate from the brain and central cord, and branch repeatedly to innervate every part of the body. Nerves are large enough to have been recognized by the ancient Egyptians, Greeks, and Romans, but their internal structure was not understood until it became possible to examine them using a microscope. A microscopic examination shows that nerves consist primarily of the axons of neurons, along with a variety of membranes that wrap around them and segregate them into fascicles. The neurons that give rise to nerves do not lie entirely within the nerves themselves—their cell bodies reside within the brain, central cord, or peripheral ganglia.

All animals more advanced than sponges have nervous systems. However, even sponges, unicellular animals, and non-animals such as slime molds have cell-to-cell signalling mechanisms that are precursors to those of neurons. In radially symmetric animals such as the jellyfish and hydra, the nervous system consists of a diffuse network of isolated cells. In bilaterian animals, which make up the great majority of existing species, the nervous system has a common structure that originated early in the Cambrian period, over 500 million years ago.

Cells

The nervous system is primarily made up of two categories of cells: neurons and glial cells.

Neurons

The nervous system is defined by the presence of a special type of cell—the neuron (sometimes called "neurone" or "nerve cell"). Neurons can be distinguished from other cells in a number of ways, but their most fundamental property is that they communicate with other cells via synapses, which are membrane-to-membrane junctions containing molecular machinery that allows rapid transmission of signals, either electrical or chemical. Many types of neuron possess an axon, a protoplasmic protrusion that can extend to distant parts of the body and make thousands of synaptic contacts. Axons frequently travel through the body in bundles called nerves.

Even in the nervous system of a single species such as humans, hundreds of different types of neurons exist, with a wide variety of morphologies and functions. These include sensory neurons that transmute physical stimuli such as light and sound into neural signals, and motor neurons that transmute neural signals into activation of muscles or glands; however in many species the great majority of neurons receive all of their input from other neurons and send their output to other neurons.

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Glial cells

Glial cells are non-neuronal cells that provide support and nutrition, maintain homeostasis, form myelin, and participate in signal transmission in the nervous system. In the human brain, it is estimated that the total number of glia roughly equals the number of neurons, although the proportions vary in different brain areas. Among the most important functions of glial cells are to support neurons and hold them in place; to supply nutrients to neurons; to insulate neurons electrically; to destroy pathogens and remove dead neurons; and to provide guidance cues directing the axons of neurons to their targets. A very important type of glial cell (oligodendrocytes in the central nervous system, and Schwann cells in the peripheral nervous system) generates layers of a fatty substance called myelin that wraps around axons and provides electrical insulation which allows them to transmit action potentials much more rapidly and efficiently.

Anatomy in vertebrates

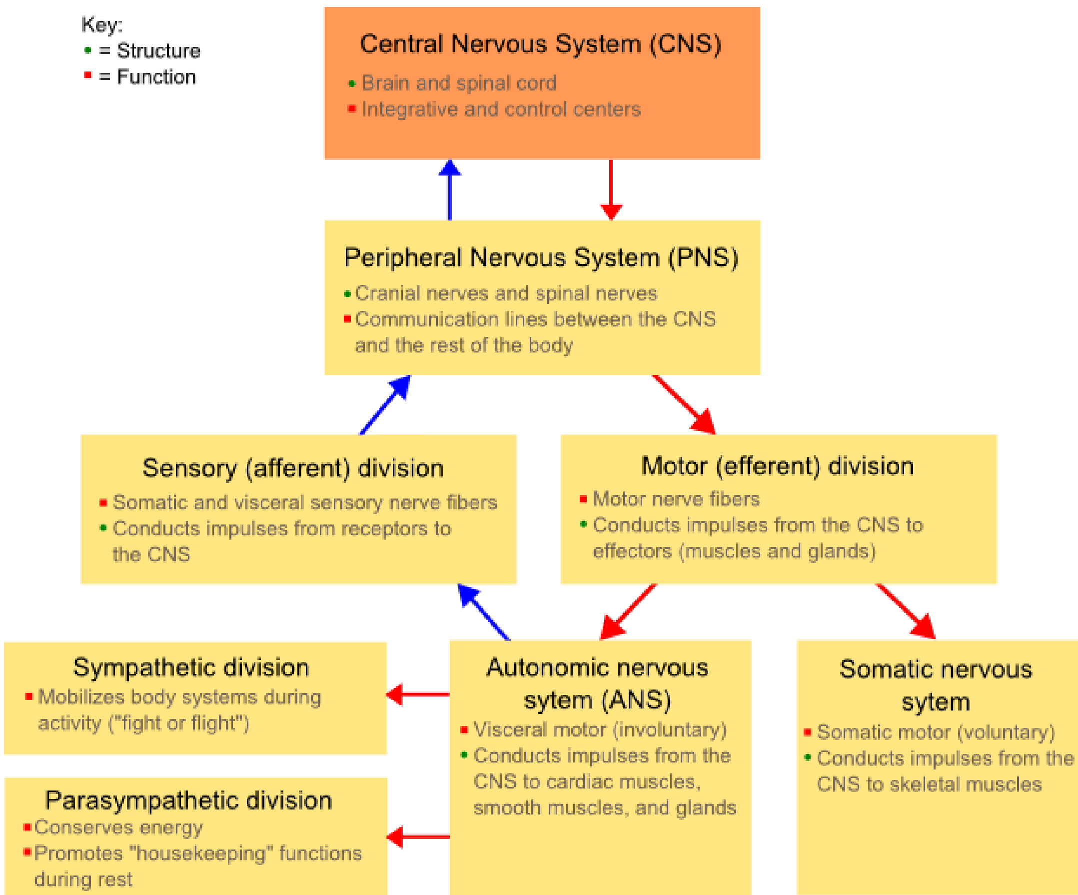


Diagram showing the major divisions of the vertebrate nervous system

The nervous system of vertebrate animals (including humans) is divided into the central nervous system (CNS) and peripheral nervous system (PNS).

The central nervous system (CNS) is the largest part, and includes the brain and spinal cord. The spinal cavity contains the spinal cord, while the head contains the brain. The CNS is enclosed and protected by meninges, a three-layered system of membranes, including a tough, leathery outer layer called the dura mater. The brain is also protected by the skull, and the spinal cord by the vertebrae.

The peripheral nervous system (PNS) is a collective term for the nervous system structures that do not lie within the CNS. The large majority of the axon bundles called nerves are considered to belong to the PNS, even when the cell bodies of the neurons to which they belong reside within the brain or spinal cord. The PNS is divided into somatic and visceral parts. The somatic part consists of the nerves that innervate the skin, joints, and muscles. The cell bodies of somatic sensory neurons lie in dorsal root ganglia of the spinal cord. The visceral part, also known as the autonomic nervous system, contains neurons that innervate the internal organs, blood vessels, and glands. The autonomic nervous system itself consists of two parts: the sympathetic nervous system and the parasympathetic nervous system. Some authors also include sensory neurons whose cell bodies lie in the periphery (for senses such as hearing) as part of the PNS; others, however, omit them.

Horizontal bisection of the head of an adult man, showing skin, skull, and brain with grey matter (brown in this image) and underlying white matter

The vertebrate nervous system can also be divided into areas called grey matter ("gray matter" in American spelling) and white matter. Grey matter (which is only grey in preserved tissue, and is better described as pink or light brown in living tissue) contains a high proportion of cell bodies of neurons. White matter is composed mainly of myelinated axons, and takes its color from the myelin. White matter includes all of the peripheral nerves, and much of the interior of the brain and spinal cord. Grey matter is found in clusters of neurons in the brain and spinal cord, and in cortical layers that line their surfaces. There is an anatomical convention that a cluster of neurons in the brain or spinal cord is called a nucleus, whereas a cluster of neurons in the periphery is called a ganglion. There are, however, a few exceptions to this rule, notably including the part of the forebrain called the basal ganglia.

Comparative anatomy and evolution

Neural precursors in sponges

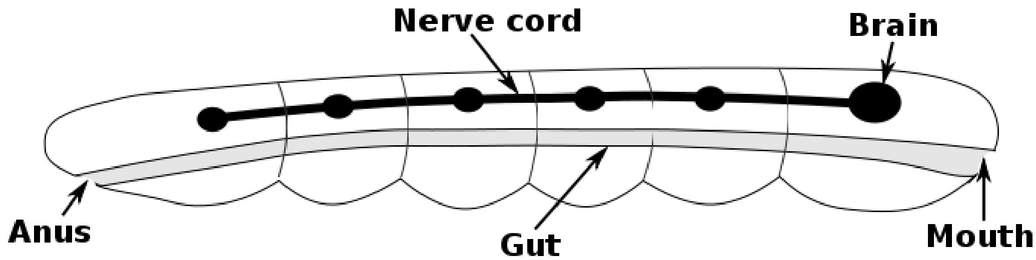
Sponges have no cells connected to each other by synaptic junctions, that is, no neurons, and therefore no nervous system. They do, however, have homologs of many genes that play key roles in synaptic function. Recent studies have shown that sponge cells express a group of proteins that cluster together to form a structure resembling a postsynaptic density (the signal-receiving part of a synapse). However, the function of this structure is currently unclear. Although sponge cells do not show synaptic transmission, they do communicate with each other via calcium waves and other impulses, which mediate some simple actions such as whole-body contraction.

Radiata

Jellyfish, comb jellies, and related animals have diffuse nerve nets rather than a central nervous system. In most jellyfish the nerve net is spread more or less evenly across the body; in comb jellies it is concentrated near the mouth. The nerve nets consist of sensory neurons that pick up chemical, tactile, and visual signals, motor neurons that can activate contractions of the body wall, and intermediate neurons that detect patterns of activity in the sensory neurons and send signals to groups of motor neurons as a result. In some cases groups of intermediate neurons are clustered into discrete ganglia.

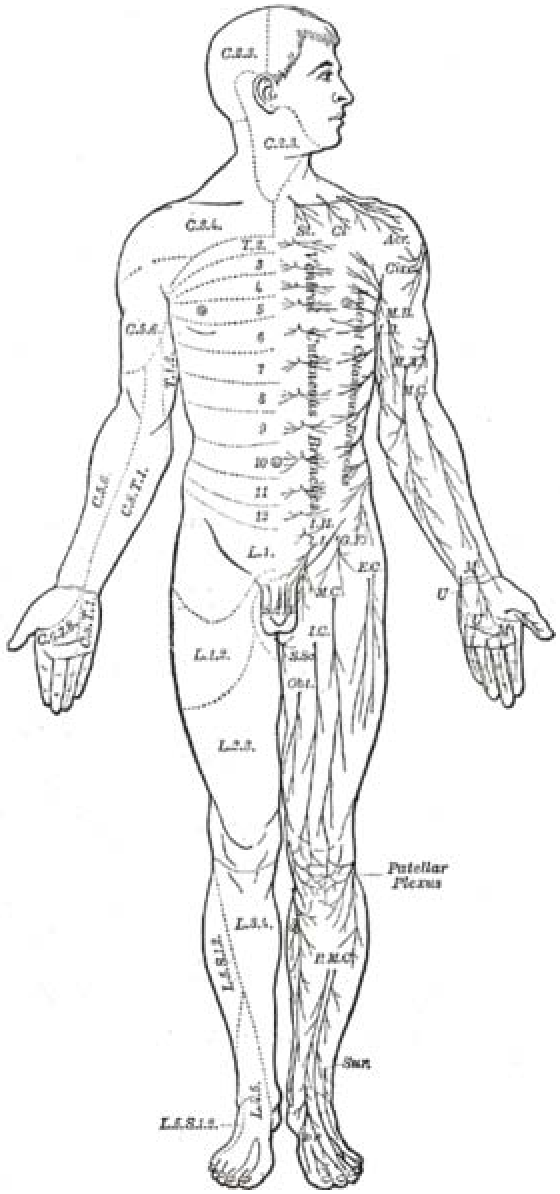
The development of the nervous system in radiata is relatively unstructured. Unlike bilaterians, radiata only have two primordial cell layers, endoderm and ectoderm. Neurons are generated from a special set of ectodermal precursor cells, which also serve as precursors for every other ectodermal cell type.

Bilateria



Nervous system of a bilaterian animal, in the form of a nerve cord with segmental enlargements, and a "brain" at the front

The vast majority of existing animals are bilaterians, meaning animals with left and right sides that are approximate mirror images of each other. All bilateria are thought to have descended from a common wormlike ancestor that appeared in the Cambrian period, 550–600 million years ago. The fundamental bilaterian body form is a tube with a hollow gut cavity running from mouth to anus, and a nerve cord with an enlargement (a "ganglion") for each body segment, with an especially large ganglion at the front, called the "brain".

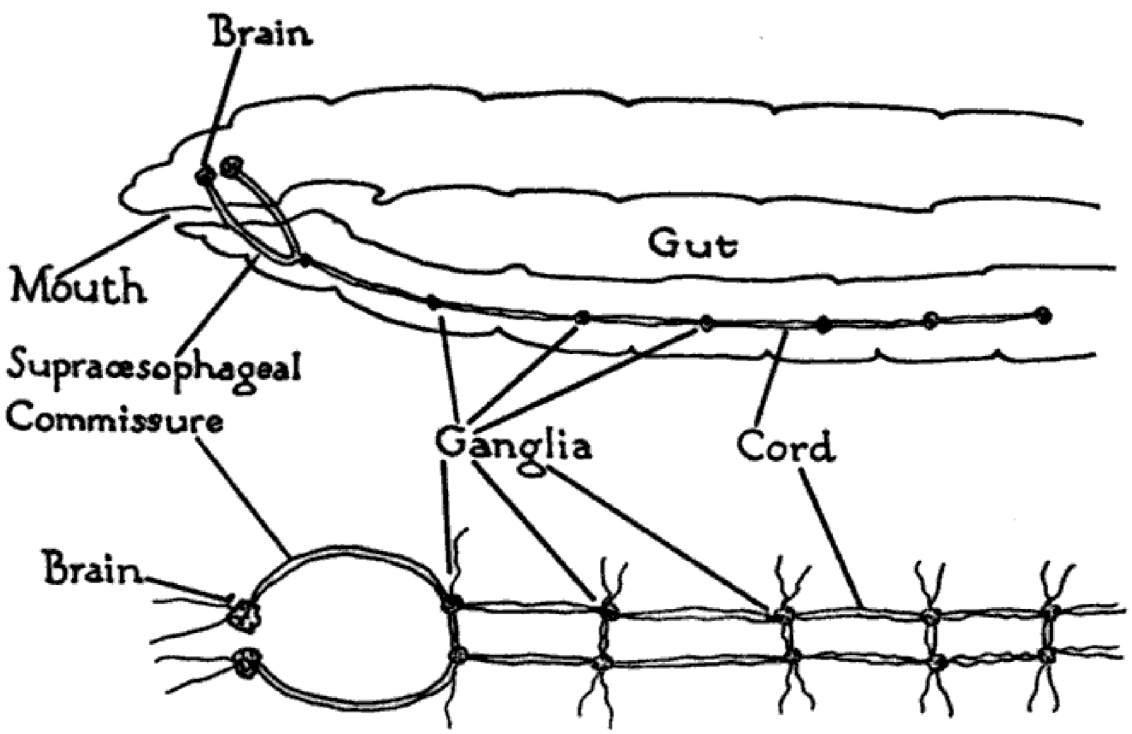


Area of the human body surface innervated by each spinal nerve

Even mammals, including humans, show the segmented bilaterian body plan at the level of the nervous system. The spinal cord contains a series of segmental ganglia, each giving rise to motor and sensory nerves that innervate a portion of the body surface and underlying musculature. On the limbs, the layout of the innervation pattern is complex, but on the trunk it gives rise to a series of narrow bands. The top three segments belong to the brain, giving rise to the forebrain, midbrain, and hindbrain.

Bilaterians can be divided, based on events that occur very early in embryonic development, into two groups (superphyla) called protostomes and deuterostomes. Deuterostomes include vertebrates as well as echinoderms, hemichordates (mainly acorn worms), and Xenoturbellidans. Protostomes, the more diverse group, include arthropods, molluscs, and numerous types of worms. There is a basic difference between the two groups in the placement of the nervous system within the body: protostomes possess a nerve cord on the ventral (usually bottom) side of the body, whereas in deuterostomes the nerve cord is on the dorsal (usually top) side. In fact, numerous aspects of the body are inverted between the two groups, including the expression patterns of several genes that show dorsal-to-ventral gradients. Most anatomists now consider that the bodies of protostomes and deuterostomes are "flipped over" with respect to each other, a hypothesis that was first proposed by Geoffroy Saint-Hilaire for insects in comparison to vertebrates. Thus insects, for example, have nerve cords that run along the ventral midline of the body, while all vertebrates have spinal cords that run along the dorsal midline.

Worms

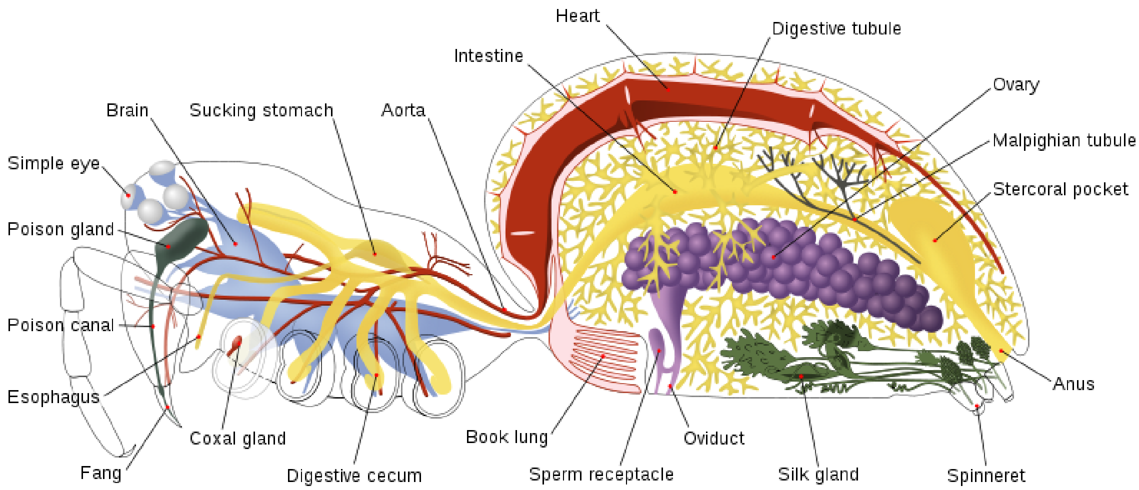


Earthworm nervous system. *Top:* side view of the front of the worm. *Bottom:* nervous system in isolation, viewed from above

Worms are the simplest bilaterian animals, and reveal the basic structure of the bilaterian nervous system in the most straightforward way. As an example, earthworms have dual nerve cords running along the length of the body and merging at the tail and the mouth. These nerve cords are connected by transverse nerves like the rungs of a ladder. These transverse nerves help coordinate the two sides of the animal. Two ganglia at the head end function similar to a simple brain. Photoreceptors on the animal's eyespots provide sensory information on light and dark.

The nervous system of one very small worm, the roundworm *Caenorhabditis elegans*, has been mapped out down to the synaptic level. Every neuron and its cellular lineage has been recorded and most, if not all, of the neural connections are known. In this species, the nervous system is sexually dimorphic; the nervous systems of the two sexes, males and hermaphrodites, have different numbers of neurons and groups of neurons that perform sex-specific functions. In *C. elegans*, males have exactly 383 neurons, while hermaphrodites have exactly 302 neurons.

Arthropods



Internal anatomy of a spider, showing the nervous system in blue

Arthropods, such as insects and crustaceans, have a nervous system made up of a series of ganglia, connected by a ventral nerve cord made up of two parallel connectives running along the length of the belly. Typically, each body segment has one ganglion on each side, though some ganglia are fused to form the brain and other large ganglia. The head segment contains the brain, also known as the supraesophageal ganglion. In the insect nervous system, the brain is anatomically divided into the protocerebrum, deutocerebrum, and tritocerebrum. Immediately behind the brain is the subesophageal ganglion, which is composed of three pairs of fused ganglia. It controls the mouthparts, the salivary glands and certain muscles. Many arthropods have well-developed sensory organs, including compound eyes for vision and antennae for olfaction and pheromone sensation. The sensory information from these organs is processed by the brain.

In insects, many neurons have cell bodies that are positioned at the edge of the brain and are electrically passive—the cell bodies serve only to provide metabolic support and do not participate in signalling. A protoplasmic fiber runs from the cell body and branches profusely, with some parts transmitting signals and other parts receiving signals. Thus, most parts of the insect brain have passive cell bodies arranged around the periphery, while the neural signal processing takes place in a tangle of protoplasmic fibers called neuropil, in the interior.

"Identified" neurons

A neuron is called *identified* if it has properties that distinguish it from every other neuron in the same animal—properties such as location, neurotransmitter, gene expression pattern, and connectivity—and if every individual organism belonging to the same species has one and only one neuron with the same set of properties. In vertebrate nervous systems very few neurons are "identified" in this sense—in humans, there are believed to be none—but in simpler nervous systems, some or all neurons may be thus unique. In the roundworm C. elegans, whose nervous system is the most thoroughly described of any animal's, every neuron in the body is uniquely identifiable, with the same location and the same connections in every individual worm. One notable consequence of this fact is that the form of the *C. elegans* nervous system is completely specified by the genome, with no experience-dependent plasticity.

The brains of many molluscs and insects also contain substantial numbers of identified neurons. In vertebrates, the best known identified neurons are the gigantic Mauthner cells of fish. Every fish has two Mauthner cells, located in the bottom part of the brainstem, one on the left side and one on the right. Each Mauthner cell has an axon that crosses over, innervating neurons at the same brain level and then travelling down through the spinal cord, making numerous connections as it goes. The synapses generated by a Mauthner cell are so powerful that a single action potential gives rise to a major behavioral response: within milliseconds the fish curves its body into a C-shape, then straightens, thereby propelling itself rapidly forward. Functionally this is a fast escape response, triggered most easily by a strong sound wave or pressure wave impinging on the lateral line organ of the fish. Mauther cells are not the only identified neurons in fish—there are about 20 more types, including pairs of "Mauthner cell analogs" in each spinal segmental nucleus. Although a Mauthner cell is capable of bringing about an escape response all by itself, in the context of ordinary behavior other types of cells usually contribute to shaping the amplitude and direction of the response.

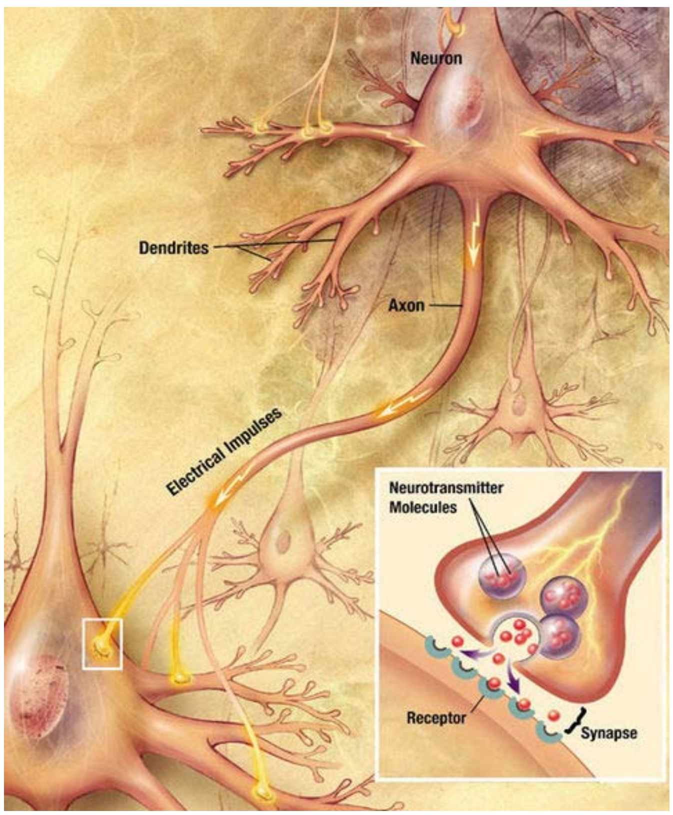
Mauthner cells have been described as command neurons. A command neuron is a special type of identified neuron, defined as a neuron that is capable of driving a specific behavior all by itself. Such neurons appear most commonly in the fast escape systems of various species—the squid giant axon and squid giant synapse, used for pioneering experiments in neurophysiology because of their enormous size, both participate in the fast escape circuit of the squid. The concept of a command neuron has, however, become controversial, because of studies showing that some neurons that initially appeared to fit the description were really only capable of evoking a response in a limited set of circumstances.

Function

At the most basic level, the function of the nervous system is to send signals from one cell to others, or from one part of the body to others. There are multiple ways that a cell can send signals to other cells. One is by releasing chemicals called hormones into the internal circulation, so that they can diffuse to distant sites. In contrast to this "broadcast" mode of signaling, the nervous system provides "point-to-point" signals—neurons project their axons to specific target areas and make synaptic connections with specific target cells. Thus, neural signaling is capable of a much higher level of specificity than hormonal signaling. It is also much faster: the fastest nerve signals travel at speeds that exceed 100 meters per second.

At a more integrative level, the primary function of the nervous system is to control the body. It does this by extracting information from the environment using sensory receptors, sending signals that encode this information into the central nervous system, processing the information to determine an appropriate response, and sending output signals to muscles or glands to activate the response. The evolution of a complex nervous system has made it possible for various animal species to have advanced perception abilities such as vision, complex social interactions, rapid coordination of organ systems, and integrated processing of concurrent signals. In humans, the sophistication of the nervous system makes it possible to have language, abstract representation of concepts, transmission of culture, and many other features of human society that would not exist without the human brain.

Neurons and synapses



Major elements in synaptic transmission. An electrochemical wave called an action potential travels along the axon of a neuron. When the wave reaches a synapse, it provokes release of a puff of neurotransmitter molecules, which bind to chemical receptor molecules located in the membrane of the target cell.

Most neurons send signals via their axons, although some types are capable of dendrite-to-dendrite communication. (In fact, the types of neurons called amacrine cells have no axons, and communicate only via their dendrites.) Neural signals propagate along an axon in the form of electrochemical waves called action potentials, which produce cell-to-cell signals at points where axon terminals make synaptic contact with other cells.

Synapses may be electrical or chemical. Electrical synapses make direct electrical connections between neurons, but chemical synapses are much more common, and much more diverse in function. At a chemical synapse, the cell that sends signals is called presynaptic, and the cell that receives signals is called postsynaptic. Both the presynaptic and postsynaptic areas are full of molecular machinery that carries out the signalling process. The presynaptic area contains large numbers of tiny spherical vessels called synaptic vesicles, packed with neurotransmitter chemicals. When the presynaptic terminal is electrically stimulated, an array of molecules embedded in the membrane are activated, and cause the contents of the vesicles to be released into the narrow space between the presynaptic and postsynaptic membranes, called the synaptic cleft. The neurotransmitter then binds to receptors embedded in the postsynaptic membrane, causing them to enter an activated state. Depending on the type of receptor, the resulting effect on the postsynaptic cell may be excitatory, inhibitory, or modulatory in more complex ways. For example, release of the neurotransmitter acetylcholine at a synaptic contact between a motor neuron and a muscle cell induces rapid contraction of the muscle cell. The entire synaptic transmission process takes only a fraction of a millisecond, although the effects on the postsynaptic cell may last much longer (even indefinitely, in cases where the synaptic signal leads to the formation of a memory trace).

There are literally hundreds of different types of synapses. In fact, there are over a hundred known neurotransmitters, and many of them have multiple types of receptor. Many synapses use more than one neurotransmitter—a common arrangement is for a synapse to use one fast-acting small-molecule neurotransmitter such as glutamate or GABA, along with one or more peptide neurotransmitters that play slower-acting modulatory roles. Molecular neuroscientists generally divide receptors into two broad groups: chemically gated ion channels and second messenger systems. When a chemically gated ion channel is activated, it forms a passage that allow specific types of ion to flow across the membrane. Depending on the type of ion, the effect on the target cell may be excitatory or inhibitory. When a second messenger system is activated, it starts a cascade of molecular interactions inside the target cell, which may ultimately produce a wide variety of complex effects, such as increasing or decreasing the sensitivity of the cell to stimuli, or even altering gene transcription.

According to a rule called Dale's principle, which has only a few known exceptions, a neuron releases the same neurotransmitters at all of its synapses. This does not mean, though, that a neuron exerts the same effect on all of its targets, because the effect of a synapse depends not on the neurotransmitter, but on the receptors that it activates. Because different targets can (and frequently do) use different types of receptors, it is possible for a neuron to have excitatory effects on one set of target cells, inhibitory effects on others, and complex modulatory effects on others still. Nevertheless, it happens that the two most widely used neurotransmitters, glutamate and GABA, each have largely consistent effects. Glutamate has several widely occurring types of receptors, but all of them are excitatory or modulatory. Similarly, GABA has several widely occurring receptor types, but all of them are inhibitory. Because of this consistency, glutamatergic cells are frequently referred to as "excitatory neurons", and GABAergic cells as "inhibitory neurons". Strictly speaking this is an abuse of terminology—it is the receptors that are excitatory and inhibitory, not the neurons—but it is commonly seen even in scholarly publications.

One very important subset of synapses are capable of forming memory traces by means of long-lasting activity-dependent changes in synaptic strength. The best-known form of neural memory is a process called long-term potentiation (abbreviated LTP), which operates at synapses that use the neurotransmitter glutamate acting on a special type of receptor known as the NMDA receptor. The NMDA receptor has an "associative" property: if the two cells involved in the synapse are both activated at approximately the same time, a channel opens that permits calcium to flow into the target cell. The calcium entry initiates a second messenger cascade that ultimately leads to an increase in the number of glutamate receptors in the target cell, thereby increasing the effective strength of the synapse. This change in strength can last for weeks or longer. Since the discovery of LTP in 1973, many other types of synaptic memory traces have been found, involving increases or decreases in synaptic strength that are induced by varying conditions, and last for variable periods of time. Reward learning, for example, depends on a variant form of LTP that is conditioned on an extra input coming from a reward-signalling pathway that uses dopamine as neurotransmitter. All these forms of synaptic modifiability, taken collectively, give rise to neural plasticity, that is, to a capability for the nervous system to adapt itself to variations in the environment.

Neural circuits and systems

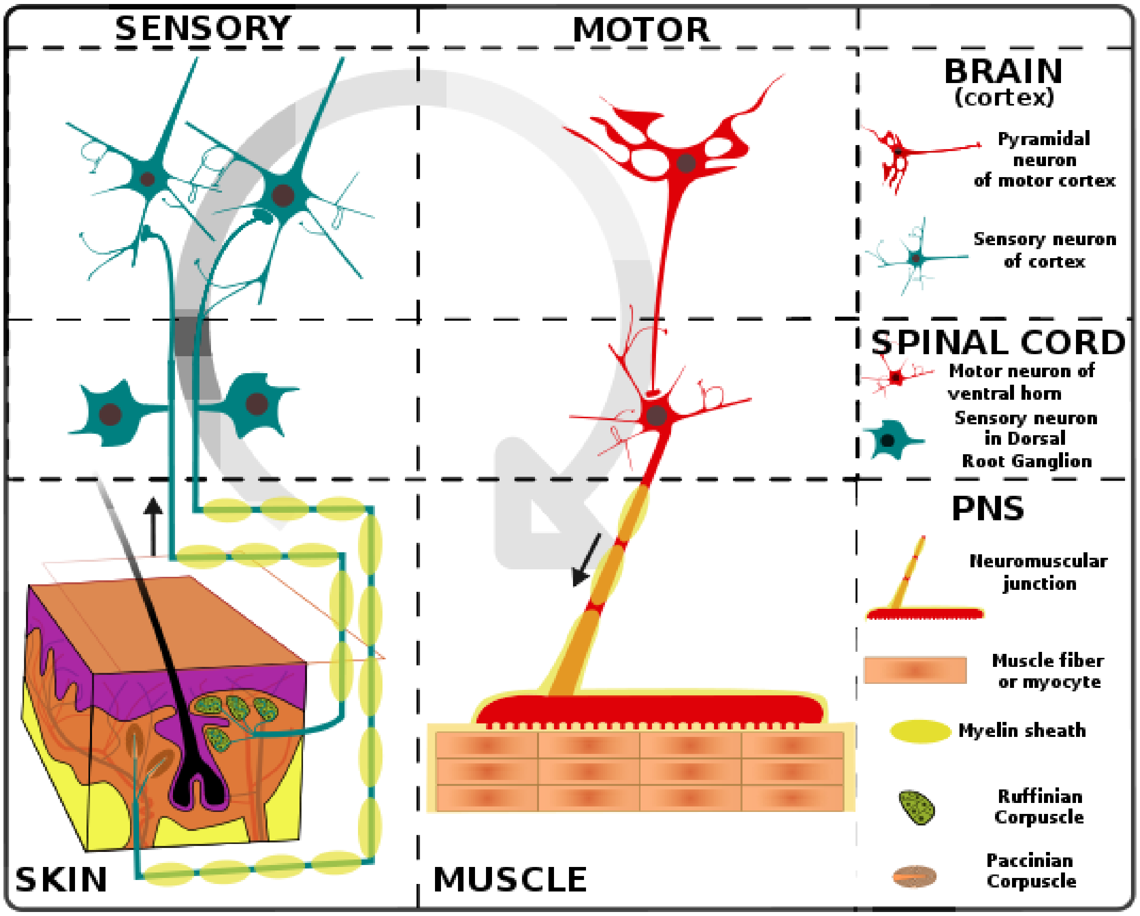
The basic neuronal function of sending signals to other cells includes a capability for neurons to exchange signals with each other. Networks formed by interconnected groups of neurons are capable of a wide variety of functions, including feature detection, pattern generation, and timing. In fact, it is difficult to assign limits to the types of information processing that can be carried out by neural networks: Warren McCulloch and Walter Pitts showed in 1943 that even networks formed from a greatly simplified mathematical abstraction of a neuron are capable of universal computation. Given that individual neurons can generate complex temporal patterns of activity all by themselves, the range of capabilities possible for even small groups of interconnected neurons are beyond current understanding.

Illustration of pain pathway, from René Descartes's *Treatise of Man*

Historically, for many years the predominant view of the function of the nervous system was as a stimulus-response associator. In this conception, neural processing begins with stimuli that activate sensory neurons, producing signals that propagate through chains of connections in the spinal cord and brain, giving rise eventually to activation of motor neurons and thereby to muscle contraction, i.e., to overt responses. Descartes believed that all of the behaviors of animals, and most of the behaviors of humans, could be explained in terms of stimulus-response circuits, although he also believed that higher cognitive functions such as language were not capable of being explained mechanistically. Charles Sherrington, in his influential 1906 book *The Integrative Action of the Nervous System*, developed the concept of stimulus-response mechanisms in much more detail, and Behaviorism, the school of thought that dominated Psychology through the middle of the 20th century, attempted to explain every aspect of human behavior in stimulus-response terms.

However, experimental studies of electrophysiology, beginning in the early 20th century and reaching high productivity by the 1940s, showed that the nervous system contains many mechanisms for generating patterns of activity intrinsically, without requiring an external stimulus. Neurons were found to be capable of producing regular sequences of action potentials, or sequences of bursts, even in complete isolation. When intrinsically active neurons are connected to each other in complex circuits, the possibilities for generating intricate temporal patterns become far more extensive. A modern conception views the function of the nervous system partly in terms of stimulus-response chains, and partly in terms of intrinsically generated activity patterns—both types of activity interact with each other to generate the full repertoire of behavior.

Reflexes and other stimulus-response circuits



Simplified schema of basic nervous system function: signals are picked up by sensory receptors and sent to the spinal cord and brain, where processing occurs that results in signals sent back to the spinal cord and then out to motor neurons

The simplest type of neural circuit is a reflex arc, which begins with a sensory input and ends with a motor output, passing through a sequence of neurons in between. For example, consider the "withdrawal reflex" causing the hand to jerk back after a hot stove is touched. The circuit begins with sensory receptors in the skin that are activated by harmful levels of heat: a special type of molecular structure embedded in the membrane causes heat to generate an electrical field across the membrane. If the electrical potential change is large enough, it evokes an action potential, which is transmitted along the axon of the receptor cell, into the spinal cord. There the axon makes excitatory synaptic contacts with other cells, some of which project to the same region of the spinal cord, others projecting into the brain. One target is a set of spinal interneurons that project to motor neurons controlling the arm muscles. The interneurons excite the motor neurons, and if the excitation is strong enough, some of the motor neurons generate action potentials, which travel down their axons to the point where they make excitatory synaptic contacts with muscle cells. The excitatory signals induce contraction of the muscle cells, which causes the joint angles in the arm to change, pulling the arm away.

In reality, this straightfoward schema is subject to numerous complications. Although for the simplest reflexes there are short neural paths from sensory neuron to motor neuron, there are also other nearby neurons that participate in the circuit and modulate the response. Furthermore, there are projections from the brain to the spinal cord that are capable of enhancing or inhibiting the reflex.

Although the simplest reflexes may be mediated by circuits lying entirely within the spinal cord, more complex responses rely on signal processing in the brain. Consider, for example, what happens when an object in the periphery of the visual field moves, and a person looks toward it. The initial sensory response, in the retina of the eye, and the final motor response, in the oculomotor nuclei of the brain stem, are not all that different from those in a simple reflex, but the intermediate stages are completely different. Instead of a one or two step chain of processing, the visual signals pass through perhaps a dozen stages of integration, involving the thalamus, cerebral cortex, basal ganglia, superior colliculus, cerebellum, and several brainstem nuclei. These areas perform signal-processing functions that include feature detection, perceptual analysis, memory recall, decision-making, and motor planning.

Feature detection is the ability to extract biologically relevant information from combinations of sensory signals. In the visual system, for example, sensory receptors in the retina of the eye are only individually capable of detecting "points of light" in the outside world. Second-level visual neurons receive input from groups of primary receptors, higher-level neurons receive input from groups of second-level neurons, and so on, forming a hierarchy of processing stages. At each stage, important information is extracted from the signal ensemble and unimportant information is discarded. By the end of the process, input signals representing "points of light" have been transformed into a neural representation of objects in the surrounding world and their properties. The most sophisticated sensory processing occurs inside the brain, but complex feature extraction also takes place in the spinal cord and in peripheral sensory organs such as the retina.

Intrinsic pattern generation

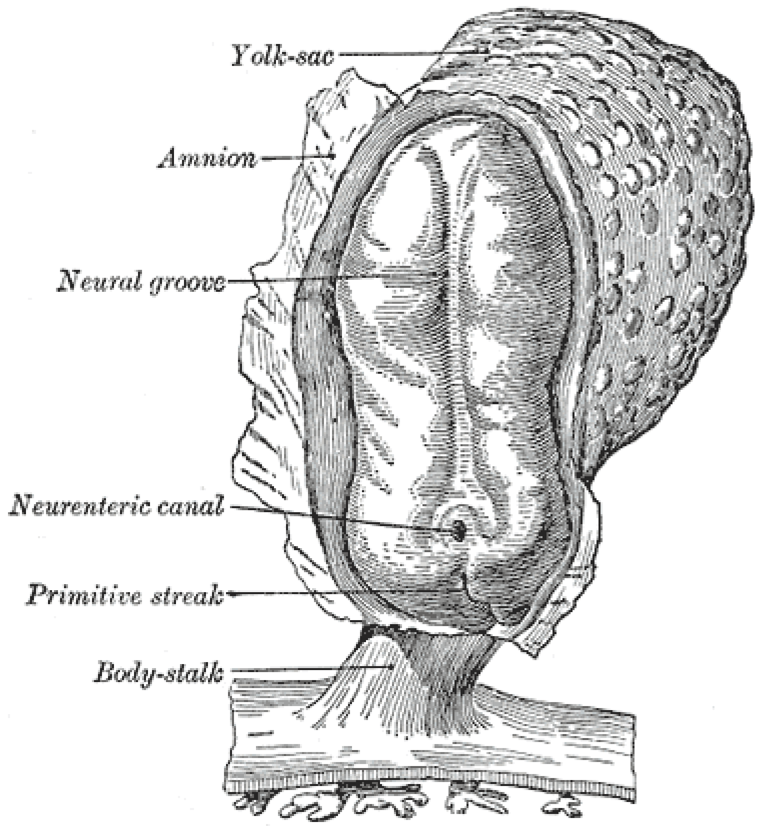
Although stimulus-response mechanisms are the easiest to understand, the nervous system is also capable of controlling the body in ways that do not require an external stimulus, by means of internally generated rhythms of activity. Because of the variety of voltage-sensitive ion channels that can be embedded in the membrane of a neuron, many types of neurons are capable, even in isolation, of generating rhythmic sequences of action potentials, or rhythmic alternations between high-rate bursting and quiescence. When neurons that are intrinsically rhythmic are connected to each other by excitatory or inhibitory synapses, the resulting networks are capable of a wide variety of dynamical behaviors, including attractor dynamics, periodicity, and even chaos. A network of neurons that uses its internal structure to generate temporally structured output, without requiring a corresponding temporally structured stimulus, is called a central pattern generator.

Internal pattern generation operates on a wide range of time scales, from milliseconds to hours or longer. One of the most important types of temporal pattern is circadian rhythmicity—that is, rhythmicity with a period of approximately 24 hours. All animals that have been studied show circadian fluctuations in neural activity, which control circadian alternations in behavior such as the sleep-wake cycle. Experimental studies dating from the 1990s have shown that circadian rhythms are generated by a "genetic clock" consisting of a special set of genes whose expression level rises and falls over the course of the day. Animals as diverse as insects and vertebrates share a similar genetic clock system. The circadian clock is influenced by light but continues to operate even when light levels are held constant and no other external time-of-day cues are available. The clock genes are expressed in many parts of the nervous system as well as many peripheral organs, but in mammals all of these "tissue clocks" are kept in synchrony by signals that emanate from a master timekeeper in a tiny part of the brain called the suprachiasmatic nucleus.

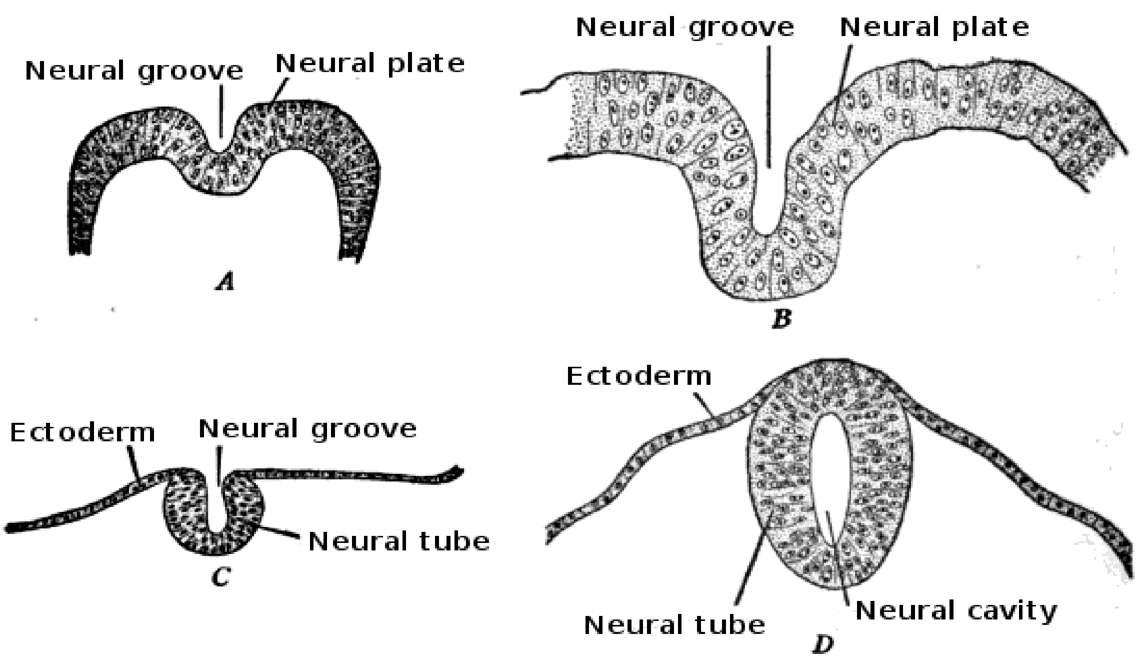
Development

In vertebrates, landmarks of embryonic neural development include the birth and differentiation of neurons from stem cell precursors, the migration of immature neurons from their birthplaces in the embryo to their final positions, outgrowth of axons from neurons and guidance of the motile growth cone through the embryo towards postsynaptic partners, the generation of synapses between these axons and their postsynaptic partners, and finally the lifelong changes in synapses which are thought to underlie learning and memory.

All bilaterian animals at an early stage of development form a gastrula, which is polarized, with one end called the animal pole and the other the vegetal pole. The gastrula has the shape of a disk with three layers of cells, an inner layer called the endoderm, which gives rise to the lining of most internal organs, a middle layer called the mesoderm, which gives rise to the bones and muscles, and an outer layer called the ectoderm, which gives rise to the skin and nervous system.



Human embryo, showing neural groove



Four stages in the development of the neural tube in the human embryo

In vertebrates, the first sign of the nervous system is the appearance of a thin strip of cells along the center of the back, called the neural plate. The inner portion of the neural plate (along the midline) is destined to become the central nervous system (CNS), the outer portion the peripheral nervous system (PNS). As development proceeds, a fold called the neural groove appears along the midline. This fold deepens, and then closes up at the top. At this point the future CNS appears as a cylindrical structure called the neural tube, whereas the future PNS appears as two strips of tissue called the neural crest, running lengthwise above the neural tube. The sequence of stages from neural plate to neural tube and neural crest is known as neurulation.

In the early 20th century, a set of famous experiments by Hans Spemann and Hilde Mangold showed that the formation of nervous tissue is "induced" by the underlying mesoderm. For decades, though, the nature of the induction process defeated every attempt to figure it out, until finally it was resolved by genetic approaches in the 1990s. Induction of neural tissue requires inhibition of the gene for a so-called bone morphogenetic protein, or BMP. Specifically the protein BMP4 appears to be involved. Two proteins called Noggin and Chordin, both secreted by the mesoderm, are capable of inhibiting BMP4 and thereby inducing ectoderm to turn into neural tissue. It appears that a similar molecular mechanism is involved for widely disparate types of animals, including arthropods as well as vertebrates. In some animals, however, another type of molecule called Fibroblast Growth Factor or FGF may also play an important role in induction.

Induction of neural tissues causes formation of neural precursor cells, called neuroblasts. In drosophila, neuroblasts divide asymmetrically, so that one product is a "ganglion mother cell" (GMC), and the other is a neuroblast. A GMC divides once, to give rise to either a pair of neurons or a pair of glial cells. In all, a neuroblast is capable of generating an indefinite number of neurons or glia.

As shown in a 2008 study, one factor common to all bilateral organisms (including humans) is a family of secreted signaling molecules called neurotrophins which regulate the growth and survival of neurons. Zhu et al. identified DNT1, the first neurotrophin found in flies. DNT1 shares structural similarity with all known neurotrophins and is a key factor in the fate of neurons in Drosophila. Because neurotrophins have now been identified in both vertebrate and invertebrates, this evidence suggests that neurotrophins were present in an ancestor common to bilateral organisms and may represent a common mechanism for nervous system formation.

Pathology

The nervous system is susceptible to malfunction in a wide variety of ways, as a result of genetic defects, physical damage due to trauma or poison, infection, or simply aging. The medical specialty of neurology studies the causes of nervous system malfunction, and looks for interventions that can alleviate it.

The central nervous system is protected by major physical and chemical barriers. Physically, the brain and spinal cord are surrounded by tough meningeal membranes, and enclosed in the bones of the skull and spinal vertebrae, which combine to form a strong physical shield. Chemically, the brain and spinal cord are isolated by the so-called blood-brain barrier, which prevents most types of chemicals from moving from the bloodstream into the interior of the CNS. These protections make the CNS less susceptible in many ways than the PNS; the flip side, however, is that damage to the CNS tends to have more serious consequences.

Although peripheral nerves tend to lie deep under the skin except in a few places such as the elbow joint, they are still relatively exposed to physical damage, which can cause pain, loss of sensation, or loss of muscle control. Damage to nerves can also be caused by swelling or bruises at places where a nerve passes through a tight bony channel, as happens in carpal tunnel syndrome. If a peripheral nerve is completely transected, it will often regenerate, but for long nerves this process may take months to complete. In addition to physical damage, peripheral neuropathy may be caused by many other medical problems, including genetic conditions, metabolic conditions such as diabetes, inflammatory conditions such as Guillain-Barré syndrome, vitamin deficiency, infectious diseases such as leprosy or shingles, or poisoning by toxins such as heavy metals. Many cases have no cause that can be identified, and are referred to as idiopathic. It is also possible for peripheral nerves to lose function temporarily, resulting in numbness as stiffness—common causes include mechanical pressure, a drop in temperature, or chemical interactions with local anesthetic drugs such as lidocaine.

Physical damage to the spinal cord may result in loss of sensation or movement. If an injury to the spine produces nothing worse than swelling, the symptoms may be transient, but if nerve fibers in the spine are actually destroyed, the loss of function is usually permanent. Experimental studies have shown that spinal nerve fibers attempt to regrow in the same way as peripheral nerve fibers, but in the spinal cord, tissue destruction usually produces scar tissue that cannot be penetrated by the regrowing nerves.

Chapter 2

Hindbrain (Rhombencephalon)

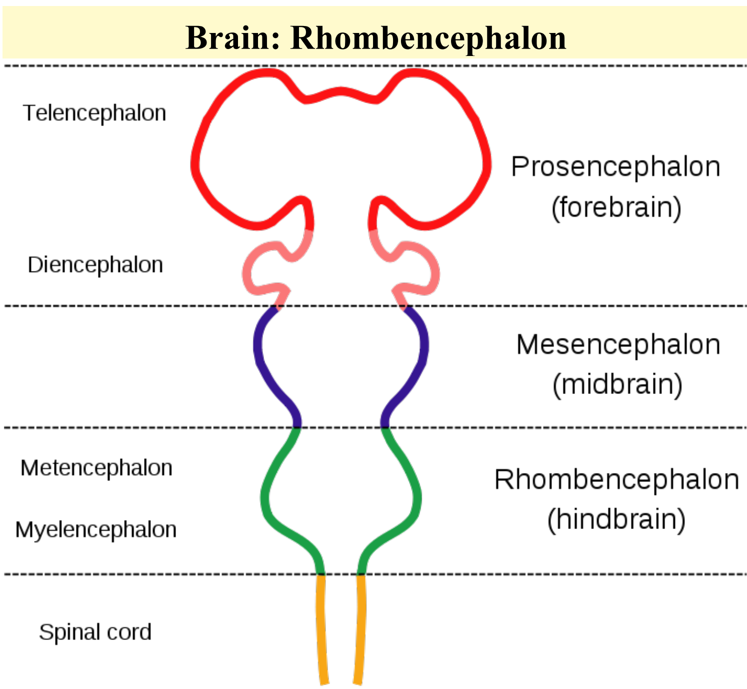
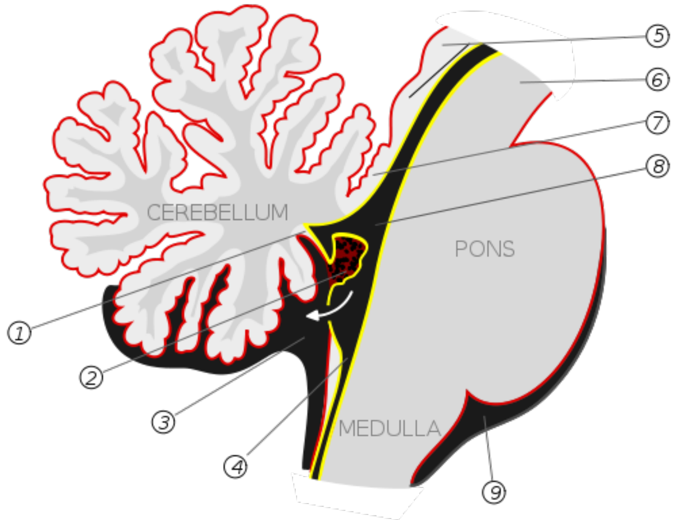


Diagram depicting the main subdivisions of the embryonic vertebrate brain. These regions will later differentiate into forebrain, midbrain and hindbrain structures.



Scheme of roof of fourth ventricle.

NeuroNames *hier-531*

MeSH *Rhombencephalon*

NeuroLex ID *birnlex_942*

The **rhombencephalon** (or **hindbrain**) is a developmental categorization of portions of the central nervous system in vertebrates.

The rhombencephalon can be subdivided in a variable number of transversal swellings called rhombomeres. In the human embryo eight rhombomeres can be distinguished, from caudal to rostral: Rh7-Rh1 and the isthmus (the most rostral rhombomere).

A rare disease of the rhombencephalon, "rhombencephalosynapsis" is characterized by a missing vermis resulting in a fused cerebellum. Patients generally present with cerebellar ataxia.

The caudal rhombencephalon has been generally considered as the initiation site for neural tube closure.

Myelencephalon

Rhombomeres Rh7-Rh4 form the myelencephalon.

The myelencephalon forms the medulla oblongata in the adult brain; it contains:

- a portion of the fourth ventricle,
- the glossopharyngeal nerve (CN IX),
- vagus nerve (CN X),
- accessory nerve (CN XI),
- hypoglossal nerve (CN XII),

- and a portion of the vestibulocochlear nerve (CN VIII).

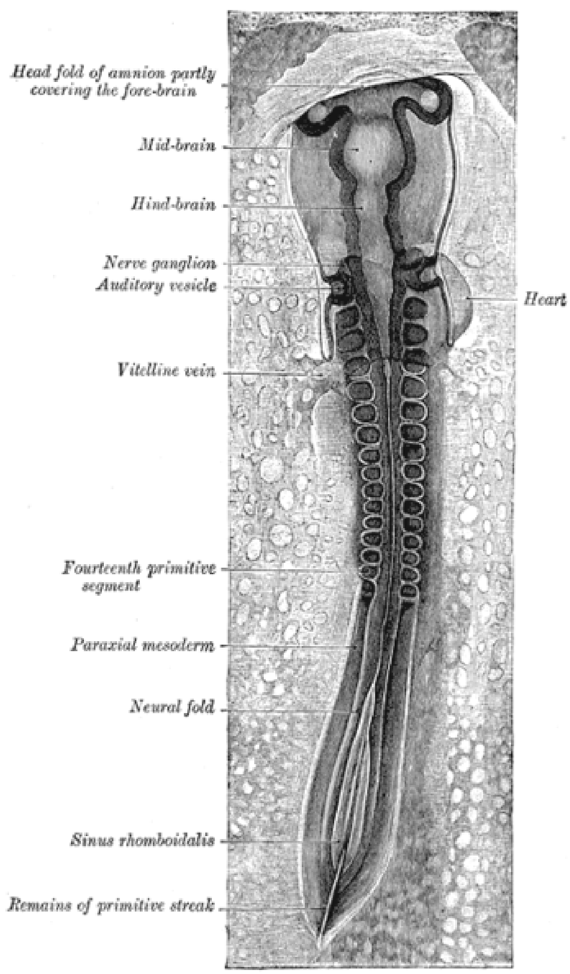
Metencephalon

Rhombomeres Rh3-Rh1 form the metencephalon.

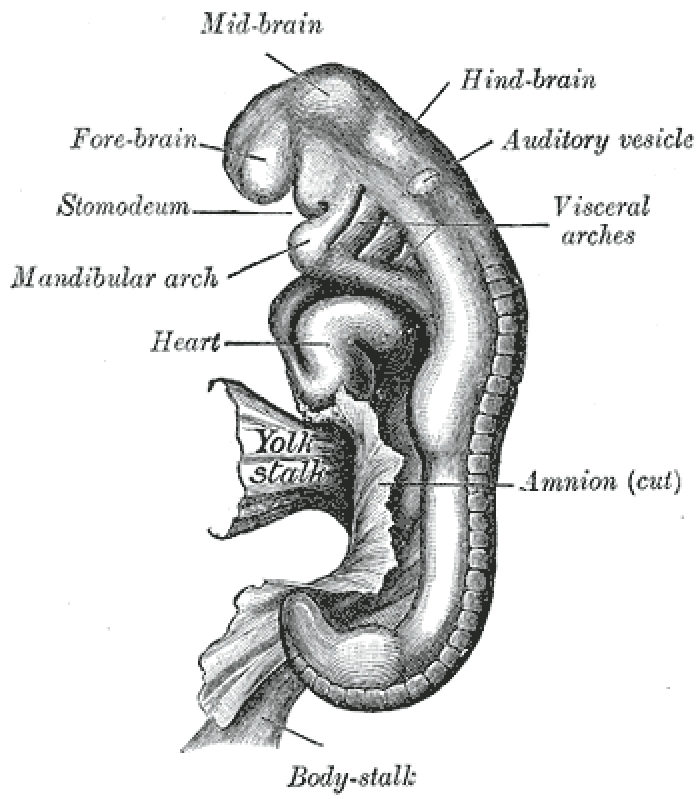
The metencephalon is composed of the pons and the cerebellum; it contains:

- a portion of the fourth ventricle,
- the trigeminal nerve (CN V),
- abducens nerve (CN VI),
- facial nerve (CN VII),
- and a portion of the vestibulocochlear nerve (CN VIII).

Additional images



Chick embryo of thirty-three hours' incubation, viewed from the dorsal aspect. X 30



Embryo between eighteen and twenty-one days

Myelencephalon

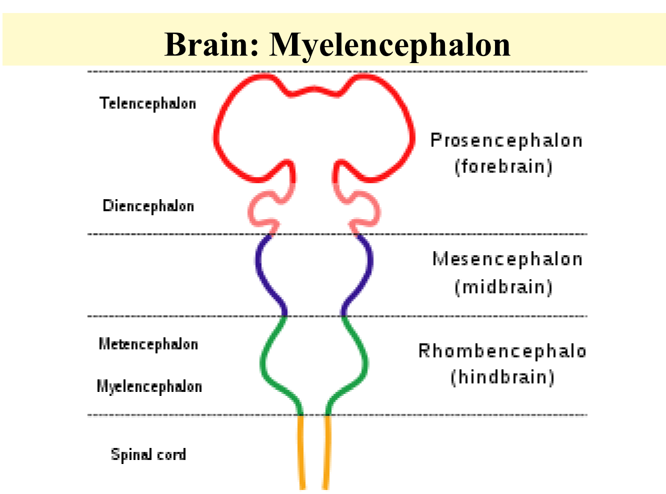


Diagram depicting the main subdivisions of the embryonic vertebrate brain. These regions will later differentiate into forebrain, midbrain and hindbrain structures.

NeuroNames	*hier-695*
MeSH	*Myelencephalon*

The **myelencephalon** is categorized as a secondary vesicle in the development of the central nervous system. The prefix "myelen" is derived from Greek for medulla (myelos). The myelencephalon differentiates primarily into the medulla oblongata and a caudal portion of the fourth ventricle, but will also contain portions of the following cranial nerves: vestibulocochlear nerve (CN VIII), glossopharyngeal nerve (CN IX), vagus nerve (CN X), accessory nerve (CN XI), and hypoglossal nerve (CN XII).

The myelencepalon develops from the primary vesicular structure called the rhombencephalon (or hindbrain), which is present in all vertebrate embryos. The rhombencephalon normally begins its differentiation into the myelencephalon and the metencephalon at approximately 5 weeks of gestational development in humans. Evolutionarily, the myelencephalon is the area of the brain which is the most ancestral, eventually controlling visceral mechanisms (basic bodily functions) such as breathing, heart and blood vessel activity, digestions, and peristalsis.

Metencephalon

Brain: Metencephalon

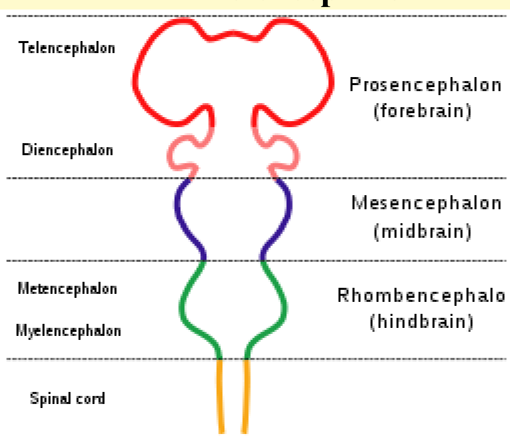
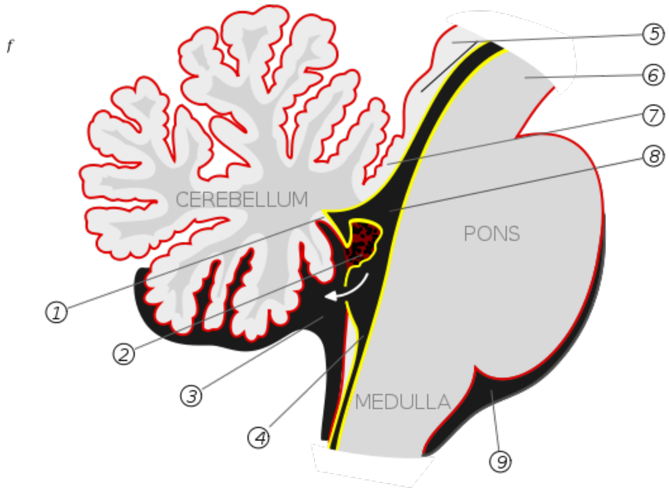


Diagram depicting the main subdivisions of the embryonic vertebrate brain. These regions will later differentiate into forebrain, midbrain and hindbrain structures.



Pons and cerebellum.

NeuroNames *hier-534*

MeSH *Metencephalon*

NeuroLex ID *birnlex_965*

The **metencephalon** is a developmental categorization of portions of the central nervous system. The metencephalon is composed of the pons and the cerebellum; contains a portion of the fourth ventricle; and the trigeminal nerve (CN V), abducens nerve (CN VI), facial nerve (CN VII), and a portion of the vestibulocochlear nerve (CN VIII).

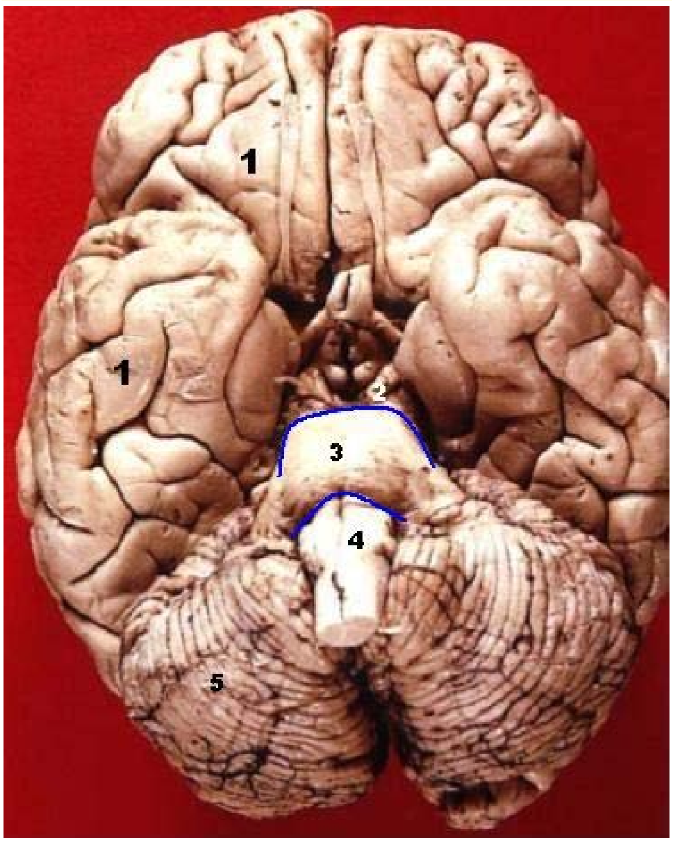
The metencephalon develops from the hindbrain, and is differentiated from the myelencephalon in the embryo by approximately 5 weeks of age. By the third month, the metencephalon differentiates into its two main structures, the pons and the cerebellum.

The pons regulates breathing through particular nuclei that regulate the breathing center of the medulla oblongata. The cerebellum works to coordinate muscle movements, maintain posture, and integrate sensory information from the inner ear and proprioceptors in the muscles and joints.

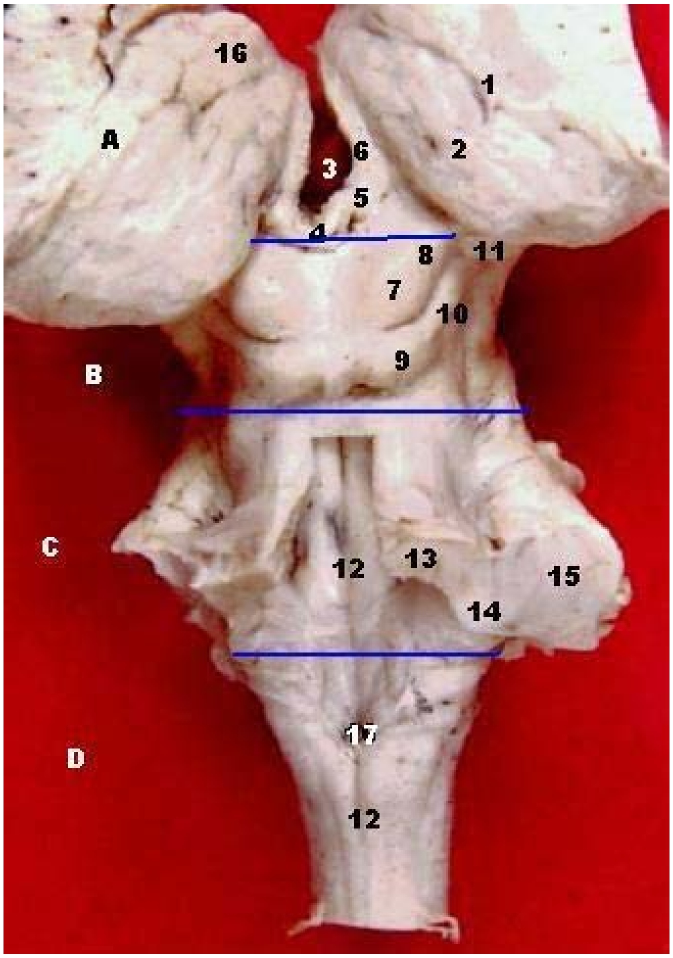
Chapter 3

Midbrain

Brain: Mesencephalon



Inferior view mesencephalon (2), above (3)



Human brainstem mesencephalon (B)

Latin	*mesencephalon*
NeuroNames	*hier-445*
MeSH	*Mesencephalon*

In biological anatomy, the **mesencephalon** (or **midbrain**) comprises the tectum (or corpora quadrigemina), tegmentum, the ventricular mesocoelia (or "iter"), and the cerebral peduncles, as well as several nuclei and fasciculi. Caudally the mesencephalon adjoins the pons (metencephalon) and rostrally it adjoins the diencephalon (Thalamus, hypothalamus, et al.).

During development, the mesencephalon forms from the middle of three vesicles that arise from the neural tube to generate the brain. In mature human brains, the mesencephalon becomes the least differentiated, from both its developmental form and within its own structure, among the three vesicles. The mesencephalon is considered part of the brain stem. Its substantia nigra is closely associated with motor system pathways of the basal ganglia.

The human mesencephalon is archipallian in origin, meaning its general architecture is shared with the most ancient of vertebrates. Dopamine produced in the substantia nigra plays a role in motivation and habituation of species from humans to the most elementary animals such as insects.

Corpora quadrigemina

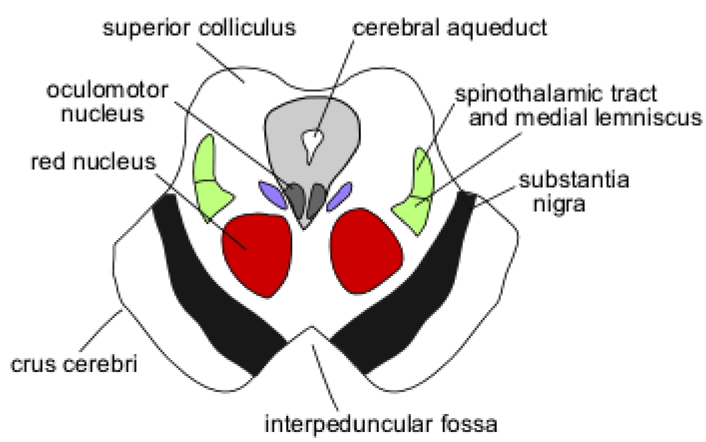
The corpora quadrigemina ("quadruplet bodies") are four solid optic lobes on the dorsal side of cerebral aqueduct, where the superior posterior pair are called the superior colliculi and the inferior posterior pair are called the inferior colliculi. The four solid optic lobes help to decussate several fibres of the optic nerve. However some fibers also show ipsilateral arrangement (i.e. they run parallel on the same side without decussating.) The superior colliculus is involved with saccadic eye movements; while the inferior is a synapsing point for sound information. The trochlear nerve comes out of the posterior surface of the midbrain, below the inferior colliculus.

Cerebral peduncle

The cerebral peduncles are paired structures, present on the ventral side of cerebral aqueduct, and they further carry tegmentum on the dorsal side and cresta or pes on the ventral side, and both of them accommodate the corticospinal tract fibres, from the internal capsule (i.e. ascending + descending tracts = longitudinal tract.) the middle part of cerebral peduncles carry substantia nigra (also called "Black Matter") which is a type of basal nucleus. It is the only part of the brain that carries melanin pigment.

Between the peduncles is the interpeduncular fossa, which is a cistern filled with cerebrospinal fluid. The oculomotor nerve comes out between the peduncles, and the trochlear nerve is visible wrapping around the outside of the peduncles. The oculomotor is responsible for pupil constriction (parasympathetic) and eye movement.

Cross-section through the midbrain



The midbrain is usually sectioned at the level of the superior and inferior colliculi

A cross-section at the level of the superior colliculus shows the red nucleus, the nuclei of the oculomotor nerve (and associated Edinger-Westphal nucleus), as well as the substantia nigra.

The substantia nigra is still present at inferior colliculus level. Also apparent are the trochlear nerve nucleus, and the decussation of the superior cerebellar peduncles.

The cerebral aqueduct runs through the midbrain, and is the communication between the third and fourth ventricle.

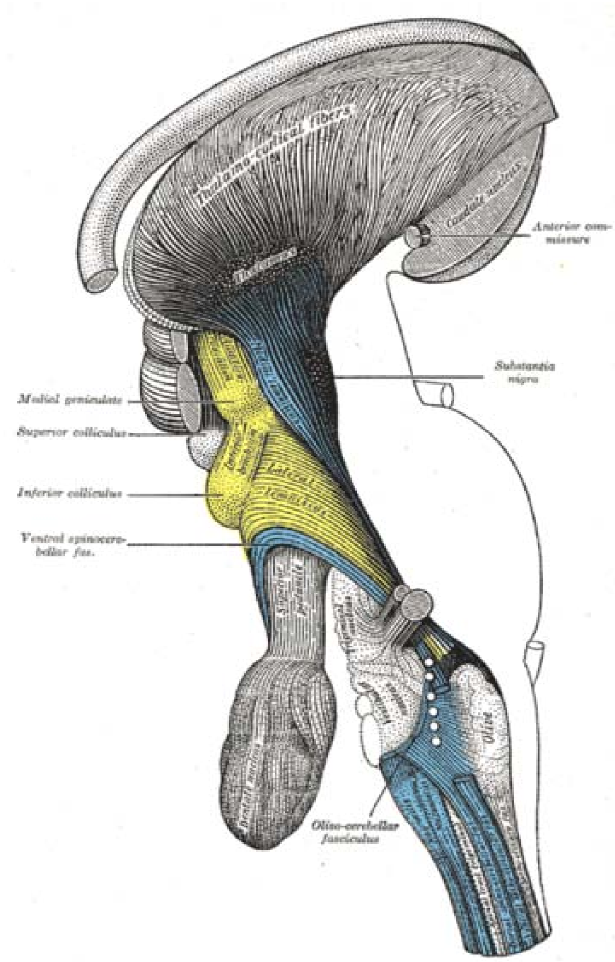
As a mnemonic the mesencephalic cross-section resembles a bear (or teddy bear) upside down with the two red nuclei as the eyes and the crus cerebri as the ears.

Organization

- mesencephalon
    - tectum
        - inferior colliculi
        - superior colliculi
    - cerebral peduncle
        - midbrain tegmentum
        - crus cerebri
        - substantia nigra

Midbrain tectum

Brain: Midbrain tectum	



Deep dissection of brain-stem. Lateral view.

Latin	*t. mesencephali*
Part of	Midbrain
NeuroNames	*hier-448*
NeuroLex ID	*birnlex_1032*
Dorlands/Elsevier	*Tectum of midbrain*

The **tectum** (Latin: *roof*) is a region of the brain, specifically the dorsal part of the mesencephalon (midbrain). This is contrasted with the tegmentum, which refers to the region ventral to the ventricular system. It is responsible for auditory and visual reflexes.

It is derived in embryonic development from the alar plate of the neural tube.

Colliculi

In adult humans it is present only in the mesencephalon as the inferior and the superior colliculi.

- The superior colliculus is involved in preliminary visual processing and control of eye movements. In non-mammalian vertebrates it serves as the main visual area of the brain, functionally analogous to the visual areas of the cerebral cortex in mammals.

- The inferior colliculus is involved in auditory processing. It receives input from various brain stem nuclei and projects to the medial geniculate nucleus of the thalamus, which relays auditory information to the primary auditory cortex.

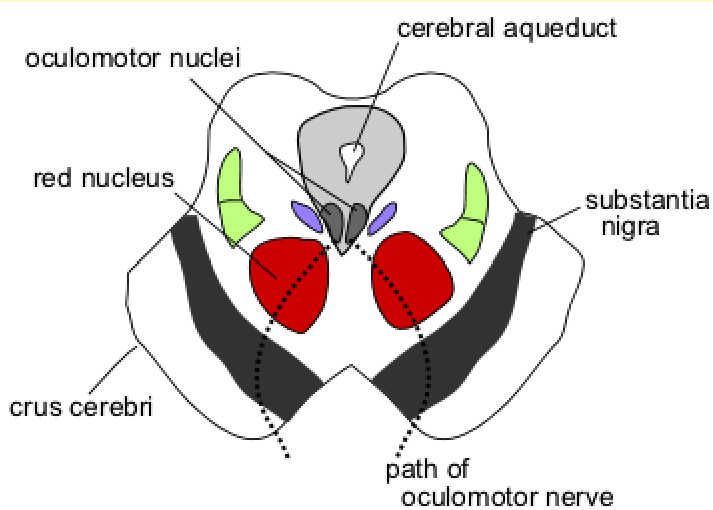
Both colliculi also have descending projections to the paramedian pontine reticular formation and spinal cord, and thus can be involved in responses to stimuli faster than cortical processing would allow. Collectively the colliculi are referred to as the corpora quadrigemina.

Related terms

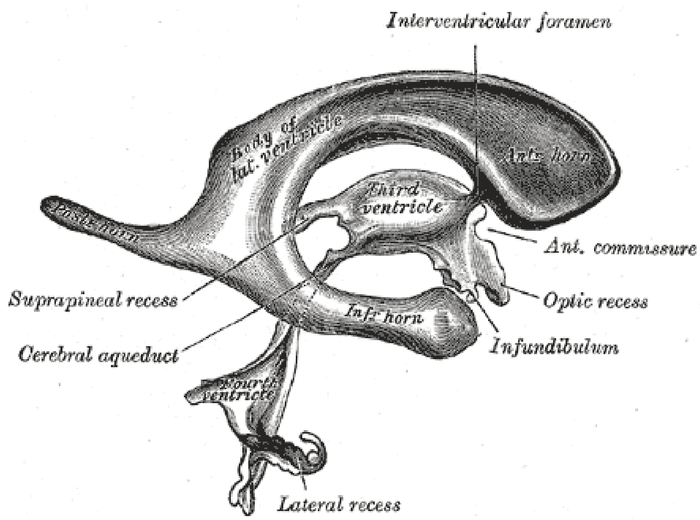
The term "tectal plate" (or "quadrigeminal plate") is used to describe the junction of the gray and white matter in the embryo. (NeuroNames *ancil-453*)

Cerebral aqueduct

Brain: Cerebral aqueduct



Section through superior colliculus showing path of oculomotor nerve.



Drawing of a cast of the ventricular cavities, viewed from the side.

Latin	*aqueductus mesencephali (cerebri)*
NeuroNames	*hier-500*
MeSH	*Cerebral+Aqueduct*

The **mesencephalic duct**, also known as the **aqueductus mesencephali**, **aqueduct of Sylvius** or the **cerebral aqueduct**, contains cerebrospinal fluid (CSF), is within the mesencephalon (or midbrain) and connects the third ventricle in the diencephalon to the fourth ventricle, which is between the pons and cerebellum.

Development

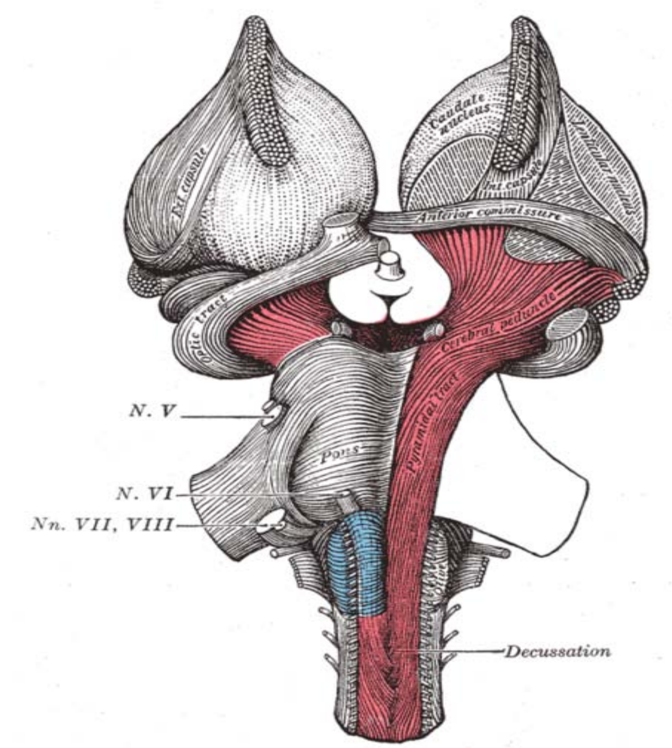
The cerebral aqueduct, similarly to other parts of the ventricular system of the brain, develops from the central canal of the neural tube. Specifically, the duct originates from the portion of the neural tube that is present in the developing mesencephalon, hence the name "mesencephalic duct."

Pathology

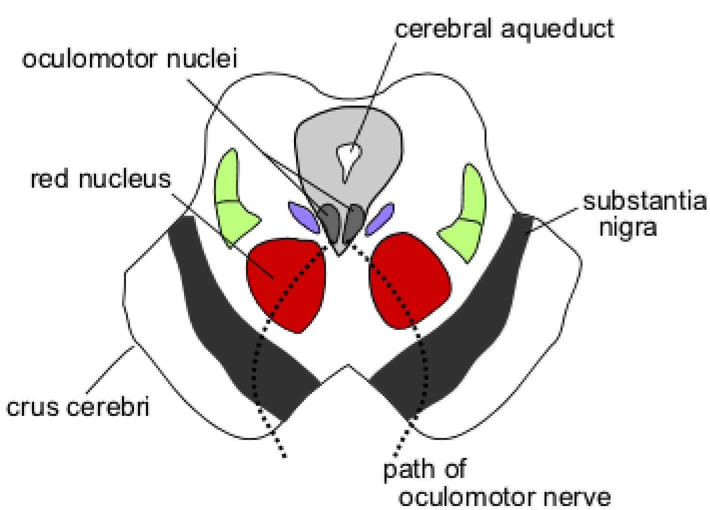
A blockage in this duct is a cause of hydrocephalus.

Cerebral peduncle

Brain: Cerebral peduncle



Superficial dissection of brain-stem. Ventral view. ("Cerebral peduncle" visible in red at center-right.)



Section through superior colliculus showing path of oculomotor nerve. (Crus cerebri labeled at lower left.)

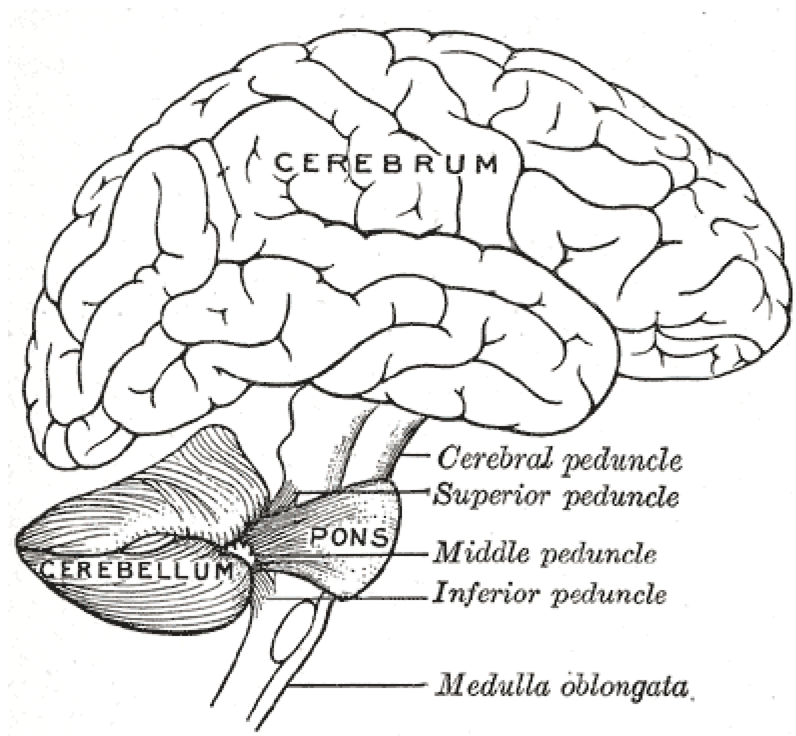
Latin	*pedunculus cerebri*

NeuroNames	*hier-478*
MeSH	*Cerebral+Peduncle*
NeuroLex ID	*birnlex_1202*

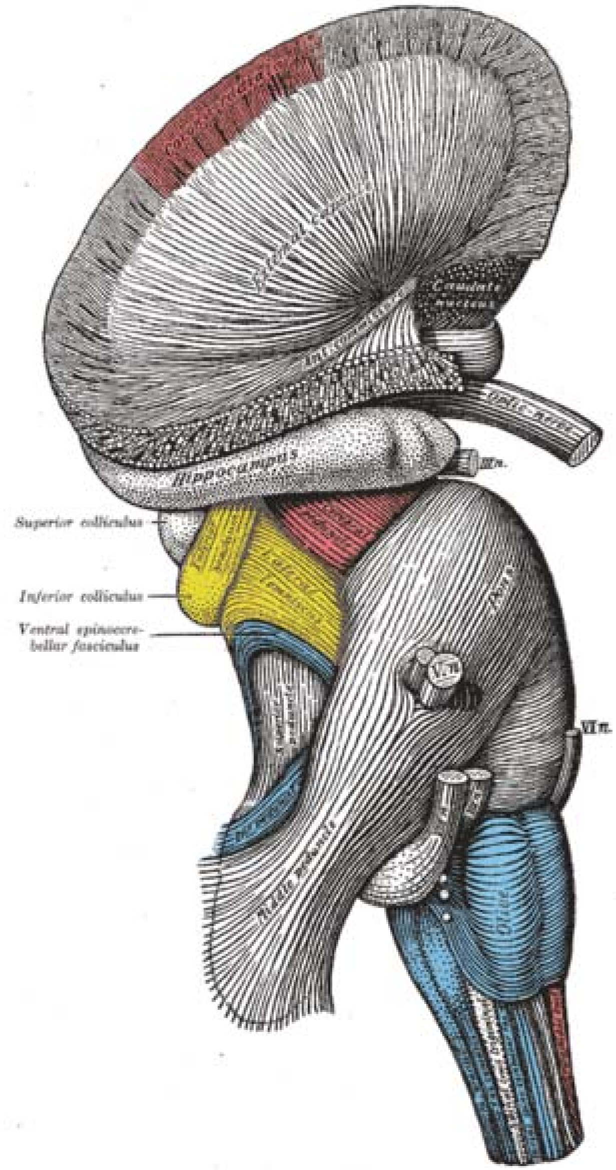
Mainly, the three common areas that give rise to the cerebral peduncles are the cortex, the spinal cord and the cerebellum. The **cerebral peduncle**, by most classifications, is everything in the mesencephalon except the tectum. The region includes the midbrain tegmentum, crus cerebri and pretectum. By this definition, the cerebral peduncles are also known as the **basis pedunculi,** while the large ventral bundle of efferent fibers is referred to as the **crus cerebri** or the **pes pedunculi**. There are numerous nerve tracts located within this section of the brainstem. Of note, in the *cerebral peduncular loop* fibers from motor areas of the brain project to the cerebral peduncle and then project to various thalamic nuclei.

Important fibers running through the cerebral peduncles include the corticospinal tract and the corticobulbar tract, among others. In as much as the peduncles are an anatomic landmark, for details regarding the function of this area interested readers are referred to the individual referenced articles. On a broad scale, though, this area contains many nerve tracts conveying motor information to and from the brain to the rest of the body.

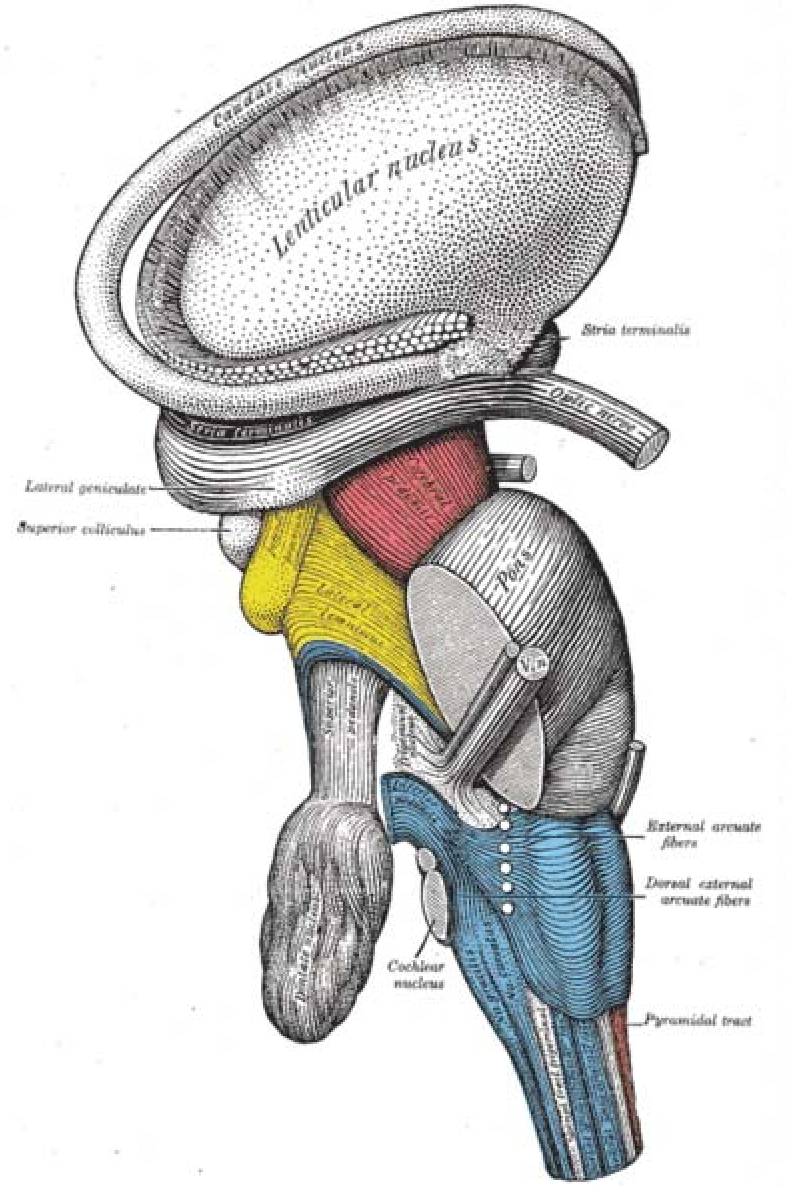
Additional images



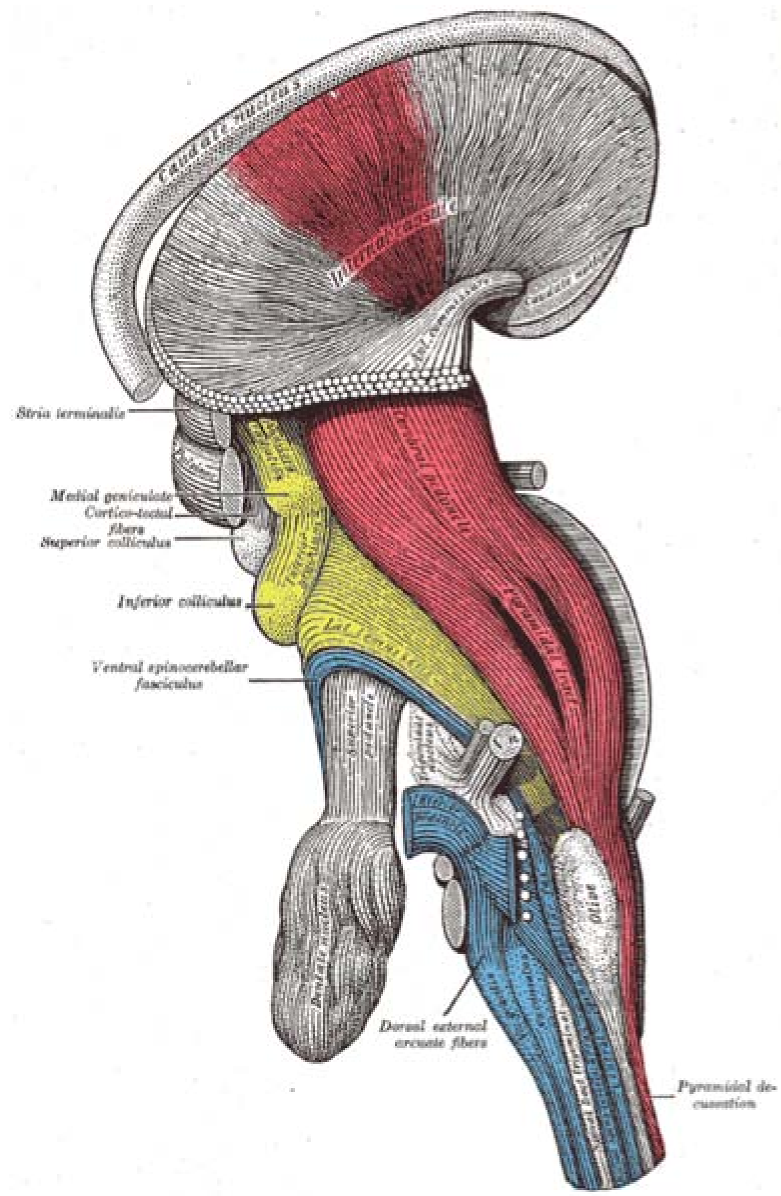
Scheme showing the connections of the several parts of the brain



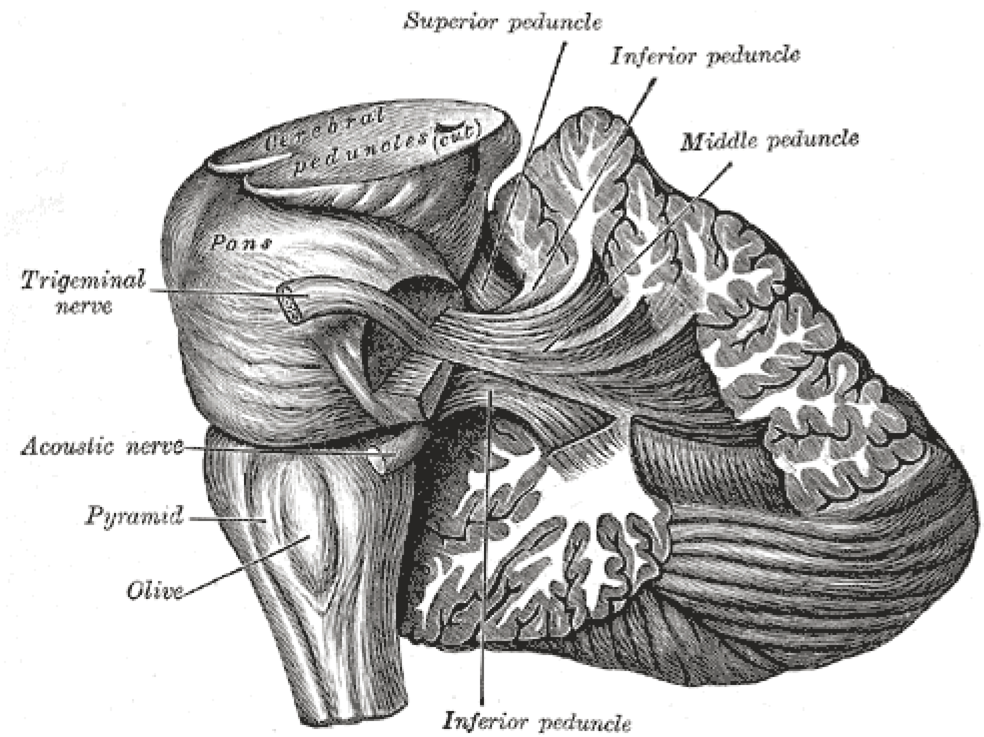
Superficial dissection of brain-stem. Lateral view.



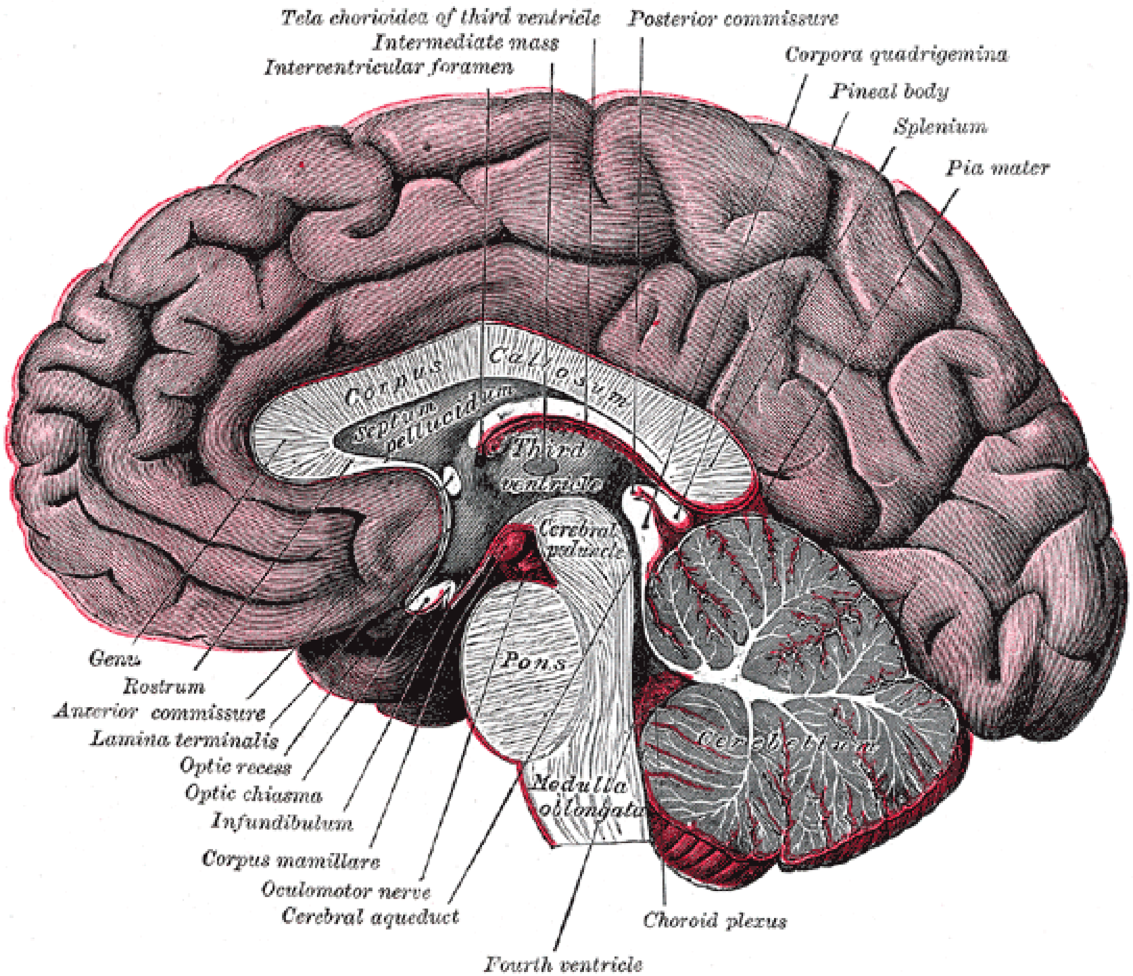
Dissection of brain-stem. Lateral view.



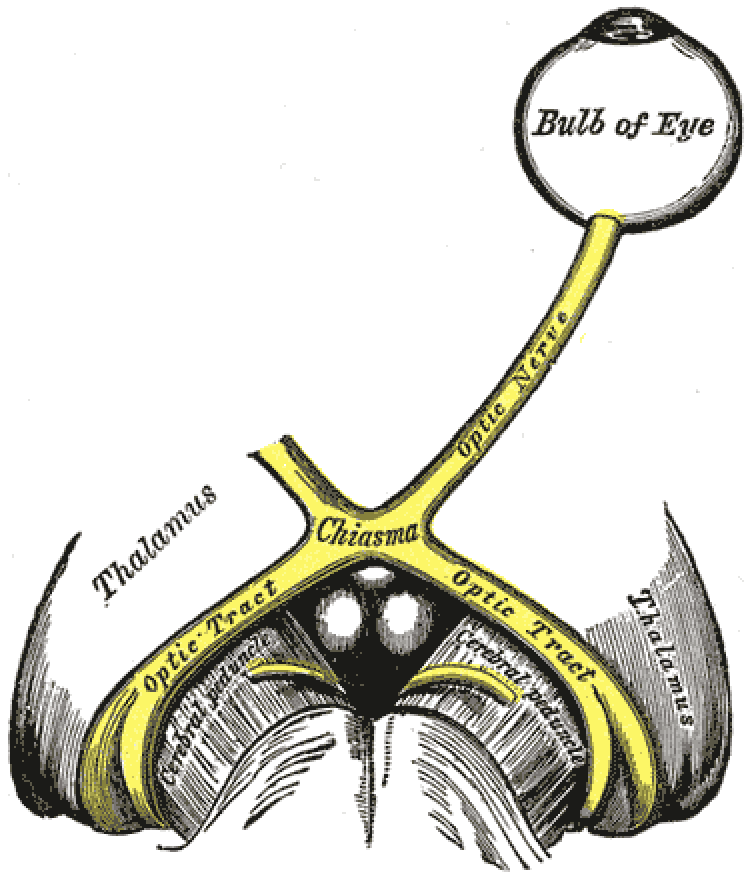
Deep dissection of brain-stem. Lateral view.



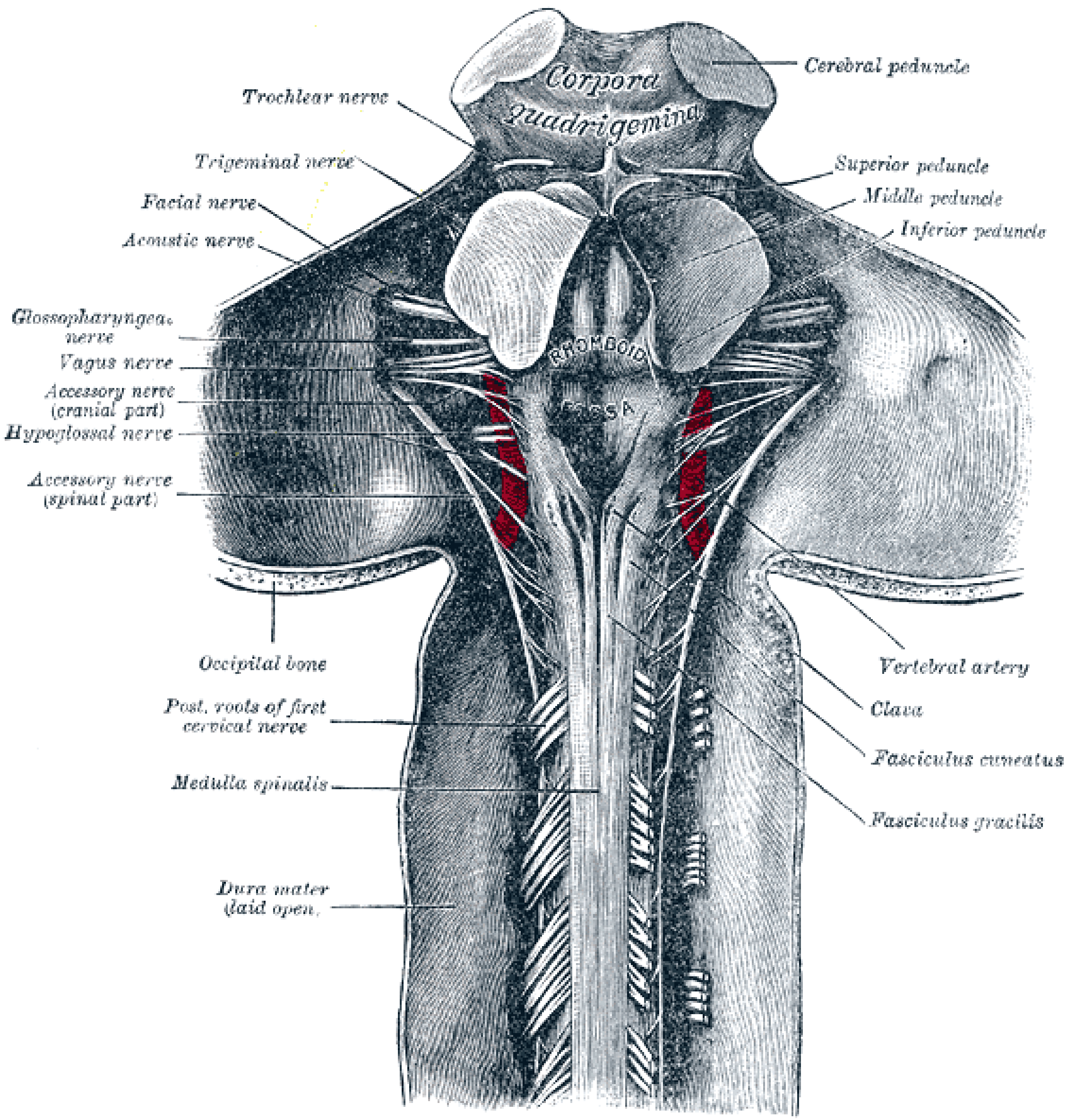
Dissection showing the projection fibers of the cerebellum



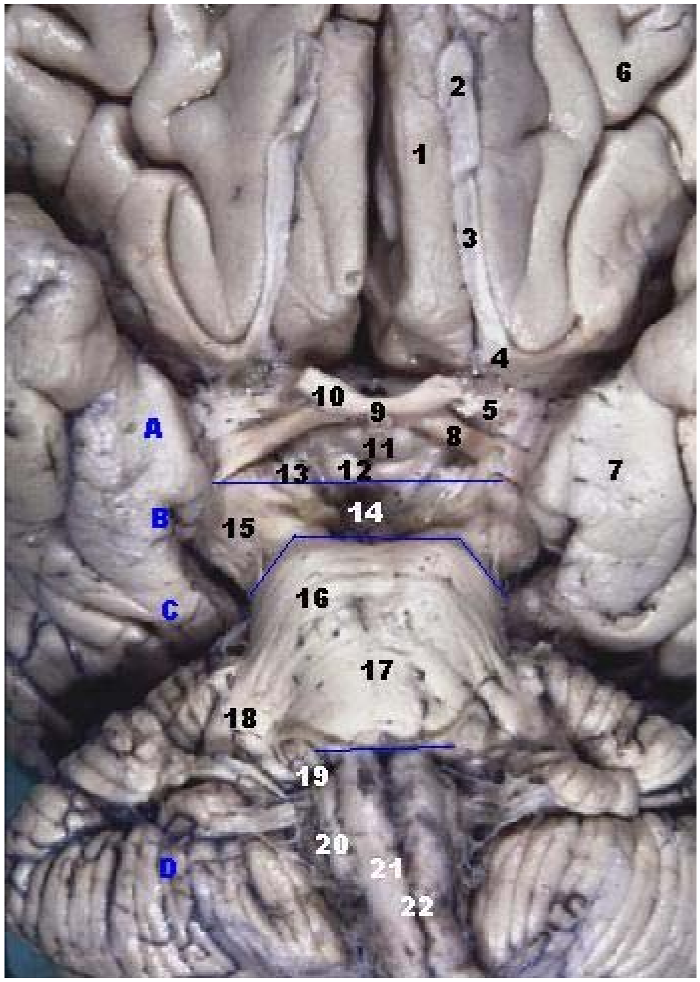
Median sagittal section of brain



The left optic nerve and the optic tracts



Upper part of medulla spinalis and hind- and mid-brains; posterior aspect, exposed in situ



Human brainstem anterior view

Chapter 4

Forebrain (Prosencephalon)

Brain: Forebrain	
Latin	=

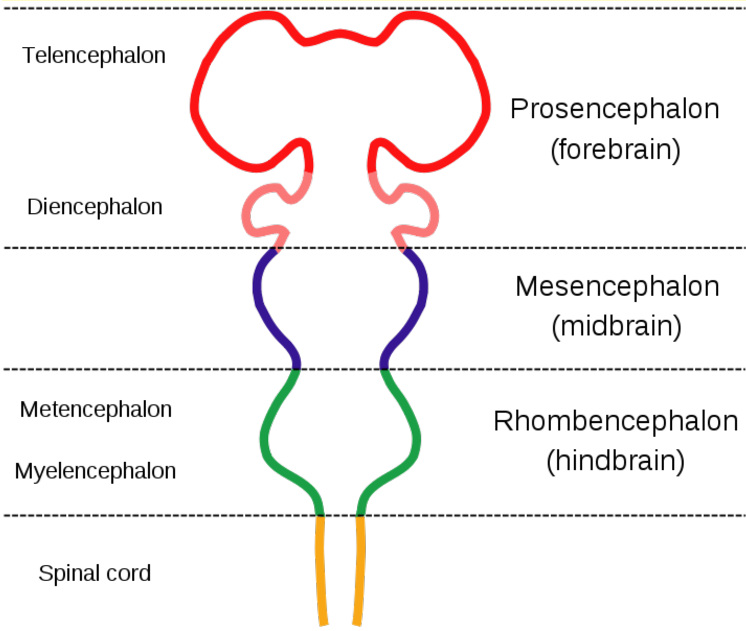


Diagram depicting the main subdivisions of the embryonic vertebrate brain. These regions will later differentiate into forebrain, midbrain and hindbrain structures.

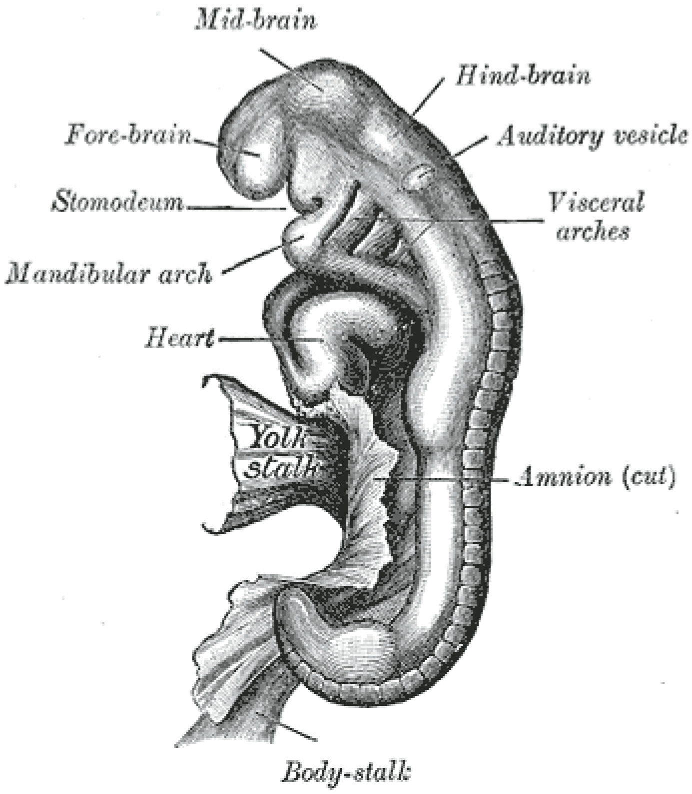
NeuroLex ID	*birnlex_1509*

In the anatomy of the brain of vertebrates, the **prosencephalon** (or **forebrain**) is the rostral-most (forward-most) portion of the brain. The prosencephalon, the mesencephalon (midbrain), and rhombencephalon (hindbrain) are the three primary portions of the brain during early development of the central nervous system. It controls body temperature, reproductive functions, eating, sleeping, and any display of emotions.

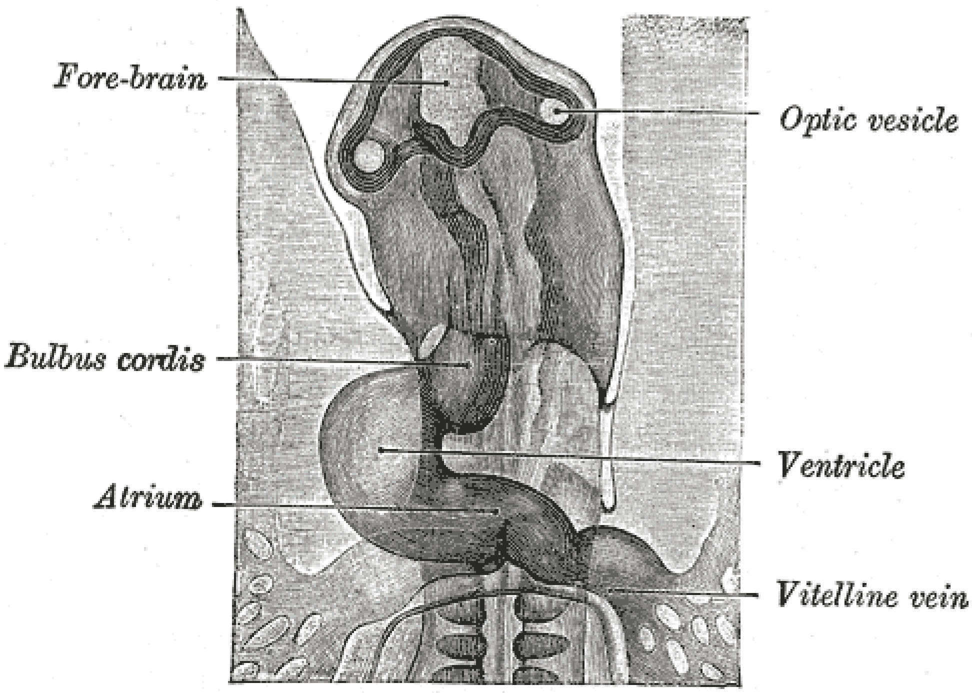
At the five-vesicle stage, the prosencephalon separates into the diencephalon (prethalamus, thalamus, hypothalamus, subthalamus, epithalamus, and pretectum) and the telencephalon (cerebrum). The cerebrum consists of the cerebral cortex, underlying white matter, and the basal ganglia.

When the embryonic prosencephalon fails to divide the brain into two lobes, it results in a condition known as holoprosencephaly.

Additional images



Embryo between eighteen and twenty-one days



Head of chick embryo of about thirty-eight hours' incubation, viewed from the ventral surface. X 26

Diencephalon

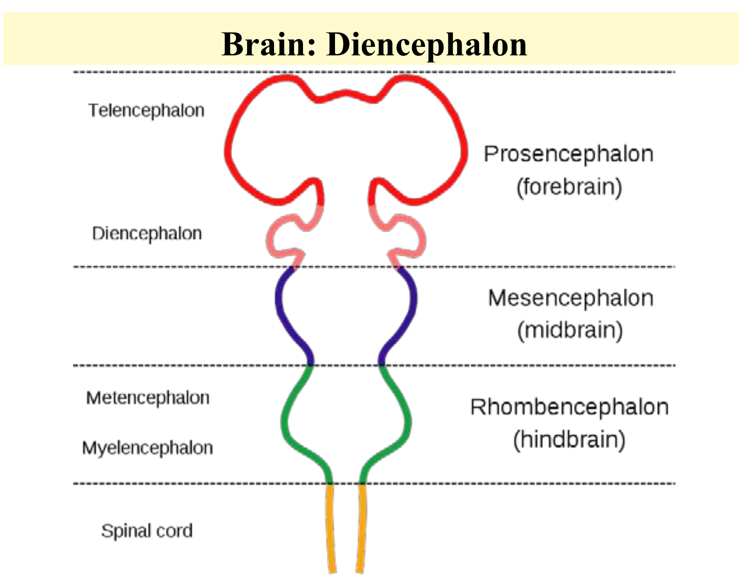
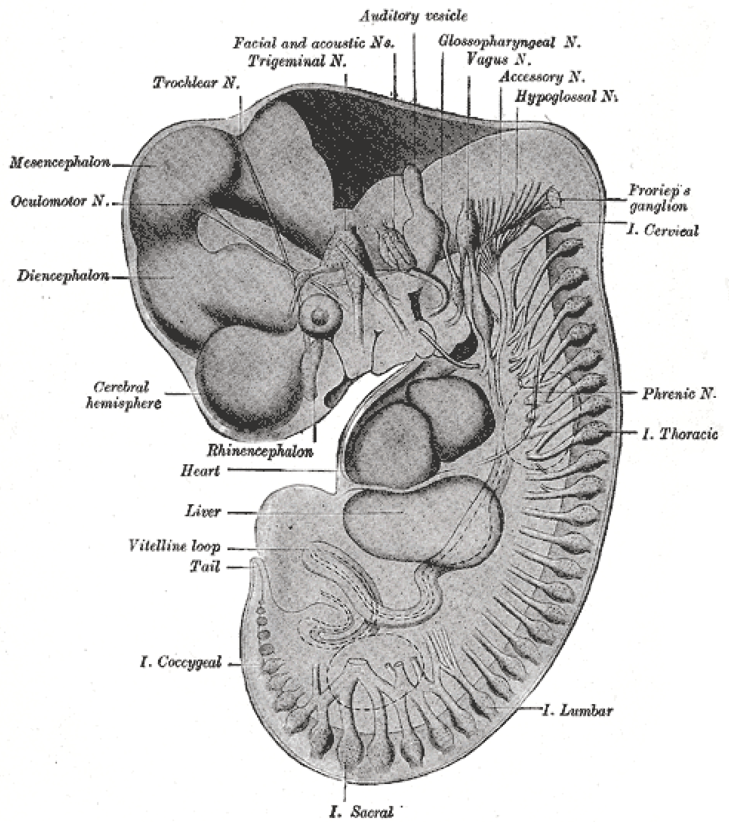


Diagram depicting the main subdivisions of the embryonic vertebrate brain. These regions will later differentiate into forebrain, midbrain and hindbrain structures.



Reconstruction of peripheral nerves of a human embryo of 10.2 mm. (Label for Diencephalon is at left.)

Latin	*diencephalon*
NeuroNames	*hier-271*
MeSH	*Diencephalon*
NeuroLex ID	*birnlex_1503*

The **diencephalon** ("interbrain") is the region of the brain that includes the thalamus, metathalamus, hypothalamus, epithalamus, prethalamus or subthalamus and pretectum. The diencephalon and the telencephalon both derive from the prosencephalon (forebrain). The diencephalon is located near the midline of the brain, above the mesencephalon (midbrain).

Organization

- diencephalon

- mid-diencephalic territory
    - prethalamus
    - zona limitans intrathalamica
    - thalamus
- hypothalamus
- epithalamus
- pretectum

Roles

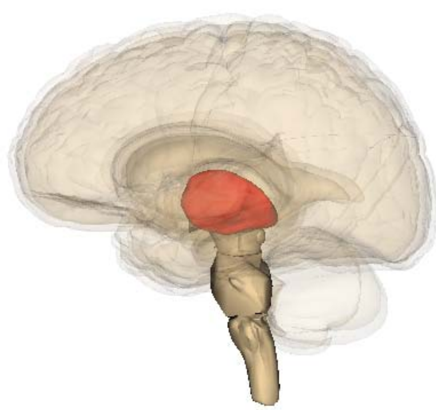
The diencephalon is the part of the forebrain that contains such important structures as the thalamus, hypothalamus, posterior portion of the pituitary gland, and pineal gland. The hypothalamus performs numerous vital functions, most of which relate directly or indirectly to the regulation of visceral activities by way of other brain regions and the autonomic nervous system.

Three-dimensional representation

Thalamus

Brain: Thalamus

MRI cross-section of human brain, with thalamus marked.

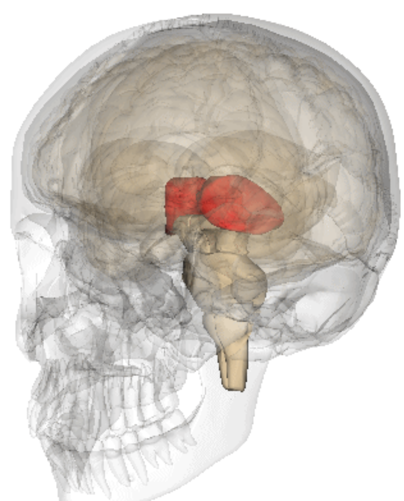


Scheme showing the parts of the thalamus

Latin	*thalamus dork*
Part of	Diencephalon
Components	
NeuroNames	*hier-283*
MeSH	*Thalamus*
NeuroLex ID	*birnlex_954*

The **thalamus** (from Greek *θάλαμος* = *room, chamber*) is a midline paired symmetrical structure within the brains of vertebrates, including humans. It is situated between the cerebral cortex and midbrain, both in terms of location and neurological connections. Its function includes relaying sensation, spatial sense and motor signals to the cerebral cortex, along with the regulation of consciousness, sleep and alertness. The thalamus surrounds the third ventricle. It is the main product of the embryonic diencephalon.

Location and topography



Thalamus

The thalamus is the largest structure in the diencephalon, the part of the brain situated between the midbrain (mesencephalon) and forebrain (telencephalon). Anatomically, the thalamus is perched on top of the brainstem, near the center of the brain, in a position to send nerve fibers out to the cerebral cortex in all directions. The diencephalon includes also the dorsally located epithalamus (essentially the habenula and annexes) and the perithalamus (prethalamus formerly described as ventral thalamus) containing the zona incerta and the "reticulate nucleus" (not the reticular, term of confusion). Due to their different ontogenetic origins, the epithalamus and the perithalamus are formally distinguished from the thalamus proper.

In humans, the two halves of the thalamus are prominent bulb-shaped masses, about 5.7 cm in length, located obliquely (about 30°) and symmetrically on each side of the third ventricle.

Anatomy

The thalamus comprises a system of lamellae (made up of myelinated fibers) separating different thalamic subparts. Other areas are defined by distinct clusters of neurons, such as the periventricular gray, the intralaminar elements, the "nucleus limitans", and others. These latter structures, different in structure from the major part of the thalamus, have been grouped together into the *allothalamus* as opposed to the *isothalamus*. This distinction simplifies the global description of the thalamus.

Arterial supply

The thalamus derives its blood supply from four arteries including the polar artery(posterior communicating artery), paramedian thalamic-subthalamic arteries, inferolateral (thalamogeniculate) arteries, and posterior (medial and lateral) choroidal arteries. These are all derived from the vertebrobasilar arterial system except the polar artery.

Function

The thalamus has multiple functions. It is generally believed to act as a relay between a variety of subcortical areas and the cerebral cortex. In particular, every sensory system (with the exception of the olfactory system) includes a thalamic nucleus that receives sensory signals and sends them to the associated primary cortical area. For the visual system, for example, inputs from the retina are sent to the lateral geniculate nucleus of the thalamus, which in turn projects to the primary visual cortex (area V1) in the occipital lobe. The thalamus is believed to both process sensory information as well as relaying it—each of the primary sensory relay areas receives strong "back projections" from the cerebral cortex. Similarly the medial geniculate nucleus acts as a key auditory relay between the inferior colliculus of the midbrain and the primary auditory cortex, and the ventral posterior nucleus is a key somatosensory relay, which sends touch and proprioceptive information to the primary somatosensory cortex.

The thalamus also plays an important role in regulating states of sleep and wakefulness. Thalamic nuclei have strong reciprocal connections with the cerebral cortex, forming thalamo-cortico-thalamic circuits that are believed to be involved with consciousness. The thalamus plays a major role in regulating arousal, the level of awareness, and activity. Damage to the thalamus can lead to permanent coma.

Many different functions are linked to various regions of the thalamus. This is the case for many of the sensory systems (except for the olfactory system), such as the auditory, somatic, visceral, gustatory and visual systems where localized lesions provoke specific sensory deficits. A major role of the thalamus is devoted to "motor" systems. This has been and continues to be a subject of interest for investigators. VIm, the relay of cerebellar afferences, is the target of stereotactians particularly for the improvement of tremor. The role of the thalamus in the more anterior pallidal and nigral territories in the basal ganglia system disturbances is recognized but still poorly understood. The contribution of the thalamus to vestibular or to tectal functions is almost ignored. The thalamus has been thought of as a "relay" that simply forwards signals to the cerebral cortex. Newer research suggests that thalamic function is more selective.

Pathology

Cerebrovascular events (strokes) can cause *thalamic syndrome*, which results in a contralateral hemianaesthesia, burning or aching sensation on one half of a body (painful anaesthesia) often accompanied by mood swings. Ischemia of the territory of the paramedian artery, if bilateral, causes serious troubles including akinetic mutism accompanied or not by oculomotor troubles. It is also related to Thalamocortical Dysrhythmia.

Korsakoff's Syndrome stems from mammillary bodies, mammilothalamic, or thalamic lesions.

Fatal familial insomnia is a hereditary prion disease in which degeneration of the thalamus occurs, causing the patient to gradually lose his ability to sleep, progressing to a state of total insomnia, which invariably leads to death.

Development

The thalamic complex is composed of the perithalamus (or prethalamus, previously also known as ventral thalamus), the mid-diencephalic organiser (which forms later the zona limitans intrathalamica (ZLI)) and the thalamus (dorsal thalamus).The development of the thalamus can be subdivide into three steps

Early brain development

After neurulation the anlage of the prethalamus and the thalamus is induced within the neural tube. Data from different vertebrate model organisms support a model, in which the interaction between two transcription factors, Fez and Otx, is from decisive importance. Fez is expressed in the prethalamus, and functional experiments show that Fez is required for prethalamus formation. Posteriorly, Otx1 and Otx2 abut the expression domain of Fez and are required for proper development of the thalamus.

The formation of the mid-diencephalic organiser (MDO)

At the interface between the expression domains of Fez and Otx, the mid-diencephalic organizer (MDO, also called the ZLI organiser) is induced within the thalamic anlage. The MDO is the central signalling organizer in the thalamus. A lack of the organizer leads to the absence of the thalamus. The MDO matures from ventral to dorsal during development. Members of the SHH family and of the Wnt family are the main principal signals emitted by the MDO.

Besides its importance as signalling center, the organizer matures into the morphological structure of the zona limitans intrathalamica (ZLI).

Maturation and parcellation of the thalamus

After its induction, the MDO starts to orchestrate the development of the thalamic anlage by release of signalling molecules such Shh. In mice, the function of signaling at the MDO has not been addressed directly due to a complete absence of the diencephalon in Shh mutants.

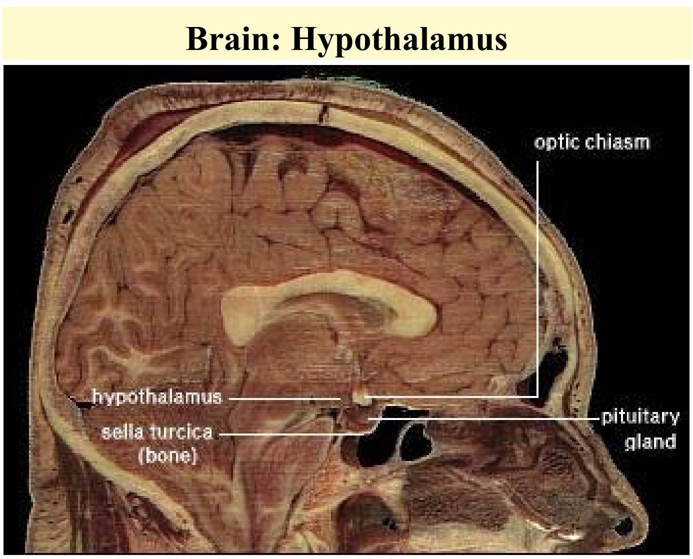
Studies in poos have shown that Shh is both necessary and sufficient for thalamic gene induction. In zebrafish, it was shown that the expression of two Shh genes, shh-a and shh-b (formerly described as twhh) mark the MDO territory, and that Shh signaling is sufficient for the molecular differentiation of both the prethalamus and the thalamus but is not required for their maintenance and Shh signaling from the MDO/alar plate is sufficient for the maturation of prethalamic and thalamic territory while ventral Shh signals are dispensable. The exposure to Shh leads to differentiation of thalamic neurons. SHH signaling from the MDO induces a posterior-to-anterior wave of expression the proneural gene Neurogenin1 in the major (caudal) part of the thalamus, and Ascl1 (formerly Mash1) in the remaining narrow stripe of rostral thalamic cells immediately adjacent to the MDO, and in the prethalamus

This zonation of proneural gene expression leads to the differentiation of glutamatergic relay neurons from the Neurogenin1+ precursors and of GABAergic inhibitory neurons from the Ascl1+ precursors. In fish, selection of these alternative neurotransmitter fates is controlled by the dynamic expression of Her6 the homolog of HES1. Expression of this hairy-like bHLH transcription factor, which represses Neurogenin but is required for Ascl1, is progressively lost from the caudal thalamus but maintained in the prethalamus and in the stripe of rostral thalamic cells. In addition, studies on chick and mice have shown that blocking the Shh pathway leads to absence of the rostral thalamus and substantial decrease of the caudal thalamus. The rostral thalamus will give rise to the reticular nucleus mainly whereby the caudal thalamus will form the relay thalamus and will be further subdivided in the thalamic nuclei.

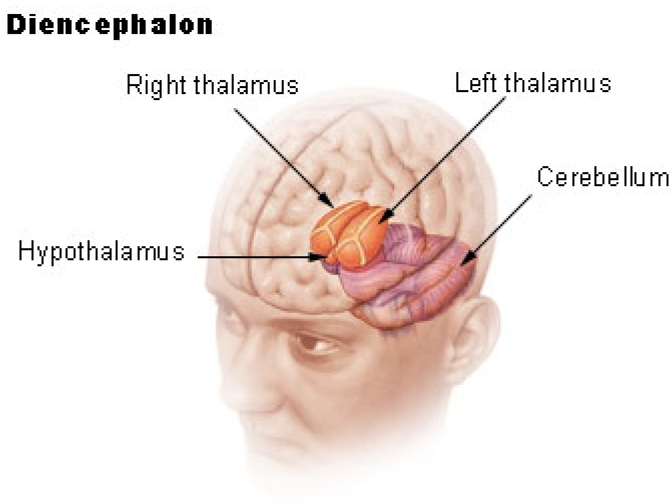
Further reading: *Building a bridal chamber: development of the thalamus.* from Steffen Scholpp and Andrew Lumsden in Trends of Neuroscience 2010

In humans, a common genetic variation in the promotor region of the serotonin transporter (the SERT-long and -short allele: 5-HTTLPR) has been shown to affect the development of several regions of the thalamus in adults. People who inherit two short alleles (SERT-ss) have more neurons and a larger volume in the pulvinar and possibly the limbic regions of the thalamus. Enlargement of the thalamus provides an anatomical basis for why people who inherit two SERT-ss alleles are more vulnerable to major depression, posttraumatic stress disorder, and suicide.

Hypothalamus



Location of the human hypothalamus



Diencephalon

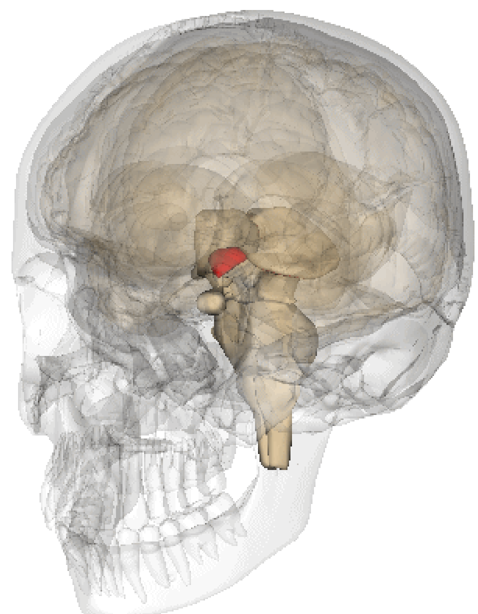
Latin	*hypothalamus*
NeuroNames	*hier-358*
MeSH	*Hypothalamus*
NeuroLex ID	*birnlex_734*

The **Hypothalamus** (from Greek *ὑπό* = *under* and *θάλαμος* = *room, chamber*) is a portion of the brain that contains a number of small nuclei with a variety of functions. One of the most important functions of the hypothalamus is to link the nervous system to the endocrine system via the pituitary gland (hypophysis).

The hypothalamus is located below the thalamus, just above the brain stem. In the terminology of neuroanatomy, it forms the ventral part of the diencephalon. All vertebrate brains contain a hypothalamus. In humans, it is roughly the size of an almond.

The hypothalamus is responsible for certain metabolic processes and other activities of the autonomic nervous system. It synthesizes and secretes certain neurohormones, often called hypothalamic-releasing hormones, and these in turn stimulate or inhibit the secretion of pituitary hormones. The hypothalamus controls body temperature, hunger, thirst, fatigue, sleep, and circadian cycles.

Inputs



Hypothalamus

The hypothalamus is an extremely complex region in the brain of humans, and even small nuclei within the hypothalamus are involved in many different functions. The paraventricular nucleus and the supraoptic nucleus contain oxytocin and vasopressin (also called antidiuretic hormone) neurons which project to the posterior pituitary, but also contain neurons that regulate ACTH and TSH secretion from the anterior pituitary, as well as gastric reflexes, maternal behavior, blood pressure, feeding, immune responses, and temperature.

The hypothalamus co-ordinates many hormonal and behavioural circadian rhythms, complex patterns of neuroendocrine outputs, complex homeostatic mechanisms, and many important behaviours.

The hypothalamus must therefore respond to many different signals, some of which are generated externally and some internally. It is thus richly connected with many parts of the central nervous system, including the brainstem reticular formation and autonomic zones, the limbic forebrain (particularly the amygdala, septum, diagonal band of Broca, and the olfactory bulbs, and the cerebral cortex).

The hypothalamus is responsive to:

- Light: daylength and photoperiod for regulating circadian and seasonal rhythms
- Olfactory stimuli, including pheromones
- Steroids, including gonadal steroids and corticosteroids
- Neurally transmitted information arising in particular from the heart, the stomach, and the reproductive tract
- Autonomic inputs
- Blood-borne stimuli, including leptin, ghrelin, angiotensin, insulin, pituitary hormones, cytokines, plasma concentrations of glucose and osmolarity etc.
- Stress
- Invading microorganisms by increasing body temperature, resetting the body's thermostat upward.

Olfactory stimuli

Olfactory stimuli are important for sex and neuroendocrine function in many species. For instance if a pregnant mouse is exposed to the urine of a 'strange' male during a critical period after coitus then the pregnancy fails (the Bruce effect). Thus during coitus, a female mouse forms a precise 'olfactory memory' of her partner which persists for several days. Pheromonal cues aid synchronisation of oestrus in many species; in women, synchronised menstruation may also arise from pheromonal cues, although the role of pheromones in humans is doubted by many.

Blood-borne stimuli

Peptide hormones have important influences upon the hypothalamus, and to do so they must evade the blood-brain barrier. The hypothalamus is bounded in part by specialized brain regions that lack an effective blood-brain barrier; the capillary endothelium at these sites is fenestrated to allow free passage of even large proteins and other molecules. Some of these sites are the sites of neurosecretion - the neurohypophysis and the median eminence. However others are sites at which the brain samples the composition of the blood. Two of these sites, the subfornical organ and the OVLT (organum vasculosum of the lamina terminalis) are so-called circumventricular organs, where neurons are in intimate contact with both blood and CSF. These structures are densely vascularized, and contain osmoreceptive and sodium-receptive neurons which control drinking, vasopressin release, sodium excretion, and sodium appetite. They also contain neurons with receptors for angiotensin, atrial natriuretic factor, endothelin and relaxin, each of which is important in the regulation of fluid and electrolyte balance. Neurons in the OVLT and SFO project to the supraoptic nucleus and paraventricular nucleus, and also to preoptic hypothalamic areas. The circumventricular organs may also be the site of action of interleukins to elicit both fever and ACTH secretion, via effects on paraventricular neurons.

It is not clear how all peptides that influence hypothalamic activity gain the necessary access. In the case of prolactin and leptin, there is evidence of active uptake at the choroid plexus from blood into CSF. Some pituitary hormones have a negative feedback influence upon hypothalamic secretion; for example, growth hormone feeds back on the hypothalamus, but how it enters the brain is not clear. There is also evidence for central actions of prolactin and TSH.

The hypothalamus functions as a type of thermostat for the body. It sets a desired body temperature, and stimulates either heat production and retention to raise the blood temperature to a higher setting, or sweating and vasodilation to cool the blood to a lower temperature. All fevers result from a raised setting in the hypothalamus; elevated body temperatures due to any other cause are classified as hyperthermia. Rarely, direct damage to the hypothalamus, such as from a stroke, will cause a fever; this is sometimes called a *hypothalamic fever*. However, it is more common for such damage to cause abnormally low body temperatures.

Steroids

The hypothalamus contains neurons that react strongly to steroids and glucocorticoids – (the steroid hormones of the adrenal gland, released in response to ACTH). It also contains specialised glucose-sensitive neurons (in the arcuate nucleus and ventromedial hypothalamus), which are important for appetite. The preoptic area contains thermosensitive neurons; these are important for TRH secretion.

Neural inputs

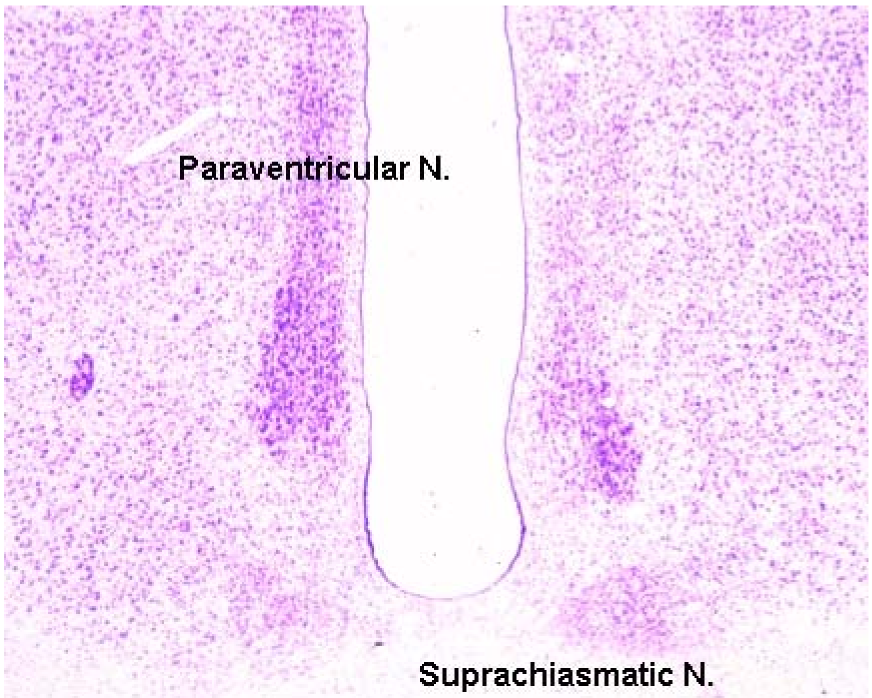
The hypothalamus receives many inputs from the brainstem; notably from the nucleus of the solitary tract, the locus coeruleus, and the ventrolateral medulla. Oxytocin secretion in response to suckling or vagino-cervical stimulation is mediated by some of these pathways; vasopressin secretion in response to cardiovascular stimuli arising from chemoreceptors in the carotid body and aortic arch, and from low-pressure atrial volume receptors, is mediated by others. In the rat, stimulation of the vagina also causes prolactin secretion, and this results in pseudo-pregnancy following an infertile mating. In the rabbit, coitus elicits reflex ovulation. In the sheep, cervical stimulation in the presence of high levels of estrogen can induce maternal behavior in a virgin ewe. These effects are all mediated by the hypothalamus, and the information is carried mainly by spinal pathways that relay in the brainstem. Stimulation of the nipples stimulates release of oxytocin and prolactin and suppresses the release of LH and FSH.

Cardiovascular stimuli are carried by the vagus nerve, but the vagus also conveys a variety of visceral information, including for instance signals arising from gastric distension to suppress feeding. Again this information reaches the hypothalamus via relays in the brainstem.

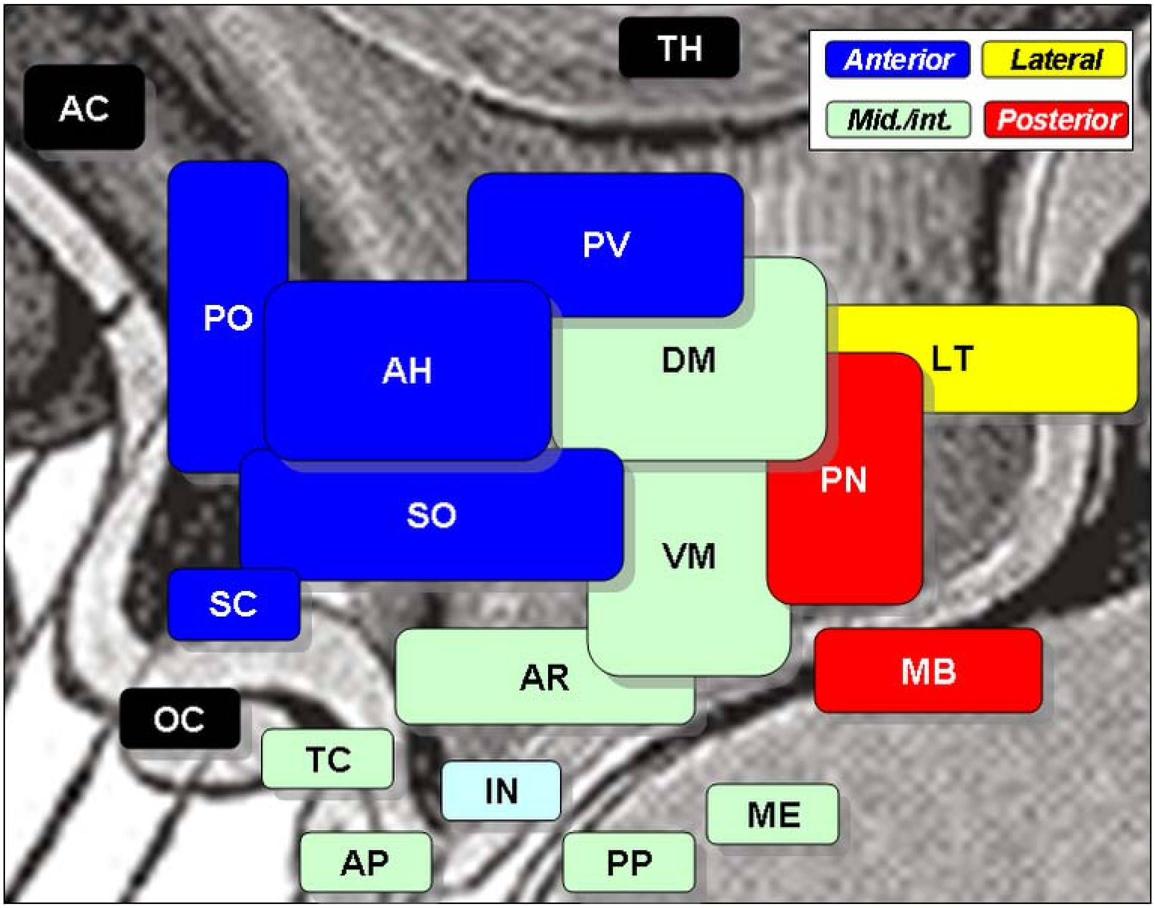
In addition hypothalamic function is responsive to --and regulated by-- levels of all three classical monoamine neurotransmitters, i.e. noradrenaline, dopamine and 5-hydroxytryptamine (serotonin), in those tracts fom which it receives enervation. For example noradrenergic inputs arising from the locus coeruleus have important regulatory effects upon CRH levels.

Nuclei

A cross section of the monkey hypothalamus displays 2 of the major hypothalamic nuclei on either side of the fluid-filled 3rd ventricle



The hypothalamic nuclei include the following:



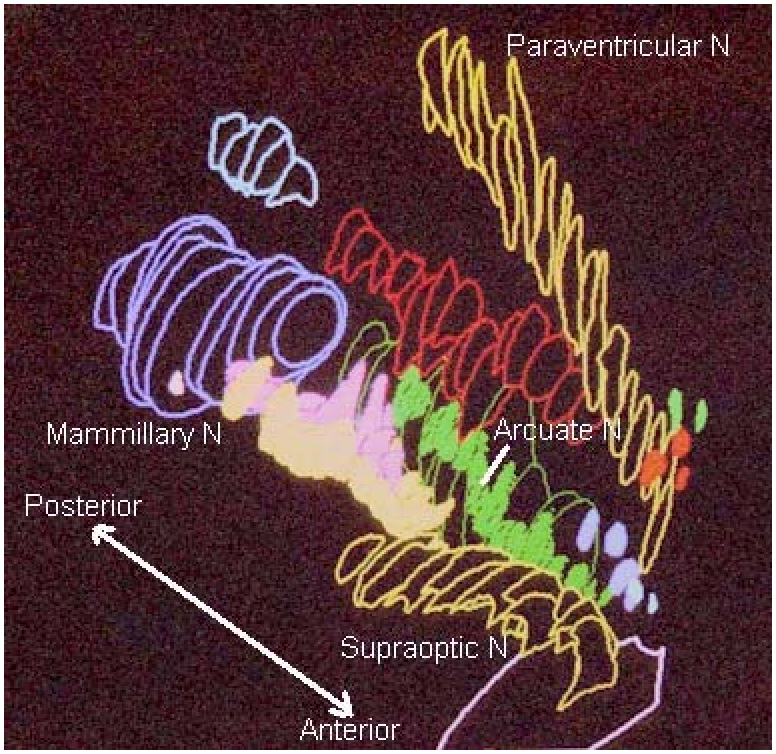
Hypothalamic nuclei

Region	**Area**	**Nucleus**	**Function**
Anterior	Medial	Medial preoptic nucleus	• urinary bladder contraction • Decreased heart rate • Decreased blood pressure
		Supraoptic nucleus (SO)	• oxytocin release • vasopressin release
		Paraventricular nucleus* (PV)	• oxytocin release • vasopressin release
		Anterior hypothalamic nucleus (AH)	• thermoregulation • panting • sweating

			• thyrotropin inhibition
		Suprachiasmatic nucleus (SC)	• vasopressin release • Circadian rhythms
	Lateral	Lateral preoptic nucleus	
		Lateral nucleus (LT)	• thirst and hunger
		Part of supraoptic nucleus (SO)	• vasopressin release
Tuberal	Medial	Dorsomedial hypothalamic nucleus (DM)	• GI stimulation
		Ventromedial nucleus (VM)	• satiety • neuroendocrine control
		Arcuate nucleus (AR)	• Lutenizing Hormone R.H. release • Follicle Stimulating Hormone Releasing Factor • feeding • Dopamine • GHRH
	Lateral	Lateral nucleus (LT)	• thirst and hunger
		Lateral tuberal nuclei	
Posterior	Medial	Mammillary nuclei (part of mammillary bodies) (MB)	• memory
		Posterior nucleus (PN)	• Increase blood pressure • pupillary dilation • shivering
	Lateral	Lateral nucleus (LT)	

- - Note: Paraventricular nucleus is *not* to be confused with periventricular nucleus.

Hypothalamic nuclei on one side of the hypothalamus, shown in a 3-D computer reconstruction:



Hypothalamic nuclei on one side of the hypothalamus, shown in a 3-D computer reconstruction

Outputs

The outputs of the hypothalamus can be divided into two categories: neural projections, and endocrine hormones.

Neural projections

Most fiber systems of the hypothalamus run in two ways (bidirectional).

- Projections to areas caudal to the hypothalamus go through the medial forebrain bundle, the mammillotegmental tract and the dorsal longitudinal fasciculus.
- Projections to areas rostral to the hypothalamus are carried by the mammillothalamic tract, the fornix and terminal stria.
- Projections to areas of the sympathetic motor system (lateral horn spinal segments T1-L2/L3 of the) are carried by the hypothalamospinal tract and they activate the sympathetic motor pathway

Endocrine hormones

The hypothalamus affects the endocrine system and governs emotional behavior, such as anger and sexual activity. Most of the hypothalamic hormones generated are distributed to the pituitary via the hypophyseal portal system. The hypothalamus maintains homeostasis; this includes a regulation of blood pressure, heart rate, and temperature.

Secreted hormone	Abbreviation	Produced by	Effect
Thyrotropin-releasing hormone (Prolactin-releasing hormone)	TRH, TRF, or PRH	Parvocellular neurosecretory neurons	Stimulate thyroid-stimulating hormone (TSH) release from anterior pituitary (primarily) Stimulate prolactin release from anterior pituitary
Dopamine (Prolactin-inhibiting hormone)	DA or PIH	Dopamine neurons of the arcuate nucleus	Inhibit prolactin release from anterior pituitary
Growth hormone-releasing hormone	GHRH	Neuroendocrine neurons of the Arcuate nucleus	Stimulate Growth hormone (GH) release from anterior pituitary
Somatostatin (growth hormone-inhibiting hormone)	SS, GHIH, or SRIF	Neuroendocrine cells of the Periventricular nucleus	Inhibit Growth hormone (GH) release from anterior pituitary Inhibit thyroid-stimulating hormone (TSH) release from anterior pituitary
Gonadotropin-releasing hormone	GnRH or LHRH	Neuroendocrine cells of the Preoptic area	Stimulate follicle-stimulating hormone (FSH) release from anterior pituitary Stimulate luteinizing hormone (LH) release from anterior pituitary
Corticotropin-releasing hormone	CRH or CRF	Parvocellular neurosecretory neurons	Stimulate adrenocorticotropic hormone (ACTH) release from anterior pituitary
Oxytocin		Magnocellular neurosecretory cells	Uterine contraction Lactation (letdown reflex)
Vasopressin (antidiuretic hormone)	ADH or AVP	Magnocellular neurosecretory neurons	Increase in the permeability to water of the cells of distal tubule and collecting duct in the kidney and thus allows water reabsorption and excretion of concentrated urine

Control of food intake

The extreme lateral part of the ventromedial nucleus of the hypothalamus is responsible for the control of food intake. Stimulation of this area causes increased food intake. Bilateral lesion of this area causes complete cessation of food intake. Medial parts of the nucleus have a controlling effect on the lateral part. Bilateral lesion of the medial part of the ventromedial nucleus causes hyperphagia and obesity of the animal. Further lesion of the lateral part of the ventromedial nucleus in the same animal produces complete cessation of food intake.

There are different hypotheses related to this regulation:

1. Lipostatic hypothesis - this hypothesis holds that adipose tissue produces a humoral signal that is proportionate to the amount of fat and acts on the hypothalamus to decrease food intake and increase energy output. It has been evident that a hormone leptin acts on the hypothalamus to decrease food intake and increase energy output.
2. Gutpeptide hypothesis - gastrointestinal hormones like Grp, glucagons, CCK and others claimed to inhibit food intake. The food entering the gastrointestinal tract triggers the release of these hormones which acts on the brain to produce satiety. The brain contains both CCK-A and CCK-B receptors.
3. Glucostatic hypothesis - the activity of the satiety center in the ventromedial nuclei is probably governed by the glucose utilization in the neurons. It has been postulated that when their glucose utilization is low and consequently when the arteriovenous blood glucose difference across them is low, the activity across the neurons decrease. Under these conditions, the activity of the feeding center is unchecked and the individual feels hungry. Food intake is rapidly increased by intraventricular administration of 2-deoxyglucose therefore decreasing glucose utilization in cells.
4. Thermostatic hypothesis - according to this hypothesis, a decrease in body temperature below a given set point stimulates appetite, while an increase above the set point inhibits appetite.

Sexual dimorphism

Several hypothalamic nuclei are sexually dimorphic, i.e. there are clear differences in both structure and function between males and females.

Some differences are apparent even in gross neuroanatomy: most notable is the sexually dimorphic nucleus within the preoptic area, which is present only in males. However most of the differences are subtle changes in the connectivity and chemical sensitivity of particular sets of neurons.

The importance of these changes can be recognised by functional differences between males and females. For instance, males of most species prefer the odor and appearance of females over males, which is instrumental in stimulating male sexual behavior. If the sexually dimorphic nucleus is lesioned, this preference for females by males diminishes. Also, the pattern of secretion of growth hormone is sexually dimorphic, and this is one reason why in many species, adult males are much larger than females.

Responses to ovarian steroids

Other striking functional dimorphisms are in the behavioral responses to ovarian steroids of the adult. Males and females respond differently to ovarian steroids, partly because the expression of estrogen-sensitive neurons in the hypothalamus is sexually dimorphic, i.e. estrogen receptors are expressed in different sets of neurons.

Estrogen and progesterone can influence gene expression in particular neurons or induce changes in cell membrane potential and kinase activation, leading to diverse non-genomic cellular functions. Estrogen and progesterone bind to their cognate nuclear hormone receptors, which translocate to the cell nucleus and interact with regions of DNA known as hormone response elements (HREs) or get tethered to another transcription factor's binding site. Estrogen receptor (ER) has been shown to transactivate other transcription factors in this manner, despite the absence of an estrogen response element (ERE) in the proximal promoter region of the gene. ERs and progesterone receptors (PRs) are generally gene activators, with increased mRNA and subsequent protein synthesis following hormone exposure.

Male and female brains differ in the distribution of estrogen receptors, and this difference is an irreversible consequence of neonatal steroid exposure. Estrogen receptors (and progesterone receptors) are found mainly in neurons in the anterior and mediobasal hypothalamus, notably:

- the preoptic area (where LHRH neurons are located)
- the periventricular nucleus (where somatostatin neurons are located)
- the ventromedial hypothalamus (which is important for sexual behavior).

Gonadal steroids in neonatal life of rats

In neonatal life, gonadal steroids influence the development of the neuroendocrine hypothalamus. For instance, they determine the ability of females to exhibit a normal reproductive cycle, and of males and females to display appropriate reproductive behaviors in adult life.

- If a *female rat* is injected once with testosterone in the first few days of postnatal life (during the "critical period" of sex-steroid influence), the hypothalamus is irreversibly masculinized; the adult rat will be incapable of generating an LH surge in response to estrogen (a characteristic of females), but will be capable of exhibiting *male* sexual behaviors (mounting a sexually receptive female).
- By contrast, a *male rat* castrated just after birth will be *feminized*, and the adult will show *female* sexual behavior in response to estrogen (sexual receptivity, lordosis behavior).

Androgens in primates

In primates, the developmental influence of androgens is less clear, and the consequences are less understood. Within the brain, testosterone is aromatized to (estradiol), which is the principal active hormone for developmental influences. The human testis secretes high levels of testosterone from about week 8 of fetal life until 5–6 months after birth (a similar perinatal surge in testosterone is observed in many species), a process that appears to underlie the male phenotype. Estrogen from the maternal circulation is relatively ineffective, partly because of the high circulating levels of steroid-binding proteins in pregnancy.

Human sexual orientation and the hypothalamus

According to D.F. Swaab, "Neurobiological research related to sexual orientation in humans is only just gathering momentum, but the evidence already shows that humans have a vast array of brain differences, not only in relation to gender, but also in relation to sexual orientation."

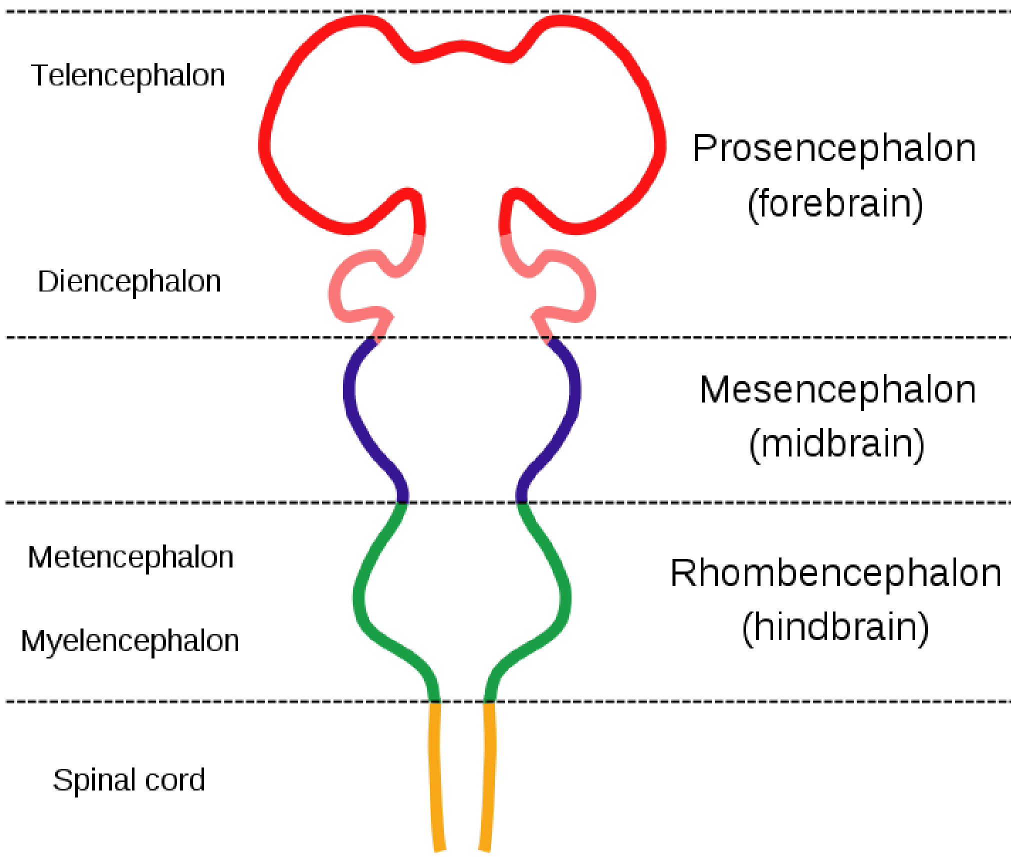
Swaab first reported on the relationship between sexual orientation in males and the hypothalamus's "clock", the suprachiasmatic nucleus (SCN). In 1990, Swaab and Hofman reported that the SCN of heterosexual men was significantly larger than in women, and the SCN of homosexual men was significantly larger than in heterosexual men. Then in 1995, Swaab et al. linked brain development to sexual orientation by treating male rats both pre- and postnatally with ATD, an aromatase blocker in the brain. This produced an enlarged SCN and bisexual behavior in the adult male rats. In 1991, LeVay showed that part of the sexually dimorphic nucleus (SDN), the interstitial nuclei of the anterior hypothalamus (INAH) 3, is twice as large in heterosexual men as homosexual men and heterosexual women, in terms of volume but not number of neurons.

In 2004 and 2006, two studies by Berglund, Lindström, and Savic used Positron Emission Tomography (PET) to observe how the hypothalamus responds to smelling common odors, the scent of testosterone found in male sweat, and the scent of estrogen found in female urine. These studies showed that the hypothalamus of heterosexual men and homosexual women both respond to estrogen. Also, the hypothalamus of homosexual men and heterosexual women both respond to testosterone. The hypothalamus of all four groups did not respond to the common odors, which produced a normal olfactory response in the brain.

Other influences upon hypothalamic development

Sex steroids are not the only important influences upon hypothalamic development; in particular, pre-pubertal stress in early life determines the capacity of the adult hypothalamus to respond to an acute stressor. Unlike gonadal steroid receptors, glucocorticoid receptors are very widespread throughout the brain; in the paraventricular nucleus, they mediate negative feedback control of CRF synthesis and secretion, but elsewhere their role is not well understood.

Cerebrum



The **cerebrum** or **telencephalon**, together with the diencephalon, constitute the forebrain. It is the most anterior or, especially in humans, most superior region of the vertebrate central nervous system. **Telencephalon** refers to the embryonic structure, from which the mature **cerebrum** develops. The dorsal telencephalon, or pallium, develops into the cerebral cortex, and the ventral telencephalon, or subpallium, becomes the basal ganglia. The cerebrum is also divided into symmetric left and right cerebral hemispheres.

With the assistance of the cerebellum, the cerebrum controls all voluntary actions in the body.

Development

During vertebrate embryonic development, the prosencephalon, the most anterior of three vesicles that form from the embryonic neural tube, is further subdivided into the telencephalon and diencephalon. The telencephalon then forms two lateral telencephalic vesicles which develop into the left and right cerebral hemisphere

Hemispheres

- left side controls right side of body
- right side controls left side of body

Structure

The cerebrum is composed of the following sub-regions:

- Cerebral cortex, or cortices of the cerebral hemispheres
- Basal ganglia, or basal nuclei
- Limbic System

Composition

Location of the human cerebrum (red)

The cerebrum comprises what most people think of as the "brain." It lies in front or on top of the brainstem and in humans is the largest and most well-developed of the five major divisions of the brain. The cerebrum is the newest structure in the phylogenetic sense, with mammals having the largest and most well-developed among all species. In larger mammals, the cerebral cortex is folded into many gyri and sulci, which has allowed the cortex to expand in surface area without taking up much greater volume.

In humans, the cerebrum surrounds older parts of the brain. Limbic, olfactory, and motor systems project fibers from the cerebrum to the brainstem and spinal cord. Cognitive and volitive systems project fibers from the cerebrum to the thalamus and to specific regions of the midbrain. The neural networks of the cerebrum facilitate complex behaviors such as social interactions, thought, judgement, learning, working memory, and in humans, speech and language.

Functions

Note: As the cerebrum is a gross division with many subdivisions and sub-regions, it is important to state that this section lists the functions that the cerebrum *as a whole* serves.

Movement

The cerebrum directs the conscious or volitional motor functions of the body. These functions originate within the primary motor cortex and other frontal lobe motor areas where actions are planned. Upper motor neurons in the primary motor cortex send their axons to the brainstem and spinal cord to synapse on the lower motor neurons, which innervate the muscles. Damage to motor areas of cortex can lead to certain types of motor neuron disease. This kind of damage results in loss of muscular power and precision rather than total paralysis.

Sensory processing

The primary sensory areas of the cerebral cortex receive and process visual, auditory, somatosensory, gustatory, and olfactory information. Together with association cortical areas, these brain regions synthesize sensory information into our perceptions of the world around us.

Olfaction

The olfactory bulb in most vertebrates is the most anterior portion of the cerebrum, and makes up a relatively large proportion of the telencephalon. However, in humans, this part of the brain is much smaller, and lies underneath the frontal lobe. The olfactory sensory system is unique in the sense that neurons in the olfactory bulb send their axons directly to the olfactory cortex, rather than to the thalamus first. Damage to the olfactory bulb results in a loss of the sense of smell.

Language and communication

Speech and language are mainly attributed to parts of the cerebral cortex. Motor portions of language are attributed to Broca's area within the frontal lobe. Speech comprehension is attributed to Wernicke's area, at the temporal-parietal lobe junction. These two regions are interconnected by a large white matter tract, the arcuate fasciculus. Damage to the Broca's area results in expressive aphasia (non-fluent aphasia) while damage to Wernicke's area results in receptive aphasia (also called fluent aphasia).

Learning and memory

Explicit or declarative (factual) memory formation is attributed to the hippocampus and associated regions of the medial temporal lobe. This association was originally described after a patient known as HM had both his hippocampuses (left and right) surgically removed to treat severe epilepsy. After surgery, HM had anterograde amnesia, or the inability to form new memories.

Implicit or procedural memory, such as complex motor behaviors, involve the basal ganglia.

Cell regeneration in Xenopus laevis

Larval stage

In a study of the telencephalon conducted in Hokkaido University on African clawed frogs (*Xenopus laevis*), it was discovered that, during larval stages, the telencephalon was able to regenerate around half of the anterior portion (otherwise known as **partially truncated**), after a reconstruction of a would-be accident, or malformation of features.

The regeneration and active proliferation of cells within the clawed frog is quite remarkable, regenerated cells being almost functionally identical to the ones originally found in the brain after birth, despite the lack of brain matter for a sustained period of time.

This kind of regeneration depends on ependymal layer cells covering the cerebral lateral ventricles, within a short period before, or within the initial stage of wound-healing. This is observed within the stages of healing within larvae of the clawed frog.

Developed stage

The regeneration within the developed stage of the clawed frog is different from that in the larval stage. Because the cells adhere to one another, they are unable to form an entity that can cover the cerebral lateral ventricles. Thus, the telencephalon remains truncated and the loss of function becomes permanent.

Effects of abnormality

After removing over half of the telencephalon in the developed stage of the clawed frog, the lack of functions within the animal was apparent, manifesting with obvious difficulties in movement, nonverbal communication between other species, as well as other difficulties thought to be similar to those seen in humans.

This kind of regeneration is still relatively unknown in regard to regeneration within larval stages, similar to the human fetal stage.

Variation among species

In the most primitive living vertebrates, the hagfishes and lampreys, the cerebrum is a relatively simple structure receiving nerve impulses from the olfactory bulb. In cartilaginous and lobe-finned fishes, and also in amphibians, a more complex structure is present, with the cerebrum being divided into three distinct regions. The lowermost (or ventral) region forms the basal nuclei, and contains fibres connecting the rest of the cerebrum to the thalamus. Above this, and forming the lateral part of the cerebrum, is the *paleopallium*, while the uppermost (or dorsal) part is referred to as the *archipallium*. The cerebrum remains largely devoted to olfactory sensation in these animals, despite its much wider range of functions in amniotes.

In ray-finned fishes, the structure is somewhat different. The inner surfaces of the lateral and ventral regions of the cerebrum bulge up into the ventricles; these include both the basal nuclei and the various parts of the pallium, and may be complex in structure, especially in teleosts. The dorsal surface of the cerebrum is membranous, and does not contain any nervous tissue.

In the amniotes, the cerebrum becomes increasingly large and complex. In reptiles, the paleopallium is much larger than in amphibians, and its growth has pushed the basal nuclei into the central regions of the cerebrum. As in the lower vertebrates, the grey matter is generally located beneath the white matter, but in some reptiles, it spreads out to the surface to form a primitive cortex, especially in the anterior part of the brain.

In mammals, this development proceeds further, so that the cortex covers almost the whole of the cerebral hemispheres, especially in more "advanced" species, such as primates. The paleopallium is pushed to the ventral surface of the brain, where it becomes the olfactory lobes, while the archipallium becomes rolled over at the medial dorsal edge to form the hippocampus. In placental mammals, a corpus callosum also develops, further connecting the two hemispheres. The complex convolutions of the cerebral surface are also found only in higher mammals.

The cerebrum of birds has evolved along different lines to that of mammals, although they are similarly enlarged, by comparison with reptiles. However, this enlargement is largely due to the basal ganglia, with the other areas remaining relatively primitive in structure. For example, there is no great expansion of the cerebral cortex, as there is in mammals. Instead, an HVC develops just above the basal ganglia, and this appears to be the area of the bird brain most concerned with learning complex tasks.

Chapter 5

Neural Pathway

A **neural pathway**, or **neural face**, connects one part of the nervous system with another and usually consists of bundles of elongated, myelin-insulated neurons, known collectively as white matter. Neural pathways serve to connect relatively distant areas of the brain or nervous system, compared to the local communication of grey matter.

Naming of neural pathways

The first named pathways are evident to the naked eye even in a poorly-preserved brain, and were named by the great anatomists of the Renaissance using cadaver material. Examples of these include the great *commissures* of the brain such as the corpus callosum (Latin, "hard body"; not to be confused with the Latin word "colossus" - the "huge" statue), *anterior commissure*, and *posterior commissure*. Further examples of this (by no means a complete list) include the pyramidal tract, crus cerebri (Latin, "leg of the brain"), and *cerebellar peduncles* (Latin, "little foot of the cerebellum"). Note that these names describe the *appearance* of a structure but give one no information on its function or location.

Later, as neuroanatomical knowledge became more sophisticated, the trend was toward naming pathways by their origin and termination. For example, the nigrostriatal pathway, which is degenerated in Parkinson's disease, runs from the substantia nigra (Latin, "black substance") to the corpus striatum (Latin, "striped body"). This naming can extend to include any number of structures in a pathway, such that the cerebellorubrothalamocortical pathway originates in the cerebellum, synapses in the red nucleus ("ruber" in Latin), on to the thalamus, and finally terminating in the cerebral cortex.

Sometimes, these two naming conventions coexist. For example, the name "pyramidal tract" has been mainly supplanted by lateral corticospinal tract in most texts. Note that the "old" name was primarily descriptive, evoking the pyramids of antiquity, from the appearance of this neural pathway in the medulla oblongata. The "new" name is based primarily on its origin (in the primary motor cortex, Brodmann area 4) and termination (onto the alpha motor neurons of the spinal cord).

Functional aspects

In general, neurons receive information either at their dendrites or cell bodies. The axon of a nerve cell is, in general, responsible for transmitting information over a relatively long distance. Therefore, most neural pathways are made up of axons. If the axons have myelin sheaths, then the pathway appears bright white because myelin is primarily lipid. If most or all of the axons lack myelin sheaths (i.e., are *unmyelinated*), then the pathway will appear a darker beige color, which is generally called *gray* (American English, or *grey* in British English).

Some neurons are responsible for conveying information over long distances. For example, motor neurons, which travel from the spinal cord to the muscle, can have axons up to a meter in length in humans; the longest axon in the human body is almost two meters long in tall individuals and runs from the great toe to the medulla oblongata of the brainstem. These are archetypical examples of neural pathways.

Major neural pathways

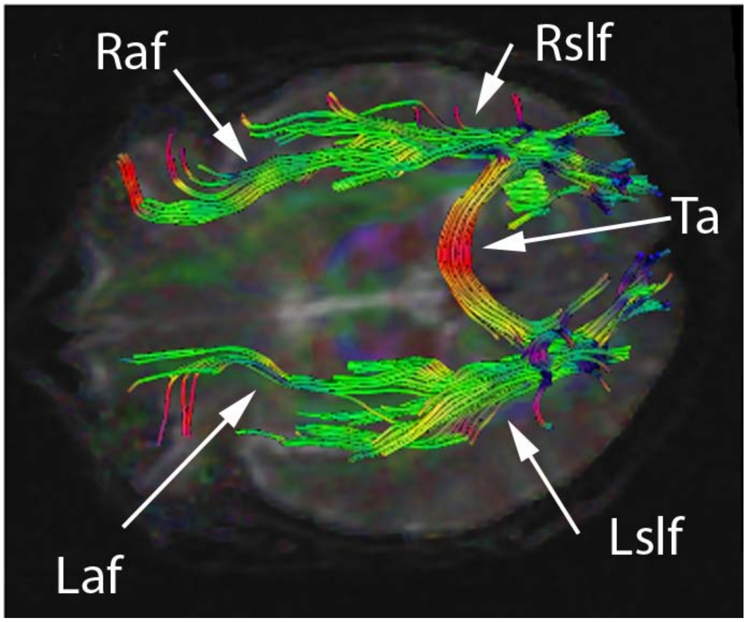
- arcuate fasciculus
- cerebral peduncle
- corpus callosum
- pyramidal or corticospinal tract

Dopamine pathways:

- mesocortical pathway
- mesolimbic pathway.
- nigrostriatal pathway
- tuberoinfundibular pathway

Arcuate fasciculus

Brain: Arcuate fasciculus



Diffusion tensor imaging image of the brain showing the right and left **arcuate fasciculus** (**Raf** & **Laf**). Also shown are the right and left superior longitudinal fasciculus (Rslf & Lslf), and tapetum of corpus callosum (Ta).

Latin	*fasciculus arcuatus*
NeuroNames	*ancil-540*

The **arcuate fasciculus** (Latin, *curved bundle*) is the neural pathway connecting the posterior part of the temporoparietal junction with the frontal cortex in the brain and is now considered as part of the superior longitudinal fasciculus.

Neuroanatomy

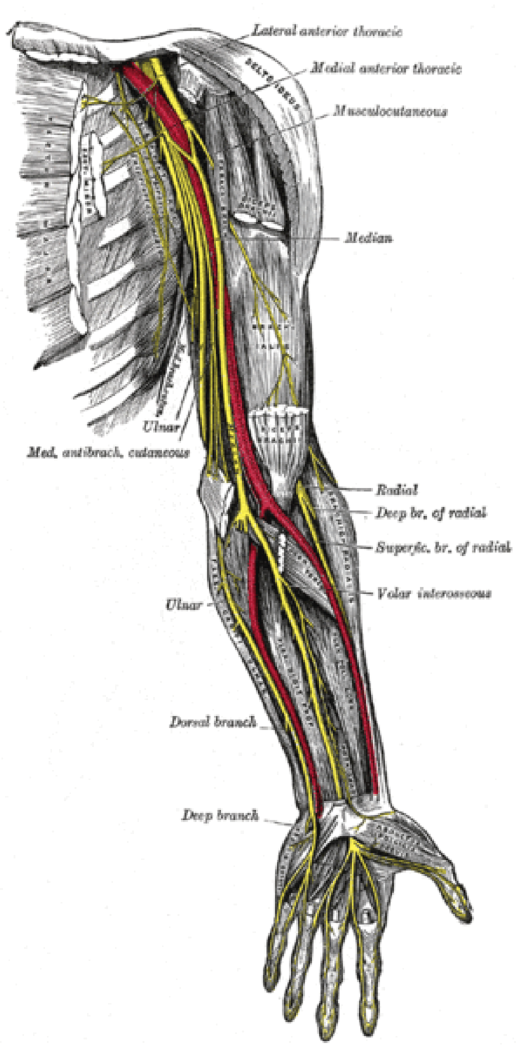
While previously thought to connect Wernicke's area and Broca's area, new research demonstrates that the arcuate fasciculus instead connects to posterior receptive areas with premotor/motor areas, and not to Broca's area.

The function of the arcuate fasciculus of the nondominant hemisphere is very little studied.

Pathology

Damage to this pathway can cause a form of aphasia known as conduction aphasia, where auditory comprehension and speech articulation are preserved, but people find it difficult to repeat heard speech.

Peripheral nerve



Nerves (yellow)

A **peripheral nerve**, or simply **nerve** is an enclosed, cable-like bundle of peripheral axons (the long, slender projections of neurons). A nerve provides a common pathway for the electrochemical nerve impulses that are transmitted along each of the axons. Nerves are found only in the peripheral nervous system. In the central nervous system, the analogous structures are known as tracts. Neurons are sometimes called *nerve cells*, though this term is potentially misleading since many neurons do not form nerves, and nerves also include non-neuronal Schwann cells that coat the axons in myelin.

Each nerve is a cordlike structure that contains many axons. These axons are often referred to as “fibres”. Within a nerve, each axon is surrounded by a layer of connective tissue called the endoneurium. The axons are bundled together into groups called fascicles, and each fascicle is wrapped in a layer of connective tissue called the perineurium. Finally, the entire nerve is wrapped in a layer of connective tissue called the epineurium.

Anatomy

Nerves are categorized into three groups based on the direction that signals are conducted:

- *Afferent nerves* conduct signals from sensory neurons to the central nervous system, for example from the mechanoreceptors in skin.
- *Efferent nerves* conduct signals from the central nervous system along motor neurons to their target muscles and glands.
- *Mixed nerves* contain both afferent and efferent axons, and thus conduct both incoming sensory information and outgoing muscle commands in the same bundle.

Nerves can be categorized into two groups based on where they connect to the central nervous system:

- *Spinal nerves* innervate much of the body, and connect through the spinal column to the spinal cord. They are given letter-number designations according to the vertebra through which they connect to the spinal column.
- *Cranial nerves* innervate parts of the head, and connect directly to the brainstem. They are typically assigned Roman numerals from 1 to 12, although cranial nerve zero is sometimes included. In addition, cranial nerves have descriptive names.

Each nerve is covered externally by a dense sheath of connective tissue, the epineurium. Underlying this is a layer of flat cells, the perineurium, which forms a complete sleeve around a bundle of axons. Perineurial septae extend into the nerve and subdivide it into several bundles of fibres. Surrounding each such fibre is the endoneurium. This forms an unbroken tube which extends from the surface of the spinal cord to the level at which the axon synapses with its muscle fibers, or ends in sensory receptors. The endoneurium consists of an inner sleeve of material called the glycocalyx and an outer, delicate, meshwork of collagen fibres. Nerves are bundled along with blood vessels, since the neurons of a nerve have fairly high energy requirements. Within the endoneurium, the individual nerve fibres are surrounded by a low protein liquid called endoneurial fluid. The endoneurium has properties analogous to the blood-brain barrier, in that it prevents certain molecules from crossing from the blood into the endoneurial fluid. In this respect, endoneurial fluid is similar to cerebro-spinal fluid in the central nervous system. During the development of nerve edema from nerve irritation or (injury), the amount of endoneurial fluid may increase at the site of irritation. This increase in fluid can be visualized using magnetic resonance neurography, and thus MR neurography can identify nerve irritation and/or injury.

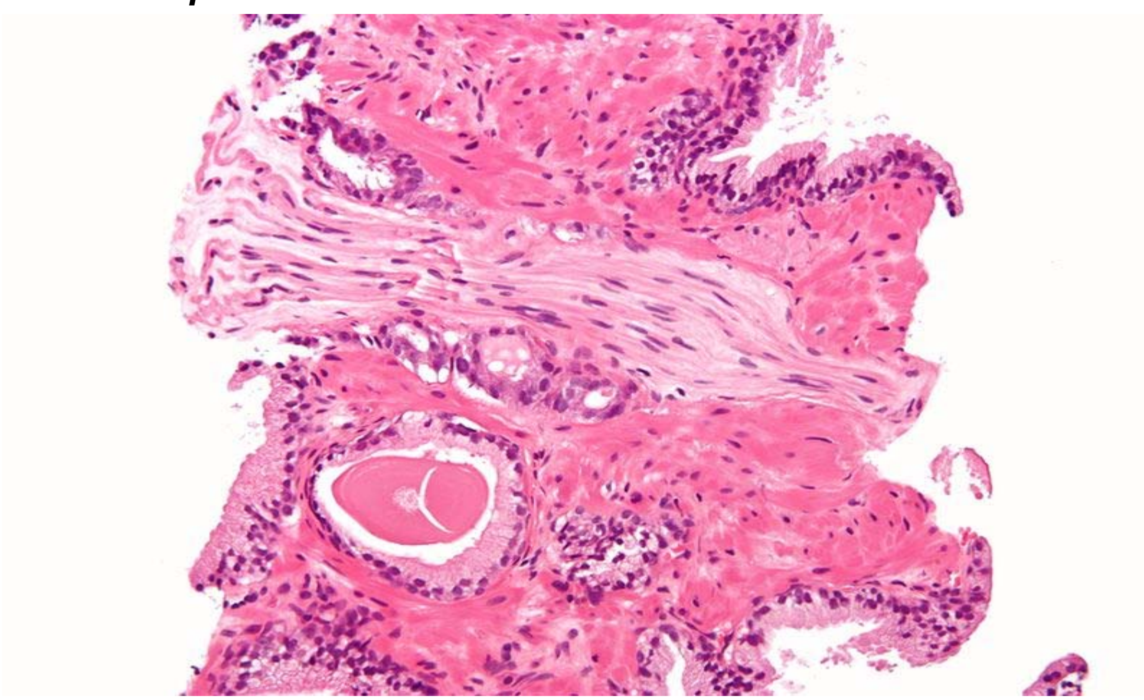
Physiology

A nerve conveys information in the form of electrochemical impulses (known as nerve impulses or action potentials) carried by the individual neurons that make up the nerve. These impulses are extremely fast, with some myelinated neurons conducting at speeds up to 120 m/s. The impulses travel from one neuron to another by crossing a synapse, the message is converted from electrical to chemical and then back to electrical.

Nerves can be categorized into two groups based on function:

- *Sensory nerves* conduct sensory information from their receptors to the central nervous system, where the information is then processed. Thus they are synonymous with *afferent nerves*.
- *Motor nerves* conduct signals from the central nervous system to muscles. Thus they are synonymous with *efferent nerves*.

Clinical importance



Micrograph demonstrating perineural spread of prostate cancer. H&E stain.

Damage to nerves can be caused by physical injury or swelling (e.g. carpal tunnel syndrome), autoimmune diseases (e.g. Guillain-Barré syndrome), infection (neuritis), diabetes or failure of the blood vessels surrounding the nerve. A *pinched nerve* occurs when pressure is placed on a nerve, usually from swelling due to an injury or pregnancy. Nerve damage or pinched nerves are usually accompanied by pain, numbness, weakness, or paralysis. Patients may feel these symptoms in areas far from the actual site of damage, a phenomenon called **referred pain**. Referred pain occurs because when a nerve is damaged, signalling is defective from all parts of the area from which the nerve receives input, not just the site of the damage. Neurologists usually diagnose disorders of the nerves by a physical examination, including the testing of reflexes, walking and other directed movements, muscle weakness, proprioception, and the sense of touch. This initial exam can be followed with tests such as nerve conduction study and electromyography (EMG).

Cancer

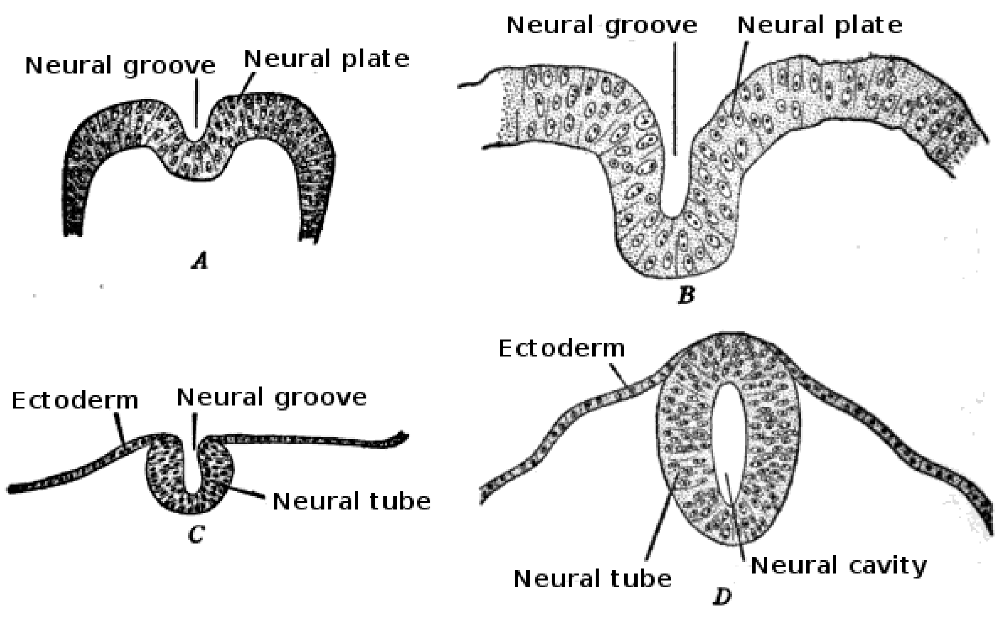
Cancer can spread along nerves; this is known as *perineural spread* and often is associated with a worse prognosis.

Chapter 6

Central Nervous System

The **central nervous system** (**CNS**) is the part of the nervous system that integrates the information that it receives from, and coordinates the activity of, all parts of the bodies of bilaterian animals—that is, all multicellular animals except sponges and radially symmetric animals such as jellyfish. It contains the majority of the nervous system and consists of the brain and the spinal cord. Some classifications also include the retina and the cranial nerves in the CNS. Together with the peripheral nervous system, it has a fundamental role in the control of behavior. The CNS is contained within the dorsal cavity, with the brain in the cranial cavity and the spinal cord in the spinal cavity. In vertebrates, the brain is protected by the skull, while the spinal cord is protected by the vertebrae, and both are enclosed in the meninges.

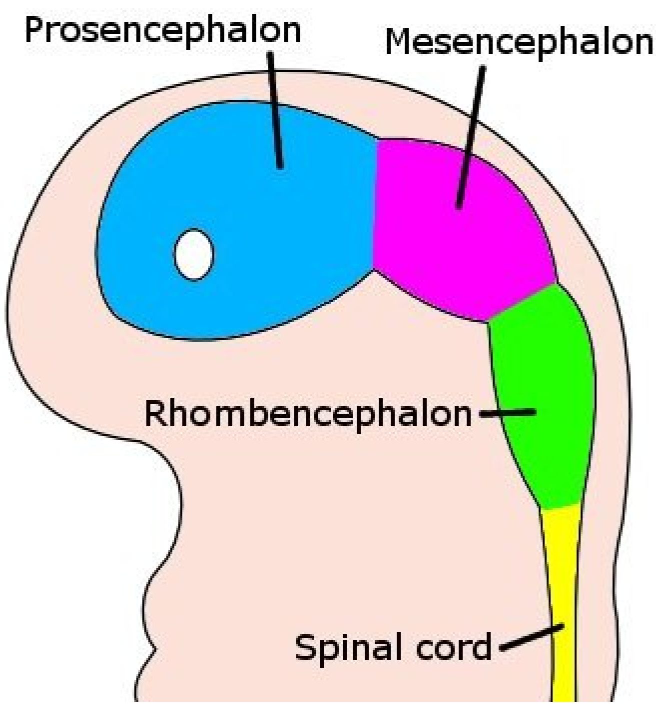
Development



Development of the neural tube

During early development of the vertebrate embryo, a longitudinal groove on the neural plate gradually deepens as ridges on either side of the groove (the neural folds) become elevated, and ultimately meet, transforming the groove into a closed tube, the ectodermal wall of which forms the rudiment of the nervous system. This tube initially differentiates into three vesicles (pockets): the prosencephalon at the front, the mesencephalon, and, between the mesencephalon and the spinal cord, the rhombencephalon. (By six weeks in the human embryo) the prosencephalon then divides further into the telencephalon and diencephalon; and the rhombencephalon divides into the metencephalon and myelencephalon.

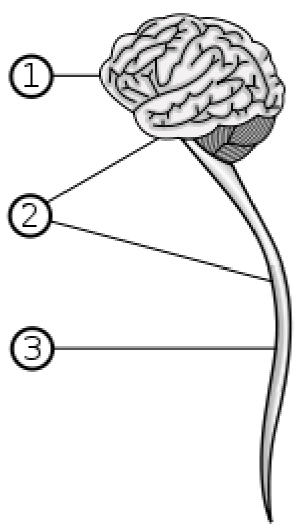
As the vertebrate grows, these vesicles differentiate further still. The telencephalon differentiates into, among other things, the striatum, the hippocampus and the neocortex, and its cavity becomes the first and second ventricles. Diencephalon elaborations include the subthalamus, hypothalamus, thalamus and epithalamus, and its cavity forms the third ventricle. The tectum, pretectum, cerebral peduncle and other structures develop out of the mesencephalon, and its cavity grows into the mesencephalic duct (cerebral aqueduct). The metencephalon becomes, among other things, the pons and the cerebellum, the myelencephalon forms the medulla oblongata, and their cavities develop into the fourth ventricle.



Brain regions of a 4 week old human embryo

<table>
<tr><td rowspan="6">Central nervous system</td><td rowspan="5">Brain</td><td rowspan="2">Prosencephalon</td><td>Telencephalon</td><td colspan="2">Rhinencephalon, Amygdala, Hippocampus, Neocortex, Basal ganglia, Lateral ventricles</td></tr>
<tr><td>Diencephalon</td><td colspan="2">Epithalamus, Thalamus, Hypothalamus, Subthalamus, Pituitary gland, Pineal gland, Third ventricle</td></tr>
<tr><td rowspan="3">Brain stem</td><td>Mesencephalon</td><td colspan="2">Tectum, Cerebral peduncle, Pretectum, Mesencephalic duct</td></tr>
<tr><td rowspan="2">Rhombencephalon</td><td>Metencephalon</td><td>Pons, Cerebellum</td></tr>
<tr><td>Myelencephalon</td><td>Medulla oblongata</td></tr>
<tr><td colspan="5">Spinal cord</td></tr>
</table>

Evolution



The central nervous system (2) is a combination of the brain (1) and the spinal cord (3)

Planarians, members of the phylum Platyhelminthes (flatworms), have the simplest, clearly defined delineation of a nervous system into a central nervous system (CNS) and a peripheral nervous system (PNS). Their primitive brain, consisting of two fused anterior ganglia, and longitudinal nerve cords form the CNS; the laterally projecting nerves form the PNS. A molecular study found that more than 95% of the 116 genes involved in the nervous system of planarians, which includes genes related to the CNS, also exist in humans. Like planarians, vertebrates have a distinct CNS and PNS, though more complex than those of planarians.

The basic pattern of the CNS is highly conserved throughout the different species of vertebrates and during evolution. The major trend that can be observed is towards a progressive telencephalisation: the telencephalon of reptiles is only an appendix to the large olfactory bulb, while in mammals it makes up most of the volume of the CNS. In the human brain, the telencephalon covers most of the diencephalon and the mesencephalon. Indeed, the allometric study of brain size among different species shows a striking continuity from rats to whales, and allows us to complete the knowledge about the evolution of the CNS obtained through cranial endocasts.

Mammals – which appear in the fossil record after the first fishes, amphibians, and reptiles – are the only vertebrates to possess the evolutionarily recent, outermost part of the cerebral cortex known as the neocortex. The neocortex of monotremes (the duck-billed platypus and several species of spiny anteaters) and of marsupials (such as kangaroos, koalas, opossums, wombats, and Tasmanian devils) lack the convolutions - gyri and sulci - found in the neocortex of most placental mammals (eutherians). Within placental mammals, the size and complexity of the neocortex increased over time. The area of the neocortex of mice is only about 1/100 that of monkeys, and that of monkeys is only about 1/10 that of humans. In addition, rats lack convolutions in their neocortex (possibly also because rats are small mammals), whereas cats have a moderate degree of convolutions, and humans have quite extensive convolutions.

Diseases of the central nervous system

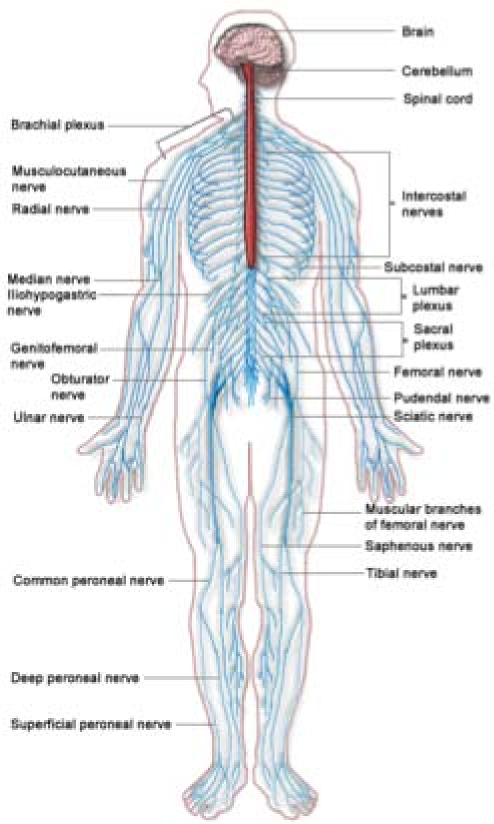
There are many central nervous system diseases, including infections of the central nervous system such as encephalitis and poliomyelitis, neurodegenerative diseases such as Alzheimer's disease and amyotrophic lateral sclerosis, autoimmune and inflammatory diseases such as multiple sclerosis or acute disseminated encephalomyelitis, and genetic disorders such as Krabbe's disease, Huntington's disease, or adrenoleukodystrophy. Lastly, cancers of the central nervous system can cause severe illness and, when malignant, can have very high mortality rates.

Chapter 7

Peripheral Nervous System and Somatic Nervous System

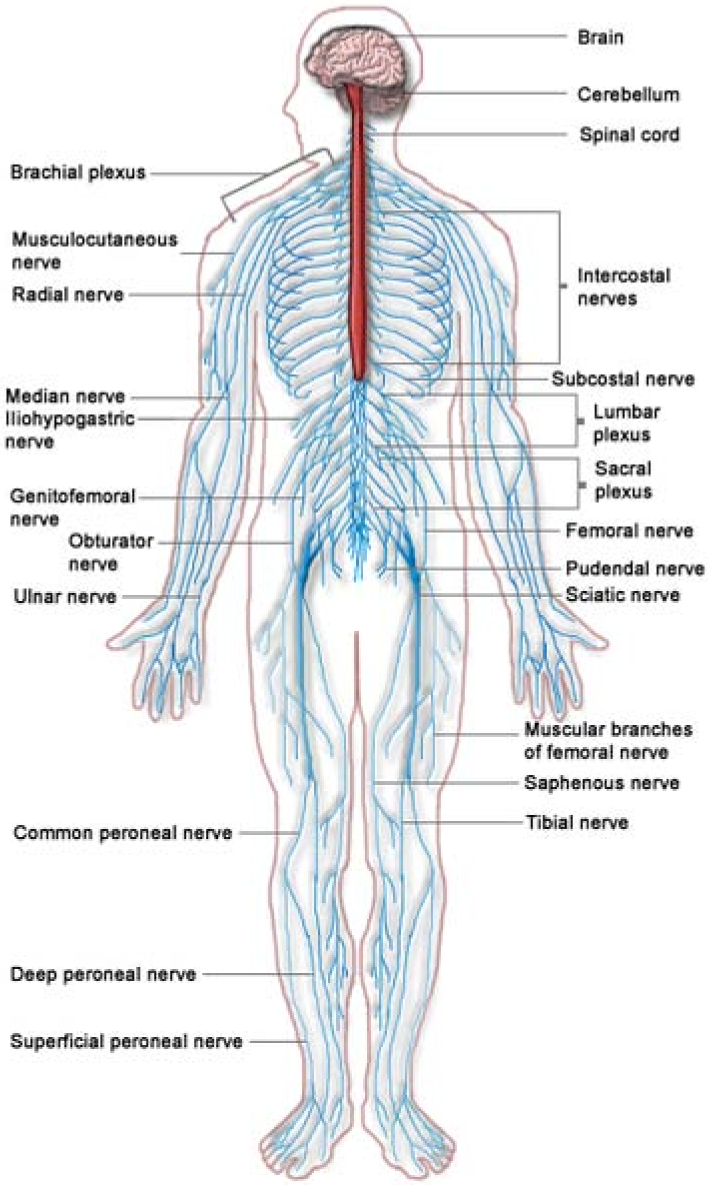
Peripheral nervous system

Brain: Peripheral nervous system



The Human Nervous System. Blue is PNS while red is CNS.

Latin *Pars peripherica; Systema nervosum periphericum*



The **peripheral nervous system**, or PNS, consists of the nerves and ganglia outside of the brain and spinal cord. The main function of the PNS is to connect the central nervous system (CNS) to the limbs and organs. Unlike the CNS, the PNS is not protected by the bone of spine and skull, or by the blood–brain barrier, leaving it exposed to toxins and mechanical injuries. The peripheral nervous system is divided into the somatic nervous system and the autonomic nervous system; some textbooks also include sensory systems.

The cranial nerves are part of the PNS.

General classification

By direction

There are two types of neurons, carrying nerve impulses in different directions. These two groups of neurons are:

- The sensory neurons are afferent neurons which relay nerve impulses toward the central nervous system.
- The motor neurons are efferent neurons which relay nerve impulses away from the central nervous system.

By function

The peripheral nervous system is functionally as well as structurally divided into the somatic nervous system and autonomic nervous system. The somatic nervous system is responsible for coordinating the body movements, and also for receiving external stimuli. It is the system that regulates activities that are under conscious control. The autonomic nervous system is then split into the sympathetic division, parasympathetic division, and enteric division. The *sympathetic nervous system* responds to impending danger, and is responsible for the increase of one's heartbeat and blood pressure, among other physiological changes, along with the sense of excitement one feels due to the increase of adrenaline in the system. ("fight or flight" responses). The *parasympathetic nervous system*, on the other hand, is evident when a person is resting and feels relaxed, and is responsible for such things as the constriction of the pupil, the slowing of the heart, the dilation of the blood vessels, and the stimulation of the digestive and genitourinary systems. ("rest and digest" responses). The role of the *enteric nervous system* is to manage every aspect of digestion, from the esophagus to the stomach, small intestine and colon.

Specific nerves and plexi

Ten out of the twelve cranial nerves originate from the brainstem, and mainly control the functions of the anatomic structures of the head with some exceptions. The nuclei of cranial nerves I and II lie in the forebrain and thalamus, respectively, and are thus not considered to be true cranial nerves. CN X (10) receives visceral sensory information from the thorax and abdomen, and CN XI (11) is responsible for innervating the sternocleidomastoid and trapezius muscles, neither of which is exclusively in the head.

Spinal nerves take their origins from the spinal cord. They control the functions of the rest of the body. In humans, there are 31 pairs of spinal nerves: 8 cervical, 12 thoracic, 5 lumbar, 5 sacral and 1 coccygeal. In the cervical region, the spinal nerve roots come out *above* the corresponding vertebrae (i.e. nerve root between the skull and 1st cervical vertebrae is called spinal nerve C1). From the thoracic region to the coccygeal region, the spinal nerve roots come out *below* the corresponding vertebrae. It is important to note that this method creates a problem when naming the spinal nerve root between C7 and T1 (so it is called spinal nerve root C8). In the lumbar and sacral region, the spinal nerve roots for travel within the dural sac and they travel below the level of L2 as the cauda equina.

Cervical spinal nerves (C1–C4)

The first 4 cervical spinal nerves, C1 through C4, split and recombine to produce a variety of nerves that subserve the neck and back of head.

Spinal nerve C1 is called the suboccipital nerve which provides motor innervation to muscles at the base of the skull. C2 and C3 form many of the nerves of the neck, providing both sensory and motor control. These include the greater occipital nerve which provides sensation to the back of the head, the lesser occipital nerve which provides sensation to the area behind the ears, the greater auricular nerve and the lesser auricular nerve. The phrenic nerve arises from nerve roots C3, C4 and C5. It innervates the diaphragm, enabling breathing. If the spinal cord is transected above C3, then spontaneous breathing is not possible.

Brachial plexus (C5-T1)

The last four cervical spinal nerves, C5 through C8, and the first thoracic spinal nerve, T1,combine to form the brachial plexus, or plexus brachialis, a tangled array of nerves, splitting, combining and recombining, to form the nerves that subserve the arm and upper back. Although the brachial plexus may appear tangled, it is highly organized and predictable, with little variation between people.

Neurotransmitters

The main neurotransmitters of the peripheral nervous system are acetylcholine and noradrenaline. However, there are several other neurotransmitters as well, jointly labeled Non-noradrenergic, non-cholinergic (NANC) transmitters. Examples of such transmitters include non-peptides: ATP, GABA, dopamine, NO, and peptides: neuropeptide Y, VIP, GnRH, Substance P and CGRP.

Somatic nervous system

The **somatic nervous system** (SNS) is the part of the peripheral nervous system associated with the voluntary control of body movements via skeletal muscles, and with sensory reception of external stimuli (e.g., touch, hearing, and sight). The SNS consists of efferent nerves responsible for stimulating muscle contraction, including all the neurons connected with skeletal muscles, skin, and sense organs.

Nerve signal transmission

The somatic nervous system processes sensory information and controls all voluntary muscular systems within the body, with the exception of reflex arcs.

The basic route of nerve signals within the efferent somatic nervous system involves a sequence that begins in the upper cell bodies of motor neurons (upper motor neurons) within the precentral gyrus (which approximates the primary motor cortex). Stimuli from the precentral gyrus are transmitted from upper motor neurons and down the corticospinal tract, via axons to control skeletal (voluntary) muscles. These stimuli are conveyed from upper motor neurons through the ventral horn of the spinal cord, and across synapses to be received by the sensory receptors of alpha motor neurons (large lower motor neurons) of the brainstem and spinal cord.

Upper motor neurons release a neurotransmitter, acetylcholine, from their axon terminal knobs, which are received by nicotinic receptors of the alpha motor neurons. In turn, alpha motor neurons relay the stimuli received down their axons via the ventral root of the spinal cord. These signals then proceed to the neuromuscular junctions of skeletal muscles.

From there, acetylcholine is released from the axon terminal knobs of alpha motor neurons and received by postsynaptic receptors (Nicotinic acetylcholine receptors) of muscles, thereby relaying the stimulus to contract muscle fibers.

Vertebrate and invertebrate differences

In invertebrates, depending on the neurotransmitter released and the type of receptor it binds, the response in the muscle fiber could either be excitatory or inhibitory. For vertebrates, however, the response of a muscle fiber to a neurotransmitter (always acetylcholine (ACh)) can only be excitatory.

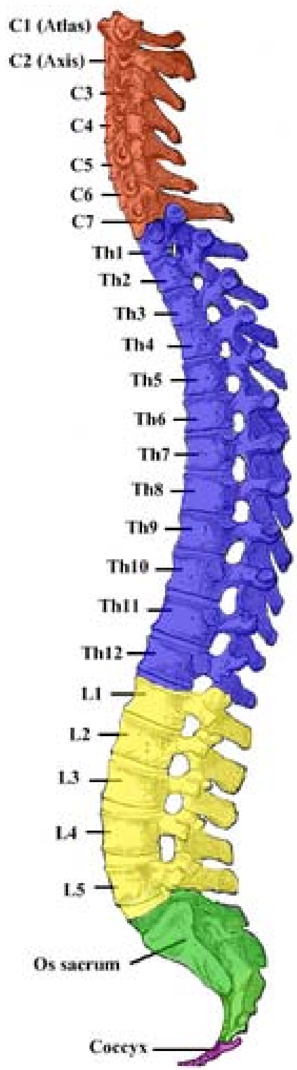
Reflex arcs

A reflex arc is a neural circuit that creates a more or less automatic link between a sensory input and a specific motor output. Reflex circuits vary in complexity—the simplest spinal reflexes are mediated by a three-element chain, beginning with sensory neurons which activate interneurons in the spinal cord, which then activate motor neurons. Some reflex responses, such as withdrawing the hand after touching a hot surface, are protective, but others, such as the patellar reflex "knee jerk" activated by tapping the patellar tendon, contribute to ordinary behavior.

Chapter 8

Vertebral Column

Divisions of Spinal Segments



Segmental Spinal Cord Level and Function	
Level	**Function**

C1-C6	Neck flexors
C1-T1	Neck extensors
C3, C4, C5	Supply diaphragm (mostly C4)
C5, C6	Shoulder movement, raise arm (deltoid); flexion of elbow (biceps); **C6** externally rotates the arm (supinates)
C6, C7	Extends elbow and wrist (triceps and wrist extensors); pronates wrist
C7, T1	Flexes wrist
C7, T1	Supply small muscles of the hand
T1 -T6	Intercostals and trunk above the waist
T7-L1	Abdominal muscles
L1, L2, L3, L4	Thigh flexion
L2, L3, L4	Thigh adduction
L4, L5, S1	Thigh abduction
L5, S1, S2	Extension of leg at the hip (gluteus maximus)
L2, L3, L4	Extension of leg at the knee (quadriceps femoris)
L4, L5, S1, S2	Flexion of leg at the knee (hamstrings)
L4, L5, S1	Dorsiflexion of foot (tibialis anterior)
L4, L5, S1	Extension of toes
L5, S1, S2	Plantar flexion of foot
L5, S1, S2	Flexion of toes

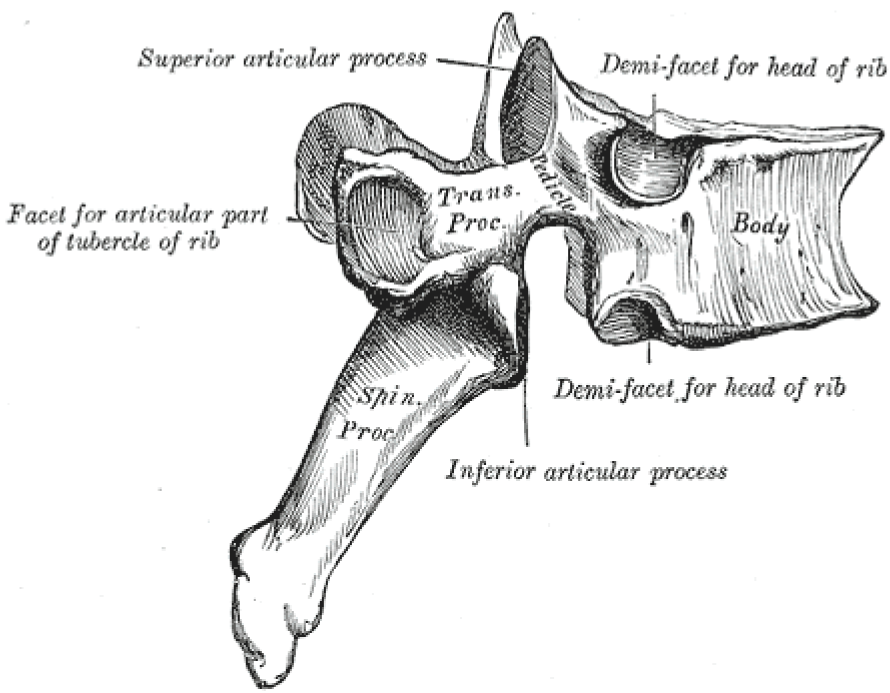
In human anatomy, the **vertebral column** (Latin − *Columna vertebralis*) (**backbone** or **spine**) is a column usually consisting of 24 articulating **vertebrae**, and 9 fused vertebrae in the sacrum and the coccyx. It is situated in the dorsal aspect of the torso, separated by intervertebral discs. It houses and protects the spinal cord in its spinal canal.

In humans

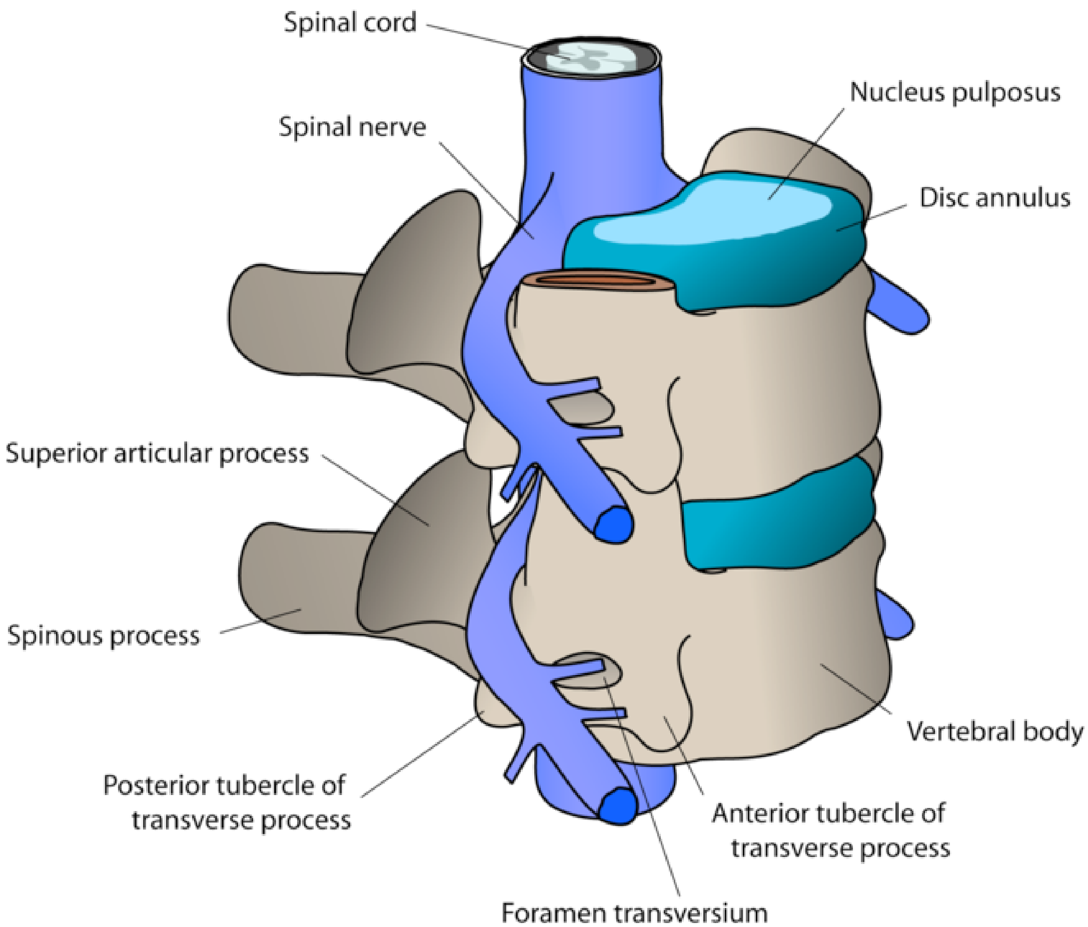
There are normally thirty-three (33) vertebrae in humans, including the five that are fused to form the sacrum (the others are separated by intervertebral discs) and the four coccygeal bones that form the *tailbone*. The upper three regions comprise the remaining 24, and are grouped under the names *cervical* (7 vertebrae), *thoracic* (12 vertebrae) and *lumbar* (5 vertebrae), according to the regions they occupy. This number is sometimes increased by an additional vertebra in one region, or it may be diminished in one region, the deficiency often being supplied by an additional vertebra in another. The number of cervical vertebrae is, however, very rarely increased or diminished.

With the exception of the first and second cervical, the true or movable vertebrae (the upper three regions) present certain common characteristics that are best studied by examining one from the middle of the thoracic region.

Structure of individual vertebrae



A diagram of a human thoracic vertebra. Notice the articulations for the ribs



Oblique view of cervical vertebrae

A typical vertebra consists of two essential parts: an anterior (front) segment, which is the vertebral body; and a posterior part – the vertebral (neural) arch – which encloses the vertebral foramen. The vertebral arch is formed by a pair of pedicles and a pair of laminae, and supports seven processes, four articular, two transverse, and one spinous, the latter also being known as the neural spine.

When the vertebrae are articulated with each other, the bodies form a strong pillar for the support of the head and trunk, and the vertebral foramina constitute a canal for the protection of the *medulla spinalis* (spinal cord). In between every pair of vertebrae are two apertures, the intervertebral foramina, one on either side, for the transmission of the spinal nerves and vessels.

Two transverse processes and one spinous process are posterior to (behind) the vertebral body. The spinous process comes out the back, one transverse process comes out the left, and one on the right. The spinous processes of the cervical and lumbar regions can be felt through the skin.

Superior and inferior articular facets on each vertebra act to restrict the range of movement possible. These facets are joined by a thin portion of the neural arch called the *pars interarticularis*.

Curves

Viewed laterally the vertebral column presents several curves, which correspond to the different regions of the column, and are called cervical, thoracic, lumbar, and pelvic.

The cervical curve, convex forward, begins at the apex of the odontoid (*tooth-like*) process, and ends at the middle of the second thoracic vertebra; it is the least marked of all the curves.

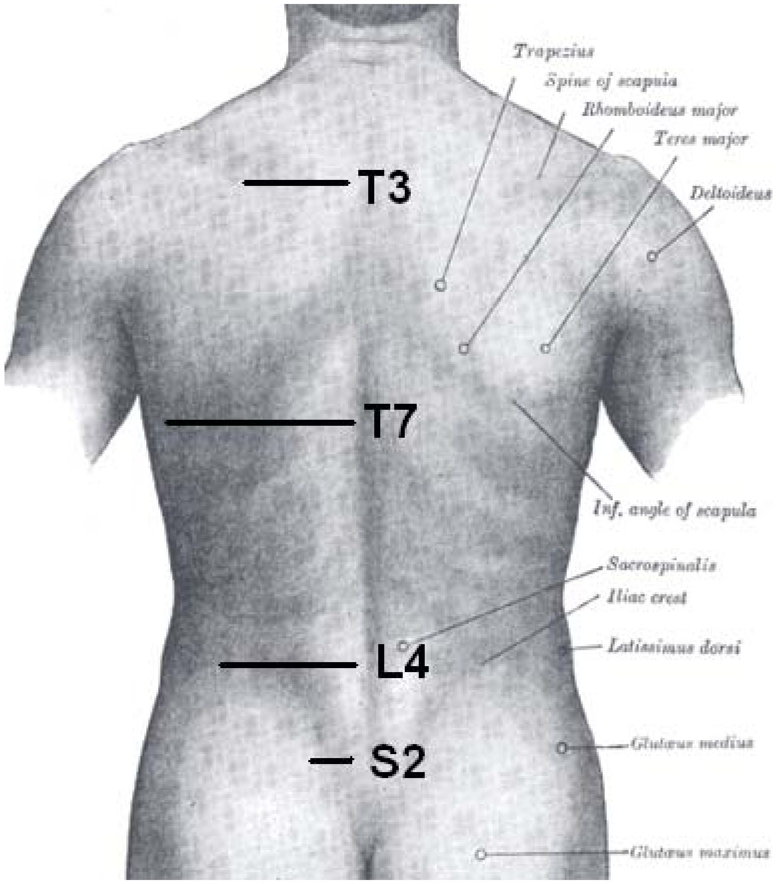
The thoracic curve, concave forward, begins at the middle of the second and ends at the middle of the twelfth thoracic vertebra. Its most prominent point behind corresponds to the spinous process of the seventh thoracic vertebra. This curve is known as a *tt curve.*

The lumbar curve is more marked in the female than in the male; it begins at the middle of the last thoracic vertebra, and ends at the sacrovertebral angle. It is convex anteriorly, the convexity of the lower three vertebrae being much greater than that of the upper two. This curve is described as a *lordotic curve*.

The pelvic curve begins at the sacrovertebral articulation, and ends at the point of the coccyx; its concavity is directed downward and forward.

The thoracic and pelvic curves are termed **primary curves**, because they alone are present during fetal life. The cervical and lumbar curves are *compensatory* or *secondary*, and are developed after birth, the former when the child is able to hold up its head (at three or four months) and to sit upright (at nine months), the latter at twelve or eighteen months, when the child begins to walk.

Regions



Orientation of vertebral column on surface. T3 is at level of medial part of spine of scapula. T7 is at inferior angle of the scapula. L4 is at highest point of iliac crest. S2 is at the level of posterior superior iliac spine. Furthermore, C7 is easily localized as a prominence at the lower part of the neck.

There are a total of 33 vertebrae in the vertebral column, if assuming 4 coccygeal vertebrae.

The individual vertebrae, named according to region and position, from superior to inferior, are:

- Cervical: 7 vertebrae (C1–C7)
- Thoracic: 12 vertebrae (T1–T12)
- Lumbar: 5 vertebrae (L1–L5)
- Sacral: 5 (fused) vertebrae (S1–S5)
- Coccygeal: 4 (3–5) (fused) vertebrae (Tailbone)

Cervical

There are seven (7) cervical bones (but 8 cervical spinal nerves) and these bones are, in general, small and delicate. Their spinous processes are short (with the exception of C2 and C7, which have palpable spinous processes). Numbered top-to-bottom from C1-C7, atlas (C1) and axis (C2), are the vertebrae that allow the neck and head so much movement. For the most part, the atlanto-occipital joint allows the skull to move up and down, while the atlanto-axial joint allows the upper neck to twist left and right. The axis also sits upon the first intervertebral disk of the spinal column. All mammals except manatees and sloths have seven cervical vertebrae, whatever the length of the neck.

Cervical vertebrae possess transverse foramina to allow for the vertebral arteries to pass through on their way to the foramen magnum to end in the circle of Willis. These are the smallest, lightest vertebrae and the vertebral foramina are triangular in shape. The spinous processes are short and often bifurcated (the spinous process of C7, however, is not bifurcated, and is substantially longer than that of the other cervical spinous processes).

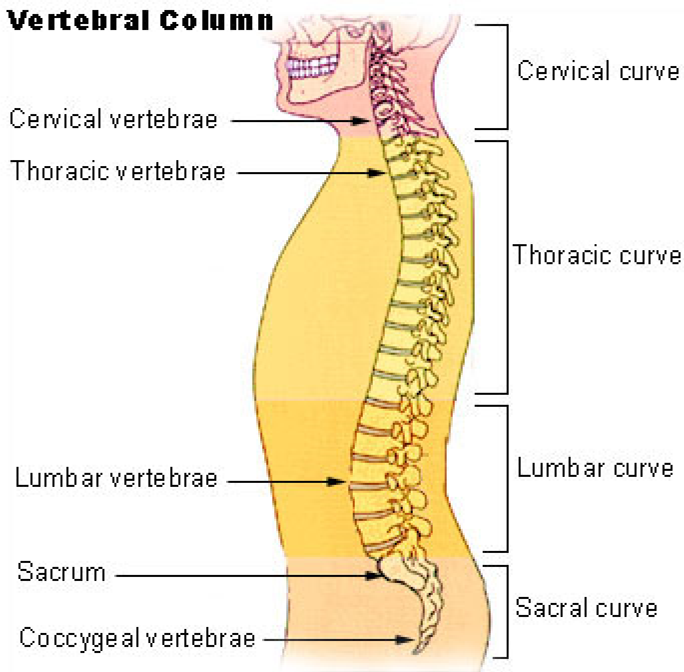
Thoracic

The twelve (12) thoracic bones and their transverse processes have surfaces that articulate with the ribs. Some rotation can occur between the thoracic vertebrae, but their connection with the rib cage prevents much *flexion* or other excursion. They may also be known as 'dorsal vertebrae', in the human context.

Bodies are roughly heart-shaped and are about as wide anterio-posterioly as they are in the transverse dimension. Vertebral foramina are roughly circular in shape.

Lumbar

These five (5) vertebrae are very robust in construction, as they must support more weight than other vertebrae. They allow significant *flexion* and *extension*, moderate lateral flexion (sidebending), and a small degree of rotation. The discs between these vertebrae create a lumbar lordosis (curvature that is concave posteriorly) in the human spine.



Sacral

There are five (5) vertebrae (S1-S5) and they are fused in maturity, with no intervertebral discs.

Coccygeal

There are usually four (4) and rarely 3-5 vertebrae (Co1-Co5), with no intervertebral discs. Many animals have a greater number of "tail vertebrae," and, in animals, they are more commonly known as "caudal vertebrae." Pain at the coccyx (tailbone) is known as coccydynia.

Development

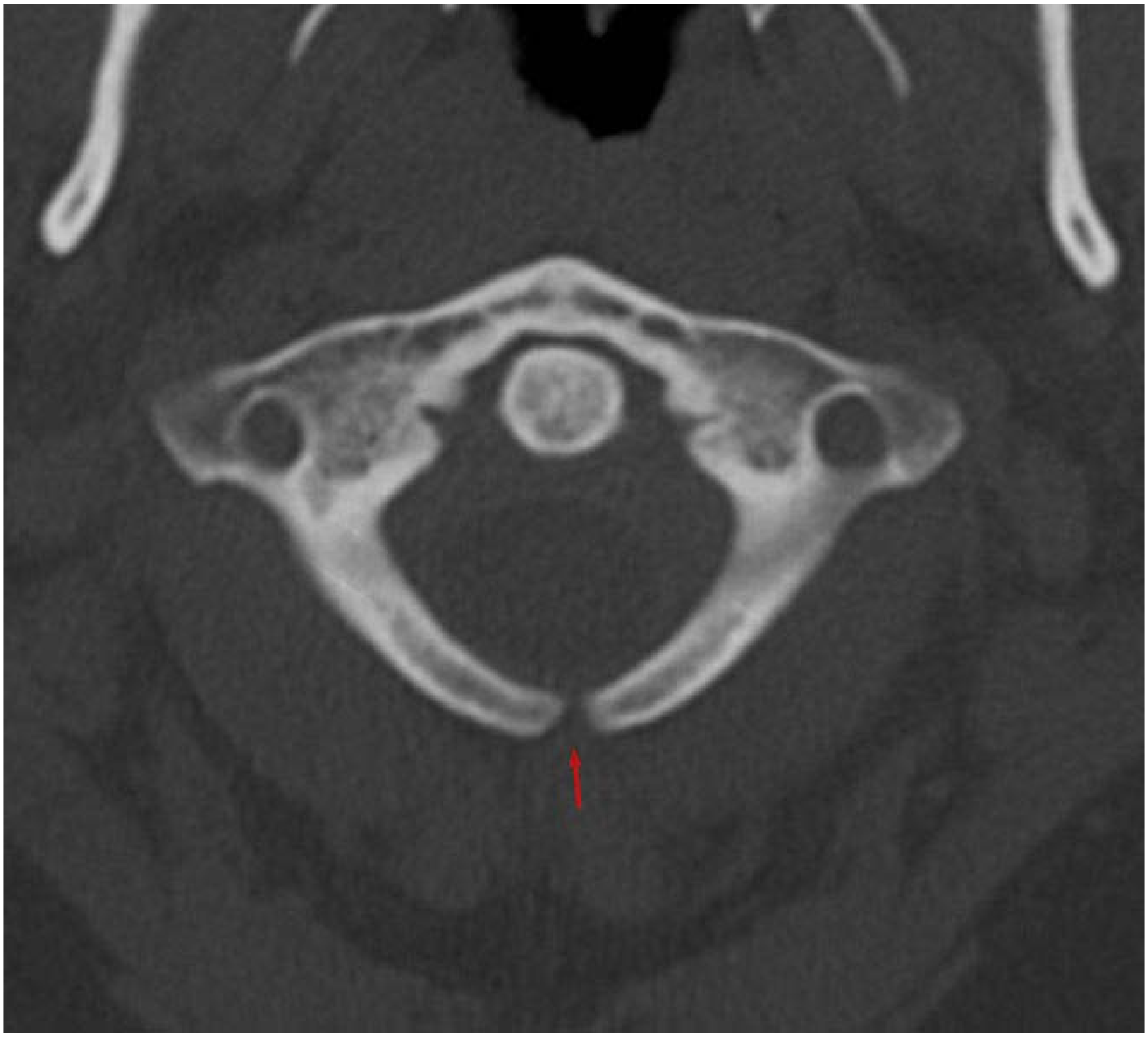
The striking segmented pattern of the human spine is established during embryogenesis when the precursor of the vertebrae, the somites, are rhythmically added to the forming posterior part of the embryo. In humans, somite formation begins around the third week post-fertilization and continues until a total of around 52 somites are formed. The somites are epithelial spheres that contain the precursors of the vertebrae, the ribs, the skeletal muscles of the body wall and limbs, and the dermis of the back. The periodicity of somite distribution and production is thought to be imposed by a molecular oscillator or clock acting in cells of the presomitic mesoderm (PSM). Somites form soon after the beginning of gastrulation, on both sides of the neural tube from a tissue called the presomitic mesoderm (PSM). The PSM is part of the paraxial mesoderm and is generated caudally by gastrulation when cells ingress through the primitive streak, and later, through the tail bud. Soon after their formation, somites become subdivided into the dermomyotome dorsally, which gives rise to the muscles and dermis, and the sclerotome ventrally, which will form the spine components. Sclerotomes become subvidided into an anterior and a posterior compartment. This subdivision plays a key role in the definitive patterning of vertebrae that form when the posterior part of one somite fuses to the anterior part of the consecutive somite during a process termed resegmentation. Disruption of the somitogenesis process in humans results in diseases such as congenital scoliosis. So far, the human homologues of three genes associated to the mouse segmentation clock (MESP2, DLL3 and LFNG) have been shown to be mutated in human patients with human congenital scoliosis suggesting that the mechanisms involved in vertebral segmentation are conserved across vertebrates. In humans the first four somites are incorporated in the basi-occipital bone of the skull and the next 33 somites will form the vertebrae. The remaining posterior somites degenerate. During the fourth week of embryonic development, the sclerotomes shift their position to surround the spinal cord and the notochord. The sclerotome is made of mesoderm and originates from the ventromedial part of the somites. This column of tissue has a segmented appearance, with alternating areas of dense and less dense areas.

As the sclerotome develops, it condenses further eventually developing into the vertebral body. Development of the appropriate shapes of the vertebral bodies is regulated by *HOX genes*.

The less dense tissue that separates the sclerotome segments develop into the intervertebral discs.

The notochord disappears in the sclerotome (vertebral body) segments, but persists in the region of the intervertebral discs as the nucleus pulposus. The nucleus pulposus and the fibers of the annulus fibrosus make up the intervertebral disc.

The primary curves (thoracic and sacral curvatures) form during fetal development. The secondary curves develop after birth. The cervical curvature forms as a result of lifting the head and the lumbar curvature forms as a result of walking.

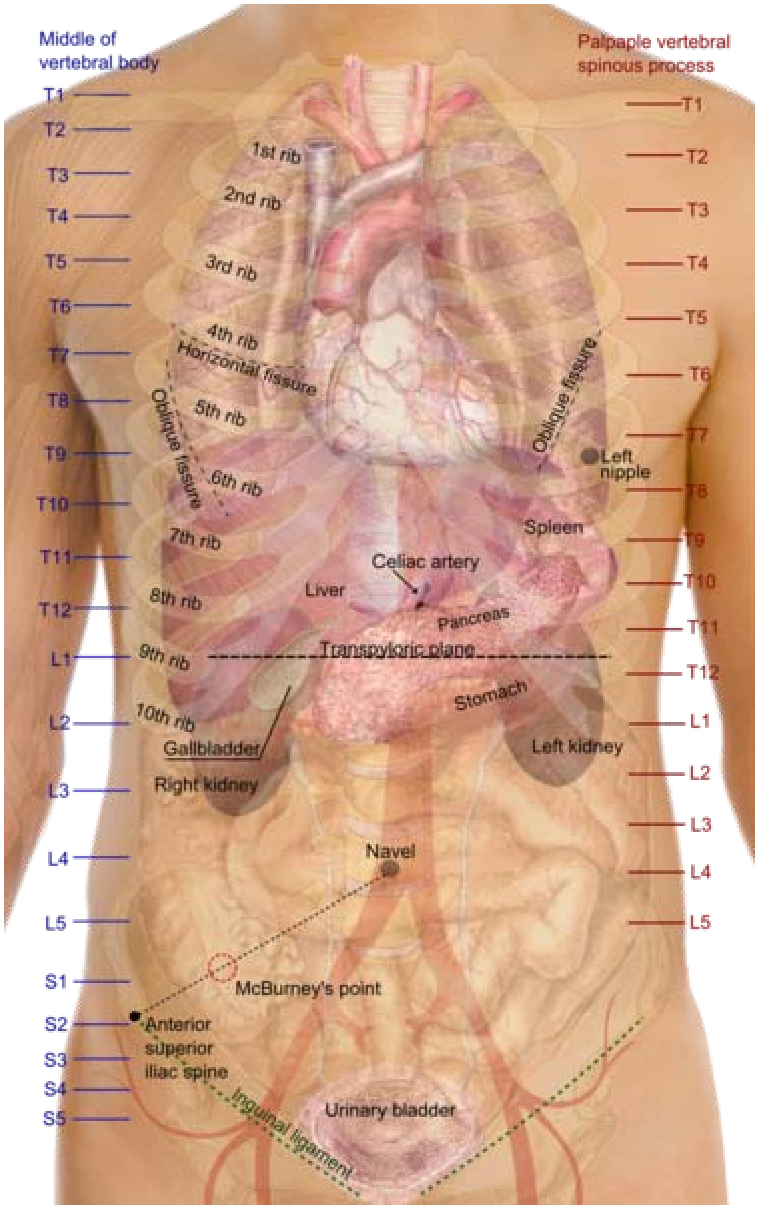


Unfused arch of C1 at CT

There are various defects associated with vertebral development. Scoliosis will result in improper fusion of the vertebrae. In Klippel-Feil anomaly patients have two or more cervical vertebrae that are fused together, along with other associated birth defects. One of the most serious defects is failure of the vertebral arches to fuse. This results in a condition called spina bifida. There are several variations of spina bifida that reflect the severity of the defect.

Surfaces

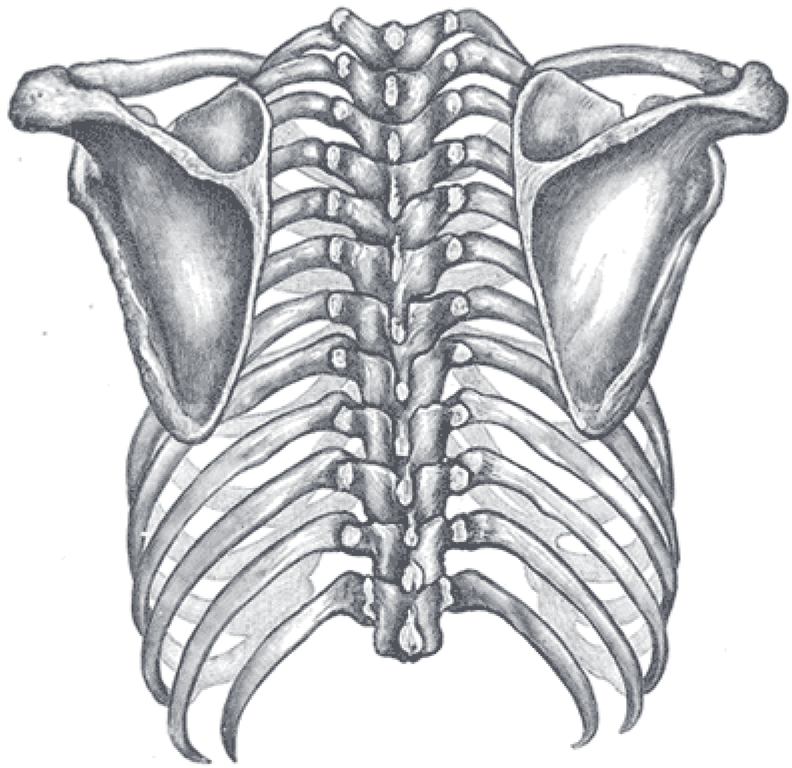
Anterior surface



The vertebrae may be used as vertical reference points to describe the locations of the organs of the trunk, such as with the transpyloric line (seen at body of L1). If not else specified, it is usually the middle of the vertebral body that is used as reference, although the palpable spinous processes may be located considerably lower.

When viewed from in front, the width of the bodies of the vertebrae is seen to increase from the second cervical to the first thoracic; there is then a slight diminution in the next three vertebrae; below this there is again a gradual and progressive increase in width as low as the sacrovertebral angle. From this point there is a rapid diminution, to the apex of the coccyx.

Posterior surface



Orientation of the rib cage on the vertebral column

The posterior surface of the vertebral column presents in the median line the spinous processes. In the cervical region (with the exception of the second and seventh vertebrae) these are short and horizontal, with bifid extremities. In the upper part of the thoracic region they are directed obliquely downward; in the middle they are almost vertical, and in the lower part they are nearly horizontal. In the lumbar region they are nearly horizontal. The spinous processes are separated by considerable intervals in the lumbar region, by narrower intervals in the neck, and are closely approximated in the middle of the thoracic region. Occasionally one of these processes deviates a little from the median line — a fact to be remembered in practice, as irregularities of this sort are attendant also on fractures or displacements of the vertebral column. On either side of the spinous processes is the vertebral groove formed by the laminae in the cervical and lumbar regions, where it is shallow, and by the laminae and transverse processes in the thoracic region, where it is deep and broad; these grooves lodge the deep muscles of the back. Lateral to the vertebral grooves are the articular processes, and still more laterally the transverse processes. In the thoracic region, the transverse processes stand backward, on a plane considerably behind that of the same processes in the cervical and lumbar regions. In the cervical region, the transverse processes are placed in front of the articular processes, lateral to the pedicles and between the intervertebral foramina. In the thoracic region they are posterior to the pedicles, intervertebral foramina, and articular processes. In the lumbar region they are in front of the articular processes, but behind the intervertebral foramina.

Lateral surfaces

The lateral surfaces are separated from the posterior surface by the articular processes in the cervical and lumbar regions, and by the transverse processes in the thoracic region. They present, in back, the sides of the bodies of the vertebrae, marked in the thoracic region by the facets for articulation with the heads of the ribs. More posteriorly are the intervertebral foramina, formed by the juxtaposition of the vertebral notches, oval in shape, smallest in the cervical and upper part of the thoracic regions, and gradually increasing in size to the last lumbar. They transmit the special spinal nerves and are situated between the transverse processes in the cervical region, and in front of them in the thoracic and lumbar regions.

Vertebral canal

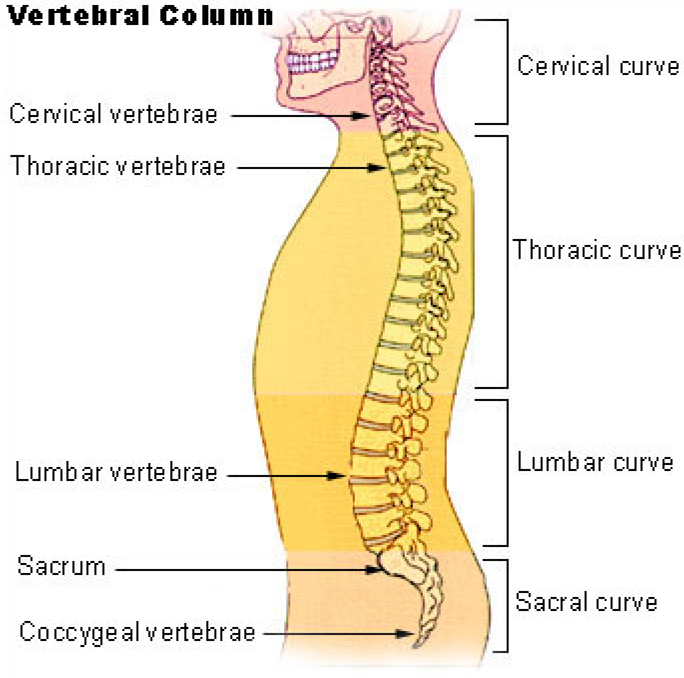
The vertebral canal follows the different curves of the column; it is large and triangular in those parts of the column which enjoy the greatest freedom of movement, such as the cervical and lumbar regions; and is small and rounded in the thoracic region, where motion is more limited.

Abnormalities

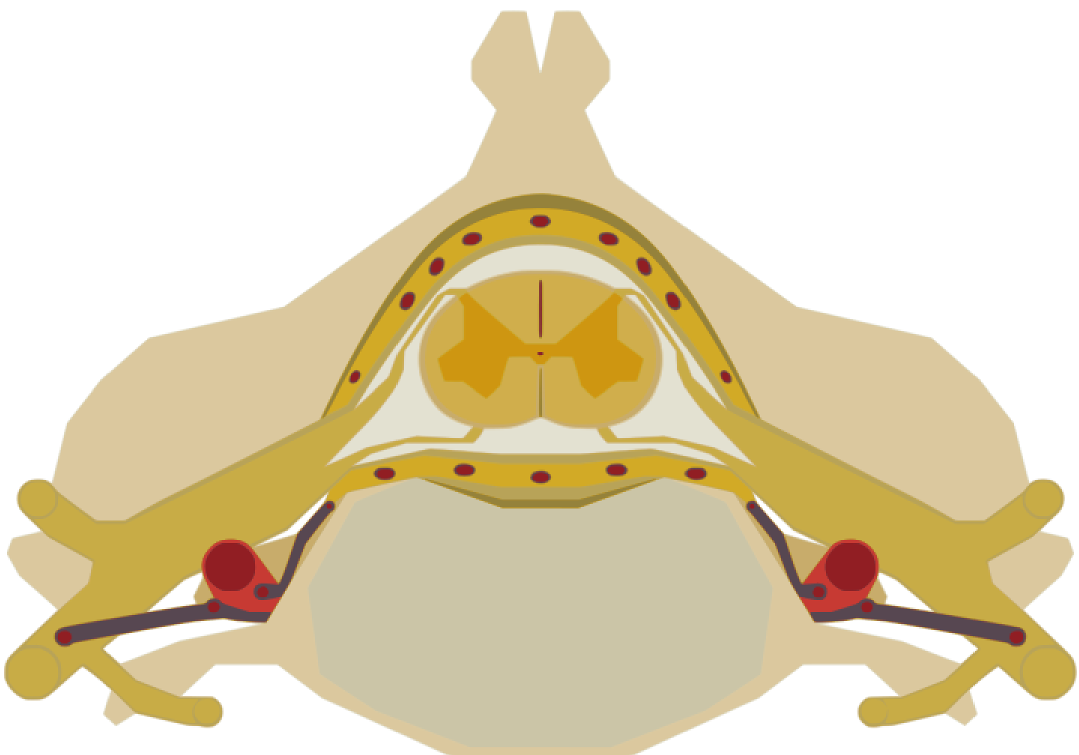
Occasionally the coalescence of the laminae is not completed, and consequently a cleft is left in the arches of the vertebrae, through which a protrusion of the spinal membranes (*dura mater* and arachnoid), and generally of the spinal cord (*medulla spinalis*) itself, takes place, constituting the malformation known as *spina bifida*. This condition is most common in the lumbosacral region, but it may occur in the thoracic or cervical region, or the arches throughout the whole length of the canal may remain incomplete.

The following abnormal curvatures may occur in some people:

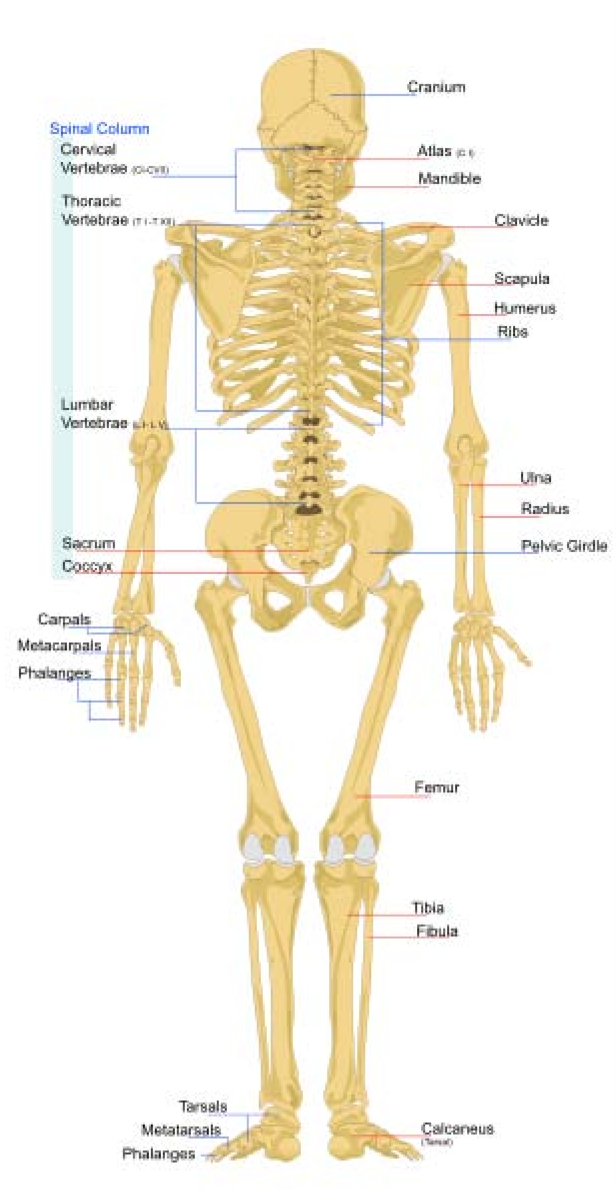
- Kyphosis is an exaggerated kyphotic (posterior) curvature in the thoracic region. This produces the so-called "humpback" or "dowager's hump", a condition commonly observed in osteoporosis.
- Lordosis is an exaggerated lordotic (anterior) curvature of the lumbar region, "swayback". Temporary lordosis is common among pregnant women.
- Retrolisthesis is a posterior displacement of one vertebral body with respect to the adjacent vertebral segment to a degree less than a luxation (dislocation).
- Scoliosis, lateral curvature, is the most common abnormal curvature, occurring in 0.5% of the population. It is more common among females and may result from unequal growth of the two sides of one or more vertebrae. It can also be caused by pulmonary atelectasis (partial or complete deflation of one or more lobes of the lungs) as observed in asthma or pneumothorax.



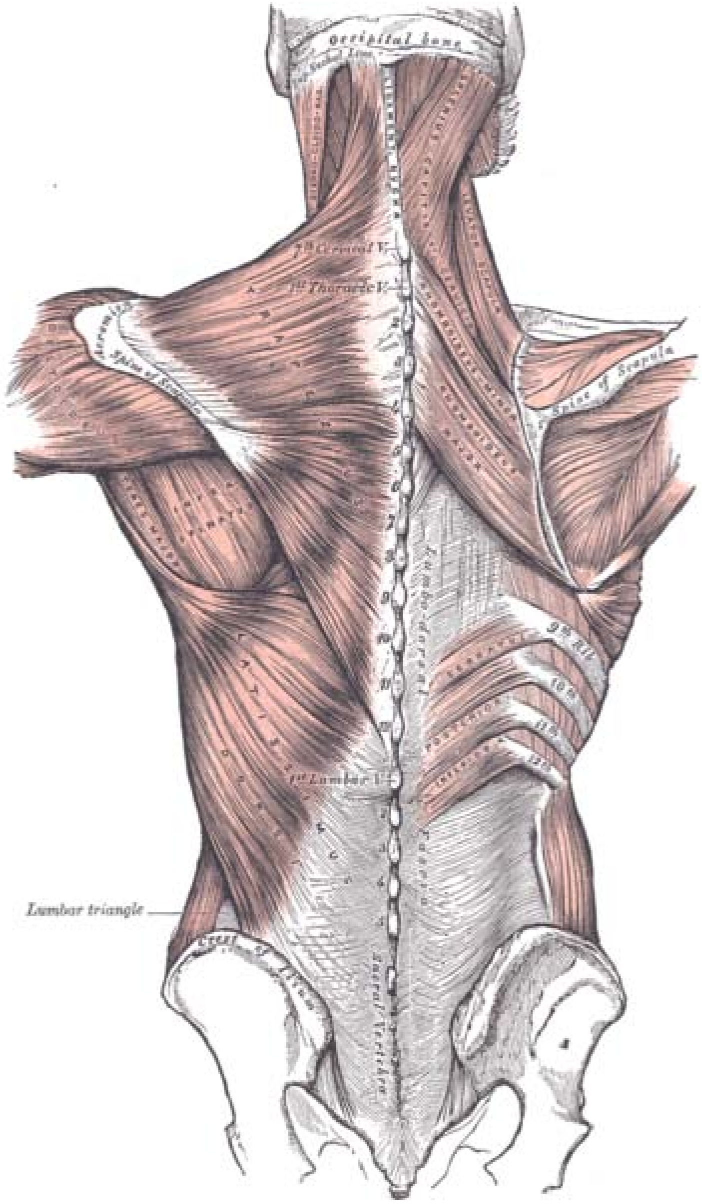
Vertebral column



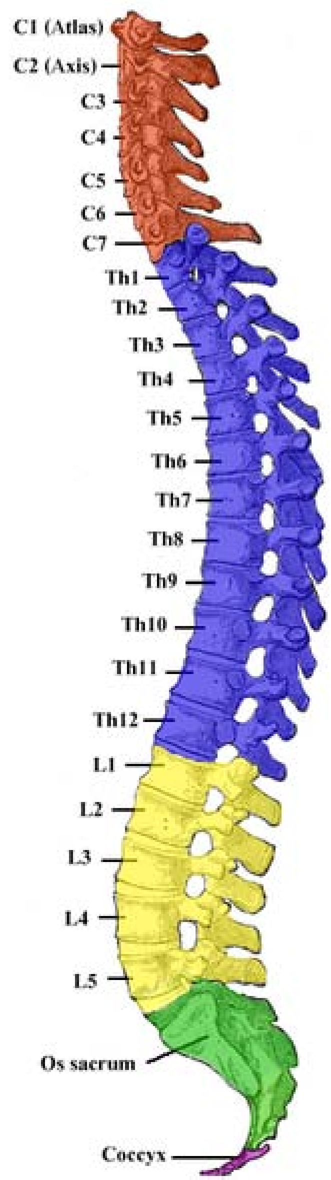
The spinal cord nested in the vertebral column



Human skeleton back



Relation of the vertebral column to the surrounding muscles



Vertebral column

In other animals

In all animals, vertebrae are defined by the regions of the vertebral column they occur in. Cervical vertebrae are those in the neck area. With exception of two sloth species (*Choleopus* and *Bradypus*) and the manatee (*Trichechus*), all mammals have seven cervical vertebrae. In other vertebrates it can range from a single vertebra in amphibians, to as many as 25 in swans or 76 in the extinct plesiosaur *Elasmosaurus*. The dorsal vertebrae range from the bottom of the neck to the top of the pelvis. Dorsal vertebrae attached to ribs are called thoracic vertebrae, while those without ribs are called lumbar vertebrae. The sacral vertebrae are those in the pelvic region, and range from one in amphibians, to two in most birds and modern reptiles, or up to 3 to 5 in mammals. When multiple sacral vertebrae are fused into a single structure, it is called the sacrum. The synsacrum is a similar fused structure found in birds that is composed of the sacral, lumbar, and some of the thoracic and caudal vertebra, as well as the pelvic girdle. Caudal vertebrae compose the tail, and the final few can be fused into the pygostyle in birds, or into the coccygeal or tail bone in chimpanzees (and humans).

Structure of individual vertebrae

Individual vertebrae are composed of a centrum (body), arches protruding from the top and bottom of the centrum, and various processes projecting from the centrum and/or arches. An arch extending from the top of the centrum is called a neural arch, while the hemal arch or chevron is found underneath the centrum in the caudal (tail) vertebrae of fish, most reptiles, some birds, and some mammals with long tails. The vertebral processes can either give the structure rigidity, help them articulate with ribs, or serve as muscle attachment points. Common types are transverse process, diapophyses, parapophyses, and zygapophyses (both the cranial zygapophyses and the caudal zygapophyses).

Classification

The centra of the vertebra can be classified based upon the fusion of its elements. In aspidospondyly, bones such as the neural spine, the pleurocentrum and the intercentrum are separate ossifications. Fused elements, however, classify a vertebra as having holospondyly.

A vertebra can also be described in terms of the shape of the ends of the centra. Centra with flat ends are *acoelous*, like those in mammals. These flat ends of the centra are especially good at supporting and distributing compressive forces. *Amphicoelous* vertebra have centra with both ends concave. This shape is common in fish, where most motion is limited. Amphicoelous centra often are integrated with a full notochord. *Procoelous* vertebrae are anteriorly concave and posteriorly convex. They are found in frogs and modern reptiles. *Opisthocoelous* vertebrae are the opposite, possessing anterior convexity and posterior concavity. They are found in salamanders. *Heterocoelous* vertebrae have saddle-shaped articular surfaces. This type of configuration is seen in turtles that retract their necks, and birds, because it permits extensive lateral and vertical flexion motion without stretching the nerve cord too extensively or wringing it about its long axis.

Fish and amphibians

The vertebrae of lobe-finned fishes consist of three discrete bony elements. The vertebral arch surrounds the spinal cord, and is of broadly similar form to that found in most other vertebrates. Just beneath the arch lies a small plate-like **pleurocentrum**, which protects the upper surface of the notochord, and below that, a larger arch-shaped **intercentrum** to protect the lower border. Both of these structures are embedded within a single cylindrical mass of cartilage. A similar arrangement was found in the primitive Labyrinthodonts, but in the evolutionary line that led to reptiles (and hence, also to mammals and birds), the intercentrum became partially or wholly replaced by an enlarged pleurocentrum, which in turn became the bony vertebral body.

In most ray-finned fishes, including all teleosts, these two structures are fused with, and embedded within, a solid piece of bone superficially resembling the vertebral body of mammals. In living amphibians, there is simply a cylindrical piece of bone below the vertebral arch, with no trace of the separate elements present in the early tetrapods.

In cartilagenous fish, such as sharks, the vertebrae consist of two cartilagenous tubes. The upper tube is formed from the vertebral arches, but also includes additional cartilagenous structures filling in the gaps between the vertebrae, and so enclosing the spinal cord in an essentially continuous sheath. The lower tube surrounds the notochord, and has a complex structure, often including multiple layers of calcification.

Lampreys have vertebral arches, but nothing resembling the vertebral bodies found in all higher vertebrates. Even the arches are discontinuous, consisting of separate pieces of arch-shaped cartilage around the spinal cord in most parts of the body, changing to long strips of cartilage above and below in the tail region. Hagfishes lack a true vertebral column, and are therefore not properly considered vertebrates, but a few tiny neural arches are present in the tail.

Amniotes

The general structure of human vertebrae is fairly typical of that found in mammals, reptiles, and birds. The shape of the vertebral body does, however, vary somewhat between different groups. In mammals, such as humans, it typically has flat upper and lower surfaces, while in reptiles the anterior surface commonly has a concave socket into which the expanded convex face of the next vertebral body fits. Even these patterns are only generalisations, however, and there may be variation in form of the vertebrae along the length of the spine even within a single species. Some unusual variations include the saddle-shaped sockets between the cervical vertebrae of birds and the presence of a narrow hollow canal running down the centre of the vertebral bodies of geckos and tuataras, containing a remnant of the notochord.

Reptiles often retain the primitive intercentra, which are present as small crescent-shaped bony elements lying between the bodies of adjacent vertebrae; similar structures are often found in the caudal vertebrae of mammals. In the tail, these are attached to chevron-shaped bones called **haemal arches**, which attach below the base of the spine, and help to support the musculature. These latter bones are probably homologous with the ventral ribs of fish. The number of vertebrae in the spines of reptiles is highly variable, and may be several hundred in some species of snake.

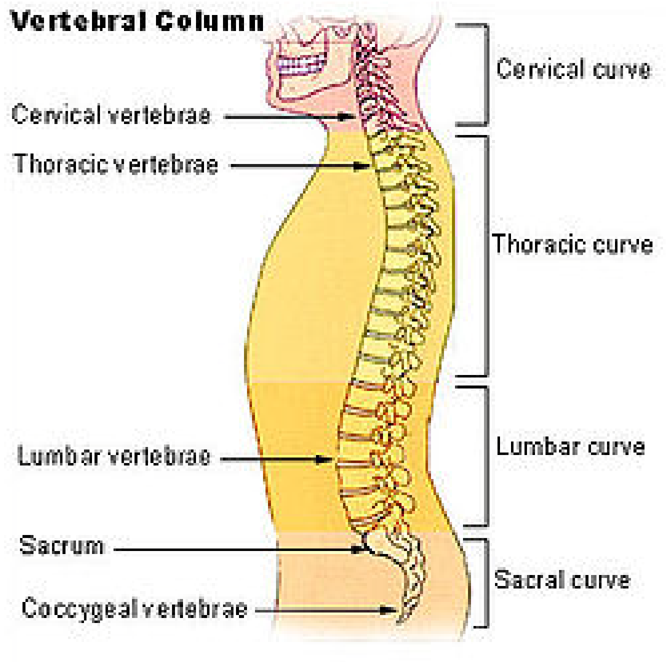
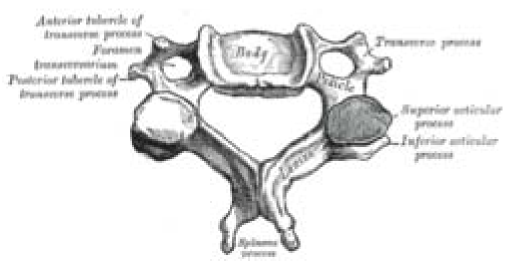
In birds, there is a variable number of cervical vertebrae, which often form the only truly flexible part of the spine. The thoracic vertebrae are partially fused, providing a solid brace for the wings during flight. The sacral vertebrae are fused with the lumbar vertebrae, and some thoracic and caudal vertebrae, to form a single structure, the

synsacrum, which is thus of greater relative length than the sacrum of mammals. In living birds, the remaining caudal vertebrae are fused into a further bone, the pygostyle, for attachment of the tail feathers.

Aside from the tail, the number of vertebrae in mammals is generally fairly constant. There are almost always seven cervical vertebrae (sloths and manatees are among the few exceptions), followed by around twenty or so further vertebrae, divided between the thoracic and lumbar forms, depending on the number of ribs. There are generally three to five vertebrae with the sacrum, and anything up to fifty caudal vertebrae.

Chapter 9

Cervical Vertebrae

Bone: cervical vertebrae	
	
Vertebral column	
	
A human cervical vertebra	
Latin	*vertebrae cervicales*
Gray's	*subject #21 97*
MeSH	*Cervical+vertebrae*

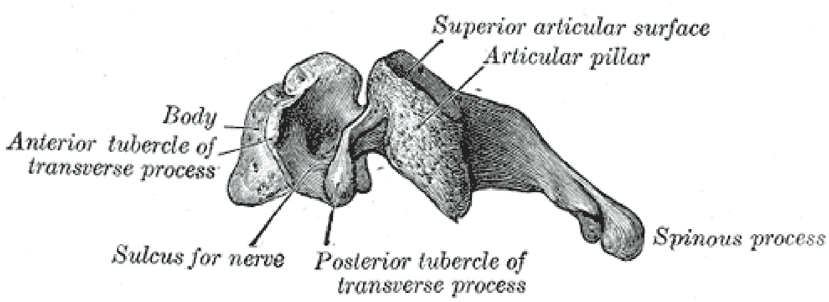
In vertebrates, **cervical vertebrae** (singular: *vertebra*) are those vertebrae immediately inferior to the skull.

Thoracic vertebrae in all mammalian species are defined as those vertebrae which also carry a pair of ribs, and lie caudal to the cervical vertebrae. Further caudally follow the lumbar vertebrae, which also belong to the trunk, but do not carry ribs. In reptiles, all trunk vertebrae carry ribs and are called dorsal vertebrae.

In many species, though not in mammals, the cervical vertebrae bear ribs. In many other groups, such as lizards and saurischian dinosaurs, the cervical ribs are large; in birds they are small and completely fused to the vertebrae. The transverse processes of mammals are homologous to the cervical ribs of other amniotes.

In humans, **cervical vertebrae** are the smallest of the true vertebrae, and can be readily distinguished from those of the thoracic or lumbar regions by the presence of a foramen (hole) in each transverse process, through which passes the vertebral artery.

General characteristics (C3-C6)



Side view of a typical cervical vertebra

These are the general characteristics of the third through sixth cervical vertebrae. (The first, second, and seventh vertebrae are extraordinary, and detailed later.)

- The body of these four vertebrae is small, and broader from side to side than from front to back.
  - The *anterior* and *posterior surfaces* are flattened and of equal depth; the former is placed on a lower level than the latter, and its inferior border is prolonged downward, so as to overlap the upper and forepart of the vertebra below.
  - The *upper surface* is concave transversely, and presents a projecting lip on either side;
  - the *lower surface* is concave from front to back, convex from side to side, and presents laterally shallow concavities which receive the corresponding projecting lips of the underlying vertebra.

- The pedicles are directed laterally and backward, and are attached to the body midway between its upper and lower borders, so that the superior vertebral notch is as deep as the inferior, but it is, at the same time, narrower.

- The laminae are narrow, and thinner above than below; the vertebral foramen is large, and of a triangular form.

- The spinous process is short and bifid, the two divisions being often of unequal size.

- The superior and inferior articular processes of cervical vertebrae have fused on either or both sides to form **articular pillars**, columns of bone which project laterally from the junction of the pedicle and lamina.

- The articular facets are flat and of an oval form:
    - the *superior* face backward, upward, and slightly medially.
    - the *inferior* face forward, downward, and slightly laterally.

- The transverse processes are each pierced by the foramen transversarium, which, in the upper six vertebrae, gives passage to the vertebral artery and vein, as well as a plexus of sympathetic nerves. Each process consists of an anterior and a posterior part. These two parts are joined, outside the foramen, by a bar of bone which exhibits a deep sulcus on its upper surface for the passage of the corresponding spinal nerve.
    - The anterior portion is the homologue of the rib in the thoracic region, and is therefore named the *costal process* or *costal element*. It arises from the side of the body, is directed laterally in front of the foramen, and ends in a tubercle, the anterior tubercle.
    - The posterior part, the true transverse process, springs from the vertebral arch behind the foramen, and is directed forward and laterally; it ends in a flattened vertical tubercle, the posterior tubercle.

Special cervical vertebrae (C1, C2, and C7)

- *C1 or atlas:* The Atlas is the topmost vertebra, and – along with C2 – forms the joint connecting the skull and spine. Its chief peculiarity is that it has no body, and this is due to the fact that the body of the atlas has fused with that of the next vertebra.

- *C2 or axis:* It forms the pivot upon which C1 rotates. The most distinctive characteristic of this bone is the strong odontoid process (dens) which rises perpendicularly from the upper surface of the body. The body is deeper in front than behind, and prolonged downward anteriorly so as to overlap the upper and front part of the third vertebra.

- *C7 or vertebra prominens:* The most distinctive characteristic of this vertebra is the existence of a long and prominent spinous process, hence the name *vertebra prominens*. In some subjects, the seventh cervical vertebra is associated with an abnormal pair of ribs, known as cervical ribs. These ribs are usually small, but may occasionally compress blood vessels (such as the subclavian artery) or nerves in the brachial plexus, causing ischemic muscle pain, numbness, tingling, and weakness in the upper limb.

Movements of the cervical spine

The movement of nodding the head takes place predominantly through flexion and extension at the joint between the atlas and the occipital bone, the atlanto-occipital joint. However, the cervical spine is comparatively mobile, and some component of this movement is due to flexion and extension of the vertebral column itself.

The movement of shaking or rotating the head left and right happens almost entirely at the joint between the atlas and the axis, the atlanto-axial joint. A small amount of rotation of the vertebral column itself contributes to the movement.

Landmarks

Base of Nose and the Hard palate corresponds to C1.

Teeth (when mouth remains closed) correspond to C2.

Mandible and Hyoid bone correspond to C3.

The thyroid cartilage is from C4 to C5.

The cricoid cartilage is from C6 to C7.

Clinical significance

Injuries to the cervical spine are common at the level of the second cervical vertebrae, but neurological injury is uncommon.

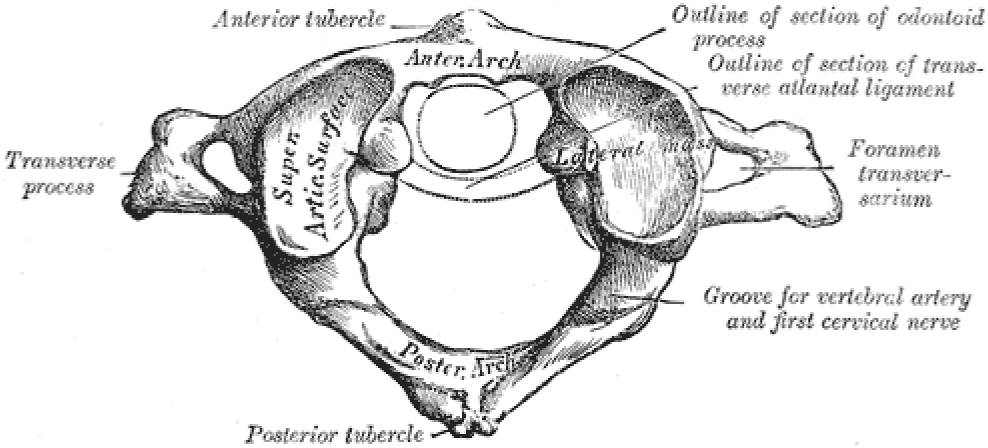
If it does occur, however, it may cause death or profound disability, including paralysis of the arms, legs, and diaphragm, which leads to respiratory failure.

Common patterns of injury include the odontoid fracture and the hangman's fracture, both of which are often treated with immobilization in a cervical collar or Halo brace.

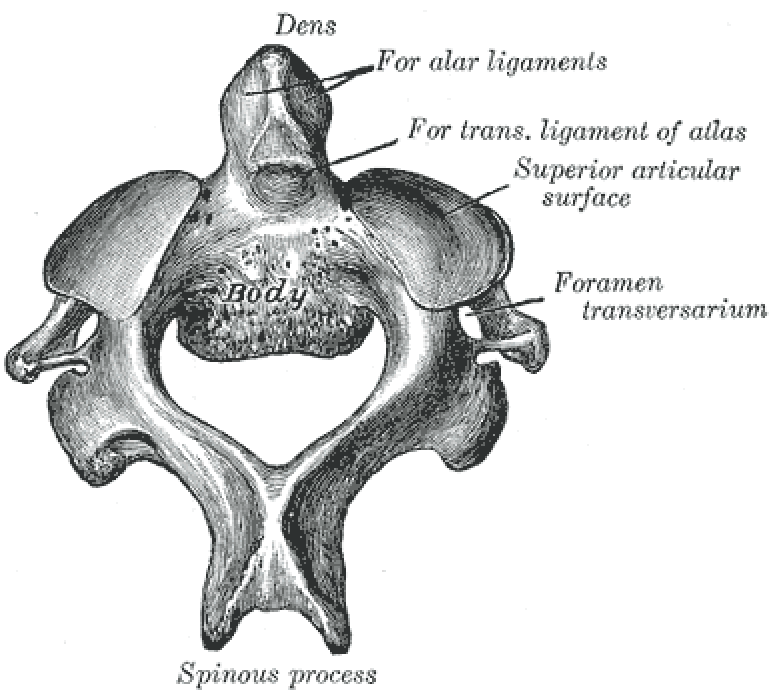
A common EMS practice is to immobilize a patient's cervical spine to prevent further damage during transport to Medical Aid. This practice has come under review recently as incidence rates of unstable spinal trauma can be as low as 2% in immobilized patients.

Canadian studies have developed the Canadian C-Spine Rule (CCR) for physicians to decide who should receive radiological imaging.

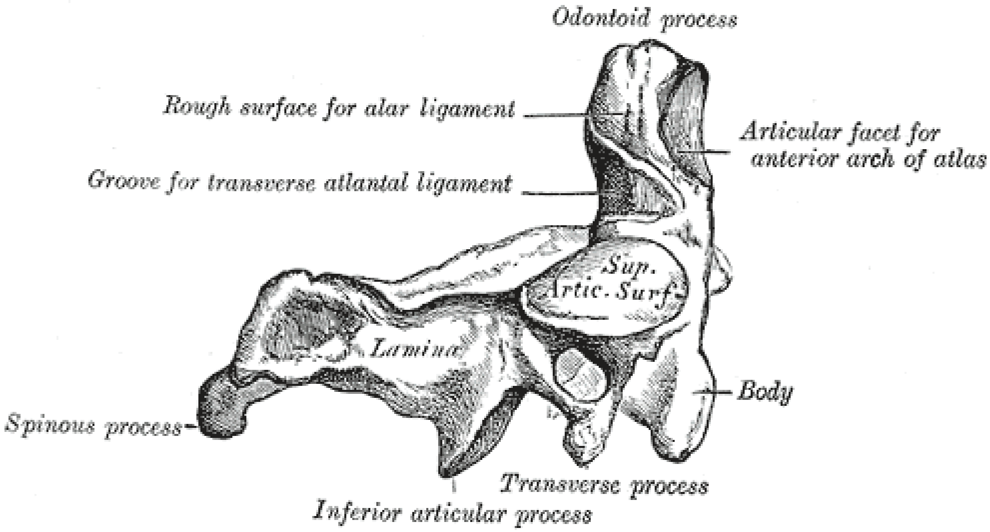
Cervical column



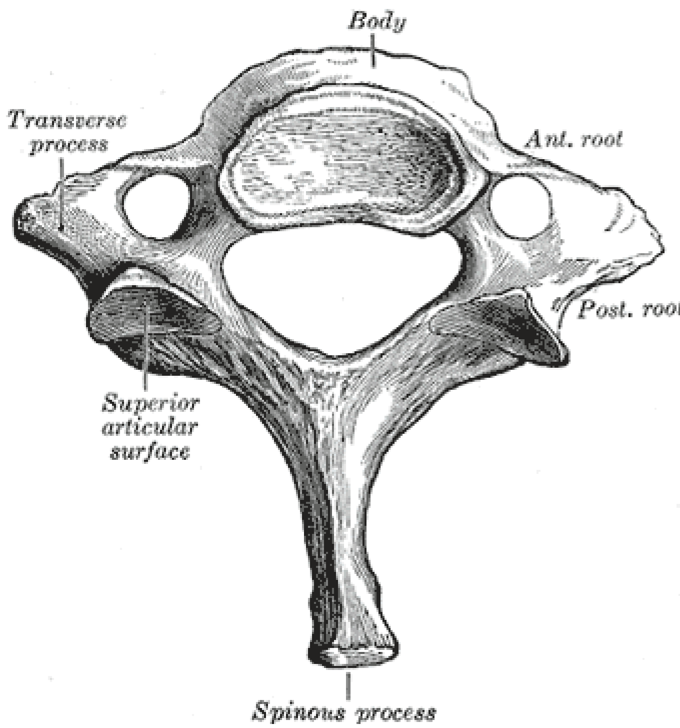
First cervical vertebra, or Atlas



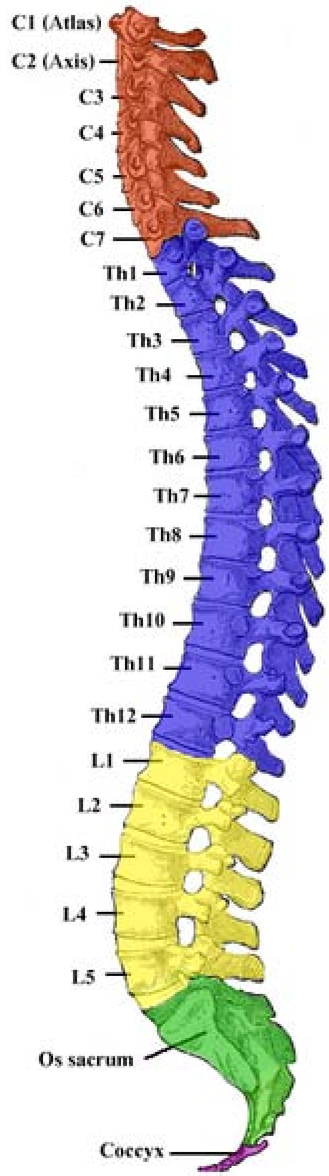
Second cervical vertebra, or epistropheus, from above



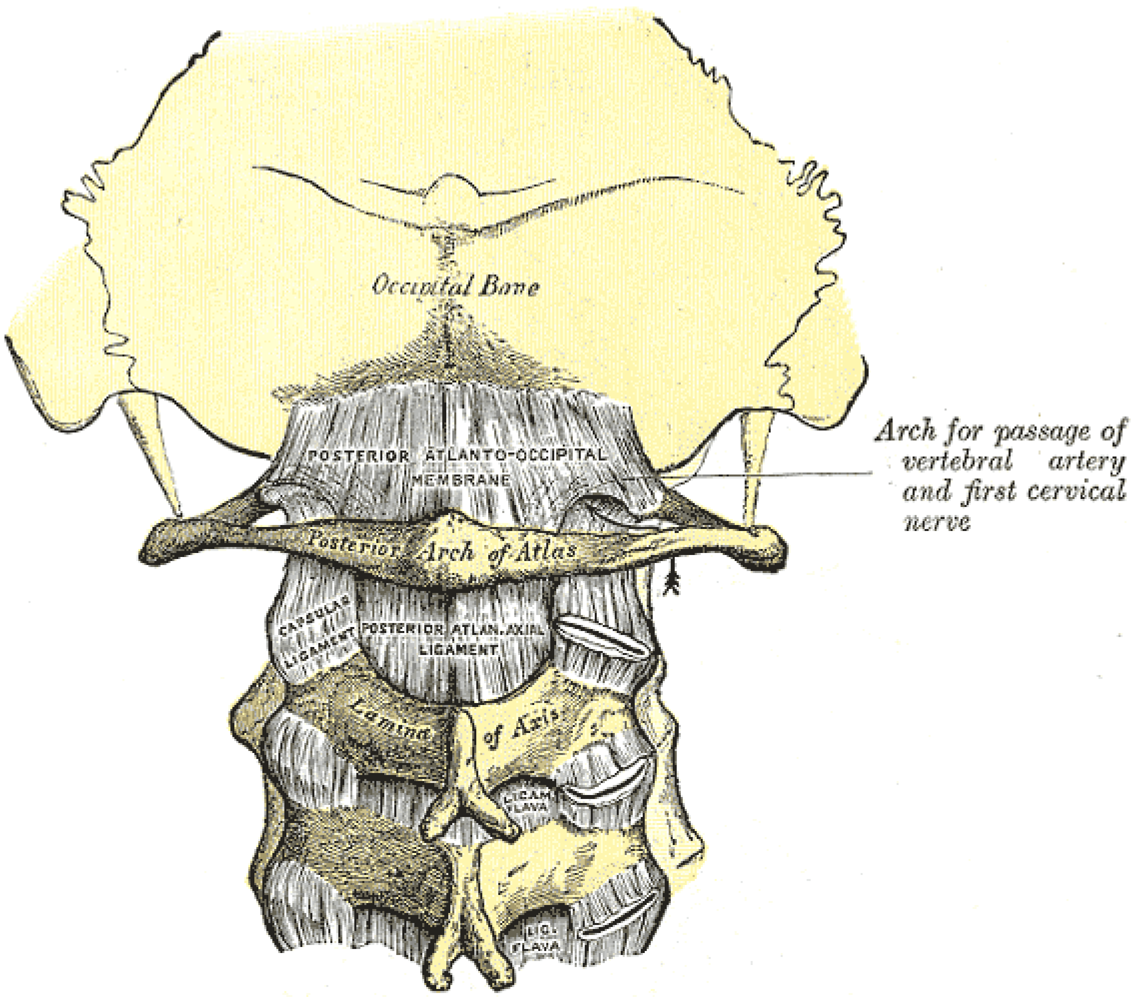
Second cervical vertebra, epistropheus, or axis, from the side



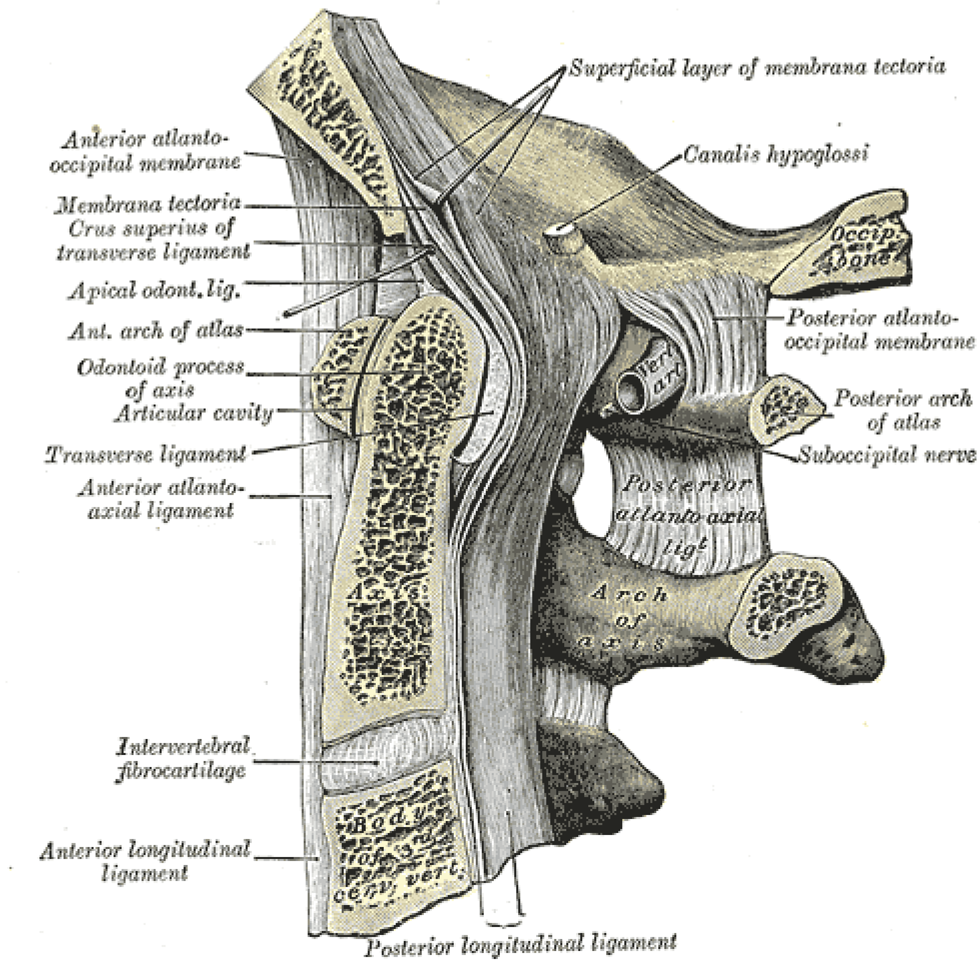
Seventh cervical vertebra



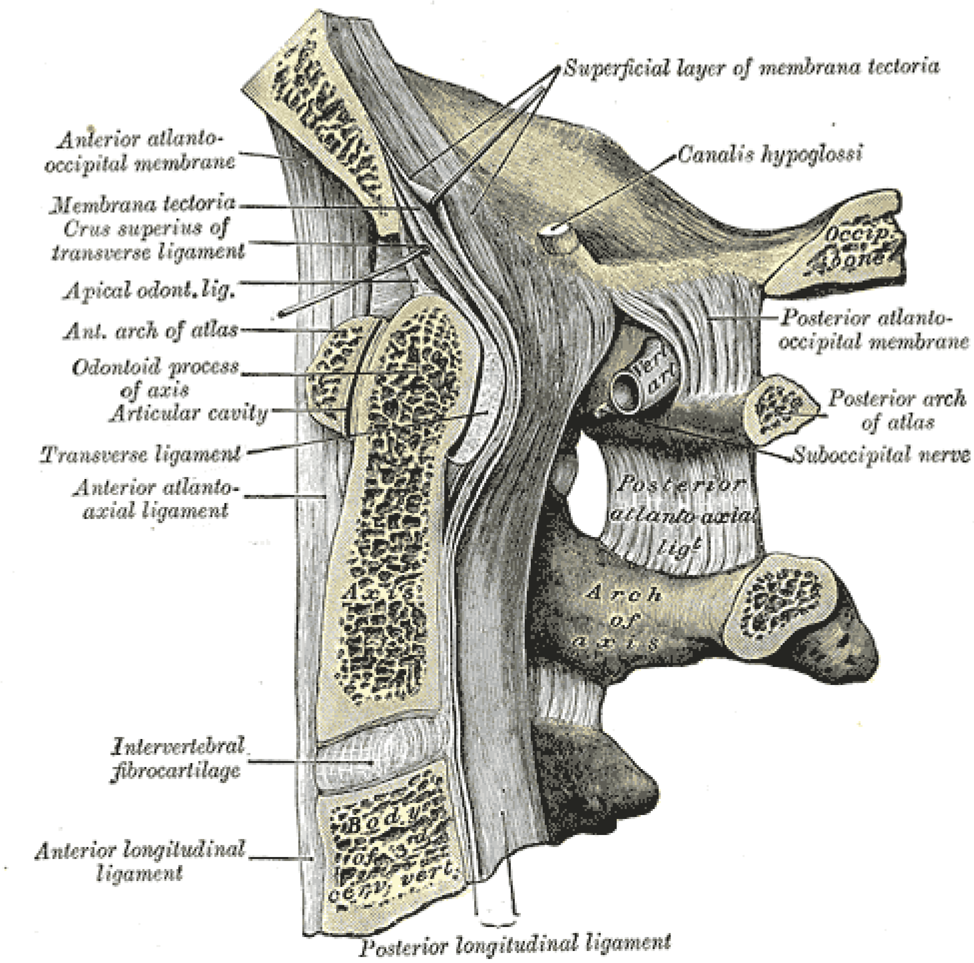
Vertebral column



Posterior atlantoöccipital membrane and atlantoaxial ligament



Median sagittal section through the occipital bone and first three cervical vertebræ

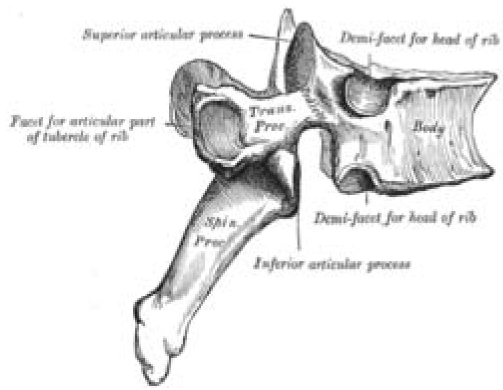


Section of the neck at about the level of the sixth cervical vertebra

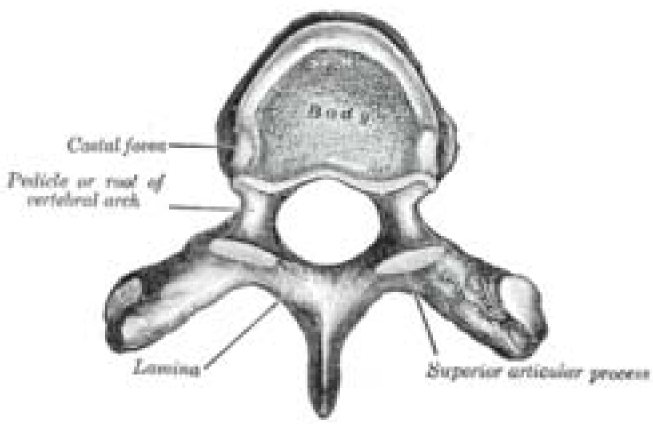
Chapter 10

Thoracic Vertebrae

Bone: thoracic vertebrae



A typical thoracic vertebra



A typical thoracic vertebra, viewed from above.

Latin	*vertebrae thoracales*
Gray's	*subject #22 102*
MeSH	*Thoracic+Vertebrae*

In human anatomy, twelve **thoracic vertebrae** compose the middle segment of the vertebral column, between the cervical vertebrae and the lumbar vertebrae. They are intermediate in size between those of the cervical and lumbar regions; they increase in size as one proceeds down the spine, the upper vertebrae being much smaller than those in the lower part of the region. They are distinguished by the presence of facets on the sides of the bodies for articulation with the heads of the ribs, and facets on the transverse processes of all, except the eleventh and twelfth, for articulation with the tubercles of the ribs.

General characteristics

These are the general characteristics of the second through eighth thoracic vertebrae. The first and ninth through twelfth vertebrae contain certain peculiarities, and are detailed below.

The **bodies** in the middle of the thoracic region are heart-shaped, and as broad in the antero-posterior as in the transverse direction. At the ends of the thoracic region they resemble respectively those of the cervical and lumbar vertebrae. They are slightly thicker behind than in front, flat above and below, convex from side to side in front, deeply concave behind, and slightly constricted laterally and in front. They present, on either side, two costal demi-facets, one above, near the root of the pedicle, the other below, in front of the inferior vertebral notch; these are covered with cartilage in the fresh state, and, when the vertebrae are articulated with one another, form, with the intervening intervertebral fibrocartilages, oval surfaces for the reception of the heads of the ribs.

The **pedicles** are directed backward and slightly upward, and the inferior vertebral notches are of large size, and deeper than in any other region of the vertebral column.

The **laminae** are broad, thick, and imbricated — that is to say, they overlap those of subjacent vertebrae like tiles on a roof.

The **vertebral foramen** is small, and of a circular form.

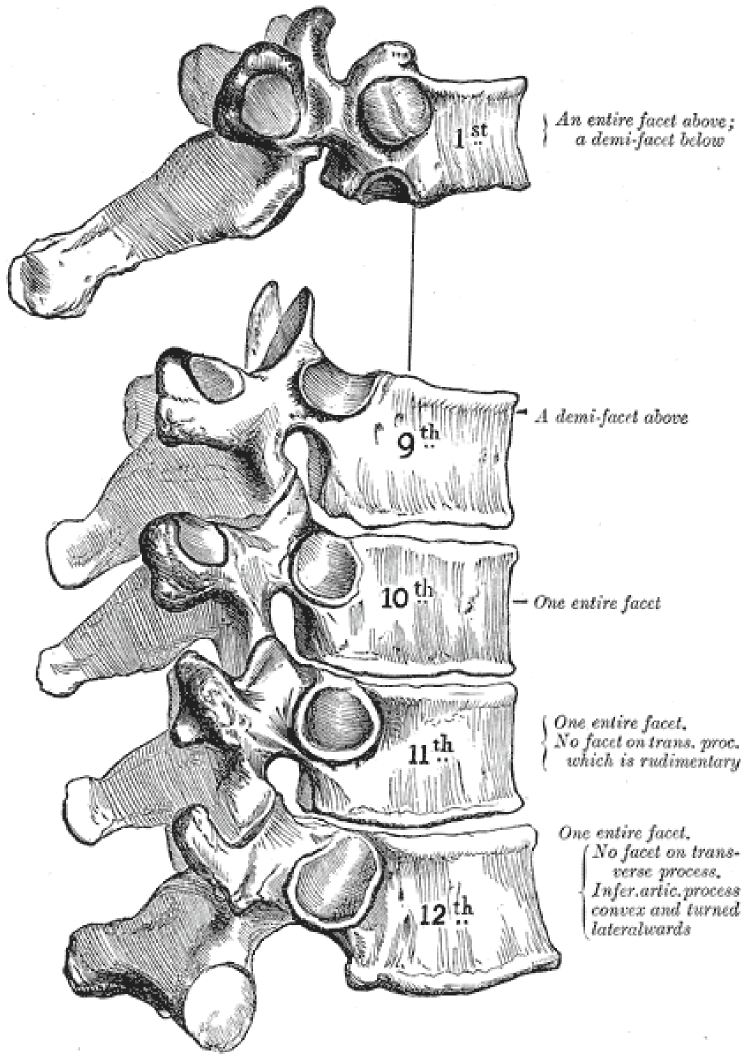
The **spinous process** is long, triangular on coronal section, directed obliquely downward, and ends in a tuberculated extremity. These processes overlap from the fifth to the eighth, but are less oblique in direction above and below.

The **superior articular processes** are thin plates of bone projecting upward from the junctions of the pedicles and laminae; their articular facets are practically flat, and are directed backward and a little lateralward and upward.

The **inferior articular processes** are fused to a considerable extent with the laminae, and project but slightly beyond their lower borders; their facets are directed forward and a little medialward and downward.

The **transverse processes** arise from the arch behind the superior articular processes and pedicles; they are thick, strong, and of considerable length, directed obliquely backward and lateralward, and each ends in a clubbed extremity, on the front of which is a small, concave surface, for articulation with the tubercle of a rib. *

Individual thoracic vertebrae



The first and ninth through twelfth thoracic vertebra have some peculiarities

First thoracic vertebra

The first thoracic vertebra has, on either side of the **body**, an entire articular facet for the head of the first rib, and a demi-facet for the upper half of the head of the second rib.

The body is like that of a cervical vertebra, being broad transversely; its upper surface is concave, and lipped on either side.

The **superior articular surfaces** are directed upward and backward; the **spinous process** is thick, long, and almost horizontal.

The **transverse processes** are long, and the upper vertebral notches are deeper than those of the other thoracic vertebrae.

The thoracic spinal nerve 1 (T1) passes out underneath it.

Second thoracic vertebra

The thoracic spinal nerve 2 (T2) passes out underneath it.

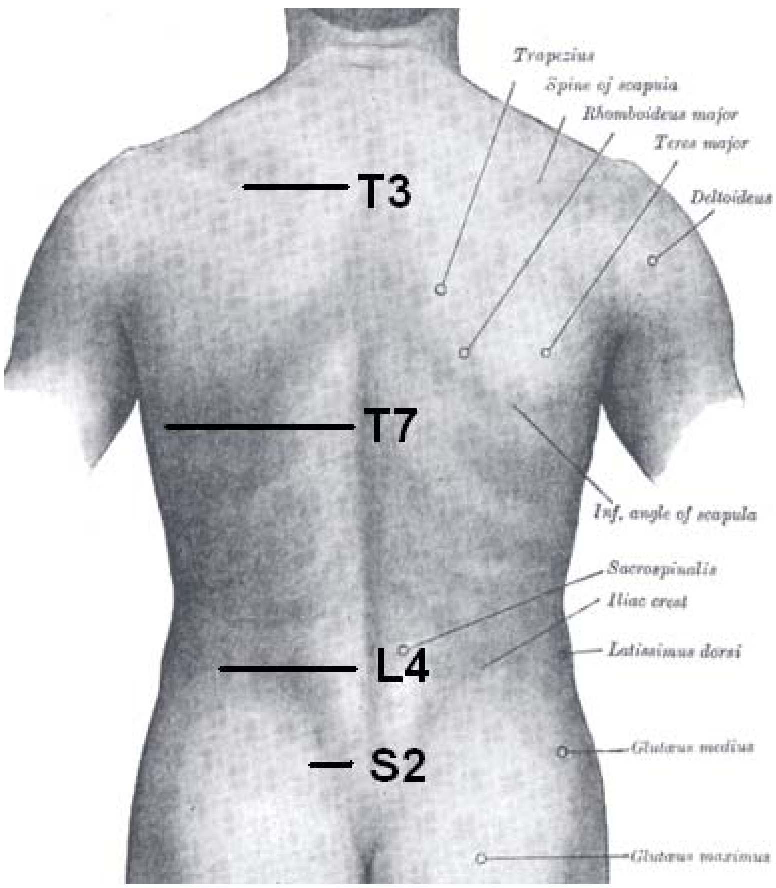
Third thoracic vertebra

The thoracic spinal nerve 3 out underneath it.

Fourth thoracic vertebra

The fourth thoracic vertebra, together with the fifth, is at the same level as the sternal angle.

The thoracic spinal nerve 4 (T4) passes out underneath it.



Surface orientation of T3 and T7, at middle of spine of scapula and at inferior angle of the scapula, respectively.

Fifth thoracic vertebra

The fifth thoracic vertebra, together with the fourth, is at the same level as the sternal angle.

The thoracic spinal nerve 5 (T5) passes out underneath it.

Sixth thoracic vertebra

The thoracic spinal nerve 6 (T6) passes out underneath it.

Seventh thoracic vertebra

The thoracic spinal nerve 7 (T7) passes out underneath it.

Eighth thoracic vertebra

The eighth thoracic vertebra is, together with the ninth thoracis vertebra, at the same level as the xiphoid process.

The thoracic spinal nerve 8 (T8) passes out underneath it.

Ninth thoracic vertebra

The ninth thoracic vertebra may have no demi-facets below. In some subjects however, it has two demi-facets on either side; when this occurs the tenth doesn't have facets but demi-facets at the upper part.

The thoracic spinal nerve 9 (T9) passes out underneath it.

Tenth thoracic vertebra

The tenth thoracic vertebra has (except in the cases just mentioned) an entire articular facet (not demi-facet) on either side, which is placed partly on the lateral surface of the pedicle. It doesn't have any kind of facet below, because the following ribs only have one facet on their heads.

The thoracic spinal nerve 10 (T10) passes out underneath it.

Eleventh thoracic vertebra

In the eleventh thoracic vertebrae the **body** approaches in its form and size to that of the lumbar vertebrae.

The articular facets for the heads of the ribs are of large size, and placed chiefly on the pedicles, which are thicker and stronger in this and the next vertebrae than in any other part of the thoracic region.

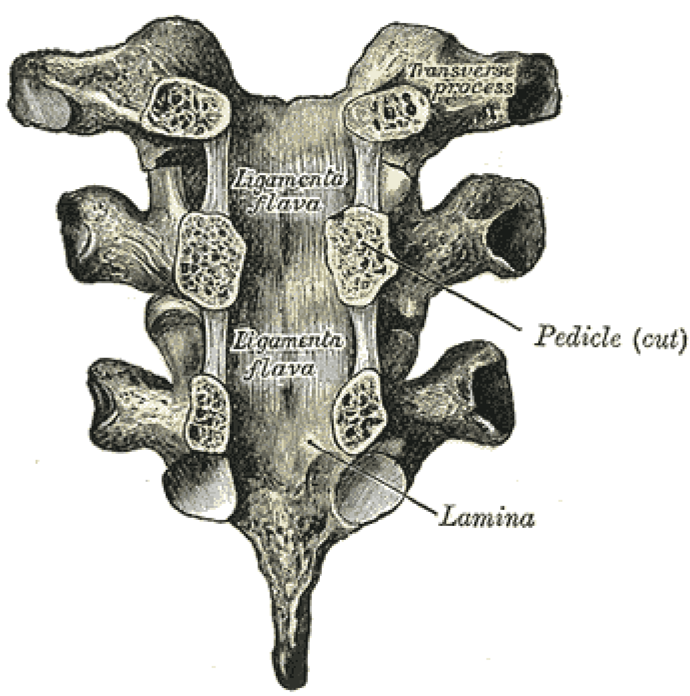
The **spinous process** is short, and nearly horizontal in direction.

The **transverse processes** are very short, tuberculated at their extremities, and have no articular facets.

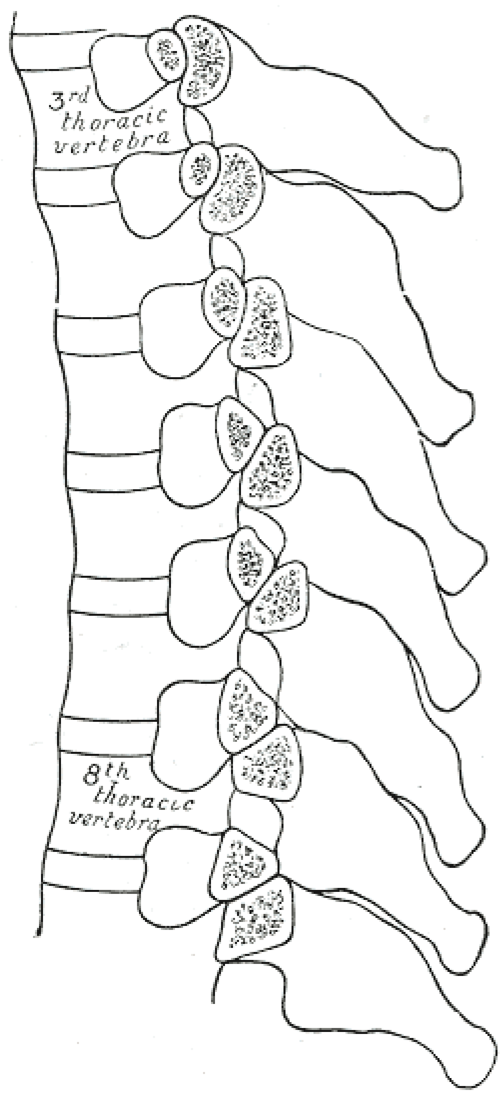
The thoracic spinal nerve 11 (T11) passes out underneath it.

Twelfth thoracic vertebra

The twelfth thoracic vertebra has the same general characteristics as the eleventh, but may be distinguished from it by its inferior articular surfaces being convex and directed lateralward, like those of the lumbar vertebrae; by the general form of the body, laminae, and spinous process, in which it resembles the lumbar vertebrae; and by each transverse process being subdivided into three elevations, the superior, inferior, and lateral tubercles: the superior and inferior correspond to the mammillary and accessory processes of the lumbar vertebrae. Traces of similar elevations are found on the transverse processes of the tenth and eleventh thoracic vertebrae.



Vertebral arches of three thoracic vertebræ viewed from the front

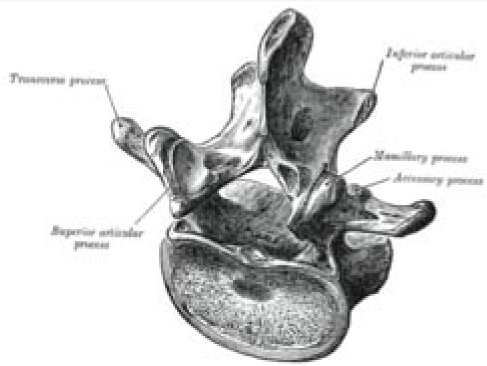


Section of the costotransverse joints from the third to the ninth inclusive

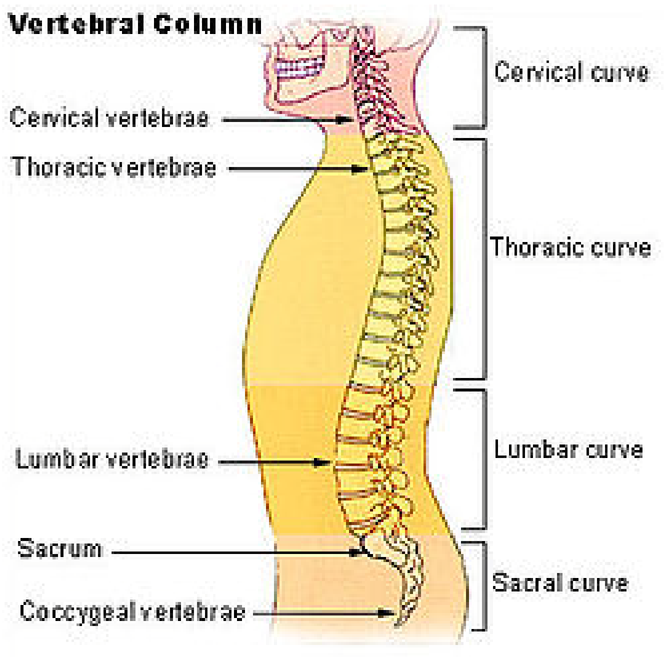
Chapter 11

Lumbar Vertebrae

Bone: Lumbar vertebrae



A typical lumbar vertebra



Vertebral column.

Gray's *subject #23 104*

The **lumbar vertebrae** are the largest segments of the movable part of the vertebral column, and are characterized by the absence of the foramen transversarium within the transverse process, and by the absence of facets on the sides of the body. They are designated L1 to L5, starting at the top.

General characteristics

These are the general characteristics of the first through fourth lumbar vertebrae. The fifth vertebra contains certain peculiarities, which are detailed below.

As with other vertebrae, each lumbar vertebra consists of a *vertebral body* and a *vertebral arch*. The vertebral arch, consisting of a pair of *pedicles* and a pair of *laminae*, encloses the *vertebral foramen* (opening) and supports seven processes.

Body

The vertebral body of each lumbar vertebra is large, wider from side to side than from front to back, and a little thicker in front than in back. It is flattened or slightly concave above and below, concave behind, and deeply constricted in front and at the sides.

Arch

The pedicles are very strong, directed backward from the upper part of the vertebral body; consequently, the inferior vertebral notches are of considerable depth. The pedicles change in morphology from the upper lumbar to the lower lumbar. They increase in sagittal width from 9 mm to up to 18 mm at L5. They increase in angulation in the axial plane from 10 degrees to 20 degrees by L5. The pedicle is sometimes used as a portal of entrance into the vertebral body for fixation with pedicle screws or for placement of bone cement as with kyphoplasty or vertebroplasty.

The laminae are broad, short, and strong. They form the posterior portion of the vertebral arch. In the upper lumbar region the lamina are taller than wide but in the lower lumbar vertebra the lamina are wider than tall. The lamina connect the spinous process to the pedicles.

The vertebral foramen within the arch is triangular, larger than in the thoracic vertebrae, but smaller than in the cervical vertebrae.

Processes

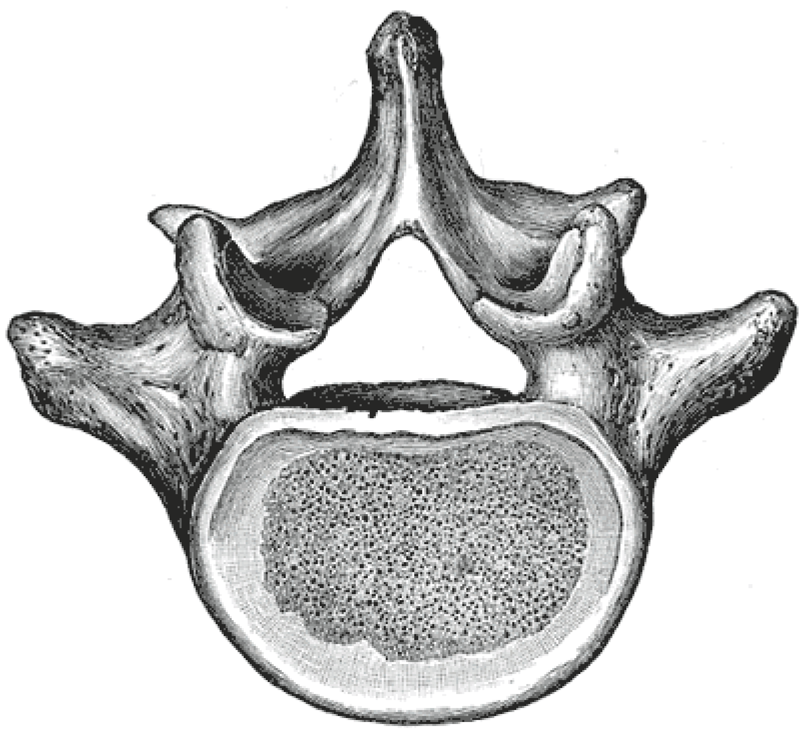
The *spinous process* is thick, broad, and somewhat quadrilateral; it projects backward and ends in a rough, uneven border, thickest below where it is occasionally notched.

The superior and inferior *articular processes* are well-defined, projecting respectively upward and downward from the junctions of pedicles and laminae. The facets on the superior processes are concave, and look backward and medialward; those on the inferior are convex, and are directed forward and lateralward. The former are wider apart than the latter, since in the articulated column the inferior articular processes are embraced by the superior processes of the subjacent vertebra.

The *transverse processes* are long and slender. They are horizontal in the upper three lumbar vertebrae and incline a little upward in the lower two. In the upper three vertebrae they arise from the junctions of the pedicles and laminae, but in the lower two they are set farther forward and spring from the pedicles and posterior parts of the vertebral bodies. They are situated in front of the articular processes instead of behind them as in the thoracic vertebrae, and are homologous with the ribs.

Of the three *tubercles* noticed in connection with the transverse processes of the lower lumbar vertebrae, the superior one is connected in the lumbar region with the back part of the superior articular process, and is named the *mammillary process*. The inferior is situated at the back part of the base of the transverse process, and is called the *accessory process*.

First to fifth lumbar vertebrae



The fifth lumbar vertebra has certain peculiarities

Some individuals have four lumbar vertebrae, while others have six. Lumbar disorders that normally affect L5 will affect L4 or L6 in these individuals.

The first lumbar vertebra is level with the anterior end of the ninth rib. This level is also called the important transpyloric plane, since the pylorus of the stomach is at this level.

The fifth lumbar vertebra is characterized by its body being much deeper in front than behind, which accords with the prominence of the sacrovertebral articulation; by the smaller size of its spinous process; by the wide interval between the inferior articular processes, and by the thickness of its transverse processes, which spring from the body as well as from the pedicles.

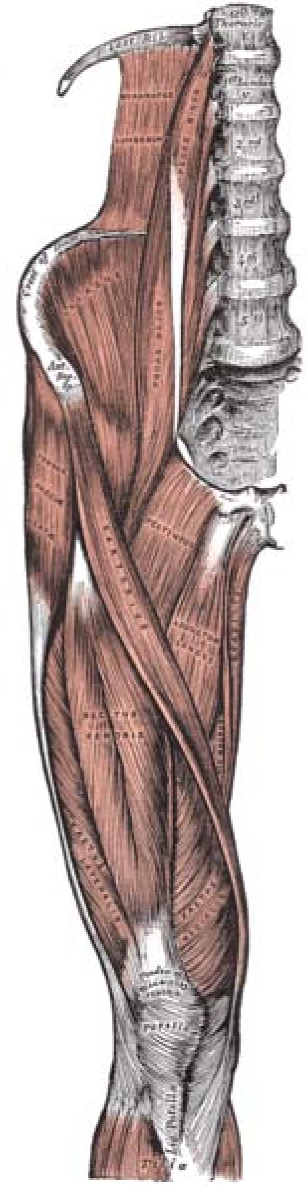
The fifth lumbar vertebra is by far the most common site of spondylolysis and spondylolisthesis.

Segmental movements

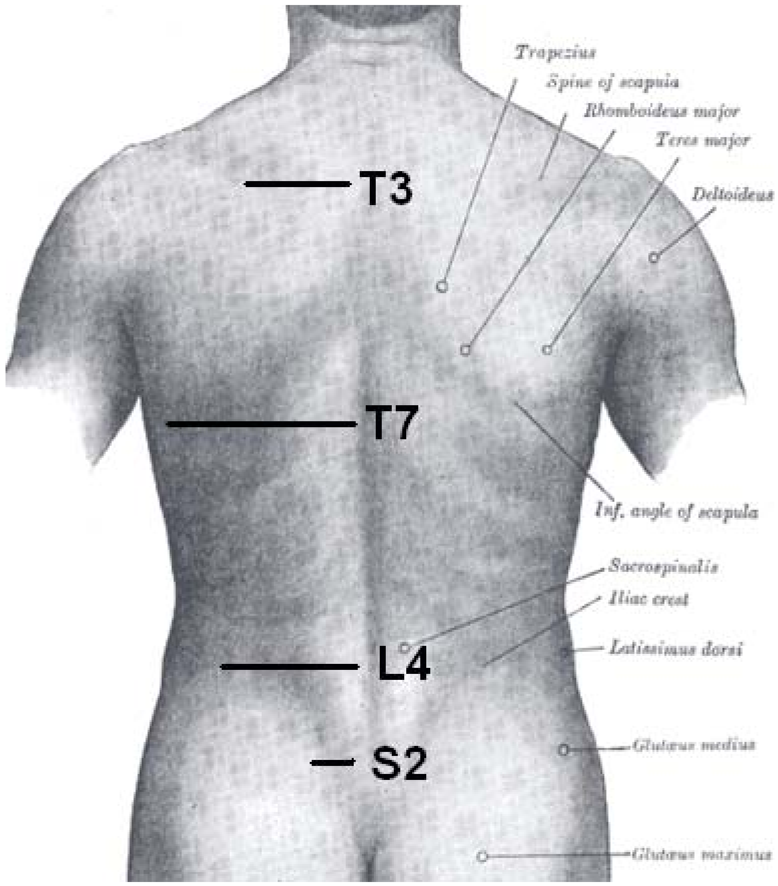
The range of segmental movements in a single segment is difficult to measure clinically, not only because of variations between individuals, but also because it is age and gender dependent. Furthermore, flexion and extension in the lumbal spine is the product of a combination of rotation and translation in the sagittal plane between each vertebra.

Ranges of segmental movements in the lumbal spine (White and Panjabi, 1990) are (in degrees):

	L1-L2	**L2-L3**	**L3-L4**	**L4-L5**	**L5-S1**
Flexion/ Extension	12	14	15	16	17
Lateral flexion	6	6	8	6	3
Axial rotation	2	2	2	2	1



Muscles of the iliac and anterior femoral regions. First lumbar vertebra second highest vertebra seen.

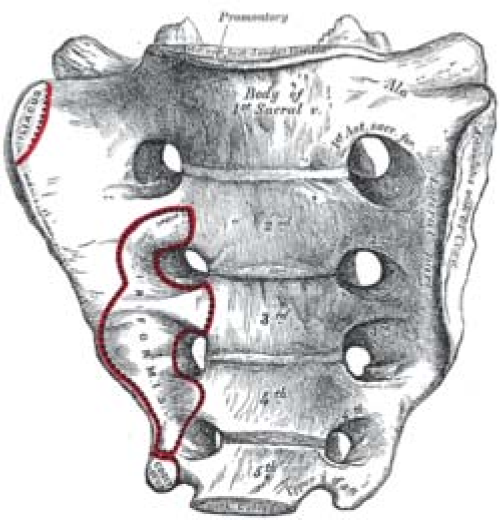


Orientation of vertebral column on surface. T3 is at level of medial part of spine of scapula. T7 is at inferior angle of the scapula. L4 is at highest point of iliac crest. S2 is at the level of posterior superior iliac spine. Furthermore, C7 is easily localized as a prominence at the lower part of the neck.

Chapter 12

Sacrum

Bone: Sacrum



Sacrum, pelvic surface

Image of pelvis. Sacrum is in center.

Latin	*os sacrum*
Gray's	*subject #24 106*
MeSH	*Sacrum*

In vertebrate anatomy the **sacrum** (plural *sacrums* or *sacra*) is a large, triangular bone at the base of the spine and at the upper and back part of the pelvic cavity, where it is inserted like a wedge between the two hip bones. Its upper part connects with the last lumbar vertebra, and bottom part with the coccyx (tailbone). In children, it consists of usually five unfused vertebrae which begin to fuse between ages 16–18 and are usually completely fused into a single bone by age 26.

It is curved upon itself and placed obliquely (that is, tilted forward). It is kyphotic — that is, concave facing forwards. The base projects forward as the sacral promontory internally, and articulates with the last lumbar vertebra to form the prominent sacrovertebral angle. The central part is curved outward towards the posterior, allowing greater room for the pelvic cavity.

Etymology

The name is derived from the Latin *sacer*, "sacred", a translation of the Greek *hieron (osteon)*, meaning sacred or strong bone. Since the sacrum is the seat of the organs of procreation, animal sacrums were offered in sacrifices. In Slavic languages and in German this bone is called the "cross bone".

Parts

- The pelvic surface of the sacrum is concave from above downward, and slightly so from side to side.
- The dorsal surface of the sacrum is convex and narrower than the pelvic.
- The lateral surface of the sacrum is broad above, but narrowed into a thin edge below.
- The base of the sacrum, which is broad and expanded, is directed upward and forward.
- The apex (*apex oss. sacri*) is directed downward, and presents an oval facet for articulation with the coccyx.
- The vertebral canal (*canalis sacralis*; sacral canal) runs throughout the greater part of the bone; above, it is triangular in form; below, its posterior wall is incomplete, from the non-development of the laminae and spinous processes. It lodges the sacral nerves, and its walls are perforated by the anterior and posterior sacral foramina through which these nerves pass out.

Articulations

The sacrum articulates with four bones:

- the last lumbar vertebra above
- the coccyx (tailbone) below
- the illium portion of the hip bone on either side

Rotation of the sacrum forward a few degrees vis-à-vis the ilia is sometimes called "nutation" (L. "nodding"), and the reverse motion "counter-nutation."

It is called the *sacrum* when referred to all of the parts combined, but *sacral vertebrae* when referred individually.

Sexual dimorphism

The sacrum is noticeably sexually dimorphic (differently-shaped in males and females).

In the female the sacrum is shorter and wider than in the male; the lower half forms a greater angle with the upper; the upper half is nearly straight, the lower half presenting the greatest amount of curvature. The bone is also directed more obliquely backward; this increases the size of the pelvic cavity and renders the sacrovertebral angle more prominent.

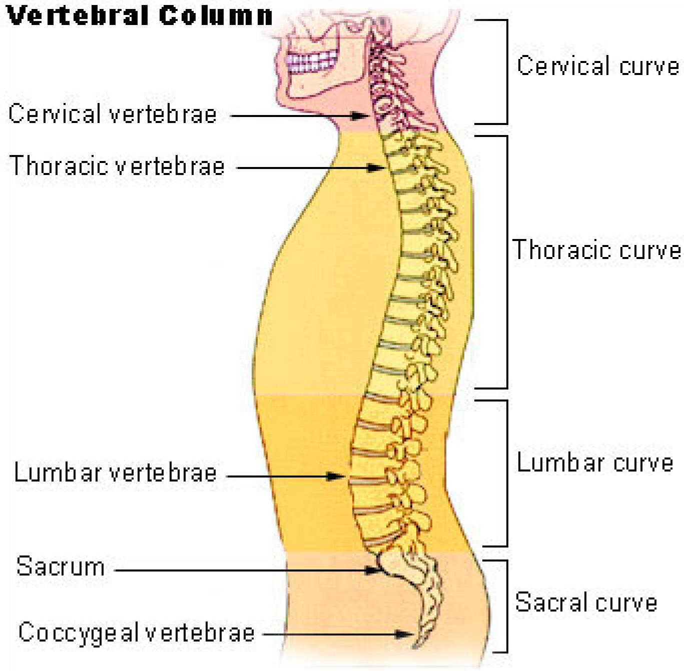
In the male the curvature is more evenly distributed over the whole length of the bone, and is altogether greater than in the female.

Variations

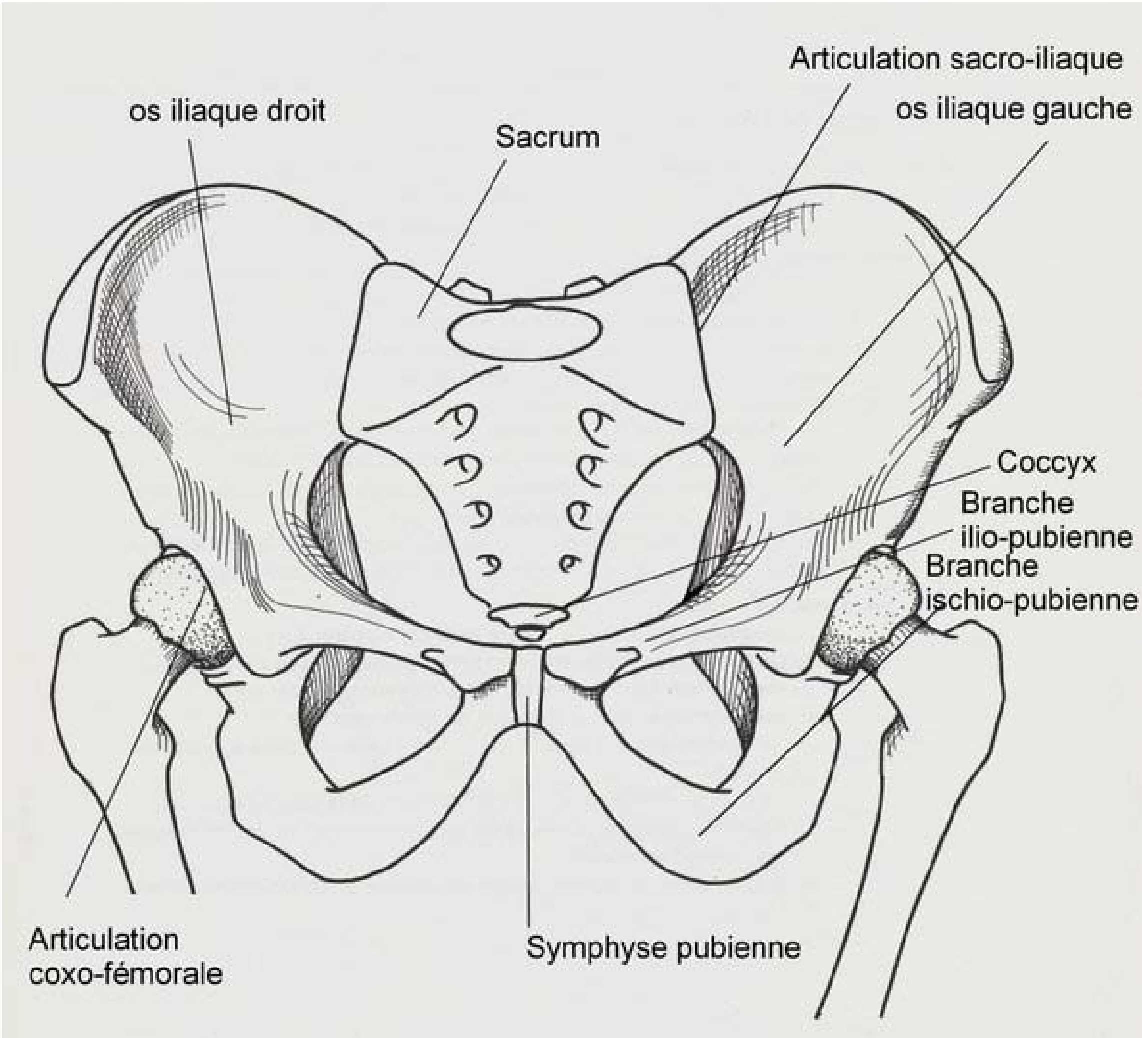
The sacrum, in some cases, consists of six pieces ; occasionally the number is reduced to four . The bodies of the first and second vertebrae may fail to unite.

Sometimes the uppermost transverse tubercles are not joined to the rest of the ala on one or both sides, or the sacral canal may be open throughout a considerable part of its length, in consequence of the imperfect development of the laminae and spinous processes.

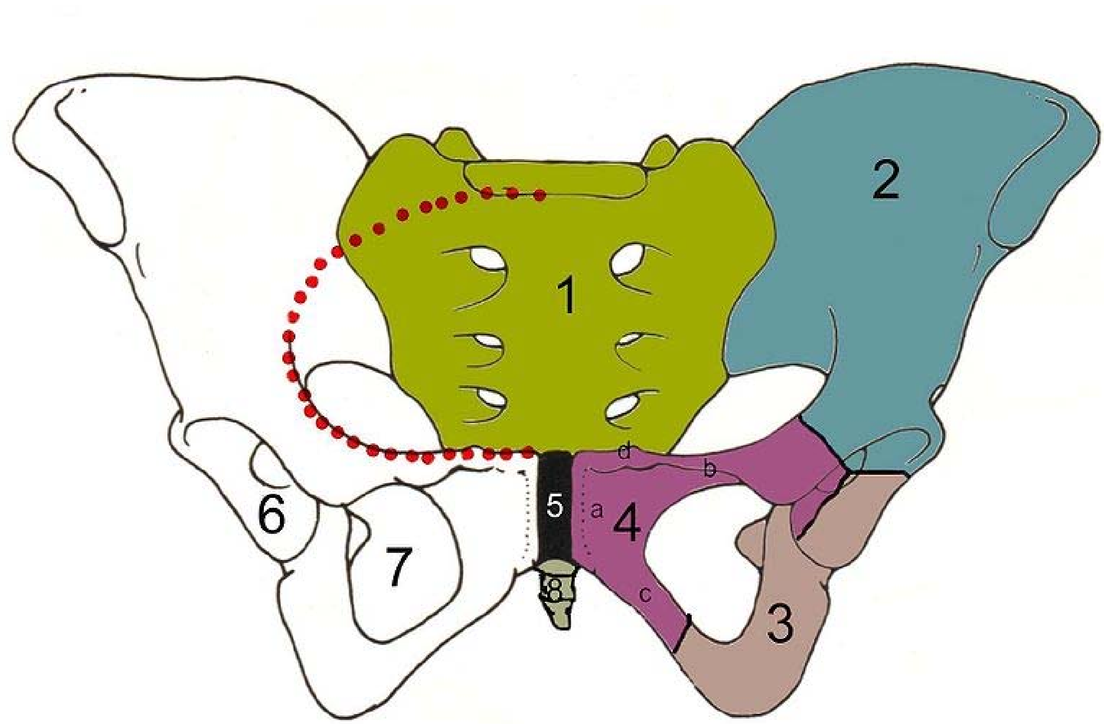
The sacrum also varies considerably with respect to its degree of curvature.



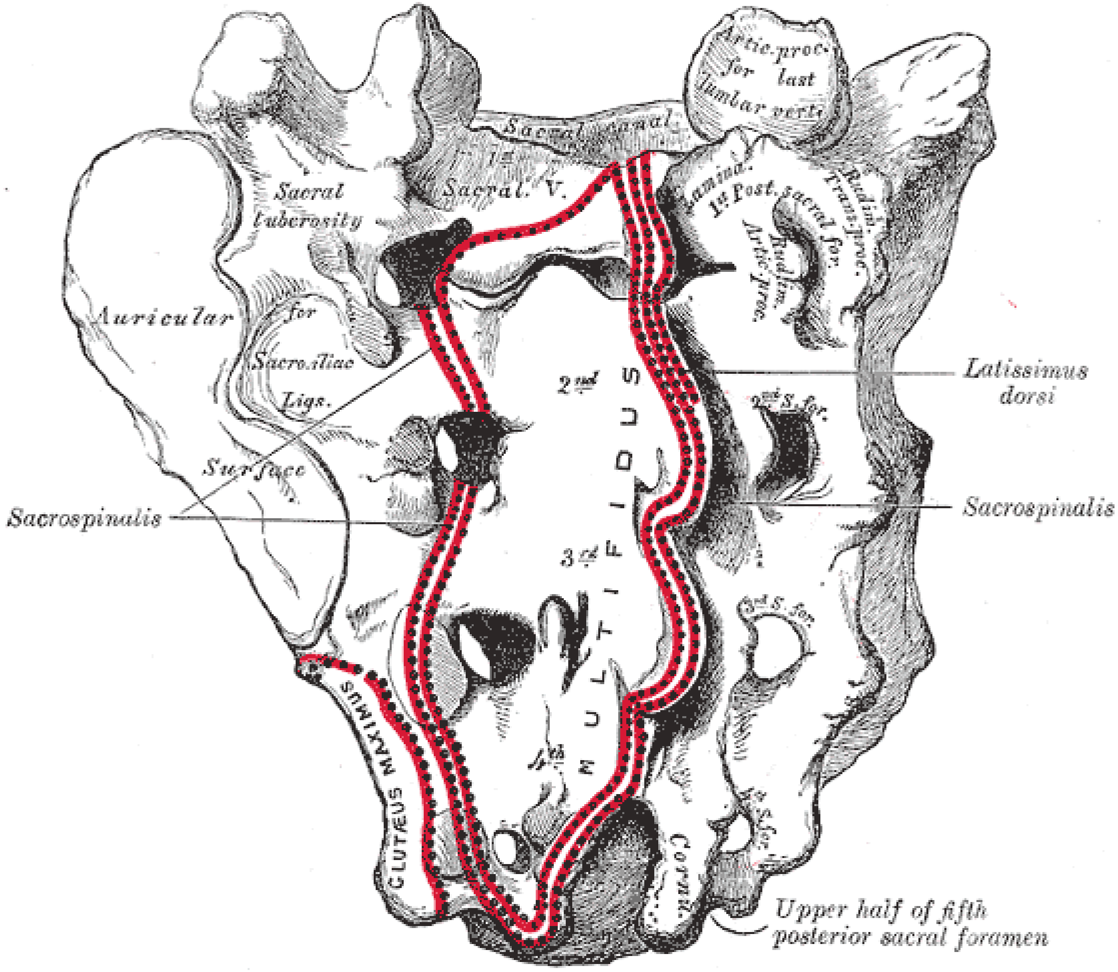
Vertebral column



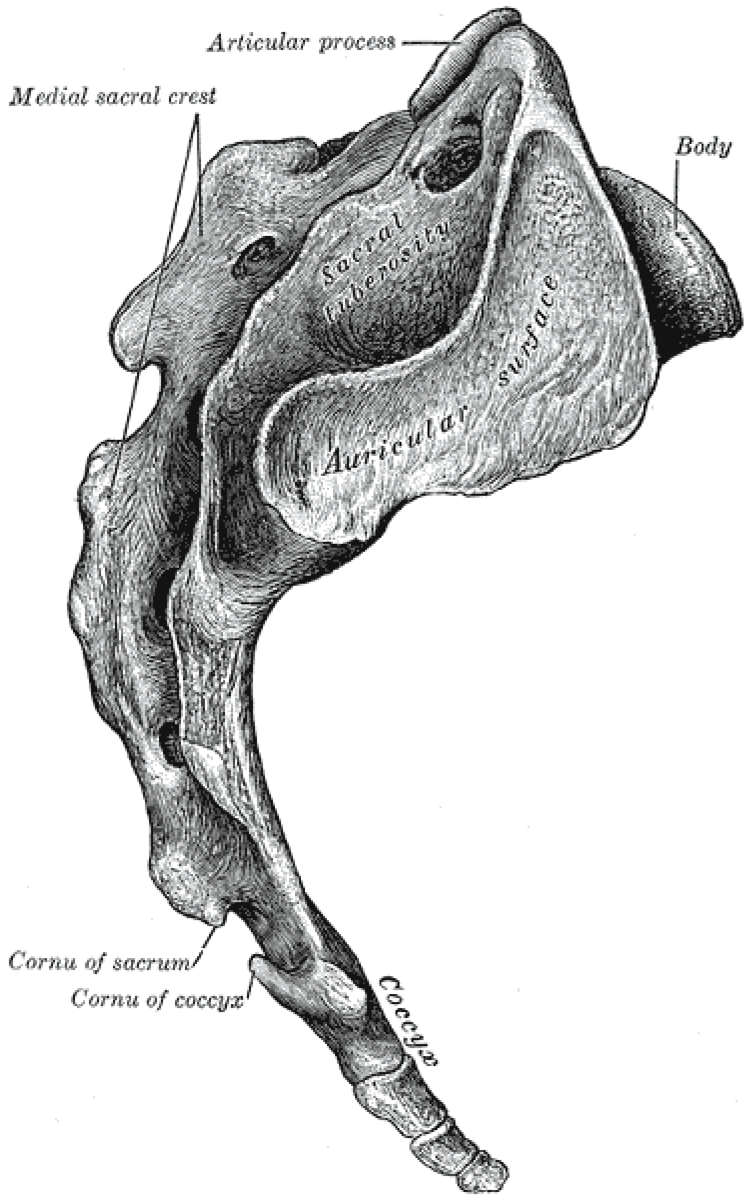
Bassin Osseux de face



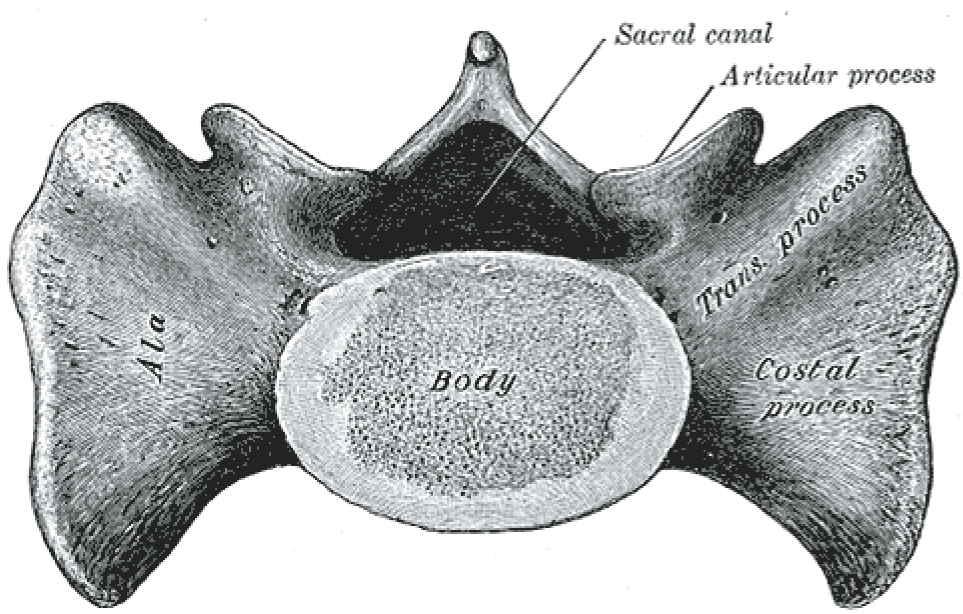
Pelvis



Sacrum, dorsal surface

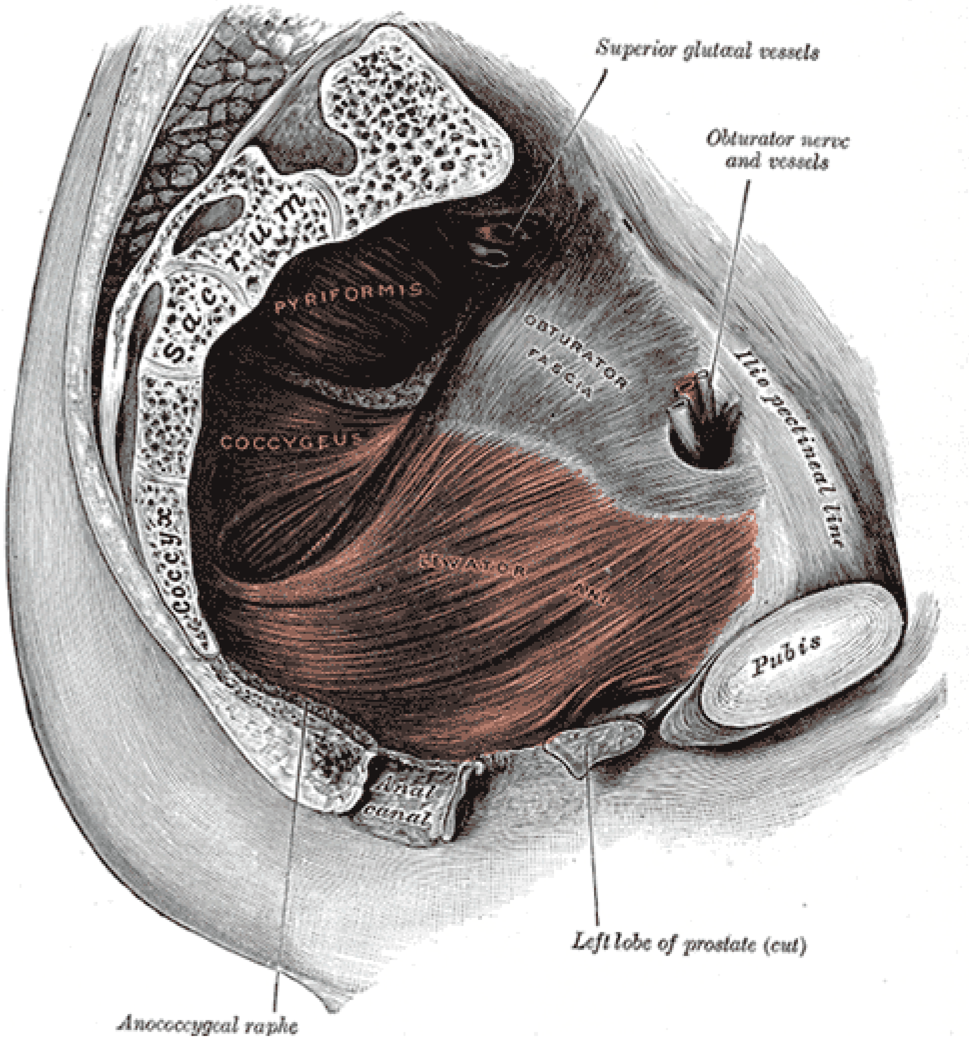


Lateral surfaces of sacrum and coccyx

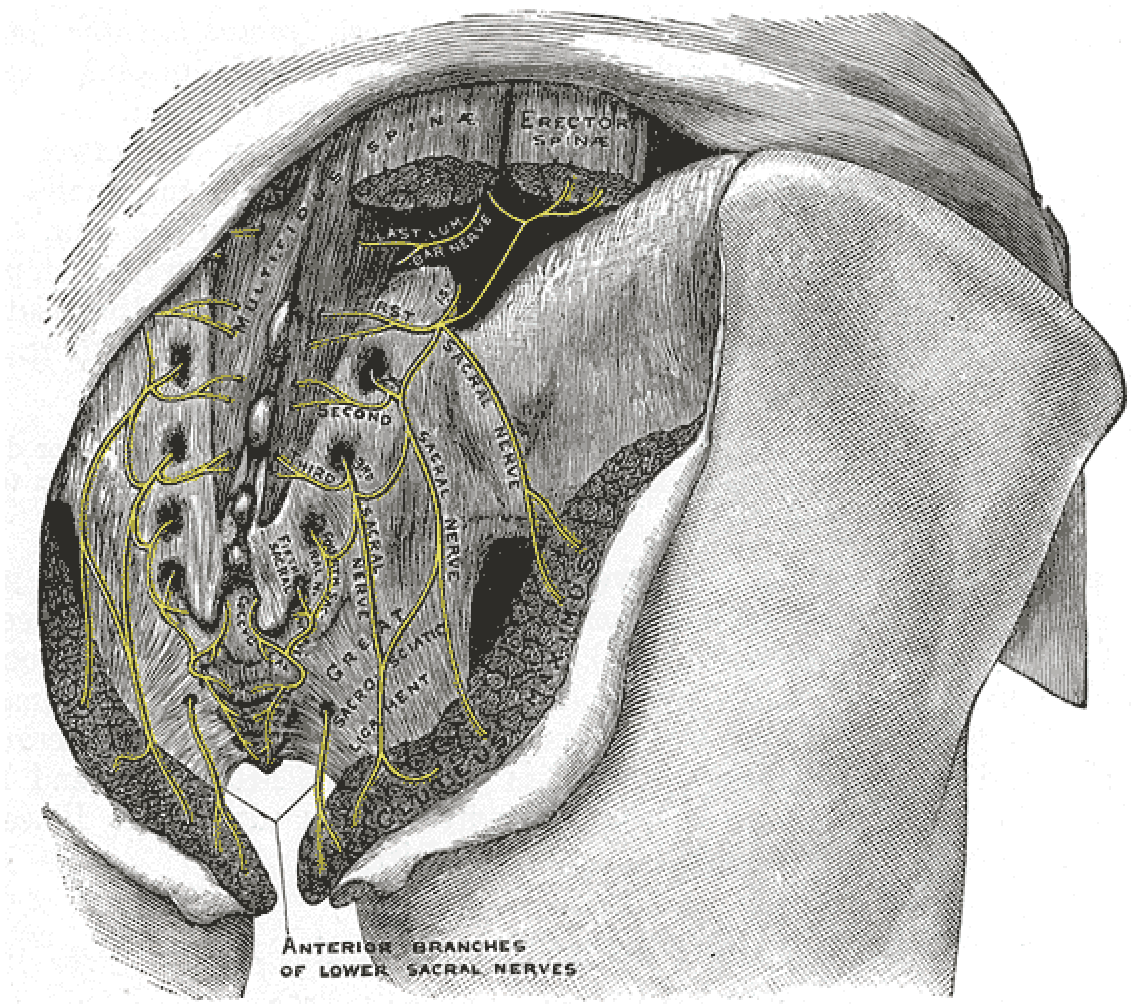


Base of sacrum

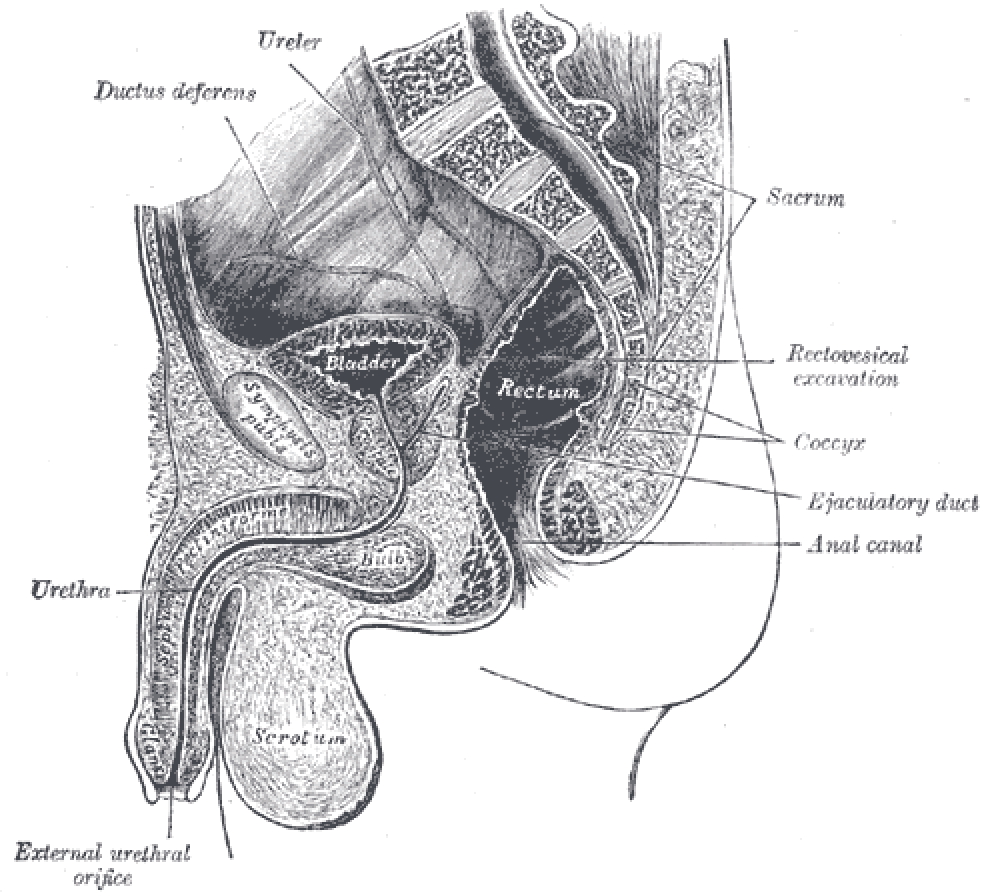
Median sagittal section of the sacrum



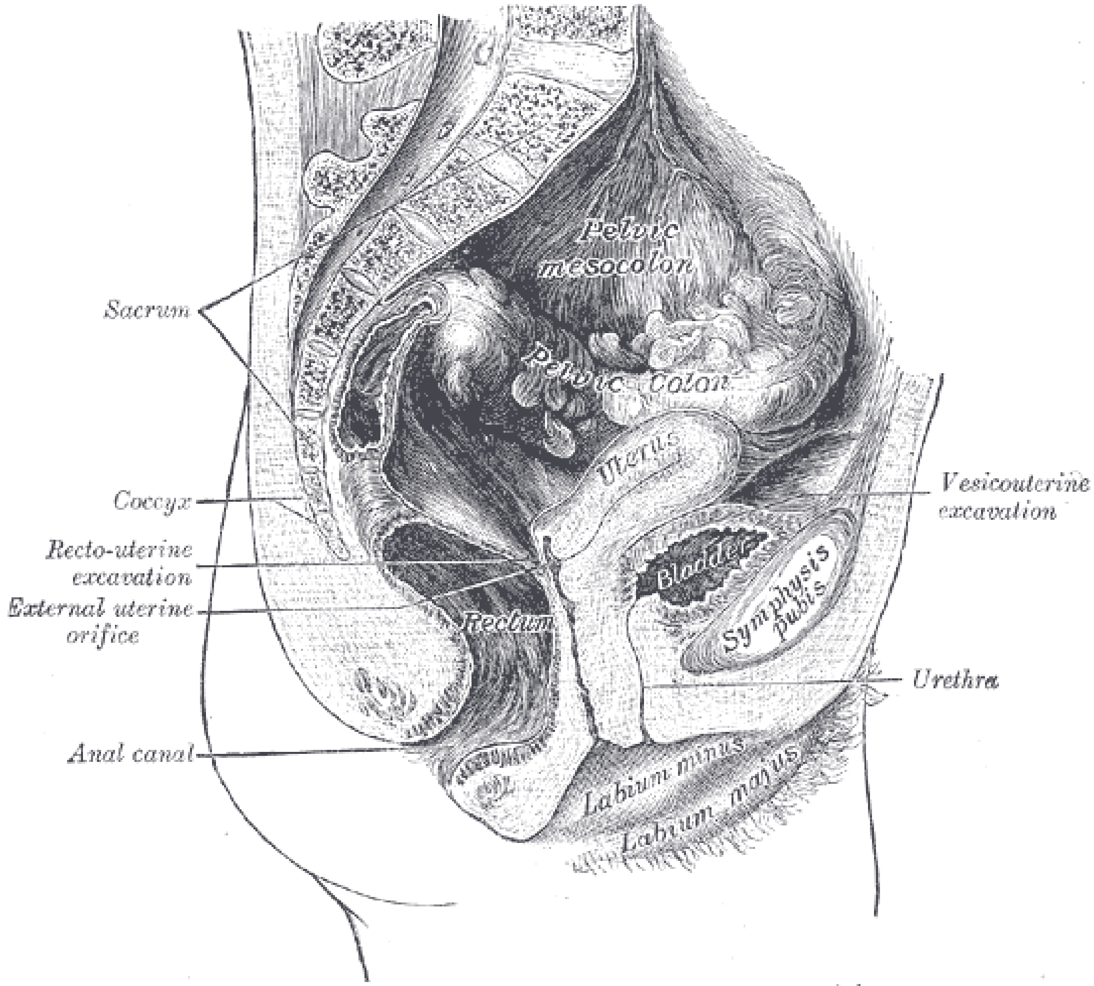
Left Levator ani from within



The posterior divisions of the sacral nerves



Median sagittal section of male pelvis

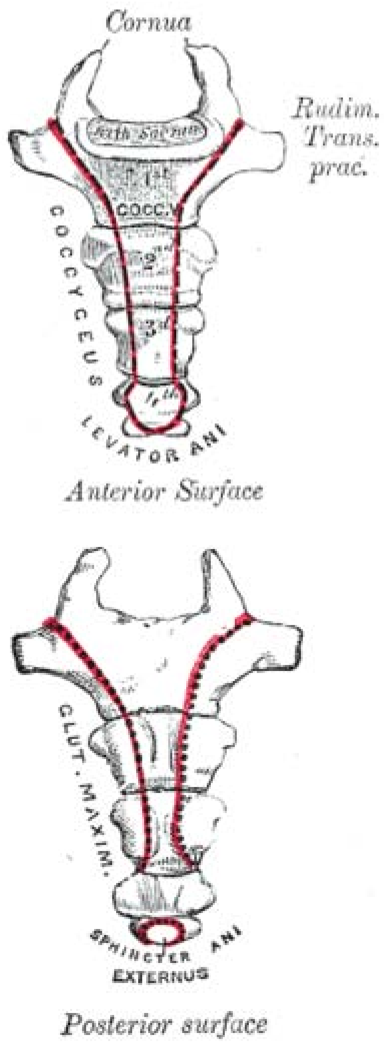


Median sagittal section of female pelvis

Chapter 13

Coccyx

Bone: Coccyx



A coccyx with four vertebrae below the sacrum.

Latin	*os coccygis*
Gray's	*subject #24 186*
MeSH	*Coccyx*

The **coccyx** is the final segment of the ape vertebral column. Comprising three to five separate or fused vertebrae (the coccygeal vertebrae) below the sacrum, it is attached to the sacrum by a fibrocartilaginous joint, the sacrococcygeal symphysis, which permits limited movement between the sacrum and the coccyx.

The term *coccyx* comes originally from the Greek κόκκυξ and means "cuckoo", referring to the curved shape of a cuckoo's beak when viewed from the side.

Function

In humans and other tailless primates (e.g. great apes) since *Nacholaphitecus* (a Miocene hominoid), the coccyx is the remnant of a vestigial tail, but still not entirely useless; it is an important attachment for various muscles, tendons and ligaments — which makes it necessary for physicians and patients to pay special attention to these attachments when considering surgical removal of the coccyx. Additionally, it is also part of the weight-bearing tripod structure which act as a support for a sitting person. When a person sits leaning forward, the ischial tuberosities and inferior rami of the ischium take most of the weight, but as the sitting person leans backward, more weight is transferred to the coccyx.

The anterior side of the coccyx serves for the attachment of a group of muscles important for many functions of the pelvic floor (i.e. defecation, continence, etc.): The levator ani muscle, which include coccygeus, iliococcygeus, and pubococcygeus. Through the anococcygeal raphé, the coccyx supports the position of the anus. Attached to the posterior side is gluteus maximus which extend the thigh during ambulation.

Many important ligaments attach to the coccyx: The anterior and posterior sacrococcygeal ligaments are the continuations of the anterior and posterior longitudinal ligaments that stretches along the entire spine. Additionally, the lateral sacrococcygeal ligaments complete the foramina for the last sacral nerve. And, lastly, some fibers of the sacrospinous and sacrotuberous ligaments (arising from the spine of the ischium and the ischial tuberosity respectively) also attach to the coccyx.

An extension of the pia mater, the filum terminale, extends from the apex of the conus, and inserts on the coccyx.

Structure

The coccyx is usually formed of four rudimentary vertebrae (sometimes five or three). It articulates superiorly with the sacrum. In each of the first three segments may be traced a rudimentary body and articular and transverse processes; the last piece (sometimes the third) is a mere nodule of bone. The transverse processes are most prominent and noticeable on the first coccygeal segment. All the segments are destitute of pedicles, laminae and spinous processes. The first is the largest; it resembles the lowest sacral vertebra, and often exists as a separate piece; the last three diminish in size from above downward.

Most anatomy books wrongly state that the coccyx is normally fused in adults. In fact it has been shown that the coccyx may consist of up to five separate bony segments, the most common configuration being two or three segments.

Surfaces

The anterior surface is slightly concave and marked with three transverse grooves that indicate the junctions of the different segments. It gives attachment to the anterior sacrococcygeal ligament and the Levatores ani and supports part of the rectum.The posterior surface is convex marked by transverse grooves similar to those on the anterior surface, and presents on either side a linear row of tubercles, the rudimentary articular processes of the coccygeal vertebrae. Of these, the superior pair are large, and are called the coccygeal cornua; they project upward, and articulate with the cornua of the sacrum, and on either side complete the foramen for the transmission of the posterior division of the fifth sacral nerve.

Borders

The lateral borders are thin and exhibit a series of small eminences, which represent the transverse processes of the coccygeal vertebrae. Of these, the first is the largest; it is flattened from before backward, and often ascends to join the lower part of the thin lateral edge of the sacrum, thus completing the foramen for the transmission of the anterior division of the fifth sacral nerve; the others diminish in size from above downward, and are often wanting. The borders of the coccyx are narrow, and give attachment on either side to the sacrotuberous and sacrospinous ligaments, to the coccygeus in front of the ligaments, and to the gluteus maximus behind them.

Apex

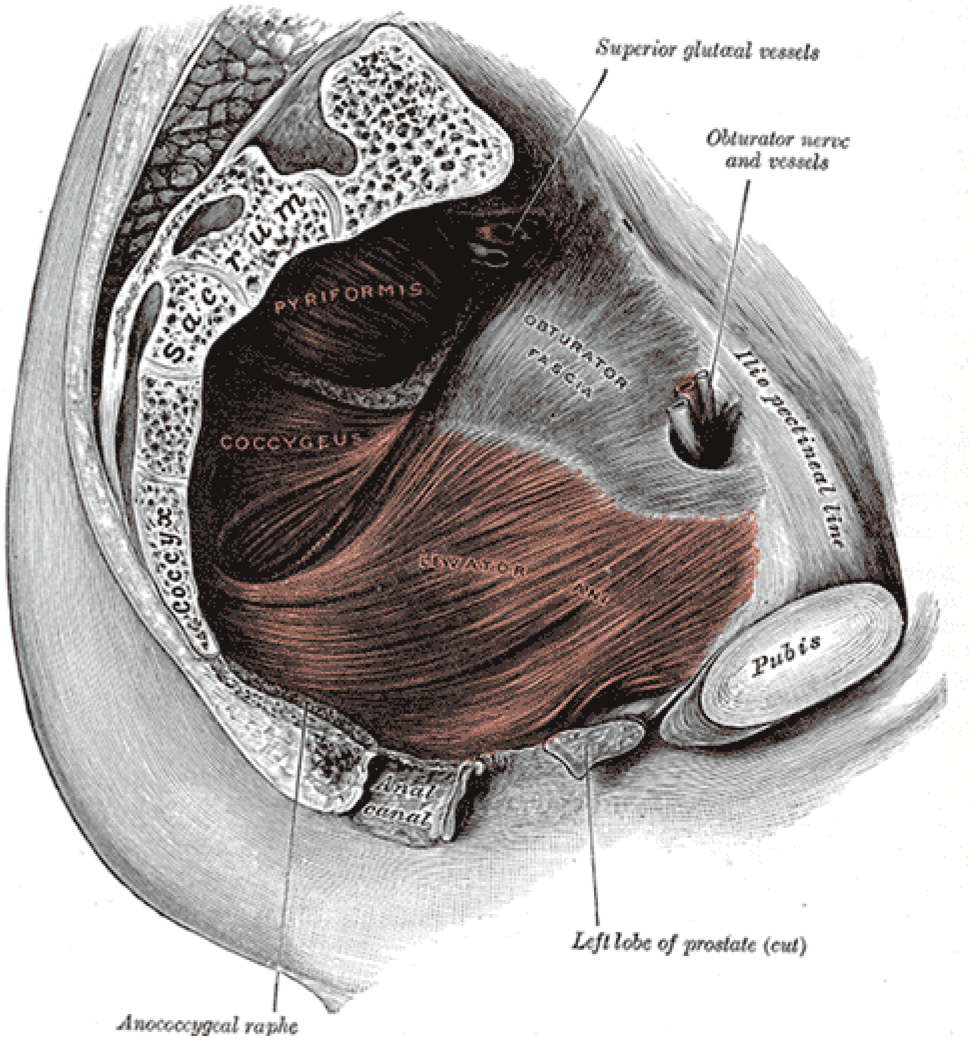
The apex is rounded, and has attached to it the tendon of the Sphincter ani externus. It may be bifid.

Sacrococcygeal and intercoccygeal joints

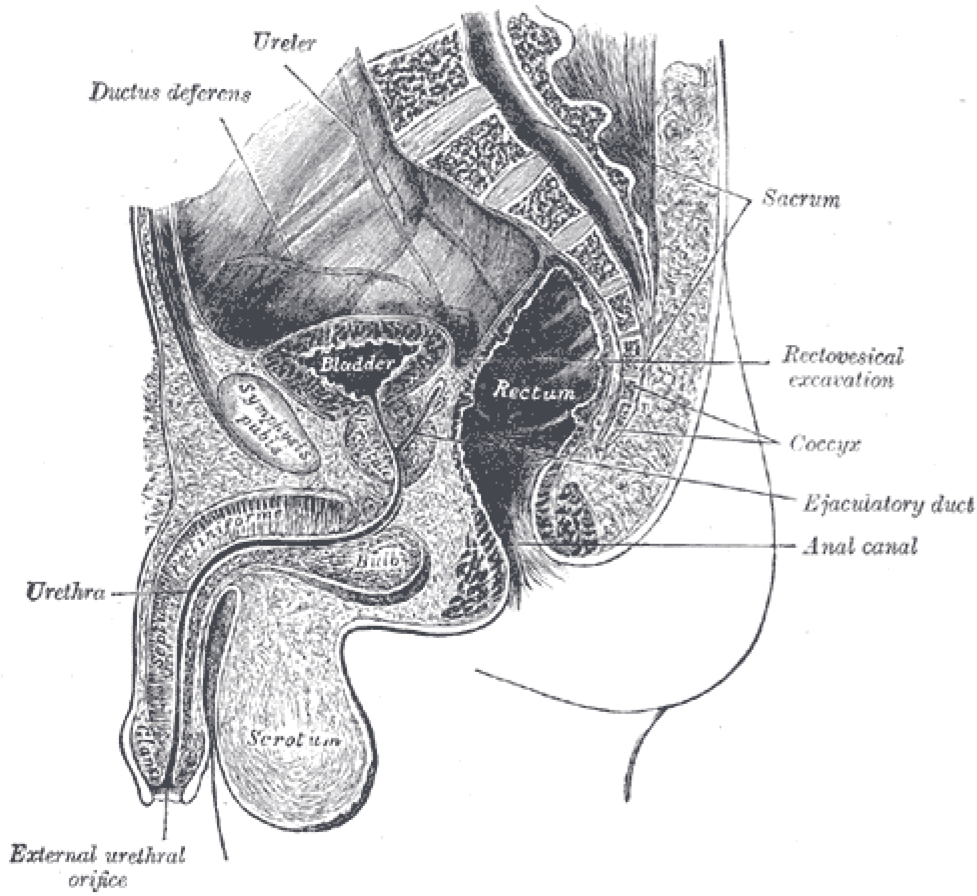
The joints are variable and may be: (1) synovial joints; (2) thin discs of fibrocartilage; (3) intermediate between these two; (4) ossified.

Pathology

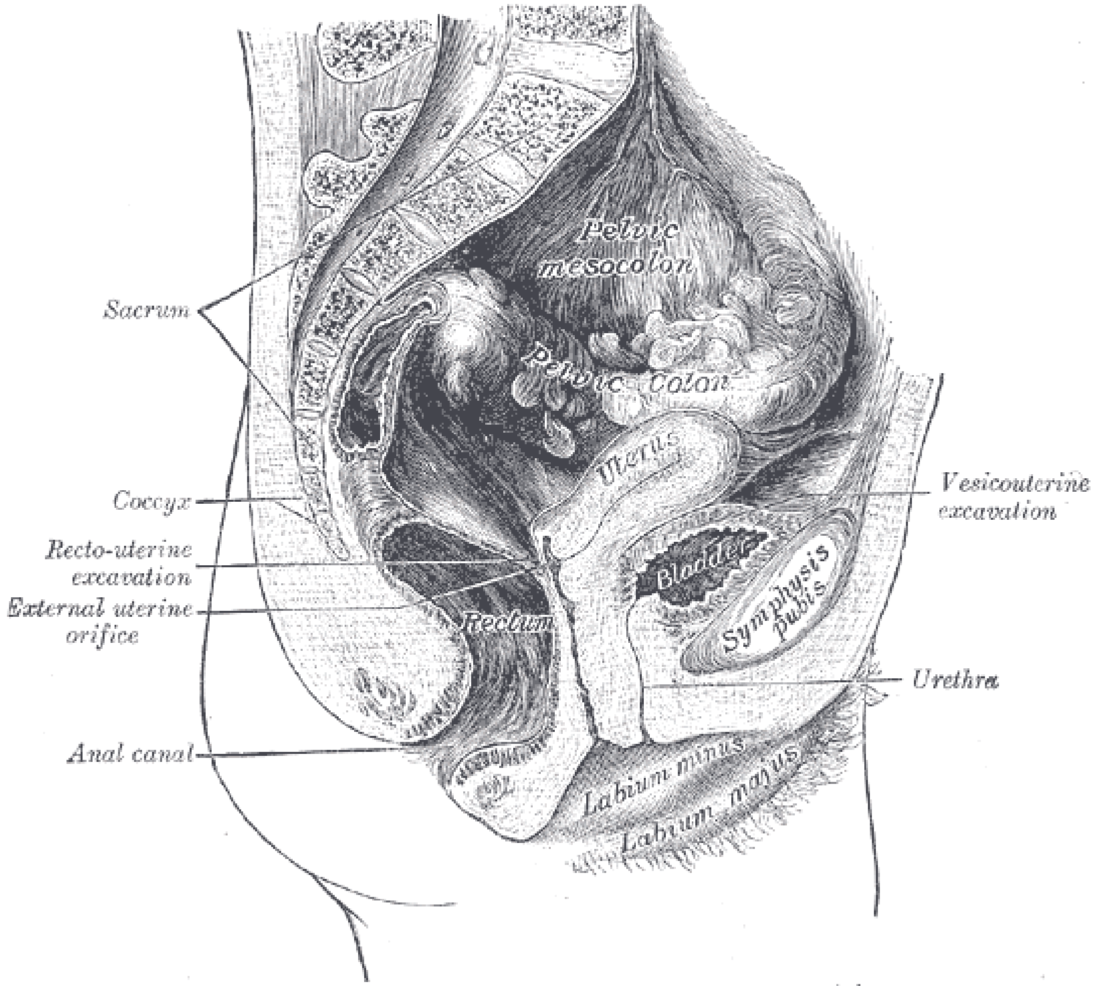
Injuring the coccyx can give rise to a condition called coccydynia. A number of tumors are known to involve the coccyx; of these, the most common is sacrococcygeal teratoma. Both coccydynia and coccygeal tumors may require surgical removal of the coccyx (coccygectomy). One complication of cocygectomy is a coccygeal hernia. Fortunately, most cases of coccyx pain respond well to nonsurgical treatment, such as medications given by local injection (often done under fluoroscopic guidance).



Left Levator ani from within



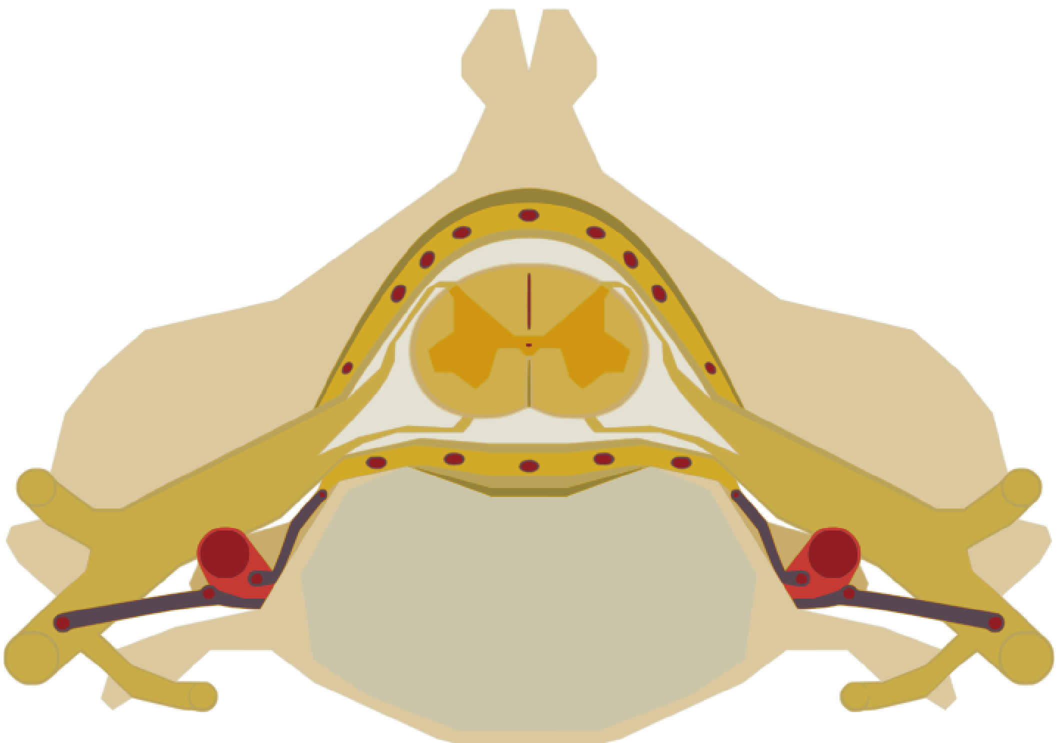
Median sagittal section of male pelvis



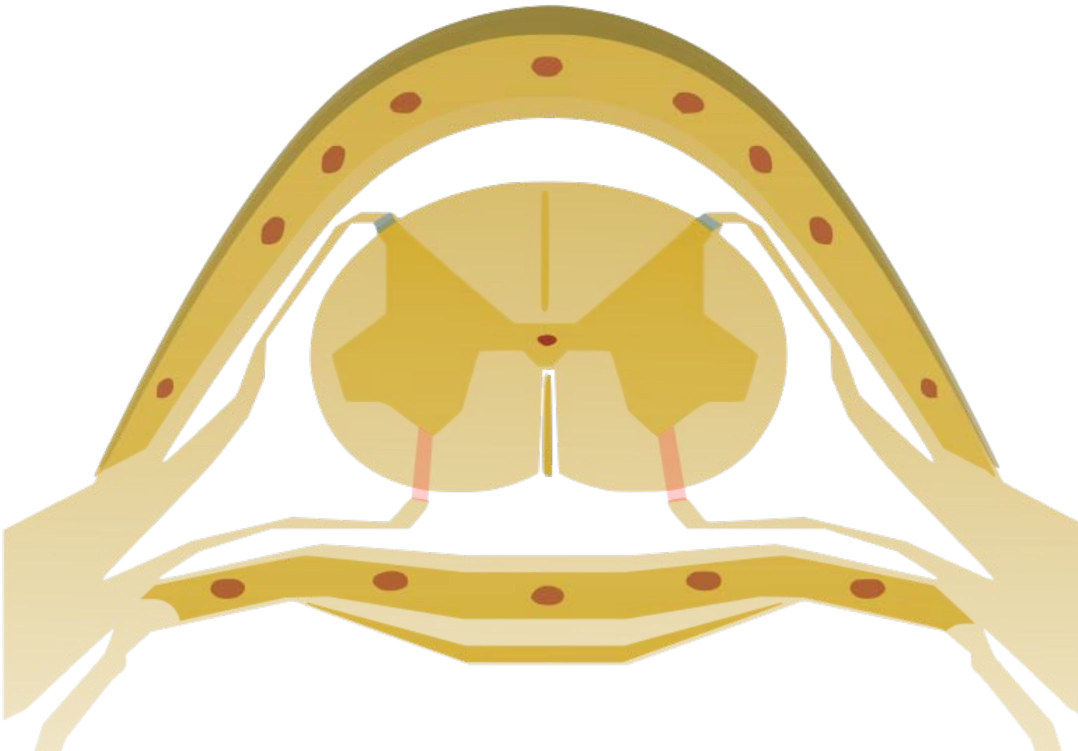
Median sagittal section of female pelvis

Chapter 14

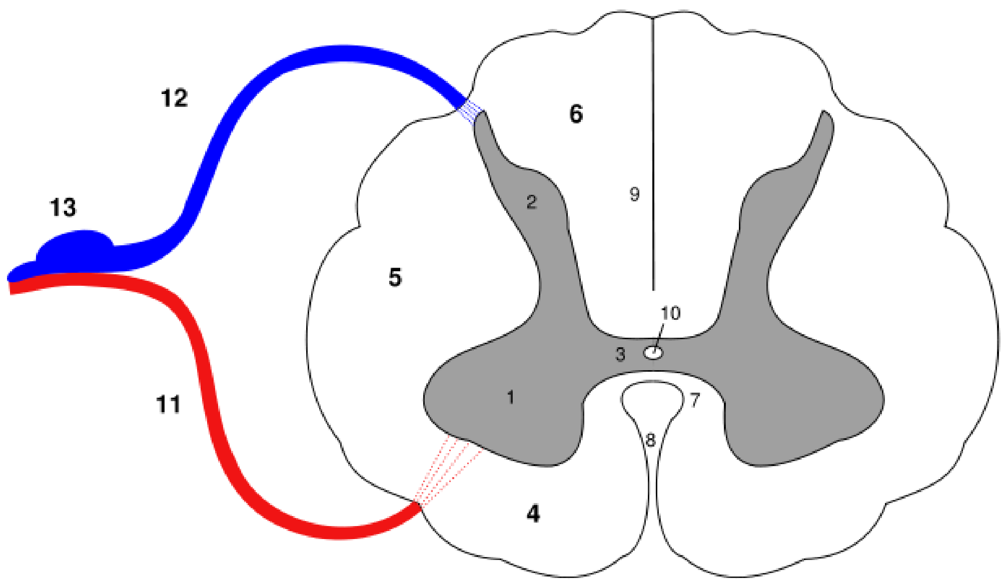
Spinal Cord



The spinal cord nested in the vertebral column



A closer look at the spinal cord



Gray matter

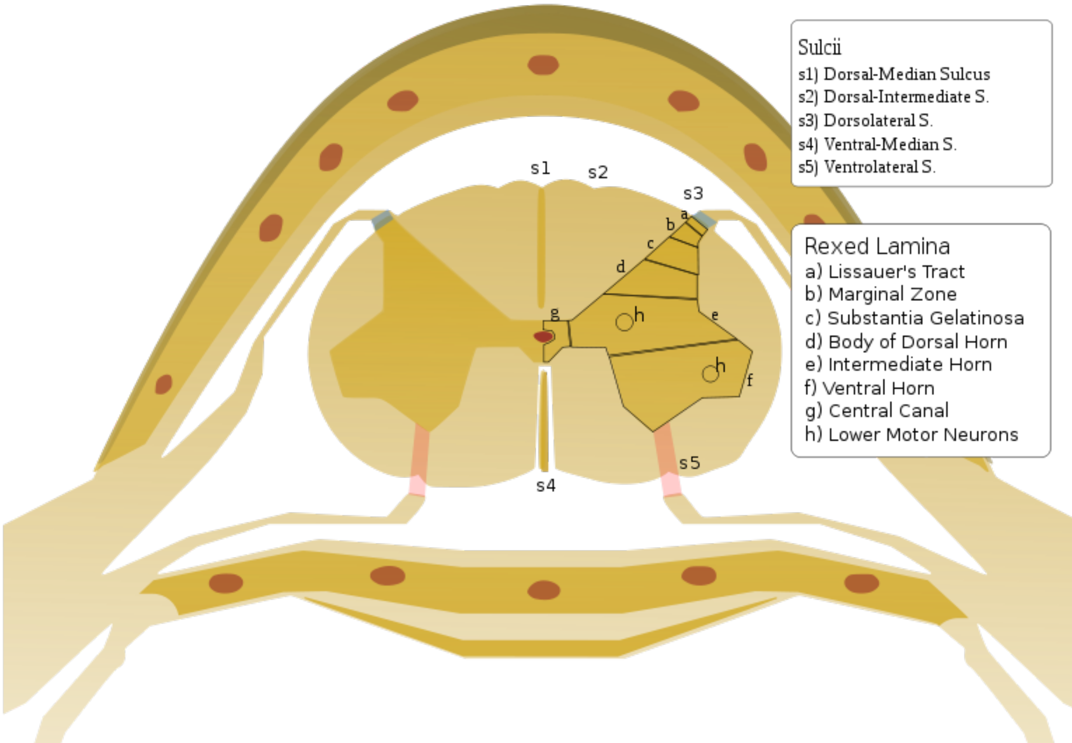
1. Anterior horn
2. Posterior horn
3. Gray commisure

White matter

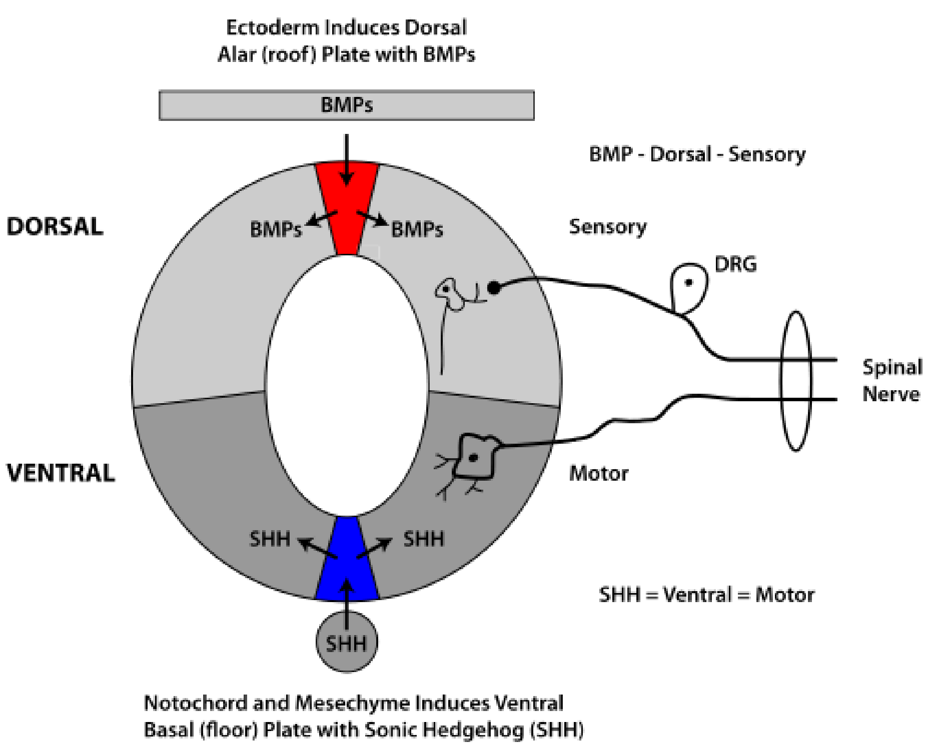
4. Anterior funiculus
5. Lateral funiculus
6. Posterior funiculus
7. Anterior commisure
8. Anterior median fissure
9. Posterior median sulcus

10. Central canal
11. Anterior root
12. Posterior root
13. Dorsal root ganglion

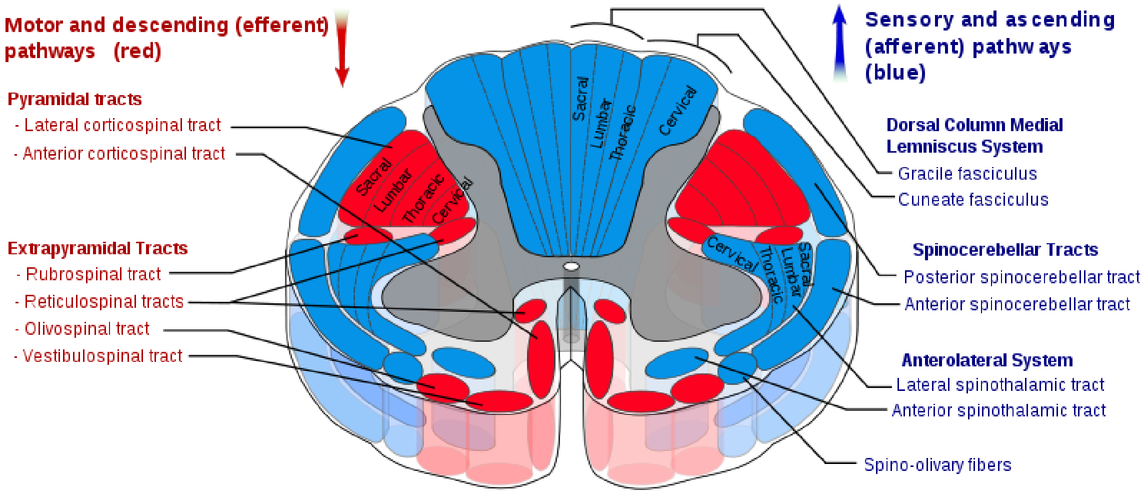
Cross-section through cervical spinal cord



Gray matter's rexed lamina

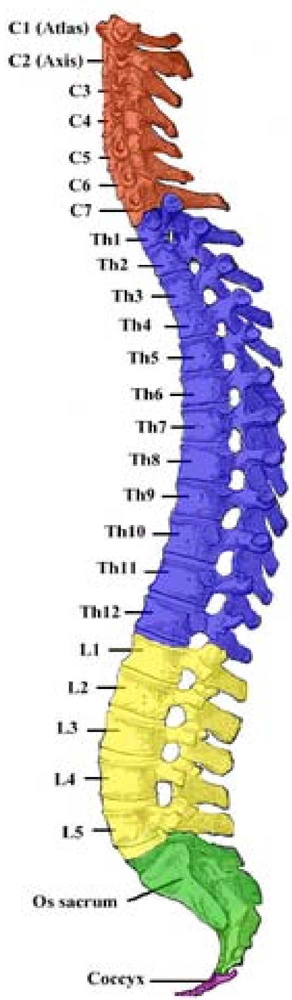


Spinal cord development of the alar and basal plates



Spinal cord tracts

Divisions of Spinal Segments



Segmental Spinal Cord Level and Function	
Level	**Function**
C1-C6	Neck flexors
C1-T1	Neck extensors
C3, C4, C5	Supply diaphragm (mostly C4)
C5, C6	Shoulder movement, raise arm (deltoid); flexion of elbow (biceps); **C6** externally rotates the arm (supinates)
C6, C7	Extends elbow and wrist (triceps and wrist extensors); pronates wrist
C7, T1	Flexes wrist
C7, T1	Supply small muscles of the hand
T1 -T6	Intercostals and trunk above the waist
T7-L1	Abdominal muscles
L1, L2, L3, L4	Thigh flexion
L2, L3, L4	Thigh adduction
L4, L5, S1	Thigh abduction
L5, S1, S2	Extension of leg at the hip (gluteus maximus)
L2, L3, L4	Extension of leg at the knee (quadriceps femoris)
L4, L5, S1, S2	Flexion of leg at the knee (hamstrings)
L4, L5, S1	Dorsiflexion of foot (tibialis anterior)
L4, L5, S1	Extension of toes
L5, S1, S2	Plantar flexion of foot

L5, S1, S2	Flexion of toes

The **spinal cord** is a long, thin, tubular bundle of nervous tissue and support cells that extends from the brain (the medulla oblongata specifically). The brain and spinal cord together make up the central nervous system. The spinal cord begins at the Occipital bone and extends down to the space between the first and second lumbar vertebrae; it does not extend the entire length of the vertebral column. It is around 45 cm (18 in) in men and around 43 cm (17 in) long in women. Also, the spinal cord has a varying width, ranging from 1/2 inch thick in the cervical and lumbar regions to 1/4 inch thick in the thoracic area. The enclosing bony vertebral column protects the relatively shorter spinal cord. The spinal cord functions primarily in the transmission of neural signals between the brain and the rest of the body but also contains neural circuits that can independently control numerous reflexes and central pattern generators. The spinal cord has three major functions: A. Serve as a conduit for motor information, which travels down the spinal cord. B. Serve as a conduit for sensory information, which travels up the spinal cord. C. Serve as a center for coordinating certain reflexes.

Structure

The spinal cord is the main pathway for information connecting the brain and peripheral nervous system. The length of the spinal cord is much shorter than the length of the bony spinal column. The human spinal cord extends from the medulla oblongata and continues through the conus medullaris near the first or second lumbar vertebra, terminating in a fibrous extension known as the filum terminale.

It is about 45 cm (18 in) long in men and around 43 cm (17 in) in women, ovoid-shaped, and is enlarged in the cervical and lumbar regions. The cervical enlargement, located from C4 to T1, is where sensory input comes from and motor output goes to the arms. The lumbar enlargement, located between L4 and S3, handles sensory input and motor output coming from and going to the legs.

The spinal cord is protected by three layers of tissue, called spinal meninges, that surround the canal. The dura mater is the outermost layer, and it forms a tough protective coating. Between the dura mater and the surrounding bone of the vertebrae is a space called the epidural space. The epidural space is filled with adipose tissue, and it contains a network of blood vessels. The arachnoid mater is the middle protective layer. Its name comes from the fact that the tissue has a spiderweb-like appearance. The space between the arachnoid and the underlyng pia mater is called the subarachnoid space. The subarachnoid space contains cerebrospinal fluid (CSF). The medical procedure known as a lumbar puncture (or *spinal tap*) involves use of a needle to withdraw cerebrospinal fluid from the subarachnoid space, usually from the lumbar region of the spine. The pia mater is the innermost protective layer. It is very delicate and it is tightly associated with the surface of the spinal cord. The cord is stabilized within the dura mater by the connecting denticulate ligaments, which extend from the enveloping pia mater laterally between the dorsal and ventral roots. The *dural sac* ends at the vertebral level of the second sacral vertebra.

In cross-section, the peripheral region of the cord contains neuronal white matter tracts containing sensory and motor neurons. Internal to this peripheral region is the gray, butterfly-shaped central region made up of nerve cell bodies. This central region surrounds the central canal, which is an anatomic extension of the spaces in the brain known as the ventricles and, like the ventricles, contains cerebrospinal fluid.

The spinal cord has a shape that is compressed dorso-ventrally, giving it an elliptical shape. The cord has grooves in the dorsal and ventral sides. The posterior median sulcus is the groove in the dorsal side, and the anterior median fissure is the groove in the ventral side.

Spinal cord segments

The human spinal cord is divided into 31 different segments. At every segment, right and left pairs of spinal nerves (mixed; sensory and motor) form. Six to eight motor nerve rootlets branch out of right and left ventro lateral sulci in a very orderly manner. Nerve rootlets combine to form nerve roots. Likewise, sensory nerve rootlets form off right and left dorsal lateral sulci and form sensory nerve roots. The ventral (motor) and dorsal (sensory) roots combine to form spinal nerves (mixed; motor and sensory), one on each side of the spinal cord. Spinal nerves, with the exception of C1 and C2, form inside intervertebral foramen (IVF). Note that at each spinal segment, the border between the central and peripheral nervous system can be observed. Rootlets are a part of the peripheral nervous system.

In the upper part of the vertebral column, spinal nerves exit directly from the spinal cord, whereas in the lower part of the vertebral column nerves pass further down the column before exiting. The terminal portion of the spinal cord is called the conus medullaris. The pia mater continues as an extension called the filum terminale, which anchors the spinal cord to the coccyx. The cauda equina ("horse's tail") is the name for the collection of nerves in the vertebral column that continue to travel through the vertebral column below the conus medullaris. The cauda equina forms as a result of the fact that the spinal cord stops growing in length at about age four, even though the vertebral column continues to lengthen until adulthood. This results in the fact that sacral spinal nerves actually originate in the upper lumbar region. The spinal cord can be anatomically divided into 31 spinal segments based on the origins of the spinal nerves.

Each segment of the spinal cord is associated with a pair of ganglia, called dorsal root ganglia, which are situated just outside of the spinal cord. These ganglia contain cell bodies of sensory neurons. Axons of these sensory neurons travel into the spinal cord via the dorsal roots.

Ventral roots consist of axons from motor neurons, which bring information to the periphery from cell bodies within the CNS. Dorsal roots and ventral roots come together and exit the intervertebral foramina as they become spinal nerves.

The gray matter, in the center of the cord, is shaped like a butterfly and consists of cell bodies of interneurons and motor neurons. It also consists of neuroglia cells and unmyelinated axons. Projections of the gray matter (the “wings”) are called horns. Together, the gray horns and the gray commissure form the “gray H.”

The white matter is located outside of the gray matter and consists almost totally of myelinated motor and sensory axons. “Columns” of white matter carry information either up or down the spinal cord.

Within the CNS, nerve cell bodies are generally organized into functional clusters, called nuclei. Axons within the CNS are grouped into tracts.

There are 33 (some EMS text say 25, counting the sacral as one solid piece) spinal cord nerve segments in a human spinal cord:

- 8 cervical segments forming 8 pairs of cervical nerves (C1 spinal nerves exit spinal column between occiput and C1 vertebra; C2 nerves exit between posterior arch of C1 vertebra and lamina of C2 vertebra; C3-C8 spinal nerves through IVF above corresponding cervica vertebra, with the exception of C8 pair which exit via IVF between C7 and T1 vertebra)
- 12 thoracic segments forming 12 pairs of thoracic nerves (exit spinal column through IVF below corresponding vertebra T1-T12)
- 5 lumbar segments forming 5 pairs of lumbar nerves (exit spinal column through IVF, below corresponding vertebra L1-L5)
- 5 (or 1) sacral segments forming 5 pairs of sacral nerves (exit spinal column through IVF, below corresponding vertebra S1-S5)
- 3 coccygeal segments joined up becoming a single segment forming 1 pair of coccygeal nerves (exit spinal column through the sacral hiatus).

Because the vertebral column grows longer than the spinal cord, spinal cord segments do not correspond to vertebral segments in adults, especially in the lower spinal cord. In the fetus, vertebral segments do correspond with spinal cord segments. In the adult, however, the spinal cord ends around the L1/L2 vertebral level, forming a structure known as the conus medullaris. For example, lumbar and sacral spinal cord segments are found between vertebral levels T9 and L2.

Although the spinal cord cell bodies end around the L1/L2 vertebral level, the spinal nerves for each segment exit at the level of the corresponding vertebra. For the nerves of the lower spinal cord, this means that they exit the vertebral column much lower (more caudally) than their roots. As these nerves travel from their respective roots to their point of exit from the vertebral column, the nerves of the lower spinal segments form a bundle called the cauda equina.

There are two regions where the spinal cord enlarges:

- Cervical enlargement - corresponds roughly to the brachial plexus nerves, which innervate the upper limb. It includes spinal cord segments from about C4 to T1. The vertebral levels of the enlargement are roughly the same (C4 to T1).

- Lumbosacral enlargement - corresponds to the lumbosacral plexus nerves, which innervate the lower limb. It comprises the spinal cord segments from L2 to S3 and is found about the vertebral levels of T9 to T12.

Embryology

The spinal cord is made from part of the neural tube during development. As the neural tube begins to develop, the notochord begins to secrete a factor known as Sonic hedgehog or SHH. As a result, the floor plate then also begins to secrete SHH, and this will induce the basal plate to develop motor neurons. Meanwhile, the overlying ectoderm secretes bone morphogenetic protein (BMP). This induces the roof plate to begin to secrete BMP, which will induce the alar plate to develop sensory neurons. The alar plate and the basal plate are separated by the sulcus limitans.

Additionally, the floor plate also secretes netrins. The netrins act as chemoattractants to decussation of pain and temperature sensory neurons in the alar plate across the anterior white commissure, where they then ascend towards the thalamus.

Lastly, it is important to note that the past studies of Viktor Hamburger and Rita Levi-Montalcini in the chick embryo have been further proven by more recent studies which demonstrated that the elimination of neuronal cells by programmed cell death (PCD) is necessary for the correct assembly of the nervous system.

Overall, spontaneous embryonic activity has been shown to play a role in neuron and muscle development but is probably not involved in the initial formation of connections between spinal neurons.

Somatosensory organization

Somatosensory organization is divided into the dorsal column-medial lemniscus tract (the touch/proprioception/vibration sensory pathway) and the anterolateral system, or ALS (the pain/temperature sensory pathway). Both sensory pathways use three different neurons to get information from sensory receptors at the periphery to the cerebral cortex. These neurons are designated primary, secondary and tertiary sensory neurons. In both pathways, primary sensory neuron cell bodies are found in the dorsal root ganglia, and their central axons project into the spinal cord.

In the dorsal column-medial leminiscus tract, a primary neuron's axon enters the spinal cord and then enters the dorsal column. If the primary axon enters below spinal level T6, the axon travels in the fasciculus gracilis, the medial part of the column. If the axon enters above level T6, then it travels in the fasciculus cuneatus, which is lateral to the fasiculus gracilis. Either way, the primary axon ascends to the lower medulla, where it leaves its fasiculus and synapses with a secondary neuron in one of the dorsal column nuclei: either the nucleus gracilis or the nucleus cuneatus, depending on the pathway it took. At this point, the secondary axon leaves its nucleus and passes anteriorly and medially. The collection of secondary axons that do this are known as internal arcuate fibers. The internal arcuate fibers decussate and continue ascending as the contralateral medial lemniscus. Secondary axons from the medial lemniscus finally terminate in the ventral posterolateral nucleus (VPL) of the thalamus, where they synapse with tertiary neurons. From there, tertiary neurons ascend via the posterior limb of the internal capsule and end in the primary sensory cortex.

The anterolateral system works somewhat differently. Its primary neurons enter the spinal cord and then ascend one to two levels before synapsing in the substantia gelatinosa. The tract that ascends before synapsing is known as Lissauer's tract. After synapsing, secondary axons decussate and ascend in the anterior lateral portion of the spinal cord as the spinothalamic tract. This tract ascends all the way to the VPL, where it synapses on tertiary neurons. Tertiary neuronal axons then travel to the primary sensory cortex via the posterior limb of the internal capsule.

It should be noted that some of the "pain fibers" in the ALS deviate from their pathway towards the VPL. In one such deviation, axons travel towards the reticular formation in the midbrain. The reticular formation then projects to a number of places including the hippocampus (to create memories about the pain), the centromedian nucleus (to cause diffuse, non-specific pain) and various parts of the cortex. Additionally, some ALS axons project to the periaqueductal gray in the pons, and the axons forming the periaqueductal gray then project to the nucleus raphe magnus, which projects back down to where the pain signal is coming from and inhibits it. This helps control the sensation of pain to some degree.

Motor organization

The corticospinal tract serves as the motor pathway for upper motor neuronal signals coming from the cerebral cortex and from primitive brainstem motor nuclei.

Cortical upper motor neurons originate from Brodmann areas 1, 2, 3, 4, and 6 and then descend in the posterior limb of the internal capsule, through the crus cerebri, down through the pons, and to the medullary pyramids, where about 90% of the axons cross to the contralateral side at the decussation of the pyramids. They then descend as the lateral corticospinal tract. These axons synapse with lower motor neurons in the ventral horns of all levels of the spinal cord. The remaining 10% of axons descend on the ipsilateral side as the ventral corticospinal tract. These axons also synapse with lower motor neurons in the ventral horns. Most of them will cross to the contralateral side of the cord (via the anterior white commissure) right before synapsing.

The midbrain nuclei include four motor tracts that send upper motor neuronal axons down the spinal cord to lower motor neurons. These are the rubrospinal tract, the vestibulospinal tract, the tectospinal tract and the reticulospinal tract. The rubrospinal tract descends with the lateral corticospinal tract, and the remaining three descend with the anterior corticospinal tract.

The function of lower motor neurons can be divided into two different groups: the lateral corticospinal tract and the anterior cortical spinal tract. The lateral tract contains upper motor neuronal axons which synapse on dorsal lateral (DL) lower motor neurons. The DL neurons are involved in distal limb control. Therefore, these DL neurons are found specifically only in the cervical and lumbosaccral enlargements within the spinal cord. There is no decussation in the lateral corticospinal tract after the decussation at the medullary pyramids.

The proprioception of the lower limbs differs from the upper limbs & upper trunk. There is a 4 neuron pathway for lower limbs proprioception. This pathway initially follows the dorsal spino-cerebellar pathway. It is arranged as follows: proprioceptive receptors of lower limb -> peripheral process -> dorsal root ganglion -> central process -> clarks column -> 2nd order neuron -> medulla oblogata (neucleus z of broadal) -> 3rd order neuron -> VPL of thalamus -> 4th order neuron -> posterior limb of internal capsule -> corona radiata -> sensory area of cerebrum.

The anterior corticospinal tract descends ipsilaterally in the anterior column, where the axons emerge and either synapse on lower ventromedial (VM) motor neurons in the ventral horn ipsilaterally or descussate at the anterior white commissure where they synapse on VM lower motor neurons contralaterally . The tectospinal, vestibulospinal and reticulospinal descend ipsilaterally in the anterior column but do not synapse across the anterior white commissure. Rather, they only synapse on VM lower motor neurons ipsilaterally. The VM lower motor neurons control the large, postural muscles of the axial skeleton. These lower motor neurons, unlike those of the DL, are located in the ventral horn all the way throughout the spinal cord.

Spinocerebellar tracts

Proprioceptive information in the body travels up the spinal cord via three tracts. Below L2, the proprioceptive information travels up the spinal cord in the ventral spinocerebellar tract. Also known as the anterior spinocerebellar tract, sensory receptors take in the information and travel into the spinal cord. The cell bodies of these primary neurons are located in the dorsal root ganglia. In the spinal cord, the axons synapse and the secondary neuronal axons decussates and then travel up to the superior cerebellar peduncle where they decussate again. From here, the information is brought to deep nuclei of the cerebellum including the fastigial and interposed nuclei.

From the levels of L2 to T1, proprioceptive information enters the spinal cord and ascends ipsilaterally, where it synapses in Clarke's nucleus. The secondary neuronal axons continue to ascend ipsilaterally and then pass into the cerebellum via the inferior cerebellar peduncle. This tract is known as the dorsal spinocerebellar tract.

From above T1, proprioceptive primary axons enter the spinal cord and ascend ipsilaterally until reaching the accessory cuneate nucleus, where they synapse. The secondary axons pass into the cerebellum via the inferior cerebellar peduncle where again, these axons synapse on cerebellar deep nuclei. This tract is known as the cuneocerebellar tract.

Motor information travels from the brain down the spinal cord via descending spinal cord tracts. Descending tracts involve two neurons: the upper motor neuron (UMN) and lower motor neuron (LMN). A nerve signal travels down the upper motor neuron until it synapses with the lower motor neuron in the spinal cord. Then, the lower motor neuron conducts the nerve signal to the spinal root where efferent nerve fibers carry the motor signal toward the target muscle. The descending tracts are composed of white matter. There are several descending tracts serving different functions. The corticospinal tracts (lateral and anterior) are responsible for coordinated limb movements.

Injury

Spinal cord injuries can be caused by trauma to the spinal column ,(stretching, bruising, applying pressure, severing, laceration, etc.). The vertebral bones or intervertebral disks can shatter, causing the spinal cord to be punctured by a sharp fragment of bone. Usually, victims of spinal cord injuries will suffer loss of feeling in certain parts of their body. In milder cases, a victim might only suffer loss of hand or foot function. More severe injuries may result in paraplegia, tetraplegia, or full body paralysis (called Quadriplegia) below the site of injury to the spinal cord.

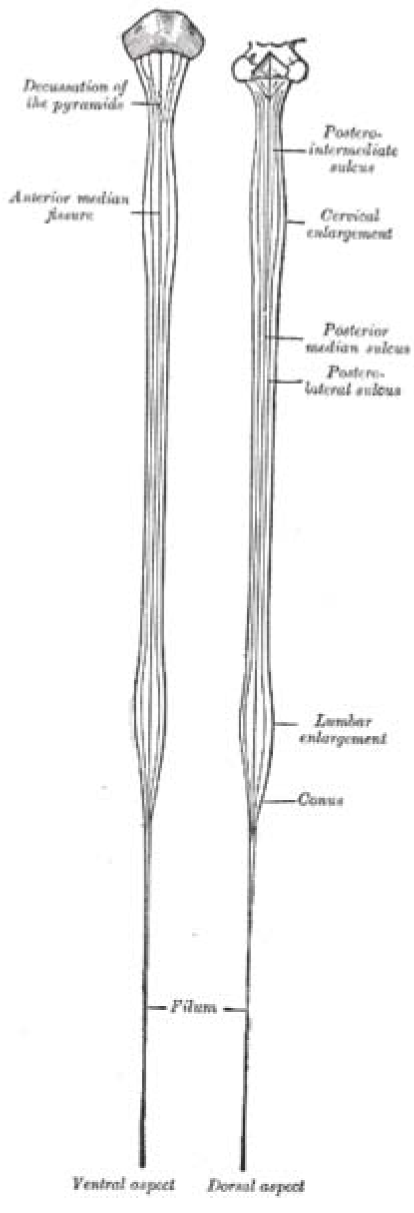
Damage to upper motor neuron axons in the spinal cord results in a characteristic pattern of ipsilateral deficits. These include hyperreflexia, hypertonia and muscle weakness. Lower motor neuronal damage results in its own characteristic pattern of deficits. Rather than an entire side of deficits, there is a pattern relating to the myotome affected by the damage. Additionally, lower motor neurons are characterized by muscle weakness, hypotonia, hyporeflexia and muscle atrophy.

Spinal shock and neurogenic shock can occur from a spinal injury. Spinal shock is usually temporary, lasting only for 24–48 hours, and is a temporary absence of sensory and motor functions. Neurogenic shock lasts for weeks and can lead to a loss of muscle tone due to disuse of the muscles below the injured site.

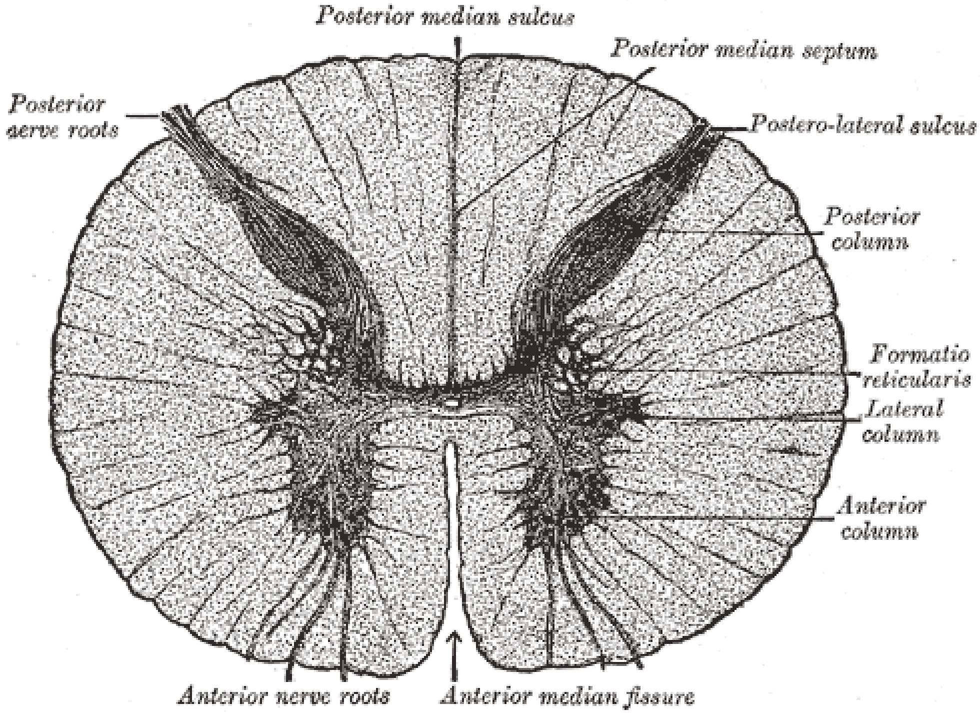
The two areas of the spinal cord most commonly injured are the cervical spine (C1-C7) and the lumbar spine (L1-L5). (The notation C1, C7, L1, L5 refer to the location of a specific vertebra in either the cervical, thoracic, or lumbar region of the spine.)

Spinal cord genomic map

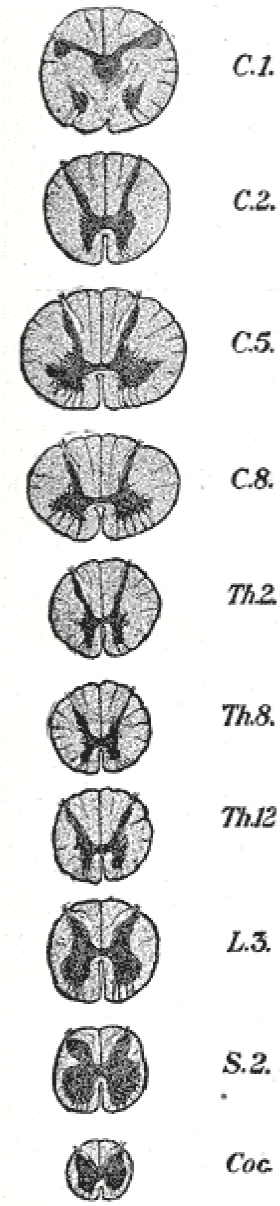
The Allen Institute for Brain Science, on July 16, 2008, launched the online "Allen Spinal Cord Atlas" (backed by Paul Allen). Its first release included 4000 sets of digital images, showing spatial expression patterns for various genes. When complete, it is planned to map 20,000 genes in adult and juvenile mouse spinal cords. The spinal cord atlas is organized like the Allen Institute's earlier atlas of the mouse brain. The Spinal Cord



Diagrams of the spinal cord



Cross-section through the spinal cord at the mid-thoracic level



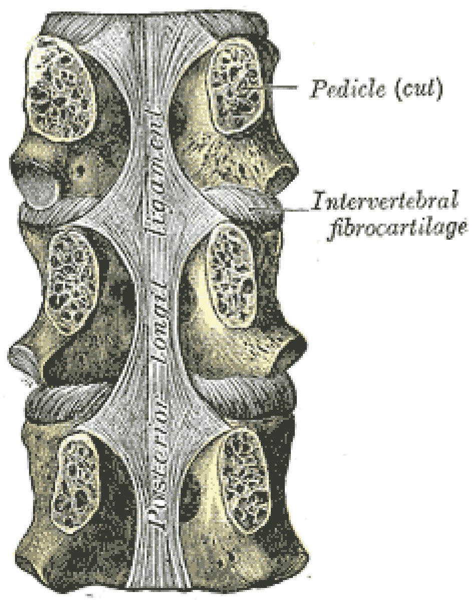
Cross-sections of the spinal cord at varying levels

Chapter 15

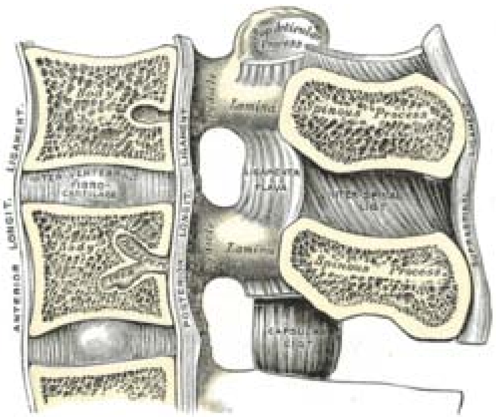
Posterior Longitudinal Ligament and Posterior Mediastinum

Posterior longitudinal ligament

Ligament: Posterior longitudinal ligament



Posterior longitudinal ligament, in the thoracic region.
(Posterior longitudinal ligament runs vertically at center.)



Median sagittal section of two lumbar vertebræ and their ligaments. (Posterior longitudinal ligament runs vertically at center left.)

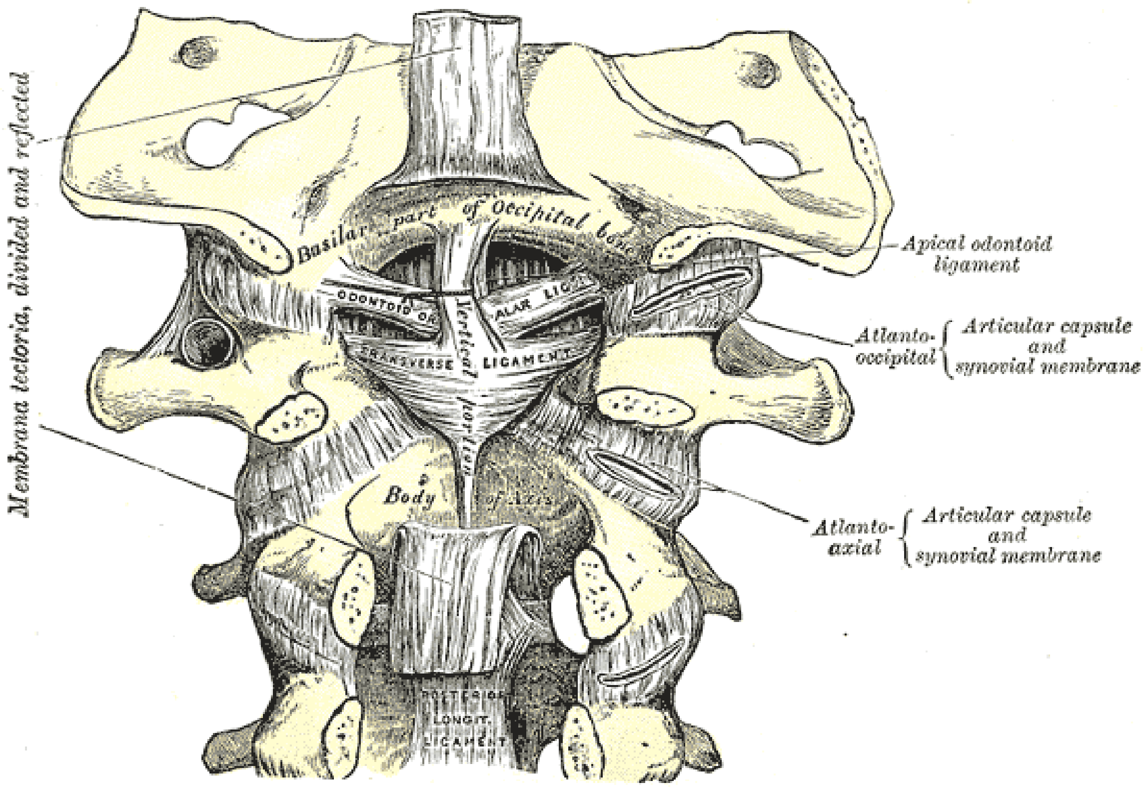
Latin	*ligamentum longitudinale posterius*
Gray's	*subject #72 288*
From	
To	
Dorlands/Elsevier	*l_09/12492528*

The **posterior longitudinal ligament** is situated within the vertebral canal, and extends along the posterior surfaces of the bodies of the vertebræ, from the body of the axis, where it is continuous with the membrana tectoria, to the sacrum.

It is broader above than below, and thicker in the than in the cervical and lumbar regions. The ligament is more narrow at the vertebral bodies and wider at the intervertebral disc space which is more pronounced than the anterior longitudinal ligament. This is significant in understanding certain pathological conditions of the spine such as the typical location for a spinal disc herniation.

In the situation of the intervertebral fibrocartilages and contiguous margins of the vertebræ, where the ligament is more intimately adherent, it is broad, and in the thoracic and lumbar regions presents a series of dentations with intervening concave margins; but it is narrow and thick over the centers of the bodies, from which it is separated by the basivertebral veins.

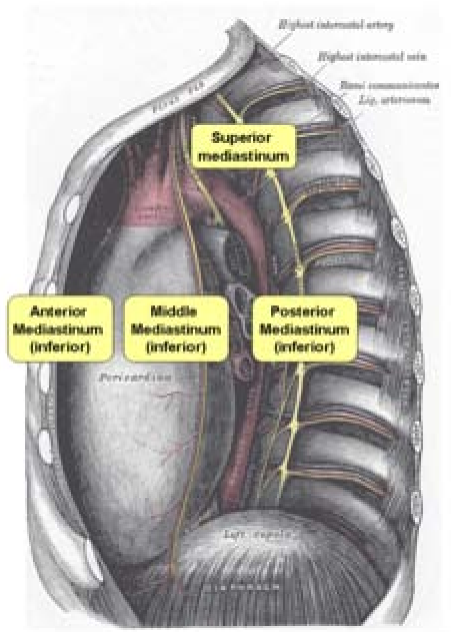
This ligament is composed of smooth, shining, longitudinal fibers, denser and more compact than those of the anterior ligament, and consists of superficial layers occupying the interval between three or four vertebræ, and deeper layers which extend between adjacent vertebræ.



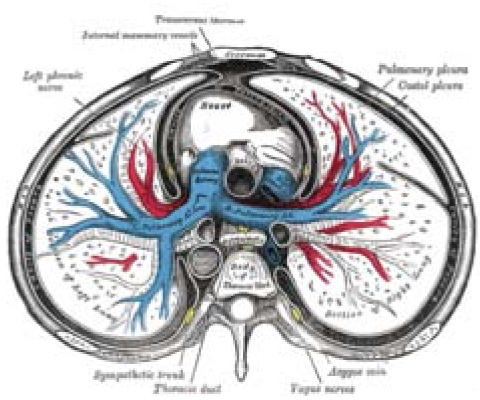
Membrana tectoria, transverse, and alar ligaments

Posterior mediastinum

Posterior mediastinum



Mediastinum



A transverse section of the thorax, showing the contents of the middle and the posterior mediastinum.

Latin	*mediastinum posterius*
Gray's	*subject #239 1093*

The **posterior mediastinum** is an irregular triangular space running parallel with the vertebral column.

Boundaries

It is bounded:

- anteriorly by the pericardium (in front of)
- inferiorly by the thoracic surface of the diaphragm (below).
- superiorly by the transverse thoracic plane (above). This plane is marked by an imaginary line travelling through the manubriosternal joint to the dividing line between the fourth and fifth thoracic vertebrae.
- posteriorally by the bodies of the vertebral column from the lower border of the fifth to the twelfth thoracic vertebra (behind).
- laterally: by the mediastinal pleura (on either side)

Content

- artery
  - thoracic part of the descending aorta
- veins
  - azygos vein
  - the hemiazygos vein and the accessory hemiazygos vein
- nerves
  - vagus nerve
  - splanchnic nerves (but not the sympathetic chain)
- esophagus
- thoracic duct
- some lymph glands

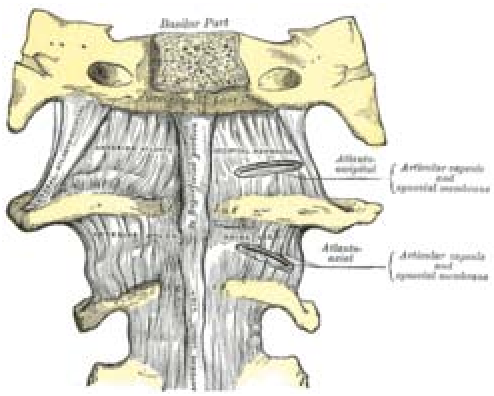
The contents of posterior mediastinum can be remembered using the mnemonic, "**DATES**", for **D**escending aorta, **A**zygous vein and hemiazygos vein, **T**horacic duct, **E**sophagus, **S**ympathetic trunk/ganglia.

Chapter 16

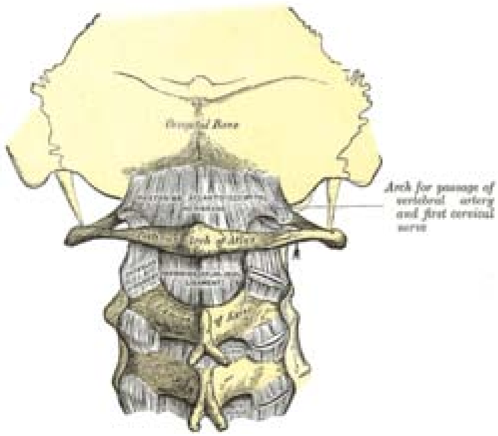
Atlanto-Axial Joint and Cauda Equina

Atlanto-axial joint

Atlanto-axial joint



Anterior atlantoöccipital membrane and atlantoaxial ligament.



Posterior atlantoöccipital membrane and atlantoaxial ligament.

Latin *articulatio atlantoaxialis mediana, articulatio* *atlantoaxialis lateralis*

Gray's *subject #73 292*

MeSH *Atlanto-Axial+Joint*

The **Atlanto-axial joint** (**articulation of the atlas with the axis**) is of a complicated nature. It consists of no fewer than four distinct joints.

There is a pivot articulation between the odontoid process of the axis and the ring formed by the anterior arch and the transverse ligament of the atlas.

Lateral and medial joints

There are two atlanto-axial joints: median and lateral:

- The median atlantoaxial joint is sometimes considered a double joint:
    - one between the posterior surface of the anterior arch of atlas and the front of the odontoid process
    - one between the anterior surface of the ligament and the back of the odontoid process

- The lateral atlantoaxial joint involves the lateral mass of atlas and axis. Between the articular processes of the two bones there is on either side an arthrodial or gliding joint.

Ligaments

The ligaments connecting these bones are:

- Articular capsules
- Anterior atlantoaxial ligament
- Posterior atlantoaxial ligament
- Transverse ligament of the atlas

The atlantoaxial joint in common terminology is actually a composition of three: two lateral and one median atlantoaxial joints. Because of its proximity to the brain stem and importance in stabilization, fracture or injury at this level can be catastrophic. Common trauma and pathologies include (but are not limited to):

The Dens: significant depression on the skull can push the dens into the brainstem, causing death. The dens itself is vulnerable to fracture due to trauma or ossification.

Transverse ligament: Should the transverse ligament of the atlas fail due to trauma or disease, the dens is no longer anchored and can travel up the cervical spine, causing paralysis. If it reaches the medulla death can result. Alar ligaments: stress or trauma can stretch the weaker alar ligaments, causing an increase in range of motion of approximately 30%.

Posterior Atlanto-Occipital Membrane: genetic traits can sometimes result in ossification, turning the groove into an foramen.

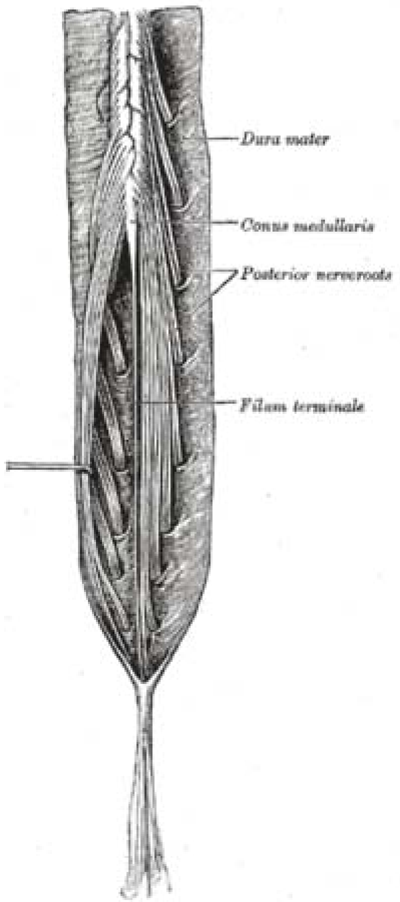
Dalley, Arthur F; Moore, Keith L. Clinically Oriented Anatomy Fourth Edition. Baltimore. Lippincott Williams & Wilkins, 1992. Saladin, Kenneth S. Anatomy &Physiology: the Unity of Form and Function. New York. McGraw Hill, 2007.

Capsule

The atlantoaxial articular capsules are thin and loose, and connect the margins of the lateral masses of the atlas with those of the posterior articular surfaces of the axis.

Each is strengthened at its posterior and medial part by an accessory ligament, which is attached below to the body of the axis near the base of the odontoid process, and above to the lateral mass of the atlas near the transverse ligament.

Cauda equina

Cauda equina	
	
Cauda equina and filum terminale seen from behind.	
Gray's	*subject #208 919*
Artery	Iliolumbar artery
MeSH	*Cauda+Equina*

The **cauda equina** is a structure within the lower end of the spinal column of most vertebrates, that consists of nerve roots and rootlets from above. The space in which the cerebrospinal fluid is present is actually an extension of the subarachnoid space.

In humans, because the spinal cord stops growing in infancy while the bones of the spine continue growing, the spinal cord in adults ends at about the level of the vertebra L1/L2 , and at birth at L3. However there is some variation in adults and the cord may end anywhere between vertebrae T12 to L3. Individual spinal nerve roots arise from the spinal cord as they do closer to the head, but as the differential growth occurs the top end of the nerve stays attached to the spinal cord and the lower end of the nerve exits the spinal column at its proper level, this results in a "bundle"-like structure of nerve fibres that extends caudally from the end of the spinal cord, gradually declining in number further down as individual pairs leave the spinal column. At the base of the Cauda Equina, there are approximately 10 fiber pairs, 3-5 lumbar, 5 sacral, and the single coccygeal nerve.

Etymology

All these roots and rootlets down the vertebral column give the appearance of a horse's tail, which is the meaning of the Latin name *cauda equina*.

Clinical relevance

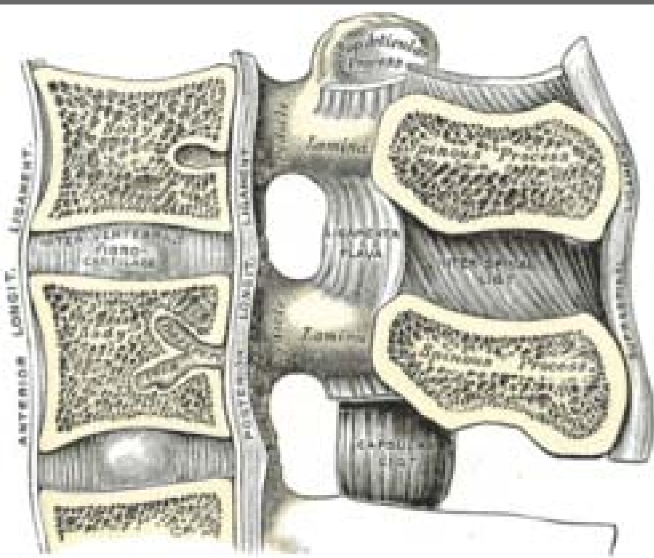
The cauda equina exists within the lumbar cistern, which is the space formed from the surrounding dural sac. Cerebrospinal fluid is drawn from this space during a lumbar puncture.

Chapter 17

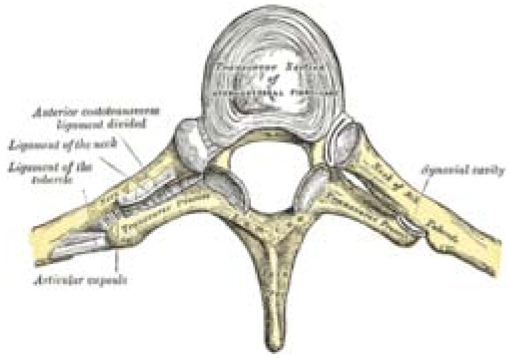
Intervertebral Disc and Ligamenta Flava

Intervertebral disc

Intervertebral disc



Median sagittal section of two lumbar vertebræ and their ligaments. (Intervertebral fibrocartilage labeled at center left.)



Costotransverse articulation. Seen from above.

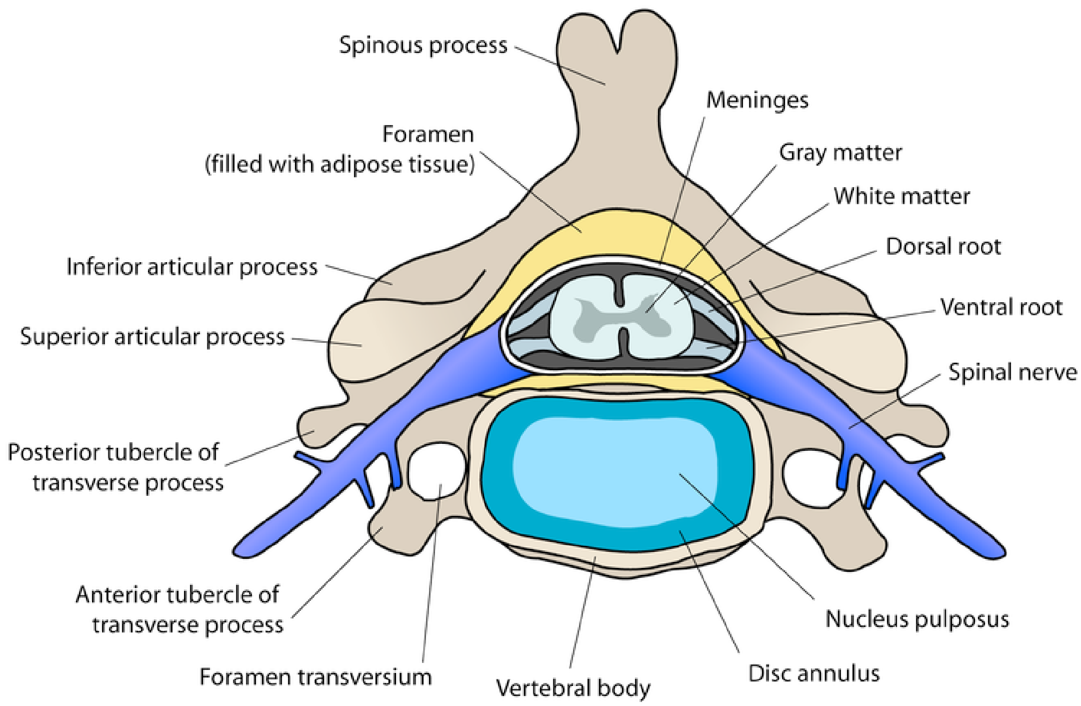
(Intervertebral fibrocartilage labeled at top center .)

Latin	*disci intervertebrales*
Gray's	*subject #72 289*
MeSH	*Intervertebral+Disk*

Intervertebral discs (or **intervertebral fibrocartilage**) lie between adjacent vertebrae in the spine. Each disc forms a cartilaginous joint to allow slight movement of the vertebrae, and acts as a ligament to hold the vertebrae together.

Structure

Discs consist of an outer *annulus fibrosus*, which surrounds the inner *nucleus pulposus*. The *annulus fibrosus* consists of several layers of fibrocartilage. The strong annular fibers contain the *nucleus pulposus* and distribute pressure evenly across the disc. The *nucleus pulposus* contains loose fibers suspended in a mucoprotein gel with the consistency of jelly. The nucleus of the disc acts as a shock absorber, absorbing the impact of the body's daily activities and keeping the two vertebrae separated. The disc can be likened to a doughnut: whereby the annulus fibrosis is similar to the dough and the nucleus pulposis is the jelly. If one presses down on the front of the doughnut the jelly moves posteriorly or to the back. When one develops a prolapsed disc the jelly/ nucleus pulposus is forced out of the doughnut/ disc and may put pressure on the nerve located near the disc. This can give one the symptoms of sciatica.

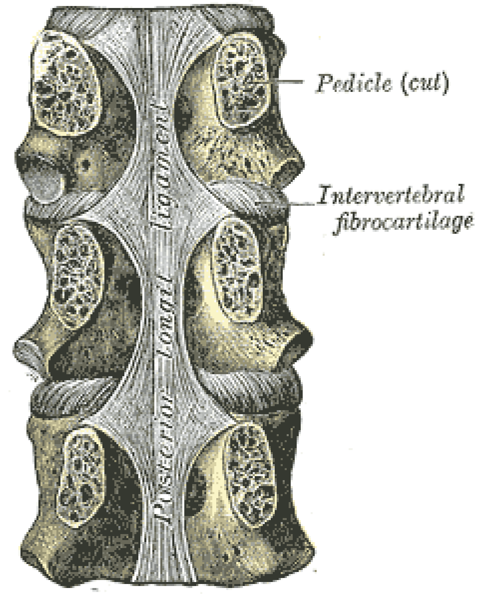


Cervical vertebra with intervertebral disc

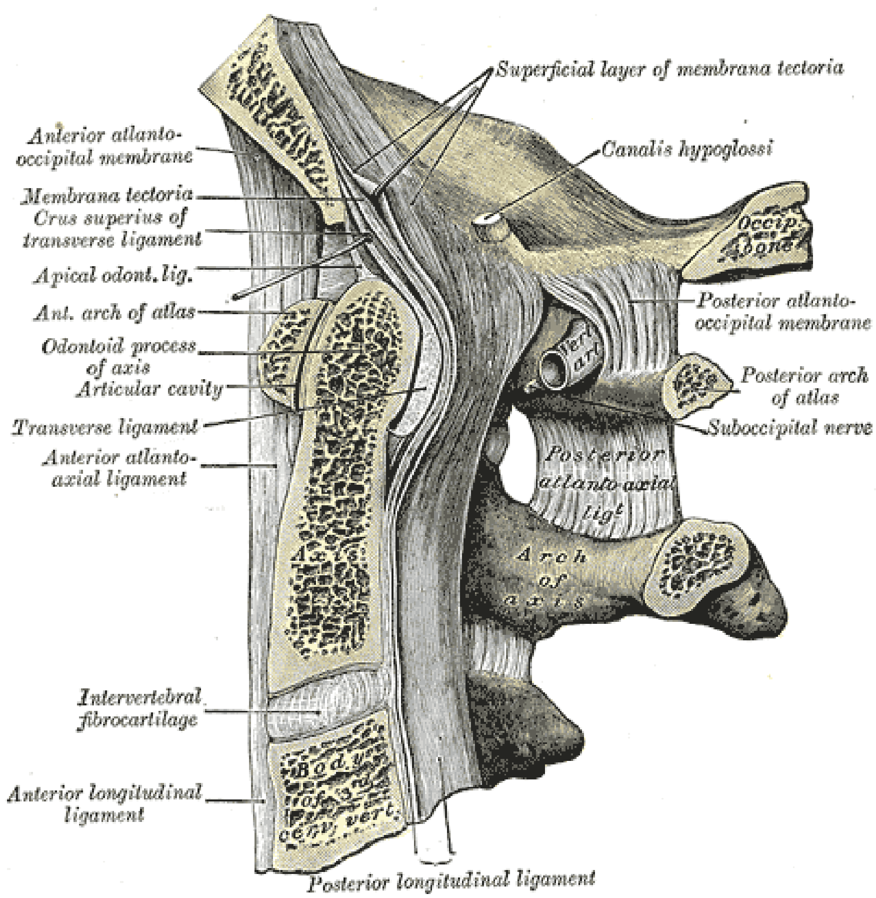
There is one disc between each pair of vertebrae, except for the first cervical segment, the *atlas*. The *atlas* is a ring around the roughly cone-shaped extension of the *axis* (second cervical segment). The axis acts as a post around which the atlas can rotate, allowing the neck to swivel. There are a total of twenty four discs in the human spine, which are most commonly identified by specifying the particular vertebrae they separate. For example, the disc between the fifth and sixth cervical vertabrae is designated "C5-6".

Medical conditions related to the intervertebral disc

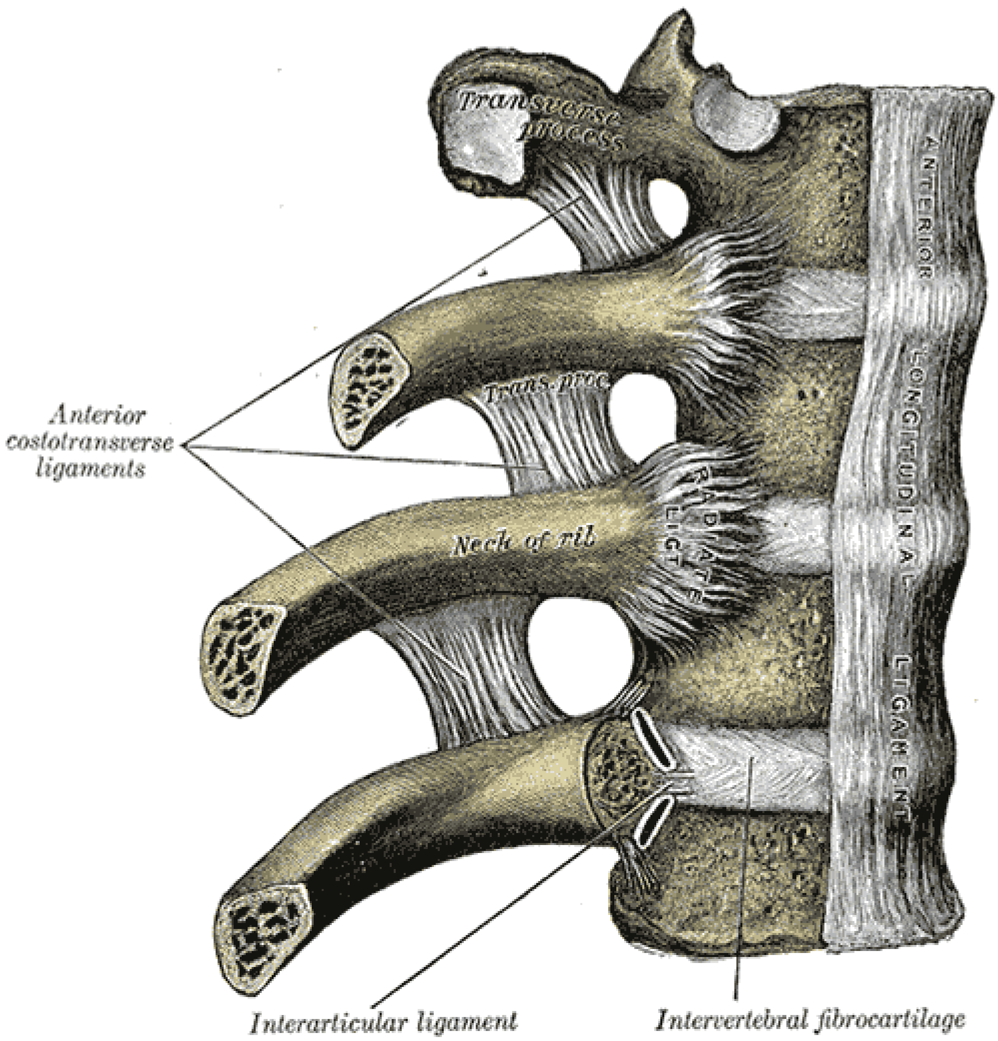
As people age, the *nucleus pulposus* begins to dehydrate, which limits its ability to absorb shock. The *annulus fibrosus* gets weaker with age and begins to tear. While this may not cause pain in some people, in others one or both of these may cause chronic pain.



Posterior longitudinal ligament, in the thoracic region



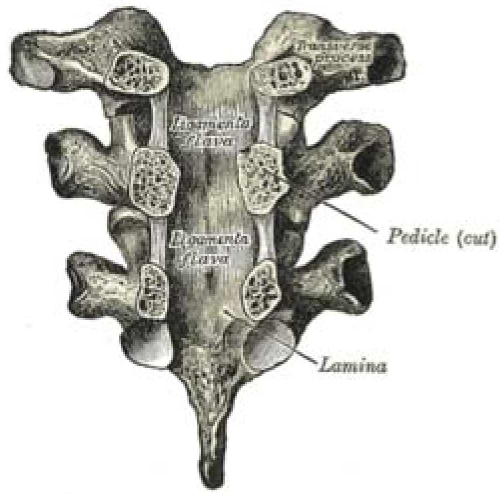
Median sagittal section through the occipital bone and first three cervical vertebræ



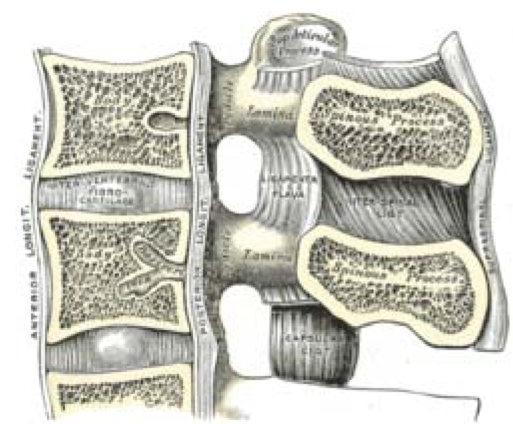
Costovertebral articulations. Anterior view.

Ligamenta flava

Ligament: Ligamenta flava	



Vertebral arches of three thoracic vertebræ viewed from the front.



Median sagittal section of two lumbar vertebræ and their ligaments.

Gray's	*subject #72 290*
From	
To	
MeSH	*A02.513.514.287*
Dorlands/Elsevier	*l_09/12492241*

The **ligamenta flava** (singular, *ligamentum flavum*, Latin for *yellow ligament*) are ligaments which connect the laminae of adjacent vertebrae, all the way from the axis to the first segment of the sacrum (C2 to S1). They are best seen from the interior of the vertebral canal; when looked at from the outer surface they appear short, being overlapped by the laminæ.

Each ligament consists of two lateral portions which commence one on either side of the roots of the articular processes, and extend backward to the point where the laminæ meet to form the spinous process; the posterior margins of the two portions are in contact and to a certain extent united, slight intervals being left for the passage of small vessels. Each consists of yellow elastic tissue, the fibers of which, almost perpendicular in direction, are attached to the anterior surface of the lamina above, some distance from its inferior margin, and to the posterior surface and upper margin of the lamina below. In the cervical region the ligaments are thin, but broad and long; they are thicker in the thoracic region, and thickest in the lumbar region.

Their marked elasticity serves to preserve the upright posture, and to assist the vertebral column in resuming it after flexion. The elastin prevents buckling of the ligament into the spinal canal during extension, which would cause canal compression. Hypertrophy of this ligament may cause spinal stenosis because it lies in the posterior portion of the vertebral canal.