Chapter 13
Anatomy of the Nervous System

In this chapter, we're going to talk about the anatomy of the nervous system and the focus will be on the central nervous system, for the first part of the chapter.

So in order to study the brain, we have to examine the embryonic development of the brain; the brain and all other nervous tissue forms from ectoderm. During embryonic development, thin, flat layer of ectoderm begins to thicken to form the neural plate, which then invaginates to form the neural groove, which is also sometimes referred to as the neural fold.

Eventually the two sides of the neural groove touch, forming an internal passageway called the neurocoel. This structure is now called the neural tube. The anterior end of the neural tube begins to enlarge, forming three prominent divisions – and you can see that here, with the formation of the primary brain vesicles. You have the forebrain, the midbrain, and the hind brain.

Somewhere around week five of development, the primary brain vesicles have changed position, and the forebrain and hindbrain have further subdivided to form secondary brain vesicles. The midbrain does not significantly change during development. As development continues, the cerebrum enlarges to the point where it covers the other portions of the brain – and you can also see in this slide what the forebrain and hindbrain structures become in the adult. The forebrain becomes the cerebrum, which is the cerebral cortex, white matter, and basal nuclei. In addition, it forms the thalamus, pineal gland, and hypothalamus – and the hind brain forms the brainstem, the pons, and the cerebellum, as well as the medulla oblongata.

Now let's look at some of the major parts of the brain. The brain contains almost 97 percent of the body's neural tissue and a typical adult brain weighs about three pounds. Brain size varies considerably among individuals. On average, the brain of males are about 10 percent larger than those of females, which gives rise to the differences in body size we see between men and women. There has not been any correlation that research has noted to date where it exists that there is a difference between brain size and intelligence. Individuals with the smallest brains and the largest brains are both found to be functionally normal. The brain possesses four fluid-filled chambers, which we will examine, called ventricles – and the ventricles contain CSF or cerebrospinal fluid.

The major regions of the brain are – the cerebrum, the cerebellum, the diencephalon, the brainstem, the midbrain – and we will take a look at each of these structures in the next few slides.

So starting with the cerebrum – The cerebrum accounts for about 80 percent of the brain’s mass. The cerebrum functions in conscious thought, memory storage and processing, sensory processing, and the regulation of skeletal muscle contractions. The surface of the cerebrum is highly folded and covered with a superficial layer of grey matter called the cerebral cortex.

There is – if we examine the cerebral cortex in a little more detail, we can see the cerebral cortex is the grey matter of the cerebrum and is responsible for all qualities associated with consciousness. Each hemisphere is concerned with the sensory and motor functions of the opposite sides of the body, so there's a contralateral function.
Even though symmetrical in structure, the two hemispheres are not equal in function and there is a lateralization or specialization of cortical function.

The right brain generally analyzes sensory information and relates the body to the sensory environment. Interpretive centers in this hemisphere enable you to identify familiar objects by touch, sight, smell, taste, or feel – and according to a myth, right-brained individuals are often more artistic, musically-inclined, or attuned to their emotions.

The left brain possesses the general interpretive and speech centers and is important in language-based skills, as well as reading; writing; speaking; math; and logic.

The cerebral cortex contains 3 functional areas. There's a motor area, which controls voluntary motor functions; a sensory area, which provides conscious awareness of sensations; an association area, which integrates all sensory and motor information.

No functional area of the brain acts alone and conscious behavior involves the entire cerebral cortex in one way or another. So if you look at the motor areas of the cerebral cortex, some of which are noted on the slide here, the primary motor cortex is located within the precentral gyrus of the frontal lobe – and this area possesses large neurons called pyramidal cells. It also allows conscious control of skilled voluntary movements of skeletal muscles.

The premotor cortex is located anterior to the precentral gyrus of the frontal lobe – and this region controls learned motor skills that are repeated or patterned – such as when you learn to play an instrument; some people might say this is called muscle memory. The premotor cortex also coordinates the movements of muscle simultaneously – or sequentially – by sending activating impulses to the primary motor cortex.

Broca's area is also known as the speech center and is located anterior to the lower part of the premotor cortex. It is involved in directing motor speech – including thinking about or planning to speak – and generally it's present in only one hemisphere, typically the left one.

The frontal eye field is located anterior to the premotor cortex and superior to Broca's. This region controls voluntary movements of the eye. It also has no role in the interpretation of visual stimuli.

This next slide shows some of those motor areas that we just talked about – but it also now shows some of the sensory and association areas.

So while examining the sensory areas of the cerebral cortex, the first one we will talk about is the somatosensory cortex, which is located in the parietal lobe of the cerebrum.

The primary somatosensory cortex is a region of that area and is located in the postcentral gyrus. In this region, neurons receive touch information – like temperature, pressure, pain – from the somatic sensory receptors of the skin and from proprioceptors in skeletal muscle. This area allows for special discrimination or for you to interpret what body region is being stimulated.
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The somatosensory association area lies posterior to the primary somatosensory cortex. This region integrates and analyzes the somatic sensory inputs from the primary somatosensory cortex and memories of previous experience, to produce an understanding about what is being felt. In other words, it allows you to recognize the cold, flat, round thing in your pocket is a quarter – as an example.

The visual cortex is located within the occipital lobe of the cerebrum – and within the visual cortex you find the primary visual cortex, which receives light information from the retina of the eye – like color, form, texture – and then you also have the visual association area, which integrates and analyzes the visual information coming from the primary visual cortex, as well as past experiences to interpret what the image is or means.

Another sensory area of the cerebral cortex is the auditory cortex, which is located within the temporal lobe. The primary auditory cortex receives sound information from the ear – like pitch, rhythm, and volume. The auditory association area integrates and analyzes the information from the primary auditory cortex and also uses past experiences to interpret what the sound stimulus is or means.

Other sensory areas are the olfactory cortex, which is located on the medial aspect of the temporal lobe and is responsible for the conscious perception of odors or smells; the gustatory cortex, which is located in the insula and portions of the frontal lobe, and is involved in the conscious perception of taste; and the visceral sensory cortex, which is located in the insula and is involved in the conscious perception of visceral sensations – for example, a full bladder or an upset stomach.

There are also some interpretive areas of the cerebrum. The prefrontal cortex, which is also called the anterior association area, and this area is involved with intellect, complex learning abilities, recall, and personality. This area is necessary for abstract ideas, judgment, reasoning, planning, concern for others, or your conscience. Tumors in this area frequently lead to personality disorders.

There is a general interpretative area, which is also called the posterior association area, and this area encompasses parts of the temporal, occipital, and parietal lobes of one hemisphere – usually the left. This region integrates sensory and motor information with emotions and plays a role in recognizing patterns and faces, localizing us and our surroundings, and in binding different sensory inputs into a coherent whole.

It also contains Wernicke's area, which is involved in understanding written and spoken language and sounding out unfamiliar words.

Now if there is damage to the cerebral cortex –

The basal nuclei is another area of the brain and this is where there are islands of grey matter located deep within the white matter of the cerebrum. The function of these islands of grey matter is to subconsciously control large autonomic – automatic, sorry – skeletal muscle contractions – for example, your arms swinging while walking – or play a role in maintaining
attention – and to produce dopamine. Disorders of the basal nuclei result in too much or too little movements, which can be seen in the disease Huntington's, where too much is produced or Parkinson's, where too little is produced. The major components of the basal nuclei are the caudate, putamen, and globus pallidus. And as I mentioned previously – diseases or damage to the basal nuclei might result in disorders like Parkinson's or Huntington's disease.

The diencephalon contains the hypothalamus and the thalamus – and the diencephalon serves as the structural and functional link between the cerebral hemispheres and the rest of the central nervous system. This region is completely covered by the cerebrum and is not visible by external examination.

The thalamus forms the super lateral walls of the third ventricle and is composed of masses of grey matter held together by a midline of commissioner fibers known as the intermediate mass. It also contains important relay and processing centers for sensory information. Almost all sensory input goes through the thalamus, with the exception of olfaction – so the thalamus is sometimes called the gatekeeper or relay station for sensory input. The thalamus also contains many nuclei, each projecting fibers to and receiving fibers from a specific region of the cerebral cortex.

The hypothalamus forms the walls of the third ventricle. The walls of the hypothalamus meet and extend to form the infundibulum, which the pituitary gland is suspended from. The hypothalamus serves as the main visceral control center. Some of its homeostatic roles include an autonomic control center, so it can influence blood pressure; heart rate; GI motility; respiratory rate and depth; and pupil size. It is the center for emotional response and behavior. It has roles in body temperature regulation, which can initiate both sweating and shivering. It regulates food intake, water balance via the thirst mechanism, it regulates the sleep/wake cycle, and it releases hormones that control the secretions of the anterior pituitary gland.

The brainstem includes the midbrain, pons, and medulla oblongata. Only portions of the brainstem are visible underneath the cerebrum. Though this region is small, it plays an extremely important role as the nerve connections of the motor and sensory systems from the main part of the brain to the rest of the body.

In looking at the midbrain, the midbrain contains nuclei that process visual and auditory information and control reflexes triggered by these stimuli. It also contains centers that help maintain consciousness.

The corpora quadrigemina is made up of 2 nuclei on each side – a superior colliculi, which contains visual reflexes and hand/eye coordination and an inferior colliculi, which contains auditory and startle reflexes.

The substantia nigra is another portion that contains various amounts of melanin. It also contains the precursor to dopamine and regulates the activity of the basal nuclei of the brain. Lesions to this region have been linked to Parkinson's disease.

The red nuclei yes contains large amounts of hemoglobin and iron and issues subconscious muscle commands that affect upper limb position and background muscle tone.
The pons is located below the midbrain and above the medulla oblongata. The pons possesses projection fibers between the higher and lower brain centers and also between the pons and the cerebellum. The pons also possesses nuclei that function in somatic and visceral motor control. Some pons nuclei are respiratory centers that help to maintain the normal rhythm of breathing.

The medulla oblongata relays information to other portions of the brainstem and to the thalamus. The medulla also contains major centers for regulating autonomic functions – like those of the hypothalamus. It controls the force and rate of heart contraction, regulates blood pressure by regulating the smooth muscle of blood vessels, regulates the rate and depth of breathing, and regulates visceral reflexes – such as vomiting, hiccupping, swallowing, and sneezing.

The cerebellum is shown here and the cerebellum is considered to be an autonomic processing center. It accounts for about 11 percent of the brain's mass. The cerebellum is partially hidden by the cerebral hemispheres and is the second largest structure in the brain. The cerebellum functions in the coordination and modulation of motor command from the cerebral cortex and maintaining balance and equilibrium. The cerebellum is separated from the cerebrum by the transverse fissure.

The cerebellum is divided into 2 hemispheres, and further subdivided into lobes – the anterior lobe and the posterior lobe. The 2 cerebellar hemispheres are separated by the vermis, while the anterior and posterior lobes are separated by the primary fissure.

The white matter of the cerebellum is called the arbor vitae and is surrounded by grey matter called the cerebellar cortex.

The spinal cord is shown in this slide and you can see a cross-section of the spinal cord – both histologically and in the figure. The adult spinal cord is about 18 inches in length and has a maximum width of about 14 millimeters. The spinal cord is located within the vertebral foramen, also known as the vertebral canal.

The anatomy of the spinal cord is shown here and there are several anatomical regions that are significant. The cervical enlargement supplies nerves to the shoulder and upper limbs; the lumbar enlargement provides innervation to the structures of the pelvis and lower limb; the conus medullaris is the tapered, conical portion of the spinal cord – inferior to the lumbar enlargement.

Because the adult spinal cord ends at the level of the first or second lumbar vertebrae, the dorsal and ventral roots of the spinal segments L2 and S5 extend inferiorly. When looking at this in gross dissection, the filament terminale and the long ventral and dorsal roots resemble a horse tail – hence this region is known as the cauda equine. The filament terminale is a slender strand of fibrous tissue that extends from the tip of the conus medullaris to the second sacral vertebra. It provides longitudinal support to the spinal cord as a component of the coccygeal ligament.

Other parts of the spinal cord are shown here.
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The posterior median sulcus is a shallow, longitudinal groove on the posterior or dorsal surface of the spinal cord. The anterior median fissure is a deep groove along the anterior or ventral surface. The central canal is a longitudinal passageway that extends the length of the spinal cord and contains cerebrospinal fluid.

The spinal cord contains grey matter and white matter. The grey matter is dominated by the cell bodies of neurons, neuroglia, and unmyelinated axons and surrounds the narrow central canal forming a butterfly shape. The grey matter can be organized into structural and functional areas.

The projections of grey matter – toward the outer surface of the spinal cord – are called horns, and you can see those clearly here. The posterior grey horn contains somatic and visceral sensory nuclei. The lateral grey horn, which is located only in the thoracic and lumbar segments of the spinal cord, contains visceral and motor nuclei. The anterior grey horn contains somatic motor nuclei.

The cell bodies of the neurons in the grey matter of the spinal cord are organized into functional groups called nuclei. Sensory nuclei receive and relay sensory information from the sensory receptors of the body to the central nervous system. Motor nuclei issue motor commands to the peripheral effectors.

The spinal cord also contains white matter. White matter contains large numbers of myelinated and unmyelinated axons and just like with grey matter, white matter can also be further subdivided into functional and structural areas.

The structural components of white matter are divided into columns. The posterior white column lies between the posterior grey horns and posterior median sulcus; the lateral white column includes the white matter on either side of the spinal cord, between the anterior and posterior columns; and the anterior white column lies between anterior grey horns and the anterior median fissure.

The meninges of the spinal cord serve to cover and protect. The meninges are delicate neural tissues that must be protected from shocks – including damaging contact within the surrounding bone boney walls of the vertebral canal. The spinal meninges are a series of specialized membranes surrounding the spinal cord and providing the necessary physical stability and shock absorption; they consist of 3 layers.

The tough, fibrous dura mater is the outermost covering of the spinal cord. It contains dense collagen fibers that are orientated along the longitudinal axis of the cord. Between the dura mater and the walls of the ventral canal, lies the epidural space – and you can see down here on this slide. This is a region that contains areolar connective tissue, blood vessels, and a protective padding of adipose. A narrow subdural space separates the dura mater from the arachnoid mater. The arachnoid mater is the middle layer. It includes simple squamous epithelium and the subarachnoid space that extends between the arachnoid mater and the pia mater. The pia mater consists of a meshwork of elastic and collagen fibers that is firmly bound to the underlying neural tissue. The subarachnoid space contains the arachnoid trabeculae, which is a network of collagen and elastic fibers that attaches the arachnoid mater to the pia mater. It is filled with
cerebrospinal fluid, which acts as a shock absorber and a diffusion media for gases; nutrients; chemical messengers; and waste products.

In adults, the CSF, or cerebrospinal fluid can be safely withdrawn in a procedure known as a lumbar puncture or spinal tap, where a needle is inserted into the subarachnoid space in the lumbar region, inferior to the tip of the conus medullaris – and here you can see the subarachnoid space and epidural space. And the cerebrospinal fluid is produced by the choroid plexus and circulates through the ventricles.

There are four ventricles of the brain – 2 lateral ventricles, a right and a left – each within one of the cerebral hemispheres. The third ventricle is located in the diencephalon and the fourth ventricle begins in the mesencephalon and extends into the superior portion of the medulla oblongata. It then narrows and is continuous with the central canal of the spinal cord.

CSF is reabsorbed into the blood, where the arachnoid membrane emerges into the dural sinuses. The blood-brain barrier of the brain helps maintain a stable environment for the central nervous system and has a distinct composition different from blood plasma. Most notably – there are fewer plasma proteins within the blood-brain barrier. It has selective permeability in the nutrients it contains, the waste and toxins, and it is ineffective against fats and gases – those can travel easily through the blood-brain barrier. The blood-brain barrier is also absent in some regions of the body – for example, in the vomiting center, so that the body can monitor the composition and if – for example – you were to take in something toxic, could initiate the vomiting reflex.

Now the connective tissue sheaths are shown here, where you can see the epineurium, which surrounds each nerve; the peri- which surrounds a fascicle or bundle of nerves; and the endo- which surrounds the axon itself. So the epi- is the outer and the endo- is the deep within.

Now nerves can be classified as either cranial or spinal – and they're based on their direction of transmission. Sensory is going afferent; motor is efferent – and we also have some mixed nerves.

We will examine the 12 pairs of cranial nerves, as well as looking at some spinal nerves. The cranial nerves can be seen here by name and number. Cranial nerves are classified as either sensory, motor, or mixed. If they’re sensory, they contain sensory neurons only; motor contains motor neurons only; or mixed meaning they contain both.

The first 2 pairs attach to the forebrain; the remaining 10 pairs attached to the brainstem – and these are the cranial nerves by name and number – as well as their function, which you will need to know. For each of the cranial nerves, make sure you can provide the name, number, and a description of or function, and be able to identify if it's sensory; motor; or mixed.

Spinal nerves are named for their respective vertebrae. A spinal nerve is composed of bundles called fascicles and as we saw previously, each fascicle is composed of numerous nerve cells called neurons, and there 3 tissue layers – the epi- being the outer; peri- being the middle; and endo- being the inner – that surround the nerves. There are 31 pairs of spinal nerves. All of the spinal nerves are mixed nerves.
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The cervical plexus consists of the spinal nerves C1 through C5, and this plexus is mostly cutaneous nerves that supply the skin. The phrenic nerve is a single most important cervical nerve that innervates the diaphragm for breathing. You may become familiar with the mnemonic C3-4-5 helps keep you alive – that's where the phrenic nerve originates from, C3 to C5.

The brachial plexus innervates the pectoral girdle and upper limbs and consists of the spinal nerves C4 through T1. The main nerves from the brachial plexus are the suprascapular nerve, the axillary nerve, the radial nerve, the ulnar nerve, and the median nerve.

The thoracic region does not form a plexus. None of the intercostal nerves intertwine. You have 12 pairs of intercostal nerves that give rise to many cutaneous branches to the chest and torso area and innervate the external intercostal muscles for breathing.

The lumbar plexus innervates the pelvic girdle and portions of the lower limb. The lumbar plexus arises from spinal nerves T12 through L4.

The femoral nerve is the largest terminal nerve of this plexus and it branches to form the saphenous nerve on the medial thigh and knee.

The obturator nerve is also part of this plexus and innervates the adductor muscles of the leg.

The sacral plexus arises from spinal nerves L4 to S4. The largest branch of the sacral plexus is the sciatic nerve, which supplies the entire lower limb – except the anterior medial thigh – and then you have one coccygeal.

Imbalances associated with the nerves are shown here. Chickenpox or shingles is a virus that can remain dormant within the nerves. You may suffer from chickenpox as a child and then the virus can remain dormant and show up later as an adult as shingles. Fainting or syncope is where you have a decrease in blood flow to the brain. Stroke is where you can suffer a lack of oxygen to the brain and the cells may die.

There are various forms of meningitis or inflammation of the meninges – and spina bifida, which is an incomplete closing of the backbone and membranes around the spinal cord. Spina bifida is not as common because of the recommendation for pregnant women – or women planning to become pregnant – in increasing their folic acid intake.

This concludes the overview of the nervous system, examining both the central nervous system and the peripheral nervous system.