Objectives

- Be able to concisely describe the gross anatomy of the spinal cord including its position inside the vertebral column and the spaces and membranes between the vertebral column and the cord.

- Be able to explain the naming convention of spinal roots relative to the vertebrae in the cervical cord and more caudally.

- Be able to explain why there is not C1 dermatome and the general locations of the muscles receiving input from the C1 spinal nerve.

- Be able to describe the structure, organization, and basic function of the cord in cross-section, including the difference between a spinal root and a spinal nerve.

- Be able to describe the motor somatotopy in the ventral horn of the spinal cord.

- Be able to explain the general differences in the gray and white matter at different levels of the spinal cord and why the cord is bigger in the cervical and lumbar regions.

- Be able to name the 3 major fasciculi in the cord.

- Be able to explain the basic organization of the stretch and withdrawal reflexes.

- Be able to describe what a central pattern generator is.

- Be able to describe, examples of descending and sensory inputs to CPGs regulating movement.

I. Overview

As the drawing to the right shows, the spinal cord is the long extension of the brain running down the middle of the back. In some ways the spinal cord looks and functions like a cable bringing sensory information from the body to the brain and sending movement commands from the brain to the body. It is also a complicated processor of sensory and motor information that regulates sensory inflow and contributes to the control of effective movements. Note that for everything discussed in sections III - VI below, there are analogous structures and functions for the head and face, mediated by cranial nuclei and other brainstem neurons.

There are 8 cervical, 12 thoracic, 5 lumbar, and 5 sacral spinal nerves. Note that the most rostral nerve, C1 exits rostral of the C1 vertebra and the last cervical nerve exits below the C7 vertebra. Thus there are 8 cervical spinal nerves but only 7 cervical vertebrae. Thoracic, lumbar, and sacral roots all exit below their associated vertebrae so that there are the same number of roots and vertebrae in these parts of the spine.
II. Spinal Cord Anatomy
   A. Gross anatomy
      1. As illustrated in the cross section to the right through the cord and vertebral column, the spinal cord rests in the spinal canal inside the vertebral column. Spinal nerves extend outward from the cord.

         Moving from the outside in we see that the large mechanically supportive part of the vertebral column is anterior (or ventral) to the spinal cord. A relatively thin layer of bone covers the lateral surface of the spinal canal which contains the cord. On the posterior (or dorsal) side of the spinal canal, there are boney protrusions or, including the spine on the midline to which axial muscles attach.

         The epidural space outside the dura containing the cord is filled with fat that cushions the cord. This is the area into which anesthesiologists inject drugs that block axon conduction to block sensation below the injection, a so called "epidural".

         Within the fat padding, the three meninges membranes cover the cord just as they cover the brain. The dura encloses the cord and the dorsal root ganglia which contain the cell bodies of sensory axons carrying somatosensory information into the cord (see below). The arachnoid is under the dura. As in the brain, there is a space under the arachnoid, the subarachnoid space, in which CSF circulates. The pia lines the cord under the subarachnoid space.

      2. Spinal nerves exit the vertebral column between two vertebrae, one above and one below. There is an inconsistent convention for naming spinal nerves for the vertebrae associated with it. In the most rostral part of the cord, the cervical segments (cervix means neck; these are the vertebrae of the neck), there are 7 cervical vertebrae and 8 cervical spinal nerves. As the picture below and to the right shows, we name each of the top 7 cervical nerves the vertebra immediately caudal to it (C1-C7). There are 8 cervical roots for 7 cervical vertebrae because we name the nerve immediately caudal to (below) the most caudal (7th) cervical vertebra C8. Caudal to the C8 root, we name each spinal root for the vertebra immediately rostral (above) it.
3. The spinal nerve at each level of the cord carries somatic sensory information from a specific region of skin at that level into the cord. Each spinal nerve also sends motor commands to specific muscles at the level of the nerve. The region of the skin from which somatosensory information enters the cord through one spinal nerve is called a dermatome. The region of the body that receives motor commands from one spinal root is called a myotome. Dermatomes and myotomes represent skin and muscles in the same parts of the body, respectively.

The drawing to the left shows the dermatomes associated with spinal nerves at each spinal segment. The arrangement of dermatomes makes some sense in that cervical segments (C2-C8) carry information from the upper part of the body while lumbar and sacral segments carry information from lower parts of the body. Still, the arrangement of dermatomes in the limbs seems different from that in the trunk. In the drawing above of a standing man, the borders of the dermatomes in the limbs are approximately vertical while those in the trunk are approximately horizontal.

A sensible way to understand the arrangement of dermatomes is to imagine our bodies on all fours, as in the drawing to the right. In this posture the borders of all of the dermatomes run approximately vertically and are roughly parallel. Further, the progression from lumbar dermatomes on the front of the legs to sacral dermatome, on the back of the legs and on the buttocks, now looks orderly.
Note on the drawing at the top of the previous page, that there is no C₁ dermatome marked on the skin above the C₂ dermatome, though, as the drawing on the bottom of page 2 shows, there is a C₁ spinal root. The sensory fibers entering the cord via the C₁ spinal nerve bring in information from the meninges around the cerebellum and medulla, not from the skin. As we will learn when we study cranial nerves, somatosensory information from the skin rostral to the C₂ dermatome enters the brain through the trigeminal nerve.

Since, as noted on the previous page, dermatomes and myotomes represent skin and muscles in the same parts of the body, and there is no C₁ dermatome, it is fair to ask where muscles are that receive the motor signals from the C₁ spinal nerve. The C₁ spinal nerve sends motor axons to a few muscles in 3 locations, the mouth, the front of the neck and the back of the skull.

I show you the muscles in each location but you do not need to name them or even know exactly where they are. Just be able to describe their 3 general locations.

**Mouth** - The geniohyoid muscle, highlighted in red in the drawing to the left (of the left side of the tongue) lies deep under the tongue.

**Front of neck** - The infrahyoid muscles highlighted in pink in the drawing below and to the left (of the front of the neck) are on the front of the neck.

**Back of skull** - The suboccipital muscles, highlighted in pink on the bottom drawing on the left (of the back of the neck) are on the bottom of the skull.
4. The spinal cord stops growing earlier in development than the rest of the body so the cord is shorter than the vertebral column. As you can see in the drawing to the right, in adults the cord ends at ~L1 (1st lumbar vertebra). Below L1 the vertebral canal contains only dorsal and ventral roots. (Anesthesiologists exploit this anatomy when they inject drugs to produce a spinal block. They inject below L1 so that their needle does not enter, and damage, the spinal cord. Below L1 the needle enters the spinal canal in the vertebral column and pushes aside the roots there without damaging them.)

5. As we see in the drawing below and to the right, a spinal nerve is composed of two components, a dorsal root and a ventral root. The dorsal root carries sensory information into the cord. The ventral root carries motor commands out of the cord.

The two roots join peripheral to the dorsal root ganglion to form a spinal nerve that exits the vertebral column at the associated vertebral level. As noted above the cord is shorter than the vertebral column. Thus as we move caudally in the cord, there is an increasingly large offset between the where roots exit the cord and where joined dorsal and ventral roots, i.e., spinal nerves, exit the vertebral column. As apparent in the drawing above and to the right, below the cervical segments, the nerve roots travel more and more caudally to reach their exit points.

6. Once outside the vertebral column spinal nerves branch to form peripheral nerves.

B. Cross sectional anatomy

1. As the drawing to the right shows, spinal gray matter (cell bodies) forms a roughly H-shaped pattern inside white matter (axons). This H is functionally arranged in the sensory-dorsal, motor-ventral organization that is a consequence of development.

2. This drawing also shows that somatosensory information enters the cord through primary afferent axons in dorsal (sensory) roots. All axons need cell bodies to support them. The cell bodies of the axons in the dorsal root are in the dorsal root ganglia (DRG; a ganglion is a collection of neuron cell bodies outside the CNS). As we will describe in more detail when we study the somatosensory system, after the sensory axons in the dorsal root enter the cord they branch. Some of the branches synapse on neurons in the ipsilateral dorsal horn of the spinal gray matter (the top arms of the H).
3. Motoneurons, i.e., those whose axons terminate on muscles, are in the ventral horn of spinal gray matter. The axons of these motoneurons leave the cord through ventral (motor) roots to terminate on ipsilateral muscles. As the drawing to the right shows, there is a relationship between the position of a motoneuron in the ventral horn and the position of the muscle that it contacts in the body. Motoneurons for axial (trunk) muscles are in the medial part of the ventral horn while the motoneurons for distal (limb) muscles are in the lateral ventral horn. The more lateral a motoneuron in the ventral horn, the more distal the muscle that the motoneuron contacts.

4. Further, as the drawing to the right shows there is a dorsal-ventral (posterior-anterior) organization in which the motoneurons of flexor muscles lie more dorsally in the ventral horn than the motoneurons of extensor muscles.

5. We call an arrangement like this, in which there is an orderly spatial representation of the body inside the CNS, a somatotopy.

6. Note in the drawing in the middle of the previous page that between the dorsal and ventral horns of the spinal gray matter there is a region called the intermediate gray. Neurons in this region are interneurons that process sensory information entering the cord from nearby spinal roots as well as motor signals descending from the brain. These neurons then send their output to motoneurons in the ventral horn.
7. The size and shape of the spinal gray matter and white matter in cross-sections of different levels of the cord, as well as of the whole section, are different depending on the cord level.

   a. The gray matter in the cervical and lumbar segments is enlarged because these parts of the cord contain sensory neurons, motoneurons, and interneurons related to the arms and legs, respectively. This makes cervical and lumbar segments bulge a little producing the cervical and lumbar enlargements. You can see the cervical and lumbar enlargements in the cord pictured in the drawing on the top right of page 5 above. The drawing to the right shows the gray matter of all spinal segments. Note the larger ventral and dorsal horns in the cervical and lumbar enlargements.

   b. There is a rostral-to-caudal decrease in the amount of white matter because each level of the cord contains the fibers ascending from, and descending to, all of the more caudal segments.

On the right you can see that cord cross sections at different levels have different shapes and sizes of both white matter and gray matter. The drawing of the cord to the left of the cross sections shows the level of each of the 4 sections on the right.

In brief summary, the distinctive features of sections at different levels are:

- S2 – smallest white matter; biggest gray/white matter ratio
- L2 – more white matter, particularly dorsal and medial; still large gray/white matter ratio
- T4 – smallest gray matter; smallest gray/white matter ratio
- C6 - largest cross section; larger lateral extension of ventral horn; large white matter

Please learn to identify the level of a section from its appearance.
8. We divide the white matter of the cord into three major structures, funiculi or ropes. These are labeled in the right side of the drawing to the right.
9. Within these funiculi run axons carrying sensory information to the brain and axons carrying motor information from the brain to motoneurons in the spinal cord. In subsequent lectures we will learn about the major sensory and motor tracts in the cord.

III. Spinal Reflexes

Stimulating somatosensory nerves entering the cord elicits stereotyped, short latency movements via reflex pathways through the spinal cord. Some examples are:

**Stretch (or monosynaptic or deep tendon) reflex** – As the drawing below and to the right shows, stretch of a receptor in a muscle (a muscle spindle) activates sensory axons that synapse directly onto and excite motoneurons for the same (homonymous) muscle and for muscles with similar action (synergists). They also activate inhibitory interneurons in the intermediate gray matter. These, in turn, synapse onto and inhibit the motoneurons of muscles with the opposite action as the stretched muscle (antagonists).

Thus, stretching a muscle makes it contract very quickly. This contraction is unopposed by contraction of antagonist muscles neurons for antagonist muscles are because antagonist motoneurons are inhibited. Note that even this simple reflex involves both agonist and antagonist muscles.

This is the reflex that physicians test when they use a reflex hammer to tap a tendon in your elbow or knee. The tap stretches muscle spindles in a muscle and that muscle contracts.

This reflex resists muscle stretching by unexpected increase in loads.
Flexion (or withdrawal) and cross-extension reflex - The drawing to the right illustrates a more complex reflex that excites and inhibits motoneurons on both sides of the cord. The spinal pathway via which stretching a tendon in the biceps muscle stretches a muscle spindle and contracts the muscle containing the spindle and its agonists while relaxing its antagonists.

A painful stimulus on the skin of the lower leg activates a pathway to the ipsilateral side of the cord that excites the motoneurons of flexor muscles (and their synergists, not shown) and inhibits the motoneurons for extensor muscles.

The same sensory input also activates a sensory pathway in the dorsal horn of the spinal gray matter that sends axons across the midline to excite the motoneuron for extensor muscles and inhibit those for flexor muscles on the other side.

Thus, a painful stimulus on your right foot, for example, will withdraw your right leg and extend your left leg to support you as your right leg supports you less. Reflexes like this can involve neurons in multiple spinal cord segments that control multiple joints.

V1. Central Pattern Generators and Descending Control

Networks of neurons in the spinal cord, called central pattern generators (CPGs), can generate repeating patterns of muscle contraction and relaxation. Examples of behaviors mediated by CPGs are rhythmic scratching, shaking (think of dogs getting rid of water on their coats), and locomotion. CPGs can produce patterned muscle activity without outside input but both descending signals from the brain and sensory input can influence them.

Using locomotion as an example, you can walk without thinking about the movements you make partly because of spinal CPGs producing these movements. Still, you can change the speed and direction of your walking movements voluntarily.

The drawing below shows the back end of a cat whose spinal cord is severed at b--b'. Despite the fact that descending commands do not reach the cord caudal to the cut, the CPG in the lumbar cord can generate alternating contractions of muscles appropriate to creating walking movements in the hind legs. Further, if we suspend the cat over a treadmill the sensory input generated by the feet on the moving surface can slow or speed the walking movements to match the speed of the treadmill.