Anatomy Lecture Notes Section 4: Nervous System

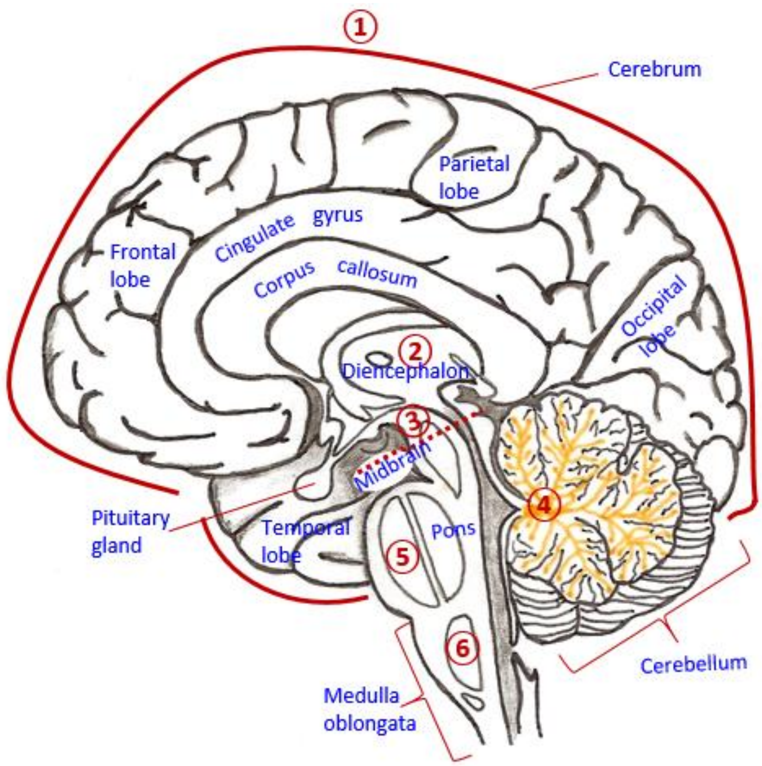
The Central Nervous System: The Brain and the Spinal Cord

The nervous system is anatomically and functionally divided into two parts, the **Central Nervous System** (the brain and the spinal cord) and the **Peripheral Nervous System** (the ganglion and nerves. There are 12 pairs of cranial nerves and 31 of pairs of spinal nerves redating out into the periphery. The Peripheral Nervous System (PNS) can be further delineated into the **Somatic Nervous System** (SNS) which integrates control over skeletal muscle, and the **Autonomic Nervous System** (ANS) which for the most part automatically regulates vital internal organs, glands and regulating systems.

The Brain

In anatomy, we can divide the brain into six (**6**) parts in terms of information processing:

1. Cerebrum
2. Diencephalon
3. Midbrain
4. Cerebellum
5. Pons
6. Medulla oblongata



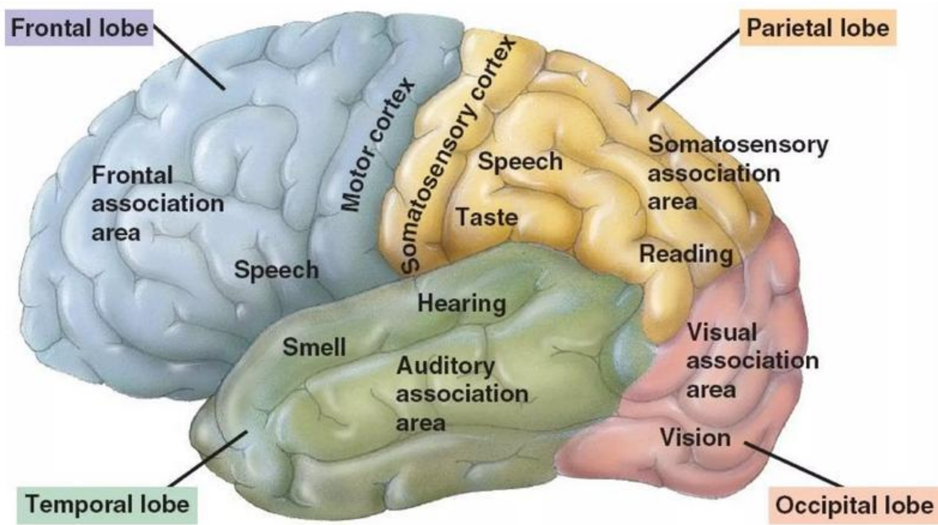
To the right is a drawing of a mid-sagittal section of the brain showing various regions and the six major divisions (red circled numbers) of the human brain from the highest to lowest level of information processing.

1. Cerebrum

The cerebrum is the largest and most developed area of the human brain (see right) and is considered to be the center of the highest functions. Its major functions include: Awareness of sensory perception; voluntary control of movement (regulation of skeletal muscle movement); language; personality traits; sophisticated mental activities such as thinking, planning, memory, decision making, predictive ability, creativity and self-consciousness. The cerebrum is composed of **5 lobes**, and below is some basic information about them.

The Frontal Lobe – Encased within the frontal bone it is the **largest** and most **complex** of the 5 lobes, concerned with higher intellectual functions and behavioral aspects of humans. These include memory, planning, emotional and behavior regulation (impulse control), language and personality. In addition, the **primary motor cortex** controls the movement of skeletal muscles of the body.

The Parietal Lobe – Protected by the parietal bones of the skull, this lobe is primarily concerned with the interpretation and integration of body **sensory** inputs. The **somatosensory cortex** is associated with reception and perception of touch, vibration, temperature, and general body senses. Also involved in spatial orientation, movement coordination, reading, writing and mathematical computation.



The Temporal Lobe - Contains the **auditory cortex** for the perception of sound, and the **olfactory cortex** for the sense of smell. Also houses the language cortex usually in left hemisphere and participates in recognition and interpretation of language. The amygdala and hippocampus (limbic system) connect to the temporal lobe and aid in memory formation related to emotions, the sense of smell and sound.

The Occipital Lobe - This lobe contains the primary **visual cortex** for visual information interpretation. The eyes transmit images to the visual cortex, which then determines colors, identify objects, shapes, and other aspects of visual perception. Visual information is sent to the parietal lobes and temporal lobes for further processing. The occipital lobe is also for reading comprehension; depth perception; recognition of object movement. The parietal and temporal lobes use visual info to perform tasks like as opening a door and connecting visuals with retained memories.

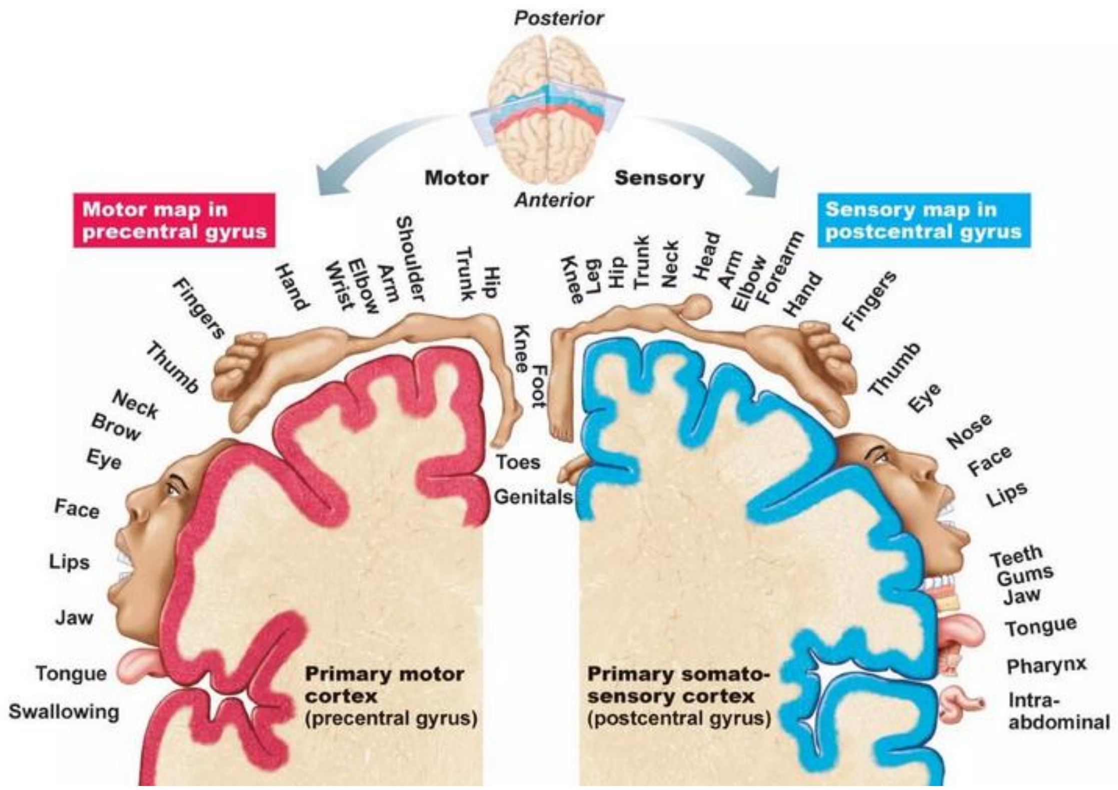
The Insula Lobe – A key role is **visceral** perception or awareness of internal organs and various bodily states. When the bladder is empty we are not consciously aware of it, but when it becomes full, we become aware of it. The **gustatory cortex** is responsible for **taste** perception, located in the insula the frontal lobes. The insular lobe also enables us to read our own emotions and be aware of them.

Intro Vocabulary for Brain Anatomy

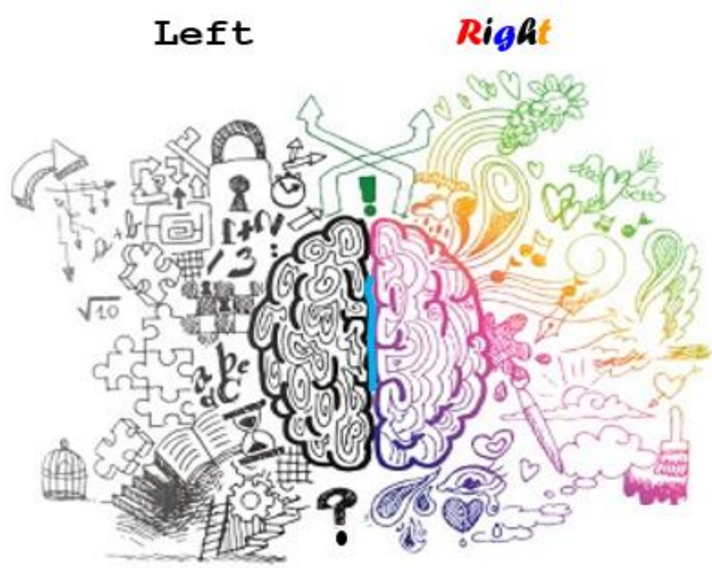
Sulcus (sulci) – grooves on surface of cerebrum.
Gyrus (gyri) – fold of brain tissue between sulci.
Fissure - deep groove, separating hemispheres.
Cerebral cortex – gray matter of outer ~4mm of the cerebrum.
Cerebral medulla – white matter of cerebrum deep to cortex.
Cerebral Nuclei – regions of gray matter deeper within the cerebrum.

There are three (3) kinds of cerebral functional area:
1) Sensory areas – for receiving incoming sensory information.
2) Association areas – for analysis and placing information into context.
3) Motor areas – for sending out a response from the cerebrum to lower levels.

<u>There are Two significant gyri on the Cerebrum for outgoing and incoming information</u> :
On the Frontal Lobe: **Precentral gyrus** (**motor**). This region is the Primary Motor Cortex.
On the Parietal Lobe: **Postcentral gyrus** (**sensory**). This region is the Primary Somatosensory Cortex.



General Anatomy of Cerebrum - there are **2 Hemispheres** - Left and Right.



The Left Hemisphere
Controls writing, movement of the right side of body. Usually dominant in language and tasks that involve symbolic reasoning. Language, logic, analytical, sequential, verbal tasks (**fragmentary** information processing).

The Right Hemisphere
Controls touch, movement of the left side of body. Typically superior at non-verbal, visual and spatial tasks. Spatial perception, artistic and musical endeavors (**holistic** information processing).

<u>Cerebral Communication</u>: The major groups of **axon fibers** and **tracts** of the central white matter.

a) Association Fibers - are axons (fibers) connecting different cortical areas on the same side of the cerebrum to each other, that is, within the same hemisphere (L or R). Short association fibers like the **arcuate fibers** connect adjacent gyri. Long association fibers, like the **longitudinal fibers**, connect distant parts of the cerebral cortices within the hemisphere.

b) Commissural Fibers - connect an area in one hemisphere with an area in the opposite hemisphere. The **corpus callosum** is the largest set of commissural fibers in the brain, having from 200 to 300 million axons crossing from one hemisphere to the other. There are two much smaller but important examples of commissural fibers called **the anterior commissure** and the **posterior commissure**.

c) Projection Fibers - also known as projection *tracts* of the brain, are a type of tract (white matter) that connects the cortex with other areas in the CNS, e.g., deep nuclei, brainstem, cerebellum or spine. They may be **efferent** (**motor**), which can sometimes be called ‘descending’ tracts, or **afferent** tracts (**sensory**) which can sometimes be called ‘ascending’ tracts, associated with the direction they convey information.

The **Reticular System** is a widespread system of connections, ideal for arousal of the brain as a whole very quickly. The role of the **Reticular activating system** (RAS) is to maintain consciousness and alertness. It also functions in sleep and importantly, arousal from sleep. This RAS is predominantly located in the Pons and the MO regions of the brainstem. When aroused, the RAS sends signals from the pons and MO “up” to the higher centers in the brain for maximum conscious awareness to occur very quickly.

The Limbic System – The Emotional Brain

Still partially within the **cerebrum**, the **limbic system** is composed of a group of structures on the medial aspect of each hemisphere and the **diencephalon**. It is more of a functional system than an anatomical one. The limbic system is the "<u>emotional brain</u>", participating in the creation of emotional states such as **fear**, **pleasure**, **anger**, **affection**, **arousal**, etc. and processing vivid memories associated with those states.

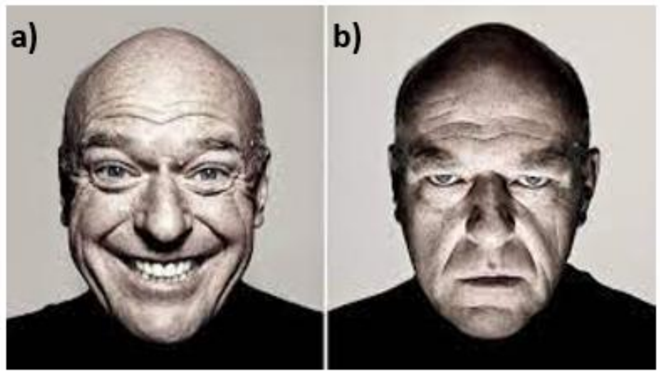
The **cingulate gyrus** is an arch-shaped convolution situated just above the **corpus callosum**, on the medial aspect of the cerebral hemispheres. It is thought to be involved in information processing for decision-making, planning, and allows us to shift between thoughts and inter-relate them. It also interprets pain as unpleasant, which is an integral part of learning and learned avoidance practice.

The **hippocampus** is a complex brain structure embedded deep in the **temporal lobe**. It is thought to have a major role in learning and memory. It’s named after its resemblance to a type of **sea-horse**. This structure is described as *plastic*, where **neuroplasticity** is the ability of the brain to create and reorganize new synaptic connections, especially in response to **learning** or after experiencing injury, since the hippocampus can become damaged by various stimuli. For example, high, prolonged levels of **cortisol** (known as the stress hormone) are associated with shrinkage of the hippocampus. Another way to think of this is that worrying too much can shrivel your brain. So please worry less.

This particular area of the brain also has a role (along with the parietal lobe) in **spatial processing** and navigation, integrating spatial relationships and memories. This may explain why some people have a better sense of direction than others, in that their hippocampus is likely more integrated with their others senses than others. What this means it, let them have the map, it’s just better for everyone. This area also functions in consolidating information and memories during restorative sleep.

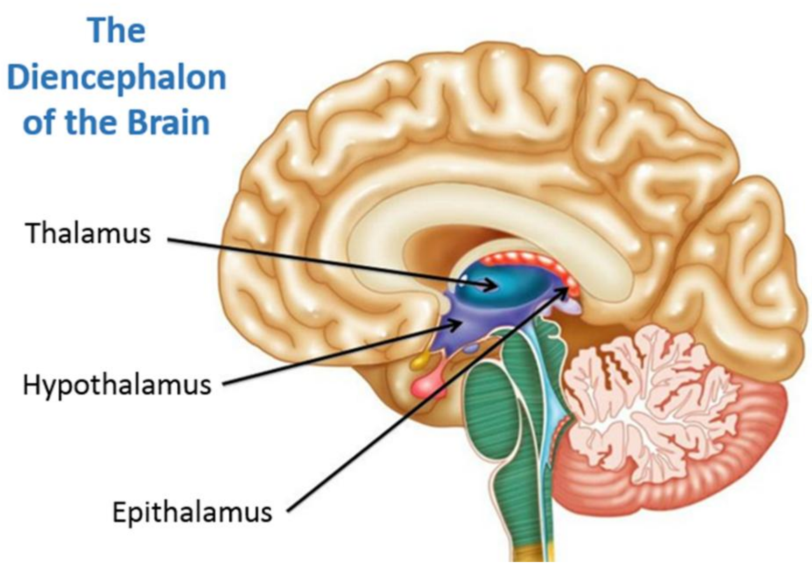
The **amygdala** takes its name after the pair of almond-shaped nuclei that are nestled within the **temporal lobe**, it is part of a collection of nuclei located here. It appears to have a primary role in detecting and processing threatening stimuli, especially **menacing facial glances** or faces that represent **expressions of fear**. As a consequence, the amygdala activates areas involved in preparation for motor functions of **fight or flight**, i.e., the **sympathetic division** of the autonomic nervous system (ANS).

The amygdala is involved in tying <u>emotional meaning</u> to our reactions. It's <u>not</u> all about fear, the amygdala also plays an important role in the storage and retrieval of **positive emotional memories**, such as **positive facial recognition** linked to emotional happiness from seeing, e.g., your grandmother's face. As an example, see the two facial expressions **a)** and **b)** in the image above (right). Which do you think would trigger the amygdala to fire because it detects possible danger? Like **b)** right? However it is worth noting that the amygdala could still be triggered by **a)**, if you recognized this face as someone you have a very positive emotional connection with.



2. Diencephalon

= **1)** Epithalamus, **2)** Thalamus and **3)** Hypothalamus



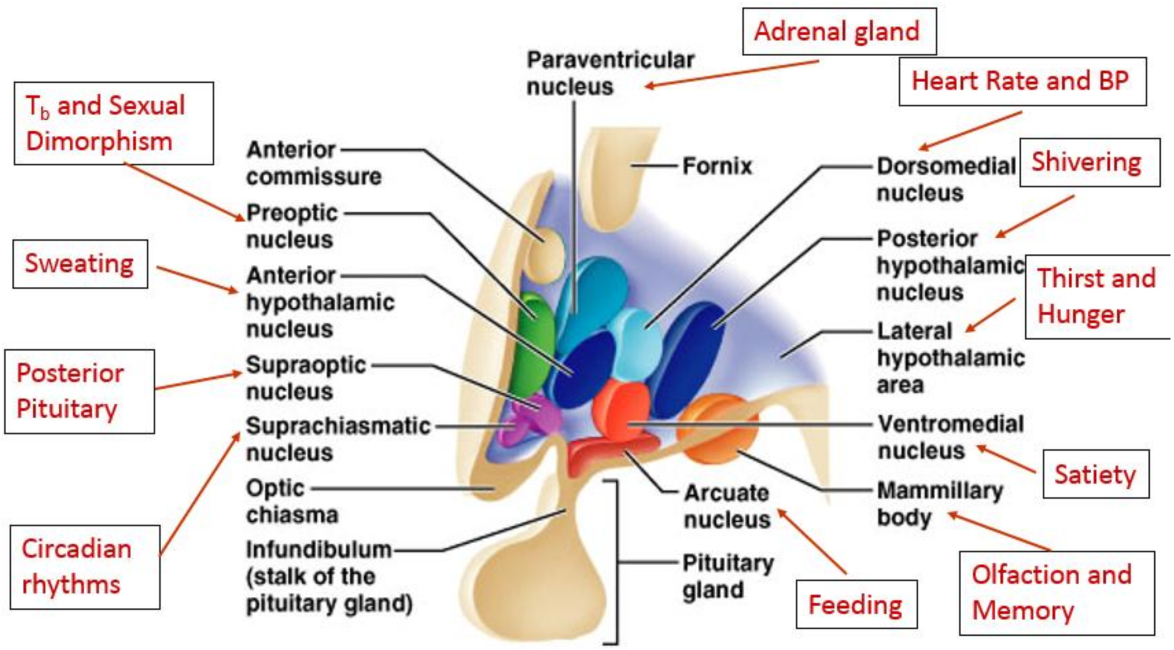
1) Epithalamus includes the pineal gland (body). Secretes hormone **melatonin**, under influence of the hypothalamus. **Dimethyl-tryptamine** (DMT), which is a very powerful endogenous hallucinogen, is also released from Pineal gland. Note: The significant blue light emitted from tv, computer and phone screens blocks the hormone melatonin, therefore suppresses your body's ability to prepare for sleep.

2) Thalamus makes up **80%** of the diencephalon. It contains at least a dozen major nuclei which act as the "gateway" to cerebral cortex. Afferent impulses converge on thalamus. Nuclei organize and amplify or tone down signals. All of the **senses**, with the exception of olfaction (sense of smell) travel through the thalamus to reach the cerebral cortex. Olfaction's travels though the mammillary body of the hypothalamus (via the limbic system to reach the cerebral cortex.

3) **Hypothalamus** controls and regulates many important functions of the body, including:
1) Control of the Autonomic Nervous System - adjusts, coordinates, and integrates the A.N.S. centers in the brain that regulate heart rate, blood pressure, bronchiole diameter, sweat glands, G.I. tract activity, etc. It does this via the Parasympathetic and Sympathetic divisions of the A.N.S.

2) Control of Emotional Responses - in association with the limbic system, it forms part of the emotional brain. Regions involved in fear, pleasure, rage and sex drive are located in the hypothalamus.

3) Regulation of Body Temperature - the body's thermostat and set point is located in the hypothalamus. There are also two (2) centers in the hypothalamus that respond to changes in the set point for body temperature.



1. <u>Heat-losing Center</u>: activation of this center causes sweating and cutaneous vasodilation.
2. <u>Heat-promoting Center</u>: activation of center causes shivering and cutaneous vasoconstriction.

4) Regulation of Hunger and Thirst Sensations - hypothalamus contains centers that regulate eating and drinking behavior, called the feeding and thirst centers*.

<u>Feeding Center</u>: this center is always active and stimulates hunger which is 'fed' by eating.
<u>Satiety Center</u>: stimulated when satisfied, this inhibits the always hungry feeding center.
<u>Thirst Center</u>: Osmoreceptors detect changes in osmotic pressure of blood, ECF, and when tonicity of bloody fluids go above 310 mOsM, this in part stimulates the thirst response.

**Note: The hypothalamus is the only region of the brain where the protective Blood Brain Barrier is missing. This is because the hypothalamus must be in direct contact with systemic blood in order to assess the condition of blood, including water concentration, levels of nutrients, and blood temperature. This can make the hypothalamus more susceptible to substance that are in the blood stream.*

5) Control of the Endocrine System – the hypothalamus controls the release of pituitary hormones. It controls the **anterior pituitary gland**, when the hypothalamus releases hormones, it can stimulate or inhibit the release of other (7) hormones from the pituitary gland. Also, it makes the 2 hormones (oxytocin and antidiuretic hormone (ADH)) that are stored in the **posterior pituitary** and released when signaled. All of these hormones regulate many other organs in the body.

3. Midbrain

The **midbrain** (also called the **mesencephalon**), is part of the **brainstem** (= midbrain, pons and medulla oblongata). It effectively connects the forebrain and the hindbrain.

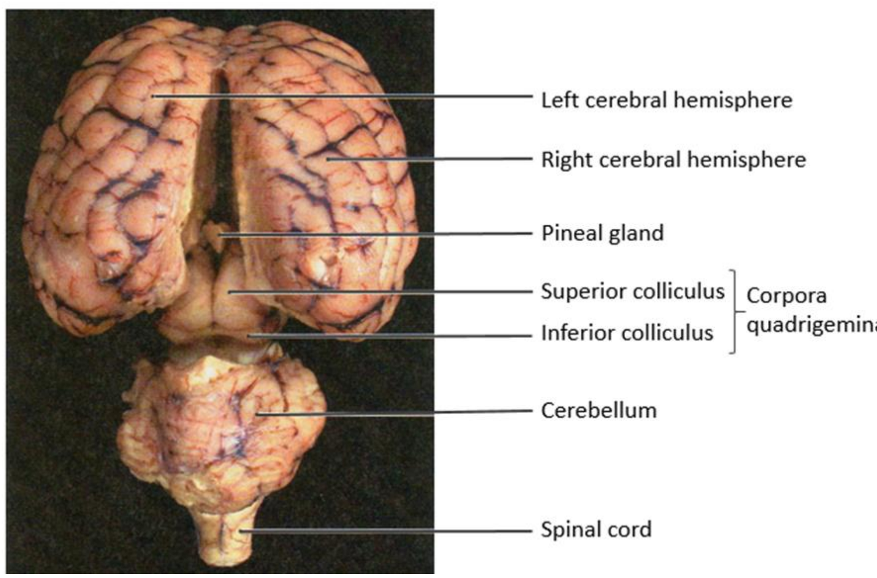
A major function of the midbrain is to aid in body movement, especially movements of the **eye**, as well as **visual** and **auditory** processing. An area called the **substantia nigra** of the midbrain is critical for smooth body movement, as in locomotion while walking or other fine body movements.

Portions of the midbrain receive visual and auditory input from the medulla oblongata in relation to protective **cranial reflexes.** The **corpora quadrigemina** of the midbrain is composed of for bodies, and contains the **superior colliculi** (the top two bodies) which are involved in **vision** processing and reflexes. The **inferior colliculi** (the lower two bodies) are involved in **auditory** processing and reflexes. Examples of these types are reflexes are common, for instance if you are walking along the street and hear tires dramatically screeching, you'll **automatically** and **rapidly** turn toward the origin of the sound, often with a defensive or protective posture. Or if your gross sister throws a wadded up piece of paper at your face when you were not expecting it, automatically your eyes will close, and your arms and hands will attempts to block the belligerent object coming your way.

<u>Functions of the midbrain include</u>:

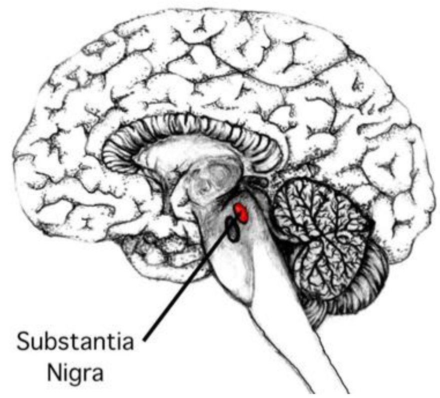
- Controlling Responses to sight
- Hearing and visual reflexes
- Eye Movement
- Pupil Dilation
- Regulating Skeletal Muscle (Body) Movement

Posterior view of a real Brain



In the midbrain there is the **substantia nigra** (meaning 'black substance'), the **corpora quadrigemina** (meaning 2 sets of twin bodies), and origins for the **oculomotor** (eye muscle) and **trochlear** (pulley) cranial nerves, which control the movements of the eyeball. Therefore, although the midbrain is a relatively small region of the brain, it has some incredibly important functional roles within the body.

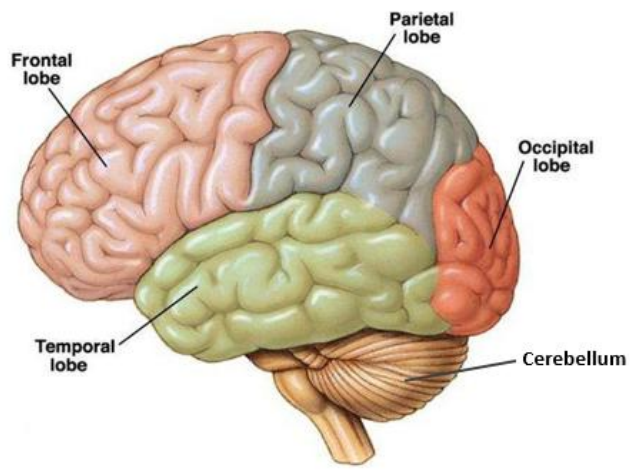
- The **substantia nigra** has fibers that connect with the frontal lobe and other areas of the brain to coordinate and control body movement. Many neurons in the substantia nigra coordinating muscle movement are **dopaminergic** (release dopamine). If there is damage here, this may result in the loss of motor control and coordination (sometimes called **Parkinson's disease**). It is characterized by slow jerky movements; tremors of the face and hands; muscle rigidity; and great difficulty in initiating voluntary movements.



- The **corpora quadrigemina** ('4 bodies') are located in the midbrain. The top two bodies are called the **superior colliculi** and these are involved in **vision** processing and reflexes. The other pair of bodies are called the **inferior colliculi** and these are involved in **auditory** processing and reflexes.

4. Cerebellum

The cerebellum is located in the lower posterior of the brain, and the word means 'little brain'.

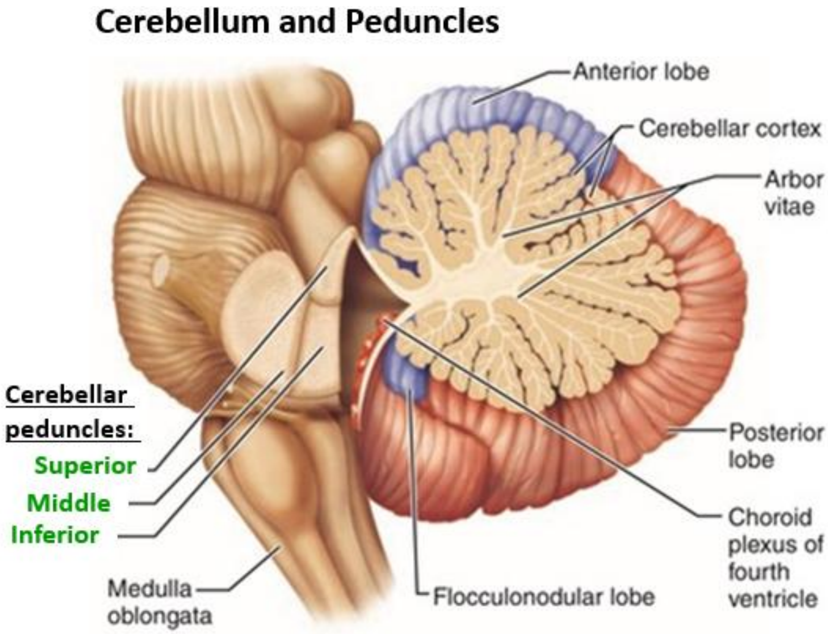


The cerebellum ("little brain") is a structure that is located at the back of the brain, underlying the occipital and temporal lobes of the cerebral cortex. The cerebellum accounts for about 10% of the total brain's volume, yet contains over 50% of the total number of neurons in the brain.

The outer portion of the cerebellum contains neurons, and the inner has tracts myelinated axons called the arbor vitae (meaning 'tree of life') because of its resemblance to branching tree, see image below. These communicates with the cerebral cortex. In basic terms the primary functions of the cerebellum are the control of motor skills such as **balance**, **coordination**, and **postural reflexes**.

The **cerebral peduncles** (which means little feet) are tracts that connect the cerebellum to brainstem and cerebrum. They play a key role in receiving and relaying information to other brain and body areas very quickly, especially signals that are required for refining body movements and learning new skilled routines.

An important aspect of how the cerebellum can coordinate body movement is because it receives input from **proprioceptors** which are located all over the body, providing information about the relative position of body parts to the orientation of the head. As discussed below, the proprioceptors are located in joints, ligaments and tendons, and as they send signals to the cerebellum it converts this information into a dynamic spatial map of body part locations in order for it to maintenance the body's balance and posture.

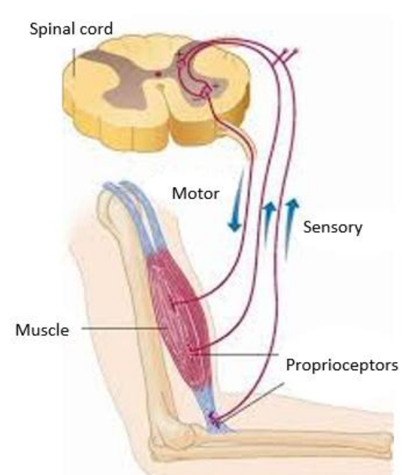


The Cerebellar Peduncles:
Superior cerebellar peduncle are tracts (white matter) carrying outgoing motor commands, plus some sensory signals, connecting the **cerebellum** to the **midbrain** and the **thalamus**.

Middle cerebellar peduncle are tracts connecting the **cerebellum** to the **pons**. This is the largest of the three peduncles and relays vast amounts of incoming information from cerebrum to cerebellum. It receives most of its input from the pons from the **pontine nuclei**. The input to the pons is from the **cerebral cortex**, which is relayed from the pontine nuclei via transverse pontine fibers to the **cerebellum**.

Inferior cerebellar peduncle are tracts integrating sensory input from the body and spinal cord to the cerebellum, particularly for posture and balance. The signals are coming in from **proprioceptors** in the body, with motor **vestibular** (balance) input for maintenance of **balance** and **posture**.

Two very important functions of the Cerebellum are:
1) The Control of Postural Reflexes in the body.
The cerebellum coordinates the rapid, automatic adjustments to body parts in order to maintain **equilibrium**, or **balance**. The coordination of the cerebellum what is responsible for quickly regaining your balance if you trip and start to fall. Receptors called **proprioceptors** are located in joints, muscles, tendons and ligaments (see image at right) all over the body. They deliver sensory information regarding the relative position of various body parts to the **cerebellum**. The reason you may flail your arms out perhaps rather ignominiously in those times, is that the cerebellum is constantly aware of where the body's limbs are in space and can very quickly calculate where they need to go in order to re-establish balance, and puts that plan in action without your conscious input. Recall that a **reflex** is a rapid, automated, stereotyped response to a stimulus, usually protective, and this is what postural reflexes involve, with the cerebellum as the integration center.



2) <u>It Produces Skilled Routines for Body Movements</u>.
The cerebellum is heavily involved in implementing routines for fine-tuned body movements. What this means is that the cerebellum takes an activity that initially is controlled or instigated at the conscious level (within the cerebrum), and after **much repetition** of this activity, the pattern of repeated actions has been formulated into a routine (after all that practice) and is transformed into a refined learned **skilled routine**. This means that action can now be done with little to no conscious thought involved in the activity.

Examples of creating skilled routines after a great deal of practice are commonplace in everyday life, for example tying shoelaces. At one point this was a complex task that required conscious attention, but mostly we have that task completely automated at an early stage of development. Other examples include driving a car, or being in the unenviable position of teaching your younger sister how to drive a stick shift in an old French car. Playing an instrument. Playing an instrument and singing at the same time (it's harder than it looks). Studying for an exam? The action, whatever it is, is practiced **repeatedly** until it becomes routine,. thus is embedded within the subconscious. This then reduces the need for conscious attention to the task.

As mentioned, the cerebellum gets incoming information from **proprioceptors** (a type of sensory receptor). These receptors are also involved in creating skilled routines, as the complex series of muscle actions is repeated over and over, it is the cerebellum which can transform these repeated patterns into a routine action, that then becomes automated. Some rightly call 'muscle memory' an example of this, seen in sports, instrumentation, and in many other areas.

5. Pons

The pons (which means 'bridge') plays a role in the regulation of the **respiratory system**. Contains two 'pontine' respiratory centers: **1)** the **pneumotaxic center** and **2)** the **apneustic center**. These two centers will be discussed in much greater detail in the respiratory system section.

The pons is not responsible for the rhythm of breathing (the medulla oblongata is) but it controls the changes in depth of breathing and the ***fine tuning*** of the rhythm of breathing that is set by the medulla oblongata. The pons also ***prevents over inflation*** of the lungs, and is therefore protective. The pons is also thought to be an active component to rapid eye movement (REM) sleep.

Pons and Cranial Nerves

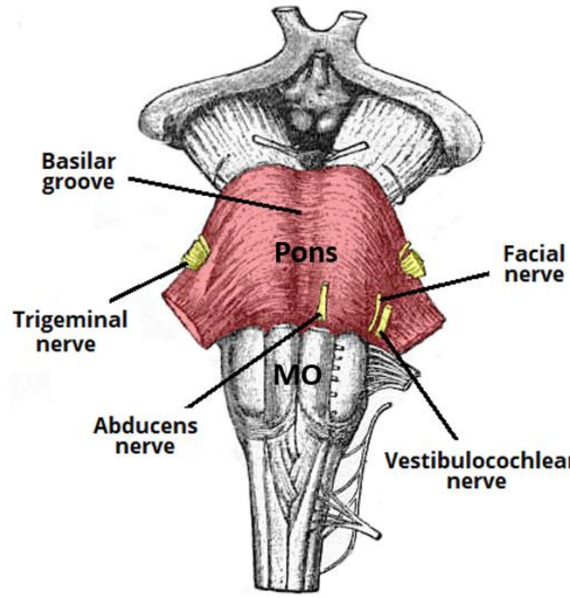
The pons has 4 cranial nerves that are associated with its function, covering a range of roles, such as hearing, balance and equilibrium, and gustation (taste), as well as touch and pain and facial sensations all from incoming sensory fibers. The cranial nerves emerging from the pons also send ***motor fibers*** out to participate in eye movement, facial expressions, chewing, swallowing, urination, and the secretion of saliva and tears.

There are four cranial nerves that originate from the pons anatomically:

- The **Trigeminal nerve**, Cranial Neve V
- The **Abducens nerve**, Cranial Neve VI
- The **Facial nerve**, Cranial Neve VII
- The **Vestibulocochlear nerve**, Cranial Neve VIII

To be specific about these four nerves, the only cranial nerve that is directly associated 'functionally with the pons is the **trigeminal nerve** (cranial nerve V). This is the largest of the 12 pairs of cranial nerves and functions both to innervate muscles and receive sensory information from three branches that cover the face. There are also three other cranial nerves are located at the pons-medullary junction (where the pons and medulla meet). They are the **abducens nerve** (cranial nerve VI), this controls the lateral rectus extrinsic eye muscle and 'abducts' the eyeball to look laterally (outward). The **facial nerve** (cranial nerve VII) which innervates muscles of facial expression and is also responsible for taste sensation on the first one third of the tongue. Finally, the **vestibulocochlear nerve** (cranial nerve VIII) which is almost exclusively a sensory nerve bringing in information from the inner ear, via two branches: The vestibular branch for balance and equilibrium; and the cochlear branch for sound sensations in the cochlea.

The Cranial Nerves of the Pons



6. Medulla Oblongata

The **medulla oblongata** (MO, or often just called the **medulla**), is the lowest anatomical part of the brain, the lowest portion of the brainstem, and is the last division of the brain before it becomes the **spinal cord**.

The Medulla Oblongata and Cranial Nerves

The last four of the cranial nerves are significantly intertwined in the functions of the medulla. The **glossopharyngeal nerve** (IX) delivers taste sensation from posterior one-third of tongue to the Medulla, and sensation from the pharynx, it senses blood pressure and O_2 and CO_2 content from the carotid artery. Parasympathetic fibers activate parotid salivary gland. It sends nerve fibers to elevate the pharynx when swallowing. The **vagus nerve** (X) motor fibers from the medulla descend to the neck for swallowing, controlling muscle of larynx; parasympathetic fibers regulate cardiac, pulmonary, and part of gastrointestinal activities. It brings sensation from the gastrointestinal tract back to the medulla as well as information for blood pressure (carotid sinus) and chemistry (carotid and aortic bodies). The **accessory nerve** (XI) comes from a union of cranial and spinal roots and emerges from the medulla to innervate the sternocleidomastoid and the trapezius to contribute to elevation of shoulders (shrugging). Also supplies motor fibers to the larynx, pharynx and soft palate. And finally, the **hypoglossal nerve** (XII) is a motor nerve from the medulla with fibers going to the intrinsic and extrinsic muscles of the tongue. It's concerned with food mixing and manipulation and also for movements of the tongue involved in speech and swallowing.

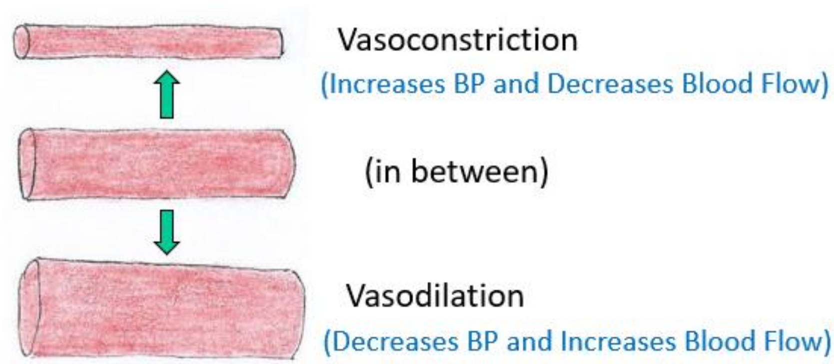
The Vital Center of the MO

The medulla oblongata plays a critical role in transmitting signals between the spinal cord and the higher parts of the brain, and in controlling autonomic activities, such as heartbeat and respiration. It houses some very important visceral centers that are also called **vital centers**, named because they regulate function that are vital to survival. The three vital centers are:

1) <u>The Cardiac Center</u> – This center provides modulation and fine tuning of the heart rate and the strength (or force) of myocardial contractility. These two elements of cardiac activity (Heart Rate and Force or Stoke Volume) generate **cardiac output**. This center adjusts the rate and force of the heartbeat when needed to meet metabolic needs of the body. This is mostly carried out by the **autonomic nervous system** (ANS), where the **parasympathetic** division slows the heart rate and force down, and the **sympathetic** division increases both the heart rate and the force of contraction.

2) <u>The Vasomotor Center</u> – This center regulates the **diameter** of peripheral **blood vessels** and therefore exerts an enormous influence on **systemic blood pressure** and **blood flow**.

See the image below for a comparison of the three different states of blood vessel diameter, as it becomes smaller (constricted) and larger (dilated). When blood vessels are constricted, this decreases blood flow but increases blood pressure (BP). When blood vessels are dilated this increases blood flow but decreases blood pressure. For the most part, it is the **sympathetic** division of **Autonomic Nervous System** (ANS) that controls blood vessel diameter throughout the body. The only exceptions are blood vessels to erectile tissue in male (penis) and females (clitoris), which is controlled by the **parasympathetic** division of the ANS. The greater the sympathetic stimulation, the more the vasoconstriction (if alpha receptors present) that occurs. Usually a lack of sympathetic stimulation will cause vasodilation.



3) <u>The Respiratory Center</u> – This center is for the maintenance and control the steady rhythm (or rhythmic pace) of breathing. For example, when we are sitting and calm, the regular rhythmic breathing rate is called **eupnea**, which is quiet normal breathing at rest. This center creates this pace. This is primarily done through the control of the diaphragm muscle, that large dome-shaped skeletal muscle immediately below the lungs. The diaphragm is controlled by the **phrenic nerve** that innervates this muscle to contract for inspiration.

Sensory receptors located inside blood vessels that measure blood pressure are called **baroreceptors**, and those that measure blood chemistry are called the **carotid** and **aortic bodies**. These relay this information to the medulla oblongata (the integration center) so that it can monitor and adjust the heart's activity and adjust blood vessel diameter in order to modify blood pressure, and blood flow to individual parts of the body. The medulla oblongata also regulates respiration rates based on incoming information and in this capacity monitors and can modify blood acidity.

Lastly, the medulla oblongata has several additional centers that regulate actions such as **sneezing**, **coughing**, **hiccupping**, **swallowing** and **vomiting**. For the most part, all of these response are protective reflexes.

The 12 Cranial Nerves

There are **12 pairs** of **cranial nerves** and because they are nerves, they are considered to be a part of the peripheral nervous system (PNS). Conventionally, each of the 12 pairs of nerves is named using a Roman numeral (I through XII) together with the descriptive name for the nerve.

I - Olfactory Nerve is a sensory nerve (a nerve carrying sensation information into the brain) that arises in the nasal mucosa, and goes up through the olfactory foramina of the cribriform plate, then conveys impulses for the sense of smell to the brain for perception of this sense. **Sensory**.

Clinical Applications
Anosmia refers to partial or total loss of the ability to smell. This may result from a fracture of the ethmoid or a lesion of olfactory fibers.

II - Optic Nerve arises from the retina of the eye and travels through the optic foramen of the orbit to deliver visual images to the brain. A 50-50 cross over of fibers occurs at the optic chiasm and continues through the thalamus. Thalamic fibers then run to the visual cortex in the occipital lobe. **Sensory**.

Clinical Applications
Damage to optic nerve results in blindness in the eye serviced by this nerve. Damage to visual pathways distal to the optic chiasm results in partial visual losses. Visual defects are called anopsias.

III - Oculomotor Nerve is a motor nerve (a nerve having only motor fibers traveling outward to muscles to cause their movement) and runs from the midbrain through the superior orbital fissures to the eyeball. It controls four of the six extrinsic muscles of the eye (inferior oblique, superior, inferior and medial rectus) to move the eye upward, downward and medially. Parasympathetic motor fibers go to muscles within the iris that are responsible for constriction of the pupil. Finally, it also travels to the levator palpebrae superioris muscle, which acts to raise the upper eyelid. **Motor**.

Clinical Applications
In oculomotor nerve paralysis, the eye cannot be moved up or inward, and at rest, the eye turns laterally (external strabismus), as the actions of the two remaining eye muscle are unopposed. Also, the upper eyelid droops (ptosis) and the person will have double vision and difficulty focusing on close objects. If the medial rectus has become weakened, the eye will tend to drift laterally, sometimes termed a 'lazy eye'. A common treatment for this is to place an eye patch on the stronger (dominant) eye in order to strengthen the weaker muscles of the affected eye.

IV - Trochlear Nerve also arises in the midbrain and goes through the superior orbital fissures. It is the smallest of the cranial nerves. Trochlea means "pulley" and this nerve innervates an extrinsic eye muscle called the superior oblique that hooks through a pulley-shaped ligament (called the trochlea) on the medial aspect of the orbit. It causes the eye to move down and outward (inferolaterally). **Motor**.

Clinical Applications
Trauma to or paralysis of trochlear nerve results in double vision, reduced ability to rotate eye inferolaterally. This nerve can affectionately be called the “cheaters nerve”, as it’s responsible for the ‘down and out’ glance of the eye when we want to check on our neighbor’s answer.

V - Trigeminal Nerve is a mixed nerve (a nerve having both sensory and motor fibers), it arises within the Pons and travels to the jaw's muscles to power chewing. The nerve also contains fibers bringing sensation from the face to the Pons. It is the largest of the cranial nerves and forms three divisions: Ophthalmic division (V1) - from skin of anterior scalp, upper eyelid, nose, nasal cavity mucosa and lacrimal gland through superior orbital fissure. Maxillary division (V2) - from lower eyelid, palate, upper teeth, skin of cheek and upper lip through the foramen rotundum. Mandibular division (V3) - from anterior tongue, lower teeth, skin of chin, temporal region of scalp through the foramen ovale. Dentist desensitize upper and lower jaws by injecting local anesthetic into alveolar branches of maxillary and mandibular division respectively. Mixed or **Both**.

Clinical Applications
Inflammation of the trigeminal nerve can cause tic douloureux or trigeminal neuralgia, a painful condition that only lasts for a few seconds to minutes but occurs frequently. The actual cause is unknown but may be due to pressure on the trigeminal nerve root. Sensory stimulus like brushing the teeth or air hitting the face can trigger an episode. Some respond to analgesics but severe cases may require cauterization, poisoning or severing of nerve proximal to trigeminal ganglion.

VI - Abducens Nerve fibers leave the inferior Pons and enter the orbit via the superior orbital fissure (along with the oculomotor III and trochlear IV nerves), going to the extrinsic eye muscle the lateral rectus. The lateral rectus is responsible for rotating the eye outward (laterally). The nerve is so named because it abducts the eyeball (turns the eye laterally, away from midline). **Motor**.

Clinical Applications
In abducens nerve paralysis, the eye cannot be moved laterally; at rest, the affected eyeball turns medially (internal strabismus), giving a person a 'cross-eyed' condition.

VII - Facial Nerve arising from the Pons and innervates (gives nerve supply to) the muscles of facial expression, the eyelids, as well as some of the muscles which assists speech and mastication. It also is involved in the control of saliva secretion. The nerve also contains fibers that bring taste sensation from anterior two-thirds of tongue to the brainstem. Mixed or **Both**.

Clinical Applications
Bell's palsy is characterized by paralysis of facial muscles on the affected side and partial loss of taste sensation. Inflammation of the facial nerve and can occur rapidly (often overnight). Symptoms include lower eyelid drooping, corner of mouth sagging (difficulty in eating and speaking), constant tear dripping and an inability to completely close eye. Can resolve spontaneously without treatment.

VIII - Vestibulocochlear Nerve arises in the inner ear and passes through the internal auditory meatus to enter the brain stem at the Pons. It is really two nerves (the vestibular n. and the cochlear n.) housed together. The vestibular component conveys equilibrium and position sense and coordinates movement of head and neck. The cochlear component coveys sound waves and is responsible for hearing. **Sensory**.

Clinical Applications
Lesions of the cochlear nerve or cochlear receptors result in central or nerve deafness, whereas damage to the vestibular division produces disturbances associated with equilibrium, such as dizziness, rapid involuntary eye movements, loss of balance, nausea and vomiting.

IX - Glossopharyngeal Nerve brings sensation from the pharynx (back of the throat), senses blood pressure and O_2 and CO_2 content from the carotid artery, delivers taste sensation from posterior one-third of tongue to the Medulla. Parasympathetic motor fibers activate the parotid salivary gland. It also sends motor nerve fibers to elevate the pharynx when swallowing. Mixed or **Both**.

Clinical Applications
Injury or inflammation to the glossopharyngeal nerves impairs swallowing and taste on the posterior third of the tongue, particularly for sour and bitter tasting substances.

X - Vagus Nerve this is the only cranial nerve that extends beyond the neck region, its name comes from the word vagrant, which means wonderer or to roam, due to how far it extends downward. Its motor fibers come from the medulla through the jugular foramen and descend to the neck, thorax and abdomen. Involved in swallowing, controlling muscle of larynx; parasympathetic motor fibers regulate cardiac, pulmonary, and part of gastrointestinal activities. It brings sensation from the gastrointestinal tract back to the medulla as well as information for blood pressure (carotid sinus) and chemistry (carotid and aortic bodies). Mixed or **Both**.

Clinical Applications
Vagus nerve paralysis can lead to hoarseness or loss of voice; other symptoms include difficulty swallowing, impaired digestive system motility. Total destruction of both vagus nerves is incompatible with life, as the parasympathetic fibers are crucial in maintaining normal visceral activity.

XI - Accessory Nerve forms from a union of cranial and spinal roots. It emerges from the medulla and exits through the jugular foramen to supply motor fibers to the sternocleidomastoid muscles for lateral rotation and flexion of the head, and the trapezius muscle which contributes to extension of the neck and the elevation of the shoulder as occurs with a "shrug". Also, it supplies motor fibers to the larynx, pharynx and soft palate. **Motor**.

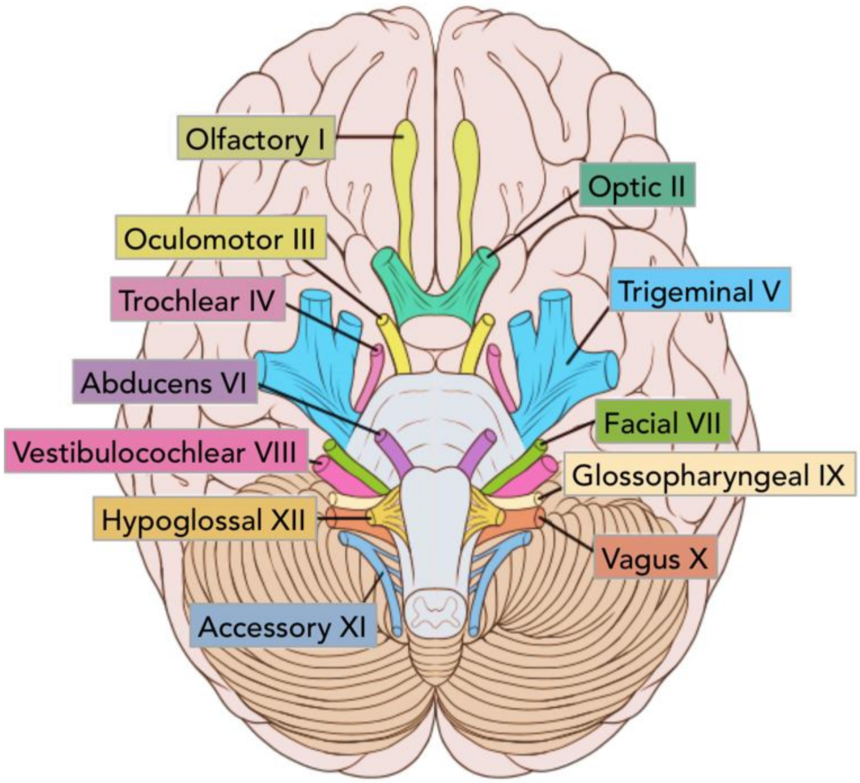
Clinical Applications
Injury to the spinal root of the accessory nerve causes head to turn toward injured side as a result of paralysis of the sternocleidomastoid. Shrugging of that shoulder becomes difficult (trapezius).

XII - Hypoglossal Nerve is a motor nerve that comes from the medulla and goes through the hypoglossal canal to the intrinsic and extrinsic muscles of the tongue. It's concerned with food mixing and manipulation and also for movements of the tongue involved in speech and swallowing. **Motor**.

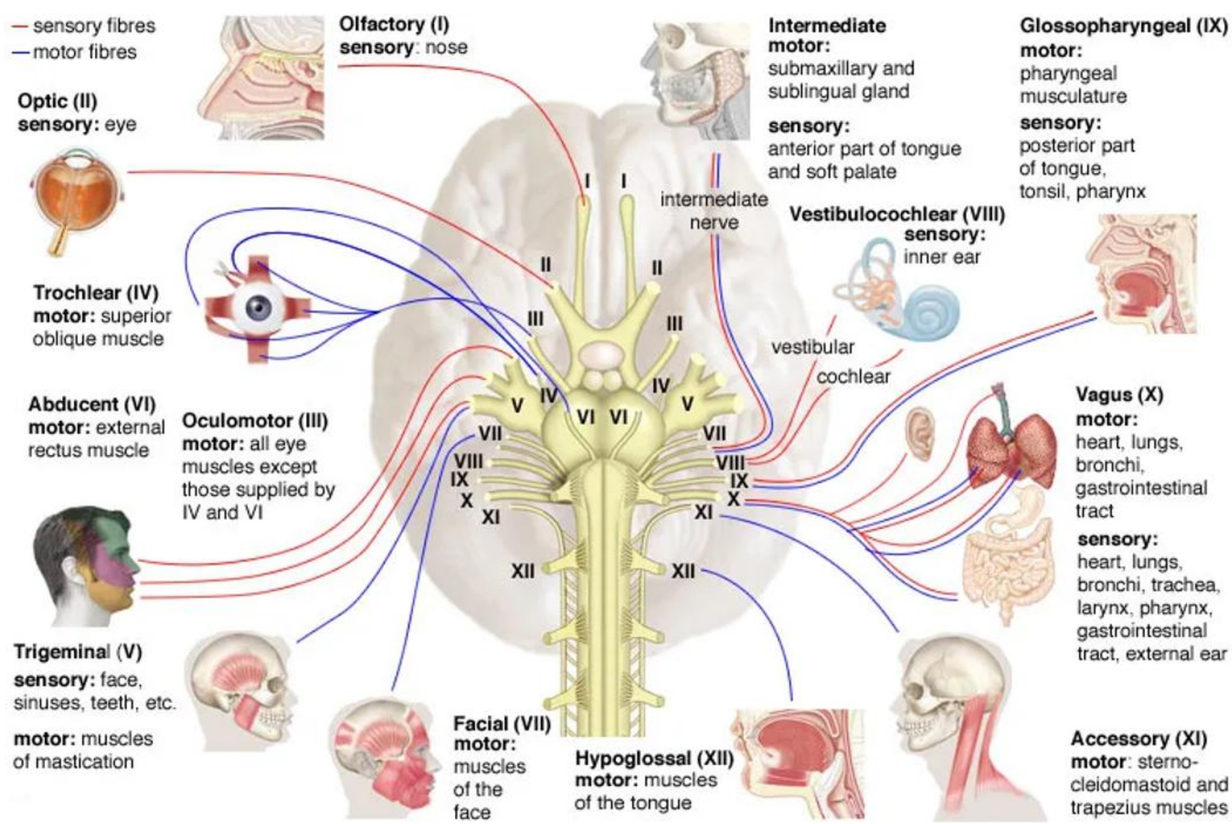
Clinical Applications
Damage to the hypoglossal nerve causes difficulties in speech and swallowing; if both nerves are impaired, the person cannot protrude the tongue; if only one side is affected, the tongue deviates (leans) toward affected side. Eventually the paralyzed side of the tongue begins to atrophy (get smaller) from lack of use.

Organization and Arrangement of the 12 Cranial Nerves

Shown below are the arrangements of the 12 cranial nerves from an inferior view of the brain. When discussing the cranial nerves the descriptive and numeric names are used together, with the number denoted using Roman numerals.



It is useful to make a basic connection for each cranial nerve to its primary function (see below).



The 12 Cranial Nerves Exit and Enter the Brain via various Foramina, Fissures and Canals of the Skull

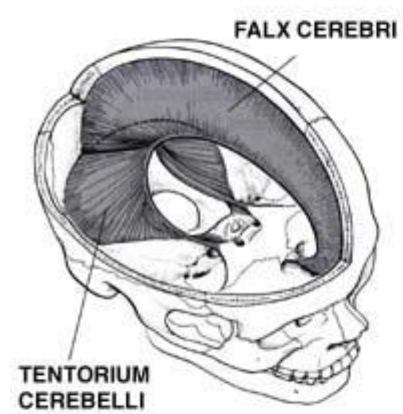
In **Tabe 1** below each of the 12 cranial nerves is listed in their numeric order and the next column shows which skull structure that nerve and its branches pass through.

Table 1. The cranial nerves and the ‘holes’ in the skull they pass through.

Cranial Nerve	Skull Structure
1. Olfactory Nerve (I)	Olfactory foramina
2. Optic Nerve (II)	Optic canal
3. Oculomotor Nerve (III)	Superior orbital fissure
4. Trochlear Nerve (IV)	Superior orbital fissure
5. Trigeminal Nerve (V): (3 branches) **1)** Ophthalmic **2)** Maxillary **3)** Mandibular	Superior orbital fissure Foramen rotundum Foramen ovale
6. Abducens Nerve (VI)	Superior orbital fissure
7. Facial Nerve (VII)	Stylomastoid foramen
8. Vestibulocochlear Nerve (VIII)	Internal auditory canal
9. Glossopharyngeal Nerve (IX)	Jugular foramen
10. Vagus Nerve (X)	Jugular foramen
11. Accessory Nerve (XI)	Jugular foramen
12. Hypoglossal Nerve (XII)	Hypoglossal canal (foramen)

Important Additional Brain Structures

The **falx cerebri** is a fold of dura mater which goes into the longitudinal fissure between the two hemispheres of the cerebrum. This is as structure that divides the Left and Right cerebral hemispheres from each other. The **falx cerebelli** is a small triangular fold of dura mater, which similarly acts to separate the two cerebellar hemispheres. The **tentorium cerebelli** is a fold dura mater that separates the cerebellum from the cerebrum.



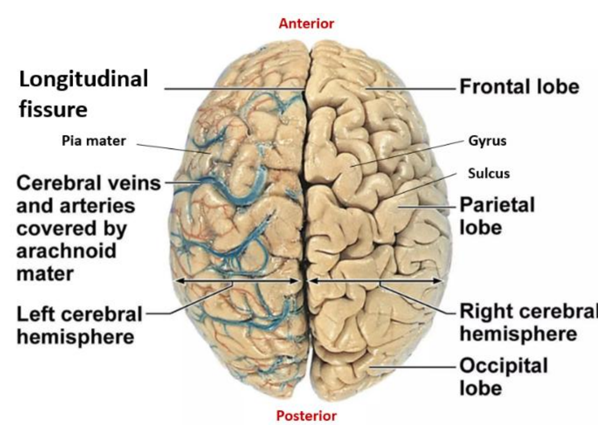
Falx means 'sickle-shaped' in terms of what it looks like; of the cerebrum is 'cerebri' and of the cerebellum is 'cerebelli'. These are just 3 structures that help to partition regions of the brain. Tentorium cerebelli literally means "tent of the cerebellum", as it does completely cover the top of the cerebellum. To the right is a diagram to help visualize these structures.

The Cranial Meninges

The protective covering of the brain is called the **cranial meninges**, it provides insulation and access for blood vessels and cerebral spinal fluid (CSF) to circulate within the brain. It consists of three layers, from outermost (superficial) to innermost (deep) are as follows:

1) The **dura mater** is the thick, tough dense fibrous connective tissue outer layer of the meninges (dura means tough and mater means mother), and it has 2 layers: **a)** Periosteal layer, which is the outer surface contacting the cranial bones; and b) Meningeal layer, which is the deep layer. The dural venous sinuses (large veins) are located in between the two layers of dura mater.

2) The **arachnoid** is the middle layer of the meninges and is a web-like structure, Composed of loose/fibrous connective tissue. that has a space below that is filled with cerebrospinal fluid (CSF) that cushions the brain;



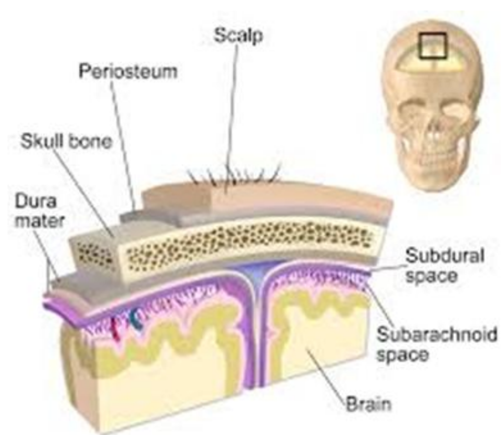
3) The **pia mater** is the most delicate and thinnest tissue, and the innermost layer that covers the nervous tissue and follows its contours and adheres directly to the surface of the brain. This layer is composed of an outer collagen layer, and inner epithelial elastic and reticular fiber layer.

Spaces Created by the Cranial Meninges

Epidural space – is a potential space superficial to the dura mater.

Subdural space – is a potential space between the dura and the arachnoid layer.

Subarachnoid space – this is a space is filled with CSF and contains the blood vessels supplying brain.



Cerebrospinal Fluid

The Central Nervous System (CNS) gets its oxygen and nutrients from cerebrospinal fluid (**CSF**) and not directly from blood. The CSF is a ***filtrate of blood***, this means it originates from blood but is filtered from the cerebral blood vessels into the CNS. The CSF is a clear, colorless fluid that directly bathes the brain and spinal cord. Compare the images below showing blood (left) and CSF (right). Blood contains plasma (the fluid component) and many cells, the red blood cells (99%) makes the color red, and there is a small number of white blood cells (1%). This is very different to cerebrospinal fluid, which has no cells or proteins. The sample of CSF in the photo is from a lumbar puncture procedure.

How is Cerebrospinal Fluid (CSF) Created

Everything starts in the **Heart**. The heart delivers blood to all the tissues of the body via blood vessels. Blood goes through a series of **choroid plexuses** in the brain, which are bundles of blood vessels located in all of the 4 **ventricles of the brain** (described below). The fluid portion of blood is called **plasma** and as blood passes through these choroid plexuses, only the plasma portion filters into the ventricles to create this special fluid that bathes and protects the delicate nervous tissue. The filtering of blood does not allow any blood cells or proteins into the CSF, hence it is clear, pale yellow color.

The Roles of CSF in the CNS

1. Cushions and insulates delicate nervous tissue.

Cerebrospinal fluid acts as a cushion to insulate or buffer the brain, much like how an air bag operates in a car. It protects the delicate brain and spinal cord tissue from traumatic injury when jolted or hit.

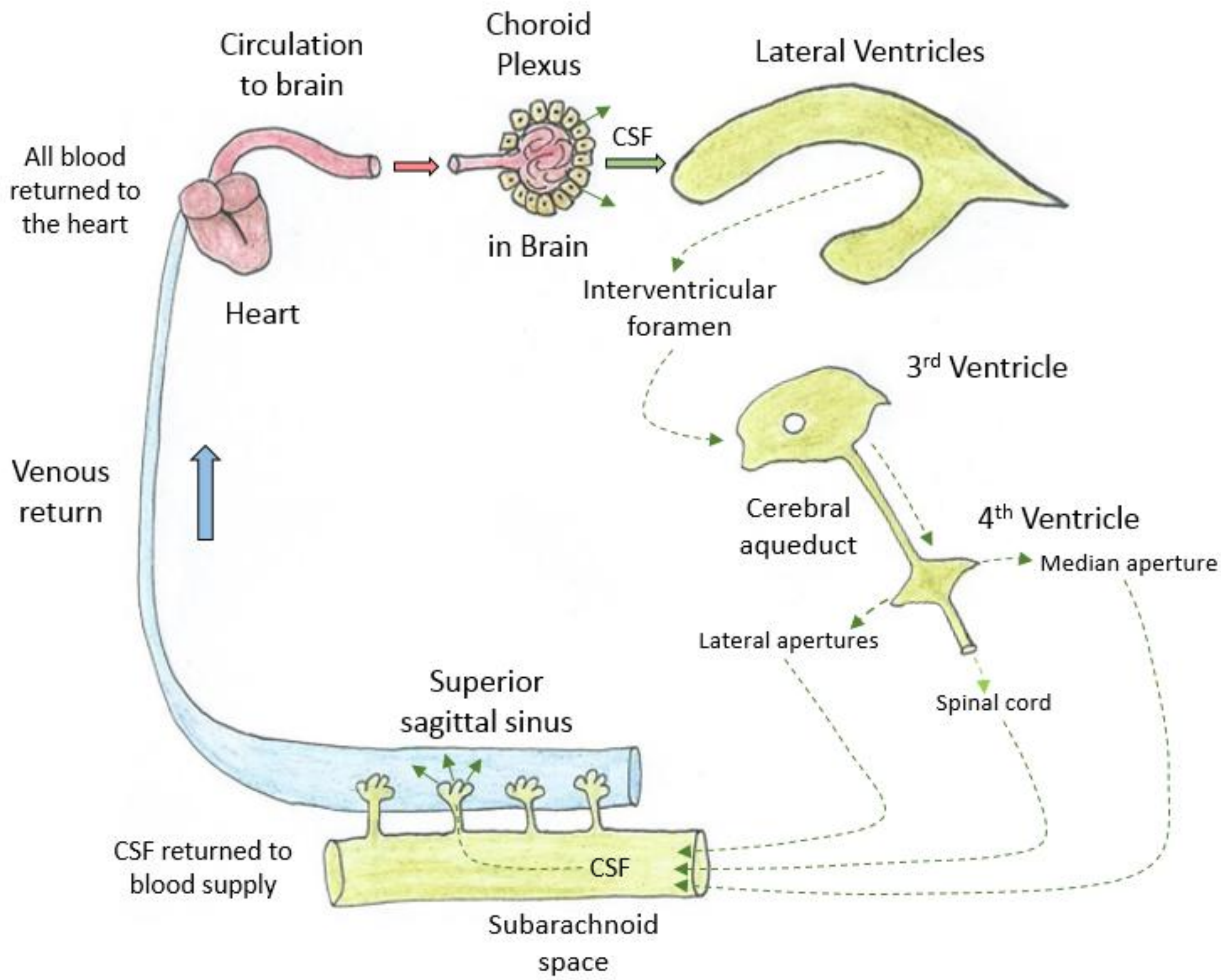
2. Gives Buoyancy to the brain ("floats" in CSF).

The mass of the adult human brain is approximately 1,400 grams (less than 3lbs). This is heavy when sitting on top of the cranial bones. Since CSF is very salty it allows the brain to be suspended in the CSF, such that the weight of brain becomes equivalent to a mass of about 25 grams!!! If not for this buoyancy provided by CSF, the brain's own weight would cut off blood supply and kill neurons in the lower sections.

3. Exchange of gases (O_2 and CO_2), nutrients and wastes.

The flow of CSF in the central nervous system (CNS) acts like the blood circulation does for other parts of the body, that is, it acts to exchange vital nutrients (glucose, fatty acids, amino acids, minerals), gases (O_2 in and CO_2 out) and metabolic wastes. CSF thereby regulates the exchange and metabolism of the CNS.

Cerebrospinal Fluid Circulation

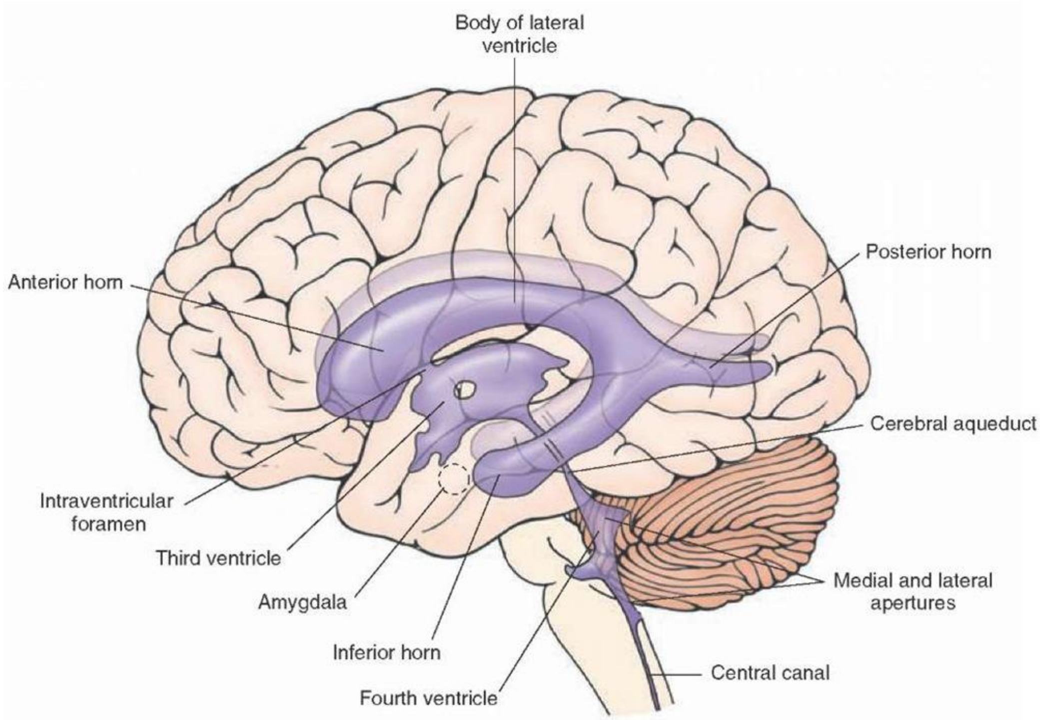


The Creation and Flow of Cerebrospinal Fluid (CSF)
Ventricles of the brain are fluid filled chambers inside the brain. Cerebrospinal fluid (CSF) is created as a filtrate of the blood from the **choroid plexuses** which are present at every **ventricle** of the brain. The word ***choroid*** loosely means 'vascular' and plexuses means 'network', so the choroid plexuses are a network of blood vessels in the brain that are surrounded by ependymal cells which help to produce most of the CSF.

There are **4 ventricles** of the brain: The lateral ventricles (1 and 2); the 3rd ventricle; and the 4th ventricle (see diagram above).

CSF is made and found in the **ventricles** inside the brain, in the **subarachnoid space** of the cranial and spinal meninges, and in the **central canal** of the spinal cord. In an adult there is usually about 140 to 170ml (average of **150ml**) of CSF in circulation at any one time within in the Central Nervous System (CNS). For children it ranges from 20 to 60 ml. In adults, there is approximately **500ml** of CSF made per day.

The basic circulation of CSF starts at the choroid plexuses of the two large **lateral ventricles** (located in the cerebrum). From here, the CSF passes through the **interventricular foramen** (these are not holes but connecting tubes) which deliver CSF to the **3rd ventricle**. The CSF then goes into the **cerebral aqueduct** on its way to the **4th ventricle**, which is located down by the cerebellum, pons and medulla oblongata (MO). The CSF then exits the 4th ventricle into the **subarachnoid space** or into the **central canal** through 3 apertures (openings) at the 4th ventricle - one **median aperture** and two **lateral apertures**.



Once the CSF is in the subarachnoid space, it can circulate all around the brain and spinal cord. Finally, the CSF needs to go back to where it came from – it started from blood and so needs to be returned to the blood supply.

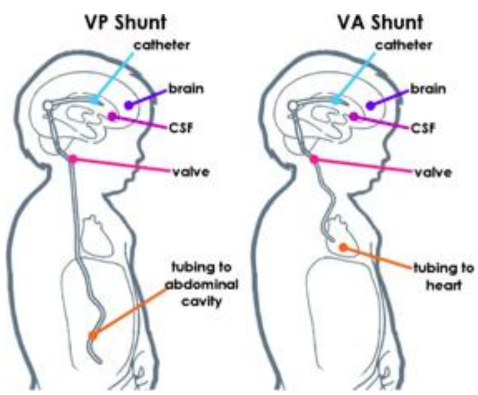
Since CSF is a filtrate of blood, it can be re-mixed with the blood and taken back to the heart for the process to start all over again from the beginning (circulate means "makes a circle"). The CSF that is in the subarachnoid space returns to the vascular system via **arachnoid villi** (or granulations) – these are connections from the subarachnoid space into the **dural venous sinuses**.

Remember a **sinus** in the cardiovascular system is a **large blood vessel, usually a vein**, and these veins are sandwiched in between the two layers of the cranial dura mater. Once the CSF enters the large dural sinuses (an example is the *superior sagittal sinus*) it is reunited with blood in the venous circulation and it flows back to the heart. That is the last part of the circulation, as it goes back to where it started. This process will repeat, where the choroid plexuses (which exist at all 4 ventricles) continue to make CSF at every ventricle and the CSF flows in the order shown in the drawing on the previous page with the dashed green arrows.

Hydrocephalus ('water on the brain') is an abnormal accumulation of cerebrospinal fluid (CSF) in the ventricles or subarachnoid space of the brain, which may cause **increased intracranial pressure** (ICP) inside the skull. It can be caused by impaired CSF flow, impaired re-absorption, or excessive production of CSF. Hydrocephalus may lead to enlargement of the cranium if it occurs during development (when fontanels are still present). It can be fatal if ICP is excessively high and not quickly alleviated.

Infant with hydrocephalus; notice how the fontanels allow for significant expansion of the cranium. Hydrocephalus is often categorized as either **intraventricular** (within the ventricles of the brain) or **extraventricular** (outside of the ventricles of the brain).

Surgical treatments commonly utilize various cerebral shunts that can act as a detour for the blocked fluid circulation. This involves inserting a catheter (tube) into the cerebral ventricles to bypass the obstruction or the malfunctioning arachnoid granulations (villi). This allows for the drainage of excess fluid into other body cavities, where it can be reabsorbed. Most shunts drain the fluid into the peritoneal cavity (**V**entriculo-**P**eritoneal shunt); alternative sites include the right atrium (**V**entriculo-**A**trial shunt).

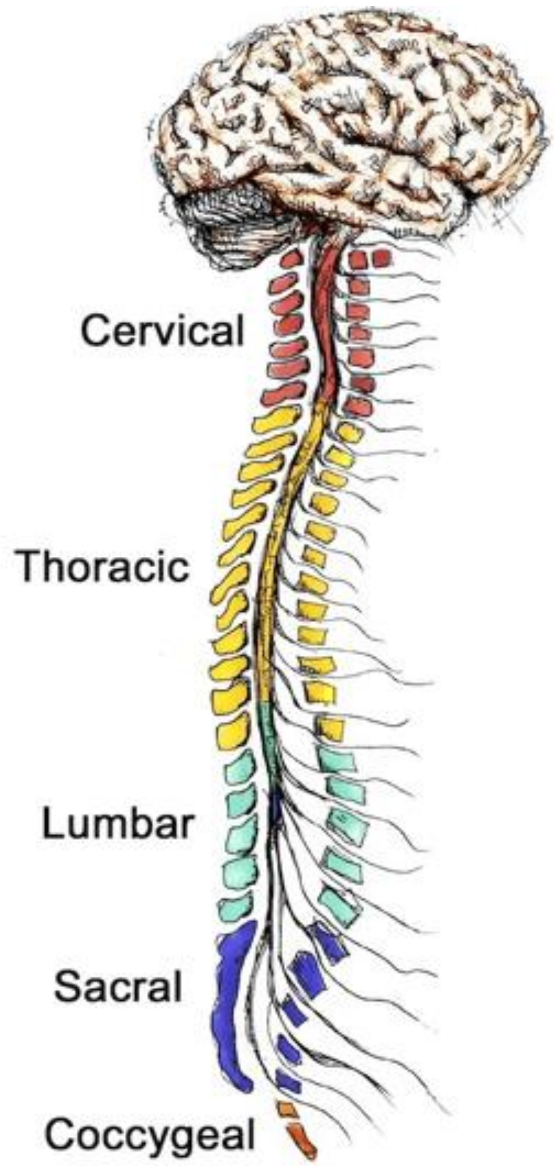


Seen above are the two common shunts to drain excess CSF: The Ventriculo-Peritoneal (VP) shunt, and the right atrium Ventriculo-Atrial (VA) shunt.

The Spinal Cord

The spinal cord is the other 'half' of the central nervous system, essentially a continuation of nervous tissue and supporting cells extending from the brainstem all the way down to the lumbar region of the vertebral column. What we will see is that the spinal nerves emanate out into the periphery of the body from the spinal cord to help create the **peripheral nervous system** (PNS) in the same way that cranial nerves radiate out from the brain into the periphery.

The spinal cord is protected by being housed inside the **vertebral canal** of the bony **vertebral column**. Apparently the spinal cord finishes growing before the bones of the vertebral column stop growing so that there's a disproportion between spinal cord growth and vertebral column growth. This results in what we observe that the spinal cord actually ends about two thirds of the way down the vertebral canal.



Just as the vertebral column has divisions with regional segments going from **cervical**, **thoracic**, **lumbar**, **sacral**, to the end at the **coccygeal** region, so too , the spinal cord is divided into segments: cervical, thoracic, lumbar, sacral, and coccygeal.

Each segment of the spinal cord provides a pair of spinal nerves which exit laterally from the vertebral canal through the intervertebral foramina. There is a total of 31 pairs of spinal nerves in this sequence:

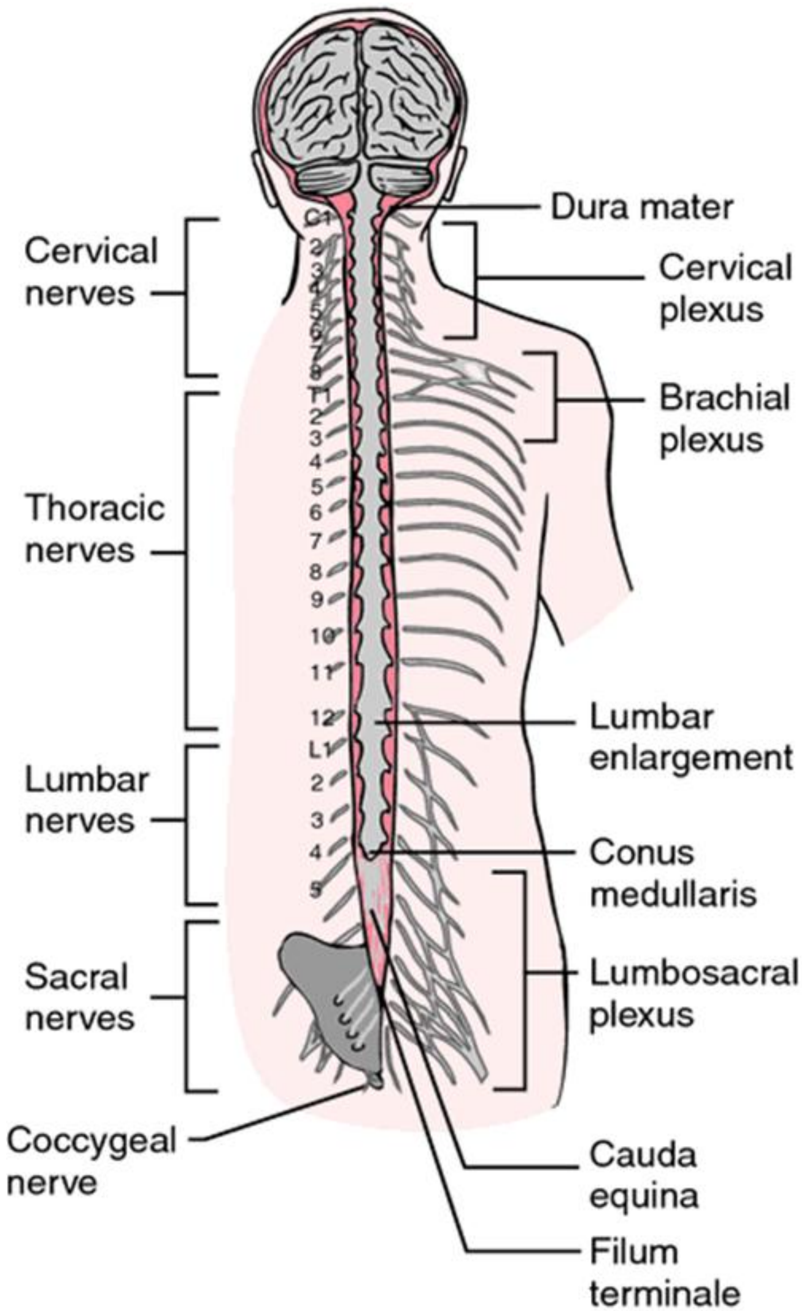
- 8 cervical nerves
- 12 thoracic nerves
- 5 lumbar nerves
- 5 sacral nerves
- 1 coccygeal nerve

The specific features of the spinal nerves and how they create the spinal plexuses are detailed below.

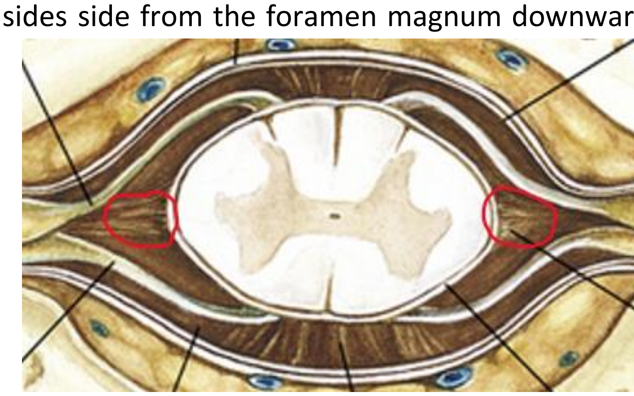
The Length-wise Anatomy of the Spinal Cord

The spinal cord measures roughly 18 inches long, about 1 ½ feet, commencing its downward extension at the foramen magnum, where is leaves the medulla oblongata of the brainstem. It officially starts at the **foramen magnum** and officially ends at the at the **conus medullaris** (= cone in the middle), which is a tapering cone-shape at the very end of the spinal cord proper. The conus medullaris is located between **L_1** and **L_2** of the lumbar vertebrae.

There is fine type of fiber called the **filum terminale** (= thread at the end) that goes from the tip of the conus medullaris to the 1^{st} coccygeal vertebra (Co_1) and this serves to anchor the spinal cord in place, providing a longitudinal stabilization of the spinal cord.



The spinal cord also had **denticulate ligaments** (dent = teeth!) for lateral stabilization of the spinal cord within the spinal canal. These are located along the sides side from the foramen magnum downward, they are projections of the pia mater that attach to the dura mater on each side along the length of the spinal cord. The image (at right) shows the denticulate ligaments on either side of the spinal cord, circled in red.



Along its length, there are two defined enlargements, called the **cervical enlargement** and the **lumbar enlargement**, where there is a thickening of nervous tissue. The enlargements are to accommodate for the innervation of the upper limbs (cervical) and lower limbs (lumbar).

The Spinal Nerves and Plexuses

Again, the spinal cord is divided into segments: cervical, thoracic, lumbar, sacral, and coccygeal, and there is a total of 31 pairs of spinal nerves. In humans, there are **31 pairs of spinal nerves** that radiate off from the spinal cord, (through the intervertebral foramen) at different levels that are coordinated with the regions of the spinal column that wea re already familiar with. The spinal nerves are grouped and named according to the specific vertebrae they leave and are grouped as follows:

- 8 Cervical (C_1-C_8)
- 12 Thoracic (T_1-T_{12})
- 5 Lumbar (L_1-L_5)
- 5 Sacral (S_1-S_5)
- 1 Coccygeal (Co_1)

The spinal cord serves as a channel for the ascending and descending fiber tracts that connect the peripheral and spinal nerves with the brain. Each of the 31 spinal segments is associated with a pair of **dorsal root ganglia** that contain nerve cell bodies only of sensory neurons. The axons from these sensory neurons enter the posterior aspect of the spinal cord via the **dorsal root**.

The axons from somatic and visceral motor neurons leave the anterior aspect of the spinal cord via the **ventral roots**. Distal to each dorsal root ganglion the sensory and motor fibers combine to form a spinal nerve - these nerves are classified as mixed nerves because they contain both afferent (sensory) and efferent (motor) fibers.

Spinal nerves are mixed nerves that leave the vertebral canal through intervertebral foramina and divide into several branches. **Dorsal rami of spinal nerves** supply structures along the dorsal (posterior) aspects of the vertebral column. **Ventral rami of spinal nerves** tend to join each other and then split again, forming a network, or plexus, of nerves innervating the ventral (anterior) and lateral sides of the torso.

The **rami communicantes** consist of two branches (an unmyelinated gray ramus and a myelinated white ramus) that connect spinal nerves to a sympathetic ganglion, which is part of the autonomic nervous system (ANS).

A ***Plexus*** is a rearrangement of the spinal nerves into a functional grouping. There are four plexuses of spinal nerves: *cervical, brachial, lumbar,* and *sacral.* The latter two are sometimes referred to as a single plexus, the *lumbosacral plexus.*

1. Cervical Plexus

The cervical plexus is positioned deep on either side of the neck. It is formed by the ventral rami of the first four cervical nerves and a portion of C_5 (C_1-C_5). Fibers from C_3-C_5 unite to become the paired *phrenic nerves,* sending motor impulses to the diaphragm muscles that contract during inspiration.

2. Brachial Plexus

The brachial plexus is formed by the ventral rami of C_5-T_1. Five major nerves (axillary, radial, musculocutaneous, ulnar and median) and several smaller ones arise from the brachial plexus.

3. Lumbar Plexus

The lumbar (T_{12}-L_4) plexus is composed of spinal nerves from the last of the thoracic nerve T_{12} to the 4th lumbar nerve L_4. It includes the femoral nerve.

4. Sacral Plexus

The sacral plexus (L_4-S_4) is composed of spinal nerves from the lumbar nerve L_4 to the 4th sacral nerve S_4. It includes the femoral nerve contains the sciatic nerve is the largest nerve arising from the sacral plexus and the largest nerve in the body.

Branches of Brachial Plexus (selected nerves)

1) Axillary n. from Posterior cord (C_5,C_6). *Innervation*: Skin of shoulder; shoulder joint, deltoid and teres minor muscles.

2) Radial n. from Posterior cord (C_5- T_1). *Innervation*: Skin of posterior lateral surface of arm, forearm, and hand; extensor muscles of posterior upper arm and forearm (triceps brachii, supinator, anconeus, brachioradialis, extensor carpi radialis brevis and longus, extensor carpi ulnaris).

3) Musculocutaneous n. from Lateral cord ($C_{5\text{-}7}$). *Innervation*: Skin of lateral surface of forearm; muscles of anterior upper arm (coracobrachialis, biceps brachii, brachialis).

4) Ulnar n. from Medial cord (C_8,T_1). *Innervation*: Skin of medial third of hand; flexor muscles of anterior forearm (flexor carpi ulnaris, flexor digitorum), medial palm, and intrinsic flexor muscles of the hand.

5) Median n. from Medial cord (C_6-T_1). *Innervation*: Skin of lateral two-thirds of hand; flexor muscles of anterior forearm, lateral palm.

Branches of Lumbar Plexus (selected nerves)

1) Genitofemoral n. from L_1,L_2. *Innervation*: Skin of middle anterior surface of thigh, scrotum in male, and labia majora in female; cremaster muscle in male.

2) Femoral from L_2-L_4. *Innervation*: Skin of anterior and medial aspect of thigh and medial aspect of leg and foot; anterior muscle of thigh (iliacus, psoas major, pectineus, rectus femoris, sartorius) and extensor muscles of leg (rectus femoris, vastus lateralis, vastus medialis, vastus intermedius).

3) Obturator n. from L_2-L_4. *Innervation*: Skin of medial aspect of thigh; adductor muscles of leg (external obturator, pectineus, adductor longus, adductor brevis, adductor magnus, gracilis)

4) Saphenous n. from L_2-L_4. *Innervation*: Skin of medial aspect of leg.

Branches of Sacral Plexus (selected nerves)

1) Sciatic n. from L_4-S_3. Composed of two nerves (tibial and common peroneal) that are encased within the sciatic sheath, splits into two portions at popliteal fossa; *Innervation*: branches from sciatic in thigh region to hamstring muscles (biceps femoris, semitendinosus, semimembranosus) and adductor magnus.

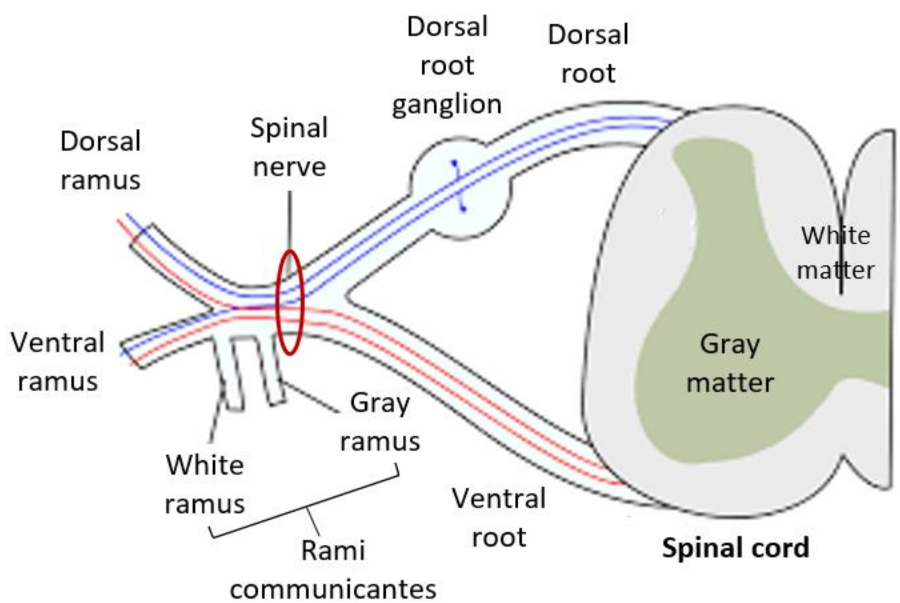
2) Tibial (sural, medial and lateral plantar) L_4-S_3. *Innervation*: Skin of posterior surface of leg and sole of foot; muscle innervation includes gastrocnemius, soleus, flexor digitorum longus, tibialis posterior, popliteus, and intrinsic muscles of the foot.

3) Common Peroneal n. (superficial and deep peroneal) from L_4-S_2. *Innervation*: Skin of anterior surface of the leg and dorsum of foot; muscle innervation includes peroneus tertius, brevis and longus, tibialis anterior, extensor hallucis longus, extensor digitorum longus and brevis.

4) Pudendal n. from S_2-S_4. *Innervation*: Skin of penis and scrotum in male and skin of clitoris, labia majora, labia minora, and lower vagina in female; muscles of perineum.

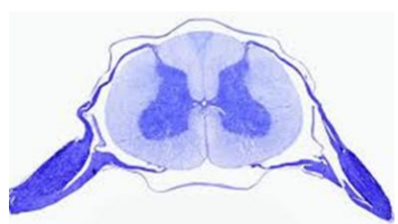
Cross Section of the Spinal Cord

In lecture, the cross section of the spinal cord is examined in order to identify the relationship between the incoming and outgoing nerve fibers and how they are arranged in a complex and elegant network that is highly functional. The image below represents one side (right) of the anatomy of the spinal cord in cross section, the dorsal is the posterior aspect and ventral is the anterior aspect.



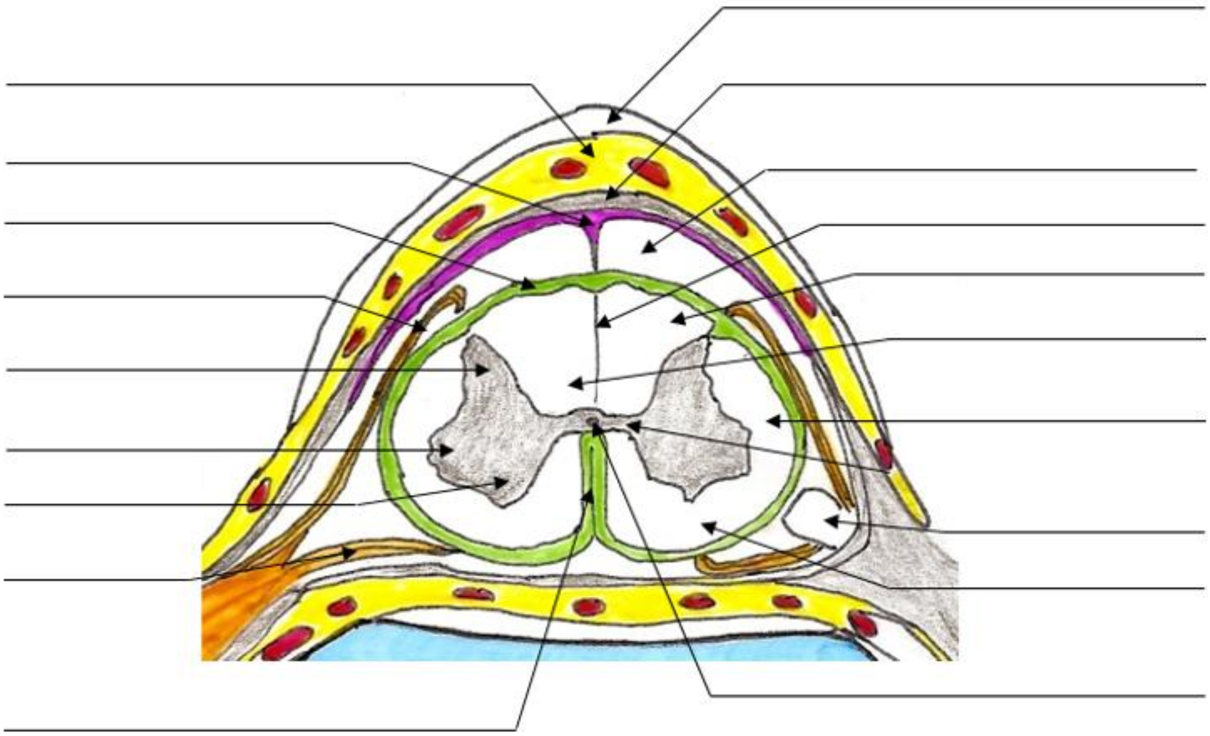
The spinal cord is made of gray and white matter just like other parts of the CNS. However, unlike much of the brain, the arrangement in the spinal cord is that the white matter is the outer portion (the columns) and the gray matter is the inner portion (the horns).

The inner **gray matter** is often referred to as the butterfly-shaped or the "H" shaped central part of the spinal cord, due to its resemblance to those things – see the histology of a cross section of a spinal cord to the left, with its district butterfly-shaped gray matter in the center of the white matter. As in the brain, the gray matter in the spinal cord is comprised of nerve cell bodies, with the main designations being the anterior, lateral, and posterior horns.



The **white matter** around the gray matter is made mostly of myelinated axons. These create the various pathways (tracts) that connect the brain with the rest of the body. See the anatomy worksheets for this section to complete the labeling of the cross section of the spinal cord on the next page.

Label this drawing of a cross section of the spinal cord and the meninge (found in the anatomy worksheets on faculty website online). Include the following structures: central canal, anterior median fissure, posterior median sulcus, ventral grey horn, dorsal horn, ventral root, dorsal root, dorsal root ganglion, ventral ramus, dorsal ramus, ventral column, dorsal column and lateral column. Also identify the 3 spinal meningeal layers and the spaces they create.



Spinal Meninges

The spinal cord and spinal nerve roots are wrapped within three layers called **spinal meninges**. Just as in the cranial meninges, the outermost is the **dura mater**, underneath it is the **arachnoid layer**, and the deepest is the **pia mater**.

These spinal meninges create 3 spaces, just as in the cranial meninges, with slight differences. Above the dura is the **epidural space**, filled with adipose and blood vessels. Deep to the dura mater is the **subdural space** (which is empty and called a 'potential' space). Deep to the arachnoid layer is the **subarachnoid space** which is filled with cerebrospinal fluid.