Basics of Vertebrate Neurobiology:

The mammalian central nervous system is touted to be the most complex biological system known. That complexity exists at a variety of structural and functional levels. The purpose of this lab exercise is to acquaint you with the rudimentary features of the gross anatomy of the mammalian brain. We are going to be using calf brains for most of our observations and dissections. In addition to the calf brains that we dissect, we also have a couple of human brains for comparison. The human brains are quite a bit larger, so some of the structures that are difficult to find on the calf brains will be more visible on the human brains. Please handle and observe the human brains carefully, because they are fragile, expensive, and may be impossible to replace. The human brains were provided by Dr. Countryman of the Psychology Department.

A bit of anatomical terminology is necessary before we begin. Because humans are bipedal with upright posture, directions and planes in our bodies differ from those of quadrupedal mammals. For us, the front of the body is anterior and the back is posterior (if we were quadrupedal, these would be ventral and dorsal, respectively). Structures that are closer to the top of the head are referred to as superior, while those closer to the bottoms of the feet are inferior (these would be anterior and posterior in quadrupeds). A plane that bisects the body into two mirror-image halves is mid-sagittal; other planes that are parallel are sagittal. A plane that cuts the body into a front (anterior) part and a back (posterior) part is coronal (AKA frontal). A third plane that is mutually perpendicular to these two is transverse. Finally, with respect to position relative to the surface of the body, there are structures that are superficial and those that are deep (these are relative terms). In the descriptions below, I will use the terms that apply to humans rather than calves.

One of the unifying synapomorphies of the Phylum Chordata (to which the vertebrates, and thus mammals, belong) is the presence of a dorsal, tubular nerve cord (DTNC). This feature distinguishes the chordates from many of the invertebrate phyla, which possess a ventral, solid nerve cord. The DTNC develops early during ontogeny through the thickening of the neurectoderm into the neural plate, which eventually develops longitudinal neural folds, which in turn grow up toward the midline and fuse to form the tubular nerve cord. The lumen of the tubular nerve cord is filled with cerebrospinal fluid, which is secreted by plexi within the lumen. The development of the DTNC is fairly hard-wired genetically – there is a set sequence of expression of genes (the homeotic or homeobox genes) that determines the various regions of the developing CNS. There is obviously regional specialization of function of the CNS, with the anterior-most region being the various parts of the brain. This will be the focus of our observations.

The brain and spinal cord are protected within bony housings, the cranium and the vertebrae. Within those bony structures are tissues that also support and protect the nervous tissue. The outer covering is the *dura mater* ("tough mother"), which, as the name implies, is a layer of fibrous tissue that is flexible but not stretchy. Inside the dura mater is the **pia mater** ("tender mother"), which is a network of tissue that covers and directly supports the brain and spinal cord. The space between the dura mater and the pia mater is filled with the "**pia-arachnoid**" tissue and with cerebrospinal fluid, which bathes and buoys the brain and spinal cord. The cerebrospinal fluid is produced within the lumen of the DTNC, and spills out into the pia-arachnoid space through the foramen of Magendie.

Before going on, it makes sense to make some distinctions. In the brain, there is gray matter and white matter. The gray matter comprises nerve cell bodies, and the white matter comprises nerve cell fibers. In general (I can't think of any exceptions) the gray matter comprises the cortex (e.g. superficial layers), primarily of the cerebrum and cerebellum, and the white matter comprises the “medulla” (deep layers) of these structures. The brainstem (see below) is primarily white matter. The standard, simple model of a nerve cell (dendrites, perikaryon, axon) does not apply in the brain. There are several different types of nerve cells in the brain, which we do not have to worry about in much detail, but the important things about them are that they typically have lots of axodendrites, that they communicate with many other nerve cells in the brain, and they do so in many ways – there are lots of different neurotransmitters in the brain.

Localized collections of nerve cell bodies communicate with one another about local function, and also communicate with other collections of nerve cell bodies in other parts of the brain. Many parts of the brain have multiple layers of nerve cell bodies that differ from one another and have different functions. Collections of nerve cell bodies in specific parts of the brain are called “nuclei” – there are many such nuclei with strange and wonderful names like the nucleus ruber, the paraventricular nuclei, and the suprachiasmic nuclei. The collections of nerve cell fibers that constitute the major communication pathways of the brain are the white matter; some of the prominent ones are referred to as “tracts.” When we dissect the brains, we will see the distinction between, and the structural relationships of, the gray and white matter.

From anterior to posterior, the brain contains five different but connected regions. These are the telencephalon, diencephalon, mesencephalon, metencephalon, and myelencephalon. The telencephalon includes the cerebral hemispheres, which are the most prominent feature of the superior aspect of the brain. The retina and optic nerves are outgrowths of the diencephalon. The diencephalon also includes the epithalamus, thalamus, and hypothalamus, as well as some visual-system relay centers and optical processing circuitry. The mesencephalon includes the corpora quadrigemina (superior and inferior colliculi), which are visual relay structures, and the cerebral peduncles, which are a major pathway of communication between the cerebral hemispheres and the cerebellum. The cerebellum, which is part of the metencephalon, is a prominent feature of the superior aspect of the calf brain. In addition to the cerebellum, the metencephalon includes the **pons**, which is continuous with the cerebral peduncles. The myelencephalon is basically the **medulla oblongata**, which connects the more anterior parts of the brain to the spinal cord. If you haven’t seen the video clip from “Waterboy” about the medulla oblongata, you should.

The most conspicuous feature of the mammalian brain is the cerebrum, because it is the superior-most, anterior-most, and largest structure of the brain. The most notable feature of the cerebrum, apart from the division into right and left hemispheres, is the convolution of the brain surface into sulci and gyri. The grooves of the surface of the brain are called “**sulci**” (singular “**sulcus**,” which translates literally as “furrow” or “groove”), and the ridges that the sulci separate are the “**gyri**” (singular “**gyrus**,” which translates literally as “ridge”).

Viewed from the superior aspect, the **cerebrum** is divided into two **hemispheres** by the mid-sagittal **longitudinal fissure**. Gently spread the cerebral hemispheres apart to see the superior aspect of the **corpus callosum** – we will return to this structure directly. Each hemisphere is subdivided into four functional units. There is the **frontal lobe**, the **temporal lobe**, the **parietal lobe**, and the **occipital lobe**. The frontal lobe is, as the name implies, in the front. It is bounded on the posterior by the **central sulcus** (AKA Fissure of Rolando) and inferiorly by the **lateral sulcus** (AKA Fissure of Sylvius). Inferior and posterior to the lateral sulcus is the temporal lobe. Posterior to the central sulcus is the **parietal lobe**, and posterior to the parietal lobe is the **occipital lobe**.

The four lobes of the cerebrum are more distinct on the human brain than on the calf brain. In humans, the frontal lobe is responsible for voluntary movements, gross and fine motor control, conscious thought, and processing and expression of emotions. The temporal lobe is where auditory and olfactory sensory input is processed, and where memories are stored, including emotional memories. The parietal lobe works on somatic sensation, proprioception, and body image, and the occipital lobe does visual sensory processing. Obviously there is a lot of communication between the lobes to accomplish their functions.

In our calf brains, the **cerebellum** is also prominent in the superior view. The cerebellum has two lateral **hemispheres** which are separated by the **vermis**. The cerebellum is responsible primarily for gross motor control of body movements. There is significant communication between the cerebrum and the cerebellum via the cerebropontocerebellar pathway.

The inferior aspect of the brain reveals a number of structures. The inferior surfaces of the frontal and temporal lobes of the cerebrum are prominent, as is the inferior surface of the **cerebellum** and **pons**. The **cerebral peduncles** of the midbrain are at the anterior-most end of the pons. The cerebral peduncles are a major pathway of white matter that communicates, via the pons and the medulla oblongata, with the cerebellum and the spinal cord. The midbrain, pons, and medulla oblongata constitute the "brainstem." A number of cranial nerves exit the inferior surface, but we will be concerned with only a few of these. The **olfactory tracts** are the anterior-most pair of cranial nerves, followed by the **optic nerves**. The optic nerves cross at the mid-line in the **optic chiasma**. The optic chiasma is associated with structures of the diencephalon, which will be more apparent with dissection. One structure of the diencephalon that is obvious in the inferior view is the base of the **infundibulum**, which is an outgrowth of the **hypothalamus**. The infundibulum is the stalk to which the pituitary gland is attached – this gland has been removed in our specimens. The **mamillary bodies** may be visible just posterior to the infundibulum; they are part of the hypothalamus. The hypothalamus is involved in regulation of autonomic functions (heart rate, blood pressure, peristalsis, etc).

There are a variety of ways to dissect a brain, and we as a group should pursue several of these. The simplest dissection is a mid-sagittal section. Place the brain inferior surface down on a dissecting tray. Gently spread apart the cerebral hemispheres to reveal the corpus callosum. Use a large, sharp knife to slice directly downward through the brain tissue. The brain should then be split cleanly into two halves.

The main alternative to a mid-sagittal dissection is a series of coronal sections, much like slicing a loaf of bread. In fact, you can first do a mid-sagittal section, then use one half of the brain for coronal sections. The coronal sections allow you to better see the spatial and structural relationships between the various brain parts. Another alternative to a mid-sagittal section is a series of parasagittal sections. You can do the same thing as with the coronal sections, using half of the brain for coronal sections and half for parasagittal sections.

Back to the mid-sagittal section. Because the brain is the anterior-most structure of the DTNC, it contains cavities. The cerebral hemispheres contain the **lateral ventricles**. These come together in the midline where they join the **third ventricle**, which is a tall narrow space between the thalami. You can insert a probe through the **interventricular foramen** (of Monro) and poke around inside the lateral ventricles. Posterior to the third ventricle is the **cerebral aqueduct** (of Sylvius; this is the cavity of the mesencephalon), which communicates with the **fourth ventricle**. The fourth ventricle (of the metencephalon) has a very thin superior wall, so it may get destroyed during your dissection. The foramen of Magendie is in the roof of the fourth ventricle, but it will not be visible in our calf brains. Beyond the medulla oblongata, the ventricle grades into the cavity of the spinal cord.

If your cut through the brain was truly mid-sagittal, in both halves of the brain you will see the **thalamus** (sort of circular in outline) that form the walls of the third ventricle. The thalami are parts of the diencephalon; the epithalamus lies above the thalamus, and the hypothalamus, oddly enough, lies below. These structures contain a number of "nuclei" which are involved, in, among other things, regulation of the circadian biological rhythm. You will also see the **choroid plexus** which extends into the lateral ventricles and which secretes the cerebrospinal fluid. There is another choroid plexus in the fourth ventricle.

There are a number of features of the internal anatomy of the brain that are now visible. Let's start with the corpus callosum, because it is a prominent landmark. Looking at the mid-sagittal aspect of the brain, the corpus callosum has an anterior bend (the **genu**), a flat middle part (the **body**) and a posterior bend (the **splenum**). The corpus callosum is white matter, and is the main relay structure between the cerebral hemispheres. Inferior to the body of the corpus callosum is the **fornix** (another tract of white matter that connects the two cerebral hemispheres). There is a prominent gyrus of the frontal lobe just superior and lateral to the corpus callosum, the **cingulate gyrus** (this gyrus is more pronounced in the human brain than in the calf brain). The cingulate cortex is responsible for expression of social and reproductive behaviors. There is another prominent gyrus inferior and lateral to the corpus callosum, the **hippocampal gyrus**. This one is better seen in coronal or parasagittal sections. The hippocampal cortex includes the hippocampus (responsible for memories) and the amygdala (responsible for emotions). Both of these structures have significant connections to the rest of the frontal lobe.

The **pineal body** may be visible tucked under the splenum of the corpus callosum. The pineal body is an important neurosecretory structure, and helps to regulate the circadian biological rhythm by secreting serotonin and melatonin, among other products. The pineal body communicates with the pituitary gland both through direct neural connections and through neurosecretion. The neurosecretory products of the pineal body are carried to the pituitary gland through the hypophyseal portal system. Posterior to the pineal body are two prominences on the superior aspect of the brainstem, the **superior and inferior colliculi**. These are important relay stations for the visual system. You will also see the gray matter and white matter of the cerebellum – the white matter has a tree-like appearance, and it is referred to as the **arbor vitae**.

Coronal sections of the brain reveal some additional structures, and make the relationship between the gray matter and white matter clearer. What you see in a coronal section depends on where you cut the brain. Sections toward the anterior part of the brain are mostly through the cerebral hemispheres, so you see sulci, gyri, and mostly gray matter in the cortex with a bit of white matter in the medulla. As you work posteriorly, especially in the region of the diencephalon, things get more complex. At the level of the the optic chiasma, you will find the lateral ventricles and their choroid plexus, the body of the corpus callosum and the associated fornix, and the **hippocampus** (a gyrus that lies on the medial side of the lateral ventricle). A bit more posteriorly, through the infundibulum, you will be able to distinguish the **lateral** and **medial nuclei** of the thalamus, and possibly the **nucleus rubber** (which is inferior to the lateral and medial nuclei). You will also be able to see the merging of the diencephalon with the mesencephalon and the rest of the brainstem.

A coronal section through the cerebellum at the level of the base of the arbor vitae reveals the great extent of the **cerebellar peduncles**. These large tracts of white matter run from the brainstem (the cerebropontocerebellar pathway) up into the body of the cerebellum, and are a major pathway of communication of the cerebellum with the cerebrum and the medulla oblongata.

Parasagittal sections, especially through the medial parts of the cerebral hemispheres, will allow you to see the extent to which the white matter of the corpus callosum, the fornix, and the **cerebral peduncles** penetrates into the gray matter of the hemispheres. You will also be able to distinguish the **hippocampus** and **amygdala** which, as stated above, are lateral and inferior to the corpus callosum, with the hippocampus being posterior to the amygdala.