Anatomy of the Brain

Overview

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

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

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

Brain

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

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

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

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

Right brain – left brain

The cerebrum is divided into two halves: the right and left hemispheres (Fig. 2). They are joined by a bundle of fibers called the corpus callosum that transmits messages from one side to the other.

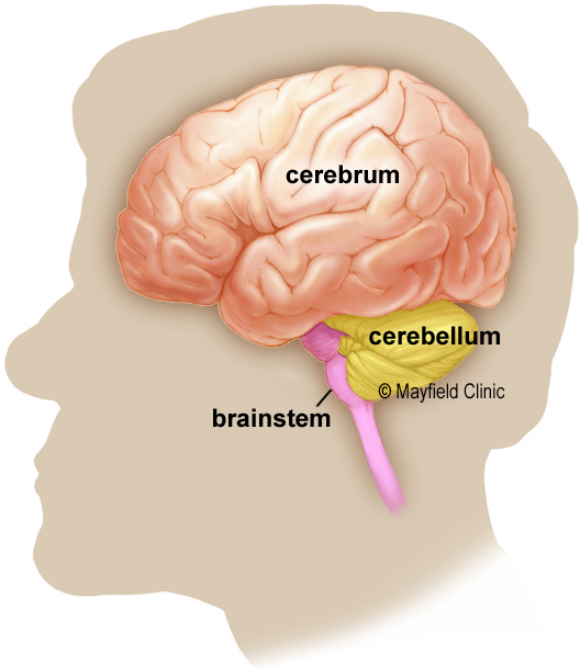

Figure 1. The brain has three main parts: the cerebrum cerebellum, and brainstem.

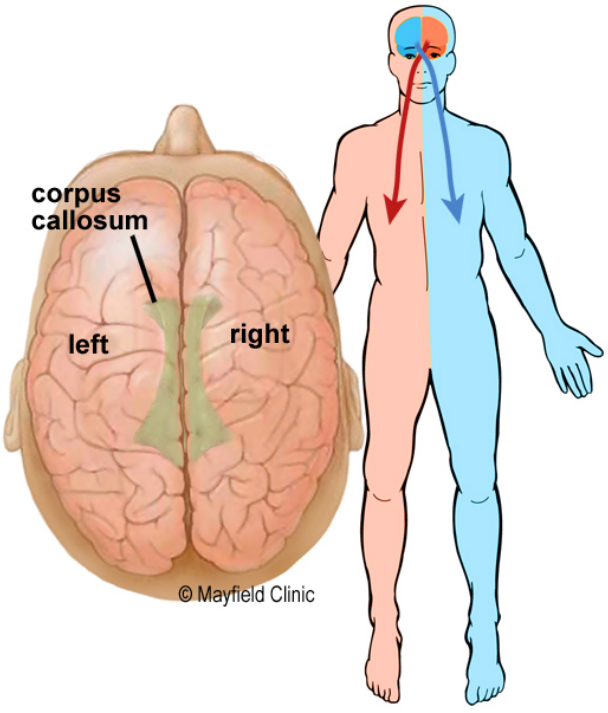

Figure 2. The cerebrum is divided into left and right hemispheres. The two sides are connected by the nerve fibers corpus callosum.

Each hemisphere controls the opposite side of the body. If a stroke occurs on the right side of the brain, your left arm or leg may be weak or paralyzed.

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

Lobes of the brain

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

Language

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

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

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

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

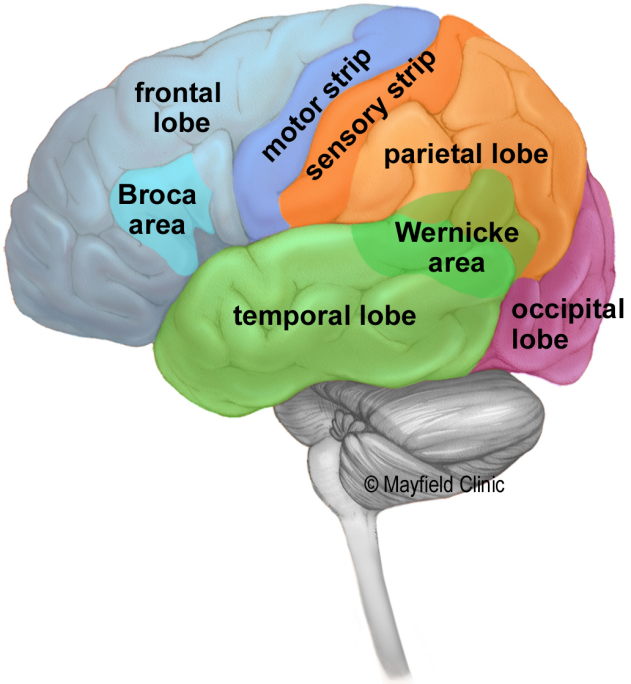

Figure 3. The cerebrum is divided into four lobes: frontal, parietal, temporal, and occipital.

Frontal lobe (blue)

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

Parietal lobe (orange)

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

Occipital lobe (purple)

- Interprets vision (color, light, movement)

Temporal lobe (green)

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

Cortex

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

The folding of the cortex increases the brain's surface area allowing more neurons to fit inside the skull and enabling higher functions. Each fold is called a gyrus, and each groove between folds is called a sulcus (Fig. 4). There are names for the folds and grooves that help define specific brain regions.

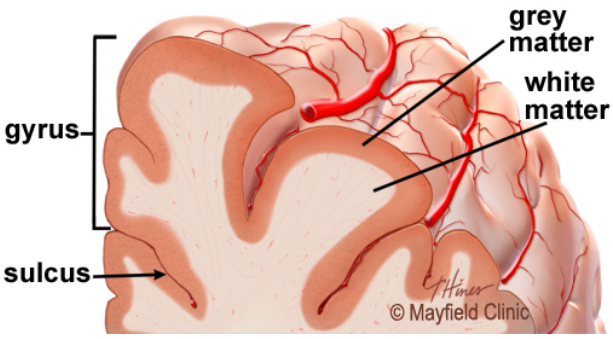

Figure 4. The cortex contains neurons (grey matter), which are interconnected to other brain areas by axons (white matter). The cortex has a folded appearance. A fold is called a gyrus and the valley between is a sulcus.

Deep structures

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

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

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

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

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

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

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

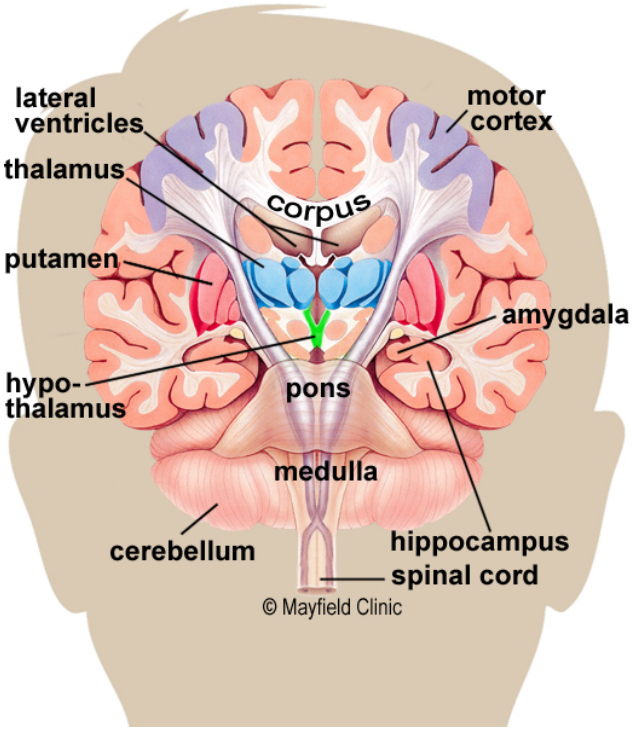

Figure 5. Coronal cross-section showing some of the deep structures of the brain.

Memory

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

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

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

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

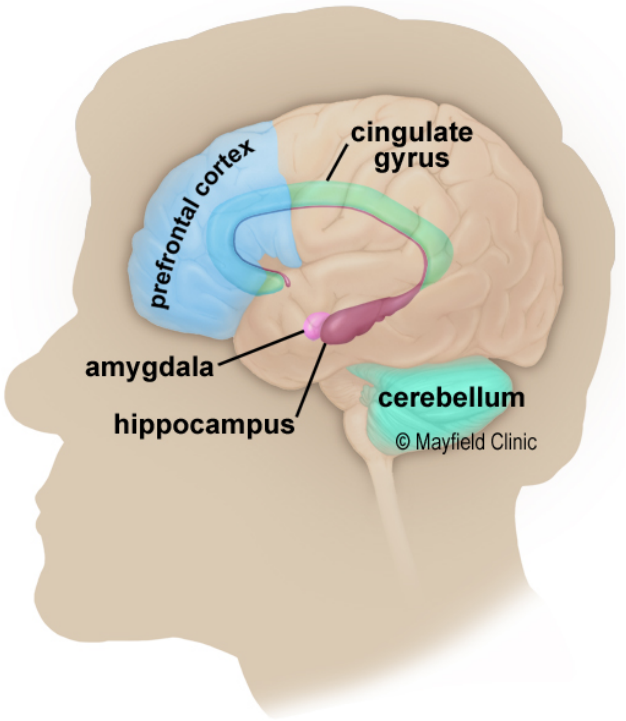

Figure 6. Structures of the limbic system involved in memory formation. The prefrontal cortex holds recent events briefly in short-term memory. The hippocampus is responsible for encoding long-term memory.

Ventricles and cerebrospinal fluid

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

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

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

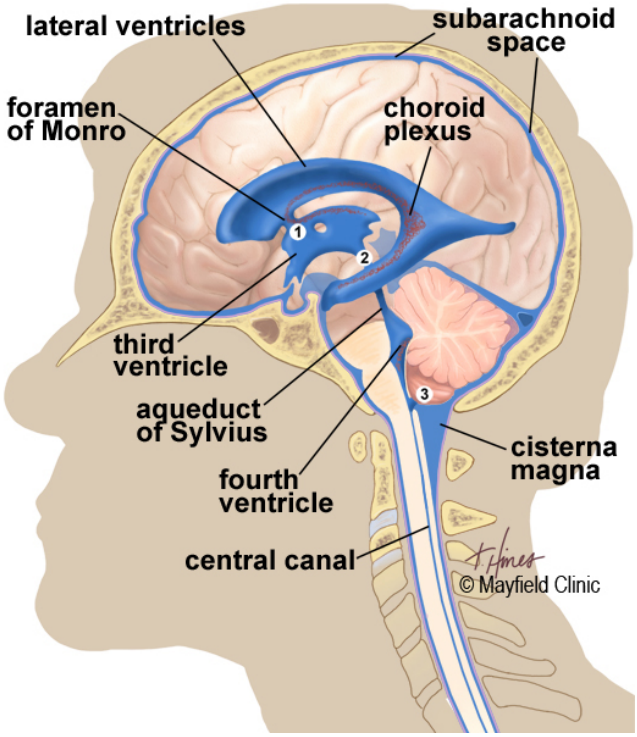

Figure 7. CSF is produced inside the ventricles deep within the brain. CSF fluid circulates inside the brain and spinal cord and then outside to the subarachnoid space. Common sites of obstruction: 1) foramen of Monro, 2) aqueduct of Sylvius, and 3) obex.

Skull

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

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

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

Cranial nerves

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

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

No.	Name	Function
I	olfactory	smell
II	optic	sight
III	oculomotor	moves eye, pupil
IV	trochlear	moves eye
V	trigeminal	face sensation
VI	abducens	moves eye
VII	facial	moves face, salivate
VIII	vestibulocochlear	hearing & balance
IX	glossopharyngeal	taste, swallow
X	vagus	heart rate, digestion
XI	accessory	moves head
XII	hypoglossal	moves tongue

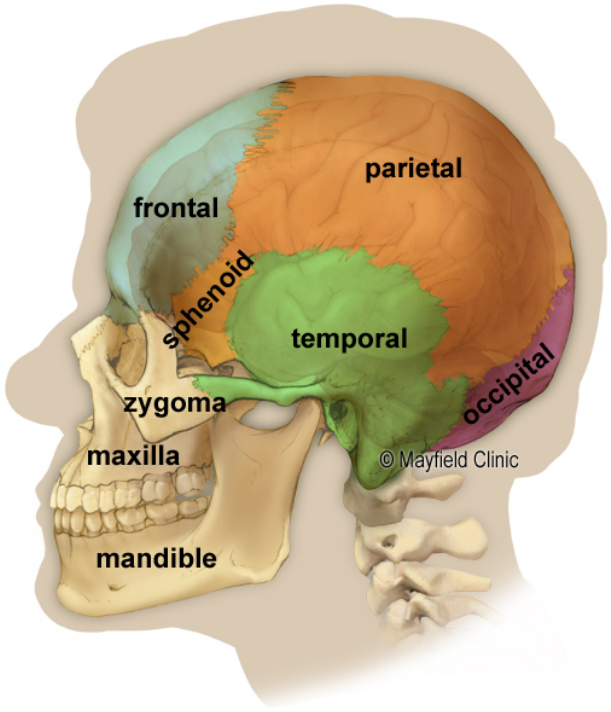

Figure 8. The brain is protected inside the skull. The skull is formed from 8 bones.

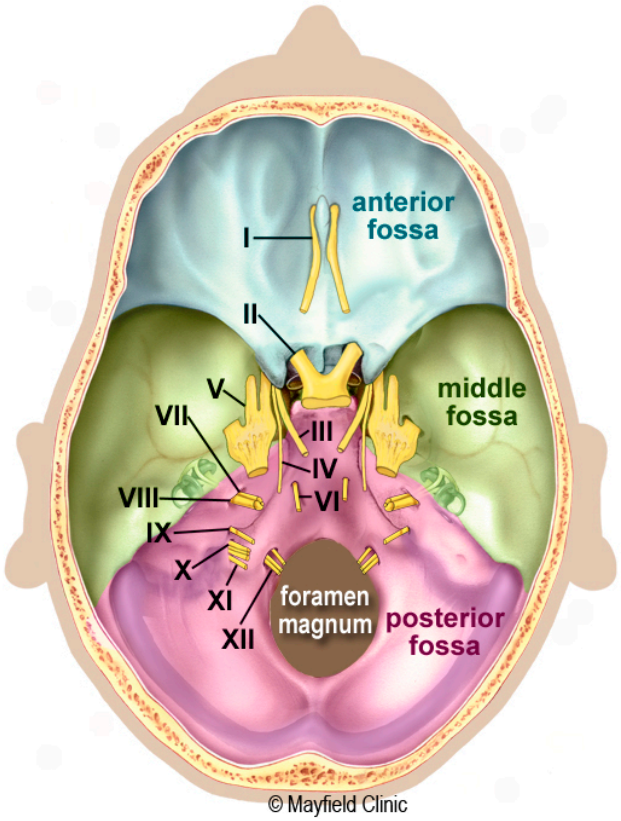

Figure 9. A view of the cranial nerves at the base of the skull with the brain removed. Cranial nerves originate from the brainstem, exit the skull through holes called foramina, and travel to the parts of the body they innervate. The brainstem exits the skull through the foramen magnum. The base of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

Meninges

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

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

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

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

Blood supply

Blood is carried to the brain by two paired arteries, the carotid arteries and the vertebral arteries (Fig. 10). The internal carotid arteries supply most of the cerebrum. The vertebral arteries supply the cerebellum, brainstem, and the underside of the cerebrum. After passing through the skull, the right and left vertebral arteries join together to form the basilar artery. The basilar artery and the internal carotid arteries "communicate" with each other at the base of the brain called the Circle of Willis (Fig. 11). The communication between the internal carotid and vertebral-basilar systems is an important safety feature of the brain. If one of the major vessels becomes blocked, it is possible for collateral blood flow to come across the Circle of Willis and prevent brain damage.

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

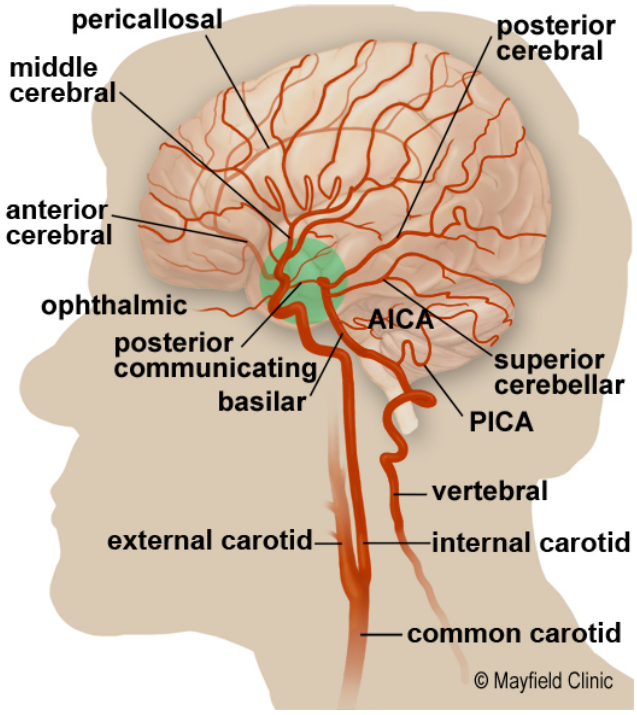

Figure 10. The common carotid artery courses up the neck and divides into the internal and external carotid arteries. The brain's anterior circulation is fed by the internal carotid arteries (ICA) and the posterior circulation is fed by the vertebral arteries. The two systems connect at the Circle of Willis (green circle).

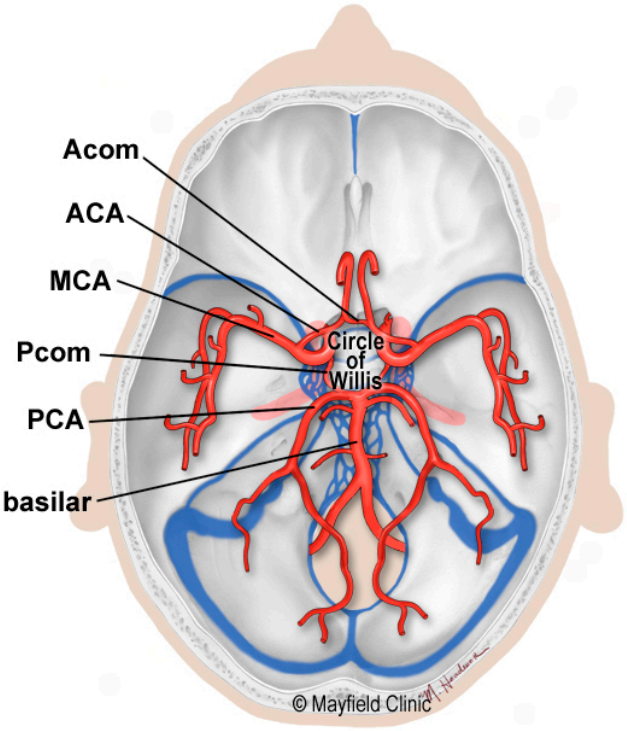

Figure 11. Top view of the circle of Willis. The internal carotid and vertebral-basilar systems are joined by the anterior communicating (Acom) and posterior communicating (Pcom) arteries.

Cells of the brain

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

Nerve cells

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

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

Glia cells

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

- Astroglia or astrocytes are the caretakers — they regulate the blood brain barrier, allowing nutrients and molecules to interact with neurons. They control homeostasis, neuronal defense and repair, scar formation, and also affect electrical impulses.
- Oligodendroglia cells create a fatty substance called myelin that insulates axons – allowing electrical messages to travel faster.
- Ependymal cells line the ventricles and secrete cerebrospinal fluid (CSF).
- Microglia are the brain's immune cells, protecting it from invaders and cleaning up debris. They also prune synapses.

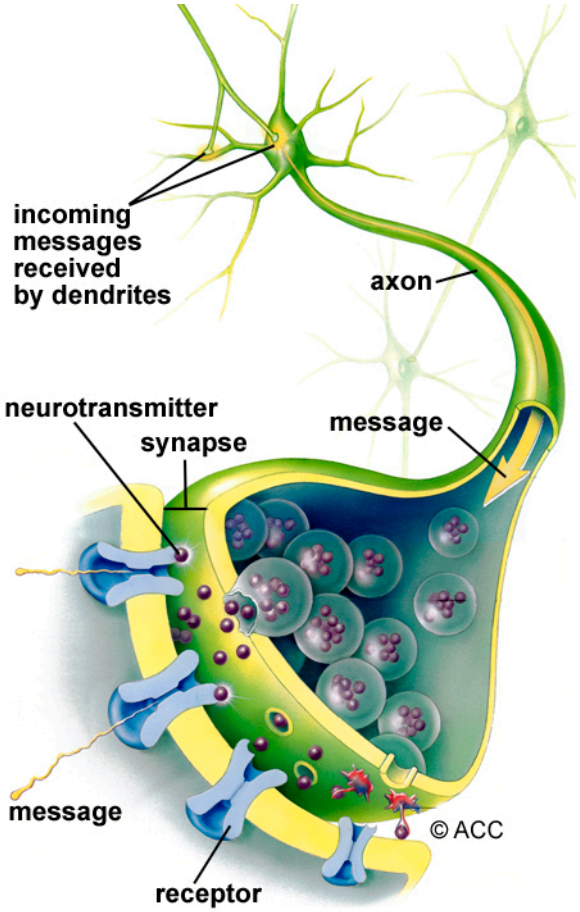

Figure 12. Nerve cells consist of a cell body, dendrites and axon. Neurons communicate with each other by exchanging neurotransmitters across a tiny gap called a synapse.

Sources & links

If you have more questions, please contact Mayfield Brain & Spine at 800-325-7787 or 513-221-1100.

Links

brainfacts.org
thebrain.mcgill.ca

updated > 4.2018
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