Dr. King -- Psyc 415

The Lower Brainstem and Spinal Cord

(slides 36-48)

The Mesencephalon

(See slide 37.) The mesencephalon or midbrain is the uppermost (most rostral) of the "encephalons" in the lower brainstem. Examination of slide 37 will reveal that it somewhat resembles a old discarded pair of swimming trunks. The legs of the swimming trunks are ventral or, in the human brain, towards the front (since humans are in the habit of standing up on their hind legs). The dorsal (or back) surface of the mesencephalon is characterized by the four mounds that we previously identified on the left image of slide 32.

Slide 37 is a photograph of a cross-section (more or less a horizontal section) of the mesencephalon. The tissue has been stained to increase contrast between the white matter and the gray matter. In this case, a myelin stain was used. This myelin stain has stained myelin black. Since myelin is responsible for giving the white matter its white appearance, in this photo the white matter has been stained black. Thus, you can sort of think of this as a negative image, in which white matter is black and gray matter is, well, still sort of gray but lighter.

There is a general rule of thumb in the lower brainstem and spinal cord, and that is the more dorsal you are, the more you are likely to be dealing with sensory structures, and the more ventral you are, the more you are likely to be dealing with motor structures. That's not a law. It is just a general, and sometimes violated, rule of thumb.

The dorsal surface of the mesencephalon (top in this image) is characterized by the four mounds we identified in slide 32 (left). These mounds are called the corpora quadrigemina, or four twin bodies. These bodies come in two pairs (twins), a rostral pair and a caudal pair. The rostal pair, which have been transected in slide 37, are called the superior colliculi. The caudal pair, not visible in slide 37, are called the inferior colliculi. (Singular colliculus, Latin for mound.)

The colliculi are sensory structures. The superior colliculi are primitive visual structures involved in visual tracking and reflexes. If you were a frog, this would be your visual system, but we humans have moved higher level visual processing into the thalamus and occipital lobe. The inferior colliculi are auditory structures. Cell bodies here send their axons to the medial geniculate nucleus and make synapses there on cells that send their axons to the primary auditory cortex in the temporal lobe.

In general, the dorsal part of the mesencephalon is called the tectum ("roof"), the primary structures in the tectum being the colliculi. The lower limit of the tectum is roughly marked by the little heart-shaped hole in the middle of a large gray area labeled periaqueductal gray. That hole is a cross-section of the cerebral aqueduct that connects the third and fourth ventricles. Cerebrospinal fluid circulates through this aqueduct and, as discussed earlier, if the aqueduct becomes blocked the result is hydrocephalus.

The periaqueductal gray matter (PAG) is an interesting area involved in the modulation of pain. Cells in PAG send their axons down to synapse on cells in the pons. There the PAG neurons release a neurotransmitter called enkephalin (related to endorphin) onto serotonin neurons, which in turn project into the spinal cord where they ultimately affect incoming pain impulses from pain receptors in the body. Electrical stimulation of PAG in rats that results in release of serotonin in the spinal cord can result in long-lasting analgesia (loss of or reduction in pain sensitivity). This analgesia is mediated through opioid receptors in the spinal cord, that can also be activated by drugs such as morphine.

Notice just ventral to the PAG is a gray area associated with cranial nerve number three, the oculomotor nerve, involved in eye movements. The oculomotor nerve was the nerve you saw lying across the ventral surface of the mesencephalon on slide 32 (right). You can see a bit of it extending beyond the ventral mesencephalon on this slide as well. As we descend through the lower brainstem, we will encounter other cranial nerve nuclei. Cranial nerves will be discussed in the peripheral nervous system lecture.

The middle portion of the mesencephalon, including the periaqueductal gray, is called the tegmentum. This area includes a lot of stuff, such as the red nucleus (named for its reddish tint in fresh tissue), that we don't need to concern ourselves with at the moment. (It's part of the motor system.) One set of structures is important to understand, however. A large number of small, diffuse nuclei are interconnected by a mesh-like network of axons. The structures are collectively known as the reticular formation (reticulum = "net"). The reticular formation (RF) is involved in keeping the cortex aroused during alert wakefulness, it's involved in the sleep-waking cycle, it regulates muscle tone, and it's also involved in creating rhythmic, repetitive movements such as those necessary for walking.

At the ventral limit of the tegmentum is a gray band called the substantia nigra ("black substance", also named for its appearance in fresh tissue). We will have reason to return to this structure later when we discuss Parkinson's disease. Recall that I said in an earlier lecture that Parkinson's disease results from a loss of the neurotransmitter dopamine in the basal ganglia of the telencephalon. The cell bodies for those dopamine neurons are located here in the substantia nigra (SN). When the dopamine cells of the SN die off in sufficient number, dopamine is lost or greatly diminished in the basal ganglia, which results in the symptoms of Parkinson's disease, the tremor, rigidity, and difficulty initiating voluntary movements. Thus, although the symptoms result from a chemical change in the basal ganglia, the actual disease process in Parkinson's disease is here in the SN. It is not definitely known why these cells die off. We know that as many as 50% of them may be lost due to normal aging, but that is not sufficient for the onset of Parkinsonian symptoms. For that about 80% must be lost. A leading theory currently says that additional cells in the SN may be killed off due to exposure to environmental toxins such as herbicides and pesticides.

The ventral portion of the mesencephalon, shown as large black areas in this myelin-stained section, are the cerebral peduncles ("stems"). As these areas have been stained dark black by the myelin stain, you should be able to deduce that these are large bundles of myelinated axons. In particular, they are descending bundles of axons. The central region of the peduncles consists of axons that originated mostly in the primary motor cortex in the precentral gyrus of the frontal lobe and are descending to the spinal cord to create voluntary movement. These are the pyramidal tracts, or corticospinal tracts. We will be following them as they continue their descent into the spinal cord, where they will synapse on the motor neurons that go out to the skeletal muscles.

The Metencephalon

(See slide 38.) The metencephalon consists of the pons and cerebellum. The pons is clearly visible on this slide, while only a bit of the cerebellum is visible near the top. The 4th ventricle is between the pons and cerebellum. The pons is the nightmare of neuroanatomy students everywhere. While the midbrain was relatively orderly and easily studied, as you can see, it looks like someone put the pons through a blender. Let's try to sort it out. We will proceed from the 4th ventricle downward (ventrally).

Laterally on this slide, you can see two large elephant ears. Er, I mean, two large, black areas. Since this is a myelin-stained section, you should already have surmised that these are large bundles of myelinated axons. Specifically, they are the middle cerebellar peduncles, which connect the pons to the cerebellum. There are three cerebellar peduncles, but only the middle one is visible here. Guess what the other two are called. (Inferior, connecting from the medulla. Superior, which is cerebellar output into the midbrain and thalamus.)

Just under (ventral to) the 4th ventricle you can see another cranial nerve nucleus and some of the myelinated fibers of this nerve. This is the seventh of the twelve cranial nerves. We will learn later that it controls muscles in the face.

Two pathways (tracts) are also worth pointing out, the lateral and medial lemniscus. These are both ascending sensory pathways. We'll learn later what sensory information they carry (auditory and touch, respectively).

Finally, near the ventral surface of the pons, we find the pyramidal tracts again. They have moved "inland" a little bit in the pons, but they will return to the ventral surface of the brainstem in the medulla. Once again, these are the primary descending motor pathways headed to the spinal cord to create voluntary movement.

(See slide 39.) After the nightmare of pontine anatomy, the cerebellum is a breath of fresh air. The cerebellum is arranged and wired up so neatly, you can almost imagine it having been wired by an electrician or an engineer. Cerebellum mean "little brain," a reference to the fact that its structure is similar to that of the cerebrum. It has an outer layer of heavily convoluted cortex, the cerebellar cortex. (The word cortex used alone almost always refers to the cerebral cortex. When the cerebellar cortex is intended, the full name is ordinarily used.) There are right and left cerebellar hemispheres, which are divided into lobes. And there are also subcortical structures, which in the cerebellum are referred to as deep nuclei. The cerebellum is connected to the rest of the brain via the three cerebellar peduncles.

The primary function of the cerebellum is motor. For one thing, it is involved in balance and coordination, and diseases in the cerebellum tend to impair these functions. People with cerebellar disease or damage tend to be clumsy and uncoordinated. They slap their feet when they walk, they stagger and sometimes appear as if they are about to fall over. They slur their speech. Remind you of anyone? In general, cerebellar damage often gives the person a drunken appearance. That's not a coincidence. Alcohol impairs the functioning of the cerebellum, which results in clumsiness, loss of coordination, and slurring of speech. Together these symptoms are referred to as cerebellar ataxia.

The cerebellum also has other functions. It is involved in some forms of motor learning, for example. Do you have a killer tennis serve? Thank your cerebellum.

The Myelencephalon

(See slide 40.) The myelencephalon is also called the medulla, or medulla oblongata (although I haven't heard anyone use the "oblongata" part of the name for some time). This is also myelin-stained tissue, so once again, black is white and vice versa. The rule of thumb still applies. Dorsal tends to be sensory, and ventral tends to be motor.

Notice in the most dorsal part of this section there are two large sensory nuclei (actually four nuclei). These receive input from the fine touch somatosensory system, which we will discuss in more detail below. Medial to those nuclei is another cranial nerve nucleus, the nucleus of the twelfth cranial nerve, which controls the muscles of the tongue. More ventrally, you can see a peculiar looking structure called the inferior olive, or inferior olivary nucleus. This nucleus connects to the cerebellum. If there is an inferior olive, then it would be reasonable to assume that there is also a superior olive. The superior olivary nucleus is at the pons/medulla border and is part of the auditory pathways.

Finally, most ventrally in this image, we see our old friends the pyramidal tracts, which we have been following since the mesencephalon. In the medulla, the tracts take on a triangular appearance and are known as the pyramids, or the pyramids of the medulla. The pyramids were named long before anyone understood their function. Once it was discovered that a major fiber pathway made up the bulk of the pyramids, that pathway became known as the pyramidal tract. Today we know that this is the main voluntary motor pathway on its way from the primary motor cortex to the spinal cord.

(See slide 41.) Just before the pyramidal tract leaves the medulla and enters the spinal cord, it hops over to the other side of the brain, which is called decussation, or crossing. On sections low in the medulla, you can visualize the X where the pyramidal tracts are decussating. The tract will then continue down along the side (laterally) of the spinal cord, where it is called the lateral pyramidal tract, or lateral corticospinal tract. The consequence of this decussation is that the primary motor cortex on the right side of the brain controls muscles on the left side of the body, and vice versa. Thus, damage to the pyramidal tract above the the level of the medulla results in contralateral motor impairment.

A final note: The decussation of the pyramidal tract is not complete at the level of the medulla. A small percentage of these fibers continue into the spinal cord ipsilaterally. These fibers then cross over the midline when they reach their targets in the spinal cord. They control mostly large muscles of the trunk.

Once in the spinal cord, pyramidal tract axons make synapses on motor neurons in the ventral spinal cord. It is these spinal motor neurons that carry the commands out to the muscles. The pyramidal motor neurons are sometimes referred to as the upper motor neurons, while the spinal motor neurons are sometimes referred to as the lower motor neurons.

(See slide 42.) Lesions of the upper vs. lower motor neurons have different consequences, which are fairly predictable if you understand the basic anatomy of this pathway. Lower motor neuron damage, or lower motor neuron disease, is usually limited in scope to one or a few segments of the spinal cord. Thus, the paresis (or paralysis) that results is usually limited to specific muscle groups ipsilateral to the lesion. Since the muscles have lost their input, they tend to go limp or flaccid, resulting in what is called a flaccid paralysis. Likewise, tendon reflexes, like the knee jerk, which depend on these motor neurons, tend to be reduced or absent. Muscle fibers that lose their input start to die off. Thus, in lower motor neuron disease, muscle atrophy is prominent. As the muscle fibers die, they twitch, which can sometimes be visualized on the surface of the body as muscle tics or fasciculations.

Upper motor neuron lesions, or disease, on the other hand, affects widespread muscle groups on the contralateral side of the body. Often an entire side of the body is paralyzed, called contralateral hemiparesis. The muscles are still receiving input from the lower motor neurons, so the muscle fibers do not die, fasciculations are absent, and in fact the muscles are often hypertonic (too tense) and tendon reflexes are exaggerated. This results in a form of paralysis called spastic paralysis. Often the flexor muscles are particularly affected, resulting in the fingers, hands, and arms curling inward. Spastic paralysis is illustrated in the color images at the lower left of slide 42.

The Spinal Cord

(See slide 44.) We continue with myelin-stained sections in which dorsal is upward in the photo. You can see in this slide that the spinal cord is organized with white matter around the outside and gray matter in the shape of a butterfly more medially. The wings of the butterfly are called horns. The dorsal horn receives sensory input from incoming sensory neurons, while the ventral horns are the origin of outgoing, or efferent, motor neurons. Sensory pathways in the white matter tend to be located dorsally. The dorsal columns are labeled on this slide. These are large ascending sensory pathways carrying touch information. These axons will make synapses in the somatosensory nuclei of the medulla (slide 40). The pyramidal tract, now the lateral pyramidal tract, is located on the lateral part of the spinal white matter. Jumping ahead a couple slides to slide 46, we see in this diagram that the sensory pathways (tracts) have been colored blue, while the motor pathways have been colored red. Thus, you see that the dorsal = sensory and ventral = motor rule is not a hard and fast law but just a general rule of thumb.

(See slide 45). Here the fine touch pathways are outlined. The body actually has two touch systems, fine touch and crude touch, and the difference between them is not what you might think. Fine touch is touch on the surface the body that can be localized. If someone is touching you on the back of the leg, and you can tell it's on the back of your leg, that's fine touch. Crude touch cannot be localized or localized only very poorly. You can tell that you're being touched, but you can't tell where.

The fine touch system begins with receptors in the skin. Sensory neurons carry this touch info into the spinal cord via the dorsal horn. No synapses are made there (following the purple fibers). Rather, the axons jump over into the dorsal columns of the spinal cord and ascend to the medulla, where they make synapses in the somatosensory nuclei we saw there on slide 40 (gracile and cuneate nuclei, and no, you don't need to remember those names). Cells in those somatosensory nuclei give rise to axons that cross the midline and then continue ascending though a tract called the medial lemniscus, which we saw in the pons (slide 38). These axons will eventually terminate (make synapses) in the somatosensory relay nucleus of the thalamus, the ventral posterolateral nucleus, or VPL. VPL cells then project their axons into the primary somatosensory cortex in the postcentral gyrus of the parietal lobe. See? It does all tie together eventually!

(See slide 47.) This diagram shows that the spinal cord itself does not actually continue all the way down through the vertebral column. It actually stops about 2/3rds of the way down. Below that there are only spinal nerves that will exit the vertebral column at a lower level. Early anatomists thought this resembled a horse's tail and called it the cauda equina (which means horse's tail). Spinal taps, or lumbar punctures, are done at this level so as not to risk damage to the spinal cord itself when the needle is inserted to withdraw cerebrospinal fluid.

(See slide 48.) Slide 48 shows the spinal cord in situ, which means surrounded by meat. (Joke! In situ means in place, in its natural surroundings so to speak.) In this diagram, dorsal is toward the bottom, ventral toward the top. Notice the spinal cord running down through the central part of the vertebral column (spine), with spinal nerves attached to it every so often. Next time we will talk about these spinal nerves. You might want to refer back to this slide, which is an excellent artistic rendering of the spinal cord and its attached nerves in situ.

The following diagram shows the spinal cord in relation to the vertebral disks. You can see that things are tucked in there fairly tightly, and it is easy to image how a slipped or ruptured disk can compress a nerve or the spinal cord itself, or how a spinal fracture could have very serious consequences if the spinal cord is injured.