Mind & Motion Anatomy
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Contents

Links to Phase 1 E-books vii

Central Nervous System and Head and Vertebral Column

Overview of the Nervous System 3
Meghan Cotter, PhD and Karen Krabbenhoft, PhD

Neural Cell Types 7
Elise Davis, PhD

Gross Anatomy of the Brain 19
Elise Davis, PhD

Anatomy of the Brainstem 94
Elise Davis, PhD

Spinal Cord and Spinal Meninges 137
Meghan Cotter, PhD

Vertebral Column and Trunk Muscles 160
Meghan Cotter, PhD

Spinal Cord Reflexes and Tracts 179
Karen Krabbenhoft, PhD and Meghan Cotter, PhD

Cranial Cavity, Meninges and Vasculature 202
Karen Krabbenhoft, PhD

Anatomy of the Orbit 225
Elise Davis, PhD

Anatomy of the Ear 275
Meghan Cotter, PhD

Cranial Nerves Summary 283
Elise Davis, PhD and Karen Krabbenhoft, PhD
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The anatomy content for all Phase 1 courses is presented in a series of e-books. You will be able to access this content throughout all 3 phases of the medical curriculum for review and for reference. Here are the links to the e-books for the other blocks of Phase 1:

- Patients, Professionalism, and Public Health – Anatomy
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- Human Family Tree – Anatomy and Embryology
- Invaders & Defense – Anatomy (Upper Respiratory System)
- Mind & Motion – Anatomy
Overview of the Nervous System

MEGHAN COTTER, PHD AND KAREN KRABBENHOFT, PHD

Chapter Sections

Basics of the Nervous System

Anatomical Divisions

Functional Distinctions

Components of the PNS

I. Basics of the Nervous System

Anatomical Divisions

The nervous system is subdivided anatomically into the Central Nervous System (CNS — the brain and spinal cord), and the Peripheral Nervous System (PNS — the nerves and ganglia). The first components of the nervous system that you dissected in the cadaver were the cutaneous nerves to the skin of the trunk. These are part of the PNS. In this dissection you found the continuity between the CNS and PNS by dissecting the spinal cord, the origin of the cutaneous nerves.
Functional Distinctions

Neurons and Glial Cells: Despite the organizational complexity of the nervous system, it consists of only two principal kinds of cells – neurons and supporting or glial cells. Neurons have electrophysiological properties, very long cellular processes, and are specialized for transmitting impulses. The glial cells have short processes, and support the neurons in a variety of ways, including maintenance of the chemical environment around neurons and production of insulating material called myelin that surrounds the neuronal processes. Supporting cells do not transmit impulses.

Types of Neurons: There are three fundamental types of neurons: motor, sensory and interneurons. Motor neurons send signals away from the CNS to cause contraction of muscles and secretion by glands, while sensory neurons take information from sensory receptors in the body's tissues toward the CNS. Interneurons are located entirely within the CNS and mediate communication among other neurons. Depending on the type of muscle innervated, or the type
of sensory information conveyed, we could describe more specific types of neurons as described in the image above.

No matter what its function, every neuron has a **cell body** that contains the nucleus, and one or more processes that extend from the cell body. Neurons can have a highly variable number of (usually) short, highly branched **dendrites** that receive input and transmit that information to the cell body. The cell body processes this information and may transmit a signal to a target through its single, usually very long, process called an **axon**.

![Generic Neuron](image)

**Components of the PNS**

In gross anatomy we study the axons in detail because they are bundled to form nerves of the PNS. The **PNS** includes:

1. **spinal nerves** that innervate the body wall of the trunk and the limbs.
2. **cranial nerves** that innervate the head in the adult and the structures that developed in the embryonic head and then migrated into the neck, shoulder, thorax, or abdomen. These nerves will be covered mainly in the units on the head and neck.
3. **splanchnic nerves** that innervate smooth muscle, cardiac muscle, and internal glands.
4. **ganglia** that are collections of sensory or motor nerve cell bodies.

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**Knowledge Check**

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Neural Cell Types

ELISE DAVIS, PHD

This chapter is a resource for the Neural Cell Types ELO. It is intended to be a very high level overview of cell and tissue types in the nervous system.

Sections

- Organization of the Nervous System
- Neurons
  - Structural Classifications of Neurons
  - Histological Appearance of Neurons
- Glial Cells
  - Glial Cells in the CNS
  - Glial Cells in the PNS
- Types of Nervous System Tissues (with or without neuronal cell bodies)
- Myelination

Learning Objectives

- Describe the structure of a neuron and identify neurons on histological images.
- Outline the properties, functional classes, and structural classes of neurons.
- Describe the types of neuroglia and outline their locations and basic functions.
- Describe the myelin sheath and its function, and outline differences between myelinated and unmyelinated axons.
The nervous system is divided into two anatomical divisions:

- the **Central Nervous System** (CNS) which consists of the brain and the spinal cord.
- the **Peripheral Nervous System** (PNS) which consists of all other nervous structures, including the nerves of the body.

Both the CNS and PNS contain two general classes of cells.

- **Neurons** are cells that conduct electricity to send signals across the body.
• **Glial cells** are cells with supporting functions, such as regulating the composition of the extracellular environment, insulation and myelination of axons, and phagocytosis.

Functionally, the nervous system has three components: sensory functions, motor functions, and integration.

• **Sensory functions** are performed by sensory neurons in the CNS and PNS. These neurons bring information from the body to the CNS (afferent). We have already encountered somatosensory neurons in the branches of spinal nerves in your first dissection in PPP. There are three types of sensory neurons.

  ◦ **Somatosensory neurons** carry pain, touch, temperature, and proprioception from the body wall and limbs.
    ▪ The axons of somatosensory neurons are part of every spinal nerve.
  ◦ **Viscerosensory neurons** carry sensations from organs, such as stretch, irritation, nausea, and hunger.
    ▪ The axons of viscerosensory neurons follow sympathetic and parasympathetic axons back to the CNS.
  ◦ **Special sensory neurons** carry sensations of vision, smell, taste, hearing, and balance (position of the head in space).
    ▪ Special sensory neurons are found only in the CNS. (Special sensory function is found only in the head and neck.)

• **Motor functions** are performed by motor neurons in the CNS and PNS. These neurons take information from the CNS to muscles and glands of the body. There are two types of motor neurons.

  ◦ **Somatomotor neurons** innervate skeletal muscle (voluntary control).
    ▪ The axons of somatomotor neurons are part of every spinal nerve.
  ◦ **Visceromotor neurons** innervate smooth and cardiac muscle and glands (involuntary control). There are two types of visceromotor neurons: sympathetic and parasympathetic.

• **Integration functions** are within the CNS only and are performed by interneurons.

  ◦ **Interneurons** process incoming information from sensory regions and send output to planning regions of the CNS to create a plan to send to motor regions.
Neurons

Neurons are cells with a cell body, dendrites, and (usually) one axon. Modified from Marieb et al., Human Anatomy, Pearson Education.

Neurons are cells that conduct electrical impulses. They are long-lived cells and (mostly) do not divide in adults. These cells have very high metabolic rates and require a large and continuous supply of oxygen and nutrients. Neurons have a characteristic structure:

- **cell body**: houses the nucleus and organelles of the neuron
- **dendrites**: processes which bring information to the cell body
  - Typically, there are many dendrites per neuron.
- **axon**: a large process that takes information away from the cell body*
  - Typically, there is one axon per neuron.*
  - Axons synapse on target organs, including other neurons, muscle cells, and cells of glands.
  - *There are some exceptions to this, which will be discussed later.
**Structural Classifications of Neurons**

Neurons come in many different shapes. There are three general structural classifications of neurons: multipolar, bipolar, and (pseudo)unipolar neurons.

- **Multipolar neurons** are the “classic” neuron shape with many dendrites and one axon. Motor neurons in the CNS are examples of multipolar neurons.

- **Bipolar neurons** have one dendrite entering the cell body and one axon leaving the cell body. Bipolar neurons are solely special sensory in function (olfactory, retinal, cochlear, and vestibular neurons).
• **Pseudounipolar neurons** (also called unipolar neurons) have a single axon which splits into an incoming axon, leading to the cell body, and an outgoing axon, leading away from the cells body. Dendrites feed into the incoming axon.

  ◦ The incoming axon of the pseudounipolar neuron is the exception to the “rule” about axons (that they leave the cell body).
  ◦ Sensory neurons of the PNS, such as somatosensory neurons in spinal nerves, are pseudounipolar.
Histological Appearance of Neurons

In histological sections, neurons are relatively large cells with large nuclei and prominent nucleoli. They are characterized by dark blue-staining, “Nissl” bodies in their cytoplasm. These are regions dense with rough endoplasmic reticulum and ribosomes. (The proximal segment of the axon, where it connects to the cell body, is typically devoid of this dark-staining Nissl substance.)
Glial Cells

Glial cells do not conduct electrical impulses, but have a myriad of critical support functions within both the CNS and PNS. There are many types and subtypes of glial cells with regionally-specific functions. This overview will deal with large classes of glial cell types.

Glial Cells in the CNS


**Astrocytes** are star-shaped cells which help regulate the extracellular environment of nervous tissue as well as produce trophic factors necessary for the maintenance and function of neurons.

**Oligodendrocytes** are cells which myelinate axons in the CNS. Each oligodendrocyte myelinates many axons. CNS axons that are unmyelinated are embedded in, and insulated by, the cytoplasm of oligodendrocytes.

**Microglia** are migratory phagocytic cells which are derived from monocytes in the bone marrow.

**Ependymal cells** are ciliated cells which line the spaces within the CNS that contain cerebrospinal fluid (ventricular system of the brain and central canal of the spinal cord).
Glial Cells in the PNS

Schwann cells myelinate and insulate PNS axons (like the oligodendrocytes in the CNS). Each Schwann cell myelinates only one axon.

Satellite cells surround neuronal cell bodies in the PNS and support the neurons metabolically.

Types of Nervous System Tissues (with or without neuronal cell bodies)

Both grossly and histologically, nervous tissue looks different depending on whether it contains neuronal cell bodies or not. The figure below shows an unstained coronal section through the brain. The darker regions contain neuronal cells bodies and the lighter regions do not.
Coronal section through the brain showing the gross appearance of gray and white matter. From SMPH collection.

Areas with Neuronal Cell Bodies: Gray Matter and Ganglia

Neuronal cell bodies surrounded by axons and dendrites (and glial cells). From medpics.ucsd.edu.
Regions of the CNS that contain neuronal cell bodies appear darker in fresh tissue. These areas are called **gray matter** and contain neuronal cell bodies, axons, dendrites, and glial cells.

- Gray matter around the edge of the brain is called **cortex**; gray matter within the substance of the brain is referred to as a **nucleus**.

In the PNS, collections of neuronal cell bodies are called **ganglia** (like the dorsal root ganglia that contain sensory cell bodies and are associated with each spinal nerve).

**Areas without Neuronal Cell Bodies: White Matter and Nerves**

![Longitudinal section through a peripheral nerve showing myelinated axons with nuclei of Schwann cells.](https://www-clinicalkey-com.ezproxy.library.wisc.edu/#!/content/book/3-s2.0-B9780323918916500131)

Regions of the CNS that contain no neuronal cell bodies are called **white matter**. These are areas with axons, dendrites, and glial cells. The light/white color is due to the presence of the myelin surrounding most of the axons.

- White matter in the CNS is organized into **tracts** which have similar origins or destinations.

In the PNS, bundles of axons are **nerves**, collections of myelinated sensory and motor axons.

- Remember that nerves and neurons are different! Neurons are cells made of cell bodies, axons, and dendrites. Nerves are made of bundles of axons from multiple neurons.
Myelination

Myelin surrounds larger axons in both the CNS and PNS. It is composed of layers of the plasma membrane of myelinating cells wrapped around the axon in concentric layers. Each segment of myelin along the length of an axon encloses the axon to prevent ions (and electric current) from leaking out of the axon. There are gaps between myelin segments which are called nodes of Ranvier. In myelinated axons, depolarization and action potential propagation hop from node to node (saltatory conduction). This arrangement significantly increases the speed of impulse conduction along the axon.

In the CNS, processes of oligodendrocytes wrap around axons to form myelin sheaths. Each oligodendrocyte sends out multiple process and myelinates multiple axons.

In the PNS, Schwann cells wrap around axons. Each Schwann cell myelinates one axon.

Smaller axons are not myelinated, but these axons are still insulated by oligodendrocytes and Schwann cells, in the CNS and PNS, respectively.
This chapter provides an overview of the anatomy and general functions of structures in the brain and cerebellum. The brainstem is discussed in a subsequent chapter. Throughout this overview, remember that structures are important because of their functions: be able to name the structures, locate them on diagrams, describe their general functions, and explain the general effects of damage to those structures. You will see these structures on whole and sectioned brain specimens during the Brain and Brainstem laboratory session.

The brain and brainstem are part of the Central Nervous System (CNS); the brainstem is continuous caudally with the spinal cord (another part of the CNS). Both the brain and brainstem are located within the cranial cavity.
Embryology

The development of the Central Nervous System was discussed in the HFT block. The entire CNS develops from a straight, hollow tube in the embryo (the neural tube). The CNS, particularly its cephalic end, grows massively during embryonic development. As it does, the straight neural tube elongates, bends, and enlarges in a specific way into a more complicated and convoluted tube. This differential growth forms the characteristic shape of the adult brain and brainstem.


As the neural tube develops, three enlargements form: the forebrain (prosencephalon), midbrain (mesencephalon), and hindbrain (rhombencephalon). The forebrain differentiates into the telencephalon and diencephalon; the midbrain remains the mesencephalon; the hindbrain differentiates into the metencephalon and myelencephalon. The central cavity of the original neural tube remains, but its shape and orientation change to form a hollow ventricular system within the CNS.
Regions of the developing neural tube. From https://clinicalgate.com/embryology

Review the HFT e-book chapter if you need more detail.

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Gross Divisions and Features of the Brain and Brainstem

Each of the regions of the developing central nervous system differentiates into a specific set of structures. From rostral to caudal:

- The telencephalon forms the cerebrum (left and right cerebral hemispheres).
- The diencephalon differentiates into the thalamus, hypothalamus, and epithalamus. The thalamus and hypothalamus are paired structures.
- The mesencephalon forms the midbrain. (The midbrain is called the midbrain from the beginning to the end of development.)
- The metencephalon forms the pons and the cerebellum.
- The myelencephalon becomes the medulla (or medulla oblongata), which is continuous caudally with the spinal cord.

The “brain” usually refers to the structures derived from the telencephalon and diencephalon. The
“brainstem” refers to the midbrain, pons, and medulla. The cerebellum is usually considered to be a separate structure.


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Before studying the structures of the central nervous system and their functions, it is important to get a general sense of the orientation of the brain and brainstem in the body. The following set of figures illustrates the directional terms used for the brain and brainstem.


Medial View of Sagittally Sectioned Brain & Brainstem


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GROSS FEATURES OF THE BRAIN

When looking at the lateral surface of the brain and brainstem, there are several obvious structural characteristics. First, the outer surface of both the cerebrum and cerebellum are extensively folded. The folding dramatically increases the amount of nervous tissue that can fit into the confined space of the cranial cavity. In the cerebrum, the folds, or ridges, are called gyri (gyrus = singular) and the grooves are called sulci (sulcus = singular). Some of these gyri and sulci will be important landmarks and we'll come back to them later in this chapter.

Also visible are two large fissures.

- The **longitudinal fissure**, in the sagittal plane, separates the right and left cerebral hemispheres.
- The **transverse fissure** separates the cerebrum from the cerebellum.

In a coronal (frontal) section through the brain, the folded surface with its gyri and sulci is obvious, as is the longitudinal fissure separating the two cerebral hemispheres.
Also in coronal section, the two basic types of tissue in the CNS are apparent: **gray matter** and **white matter**.

- The **gray matter** is darker in color in an unstained brain section. Gray matter contains neurons and supporting cells. There are two types of gray matter in the CNS.
  - In the cerebrum, the outer, convoluted layer of gray matter is called the **cerebral cortex** (*cortex* means 'bark'). The extensive folding of this layer increases the surface area of the cortex, which increases the number of neurons which can be packed into the cranial cavity.
  - Deeper areas of gray matter in the CNS are called **nuclei**, concentrations of neurons within the substance of the brain and brainstem (and within the spinal cord, as well). (Nuclei in the CNS are analogous to **ganglia** in the PNS.)
- In an unstained brain section, the **white matter** is very light in color. It is comprised of bundles of axons traveling through the CNS. The myelin which surrounds the larger axons is responsible for the white color of this tissue. Bundles of axons in the CNS are called **tracts**.
(Tracts in the CNS are analogous to nerves in the PNS.) Some of these tracts connect regions within the cerebrum. Others contain axons traveling from more caudal parts of the CNS into the brain (ascending tracts) or axons traveling from the brain to more caudal regions in the CNS (descending tracts).

- The most obvious white matter tract in the brain is the **corpus callosum** which connects the right and left cerebral hemispheres.

**Gray Matter**
- **Cortex** *outer layer*
- **Nuclei** *deep in brain*

**White Matter**
- **Tracts (=Axons)**

Gray matter (neurons) is found in the cerebral cortex (the outer layer) and in nuclei (deep in the brain). Tracts of white matter (axons) are deep to the cortex. The corpus callosum is the largest tract of white matter; it connects the right and left cerebral hemispheres. Modified from Marieb et al., Human Anatomy, 5th edition, Pearson Education, 2008.

The CNS begins embryologically as a hollow tube and it remains hollow throughout life. The core of the CNS is a continuous series of spaces, filled with cerebrospinal fluid (CSF) which is constantly produced and resorbed. These spaces have a distinctive form. There are four enlarged chambers (ventricles) connected by narrower passageways. In the cerebrum, there are two large C-shaped ventricles, the right and left lateral ventricles. The lateral ventricles extend from the frontal lobes through the parietal, occipital, and temporal lobes. They are connected to the single, midline third ventricle by two openings, the interventricular foramina.

The third ventricle is located within the diencephalon between the right and left thalami and hypothalami. From the third ventricle, CSF drains inferiorly into the cerebral aqueduct, a narrow tube which passes through the midline of the midbrain. The cerebral aqueduct leads to the fourth ventricle, a diamond-shaped space bounded anteriorly by the pons and medulla and posteriorly by the cerebellum. Inferiorly, the fourth ventricle is continuous with the central canal of the spinal cord. The fourth ventricle also connects to the subarachnoid space in the cranial cavity through three small openings in its posterior wall.
The ventricular system of the brain. Lateral ventricles are blue; interventricular foramina are teal; third ventricle is yellow; cerebral aqueduct is red; fourth ventricle is purple; central canal of the spinal cord is green. From BodyParts3D, © The Database Center for Life Science licensed under CC Attribution-Share Alike 2.1 Japan.

KNOWLEDGE CHECK
Cerebrum

CEREBRAL CORTEX: Lobes and Fissures

The surface of the cerebral cortex is divided into five lobes, each of which is generally associated with a set of functions. Two prominent fissures on the cerebral cortex are good landmarks and define some of the lobes. The central sulcus is located approximately in the coronal plane, at about the anteroposterior midpoint of the brain. The lateral sulcus runs horizontally, roughly in the axial plane. (If the lateral surface of the cerebral cortex looks like a mitten (and it does!), the lateral sulcus separates the thumb part of the mitten from the fingers part.)

The lobes of the cerebral cortex are (mostly) named for the adjacent bones of the skull. Each lobe is paired, with one in each cerebral hemisphere.

- **The frontal lobe** extends from the anterior pole of the cerebrum to the central sulcus posteriorly, and from the superior surface of the brain to the lateral sulcus inferiorly. The inferior surfaces of the frontal lobes are directly superior to the orbits in the skull.
  - The frontal lobe is the site of somatomotor (voluntary motor) function as well as of planning for motor activities. It also contains Broca's area which is crucial to the production of language. The frontal lobe is critical for executive functions, intuition, and working memory.
- **The parietal lobe** extends from the central sulcus anteriorly to the parieto-occipital sulcus posteriorly. The lateral sulcus forms part of its inferior border.
  - The parietal lobe contains the somatosensory areas of the brain. These areas are responsible for conscious sensations such as pain, touch, temperature, vibration, and proprioception from the head and body.
- **The occipital lobe** occupies the posterior pole of the cerebrum. Its anterior border is the parieto-occipital sulcus.
  - The occipital lobe contains the visual centers of the brain.
- **The temporal lobe** is inferior to the lateral sulcus. (The temporal lobe is the thumb of the mitten.) It has a very large surface inferiorly and sits in the skull just superior to the petrous part of the temporal bone.
  - The temporal lobe contains the auditory cortex, olfactory cortex and areas that deal with the comprehension of language. It is also home to much of the limbic system of the brain which is responsible for emotion and memory.
- **The insula** is the “hidden” lobe of the cerebral cortex. It is a large area of cortex which is located deep to the lateral sulcus and is covered by overhanging parts of the frontal, parietal, and temporal lobes (evidence of the extensive folding of the cerebral cortex during development).
  - The insula contains areas of the brain responsible for taste, conscious sense of balance, and visceral sensations.
Four of the five lobes of the cerebrum shown within the skull. (Frontal is red; parietal is dark yellow; occipital is light yellow; temporal is green; the cerebellum is blue.) By Polygon, data were generated by Database Center for Life Science (DBCLS)[2]. -- Polygon data are from BodyParts3D[1], CC BY-SA 2.1 jp, https://commons.wikimedia.org/w/index.php?curid=42966268
Lateral view of the insula, a lobe of the cerebral cortex which is found deep to the lateral sulcus. The frontal, parietal, and temporal lobes overhang the insula. Modified from Marieb et al, Human Anatomy, 5th edition, Pearson Education, 2008.

As you study these regions, remember that these lobes can be seen from all views of the brain (laterally,medially,superiorly, and inferiorly) and can be identified in sections.
A coronal section through the cerebrum shows the location of the insula deep to the parietal and temporal lobes and the lateral sulcus. Modified from Marieb et al., Human Anatomy, 5th edition, Pearson Education, 2008.
Dissected view of the insula, which is located deep to the lateral sulcus. http://www.neuroanatomy.ca/functional_areas
Lobes of the cerebral cortex viewed from the medial side of a sagittally sectioned brain. The corpus callosum, the large white matter tract which connects the two hemispheres, is highlighted in red. Modified from Marieb et al, Human Anatomy, 5th edition, Pearson Education, 2008.
FUNCTIONAL ORGANIZATION OF THE CEREBRAL CORTEX

Functions have been determined for many regions of the cerebral cortex. When studying the functions of different regions of the brain and brainstem, it is important to keep in mind that the entire CNS is characterized by extensive interconnections between regions, making functional ‘maps’ almost always oversimplified.
One of the most widely-used functional maps was developed in the early twentieth century by a neurologist (Dr. Brodmann). He mapped (and numbered) 47 structural regions of the cortex using histological characteristics. These Brodmann’s Areas are used to localize some functional regions in the cerebral cortex. For example, area 17 corresponds to the primary visual cortex; area 4 is roughly the primary motor cortex. You do not need to memorize Brodmann’s Areas, but you may hear reference to them in your training.

Brodmann’s Areas of the cerebral cortex. These areas were defined histologically, but are useful for describing functional regions of the brain as well. http://thebrain.mcgill.ca/flash/capsules/outil_jaune05.html

Generally, the cerebral cortex is the site of conscious functions of the brain, such as the awareness of sensations and the execution of voluntary motor functions. There are three general types of functional areas in the cerebral cortex:

- **Sensory areas** are involved in conscious awareness of sensation. This includes both somatic sensation (sensation from the body: pain, touch, temperature, vibration, conscious proprioception) and special sensation (vision, hearing, balance, smell, and taste). Sensory
areas are located in the parietal, occipital, temporal, and insular lobes (i.e. in all lobes except the frontal lobe).

• **Motor areas** send somatomotor (voluntary motor) instructions to move muscles of the head and body. Motor areas are located primarily in the frontal lobe.

• **Association areas** integrate information from multiple sensory regions (i.e. *seeing and hearing a dog*) and integrate sensation with memory (i.e. *I know that’s a dog!*). There are many association areas in the brain.

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Primary Sensory Areas and Sensory Association Areas

There is a distinct area of the cerebral cortex, a **primary sensory cortex**, devoted to each of the major senses. Each of these areas is responsible for conscious awareness of a given class of sensations: somatic sensations (pain, touch, and temperature from the head and body), vision, hearing, olfaction, taste, conscious proprioception, and visceral sensations (from the organs). Development of these areas of the brain requires sensory input and experience.
Each type of sensation also has a related **association area**. These areas integrate different aspects of a particular sensation (i.e. integrating the touch and temperature of an object (two somatic sensations from the skin) or integrating the shape and color of an object (both sensed by the retina of the eye). Association areas also link sensations to memories. These linkages enable us to recognize things that we've encountered before.

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Back to Top
The primary somatosensory cortex is located in the postcentral gyrus of the parietal lobe. (The postcentral gyrus is immediately posterior to the central sulcus. It is largest on the lateral surface of the cerebrum, but extends onto the medial side as well.) The primary somatosensory cortex receives sensory input from pathways carrying information about pain, touch, temperature, and vibration from the skin and about conscious proprioception from the muscles and joints. Inputs arrive at the primary somatosensory cortex from the contralateral (opposite) side of the body. (The right primary somatosensory cortex receives input from the left side of the body, and vice versa.)

The region is organized topographically. Each area of the primary somatosensory cortex receives input from a particular region of the body. This organization is called somatotopy.

(Somatotopy exists throughout the extent of the somatosensory pathways, beginning in the spinal cord and continuing cranially to the cerebral cortex. As we will see, other areas of the sensory cortex are also organized topographically, as are their ascending pathways. The primary motor cortex, and its descending pathways, are similarly organized.)

Mapping the regions of the body onto the postcentral gyrus forms a sensory homunculus, as shown in the figure below. (Homunculus means 'little human.') The amount of cortex responsible for a given region of the body is related to the number of sensory receptors in that region. Areas of the body with better sensory discrimination have more sensory receptors and are more sensitive to pain, touch, and temperature. These areas have a larger representation on the postcentral gyrus. Areas of the body with poorer sensory discrimination and fewer sensory receptors have smaller areas of the postcentral gyrus associated with them. For example, the lips, tongue, and fingertips have large areas of primary sensory cortex devoted to them, while the areas devoted to the back and thigh are relatively small.
The sensory homunculus is a map of the topographic distribution of sensory inputs from the body to the postcentral gyrus. Areas with finer sensory discrimination (which have more sensory neurons devoted to them) have larger representations in the primary sensory cortex.
If a person has damage to a region of the primary somatosensory cortex, they will be unaware of pain, touch, temperature, and vibration from the skin and conscious proprioception from the muscles and joints in the corresponding region of the body. Because of the somatotopic organization of the postcentral gyrus, localized damage will affect specific regions of the body. For example, damage to the medial part of the postcentral gyrus will result in loss of conscious sensation from the lower limb, while damage to the mid-lateral region of the postcentral gyrus will result in loss of sensation from the hand or face.

Though a person with damage to the primary somatosensory cortex does not ‘feel pain’ from a given region, reflexes that are triggered by painful stimuli are still functional (even though the painful sensation doesn’t reach consciousness). With this damage, a person who touches a hot pan will still withdraw their hand, but would not feel the pain of the burn. Since reflexes often occur at the level of the spinal cord, they do not require function in the cerebral cortex. (So, many reflexes do not require a functioning primary somatosensory cortex.)
Adjacent to the postcentral gyrus posteriorly is the **somatosensory association area** which occupies most of the superior part of the parietal lobe. This association area integrates input from multiple somatic sensations as well as inputs from memory systems in order to develop an understanding of objects in the environment. For example, if you are feeling for something at the bottom of your backpack, the texture, temperature, and weight of the object would be integrated by the somatosensory association area, and combined with memories, to form a ‘picture’ of the object you’re feeling with your hand. You would know that the hard, slightly bumpy, and cold object at the bottom of your backpack is a coin, even though you couldn’t see it.

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**Primary Visual Cortex and Visual Association Area**

The **primary visual cortex** is in the medial side of the occipital lobe on either side of, and within, the **calcarine sulcus** (or calcarine fissure). This region receives input from the retinas of the eyes. The visual cortex on each side of the cerebrum receives information about the contralateral visual field in a topographic organization. Specific parts of the visual field map onto the primary visual cortex (visuotopy), another form of topographic organization in this primary sensory cortex.
The calcarine fissure (or calcarine sulcus) is located on the medial surface of the occipital lobe. The primary visual cortex surrounds it and extends within it. Modified from Marieb et al, Human Anatomy, 5th edition, Pearson Education, 2008.

Damage to the primary visual cortex causes a loss of conscious awareness of visual information. Visual reflexes, though, would still occur. (A person would blink if an object was flying toward her face, though she would not be conscious of seeing the object.)

The rest of the occipital lobe is devoted to visual association areas which process and integrate different classes of visual information, such as color, form, or direction of movement, and also integrate information from the memory systems of the brain.

Primary Auditory Cortex and Auditory Association Area

The primary auditory cortex is located on the superior part of temporal lobe adjacent to and within the lateral sulcus. As with other primary sensory areas, the primary auditory cortex is organized topographically, according to frequency of sound (tonotopy).
The primary auditory cortex is organized tonotopically, according to the frequency of sound sensed by the cochlea (the organ of Corti, the receptor for sound in the inner ear). From: https://www.researchgate.net/profile/Floriana_Volpicelli/publication/312588934/figure/fig1/AS:453964232695808@1485244915290/Tonotopy-in-the-auditory-system-Different-regions-of-the-basilar-membrane-in-the-organ.ppm

The auditory association area is posterior and lateral to the primary auditory cortex. This area integrates auditory stimuli with memory and evaluates sounds (i.e. recognizing a sound or someone's voice).

Other Sensory Areas of the Cerebral Cortex

The primary olfactory cortex is found on the inferomedial aspect of the temporal lobe. Olfactory input is highly integrated with the limbic system and has roles in emotion and memory.

The insula contains three primary sensory areas:

- The primary vestibular cortex is responsible for conscious awareness of balance and proprioception from the head (position and movements of the head in space).
- The primary gustatory cortex is involved in the conscious awareness of taste.
- The viscerosensory cortex receives sensory information from thoracic and abdominal
organs, such as pain, pressure, hunger, and nausea.

Motor Areas

Motor regions of the cerebral cortex plan and initiate voluntary motor actions and send signals to muscles in the body to effect those actions. All motor areas in the cerebral cortex are located in the frontal lobe.

The **primary motor cortex** is found in the **precentral gyrus**. As was true with the postcentral gyrus, the precentral gyrus is largest on the lateral surface of the cerebrum, but extends onto the medial surface as well. Large neurons in this region, pyramidal cells, give rise to axons which descend through the CNS to effect voluntary movements by stimulating motor neurons in the brainstem and spinal cord. All voluntary motor instructions from the brain to the brainstem and spinal cord must come from the precentral gyrus. Each precentral gyrus controls the muscles of the **contralateral** body. (The right precentral gyrus controls muscle function on the left side of the body, and vice versa.)
Motor areas are located in the frontal lobe. The precentral gyrus is the primary motor cortex, Modified from Marieb et al, Human Anatomy, 5th edition, Pearson Education, 2008.
Like the primary somatosensory cortex, the primary motor cortex is arranged somatotopically. The map formed by this arrangement is called the **motor homunculus**. Areas of the body which have finer motor control (and more motor neurons devoted to their movement), such as the face and hands, are represented by larger areas in the precentral gyrus. Areas with fewer motor neurons and less precise motor control, like the trunk, have smaller areas of the precentral gyrus devoted to them.
The motor homunculus is a topographic representation of the body on the precentral gyrus. Areas of the body with finer motor control (more motor neurons devoted to them) have a larger representation on the primary motor cortex.

Just anterior to the primary motor cortex in the frontal lobe is the **premotor cortex** which is responsible for planning and initiating complex voluntary movements and motor patterns. The premotor cortex sends a motor plan to the primary motor cortex. Then the primary motor cortex puts the plan into action by sending the appropriate signals to the motor neurons in the brainstem and/or spinal cord to cause the right muscles to contract the right amount and in the right sequence.

**KNOWLEDGE CHECK**
Multimodal Association Areas of the Cerebral Cortex

Multimodal association areas in the cerebral cortex are larger association areas which receive input from multiple primary sensory areas and sensory association areas. These regions integrate inputs from multiple sensations with each other and with memories. Multimodal association areas then send an output to the premotor cortex. The premotor cortex then plans a motor response and sends that plan to the primary motor cortex. The primary motor cortex then sends an output to the motor neurons in the brain and spinal cord. Remember that all voluntary motor instructions from the brain to the brainstem and spinal cord must come from the precentral gyrus. The generalized sequence of activity in the cerebral cortex is Sensation-Integration-Reaction.

The posterior association area in the parietal lobe integrates visual, auditory, somatosensory, and proprioceptive information to form a “body sense” of the location of the body in space.

The anterior association area in the frontal lobe (also known as the prefrontal cortex) receives integrative sensory information from the posterior association area as well as memories of past experiences (from the limbic system, below). The anterior association area sends its information to the premotor cortex which plans motor actions; these plans will be implemented by the primary motor cortex.

The anterior association area is also the site of higher order, “executive” functioning, such as long-term planning, complex problem-solving, and conscience. The prefrontal cortex is one of the last areas of the brain to develop and is not fully formed until early adulthood. Damage to the prefrontal cortex can result in personality disorders, and changes in mood, attentiveness, inhibitions, and judgement.
The anterior association area is also known as the prefrontal cortex and is located at the rostral pole of the frontal lobe. The posterior association area is located at the junction of the parietal, occipital, and temporal lobes at the posterior end of the lateral sulcus. Modified from Marieb et al, Human Anatomy, 5th edition, Pearson Education, 2008.

Limbic System

The **limbic system** is a functional system in the brain which mediates emotional responses and memory. It includes several structures in the temporal lobe as well as in several other regions of the cerebral cortex and deep cerebral nuclei. Limbic structures surround the external borders of the lateral ventricles. Functionally, the limbic system has extensive connections with many other parts of the cerebral cortex as well as areas of the diencephalon and brainstem. There are several important structures within the limbic system.
Limbic system structures include the cingulate gyrus, amygdala, and hippocampus/parahippocampal gyrus. There are extensive connections to the olfactory system and to the hypothalamus. Modified from Marieb et al, *Human Anatomy*, 5th edition, Pearson Education, 2008.

- The **amygdala**, a subcortical nucleus within the anterior temporal lobe, processes fearful stimuli and formulates responses to those stimuli.
- The **cingulate gyrus** is the region of cerebral cortex on the medial side of each cerebral hemisphere, immediately superior to the corpus callosum. The cingulate gyrus is involved in shifting between thoughts, selective attention, and retrieval of memory, among other things.
- The **hippocampus** and **parahippocampal gyrus** are located in the inferomedial temporal lobe, just inferior to the inferior horn of the lateral ventricle. The parahippocampal gyrus is visible on the inferior surface of the brain; the hippocampus is located deep to it. In these regions, memories are encoded and consolidated to be stored elsewhere in the cerebral cortex as long-term memories.
- The **fornix** is a fiber tract which connects the structures of the limbic system with other structures, such as the hypothalamus and the olfactory system. The fornix contains many of the inputs to and outputs from the hippocampus. It arches over the thalamus and third ventricle as it travels between the hippocampus and the **mammillary bodies** (part of the hypothalamus in the diencephalon, below). Disruptions of the fornix can cause memory deficits.
Dissection of the brain which shows the hippocampus and fornix. The lateral ventricle has been opened to see the hippocampus in the floor of the inferior horn of the lateral ventricle. http://www.neuroanatomy.ca/functional_areas

The location of the limbic system deep within the cerebrum makes it difficult to visualize in just one view of the brain. Above is a specimen in which the roof of the inferior horn of the lateral ventricle has been removed in order to expose the hippocampus in the temporal lobe.

Below is a series of three sequential coronal sections through the brain in which you can see the structures of the limbic system. In the first (most anterior) section, the amygdala is visible in the inferior part of the temporal lobe (on the left side of the image). On the second and third sections, which are more posterior, the hippocampus is visible in the same part of the temporal
lobe. The hippocampus is posterior to the amygdala and just inferior to the inferior horn of each of the lateral ventricles within the temporal lobe.
Language Association Areas: Broca’s Area and Wernicke’s Area

In the left cerebral hemisphere, there are two areas of cortex which are critical to the production and comprehension of meaningful language: Broca’s area and Wernicke’s area. Broca’s and
Wernicke’s areas are extensively connected to each other and work in concert, though damage to each area produces specific deficits.

**Broca’s area** is located in the inferior part of the left prefrontal cortex. It controls the motor patterns necessary for the production of language whether that language is spoken or signed. **Broca’s area allows you to say what you understand** (In the right hemisphere, the analogous area of cortex controls the emotional composition, rather than the literal meaning, of language.)

- People with damage to Broca’s area have **expressive aphasia**. These patients may understand what is being said to them and know what they want to say, but have difficulty finding words to express their thoughts and often struggle forming complete sentences.

**Wernicke’s area** is found at the posterior end of the left lateral sulcus and spans parts of the parietal and temporal lobes. This region is important for language comprehension (for spoken, signed, or written language). **Wernicke’s area allows you to understand what you say**. (In the right hemisphere, the corresponding area of cortex is concerned with understanding the emotional meanings and contexts of language.)

- People with damage to Wernicke’s area have **receptive aphasia**. These people are able to produce language, even long complete sentences, but the language is nonsensical. Because these patients cannot understand what they say, they speak unintelligibly and are often
unaware of their spoken, written, or signed mistakes.

Below is a video of a young woman who had a stroke that affected Broca’s area of the brain which shows the difficulty that she has producing the words that she is thinking.

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Here is a short video of a man with Wernicke’s aphasia. He can produce long strings of words, but they make no sense.

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**WHITE MATTER IN THE CEREBRUM**

White matter tracts are bundles of axons. The white color of these tracts in unstained brain tissue is due to the myelin coatings of the larger axons. Tracts of white matter connect different regions of the central nervous system. White matter tracts are classified according to the regions that they connect.

- **Association tracts** (or fibers) connect different regions within the same cerebral hemisphere.
- **Commissural tracts** (or fibers) contain axons which travel between the right and left cerebral hemispheres. The **corpus callosum** is the largest commissural tract and is easily visible on the medial surface of a sagittally sectioned brain.
- **Projection tracts** (or fibers) travel into or out of the cerebrum to communicate with more caudal regions of the CNS. Sensory information ascends to the cerebrum (ascending pathways/tracts). Motor signals descend to the brainstem and spinal cord (descending pathways/tracts). Within the substance of the cerebrum, the projection fibers form the **corona radiata** (just deep to the cerebral cortex) and continue as the **internal capsule** more inferiorly, as the fibers pass between the deep nuclei of the cerebrum.
Projection tracts form the corona radiata just deep to the cerebral cortex, then coalesce into the internal capsule as they travel toward the brainstem. Modified from Marieb et al, Human Anatomy, 5th edition, Pearson Education, 2008.
Left cerebral hemisphere dissected to show the white matter tracts. http://163.178.103.176/Temas/Temab2N/APortal/FisoNerCG/LaUII/Neuro/BrainAn/Ch5Text/Section10.html
A coronal section through the brain. The corpus callosum is a commissural tract which connects the right and left cerebral hemispheres. The corona radiata and internal capsule are parts of the projection tract which carry fibers ascending to and descending from the cerebral cortex. [https://neupsykey.com/cerebral-hemisphere-and-cerebral-cortex/](https://neupsykey.com/cerebral-hemisphere-and-cerebral-cortex/)

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**DEEP CEREBRAL NUCLEI: Basal Nuclei (Basal Ganglia) / Striatum**

In addition to the cerebral cortex, there are regions of gray matter that are deep within the
cerebrum: the **basal ganglia** (or **basal nuclei**). This group of interconnected, subcortical nuclei consists of the **caudate nucleus**, the **putamen**, the **globus pallidus**, and the nucleus accumbens.

The **caudate nucleus** is medial to the internal capsule and forms an arch that follows the curve of the cerebrum (and lateral ventricles). The **putamen** and **globus pallidus** are located lateral to the internal capsule, just deep to the insular cortex. The nucleus accumbens is located rostral to the caudate and putamen (just rostral to the hypothalamus). Together, the caudate, putamen, nucleus accumbens, and (usually) the globus pallidus are referred to as the **striatum** or **corpus striatum**.
Lateral view of the cerebrum which includes a projection of the basal ganglia (basal nuclei). (Remember that the basal nuclei are deep within the cerebrum.) In the figure, the full extent of the caudate nucleus is visible. It follows the curve of the lateral ventricle. The putamen and nucleus accumbens are shown, but the globus pallidus is not visible (it is deep to the putamen). The purple structure shown ‘behind’ the putamen is the thalamus, part of the diencephalon. The substantia nigra of the midbrain is connected to the basal nuclei by an important dopaminergic pathway. Modified from Marieb et al, Human Anatomy, 5th edition, Pearson Education, 2008.

The striatum is divided into two functional parts.

- The dorsal striatum consists of the caudate, putamen, and globus pallidus. Together these nuclei act with the cerebral cortex and areas of the midbrain to control voluntary movements, playing important roles in motor control and learning motor patterns. These nuclei are extensively connected to the cerebral cortex, subthalamic nuclei of the diencephalon, and substantia nigra of the midbrain. The basal nuclei receive inhibitory inputs from the substantia nigra of the midbrain and excitatory inputs from the cerebral cortex. Basal nuclei send their output to the cerebral cortex, via the thalamus, to coordinate and modify movements.

  - Parkinsonian syndromes are the result of the degeneration of regions of the substantia nigra in the midbrain. These regions normally send inhibitory signals to the basal nuclei. The loss of those signals results in the rigidity, akinesia/bradykinesia, and resting tremor that are characteristic of Parkinsonian syndromes. (The effects of these syndromes on the basal nuclei are secondary to the loss of dopaminergic cells in the substantia nigra.)
• The ventral striatum consists of the nucleus accumbens and other nuclei are involved in reward-related behaviors. The nucleus accumbens receives extensive dopaminergic projections from the ventral tegmental area of the midbrain.

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**Diencephalon**

The diencephalon is deep within the forebrain, just superior to the midbrain of the brainstem. It is made up of three paired structures: the thalamus, hypothalamus, and epithalamus. These structures surround the third ventricle, which is unpaired and located in the midline.

*Location of the diencephalon in the brain. It is surrounded by the cerebrum. From Life Science Databases (LSDB) – from Anatomography,*
The thalamus is a roughly egg-shaped collection of about twelve nuclei in the superior part of the diencephalon. It is sometimes referred to as the ‘gateway to the cerebral cortex.’ All sensory signals from the body, with the exception of olfaction, synapse in the thalamus before being relayed to the sensory areas of the cerebral cortex. Sensory information is processed, amplified, and edited in the thalamus before it gets to the cerebral cortex.

Though specific details are beyond the scope of this introduction, it is important to understand that each nucleus in the thalamus receives information from a particular sensory pathway and sends that information to the related sensory area within the cerebral cortex. For example, the lateral geniculate nucleus of the thalamus receives information from the retina and relays it to the primary visual cortex in the occipital lobe. Similarly, the ventral posterolateral nucleus of the thalamus receives information from somatosensory pathways and relays it to the postcentral gyrus in the parietal lobe. Just as the sensory areas of the cerebral cortex are organized topographically, so are the nuclei of the thalamus. For example, the ventral posterolateral nucleus of the thalamus is somatotopically organized, just like the postcentral gyrus is.
The **hypothalamus** is inferior to the thalamus and lies just superior to the optic chiasm (where the two optic nerves cross on the inferior surface of the brain). The pituitary gland is attached to the inferior hypothalamus. The hypothalamus consists of about twelve nuclei. These nuclei are highly interconnected within the hypothalamus in addition to being extensively connected to other parts of the CNS. The hypothalamus is the main control center for visceral functions, such as the autonomic nervous system, body temperature, hunger and thirst, sleep-wake cycles, and the endocrine system. The hypothalamus has extensive connections to the limbic system. (The mammillary bodies, which are hypothalamic nuclei, are the terminus of the fornix, the main output from the hippocampus.) When you are nervous, your heart rate may go up or you may start.
sweating. These responses are due to the connection between the limbic system (emotion) and hypothalamus (autonomic functions).

The **pituitary gland** is connected to the inferior side of the hypothalamus by a stalk of neural tissue called the *infundibulum*. The pituitary gland is an endocrine gland which is regulated by inputs from the hypothalamus.

![Diagram of the hypothalamus and its nuclei](image)


The **epithalamus** is the most dorsal part of the diencephalon. A small, unpaired gland hangs off of the posterior epithalamus: the *pineal gland*. This is an endocrine gland that secretes melatonin,
which is involved in regulating circadian rhythms. The pineal gland is under the control of the hypothalamus.

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Introduction to the Brainstem

The brainstem is discussed in much more detail in the next chapter.

Though it is the site of many critical functional areas, the brainstem is surprisingly small, only 3-4 inches long. It contains three regions, from rostral to caudal: the midbrain, pons, and medulla (oblongata). The entire brainstem lies in the posterior cranial fossa adjacent to the basilar part of the occipital bone. Caudally, it is continuous with the spinal cord. The cerebral aqueduct and fourth ventricle are located in the brainstem. The brainstem is discussed in more detail in a subsequent chapter.
Diagrammatic overview of the structures of the brainstem. The thalamus is not part of the brainstem, but is shown for reference. The cerebellum has been removed in these views. Modified from Marieb et al, Human Anatomy, 5th edition, Pearson Education, 2008.

Generally, the brainstem has three basic functions:

- It **regulates automatic functions** that are necessary for life, such as respiration, heart rate, and blood pressure.
- It is a passageway for **ascending and descending fiber tracts** which enter and leave the cerebrum and cerebellum.
- It contains the **nuclei of origin for most of the cranial nerves** (both the motor and sensory parts of these nerves).
  - Testing cranial nerve function is a good way to assess a patient for localized damage to the brainstem. Brainstem anatomy and function is the foundation of a basic neurological exam.

Each segment of the brainstem has a typical structure in cross section. The overall shape of the brainstem varies by region, as does the arrangement of prominent structures in each region. The specific structures of each region will be discussed in the next chapter.
Cerebellum

Both grossly and histologically, the cerebellum is the most beautiful part of the central nervous system! It looks like a tiny brain stuck to the back of the brainstem and is separated ventrally from the pons and medulla by the fourth ventricle. The cerebellum is located in the posterior cranial fossa and sits just superior to the occipital bone. It has a very convoluted surface.
Three-dimensional view of the cerebellum in situ. Life Science Databases (LSDB) [CC BY-SA 2.1 jp (http://creativecommons.org/licenses/by-sa/2.1/jp/deed.en)], via Wikimedia Commons
Like the cerebrum, the cerebellum has gray matter (a cortex as well as deep nuclei) and white matter. The cerebellar cortex is convoluted into folia (the ridges) and fissures (the grooves). As in the cerebral cortex, the extensive folding of the cerebellar cortex allows more neurons to fit into a small space. The cerebellum has two hemispheres connected by a midline region called the vermis.
A posterior view of a coronal section through the cerebellum shows the cerebellar cortex (gray matter) and the white matter core. Within the core of the cerebellum are a series of deep nuclei (gray matter). The largest and most distinctive of these nuclei is the dentate nucleus. Modified from Marieb et al, Human Anatomy, 5th edition, Pearson Education, 2008.

Each hemisphere of the cerebellum is divided into three lobes: the anterior, posterior, and flocculonodular lobes. (The cerebellar lobes are not as well defined as those in the cerebral cortex are, nor are they as functionally distinct.) The most inferior part of the posterior lobe is the cerebellar tonsil. Traumatic tonsillar herniation (through the foramen magnum) is a life-threatening situation due to the pressure put on the adjacent parts of the medulla, which contain the respiratory control centers.
Functions of the cerebellum are unconscious; we are not aware of all the things that our cerebells are doing for us. There are three functional divisions of the cerebellum: the vestibulocerebellum, spinocerebellum, and cerebrocerebellum (neocerebellum/pontocerebellum). These divisions are distinguished primarily by the sources of their inputs, which determine their function.

The **vestibulocerebellum** receives most of its inputs from the vestibulocochlear nerve (CN VIII) which provides information about the position of the head in space. It consists primarily of the flocculonodular lobe. Damage to this region results in vertigo and nystagmus.

The **spinocerebellum** receives extensive proprioceptive input from the spinal cord and regulates muscle tone and coordination of the extremities. This region spans the vermis and the paramedian areas of the anterior and posterior lobes.

The **cerebrocerebellum** (or **neocerebellum**, or **pontocerebellum**) receives inputs from the cerebral motor cortex: information about the motor instructions that the cerebral cortex is sending to the body. These inputs are relayed through the pontine nuclei and then travel through the **middle cerebellar peduncles** to enter the cerebellum. The cerebrocerebellum regulates and modulates the motor output of the cerebral cortex. This region encompasses the lateral parts of the anterior and posterior lobes. The **dentate nucleus**, the largest of the deep cerebellar nuclei, is part of the cerebrocerebellum. It is involved in voluntary movements and cognition. The dentate nucleus contributes to the output pathways which ascend to the cerebrum.

In summary, the cerebellum receives three classes of input:
1. information about equilibrium (position of the head in space), from the vestibular system
2. proprioceptive information (positions and movements of the body), from the spinal cord
3. information about intended movements, from the cerebral motor cortex.

All of these inputs are combined and the cerebellum sends output signals to the cerebral motor cortex in order to continuously adjust motor commands. These cerebellar signals serve to fine tune and coordinate muscle actions, so that the actual movements that are produced closely match those intended by the motor cortex.

Fibers enter and exit the cerebellum through one of three pairs of fiber tracts: the cerebellar peduncles. The **superior cerebellar peduncles** connect the cerebellum to the midbrain and consist mostly of output fibers that are ascending to the cerebral cortex (via the thalamus). The **middle cerebellar peduncles** are the largest of the cerebellar peduncles. They connect the cerebellum to the pons and carry input fibers from the cerebral cortex into the cerebellum (via the pontine nuclei). The **inferior cerebellar peduncles** carry input fibers from the medulla (including cranial nerve VIII) and the spinal cord to the cerebellum. The cerebellum receives information from and affects the function of the *ipsilateral* side of the body.

This video of a clinical examination of cerebellar function gives a good explanation of what the cerebellum does by illustrating what happens with cerebellar disease.
Blood Supply to the Brain

As you saw in the cranial cavity dissection, the brain has an extensive blood supply which anastomoses on the inferior surface of the brain. The right and left **vertebral** and **internal carotid arteries** enter the skull independently, then anastomose in the **circle of Willis**.

The vertebral arteries enter the skull through the foramen magnum. The arteries converge to form a single **basilar artery** that courses over the ventral surface of the pons. Arteries that supply the cerebellum branch from the vertebral-basilar system (**posterior inferior**, **anterior inferior** and **superior cerebellar arteries**). After sending branches to the cerebellum and brainstem, the basilar artery bifurcates to form the **posterior cerebral arteries**, which supply the occipital and inferior temporal lobes. The internal carotid arteries enter the skull through the carotid canals, traverse the cavernous sinuses, then bifurcate within the cranial cavity to form the **middle** and **anterior cerebral arteries** which supply the rest of the cerebrum.

As you will see in the lab, these vessels are not always symmetrical and often show signs of vascular disease.
Each cerebral and cerebellar artery supplies a particular region of the brain or brainstem. The general territories supplied by each of the cerebral and cerebellar arteries are illustrated in the color-coded diagrams below. (There is overlap between territories and, of course, there are variations between individuals.) An understanding of the distribution of each of these vessels can help predict functional deficits that could result from an obstruction. Conversely, if a patient presents with particular deficits, you can predict the site of vascular disruption in a general way using these anatomical relationships.
Distribution of Cerebellar Arteries. Figure from Blumenfeld, Neuroanatomy through Clinical Cases, p. 668.

The courses of the cerebral arteries. Modified from Netter Presenter.
After they branch from the circle of Willis, the cerebral arteries have specific courses around the surface of the brain. (They travel in the subarachnoid space.) The basic rule of thumb is that the arteries will supply the structures that they are near. Generally, the courses of and structures/regions supplied by the cerebral arteries are:

- **Anterior cerebral arteries**
  - Run dorsal to the corpus callosum to supply superior and medial parts of the cerebrum
  - Supplies the medial and superior parts of the frontal and parietal lobes

- **Middle cerebral arteries**
  - Run through the lateral sulcus just superficial to the insula to supply the lateral cerebrum
  - Supplies the lateral parts of the frontal and parietal lobes, the insula, and the superior temporal lobe
  - Also sends branches to the basal nuclei (*lenticulostriate arteries*)

- **Posterior cerebral arteries**
  - Run superficial to the posterior midbrain and the medial occipital lobe to supply posterior and inferior parts of the cerebrum
  - Supplies the inferior temporal lobe and the occipital lobe

As you learn these blood vessels and follow their courses in the lab, relate those courses to the general organization of the brain. Below is a diagram showing the regions within the postcentral gyrus (primary somatosensory cortex) that are supplied by the anterior (*yellow*) and middle (*red*) cerebral arteries. Based on the somatotopic organization of this gyrus, obstructions in the anterior and middle cerebral arteries would cause different patterns of sensory loss. The anterior cerebral artery supplies parts of the postcentral gyrus that deal with sensation from the lower extremity and trunk whereas the middle cerebral artery supplies parts of the gyrus which deal with sensation from the face and upper extremity. There is a similar arrangement in the precentral gyrus, the primary motor cortex; an obstruction of the anterior cerebral artery could affect movement of the lower extremity while an obstruction of the middle cerebral artery could cause loss of motor function in the face and/or upper extremity. An understanding of the pathways of these blood vessels and the general organization of the brain will allow you to start applying this anatomy to clinical problems.
The cerebellar arteries also supply structures that they travel over or near. These arteries will be discussed in more detail in the Anatomy of the Brainstem ELO and chapter. Here are the general regions that each cerebellar artery supplies:

- **Superior cerebellar arteries**
  - Supply the midbrain and superior cerebellum
- **Anterior inferior cerebellar arteries**
  - Supply the pons and the anterior inferior cerebellum
- **Posterior inferior cerebellar arteries**
  - Supply the medulla and the posterior inferior cerebellum

Distribution of the Anterior Cerebral Artery
Distribution of the Middle Cerebral Artery

Distribution of the Posterior Cerebral Artery

Knowledge Checks

Back to Top
Review Video

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Anatomy of the Brainstem

ELISE DAVIS, PHD

Sections

- Overall Organization of the Brainstem
  - Tectum
  - Tegmentum
    - Cranial nerve nuclei
    - Ascending tracts
    - Integrative centers
  - Basis (Descending tracts)
- Features of Each Brainstem Region
  - Midbrain
  - Pons
  - Medulla
- Summary of Brainstem Structures
- Blood Supply of the Brainstem
  - Anatomical basis of brainstem syndromes (as examples of concept)
- Dissections of Brainstem
- Review Video

The goal of this chapter is to provide an outline of the structure of the brainstem and the functional areas within it: a big picture view of the brainstem. As you learn about specific structures within the brainstem in your clinical lectures in M&M, you can use this chapter as reference to put those structures in an anatomical context.

If you need to review the development of the brainstem (which helps to understand its structure), see the Development of the Nervous System and Structures of the Head and Neck chapter in the HFT book.

OVERALL ORGANIZATION OF THE BRAINSTEM

The brainstem connects the brain to the spinal cord. It contains the nuclei of cranial nerves III-X and XII; is a conduit for tracts of axons traveling to and from the cerebrum and cerebellum; and contains important integrative and visceral control centers. You have already learned most of
the structures of the brainstem in previous lectures. This chapter will explain how the different nuclei and tracts of the brainstem are organized within the brainstem and in relation to their blood supply.

Though it is the site of many critical functional areas, the brainstem is surprisingly small: only 3-4 inches long. It contains three regions, from rostral to caudal: the midbrain, pons, and medulla (oblongata). The entire brainstem lies in the posterior cranial fossa adjacent to the basilar part of the occipital bone. Caudally, it is continuous with the spinal cord at the foramen magnum. The cerebral aqueduct and fourth ventricle are located in the brainstem. Blood is supplied primarily by the branches of the vertebral and basilar arteries (the posterior circulation within the cranial cavity).

There are three basic types of structures in the brainstem.

- **Nuclei associated with cranial nerves III-X and XII** (both the motor and sensory nuclei).
  - Testing cranial nerve function is a good way to assess a patient for localized damage to the brainstem. Brainstem anatomy and function is the foundation of a basic neurological exam.

- **Ascending (sensory) and descending (motor) tracts** which enter and leave the cerebrum and cerebellum.
  - Note: In the CNS, bundles of axons have many different names: tracts, fascicles/fasciculus/fasciculi, brachium, peduncle, lemniscus. All of these terms refer to bundles of axons traveling through the CNS.

- **Integrative centers** which control arousal, consciousness, and wakefulness; modulate pain sensations; and regulate automatic functions that are necessary for life (respiration, heart rate, and blood pressure).

The brainstem is organized fairly systematically. In each section of the brainstem (midbrain, pons, and medulla), there are distinct longitudinal regions. From dorsal to ventral:

- The **tectum** is significant only in the midbrain and contains the superior and inferior colliculi.
(In the pons and medulla, the tectum makes up the roof of the fourth ventricle.)

- The **ventricular system** (*cerebral aqueduct* and *fourth ventricle*) lies just ventral to the tectum (between the tectum and the tegmentum).

- The **tegmentum** contains three types of structures:
  
  ◦ Most dorsally are the **nuclei (sensory and motor) of cranial nerves**.
  
  ◦ More ventrally are the **ascending (sensory) tracts** of axons traveling from the spinal cord to the cerebellum and cerebrum.
  
  ◦ Scattered between the tracts and nuclei of the tegmentum are the integrative regions of the **reticular formation**.

- The **basis** is the most ventral part of the brainstem and consists of descending (motor) tracts which travel from the cerebral motor cortex to the cranial nerve nuclei (*corticobulbar, or corticonuclear, axons*) and to the ventral horn of the spinal cord (*corticospinal axons*).
Tectum

The tectum is functionally significant only in the midbrain where it contains the superior and inferior colliculi. In the pons and medulla, the tectum forms the roof of the fourth ventricle.

Tegmentum

The **tegmentum** contains the cranial nerve nuclei, ascending (sensory) tracts, and the reticular formation.

**Cranial nerve nuclei** are located dorsally within the tegmentum. In the brainstem, there is a cranial nerve nucleus that corresponds to each type of axon carried by a cranial nerve (see below). Almost always, cranial nerve nuclei control function on the ipsilateral side of the head and neck. (There are exceptions that you will learn later.)

Within the brainstem, the cranial nerve nuclei are organized into functional columns (by modality), as shown in the figures below. Generally, somatomotor nuclei are located most medially, in a column just lateral to the midline. Branchiomotor and visceromotor nuclei are located just lateral to the somatomotor column. The columns of sensory nuclei (visceral and somatic sensations) have the most lateral position in the tegmentum. The key point to understand is that nuclei with similar modalities are localized in particular columns within the tegmentum of the brainstem.
• Knowing this general pattern of organization of the nuclei of the cranial nerves can help you understand the clinical signs of brainstem damage.
  
  ◦ Damage to the medial brainstem is more likely to affect somatomotor cranial nerve nuclei. Likewise, damage to the lateral brainstem is more likely to affect sensory nuclei of cranial nerves.

The diagram below illustrates a cross-section through the generalized brainstem and the organization and positioning of the longitudinal columns of cells within it. Each colored dot or region represents a column of neurons that runs longitudinally through the entire brainstem. At different levels, cells in these columns give rise to specific cranial nerves. (The columns are discontinuous, forming nuclei only where cranial nerves arise. For example, somatomotor nuclei exist only where somatomotor cranial nerves form: in the midbrain (III, IV), rostral pons (VI), and caudal medulla (XII).

Each cranial nerve is associated with one or more brainstem nuclei. Cranial nerves which contain more than one modality of axon will be associated with multiple brainstem nuclei. For example, the oculomotor nerve (cranial nerve III) contains both somatomotor and visceromotor axons. It is associated with two nuclei in the midbrain: the oculomotor nucleus, which contains somatomotor neurons, and the Edinger-Westphal nucleus, which contains parasympathetic (visceromotor) neurons. Axons from both of these nuclei will exit the midbrain together to form the oculomotor nerve. By contrast, the abducens nerve (cranial nerve VI) contains only somatomotor fibers and is associated with only one nucleus: the abducent nucleus (in the pons).

**Important take-home point:** Every axon type in a cranial nerve is associated with a specific brainstem nucleus.

More detail about specific cranial nerve nuclei can be found later in this chapter.
Cross-sectional diagram of the columns of cranial nerve nuclei in the brainstem. Somatomotor nuclei are closest to the midline; branchiomotor and visceromotor nuclei are just lateral to those. Sensory nuclei (both visceral and somatic) are in the lateralmost columns of nuclei. Image modified from https://neupsykey.com/nuclei/
Take-home messages:

- Each cranial nerve arises from a specific region of the brainstem: midbrain, pons, or medulla.
- Brainstem nuclei are arranged into columns, each of which corresponds to a particular modality (axon/fiber type) in the cranial nerves.
- Each modality of a cranial nerve is associated with a particular nucleus or particular nuclei in the brainstem.
  - Cranial nerves with multiple types of axons/modalities are associated with multiple brainstem nuclei, as described in the chart below. More detail about the individual nuclei will be discussed in a later section.
- Cranial nerve nuclei generally control function on the ipsilateral side. This is true for both motor and sensory functions. (There are some exceptions.)
### Ascending (sensory) tracts

Travel through the tegmentum of the brainstem.

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**KNOWLEDGE CHECK**

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**Cranial Nerve Nuclei Chart (Medial to Lateral)**

<table>
<thead>
<tr>
<th>CN</th>
<th>Region</th>
<th>Sensory/Parasympathetic</th>
<th>Branchiomotor</th>
<th>Visceromotor (Parasympathetic)</th>
<th>General Viscerosensory</th>
<th>Special Viscerosensory</th>
<th>General Somatosensory</th>
<th>Special Somatosensory</th>
</tr>
</thead>
<tbody>
<tr>
<td>III</td>
<td>midbrain</td>
<td>Oculomotor nu.</td>
<td>Edinger-Westphal nu.</td>
<td>Mesencephalic (in midbrain) proprio; Main sensory nucleus of V (taste, pressure)</td>
<td>Spinal nucleus of V (in medulla; pain, temp)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>midbrain</td>
<td>Trochlear nu.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>pons</td>
<td>Motor nucleus of V</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VI</td>
<td>midbrain</td>
<td>Abducens nu.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VII</td>
<td>medulla</td>
<td>Facial motor nu.</td>
<td>Superior salivatory (lacrimal) nu.</td>
<td>Nucleus solitarius (gustatory nu.)</td>
<td>*anosynapse in spinal nu. of V</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VIII</td>
<td>medulla</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Vestibular and cochlear nu.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IX</td>
<td>medulla</td>
<td>Nucleus ambiguus</td>
<td>Inferior salivatory nu.</td>
<td>Nucleus solitarius (gustatory nu.)</td>
<td>Nucleus solitarius (gustatory nu.)</td>
<td>*anosynapse in spinal nu. of V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>medulla</td>
<td>Nucleus ambiguus</td>
<td></td>
<td>Nucleus solitarius (gustatory nu.)</td>
<td>Nucleus solitarius (gustatory nu.)</td>
<td>*anosynapse in spinal nu. of V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>XII</td>
<td>Hypoglossal nu.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*CN XI originates from the cervical spinal cord*
Ascending axon tracts run through the tegmentum of the brainstem. Image modified from Marieb et al.

- **Spinothalamic tracts** carry pain and temperature from the body and travel dorsolaterally through the brainstem to reach the thalamus.
- The **medial lemniscus** is comprised of second-order axons of the dorsal columns system (cell bodies in the nucleus cuneatus and gracilis). These axons carry fine touch, vibration, and conscious proprioception. In the pons and medulla, the medial lemniscus is located medially within the tegmentum; in the midbrain, it runs more dorsolaterally.
- **Spinocerebellar tracts** carry unconscious proprioception from the body and travel dorsolaterally through the medulla to the inferior cerebellar peduncle to enter the cerebellum.
- With the exception of the spinocerebellar tracts, ascending tracts in the brainstem are carrying sensation from the contralateral body.

**Integrative centers** of the brainstem are located diffusely within the tegmentum of the midbrain, pons, and medulla.
The integrative centers of the brainstem include the periaqueductal gray (in the midbrain; pain modulation) and the reticular formation (midbrain, pons, and medulla). Image adapted from Biorender.com

• In the midbrain, the region surrounding the cerebral aqueduct is the **periaqueductal gray**. This region is involved in the modulation of pain.

• The **reticular formation** is comprised of a diffuse network of nuclei and axons in the tegmentum. This system has extensive connections to more cranial and more caudal regions of the nervous system.
  - In the midbrain and rostral pons, the reticular formation is involved in arousal, consciousness, and wakefulness. Its activity is depressed by alcohol, general anesthesia, and sleep-inducing drugs. Bilateral lesions of this part of the reticular formation can lead to coma. The more rostral parts of the reticular formation also contain the gaze centers which coordinate the muscles of both eyes during vertical and horizontal movements.
  - In the caudal pons and medulla, the reticular formation is involved in the control of autonomic visceral functions such as respiration, heart rate, and blood pressure.

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**Basis**

The most ventral region of the brainstem is called the **basis** (or **basilar region**). This region
consists of tracts of motor axons descending from the cerebral cortex to the motor neurons of the cranial nerves and spinal cord. These axons are arranged somatotopically through their course. The more medial fibers within the basis control more cranial muscles. For the most part, descending motor axons in the brainstem control muscles on the contralateral side of the head and body.

- **Corticobulbar axons** arise from motor neurons of the primary motor cortex and synapse in the brainstem on motor nuclei of cranial nerves which innervate skeletal muscles of the head and neck (both branchiomotor and somatomotor nuclei).
- **Corticospinal axons** arise from motor neurons of the primary motor cortex and synapse in the spinal cord on ventral horn motor neurons which innervate skeletal muscles of the body. These axons include the lateral corticospinal tract (LCST).
- The neurons that give rise to both corticobulbar and corticospinal axons are the upper motor neurons. The neurons in the cranial nerve nuclei and ventral horn are the lower motor neurons.

Cross-sections through the three regions of the brainstem illustrating the extent of the basis. Midbrain: https://radiopaedia.org/images/23668; Pons: http://etc.usf.edu/clipart/55700/55758/55758__pons.htm; Medulla: http://etc.usf.edu/clipart/55700/55754/55754__medulla.htm
Descending axon tracts run through the basis of the brainstem. Image modified from Marieb et al.
FEATURES OF EACH BRAINSTEM REGION

This section is designed to give you a broad, high-level overview of the structures of the brainstem and their general functions using cross-sectional diagrams. You will learn more about the specific functions and clinical importance of these structures in the upcoming weeks of the block. The cross-sectional diagrams of different regions of the brainstem are designed to give you an overview of the general locations of the structures listed here. These are the questions you should be able to answer after this lecture / chapter:

- Is the structure in the midbrain, pons, or medulla?
- Is the structure located in tectum, tegmentum, or basis?
  - If it is in the tegmentum, is it located ventromedially or dorsolaterally?
Each segment of the brainstem has a typical structure in cross section. The overall shape of the brainstem varies by region, as does the arrangement of prominent structures in each region. The specific structures of each region will be discussed below.

Midbrain

The **midbrain** lies between the diencephalon and the pons.
Midbrain Tectum
The tectum of the midbrain consists of two superior colliculi and two inferior colliculi.

- **Superior colliculi** are paired nuclei which are involved with visual reflexes and coordinating gaze.
- **Inferior colliculi** are paired nuclei which are involved with auditory reflexes and sound localization.

Midbrain Ventricular System
Just ventral to the tectum in the midbrain is the cerebral aqueduct of the ventricular system.

Midbrain Tegmentum

- **Periaqueductal gray** (pain modulation)
- Cranial nerve nuclei (Motor nuclei are more medial; sensory nuclei are more lateral.)
  - CN III (Oculomotor):
    - **Oculomotor nucleus** (somatomotor)
    - **Edinger–Westphal nucleus** (parasympathetic)
  - CN IV (Trochlear):
• **Trochlear nucleus** (somatomotor)
  - This nucleus is not shown in the figure, but is in the same column as the oculomotor nucleus and slightly caudal.

  - **CN V (Trigeminal):**
    - (Though CN V originates from the pons, one of its sensory nuclei is in the midbrain; see section about the pons for the explanation.)
      - **Mesencephalic nucleus of V** (proprioceptive information from structures of mastication)
        - Not shown; located laterally in the midbrain

• **Ascending Tracts:**
  - Dorsolateral:
    - **Spinothalamic tract**
    - **Medial lemniscus** (second-order axons of dorsal columns system)
      - These axons travel through the midbrain laterally, but have a more ventromedial position in the pons and medulla.

    - **Superior cerebellar peduncle**
      - Not shown; found in the caudal midbrain and rostral pons
      - Large fiber tracts connecting the midbrain to the cerebellum
      - Convey axons from the cerebellum to thalamus (input to the cerebral cortex).

• **Reticular Formation**
  - Involved with arousal, consciousness, and wakefulness (extends into rostral pons)

• **Other Regions**
  - **Red nucleus**
    - Involved in coordination and motor control; functionally associated with the cerebellum.
  - **Substantia nigra**
    - A pigmented nucleus which is obvious in a freshly sectioned midbrain, its neuronal cell bodies contain melanin. The substantia nigra sends inhibitory signals to the basal ganglia via dopaminergic neurons. These neurons and their inhibitory signals are involved in the control of voluntary movements. Degeneration of dopaminergic neurons in the substantia nigra is a cause of Parkinsonian syndromes.
  - **Ventral tegmental area** (not shown in cross section/see below)
    - Dopaminergic region with outputs to the limbic system and cerebral cortex; part of the motivation and reward systems of the CNS. The ventral tegmental area is not obvious grossly in sections through the midbrain.
**Midbrain Basis (Descending Tracts)**

The ventral part of the midbrain (basis) consists of very large white matter tracts, the *crus cerebri*. These are the motor tracts that are descending from the primary motor cortex (precentral gyrus) to the motor nuclei of the cranial nerves in the brainstem and to the ventral horn neurons of the spinal cord. These tracts are continuous superiorly with the corona radiata and internal capsule.
Coronal section through the brain illustrating the continuity between the projection tracts of the brain (the corona radiata and internal capsule) and the crus cerebri of the midbrain. https://neupsykey.com/cerebral-hemisphere-and-cerebral-cortex/

The terms cerebral peduncles and crus cerebri are often used interchangeably. This can be confusing. “Cerebral peduncle” sometimes refers to the crus cerebri alone and, other times, the term refers to the crus cerebri and the midbrain tegmentum together. Just be aware that the term ‘cerebral peduncle’ is somewhat vague. The big fiber tract (the basis of the midbrain) is the crus cerebri and the various nuclei are part of the tegmentum of the midbrain.

KNOWLEDGE CHECK

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The **pons** is characterized by a large tract of horizontally-oriented fibers on its ventral side. It's pretty!

Diagram of cross-section through the rostral pons at the level of the trigeminal nerve (cranial nerve V). Adapted from Biorender.com.

**Tectum**
There are no important structures in the tectum of the pons. (It forms the roof of the fourth ventricle.)

**Ventricular System**
The pons is separated from the cerebellum dorsally by the superior part of the fourth ventricle.

**Tegmentum**

- Cranial nerve nuclei (Motor nuclei are more medial; sensory nuclei are more lateral.)
  - **CN V (Trigeminal)**
    - *Motor nucleus of V* (branchiomotor)
    - Sensory nuclei of V (three parts): There are three sensory nuclei associated with cranial nerve V. Collectively, these three nuclei extend through all three regions of the brainstem, as shown in this figure (far left column in gold).
• **Mesencephalic nucleus of V** (in midbrain)
  • Receives conscious proprioceptive information from structures of mastication (muscles of mastication, mandible/TMJ, periodontal membrane).

• **Sensory nucleus of V** (in pons)
  • Receives fine touch and vibration sense from the face. This nucleus is analogous to the nucleus cuneatus/gracilis of the dorsal columns system.

• **Spinal nucleus of V** (in pons and medulla as well as cervical spinal cord)
  • Receives pain and temperature sensations from the face. This region is continuous with and analogous to the dorsal horn of the spinal cord.
  • *This nucleus also receives somatosensory inputs from the skin in and around the ear via cranial nerves VII, IX, and X. It is the nucleus associated with the general somatosensory axons of VII, IX, and X. (This is weird, but that’s just the way it is.)

• **CN VI (Abducens)**
  • *Abducent nucleus* (somatomotor)

• **CN VII (Facial)**
  • *Facial motor nucleus* (branchiomotor)
  • *Superior salivatory (lacrimal) nucleus* (parasympathetic)
  • *Nucleus solitarius (gustatory nucleus)* (viscerosensory)
    • This nucleus extends into the medulla and receives all of the viscerosensory input from CN VII, IX, and X—both general viscerosensory information
(baroreceptors/chemoreceptors in the blood vessels, for example) and special viscerosensory information (taste).

- **Spinal nucleus of V** (general somatosensory)
  - General somatosensory axons (pain and temperature sensation) of VII from skin near the ear synapse in the spinal nucleus of V.

- **CN VIII (Vestibulocochlear)**
  - **Cochlear nuclei** (special somatosensory; auditory)
  - **Vestibular nuclei** (special somatosensory; vestibular)
    - There are several vestibular nuclei. Some of them extend into the medulla.

- Ascending Tracts
  - Dorsolateral:
    - **Spinothalamic tract**
  - Ventromedial:
    - **Medial lemniscus** (second-order axons of dorsal columns system)

- **Reticular Formation**
  - In the rostral part of the pons, the reticular formation controls arousal, consciousness, and wakefulness (as in the midbrain). In the caudal part of the pons, the reticular formation is involved in the control of autonomic functions like heart rate, respiration, and blood pressure (as in the medulla).

**Important Anatomical Relationship between Branchiomotor Axons of Facial Nerve and Abducent Nucleus.**

The branchiomotor axons that leave the facial motor nucleus have an unusual course through the brainstem. Because the nucleus migrates laterally during development, the axons leave the facial motor nucleus posteriorly and wrap around the abducent nucleus (forming the internal genu of the facial nerve). The branchiomotor axons join parasympathetic and viscerosensory axons to emerge from the pons as the facial nerve ventrolaterally. The branchiomotor axons form in a bulge on the anterior wall of the fourth ventricle in the pons as they wrap around the abducent nucleus. *(This bump is called the facial colliculus).* Damage to the dorsal midline of the pons, or swelling of the fourth ventricle, can impinge on both CN VI and the branchiomotor part of VII.
Another Thing about the Facial Motor Nucleus

Within the brainstem, the neurons of the facial motor nuclei control ipsilateral muscles of facial expression. These are the lower motor neurons. The upper motor neurons for this system (and for all cranial nerves which innervate skeletal muscles) are the corticobulbar neurons that have cell bodies in the primary motor cortex. Generally, corticobulbar axons cross the midline before they synapse on cranial nerve motor neurons. So, just like in the body, the precentral gyrus controls the contralateral muscles of the head and neck. However, the corticobulbar axons which synapse on the neurons of the facial motor nucleus that innervate muscles of the upper face only partially cross before synapsing on the facial motor nucleus. (Some of the axons cross the midline before synapsing on the facial nerve motor neurons; other axons do not cross.) Because of this, muscles of the upper face receive input from both the ipsilateral and contralateral cerebral hemispheres. Corticobulbar input to the neurons of the facial motor nucleus which innervate the muscles of the lower face do completely cross in the brainstem, so muscles of the lower face are controlled solely by the contralateral precentral gyrus.

- Because of the incomplete crossing of cortical input to the facial motor neurons that supply the upper face, a unilateral upper motor neuron lesion might not cause facial paralysis on the upper face. An upper motor neuron lesion affecting the innervation of lower facial muscles would cause contralateral facial paralysis.
- Another fun fact: The facial motor nucleus also receives input from the reticular formation.
which is involuntary–for emotional control of facial expressions.

**Basis (Descending Tracts)**

The basis (ventral, or basilar, pons) contains the descending motor tracts. (Pontine nuclei are interspersed among the fibers. The pontine nuclei relay information from the cerebral motor cortex to the cerebellum. This brings information about intended movements to the cerebellum.) The descending motor tracts in the basilar pons include both corticospinal and corticobulbar axons, traveling to the motor nuclei in the spinal cord and brainstem, respectively. The large fiber tracts connecting the pons and cerebellum are the **middle cerebellar peduncles** which convey axons from the pontine nuclei to the cerebellum.

![Diagram of the pons with labels for middle cerebellar peduncles and pontine nuclei](image)


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Medulla (Medulla Oblongata)

The **medulla** is continuous caudally with the spinal cord at the foramen magnum of the skull. The structure of the medulla varies quite a bit from rostral to caudal as the brainstem transitions to the spinal cord.

Diagram of cross-section through the rostral medulla at the level of the vagus nerve (cranial nerve X). The squiggly structure just dorsal to the medullary pyramid is the inferior olivary nucleus. Adapted from Biorender.com.
Tectum
There are no important structures in the tectum of the medulla. (It forms the roof of the fourth ventricle.)

Ventricular System
The inferior part of the fourth ventricle separates the medulla from the cerebellum dorsally. In the caudal medulla, the fourth ventricle significantly narrows as it approaches the central canal of the spinal cord.

Tegmentum

• Cranial nerve nuclei (Motor nuclei are more medial; sensory nuclei are more lateral.)
  • CN IX (Glossopharyngeal):
    • Nucleus ambiguus (branchiomotor)
      • Nucleus ambiguus is the branchiomotor nucleus for both CN IX and X.
    • Inferior salivatory nucleus (parasympathetic)
      • Not shown in these sections; it is in the same column of cells as the dorsal motor nucleus of X (just rostral).
    • Nucleus solitarius (gustatory nucleus) (general and special viscerosensory)
This nucleus extends into the pons and receives all of the viscerosensory input from CN VII, IX, and X.

- **Spinal nucleus of V** (general somatosensory)
  - General somatosensory axons (pain and temperature sensation) of IX from the tympanic membrane and middle ear synapse in the spinal nucleus of V.

- **CN X (Vagus):**
  - **Nucleus ambiguus** (branchiomotor)
    - Nucleus ambiguus is the branchiomotor nucleus for both CN IX and X.
  - **Dorsal motor nucleus of X** (parasympathetic)
  - **Nucleus solitarius** (gustatory nucleus) (general and special viscerosensory)
    - This nucleus extends into the pons and receives all of the viscerosensory input from CN VII, IX, and X.
  - **Spinal nucleus of V** (general somatosensory)
    - General somatosensory axons of X from the external auditory canal synapse in the spinal nucleus of V.

- **CN XII (Hypoglossal)**
  - **Hypoglossal nucleus** (somatomotor)

- **Ascending Tracts + Descending Sympathetic Axons:**
  - **Dorsolateral:**
    - **Dorsal spinocerebellar tract (DCST)**
      - DSCT travels dorsolaterally through the caudal medulla then enters the *inferior cerebellar peduncle* as the axons travel to the cerebellum.
    - **Fasciculi (and nuclei) gracilis and cuneatus**
      - First-order axons (in the tracts/fascicles) and second-order neuronal cell bodies (in the nuclei) of the dorsal columns pathway are in the caudal medulla. Axons of the cell bodies in the nucleus gracilis and cuneatus cross the midline and ascend through the brainstem to the thalamus as the *medial lemniscus*.
  - **Spinothalamic tract**
  - **Descending sympathetic axons**

  - Central sympathetic pathways arise from the hypothalamus as well as from diffuse, interconnected nuclei in the reticular formation. These axons will synapse on the preganglionic sympathetic neurons in the lateral horn of the spinal cord (T1-L2).
  - **Ventromedial:**
    - **Medial lemniscus** (second-order axons of dorsal columns system)

- **Reticular Formation**

  - In the medulla and caudal part of the pons, the reticular formation is involved in the control of autonomic functions like heart rate, respiration, and blood pressure.
Basis

• Descending Tracts
  - *Corticospinal and corticobulbar tracts* make up the *medullary pyramids*. The axons in these tracts are continuous with those in the corona radiata, internal capsule, and crus cerebri. They are descending motor axons (upper motor neurons) traveling to cranial nerve and spinal cord motor neurons.
    - Corticospinal tracts cross the midline in the caudal medulla at the *decussation of the pyramids*.
  - *Inferior olivary nuclei* (underlie the olives, protrusions on the ventrolateral surface of the medulla)
    - Relay center for proprioceptive information that is going to the cerebellum

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Summary of Brainstem Structures

Summary of Brainstem Structures by Location: Ventromedial v. Dorsolateral

pdf of this chart: BrainstemStructuresChart
Cranial Nerve Nuclei Summary Chart

<table>
<thead>
<tr>
<th>Cranial Nerve Nuclei</th>
<th>Descending / Ascending Tracts</th>
<th>Integrative Regions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ventromedial</td>
<td>Dorsolateral</td>
</tr>
<tr>
<td>Midbrain</td>
<td>III, IV</td>
<td></td>
</tr>
<tr>
<td>Pons</td>
<td>VI</td>
<td>V, VII, VIII</td>
</tr>
<tr>
<td>Medulla</td>
<td>XII</td>
<td>VIII (vestibular), IX, X</td>
</tr>
</tbody>
</table>

The most medial CN nuclei are somatomotor.
The more lateral CN nuclei are branchiomotor & sensory.

Cranial Nerve Nuclei (Medial to Lateral)

<table>
<thead>
<tr>
<th>CN</th>
<th>Region</th>
<th>Somatomotor</th>
<th>Branchiomotor</th>
<th>Visceromotor</th>
<th>General Viscerosensory</th>
<th>Special Viscerosensory</th>
<th>General Somatosensory</th>
<th>Special Somatosensory</th>
</tr>
</thead>
<tbody>
<tr>
<td>III</td>
<td>midbrain</td>
<td>Oculomotor nu.</td>
<td>Edinger-Westphal nu.</td>
<td>Motor nucleus of V</td>
<td></td>
<td>Mecephaloic (in midbrain, proprio); Main sensory nucleus of V (touch, pressure); Spinal nucleus of V (in medulla, pain, temp)</td>
<td>Vestibular and cochlhar nu.</td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>pons</td>
<td></td>
<td>Motor nucleus of V</td>
<td>Superior salivatory (bercinal)</td>
<td>Nucleus solitarius (gustatory nu.)</td>
<td>*axon synapse in spinal nu. of V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VI</td>
<td></td>
<td>Abducent nu.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VII</td>
<td></td>
<td>Facial motor nu.</td>
<td>Superior salivatory (locomotor)</td>
<td>Nucleus solitarius (gustatory nu.)</td>
<td>*axon synapse in spinal nu. of V</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VIII</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IX</td>
<td>medulla</td>
<td>Nucleus ambiguus</td>
<td>Inferior salivatory nu.</td>
<td>Nucleus solitarius (gustatory nu.)</td>
<td>*axon synapse in spinal nu. of V</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td></td>
<td>Nucleus ambiguus</td>
<td>Dorsal motor nu.</td>
<td>Nucleus solitarius (gustatory nu.)</td>
<td>Nucleus solitarius (gustatory nu.)</td>
<td>*axon synapse in spinal nu. of V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>XII</td>
<td></td>
<td>Hypoglossal nu.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CN XI originates from the cervical spinal cord
Blood Supply to the Brainstem

The vertebral-basilar system of arteries (the posterior circulation of the cranial cavity) provides most of the blood supply to the brainstem. These arteries run between the ventral brainstem and the occipital bone. Their branches travel posteriorly to perfuse the brainstem, cerebellum, and occipital lobe. This system connects to the circle of Willis through the posterior communicating arteries. As with all vasculature in the body, it is important to remember that there are huge variations between individuals in branching patterns, perfusion territories, and arterial origins.

There are three general classes of branches from the vertebral-basilar system.

- **Long circumferential branches** supply the dorsolateral parts of the brainstem. These are the named arteries that branch from the vertebral and basilar arteries.
  - **Posterior cerebral artery**
- Superior cerebellar artery
- Anterior inferior cerebellar artery (AICA)
- Posterior inferior cerebellar artery (PICA)

- **Short circumferential branches** supply the ventrolateral parts of the brainstem. These arteries can branch directly off of the basilar or vertebral arteries or can be branches of the long circumferential arteries.

- **Paramedian branches** supply the ventromedial brainstem, roughly flanking the midline. These arteries generally branch directly from the basilar and vertebral arteries.

Vascular territories of the branches from the vertebral-basilar system. Modified from https://link.springer.com/chapter/10.1007/978-3-030-03283-8_5

Vascular territories superimposed on cross sections of brainstem regions. Adapted from Biorender.com
The territories in the above figures are approximate. Remember that individual arterial patterns vary quite a bit and vascular territories of different arteries overlap to varying degrees. From these figures, you can get a general idea of which brainstem structures will be affected if paramedian, short circumferential, or long circumferential arteries are occluded.

**KNOWLEDGE CHECK**

An interactive H5P element has been excluded from this version of the text. You can view it online here: [https://wisc.pb.unizin.org/mindmotionanatomy/?p=2177#h5p-174](https://wisc.pb.unizin.org/mindmotionanatomy/?p=2177#h5p-174)

**Anatomical basis of brainstem syndromes (as examples of concept)**

In clinical lectures, you will learn about signs and symptoms of different kinds of stroke. The following section outlines the anatomical basis of some general signs of vascular insult in different parts of the brainstem. If you know the general location of brainstem structures (midbrain, pons, or medulla? dorsolateral or ventromedial?) and their general function, you can use the clinical signs and symptoms to get an idea of where in the brainstem a vascular insult might be. This is oversimplified, but provides a good, systematic way to start applying brainstem anatomy to clinical situations. Think about this conceptually; don’t get too hung up on the details yet.

**Brainstem Lesions in General**

Cross-sections through the midbrain, pons, and medulla. Adapted from Biorender.com
Generally, a vascular injury in the brainstem will have two classes of effects.

- **Contralateral loss of movement of or sensation from the extremities.**
  - From your knowledge of ascending and descending spinal cord tracts, remember where tracts cross.
    - The (ascending) motor tract (LCST) crosses the midline in the caudal medulla.
    - The (descending) sensory tracts (dorsal columns and spinothalamic tract) cross the midline in the spinal cord or caudal medulla.
    - Lesions of any of these tracts **in the brainstem** will affect function on the **opposite** side of the body.

- **Ipsilateral loss of cranial nerve function.**
  - Cranial nerve nuclei in the brainstem (mostly) control function on the ipsilateral side of the head and neck. This includes both motor and sensory function. *(This is not 100% true. You will learn exceptions later (i.e. trochlear nerve crosses the midline after exiting the brainstem). For now, it's good enough.)*

General questions to ask about specific clinical signs

**Do the symptoms indicate a problem on the medial or lateral part of the brainstem? (Longitude)**

- Are the affected functions controlled by structures that are located ventromedially or dorsolaterally in the brainstem? Knowing this gives you a longitude (a rough idea of what vertical line through the brainstem the damage located on: lateral or medial).
  - **Medial syndromes** will affect structures that are located near the midline of the brainstem: descending tracts (i.e. LCST), somatomotor cranial nerve nuclei, and (in pons and medulla) medial lemniscus.
  - **Lateral syndromes** will affect spinothalamic tract, dorsal spinocerebellar tract, descending sympathetics (medulla), as well as sensory (and maybe branchiomotor) cranial nerve nuclei.

**Do the symptoms indicate a problem in the midbrain, pons, or medulla? (Latitude)**

- Which cranial nerve functions are affected? Knowing this gives you a latitude: is the damage in the midbrain, pons, or medulla?
  - Midbrain
    - CN III and IV (most eye movements)
  - Pons
    - CN V (muscles of mastication)
    - CN VI (eye abdution/movement of the eyeball away from the nose)
    - CN VII (muscles of facial expression)
Medulla

- CN X (swallowing (pharyngeal muscles) / speech (laryngeal muscles))
- CN XII (muscles of tongue)

As a demonstration of these general concepts, some brainstem syndromes are below. Again, the specifics are not important; you will learn about them later. The purpose of this section is to show you how to apply the anatomy in this chapter to a clinical(ish) situation.

Lateral Medullary Syndrome

The area outlined in red represents the vascular territory of a long circumferential artery (i.e. posterior inferior cerebellar artery). Affected structures and (very general) associated clinical signs are:

**Longitude: Lateral Brainstem**
Which structures are located laterally (dorsolaterally) in the brainstem? (These structures are (mostly) located throughout the length of the brainstem.)

- **DCST** (within the inferior cerebellar peduncle): ipsilateral ataxia
- **Spinal nucleus (and tract) of V**: loss of pain/temperature sensation from ipsilateral face
- **Spinothalamic tract**: loss of pain/temperature sensation from contralateral extremities (body)
- **Descending sympathetics**: ipsilateral Horner's syndrome (miosis, ptosis, anhidrosis)

**Latitude: Medullary Cranial Nerve Effects**
Which cranial nerves are located in the medulla?
• Nucleus ambiguus (IX and X; branchiomotor): dysphagia, hoarseness, reduced gag reflex
• Hypoglossal nucleus (not shown; XII, somatomotor): ipsilateral paralysis of the tongue

Medial Brainstem Syndromes

Damage to paramedian branches of the basilar or vertebral artery would disrupt blood flow to a region of the brainstem near the midline.

**Longitude: Medial**
Some of the clinical signs will be the same for all medial brainstem syndromes because some of the structures that are disrupted will span multiple levels of the brainstem, i.e. structures that run longitudinally (same longitude!). In the cases depicted in the figure above, both medial midbrain and medial pontine syndromes affect the corticospinal and corticobulbar tracts.

• Corticospinal/corticobulbar tract: contralateral hemiplegia (body/lower face)

**Latitude: Midbrain, Pontine, or Medullary Cranial Nerve Effects?**
Some effects of damage are different in the midbrain, pons, or medulla. Examination of cranial nerve function is necessary to determine the craniocaudal location of the damage.

• Midbrain:
  ◦ Oculomotor nucleus (III; somatomotor): ipsilateral eye palsy (down and out); ptosis; diplopia
  ◦ Edinger-Westphal nucleus (III; parasympathetic): ipsilateral pupil dilation
• Pons:
  ◦ Facial motor nucleus (VII; branchiomotor): ipsilateral facial paralysis
  ◦ Abducent nucleus (VI; somatomotor): ipsilateral paralysis of lateral rectus muscle of the eye (medial deviation of ipsilateral eye)
• Medulla (not pictured)
- Nucleus ambiguus (IX and X; branchiomotor): dysphagia, hoarseness, reduced gag reflex
- Hypoglossal nucleus (XII; somatomotor): ipsilateral paralysis of tongue
Dissections of Brainstem

A dissection of the dorsal brainstem. The cerebellum and cerebrum have been removed. 
http://www.neuroanatomy.ca/functional_areas/brainstem.html

Review Video

One or more interactive elements has been excluded from this version of the text. You can view them online here: 
https://wisc.pb.unizin.org/mindmotionanatomy/?p=2177#oembed-1
Spinal Cord and Spinal Meninges

MEGHAN COTTER, PHD

Chapter Sections

• Nervous System Overview
• Spinal Cord
• Spinal Nerves
  ◦ Parts of Spinal Nerves
  ◦ Dermatomes
• Spinal Meninges

Nervous System Overview

Nervous tissue consists of neurons (the functional cells of the nervous system that conduct electrical impulses) and the neuroglia (cells that support and protect neurons). The nervous system is made of billions of these cells and is responsible for control of the body and much of the communication throughout the body. The nervous system can be divided functionally and anatomically. Functionally the nervous system is divided into neurons that bring information from the body to the brain (sensory/afferent input), neurons that send information from the brain to the body (motor/efferent output) and neurons that process and interpret information (integration). Anatomically, the nervous system can be divided up into the central nervous system (the brain and spinal cord) and the peripheral nervous system (nerves) that extend from the brain and spinal cord and collections of neuron cell bodies called ganglia. Lastly, the targets of the nervous system can be organized into somatic targets (skin and skeletal muscles) and visceral targets (organs).
Neurons are highly specialized cells that carry sensory input, motor output or integration signals as electrical impulses throughout the body. Neuronal cells consist of a cell body (soma) containing a nucleus and organelles. Most cell bodies are found within the CNS (as groups they are called "nuclei"), but other cell bodies also reside in the PNS (as groups these cell bodies are known as ganglia). A neuronal cell body has a number of processes that extend from it. Dendrites are receptors of electrical impulses bringing them to the cell body, and there can be many dendrites on one neuronal cell body. Axons are processes that carry electrical impulses away from the cell body, and there is only one axon per neuron. Axons will often be referred to as fibers in this and other anatomy and neuroanatomy courses. The site where one neuron communicates with another neuron is a synapse. Most of the neurons we will encounter in this class will be one of two types. Multipolar neurons are those with many dendrites on the cell body and a single axon. These types of neurons generally act as motor or integration neurons. Unipolar (or pseudounipolar) neurons have one short process that connects to a central process and a peripheral process (that make up an axon), and a unipolar neuron has no dendrites. Unipolar neurons conduct sensory information. Bipolar neurons have a single axon and single dendrite coming from the cell body. Bipolar neurons are rare and found in very specific spots in the body (eye, ear, nose).

It is important to point out now that a neuron and a nerve are NOT synonymous. A nerve is made up of the axons/fibers of neurons plus their neuroglia and connective tissue that holds the fibers together. A nerve can carry both sensory and motor information (conversely a neuron can only carry motor or sensory information). You will encounter questions on your exams (many, many times) asking what types of fibers are found in a given nerve.
The electrical impulses that travel along neurons are called **action potential**. (Action potentials are also the signals that run along the sarcolemma to muscle fibers to initiate contraction). Damage to neurons can inhibit the propagation of an action potential down the length of the neuron’s axon.

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**Spinal Cord**

The **spinal cord** lies within the vertebral canal. It is a continuation of the medulla oblongata, the last part of the brainstem. It extends from the foramen magnum – the large foramen in the base of the skull – to the level of the 1st or 2nd lumbar vertebra. The terminal portion of the cord is called the **conus medullaris**. The diameter of the spinal cord is small, relative to the diameter of the vertebral canal, but it is enlarged in the cervical and lumbar regions. Nerves to the upper and lower limbs arise from these regions. The regions of increased diameter are called the **cervical** and **lumbar enlargements**. Although the spinal cord is a continuous structure, it can be divided into segments corresponding with the 31 pairs of spinal nerves. There are eight cervical segments with eight cervical nerves (not seven as in the number of cervical vertebrae), twelve thoracic segments, five lumbar, five sacral, and one coccygeal segment. Each of the spinal cord segments has an
alphanumeric name similar to those seen in the vertebral column, such as C5, T8 or L2. There is one exception to this. There is a C8 spinal cord segment, but no C8 vertebra.

The spinal cord is shorter than the vertebral canal. This occurs because of a greater rate of growth
of the bony vertebral column relative to the rate of growth of the spinal cord. Because the spinal cord is shorter than the vertebral canal, a disparity exists between the spinal cord segmental levels and their respective bony vertebral levels, especially at caudal levels. Thus, injury to a lower thoracic or lumbar bony vertebra would affect a more caudal segmental level of the spinal cord. Nerve roots that form the spinal nerves exit the intervertebral foramen in a horizontal orientation in cervical and upper thoracic areas. The more caudal nerve roots – especially the lumbar and sacral – run in an almost vertical direction to reach their appropriate intervertebral foramina. These elongated nerve rootlets are called, collectively, the cauda equina.
The spinal cord is made up of two components which at the gross level are described on the basis of their color: the **white matter** and **gray matter**. The gray matter of the cord consists primarily of the cell bodies of neurons, their dendrites, and the proximal parts of axons. It is divided into **dorsal** and **ventral horns** and the **gray commissure**. The dorsal horn of the spinal cord contains cell bodies of **interneurons** that communicate with incoming sensory nerve fibers. The gray commissure contains nerve fibers connecting the right and left halves of the spinal cord. The ventral horn contains the large somatic motor neuron cell bodies along whose axons impulses are sent to the striated, skeletal muscles. The appearance of the gray matter varies considerably, depending upon the cord level. For example, the ventral horn is greatly enlarged in the areas of the cervical and lumbar enlargements which contain the motor neurons innervating limb muscles. (The cervical enlargement extends from C4- T1; the lumbar enlargement extends from L1-S2.) Thoracic segments have a very small ventral horn, but there is a **lateral horn** in the thoracic segments. It contains sympathetic nerve cell bodies of the autonomic nervous system.

The **white matter** of the spinal cord surrounds the gray matter. It consists primarily of myelinated nerve fibers which run up and down the cord. These fibers convey information to the higher centers of the CNS from the spinal cord (ascending fibers), and from the higher centers of the CNS to the cells in the spinal cord (descending fibers). Collections of these nerve fibers conveying similar information are grouped in bundles called **tracts**.

Like the brain, the spinal cord is a hollow tube. In the cord this tube is represented by the **central canal** which runs through the gray commissure. This canal is filled with **cerebrospinal fluid**.
Since it spans much of the length of the trunk, the spinal cord is supplied by many arteries. Longitudinal arteries branch from the vertebral arteries to run the entire length of the spinal cord. There are two posterior longitudinal spinal arteries and one anterior longitudinal spinal artery. The spinal arteries send branches into the tissue of the spinal cord to supply blood to the gray and white matter. The anterior spinal artery supplies approximately the anterior 2/3 of the spinal cord, and the posterior spinal arteries supply the posterior 1/3.
The blood supply from the longitudinal arteries is augmented by branches of intercostal and lumbar arteries that travel through intervertebral foramina to reach the spinal cord. **Segmental medullary arteries** anastomose travel along the spinal nerves are multiple (but not all spinal nerve levels) to anastomose with the longitudinal arteries. The most significant of the segmental medullary arteries is the **artery of Adamkiewicz** that supplies the lumbar and sacral parts of the spinal cord. Spinal nerve levels that do not have a segmental medullary artery are supplied with **radicular arteries**. These smaller arteries do not anastomose with the longitudinal spinal arteries.
Spinal Nerves

There are usually 31 pairs of spinal nerves that originate at regular intervals from the spinal cord. Each spinal nerve has an alphanumeric name that corresponds to its spinal cord segment and the vertebral bodies that pass as they exit (for example, C5, T8 or L2). Since there is a C8 spinal nerve and no C8 vertebra, spinal nerves in the cervical region are associated with the vertebral body/pedicle they pass superiorly to and to the vertebral body/pedicle they pass inferiorly to in the rest of the vertebral column.


Naming of spinal nerves. Image from Drake, Gray's Anatomy for Students, 2010.
Parts of Spinal Nerves

The spinal nerves supply the sensory and motor fibers to structures of the posterior head, neck, trunk and limbs. The spinal nerves carry the axons to/from the spinal cord. The cell bodies of motor neurons in the ventral and lateral horns send their axons (fibers) out of the spinal cord through ventral rootlets. The interneurons in the dorsal horn receive information from sensory fibers in the dorsal rootlets. The cell bodies of these sensory fibers are located in structures called dorsal root ganglia (DRG). The dorsal root ganglia are located just outside of the spinal cord and form swellings/enlargements on each of the dorsal roots. The ventral rootlets converge to form a ventral root, and the dorsal rootlets converge to form a dorsal root. Rootlets and root carry either motor or sensory fibers (never both).

Each (mixed) spinal nerve is formed by the joining of a dorsal root, carrying sensory fibers, and a ventral root, carrying motor fibers (both somatic motor and autonomic). The dorsal roots join together to form mixed spinal nerves at the level of their appropriate intervertebral foramina. The remainder of the spinal nerve and its branches now carry both motor and sensory fibers. When the spinal nerve passes through the intervertebral foramen, it divides into a small dorsal ramus (plural = rami) and a large ventral ramus. The dorsal rami of the spinal nerves supply sensory and motor fibers to the intrinsic muscles of the back and skin along the dorsum of the neck and trunk. The ventral rami carry motor and sensory fibers to the remainder of the body, except the head. Structures in the head are innervated by cranial nerves.

Thoracic spinal nerve diagram with somatomotor, somatosensory and viceromotor fibers.
Some of the ventral rami interconnect with each other to form plexuses. The three plexuses are the cervical plexus, which innervates structures in the neck region, the brachial plexus (C5 through T1), which innervates the upper limb, and the lumbosacral plexus (L4 through S2/3), which provides innervation for the lower limb.

Each nerve of the peripheral nervous system contains multiple different neurons. When you are looking at a nerve, it is important to know what types of fibers it contains and where the cell bodies are located. The following table outlines where you can find cell bodies associated with fiber types. While we have primarily discussed somatic fibers thus far, visceral fibers have been added for completeness. See the reading on the Autonomic Nervous System for further discussion of visceral fiber locations and routes.
<table>
<thead>
<tr>
<th>Fiber Type</th>
<th>Cell Body Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Somatic Sensory</td>
<td>Dorsal root ganglia</td>
</tr>
<tr>
<td>Somatic Motor</td>
<td>Ventral horn of gray matter</td>
</tr>
<tr>
<td>Visceral Sensory</td>
<td>Dorsal root ganglia</td>
</tr>
<tr>
<td>Preganglionic sympathetic</td>
<td>Lateral horn of gray matter (T1-L2)</td>
</tr>
<tr>
<td>Postganglionic sympathetic</td>
<td>Sympathetic chain ganglia or collateral ganglia</td>
</tr>
<tr>
<td>Preganglionic parasympathetic</td>
<td>Brainstem or lateral horn of gray matter (S2-S4)</td>
</tr>
<tr>
<td>Postganglionic parasympathetic</td>
<td>Terminal ganglia</td>
</tr>
</tbody>
</table>

**Clinical Correlation**

Reread the clinical correlation on disc herniation in the vertebral column reading. Recall that intervertebral disc herniation can cause compression of the spinal nerve. The orientation of the spinal nerve roots as they head out the intervertebral foramen determine which spinal nerve (roots) become compressed (see the figure below). In the lumbar region, if the disc herniates posteriorly, the general rule is that the nerve that is compressed in the one that is second in the name of the intervertebral disc. For example, if the L4/L5 disc is herniated, the L5 spinal nerve will be affected. If the disc herniates more posterolaterally and herniates into the intervertebral foramen, the nerve exiting at that level will be compressed (in this example the L4 spinal nerve).

Even though the spinal nerves in the cervical region pass superior to the vertebra for which they are named, the horizontal orientation of the nerves causes the general rule to still work. Therefore, if the C3/C4 disc herniates, it will compress C4. Don't worry too much about what is happening at the C8/T1/T2 levels, those are the exceptions to the rule.
Dermatomes

As mentioned above, the 31 pairs of spinal nerves originate at regular intervals from the spinal cord. Each spinal nerve is associated with the cutaneous innervation of a very specific region of skin. The area of skin supplied by sensory/cutaneous branches from a single spinal nerve is called a dermatome, or, literally, a “skin segment.” All spinal nerves, except C1, have sensory fibers that distribute to areas of skin. The map was constructed – over a long period of time – by recording areas of numbness in patients who had injured specific spinal nerves. In the trunk region, the dermatomes are almost horizontal and indicate the course of each nerve around the body. They are uniform in width. The nerves that supply the cutaneous sensory fibers to the skin in the trunk
are branches of the intercostal nerves we saw traveling in the neurovascular bundle between the intercostal muscles. In the limbs, the pattern of dermatomes is less straightforward and their organization is dependent on the intricacies of limb development.
Unfortunately, the lines of the dermatomes are not strict boundaries, and some fibers from adjacent spinal nerves will innervate adjacent dermatomes. Additionally, dermatome maps will vary a bit between different textbooks. Thankfully, it is not necessary to memorize the exact locations of all of the dermatomes (and all versions of the dermatome maps). To help you clinically, it is best to know the landmarks for a few dermatomes, then you can count up or down to figure out which dermatome is affected in your patient. Below is a table of landmarks for the head and trunk, we will add to this in the limbs in later units.

<table>
<thead>
<tr>
<th>Dermatome</th>
<th>Landmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Back of head</td>
<td>C2</td>
</tr>
<tr>
<td>Nipples</td>
<td>T4</td>
</tr>
<tr>
<td>Umbilicus</td>
<td>T10</td>
</tr>
<tr>
<td>Suprapubic</td>
<td>T12</td>
</tr>
</tbody>
</table>

Clinical Correlation

Shingles is a disease in which viruses take advantage of axonal transport, the normal process by which substances are transported along the axons of neurons. Shingles is a viral infection of sensory neurons to the skin and is characterized by a rash of scaly, painful blisters which are usually confined to a narrow strip of skin on one side of the trunk. This narrow strip of skin, in most cases, represents the area of a dermatome.

Shingles occurs in 1 or 2 people per 1000 and usually only after age 50. It is caused by the varicella-zoster virus which also causes chicken pox. The disease stems from a childhood infection, during which time the viruses are transported from the skin lesions, through the peripheral processes (axons) of the sensory neurons, to the cell bodies in a dorsal root ganglion. The viruses are commonly held in check by the immune system and can remain dormant in the ganglion (or ganglia) for years. When the immune system is weakened, the viruses multiply and travel back through the sensory axons to the skin, producing the rash of shingles. Stress is a common cause of an outbreak, and an attack may last for several weeks.

The skeletal muscles of the limbs are also innervated in a segmental fashion called myotomes. It is possible to test the function of different spinal cord and spinal nerve levels by having your patient perform different actions at different joints. Again, it is possible to memorize all of these exactly, but sometimes it is easier to use mnemonics, shorthand, or even dances to remember which dermatome and myotome are located where:
Spinal Meninges

The brain and spinal cord are enclosed in three connective tissue layers called meninges. Protection and support of the central nervous system are their major functions. One may think of the meninges as forming completely sealed bags surrounding the brain and spinal cord.

The outermost meningeal investment is the dura mater (“tough mother”). It is composed of dense collagenous connective tissue. It is separated from the inner wall of the vertebral canal by a space called the epidural space which in life is filled with fatty tissue and a venous plexus. In the head, the dura is fused with the inner layer of periosteum of the skull and there is no epidural space. The dural sac extends to the bottom of the vertebral canal in the sacrum. The presence of an epidural space allows for movement of the vertebral column without affecting the spinal cord.
The middle investment of the central nervous system is the **arachnoid** layer. It consists of a loose connective tissue. This layer is separated from the dura by a potential space called the **subdural space**. The **subarachnoid space**, in life, is filled with **cerebrospinal fluid** (CSF). This is a clear, colorless fluid that is similar in composition to blood plasma. There are about 150 ml of CSF in an adult. It is continually produced by structures within the ventricular system of the brain called choroid plexuses, and it is continually reabsorbed from the subarachnoid space by structures called arachnoid villi. Because the brain and spinal cord cannot support their own weight, this fluid plays an important role in providing the necessary support/buoyancy for the central nervous system (Archimedes’ Principle). For example, a brain weighing 1500 grams in air weighs 50 grams when suspended in CSF.

The outer part of the arachnoid is pressed up against the dura mater by the CSF in the subarachnoid space. The inner surface of the arachnoid is characterized by numerous branching, thread-like strands that pass through the subarachnoid space and attach to the pia mater, the innermost of the three meningeal layers. The network of branching strands is called **arachnoid trabeculae**.
The **pia mater** is the innermost of the three meningeal layers and intimately invests the brain and spinal cord and its nerve roots. Pia is a loose connective tissue layer. Blood vessels traveling on the surface of the brain or spinal cord travel within the pial layer. Arising laterally from the pia on either side is a band of connective tissue that attaches the spinal cord to the dura and thus helps to suspend the cord within the subarachnoid space. These bands are called **denticulate ligaments**. They are located between the dorsal and ventral rootlets and can be difficult to see. A thin strand of pia mater extends from the conus medullaris of the spinal cord called the **terminal filum**. It can be found amongst the nerve roots that make up the cauda equina (hint: to find it, look for the one unpaired structure in the cauda equina). The terminal filum anchors the spinal cord in the dural sac. At the end of the dural sac, the pia pierces the dural sac, picks up a layer of dura and extends to the sacrum anchoring both the spinal cord and dural sac to the vertebral column.

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**Cauda equina.**

**Clinical Correlation**

In some diseases, such as meningitis, it can be useful to examine a sample of cerebrospinal fluid. The procedure for obtaining a sample is called a lumbar puncture or spinal tap. The procedure is done in the lower
lumbar area. To obtain a sample, the individual is asked to grab his or her knees as shown in the sketch to the right. This position maximizes the space between the spinous processes and laminae of the lumbar vertebrae. The “puncture”, or insertion of a needle into the subarachnoid space, is usually made in the midline between L3/L4 or L4/L5.

The L4/L5 interspace is at the level of the iliac crests.

The needle that is passed into the subarachnoid space will pass through skin and subcutaneous tissue, supraspinous and interspinous ligaments (not mentioned previously in this course), the ligamentum flavum, epidural space, dura mater, subdural space, arachnoid, and finally the subarachnoid space. This is a relatively safe space in adults because one is entering the subarachnoid space where the cauda equina is floating. Why could this procedure be contraindicated in very young children?

You may be aware that an introduction of anesthesia into the epidural space can be accomplished using a “similar” procedure, but there would be no need for the needle to pass deeper than the epidural space. This procedure is called an “epidural”, and the injected anesthetic can diffuse through the connective tissue of the space. There are variations on the procedure.

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B  LIV vertebral spinous process  LV vertebral spinous process  Tip of coccyx

Needle

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Lumbar puncture placement.
I. Axial and Appendicular Skeletons

The skeleton consists of 206 bones that are grouped into two major divisions: the axial skeleton and the appendicular skeleton. The axial skeleton includes the bones of the head and trunk – the skull, vertebral column, ribs, and sternum. The appendicular skeleton includes the bones of the limbs – both the limb girdles and the bones within the free limbs.
II. Vertebral Curvatures

The vertebrae enclose the spinal cord within the vertebral canal. Typically there are 7 cervical, 12 thoracic, 5 lumbar, 5 sacral (fused), and 4 coccygeal (more or less fused) vertebrae.

The vertebrae between C2 and S1 are separated by intervertebral discs, which contribute to the curvatures at different spinal levels and the mobility of the vertebral column. As illustrated in the figure below, there are four curvatures in adults, two primary curvatures in the thoracic and sacral
areas, and two secondary curvatures in the cervical and lumbar regions. The primary curvatures develop in the fetus and the secondary curvatures develop after birth.

A variety of causes including muscle weakness, structural abnormality, pregnancy, and genetic
defects can lead to various abnormal curvatures of the vertebral column. An exaggerated curvature in the thoracic region is called kyphosis, while an exaggerated curvature in the lumbar region is lordosis. Finally, a lateral curvature of the vertebral column is called scoliosis. Idiopathic scoliosis is usually first seen around puberty and occurs in females at a slightly greater frequency than in males. The most common form of scoliosis seen in the clinic is acquired/degenerative scoliosis that is predominant in the lumbar spine in older individuals.

![Spinal Curvatures](https://wisc.pb.unizin.org/mindmotionanatomy/?p=58#oembed-2)

**III. Typical Vertebrae**

**Body** – This weight-bearing, anterior portion of the vertebra increases in size from the cervical region to the lumbar region to support the increasing weight that is carried.

**Arch** – This posterior portion of the vertebra is composed of two pedicles and two laminae. The pedicle has superior and inferior vertebral notches that align with the notches of adjacent vertebrae to form intervertebral foramina where the spinal nerves exit the vertebral column.

**Vertebral canal** – The arch and body of each vertebra form a vertebral foramen that aligns with those of the other vertebrae to form the vertebral canal, which contains and protects the spinal cord.

**Processes:**
• **Spinous process** – This arises where the two laminae meet and projects posteriorly. It is an attachment site for ligaments and muscles.

• **Transverse processes** – These arise at the lamina/pedicle junctions. They are also attachment sites for muscles and ligaments.

• **Superior and inferior articular processes** – These form facet (zygapophyseal) joints with adjacent vertebrae.

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**IV. Distinguishing Vertebrae from Different Levels**

Although vertebrae share certain common features, this figure illustrates the distinctive features of the cervical, thoracic, and lumbar vertebrae.

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**Cervical vertebrae** are characterized by:

- a small body.
- articular processes in the horizontal plane.
- a foramen in each transverse process.
The first two cervical vertebrae are highly modified. The first cervical vertebra (C1) is the atlas. It looks very different from a typical vertebra because it has neither a spinous process nor a body. The second cervical vertebra (C2), the axis, has a large tooth-like vertical projection called the odontoid process, or dens. The atlas rotates around the odontoid process.

Additionally, C3-C7 cervical vertebrae are characterized by having uncovertebral joints (of Luschka) between bilateral uncinate processes that arise as lips of bone curving superiorly from the lateral borders of the vertebral body. This joint forms the anterior border of the intervertebral foramen and lies medial to the vertebral artery and spinal nerve roots. It is thought that these processes/joints provide stability and mobility by limiting lateral movements of the cervical vertebrae. However, they are clinically important because osteophytes or bony growths can form on these uncinate processes and impinge on the adjacent vertebral artery or spinal nerve.
Lastly, the 7th cervical vertebra has a large spinous process that may be quite long and almost horizontal; it causes a visible elevation in the upper back.

**Thoracic vertebrae** are characterized by:

- spinous processes that point inferiorly.
- articular processes in the coronal plane.
- costal facets on the transverse processes and bodies for articulating with the ribs.

**Lumbar vertebrae** are characterized by:

- a large body.
- articular processes in the sagittal plane.
- large squarish spinous processes.

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**Knowledge Check**

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://wisc.pb.unizin.org/mindmotionanatomy/?p=58#h5p-66
V. Movements of the Vertebral Column

Movement at each intervertebral joint is minimal, but when combined, the range of movement of the entire vertebral column is quite extensive. As shown in the figure, possible movements of the vertebral column include flexion/extension around a transverse axis, lateral bending/flexion around an anteroposterior axis, and rotation around a vertical axis.

Mobility varies at different levels depending on a variety of features including the thickness of the intervertebral discs and the position and orientation of the facet joints. The facet joints have prominent joint capsules. The joints are of the plane variety, allowing only simple gliding movements. The joints are believed to have an important function in maintaining stability of the column during movement. They also play a significant role in limiting unwanted or excessive
movement. An examination of the shape and orientation of the articular processes on an intact vertebral column can provide insight concerning the movements allowed at each segment.

- In the cervical region, the articular surfaces are at an oblique slant between a horizontal and vertical plane. This orientation does not have a significant limiting effect on movement; the cervical region can perform movement in all three planes.
- In the thoracic region, the articular surfaces are oriented in a coronal plane. This orientation limits flexion and extension.
- In the lumbar region, the orientation of the articular surfaces is in a sagittal plane. This orientation markedly limits rotation and lateral flexion between adjacent vertebrae.

A. Cervical Joints

The atlantooccipital joint is specialized for flexion/extension and is often called the “yes” joint. The atlantoaxial joint is specialized for rotation around the odontoid process and is often called the “no” joint. Among the remaining cervical vertebrae, all three types of movement are permitted because of the relatively thick intervertebral discs and somewhat horizontal orientation of the facet joints.

B. Thoracic Joints

In the thoracic region, movement is very restricted because of the thin discs, the frontal direction of the facet joint spaces, the articulation of the ribs to the vertebral column and sternum, and the overlapping spinous processes. As a result, flexion and extension are restricted, but some rotation and lateral bending are possible.

C. Lumbar Joints

In the lumbar region, the discs are thick and the articular processes forming the facet joints are in the sagittal plane, so flexion and extension are extensive. Laxity of the articular facets also permits a small amount of lateral flexion. Rotation is severely limited.

The major movements permitted in each region from cervical to thoracic to lumbar, are summarized as 3-2-1. Cervical movements occur in all three planes; thoracic movements occur in two planes (lateral bending and rotation); lumbar movements occur in one plane (flexion/extension).
Approximate values of ranges of motion between adjacent vertebral bodies based on White and Panjabi, 1990.

Knowledge Check

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://wisc.ph.unizin.org/mindmotionanatomy/?p=58#h5p-68
VI. Ligaments of the Vertebral Column

Several ligaments limit the amount of movement at the intervertebral joints.

1. **Anterior longitudinal ligament**: This strong, broad ligament extends along the entire length of the vertebral column covering the anterior 1/3 of each body. It helps to prevent hyperextension and reinforces the anterior portion of the anulus fibrosus.

2. **Posterior longitudinal ligament**: It is narrower and weaker than the anterior longitudinal ligament. It lies on the anterior wall of the vertebral canal (posterior surface of the vertebral body). It is narrow as it crosses the posterior surfaces of the vertebral bodies but flares out to blend with the anulus fibrosus of the intervertebral discs. However, it incompletely reinforces the anulus fibrosus posteriorly. Consequently, disc herniation occurs in the posterior or posterolateral direction, where the anulus is not reinforced.

3. **Ligamentum flavum**: This ligament links the laminae of adjacent vertebrae along the posterior wall of the vertebral canal. It is unique because of the high content of yellow elastic tissue. The ligamentum flavum is stretched, similar to a rubber band, during flexion of the vertebral column, and its elastic recoil assists in extension of the column.

4. **Supra- and interspinous ligaments**: These attach spinous processes of adjacent vertebrae and prevent hyperflexion. They are usually very weak in humans. During a midline approach for a spinal tap, the needle traverses these ligaments.
VII. Intervertebral Disc Structure and Herniations

Intervertebral discs separate the bodies of adjacent vertebrae. The discs are composed of a peripheral area of fibrocartilage called the **anulus fibrosus**, and a core of gelatinous tissue called the **nucleus pulposus**. The nucleus pulposus is deformable and serves as a shock absorber. The thickness of the disc affects the amount of movement that is possible between vertebrae. The thicker the disc, the greater the movement. Discs are thickest in the cervical and lumbar regions and contribute to the greater degree of movement at these levels.

Intervertebral Discs

Posture
How Posture Changes Affect the Disc

The combination of the high water content of the nucleus pulposus, and the stresses on the disc, due to poor posture and aging, account for herniations of the central nucleus pulposus through the anulus fibrosus. Although discs can herniate in any direction, they usually herniate posteriorly or posterolaterally because the anulus fibrosus is thinner posteriorly and because there are no strong ligaments in this region.

Rupture of the Anulus Fibrosis

The most common sites for herniations are the L4-5 disc or the L5-S1 disc, because the lumbar discs bear more weight. By far the most common herniation seen in the clinic is a straight herniation that occurs in the posterior or inferior direction and is in the central or paracentral region of the disc. If a straight herniation becomes large enough, it can compress the traversing nerve root that exits at the level below the herniation (if L4-L5 straight herniation, L5 spinal nerve can be compressed). Smaller straight hernias can be sources of focal pain. The other type of herniation is one that occurs in the posterolateral or posterosuperior direction and can extend into the intervertebral foramen. Posterolateral herniations are more likely to compress the nerve root that exits at the level of the herniation and cause radicular symptoms associated with nerve root impingement (if L4-L5 posterolateral herniation, L4 spinal nerve can be compressed).
VIII. Back Muscles

The most superficial muscles of the back (trapezius, rhomboids, latissimus dorsi, etc.) are extrinsic back muscles and they work to move the shoulder and arm. We will reflect these muscles in this dissection and study them carefully during the limb dissections. Deep to these muscles are the true or intrinsic back muscles that move the trunk, neck and head. Each of the three intrinsic layers may or may not run the entire length of the axial skeleton.
Extrinsic Back Muscles and Thoracolumbar Aponeurosis

The most superficial layer of the intrinsic back muscles is the *spinotransverse* group. These muscle fibers originate on the midline where they attach to spinous processes of the vertebrae, then pass obliquely in a superolateral orientation before inserting on either transverse processes of cervical vertebrae or the base of the skull. The *spleenius capitis muscle* is an example of this group. When looking at the right and left splenius muscles, their fibers are in a “V” formation. Spinotransverse muscles are located only in the upper thoracic and cervical regions.

The intermediate layer, the *erector spinae* group, includes muscles whose fibers pass vertically between its attachment points. This group is located along the entire length of the vertebral column and includes three subdivisions that can be differentiated based on their bony attachments and positions relative to the midline. The most lateral subdivision is the *iliocostalis*, which originates from the iliac crest and passes superiorly to insert on the ribs. The *longissimus* is medial to the iliocostalis and originates from the sacrum and inserts on the transverse processes of vertebrae. The most medial subdivision is called *spinalis*. Spinalis fibers span between spinous processes of the vertebrae.
The deepest layer, the transversospinae group, passes from lateral to medial as it passes superiorly from its origin on the transverse processes to its insertion on spinous processes. This group can also be further subdivided based on the number of intervertebral joints that are crossed between the origin and insertion. The semispinalis muscle fibers cross 4-6 joints, the multifidus muscles cross 2-4 joints and the rotatores cross 1-2 joints. The transversospinae muscles are found along the entire length of the spinal column.
A large aponeurosis, a large flat tendon, acts as an attachment point for many of the intrinsic back muscles. This aponeurosis is called the **thoracolumbar aponeurosis** and is also an attachment point for extrinsic back muscles. The muscles of this group all extend the vertebral column. However, due to differences in their attachments and the orientation of their fibers, they have different rotational functions.
Overview of the Intrinsic Back Muscles

Actions of the Intrinsic Back Muscles

Muscle Group Working Bilaterally Working Unilaterally
Spinotransverse Extension of neck and head Lateral flexion of neck and head to same side Rotation of neck and head to same side Erector Spinae Extension of back Lateral flexion of neck and head to same side Transversospinae Extension of back, neck and head Rotation of back, neck and head (to opposite side)

Knowledge Check

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://wisc.pb.unizin.org/mindmotionanatomy/?p=58#h5p-71
I. Spinal Cord Functions

As a major component of the central nervous system, and due to its anatomical position between with the peripheral nervous system and brain, the spinal cord serves many functions such as:

1. providing sensory and motor innervation of the trunk and limbs via spinal nerves.
2. mediating rapid responses to stimuli via simple reflex circuits.
3. conducting information to and from the brain for processing via tracts.
II. Sensory Receptors

Information sensed by the body (from the outside world, or from inside the body) is sensed by different receptors. The general sensations of touch, pain, temperature, pressure, chemical, and proprioception are found in the skin and in organs throughout the body. The special senses of olfaction, vision, hearing, balance and taste are found in specific organs in the head. Different sensations have different types of sensory receptors that bring the information to the neurons and nerves that transmit the signals to the spinal cord and brain.

There are many ways to categorize sensory receptors: modality (type of sense it takes in), free or encapsulated endings, fiber diameter, myelination, signaling molecules, conduction velocity, spinal cord tract, etc. This is an expanding area of neuroscience, and new discoveries are ongoing. We will concentrate on general categories of modality and spinal cord tract with very limited discussion of free or encapsulated endings, fiber diameter and conduction velocity.
General Senses

Somatosensation can be divided into the sensation from the skin (cutaneous) and limbs (proprioception).

Cutaneous Sensation

Sensation from the skin can generally be grouped into the sensations of pain, temperature, and touch. **Pain** is sensed by receptors called **nociceptors**. Pain is a very general concept as a modality and can be further subdivided into things like sharp pain, aching pain, itch, and even tickle. The different subdivisions transmit each pain sensation using both medium-diameter (and therefore medium conduction velocity) neurons or through small-diameter (and therefore slow conduction velocity) sensory neurons. **Temperature** is sensed by receptors called **thermoreceptors**. There are separate thermoreceptors for cold and warm temperatures. Similar to nociceptors, thermoreceptors can have either medium- or small-diameter neurons (with similarly corresponding conduction velocities). Nociceptors and thermoreceptors are both types of **free-nerve endings** meaning that the ends of these sensory neurons do not have associated connective tissue structures and are in direct contact with the connective tissue of the dermis. Additionally, both pain and temperature sensation is transmitted through the **anterolateral spinothalamic spinal cord tract**.

**Touch** sensation is sensed through **mechanoreceptors** (literally sensing movement of the surrounding skin relative to objects outside the body). Touch sensation is another general concept and can be broken down into basic subcategories: **crude touch** and **discriminative touch**. Crude touch is a poorly localized sensation that something has been in contact with the skin, but it does not give information about what that something is. Discriminative touch allows for an individual to sense what object is touching the skin (through sensing texture, edges, and shapes) and whether multiple objects or surfaces within close proximity of each other are touching the skin (a good example is touching something with a many points like a pine cone or edge of a key and being able to discern between the individual points). **Pressure** and **vibration** are also aspects of touch that are sensed in the skin, and these are often sense through movement of the skin relative the object touching the skin (think of dragging your hand along a surface and being able to tell if the texture of the surface changes).

While crude touch seems like it should be generally categorized with the other types of touch, its nerve endings, fiber diameter, conduction velocity, and spinal cord tract align with pain and temperature instead. Crude touch is sensed through free nerve endings with medium-diameter fibers and medium conduction velocity. Additionally, crude touch travels through the anterolateral spinothalamic tract.

Discriminative touch, pressure, and vibration are sensed by a variety of sensory receptors with **encapsulated** ends. The ends of the sensory neurons are surrounded by connective tissue structures that transmit a particular type of sensation and can be discerned histologically (Note:
we will not delve into the differences between them, but there is an illustration and video below that will help you appreciate the many different types). The diameters of the neurons for touch, pressure, and vibration are large, and their conduction velocity is fast. The neurons travel to the brain via the **dorsal column** (aka dorsal column-medial lemniscus) **spinal cord tract**.

*Cutaneous receptors from Netter’s Atlas of Neuroscience, 2016*
Proprioception

Proprioception tells the brain and spinal cord the position of the body in space. Proprioception monitors the length of muscles and tendons and the position of joints to give the CNS a sense of whether the body is stationary or in motion and whether the current body position is safe or perhaps in a position that could cause damage to surrounding tissues. For example, think of moving a joint like the shoulder through its full range of motion. If the joint and muscles are moving within a safe range, the proprioceptive sensory receptors will report that to the CNS. However, if the shoulder is extended too far in a particular direction (think of your dog pulling on its leash suddenly and then yanking your arm backwards), your proprioceptive fibers will report that damage to the joint is imminent and the muscles of the arm need to react quickly to prevent injury. Additionally, along with vision and the vestibular system, proprioception is important for maintaining proper balance of the body. If two of the three systems are not working, the brain cannot keep track of the position of the body and whether it is moving or not (this is the basis of having someone close their eyes to test balance).

The sensory receptors that sense proprioception are muscle spindles and golgi tendon organs. Muscle spindles are groups of specialized muscle cells within skeletal muscles. The sensory fibers within muscles spindles sense the stretch of the muscle cells (muscle spindles also have motor fibers). The amount of muscle spindles in a given skeletal muscle can vary. They are most abundant in the postural muscles of the neck, back, and lower limb as well as being abundant in the intrinsic muscles of the hands. Golgi tendon organs are sensory fibers that wrap around the connective tissue in tendons. Golgi tendon organs are very concerned with the amount of force that is being generated by a muscle through a tendon to a bone. The sensory fibers of muscle spindles and golgi tendon organs are both large diameter fibers with very fast conduction velocity.

Proprioceptive fibers travel to different parts of the brain and take two different pathways to get there. Some proprioceptive function travels to the primary somatosensory cortex and becomes conscious. The rest of the proprioceptive function travels to the cerebellum and never reaches a conscious level. Conscious proprioception describes consciously knowing the position of the body without needing to look at that body part (for example, touch your hand to your ear without watching your hand. You know that your hand is moving toward your ear before it touches your ear.) Unconscious proprioception is involved with the many complicated motor coordination systems of the CNS that sense and correct conscious movements so that they match the intent of the movement (for example, unconscious proprioception lets your brain know if your hand was headed more toward your nose or the back of your head as you were going to touch...
your ear. If that happened your brain could help correct the movement to make sure your touch
your ear). Unconscious proprioception also assists with keeping intended movements smooth and
not choppy and at the proper speed (for example, to move your hand smoothly toward your ear
and to not hit yourself hard in the side of the head). Conscious proprioception travels through
the dorsal column spinal cord tract, and unconscious proprioception travels through the dorsal
spinocerebellar spinal cord tract.

Visceral Sensation

Visceral sensation informs the brain and spinal cord about the internal state of the body. Types of
visceraisensory categories are blood pressure, carbon dioxide levels in the blood, hunger, nausea,
bloating. Chemoreceptors, stretch receptors, and nociceptors are the types of sensory receptors
that monitor the internal environment of the body. Pain is not sensed in the organs like it is on
the skin because the same type of nociceptors that carry sharp pain do not exist in the organs.
Instead, pain from organs is generally experienced through the mechanism of referred pain.

Sensory modalities and spinal cord tracts. Adapted from Netter’s Atlas of Neuroscience, 2016.
Special Senses

The special sense receptors of olfaction, vision, hearing, balance, and taste are all highly specialized to their particular sense. Commonalities do exist, however! All of the special senses receptors are found in the head and are associated with cranial nerves. Additionally, all of the special senses are related to a placodes that develop in the head during embryological development. We will discuss the individual special senses as we discuss the cranial nerves and the clinical significance of the different special senses.

Knowledge Checks

III. Spinal Reflexes

Each spinal cord segment gives rise to a pair of spinal nerves (right and left) that innervate both skeletal muscles and a dermatome. Because they all innervate comparable targets, spinal nerves all carry the same combination of components. This diagram of a thoracic spinal nerve illustrates how the dorsal and ventral roots converge to form the spinal nerve, which quickly branches to dorsal and ventral rami. Note the components in each of these structures, and the particular sites of their cell bodies.
We have discussed the structure of a typical spinal nerve to understand how each spinal cord level is related to its segment of the body. We can use these neurons to form the simplest possible circuit in the form of a reflex. In this situation, incoming sensory information causes a rapid motor response. There are many types of reflexes. For example, in the **withdrawal reflex** we withdraw our body from a painful stimulus. Imagine a scenario of touching an iron or a hot stove, or stepping on a sharp object. This reflex is advantageous because the rapid response helps minimize injury. If either the sensory or motor component of the reflex were damaged, this could lead to substantial injury.
The myotactic/stretch reflex is commonly used in clinical practice to test for the integrity of particular nerves. When the provider taps a tendon with a reflex hammer there is a small stretch in the muscle. The sensory axon enters the spinal cord, synapses on a motor neuron that stimulates contraction to return the muscle to its resting length. The patellar reflex is probably the most familiar, but many reflex arcs can be tested in a similar way.
IV. Spinal Cord Tracts

While reflexes are important for quick responses to stimuli, it is also necessary to send signals from the spinal cord up to the brain for analysis, and to send signals from the brain down to the spinal cord to generate the response to that stimulus. This vertical communication depends on massive bundles of axons that ascend or descend within the white matter. These pathways that carry information to and from the brain are called tracts, and each one is located in a particular region of the white matter. Similar to how we describe the gray matter as including dorsal, lateral and ventral horns, the white matter includes the dorsal, lateral and ventral funiculi (rope).

Subdivisions of the Gray and White Matter

Some of the tracts ascend, carrying sensory information to the brain. Other tracts descend carrying motor information from the brain to the spinal cord. When learning the different tracts, notice that their names commonly indicate the position and/or connections of the axons they contain. We will study the subset of the tracts that is labeled on the diagram below.

**Note that the following descriptions portray the major features of each tract. In depth analysis has revealed exceptions and variations on these descriptions. For the purposes of this course's learning objectives and assessments, use the information below**
Sensory/Ascending Tracts

All sensory axons enter the spinal cord through the dorsal root and their cell bodies are in the dorsal root ganglia. After entering the CNS, some sensory axons participate in reflexes, but they also follow specific ascending pathways depending upon the particular kind of sensory information that they transmit. We will discuss three major sensory pathways: the **dorsal columns**, the **lateral spinothalamic tract** and the **dorsal spinocerebellar tract**. As the information ascends in sensory pathways, multiple neurons and synapses are involved. The pathways terminate in different regions of the brain, and may travel entirely on the **ipsilateral** (same) side of the CNS or may cross to the **contralateral** (opposite) side of the nervous system somewhere along the way. As we will see it is very common that sensory information from one side of the body terminates in the contralateral side of the brain, and that motor information from one side of the brain causes contraction of muscles on the contralateral side of the body. As one might imagine, there are exceptions to this rule.
1. Dorsal columns

These tracts are located in the dorsal funiculus of the white matter and carry sensory information concerning **fine touch**, **vibration** and **conscious proprioception**. This
information originates in highly specialized receptors in the skin or in joints. The fine touch sensation allows you to discriminate the texture that you are feeling. Is it glass, sandpaper, or fleece? The vibration information helps you sense a train rumbling by on nearby tracks. The conscious proprioception provides awareness of your body position in space without seeing it. For example, you can close your eyes and successfully touch your nose with your finger.

The dorsal columns contain two parallel tracts called fasciculus cuneatus and fasciculus gracilis. They both carry the same kinds of sensory information, just from different levels of the body. Specifically, the fasciculus cuneatus transmits information from dermatomes C2-T6, while the fasciculus gracilis transmits information from dermatomes T7-S5. Refer to the dermatome map if you need a refresher. This is an example of somatotopy, the extraordinary organization of the nervous system that organizes information related to different body parts in specific locations. All spinal cord tracts exhibit somatotopy in the arrangement of their fibers.
To be conscious of these sensations, the pathway must ultimately ascend to the cerebral area of the brain. Stimulation of a receptor in the periphery initiates an action potential in a **first order neuron**. The information streams centrally, passes through the dorsal root ganglion and enters the spinal cord. The axon enters the dorsal columns and immediately ascends toward higher levels of the CNS. When the axon reaches the **medulla** of the brainstem, it synapses on the **second order neuron** within the **nucleus gracilis/cuneatus**. The axon from this neuron decussates (crosses) to the contralateral side of the brainstem and ascends within a tract called the **medial lemniscus** to the **thalamus**, where it synapses on the **third order neuron**. The axon from the thalamic neuron ascends even further to synapse on a neuron in the **postcentral gyrus** of the parietal lobe. The fine touch, vibration or conscious proprioception information has now reached consciousness and can be processed.

By integrating input regarding fine touch, we can reach into a bag and selectively remove a pencil, a sandwich or set of keys, an ability called **stereognosis**. Integration of fine touch input is also used for an ability called **graphesthesia**, the ability to interpret a shape that is being drawn on the skin.
2. Spinothalamic Tracts/Anterolateral System

This system carries sensory information concerning pain and temperature and crude touch that originates in naked nerve endings in the periphery. It is involved in withdrawal reflexes and ascends to consciousness.

How does this information reach consciousness? Pain, temperature or crude touch stimulation initiates an action potential in a first order neuron. The information streams centrally, passes through the dorsal root ganglion and enters the spinal cord. The axon enters the dorsal horn of the gray matter and synapses on the second order neuron located in one of several nuclei of the dorsal horn, most commonly in the substantia gelatinosa or nucleus proprius. The axon from this neuron decussates (crosses) to the contralateral side of the spinal cord and ascends in a tract in the lateral funiculus of the white matter. Pain and temperature information specifically ascends in the lateral funiculus of the white matter, while crude touch information specifically ascends in the anterior funiculus of the white matter. Due to their locations and connections, the tracts are called the lateral and anterior spinothalamic tracts. For the purposes of this course we will focus on the pain and temperature sensations and the lateral spinothalamic tracts. Axons in these tracts reach the thalamus then synapse on the third order neurons. The axon from this neuron ascends and synapses on a neuron in the cerebral cortex. The pain, temperature and crude touch information has now reached consciousness.
Somatotopy

If we mapped the projections of the dorsal columns and lateral spinothalamic tract to the cerebral cortex we would see somatotopy. Sensory information from particular regions of the body terminate in predictable regions of the cortex. Interestingly, the projections are not proportional as one might expect. Instead, the amount of cortex dedicated to a particular body part is proportional to the sensitivity of that body part. If the body were constructed accordingly, the face, lips, hands, and genitals would be much larger than they are in reality. The distorted represented is called a **homunculus**.

3. Dorsal Spinocerebellar Tract (DSCT)

This sensory pathway is unique in several ways. It involves only two neurons, is entirely ipsilateral, and it terminates in the cerebellum. The DSCT carries information from sensory receptors within skeletal muscles that measure the state and rate of contraction, so called **unconscious proprioception**. This is the sensory input for myotactic stretch reflexes that also helps coordinate motor activity due to its projection to the brain.

When a muscle changes in length, receptors in muscle spindles or the tendon are stimulated. This information enters the spinal cord via the **first order neuron**, whose cell body is in the **dorsal root ganglion**. The location of the **second order neuron** varies depending on the entry point of the first order neuron. **We will simplify the details and focus on the major pathway for the purposes of this course!** The first order neurons enter the dorsal horn of the gray matter and synapse on second order neurons in a region called **Clarke's column**. The second order axons pass into the lateral funiculus of the white matter and ascend to the medulla in the ipsilateral **dorsal spinocerebellar tract**. These axons enter the cerebellum.
through the **inferior cerebellar peduncle** where they synapse on neurons that monitor and modulate muscular contraction.

Motor/Descending Tract

Somatomotor neurons of the ventral horn exit the spinal cord and follow nerves to their target skeletal muscles. These neurons may be stimulated either via reflexes or because we consciously want to execute a movement. That voluntary contraction begins with a neuron in the brain that travels in the major descending spinal cord tract.
Lateral Corticospinal Tract (LCST)

This descending tract allows us to voluntarily initiate contraction. The signal begins in an upper motor neuron that is located in the precentral gyrus of the frontal lobe of the cerebral cortex. Specifically, the signal initiates from a pyramidal neuron, which is diagnostic of the cerebrum. Its axon descends through the brain and brainstem before it enters the upper spinal cord. Collectively, the corticospinal fibers form an enormous bundle of axons that can easily be traced through all levels of the CNS. The fibers descend from the cortex within the internal capsule and enter the midbrain through the crus cerebri. The fibers intermingle somewhat with nuclei of the pons then coalesce in the medulla as the pyramids. This name relates to the origin of the axons. Axons of the pyramidal neurons form the pyramidal tracts/pyramids. The fibers cross to the contralateral side in the decussation of the pyramids as they transition from the medulla to the spinal cord, then continue to descend in the lateral funiculus of the white matter within the lateral corticospinal tract. After reaching the appropriate spinal cord segment the axon turns medially into the ventral horn and synapses on the lower motor neuron. The axon of the lower motor neuron exits via the ventral root then follows a spinal nerve branch to reach its target. This is the same somatomotor neuron that we discussed with our typical spinal nerve.

This motor pathway reiterates a theme that we have seen with two of the three ascending tracts. That is, the brain commonly relates to the contralateral side of the body. Practice drawing the four motor and sensory pathways, including the positions of all axons, cell bodies, tracts, synapses, etc.
Overview of the Lateral Corticospinal Tract; Image modified from Pearson Education
Knowledge Checks

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Challenge yourself to predict the deficits that will result from injuries in these pathways. These are some questions to consider:

- Following damage to the ascending tracts, what are the deficits and the laterality of the deficits (is the deficit ipsi or contra to the injury)?
- Following damage to the major descending tract what are the deficits? Differentiate upper and lower motor neuron syndromes. What are the signs? Is the deficit ipsi or contra to the injury?
Cranial Cavity, Meninges and Vasculature

KAREN KRABBENHOFT, PHD

This chapter includes information on:

- Cranial Cavity
- Cranial Meninges
- Intracranial Hematoma
- Cranial Fossae and Nerves
- Ventricular System and Cerebrospinal Fluid

I. Cranial Cavity

The body contains several cavities that enclose internal organs. The ventral body cavities include the pleural, pericardial and peritoneal cavities, which enclose and protect the thoracic and abdominopelvic organs. The dorsal body cavity includes the cranial and vertebral cavities, which enclose and protect the brain and spinal cord of the central nervous system.
The main purpose of the cranial cavity is to provide protection for the brain. To accomplish this, the skull base conforms to the shape of the brain to better support this vital organ. When examining the skull base from a superior view, its irregular contours are apparent. There are three major concavities, or fossae, in the skull base that contain major parts of the brain. The anterior cranial fossa houses the frontal lobes of the cerebrum and has the frontal, ethmoid and lesser wing of the sphenoid bones as walls. The middle cranial fossa houses the temporal lobes of the cerebrum and has the temporal, parietal and greater wing of the sphenoid as walls. The posterior cranial fossa has the occipital, some sphenoid and some temporal bone as walls and the foramen magnum at its center.
II. Cranial Meninges

In addition to being encased by the skull for protection, the brain is surrounded by several tissue and fluid layers that minimize the risk of injury. These are the cranial meninges and associated spaces.
Cranial Meninges

Dura Mater (“tough mother”)

The outermost layer of the meninges is the dura mater. In the cranial cavity, the dura mater has two layers. The outer periosteal dura fuses to the internal surface of the skull bones and forms the periosteum of the skull. As a result there is no epidural space. The inner meningeal dura is in closer proximity to the brain. Recall that within the vertebral cavity the dura mater and periosteum are separated anatomically resulting in a significant epidural space filled with adipose tissue. This allows movement between the vertebral column and spinal dura. Such movement is absent between the cranial dura and skull.

Dural Reflections

Usually the periosteal and meningeal layers are fused to each other, but in select areas, they separate to form three prominent dural reflections. The three major dural reflections are the falx cerebri, tentorium cerebelli and falx cerebelli. These flaps of meningeal dura separate major parts of the brain from each other and help stabilize the position of the brain.
Dural Venous Sinuses

The cranial dura mater is also specialized to envelop and reinforce enlarged veins that drain blood from the brain. These dural venous sinuses are lined by endothelium, but otherwise do not have the typical muscular and connective tissue layers in their walls. Instead, their structural support is due to the surrounding dura mater. Similar to the dural reflections, the dural venous sinuses form in specific locations where the layers of dura separate. The normal pattern of dural sinuses is illustrated below, with the major venous sinuses including the superior sagittal, inferior sagittal, straight, transverse, jugular and cavernous sinuses. The superior and inferior sagittal sinuses are located within the superior and inferior margins of the falx cerebri, respectively. The straight sinus is in the midline at the intersection of the falx cerebri and tentorium cerebelli. Blood flows posteriorly in these three sinuses toward a common point called the confluence of sinuses. From here, blood flows toward the right or left through the transverse sinuses, continues through the sigmoid sinuses and ultimately flows through the jugular foramina where it enters the internal jugular veins. The sinuses do not contain valves, so blood flow can be reversed depending on the pressures. Several of the venous sinuses are located immediately deep to the skull and create impressions on the internal surfaces of the bones. Look for those impressions on a skull.
Veins on the surface of the cerebral hemispheres drain to the dural venous sinuses. Those at the top (superior cerebral veins) enter the superior sagittal sinus; the inferior and anterior veins enter the cavernous sinus via the sphenoparietal sinus; the inferior and posterior veins enter the transverse sinus at the base of the skull. The internal cerebral veins unite to form the great cerebral vein that empties directly into the straight sinus. This sinus receives venous blood from the inferior surface of the cerebral hemispheres and from the brainstem. **The take-home message is that venous blood from the outer surface of the hemispheres drains superiorly into the superior sagittal sinus; inferiorly and anteriorly into the cavernous sinus; and posteriorly and inferiorly into the transverse sinus. The deep cerebral veins empty into the straight sinus.**

The dural venous sinuses have anastomoses with extracranial veins. In particular, the cavernous sinus is connected to the facial vein via the angular and ophthalmic veins. Because these veins are not valved, blood from the face may either drain inferiorly through the facial vein or may flow through the anastomoses to the cavernous sinus. The reversibility of this venous flow allows for a rare but dangerous situation when infectious material from the face (i.e., by squeezing pimples in the “danger area” around the upper lip to side of the nose) is carried into the cavernous sinus. Thrombosis of the cavernous sinus and subsequent meningitis may occur, particularly because blood flow through this sinus is very slow. Serious neurological damage or even death may result. Suppuration (pus!) in the upper nasal cavities and paranasal sinuses may also lead to septic thrombosis of the cavernous sinuses, with subsequent meningitis.

**Anastomoses of the Cavernous Sinus**

The arachnoid lies close to the dura mater in living tissue although there is a small amount of fluid in the subdural space that separates them. The arachnoid (Gr. arachnoeides, cobweb like) has two
components: a layer in contact with the dura mater, and a system of trabeculae connecting it with the pia mater. The portion in contact with the dura is composed of flattened cells bound together by extensive occluding junctions. This portion of the arachnoid forms a selective barrier called the arachnoid barrier. This barrier prevents harmful substances from migrating from the dura or extracerebral capillaries and entering the space internal to the arachnoid called the subarachnoid space. The subarachnoid space is filled with cerebrospinal fluid, and the pressure of the fluid holds the arachnoid against the dura mater. The second component of the arachnoid is formed by the delicate trabeculae that interconnect and pass through the subarachnoid space to attach to the pia mater. Blood vessels that travel in the subarachnoid space are supported by the arachnoid trabeculae. At the superior sagittal sinus, the arachnoid penetrates the dura mater and extends into the sinus as the arachnoid granulations/villi. These granulations or villi serve as one way valves to return CSF to the circulatory system.

Pia Mater

The pia mater is attached to the brain and is not as thick as it is around the spinal cord where it forms the denticulate ligaments and filum terminale. Unlike the arachnoid, which follows the dura mater, the pia mater follows all the contours of the brain.

At certain places where the brain contour changes abruptly, the space between the pia and the arachnoid is enlarged to form a cistern. Cisterns are simply dilated subarachnoid spaces and consequently they are filled with CSF. Many of the cisterns, including the largest one, the cisterna magna (cerebellomedullary cistern), can be seen inferior to the cerebellum in a midsagittal view of the brainstem to the right.
Circulation of Cerebrospinal Fluid
III. Epidural, Subdural and Subarachnoid Hematoma

Examining the internal surface of the skull, one can see branches of the middle meningeal artery. This artery supplies blood to the dura mater and bones of the cranial vault. It enters the skull through the foramen spinosum and its branches occupy the grooves on the cranial surface of the bones it supplies.
Epidural Position of Meningeal Arteries Erodes the Internal Surface of the Skull
Fractures of the skull, particularly in the temporal region where the bone is thin, can tear the middle meningeal artery. This results in **arterial bleeding** within the skull, between the bone and dura mater. Arterial pressure is about 13 times greater than pressure of the cerebrospinal fluid surrounding the brain. The pressure of this bleeding separates the dura from the inner surface of the bone, allowing blood to accumulate in this position. The blood forms an **epidural hematoma** and adds mass to the cranial cavity where there is no room for it. The increased pressure can interrupt brain function and cause death by forcing the brainstem out the foramen magnum and compressing vital respiratory and cardiovascular centers of the brainstem. Consciousness is lost soon after the injury and treatment requires rapid intervention to remove the accumulated blood and repair the bleeding vessels.
**Epidural Hematoma**

*Subdural hematoma* is venous bleeding into the subdural space. This can result from a blow to the head. The shearing forces created by the blow may tear the superior cerebral veins where they penetrate the dura mater to enter the superior sagittal sinus. The blood in the torn vein, and the blood in the sinus, will seep into the subdural space and cause it to expand. Blood may also access the subarachnoid space in this manner causing a *subarachnoid hematoma*, but the most common cause of blood in the subarachnoid space is due to rupture of cerebral veins or arteries on the surface of the brain. Like epidural bleeding, subdural bleeding adds mass to the cranial cavity but because venous pressure is low, the onset of unconsciousness may be greatly delayed. When subdural bleeding is suspected in a conscious patient, the patient should be carefully observed in case consciousness is lost. Treatment requires surgical intervention to remove the clotted blood. Many cases of intracranial venous bleeding are probably not diagnosed. The blood clot is gradually resorbed, leaving a scar on the inner surface of the dura mater.
Subdural Hematoma

Knowledge Check

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IV. Cranial Fossae and Nerves

After removing the brain, we can examine the skull base more carefully. Recall that there are three depressions on the floor of the skull, the anterior, middle and posterior cranial fossae, that provide physical support and protection for the brain. Particular foramina perforate the skull in each cranial fossa. These openings allow vessels and nerves to enter or exit the cranial cavity.

The fossae, foramina and their contents are tabulated here.
**Cranial Fossa** | **Major Openings** | **Contents**
--- | --- | ---
**Anterior** | cribriform plate | CN I
| optic canal | CN II
| superior orbital fissure | CNs III, IV, V1, VI
| foramen rotundum | CN V2
| foramen ovale | CN V3
| foramen spinosum | middle meningeal artery
| carotid canal | internal carotid artery
**Middle**
| internal acoustic meatus | CNs VII, VIII
| jugular foramen | CNs IX, X, XI
| hypoglossal canal | CN XII
| foramen magnum | spinal cord and vertebral arteries

Inspection of the skull base reveals where each cranial nerve pierces the dura, which is NOT necessarily where the nerve exits the skull. **The majority of the cranial nerves (III through XII) pierce the dura mater in the posterior cranial fossa.** This is because the portion of the brainstem from which these nerves arise lies below the tentorium cerebelli (that is present on the left side of the figure and cut away on the right). Cranial nerves VII through XII enter their foramina directly at the sites where they pierce the dura mater. Thus, these nerves both pierce the dura mater and exit the skull from the posterior cranial fossa. By contrast, cranial nerves III through VI pierce the dura in the posterior cranial fossa, then run an epidural or intradural course to the middle cranial fossa to where they ultimately exit the skull. Upon inspection of the middle cranial fossa with the dura still intact (left side of the Netter figure) note that the foramina are not visible. The structures that traverse these foramina (superior orbital fissure, rotundum, ovale, carotid canal) run an epidural course for at least a portion of their intracranial route.
It is important to understand that when cranial nerves enter the dura in their course out of the cranial cavity they become “bound down” or tethered by the dura. Thus in cases where there is a change in intracranial pressure that shifts the position of the brain, traction stresses can be placed on the nerves. In addition, because the nerves adhere to the bone along their intradural course they are susceptible to injury in the event of fractures. The cranial nerve with the longest intradural course is CN VI. Another factor that contributes to nerve injury is simply that the nerves with the longest intracranial course are most susceptible to injury from disease processes etc. Cranial nerves III–VI have long intracranial courses because they leave the brainstem in the posterior fossa but don't leave the skull until they reach the middle cranial fossa.

Cavernous Sinus

All the cranial nerves with this curious intradural course pass through the cavernous sinus on their way to exit points in the middle cranial fossa. The internal carotid artery also traverses this venous...
sinus on its circuitous route into the cranial cavity. As such, pathology within the cavernous sinus can disrupt function of all these structures. For example, formation of an arteriovenous communication between the internal carotid artery and the cavernous sinus could increase pressure in the sinus. This may result from various conditions such as a penetrating wound, a fracture of the base of the skull or a ruptured aneurysm of the internal carotid artery. Ligation of the internal or common carotid artery has sometimes been performed in these cases. In addition to impeding flow through the carotid artery and depriving its target tissues, cranial nerves III, IV, V1, V2 and VI pass through the sinus, and their targets could be denervated.


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**Knowledge Checks**

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V. Ventricular System and Cerebrospinal Fluid (CSF)

Recall that the CNS develops as a tube and although it becomes highly distorted through differential growth, its original lumen persists in the form of the ventricular system, a continuous series of fluid filled chambers.

![Development of the CNS](image)
Each cerebral hemisphere contains a **lateral ventricle**. This is a large C-shaped chamber that follows the contour of the cerebrum. Both lateral ventricles connect via **interventricular foraminae** to a single, midline **third ventricle**, which is situated between the thalamic hemispheres. From here, the ventricular system continues as the **cerebral aqueduct** within the midbrain, which expands as the **fourth ventricle**, positioned between the pons and cerebellum. The fourth ventricle is continuous with the central canal of the spinal cord, and the subarachnoid space via three minute apertures.
The ventricles are not simply embryologic carryovers, but serve a critical protective function for the brain. There is specialized tissue in the lining of each ventricle, the choroid plexus, that produces cerebrospinal fluid, (CSF). CSF fills both the ventricles and subarachnoid space and acts as a shock absorber. Being suspended in fluid, this effectively decreases the brain weight. The choroid plexus is unique because in these regions, there is no blood brain barrier, so plasma can leak from the capillary beds and accumulate in the ventricles. We produce about 500 ml CSF/day, with the ongoing production causing flows through the ventricular system. Some of the CSF leaks out of the cranial and spinal nerves, some moves down into the spinal column, but most circulates upward to the midline where it returns to the circulatory system through arachnoid villi or granulations projecting into the superior sagittal sinus.
Circulation of CSF. Image modified from Netter Presenter.
Hydrocephalus

With such a dynamic system of CSF production, circulation and resorption, sometimes there are problems. Any kind of pathology that results in over-accumulation of CSF can lead to hydrocephaly. This may be congenital or may be acquired later in life. A few select conditions that could lead to hydrocephalus include obstruction due to underlying anatomy, a tumor or inflammation related to an infection.

There are two major classes of hydrocephalus based on whether or not the fluid can pass from the ventricles and into the subarachnoid space. With noncommunicating hydrocephalus the CSF is trapped within the ventricular system. With communicating hydrocephalus the fluid cannot exit the subarachnoid space. We have a stunning example of this in the prosection tank.

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Anatomy of the Orbit

ELISE DAVIS, PHD

Chapter Sections

Structure of the Eyeball
- Fibrous Layer of the Eye: Sclera & Cornea
- Vascular Layer: Choroid, Ciliary Body, & Iris
- Neural (Inner) Layer: Retina

Bony Orbit and Associated Foramina

Fascia of the Orbit

Structure of the Eyelids

Lacrimal Gland

Extraocular Muscles
- Movements of the Eye
- Muscle Function and Innervation
  - Table: Extraocular Muscles
- Testing Extraocular Muscles
  - Table: Extraocular Muscle Testing
  - Table: Actions & Test Positions of Extraocular Muscles

Innervation of the Orbit
- Branchiomotor Innervation (to Eyelid): Facial Nerve (VII)
- Special Somatosensory Innervation: Optic Nerve (II)
- General Somatosensory Innervation: Ophthalmic Division of Trigeminal Nerve
  - Corneal (Blink) Reflex
- Somatomotor Innervation: Oculomotor (III), Trochlear (IV), and Abducens (VI) Nerves
- Autonomic (Visceromotor) Innervation: Oculomotor (III) and Facial (VII) Nerves + Sympathetics
  - Oculomotor Nerve & Ciliary Ganglion: Targets within the Eyeball
    - Pupillary Light Reflex
  - Facial Nerve and Pterygopalatine Ganglion: Target outside the Eyeball
    - Sympathetics
  - Table: Nerves of the Orbit

Ophthalmic Artery
- Arterial Anastomoses between Internal and External Carotid Arteries
- Venous Drainage of the Orbit (& More Anastomoses)
The bony structure and fascia of the orbit provide protection for the eyeball and its associated structures. The eyeball is also protected by the eyelids and by secretions from the lacrimal gland. Extraocular muscles originate from the walls of the orbit and insert on the eyeball and move the eye within the orbit. Abnormal eye movements may indicate cranial nerve damage.

Orbital contents develop from multiple embryonic primordia, so are innervated by multiple cranial nerves: II, III, IV, V1, VI and VII. Sympathetic fibers also innervate targets in the orbit. The ophthalmic artery provides blood to the orbital contents, but there are multiple venous drainage pathways.

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**Structure of the Eyeball**

Though most of our focus in the anatomy dissection will be on the orbital contents, it is important to understand that all of the structures within the orbit exist to move, control, and protect the eyeball, a critical part of our sensory system. The number of structures that are devoted to the protection and maintenance of the eyeballs is testament to the importance of the eyes to humans. The eyeball is a highly developed sensory organ containing photoreceptor cells which convert light into electrical signals. Information sensed by the retina is crucial for both vision and for diurnal rhythms.

The eyeball (aka *bulb* or *globe*) consists of three layers of structures, from superficial to deep:

- Fibrous Layer
- Vascular Layer
- Neural (Inner) Layer
Fibrous Layer of the Eye: **Sclera & Cornea**

The outermost layer of the eyeball is a thick layer of regularly arranged collagen fibers. Most of the eyeball is covered with the **sclera**, the “white of the eye.” The most anterior part of the fibrous layer is covered by the **cornea**, which is transparent (due to the crystalline arrangement of its collagen fibers). The cornea is avascular and must get its nourishment from tears on the superficial side and the fluid within the anterior eyeball (*aqueous humor*) on the deep surface. The cornea is highly innervated by sensory fibers from the ophthalmic division of the trigeminal nerve (V$_1$). Sensory stimulation of the cornea causes a **blink reflex**. The motor part of this reflex is mediated by the facial nerve (cranial nerve VII) which innervates the orbicularis oculi muscle, the only muscle which closes the eye. ([See below for more about the blink reflex.](#))
The middle layer of the eyeball contains massive amounts of blood vessels. There are three parts of this layer which are continuous with each other from posterior to anterior. The posterior 5/6 of the vascular layer is the choroid, a highly vascularized layer of tissue which also contains melanocytes. The extensive blood vessels in this layer help to dissipate the heat generated by the light entering the eyeball. The pigmented melanocytes absorb stray light and prevent overstimulation of the retina.

Moving anteriorly, the vascular layer is specialized to form the ciliary body, a little bulge of tissue that encircles the lens of the eye and contains a smooth muscle, the ciliary muscle. The ciliary body is connected to the lens by fibrils. When the ciliary muscle contracts, the tension on those fibrils is released, allowing the elastic lens to bulge. Contraction of the ciliary muscle (and the resulting changes in shape of the lens) are critical to accommodation for seeing objects close-up. As people age, the lens becomes less flexible and it becomes harder to focus on closer objects (presbyopia). The ciliary muscle is innervated by parasympathetic fibers from the oculomotor nerve (cranial nerve III).
The most anterior part of the vascular layer is the **iris**. The amount of melanin in the iris determines the color of the eye. There is an opening in the middle of the iris, the **pupil**, through which light enters the eye. Changes in the size of the pupil regulate the amount of light that gets to the photoreceptors of the retina. Two different smooth muscles in the iris control the size of the pupil: the pupillary dilator and the pupillary sphincter.

- **The pupillary dilator** consists of radially-oriented smooth muscle fibers which pull the pupil open when they contract. It is innervated by sympathetic fibers which originate in the superior cervical ganglion.
- **The pupillary sphincter** has circularly-arranged smooth muscle fibers which will make the pupil smaller when they contract. It is innervated by parasympathetic fibers from the oculomotor nerve (cranial nerve III).

The size of the pupil is determined by a balance between the sympathetic and parasympathetic inputs to the muscles within the iris.
Neural (Inner) Layer of the Eye: *Retina*

The *retina* connects to the brain via the optic nerve (cranial nerve II). During development, both the retina and the optic nerve are formed as an outgrowth of the diencephalon. Light travels through the pupil and enters the eyeball to reach the photosensitive retina. The retina consists of a *pigmented outer layer (pigment epithelium)* and an *inner neural layer*, made of a series of three types of neurons which convert light stimuli into electrical signals. From external to internal, the three layers of the neural retina are *photoreceptors (rods and cones)*, *bipolar cells*, and *ganglion cells*. 
The pigment epithelium is the outermost layer of cells in the retina and is just deep to the choroid layer.

The photoreceptor layer of neurons lies within the pigment epithelium. Light must pass through the other layers of the neural retina (ganglion cells and bipolar cells) to reach the photoreceptors. Once the rods and cones are stimulated with light, the electrical signals travel in the opposite direction from the light. Electrical signals travel from the photoreceptors to the bipolar cells to the ganglion cells. The axons of the ganglion cells leave the eyeball as the **optic nerve** (cranial nerve II).

There are two landmark structures in the posterior retina that are crucial to an eye exam: the optic disk and the macula lutea/fovea centralis. The **optic disk** is the part of the retina through which the axons of the ganglion cells exit the eyeball to form the optic nerve (cranial nerve II). There are no photoreceptors in this part of the retina, so there is no vision from this part of the retina. This region is also called the **blind spot**.
The **macula lutea** (literally ‘clear spot’) is the part of the retina that is aligned with the anteroposterior axis of the eye. The **fovea centralis** is the central part of the macula lutea. The fovea centralis contains only cones and is the area of the retina with the highest visual acuity.

The **macula lutea** is aligned with the anteroposterior axis of the eyeball. Its center, the **fovea centralis**, is the region of the retina with the highest visual acuity. Modified from Gilroy et al., *Atlas of Anatomy, 2nd Edition*, Thieme Medical Publishers, 2012.
Video overview of the anatomy of the eye

The optic disk, macula lutea, and fovea centralis are all visible in an eye examination using an ophthalmoscope. Below is a great summary of an ophthalmoscopic exam:

KNOWLEDGE CHECKS

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Bony Orbit and Associated Foramina

The orbits are bony chambers in the skull, lateral to the nasal cavity and the ethmoid sinuses, inferior to the cranial cavity, and superior to the maxillary sinuses. Though relatively small in size, the space within the orbit is filled with structures and an incredible amount of fat. In addition to the eyeball itself, the orbit contains numerous muscles, nerves, blood vessels, and the lacrimal gland.
The orbit is formed by seven different bones and is shaped like a four-sided pyramid. The medial wall of the orbit is made up mostly of the very thin ethmoid bones, with contributions from the maxilla, lacrimal, and palatine bones. The lateral wall of the orbit is formed by the frontal, sphenoid, and zygomatic bones. Though the medial walls of the two orbits are parallel to each other, the lateral walls run from medial to lateral (which has functional implications for the extraocular muscles).
The medial walls of the orbits are parallel to each other. The lateral walls run from medial to lateral within the skull. This affects the function of the extraocular muscles. Modified from Gilroy et al., Atlas of Anatomy, 2nd Edition, Thieme Medical Publishers, 2012.

The roof of the orbit is formed by the frontal bone. The floor of the orbit is formed by the zygomatic bone and maxilla. Superficially, the maxillary, frontal and zygomatic bones form the rim of the orbit. The superior, lateral and inferior rims of the orbit are made up of dense bone, which generally is able to withstand the force of trauma very well. However, trauma to the medial rim of the orbit can inflict significant damage because the bones are not as dense and fractures can occur.

The most serious damage to the orbit can occur as a result of frontal trauma which fractures the floor of the orbit. These can be “blowout” fractures in which contents of the orbit herniate inferiorly into the maxillary sinus. These types of fractures can result in damage to the infraorbital nerve (a branch of V2) or entrapment of the inferior rectus muscle and/or fasciae of the orbit. In cases where the muscle or fascia is entrapped, vertical movements of the eye maybe limited and/or painful.
The orbit has many openings to other regions of the skull through which neurovascular structures travel.

Bones of the orbit, anterior view. Modified from Netter Presenter, http://netterreference.com.ezproxy.library.wisc.edu/content/netter_atlas_6e/?task=home

• Two foramina connect the orbit to the cranial cavity (posterior to the orbit).
  ◦ **Optic canal**: This hole in the sphenoid bone transmits the optic nerve (cranial nerve II), along with the meningeal coverings of the nerve, and the ophthalmic artery, a branch of the internal carotid artery.
  ◦ **Superior orbital fissure**: This large, diagonal opening in the sphenoid bone transmits cranial nerves III, IV, VI, the ophthalmic division of the trigeminal nerve (V₁), and the ophthalmic veins.
• One opening connects the floor of the orbit with the pterygopalatine fossa (inferior to the orbit and posterior to the maxilla).
  ◦ **Inferior orbital fissure**: This elongated hole in the orbital floor transmits the infraorbital branch of the maxillary division of the trigeminal nerve (V₂).
• Two small openings transmit cutaneous branches of the trigeminal nerve to the surface of the face.
  ◦ **Supraorbital foramen or notch**: Either a hole or a notch in the frontal bone, this opening transmits the supraorbital nerve, a branch of V₁, and the supraorbital branch of the ophthalmic artery to the surface of the face.
  ◦ **Infraorbital foramen**: This opening is in the maxilla and transmits the infraorbital branch of V₂ to the surface of the face.
• Several small openings connect the orbit with the ethmoid sinuses and nasal cavity.
  ◦ **Ethmoidal foramina**: Small openings between the frontal and ethmoid bones on the medial wall of the orbit transmit branches of V₁ from the orbit into the ethmoid sinuses and nasal cavity.

Foramina which connect the orbit to other areas of the skull.
Modified from Netter Presenter,
http://netterreference.com.ezproxy.library.wisc.edu/content/netter_atlas_6e/?task=home
**Fascia of the Orbit**

There are many impressive layers of fascia surrounding the eyeball and associated structures within the orbit, in addition to a truly astonishing amount of fat. There are four layers of fascia in the orbit. From superficial to deep, they are: **periorbita, optic nerve sheath, bulbar fascia, and fascia of the extraocular muscles.**
The periorbita is immediately deep to the bony orbit. This very tough layer of connective tissue is continuous with the periosteal dura mater of the cranial cavity. It enters the orbit through the optic canal and encloses the entire pyramidal orbital space.

The optic nerve sheath is continuous with the meningeal dura mater of the cranial cavity. It lines the external surface of the optic nerve as the nerve travels through the orbit to the eyeball. At the back of the eyeball, the meningeal dura becomes continuous with the sclera, the outer white layer of the eye.

Like the meningeal dura mater in the cranial cavity, the optic nerve sheath encloses arachnoid...
and pia mater, and subarachnoid space, all the way to the back of the eyeball. This subarachnoid space around the optic nerve contains cerebrospinal fluid (CSF) that is continuous with the CSF around the brain. Clinically, this is particularly relevant. If CSF pressure increases intracranially, the subarachnoid space at the back of the eyeball will bulge. This is visible with an ophthalmoscope as swelling around the optic disk and is called papilledema, or a choked disk.

The four layers of fascia in the orbit seen in a transverse section. Modified from Netter Presenter, [http://netterreference.com.ezproxy.library.wisc.edu/content/netter_atlas_6e/?task=home](http://netterreference.com.ezproxy.library.wisc.edu/content/netter_atlas_6e/?task=home)

The **bulbar fascia** (or **bulbar sheath**) is a cup-shaped fascia which surrounds the sclera of the eyeball, separating it from the rest of the orbital contents. It is fused to the optic nerve sheath posteriorly and the sclera and muscular fascia anteriorly. There is a space between the sclera and the bulbar fascia, the **episcleral space**. When the eyeball moves, it moves within the bulbar fascia and episcleral space. (The eyeball moves, but the bulbar fascia does not move.)

The **fascia of the extraocular muscles** surrounds each of the skeletal muscles within the orbit; it is the **epimysium** of those little muscles. This fascia attaches each muscle to the sclera of the eyeball. Fibrous expansions of this fascia also attach to the periorbita, which helps to hold the eyeball in place within the orbit.

**KNOWLEDGE CHECK**

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Anatomy of the Orbit | 241
Structure of the Eyelids

The eyelids are moving folds of skin that protect the eyes from injury and are crucial for keeping the cornea moist by pushing tears across the surface of the eyeball. From superficial to deep, the structures of the eyelids are: thin skin and subcutaneous tissue, three muscles which move the superior eyelid, tarsal plates, and conjunctiva.

Eyelids

There are three muscles within the upper eyelids. The most superficial is the orbicularis oculi muscle, which encircles the orbit (it is essentially a sphincter of the eye). Orbicularis oculi is a muscle of facial expression, a skeletal muscle innervated by the facial nerve (cranial nerve VII). It is the only muscle which closes the eyelid and is critical for spreading tears from the lacrimal gland across the surface of the eye.

Two muscles open the upper eyelid, levator palpebrae superioris (a skeletal muscle) and the superior tarsal muscle (a smooth muscle which interdigitates with levator palpebrae superioris). Levator palpebrae superioris inserts into the tarsal plate of the eyelid and is innervated by somatomotor fibers of the oculomotor nerve (cranial nerve III). Levator palpebrae superioris is the
most superior muscle within the orbit, and is the first muscle that you see in a dissection of the orbit from the cranial cavity.

The superior tarsal muscle is innervated by sympathetic nerve fibers from the superior cervical ganglion. It is responsible for maintaining an open eye involuntarily. Damage to the superior cervical ganglion results in an ipsilateral loss of function of the superior tarsal muscle, which causes drooping of the eyelid (ptosis), as well as a flushed face, a constricted pupil, and loss of sweating (known as Horner’s syndrome).

The superior and inferior tarsal plates form the main structural support of the eyelids, giving them stiffness and providing an attachment point for muscles which elevate the eyelid.

The conjunctiva is a moist mucous membrane that lines the inner surface of the eyelids (palpebral conjunctiva) and reflects onto the anterior surface of the eye (bulbar conjunctiva). The bulbar conjunctiva attaches to the eye close to the periphery of the cornea. The reflection of the conjunctiva from the eyelids onto the eye creates the superior fornix and inferior fornix. This continuity of the conjunctiva is why a contact lens cannot slip behind your eye. When the eyelids are closed, the compartment in front of the eye is called the conjunctival sac. While the palpebral conjunctiva is a very vascular tissue that gives the eyelids their deep pink appearance, the bulbar conjunctiva is usually transparent, so you can see the sclera through it. However, if the blood vessels in the bulbar conjunctiva dilate, as with allergy or infection, the sclera (whites) of the eyes look “bloodshot.”

Lacrimal Gland

The lacrimal gland is in the superolateral part of the orbit. Tears are secreted by the gland, stimulated by parasympathetic fibers of the facial nerve (cranial nerve VII). With every blink of the eyelids, tears are washed across the front of the eyeball toward the medial part of the orbit. At the medial part of the eye, there are two holes (puncta) which lead to the lacrimal sac and nasolacrimal...
duct, a tube that drains into the inferior nasal meatus within the nasal cavity. (That's why your nose runs when you cry.)

Tears are absolutely necessary to nourish and maintain the health of the cornea. The cornea is avascular and depends upon tears for nourishment and waste removal on its superficial surface (and upon the aqueous humor of the eye on its deep surface). People who have facial nerve (cranial nerve VII) damage, and cannot close their eyelid, are at risk for permanent corneal damage since they lack the ability to spread tears across the cornea. As a substitute, these people have to be vigilant about putting drops in their eyes and/or taping the affected eyelid closed to prevent corneal blindness.

Diagram of the lacrimal gland in the superolateral orbit. Tears are pushed across the surface of the eye during blinking and drain into the nasolacrimal duct which connects the orbit and the nasal cavity. Modified from Netter Presenter, http://netterreference.com.ezproxy.library.wisc.edu/content/netter_atlas_6e/?task=home

KNOWLEDGE CHECK
Extraocular Muscles

There are three classes of muscles in the orbit, two of which have been discussed previously in this chapter:

- **Muscles located within the eyelids** open and close the eyelids, protecting the eyes from injury and from drying (levator palpebrae superioris, superior tarsal muscle, and orbicularis oculi).
- **Muscles located within the eyeball** change the shape of the lens (ciliary muscle) or regulate the amount of light that reaches the retina (pupillary sphincter and pupillary dilator).
- **Muscles which attach to the walls of the orbit and to the eyeball** (six extraocular muscles) move the eyeball within the orbit and change the direction of gaze.

![Extraocular Muscles](https://netterreference.com.ezproxy.library.wisc.edu/content/netter_atlas_6e/?task=home)

Lateral view of extraocular muscles within the orbit. Notice that levator palpebrae superioris (which moves the eyelid, not the eyeball) is the most superior muscle within the orbit. Modified from Netter Presenter, [http://netterreference.com.ezproxy.library.wisc.edu/content/netter_atlas_6e/?task=home](http://netterreference.com.ezproxy.library.wisc.edu/content/netter_atlas_6e/?task=home)
Four of the extraocular muscles are relatively straight (and straightforward). They originate from a common tendinous ring, which surrounds the optic canal in the posterior orbit. These are the superior rectus, inferior rectus, medial rectus, and lateral rectus muscles. All four of these muscles pull posteriorly on the eyeball.

There are two other muscles, superior oblique and inferior oblique, which have slightly different orientations within the orbit. Superior oblique originates in the posterior part of the orbit and travels anteriorly along the medial side of the orbit. In the superomedial orbit, it loops through a fibrocartilaginous pulley (the trochlea), and then attaches to the superior surface of the eyeball from the front. Because of this pulley system, superior oblique pulls the top of the eyeball anteriorly. Inferior oblique is the only extraocular muscle which originates from the anterior part of the orbit. It originates inferomedially within the orbit and attaches to the inferior surface of the eyeball. Like superior oblique, inferior oblique pulls anteriorly on the eyeball.

Movements of the Eye

Movements of the eye are described with respect to the three cardinal axes: horizontal, vertical, and anteroposterior. The best way to think about the axes is to imagine a stick stuck through the
eyeball. Then visualize how the eyeball could move by spinning around the stick. Two movements are possible around each axis, as shown and described below.

Around the **horizontal axis**, the eyeball can either roll up (**elevate**) or roll down (**depress**), like when you're watching someone bounce on a trampoline.

Around the **vertical axis**, the eyeball can move away from the nose (midline) (**abduction**) or toward the nose (midline) (**adduction**), like when you're watching a tennis match.

Around the **anteroposterior axis**, the top of the eyeball can roll toward the nose (**medial rotation/intorsion**) or away from the nose (**lateral rotation/extorsion**). These movements are defined by the movement of the top of the eyeball and are important for keeping your eyes level, even as you tilt your head from side to side. Try it! If you tilt your head to the right, the image you see doesn't start to seem 'tilted' until your head is bent very far laterally. Movements of your eyeballs around the anteroposterior axis compensate for the tilting of your head.

**Axes of movements of the eyeball. Modified from Wilson-Pauwels et al., Cranial Nerves: Function & Dysfunction, 3rd Edition, [https://bmc.med.utoronto.ca/cranialnerves/](https://bmc.med.utoronto.ca/cranialnerves/)**
Muscle Function and Innervation

Here is a link to the worksheet used in the Eye Muscle Analysis Workshop to help you learn to actions of the extraocular muscles and how they relate to Extraocular Muscle testing:

2022.11.04EyeMuscleAnalysisWorkshop

Each of the extraocular muscles performs a unique combination of actions. There is a certain amount of redundancy in the control of eye movements. Multiple muscles can perform each movement around an axis; each movement is controlled by more than one nerve. So loss of one muscle or one nerve can be compensated for, to some extent, by the remaining muscles or nerves.

Below is a summary of the actions and innervation of each extraocular muscle. You should learn to sort this information in multiple ways: by muscle, by innervation, and by function/muscle action.

Medial Rectus

- Innervation: Oculomotor nerve (cranial nerve III).
- Action:
  - Adduction
Lateral Rectus:

- Innervation: Abducens nerve (VI)
  - Lateral rectus is the only muscle innervated by the abducens nerve.
- Action:
  - Abduction
  - Abducens nerve innervates the primary abductor of the eyeball.

**Lateral and medial rectus only have one action each.** Because of their orientation, they act around the vertical axis only.

Superior Rectus

- Innervation: Oculomotor nerve (cranial nerve III)
- Actions:
  - Elevation
  - Adduction
  - Medial rotation/Intorsion

Inferior Rectus

- Innervation: Oculomotor Nerve (cranial nerve III)
- Actions:
  - Depression
  - Adduction
Of the four rectus muscles, only lateral rectus abducts the eye.

Superior Oblique

- Innervation: Trochlear nerve (cranial nerve IV)
  - Superior oblique is the only muscle that is innervated by the trochlear nerve.
- Actions:
  - Depression
  - Abduction
  - Medial Rotation/Intorsion

Inferior Oblique

- Innervation: Oculomotor nerve (cranial nerve III)
- Actions:
  - Elevation
  - Abduction
  - Lateral Rotation/Extorsion
You can use the bogus chemical formula $\text{LR}_6 (\text{SO}_4)_3$ to remember which nerve innervates each muscle: the lateral rectus muscle (LR) is innervated by CN VI (6), the superior oblique muscle (SO) is innervated by CN IV (4), and all the other muscles are innervated by CN III (3).

### Extraocular Muscles

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Innervation</th>
<th>Action around Transverse Axis</th>
<th>Action around Vertical Axis</th>
<th>Action around Anteroposterior Axis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral Rectus*</td>
<td>Abducens Nerve (VI)</td>
<td>none</td>
<td>Abduction</td>
<td>none</td>
</tr>
<tr>
<td>Medial Rectus*[^]</td>
<td>Oculomotor Nerve (III)</td>
<td>none</td>
<td>Adduction</td>
<td>none</td>
</tr>
<tr>
<td>Superior Rectus[^+]</td>
<td>Oculomotor Nerve (III)</td>
<td>Elevation</td>
<td>Adduction</td>
<td>Medial Rotation (Intorsion)</td>
</tr>
<tr>
<td>Inferior Rectus[^+]</td>
<td>Oculomotor Nerve (III)</td>
<td>Depression</td>
<td>Adduction</td>
<td>Lateral Rotation Extorsion</td>
</tr>
<tr>
<td>Superior Oblique[^+]</td>
<td>Trochlear Nerve (IV)</td>
<td>Depression</td>
<td>Abduction</td>
<td>Medial Rotation Intorsion</td>
</tr>
<tr>
<td>Inferior Oblique[^+]</td>
<td>Oculomotor Nerve (III)</td>
<td>Elevation</td>
<td>Abduction</td>
<td>Lateral Rotation Extorsion</td>
</tr>
</tbody>
</table>

*Lateral & Medial Rectus have only one action each.*
All of the rectus muscles, except Lateral Rectus, adduct the eye.

Both of the “superior” muscles medially rotate the eye. Both of the “inferior” muscles laterally rotate the eye.

KNOWLEDGE CHECKS

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://wisc.pb.unizin.org/mindmotionanatomy/?p=108#h5p-1

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://wisc.pb.unizin.org/mindmotionanatomy/?p=108#h5p-9

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://wisc.pb.unizin.org/mindmotionanatomy/?p=108#h5p-8

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://wisc.pb.unizin.org/mindmotionanatomy/?p=108#h5p-7
Testing Extraocular Muscles

The function of extraocular muscles can be assessed easily in a physical exam by testing the movement of the eye in different positions. For example, if a person has difficulty depressing their eye, either the superior oblique or inferior rectus muscle could be involved because both of those muscles can depress the eye. The two muscles, though they have the same action, attach to the eyeball in different places and have slightly different pulls on the eyeball. It is possible to determine which muscle is not functioning properly by moving the eyeball and testing the patient's ability to depress the affected eye in different positions. This process is outlined in the paragraphs and figures below.

The principle behind this testing is this: In order to isolate the function of one of the two muscles which depress the eye, you must position the eye so that one of the muscles is mostly perpendicular to the axis being tested and the other muscle is mostly parallel to that axis. Only the muscle that is perpendicular to the axis will be able to cause movement around that axis. (When the eyeball moves, the axis of rotation moves with it. Since the muscles are fixed in their attachments to the orbit, the pulls of the muscles remain the same regardless of the position of the eyeball.)

In the figure below, the right eye is looking straight ahead. The horizontal axis and muscle positions are diagrammed. (Remember that inferior rectus attaches to the inferior eyeball and pulls posteriorly to depress the eyeball, while superior oblique attaches to the superior eyeball and pulls anteriorly to depress the eyeball.) When the eye is looking straight ahead, both inferior rectus and superior oblique are oriented in such a way that they can pull on the eyeball and cause
depression of the eye around the horizontal axis. In this position (eyes straight ahead), either muscle (or both) could be effective.

Diagram of the right eye looking straight ahead. Inferior rectus is pink; superior oblique is green.

To isolate the function of inferior rectus muscle, ask the patient to look laterally – to abduct their eye, as illustrated below. (“Look right,” if testing the right eye.) Notice that when the eyeball moves laterally, the horizontal axis moves too. But, the muscles are in the same place. In this abducted position, inferior rectus muscle is perpendicular to the horizontal axis, and has maximal pull on the eyeball. The superior oblique muscle, on the other hand, is now parallel to the horizontal axis and will not move the eyeball effectively around that axis. In this position, the patient can look down only by contracting their inferior rectus muscle. So, testing a patient’s ability to depress the abducted eye is testing for the function of the inferior rectus muscle.
To isolate the function of the superior oblique muscle, ask the patient to look medially – to adduct their eye, as shown below. (“Look left,” if testing the right eye.) In this adducted position, the inferior rectus muscle is now parallel to the horizontal axis and can, therefore, produce no movement on this axis. However, the superior oblique muscle is perpendicular to the horizontal axis and is in the ideal position to depress the eye. So, testing a patient's ability to depress the adducted eye is testing for the function of the superior oblique muscle.
Here is a good video and explanation of the concept described above:  
https://apps.medsch.ucla.edu/medyear1/Anatomy/extraocularMuscles/ClinicalTesting.htm

Using these principles, you can test any of the extraocular muscles and/or the integrity of the nerves which supply them.

For clinical testing, the tables below indicate the movement that each muscle can perform in its position of greatest efficiency. In order to test each muscle, the eye must be moved to the given starting position and then tested.

Extraocular Muscle Testing

Specific positions of the eyeball are used to test the function of specific extraocular muscles.
### Actions and Test Positions of Extraocular Muscles

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Actions</th>
<th>Evaluated by Ability to:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superior Oblique</td>
<td>Depression, Abduction, Medial Rotation</td>
<td>Depress the adducted eye</td>
</tr>
<tr>
<td>Inferior Oblique</td>
<td>Elevation, Abduction, Lateral Rotation</td>
<td>Elevate the adducted eye</td>
</tr>
<tr>
<td>Superior Rectus</td>
<td>Elevation, Adduction, Medial Rotation</td>
<td>Elevate the abducted eye</td>
</tr>
<tr>
<td>Inferior Rectus</td>
<td>Depression, Adduction, Lateral Rotation</td>
<td>Depress the abducted eye</td>
</tr>
<tr>
<td>Lateral Rectus</td>
<td>Abduction</td>
<td>Abduction of neutral eye</td>
</tr>
<tr>
<td>Medial Rectus</td>
<td>Adduction</td>
<td>Adduction of neutral eye</td>
</tr>
</tbody>
</table>
Innervation of the Orbit

Six cranial nerves send fibers to or through the orbit, and sympathetic fibers from the superior cervical ganglion reach the orbit via various pathways. These nerves have targets both in and near the orbit.

- Optic nerve (II): special somatosensory fibers
- Oculomotor nerve (III): somatomotor and parasympathetic fibers
- Trochlear nerve (IV): somatomotor fibers
- Ophthalmic division of trigeminal nerve (V1): general somatosensory fibers
- Abducens nerve (VI): somatomotor fibers
- Facial nerve (VII): parasympathetic fibers (as well as branchiomotor fibers to the orbicularis oculi; these fibers do not travel through the orbit.)
- Sympathetic fibers to the orbit from superior cervical ganglion
General Somatosensory Innervation: Ophthalmic Division of Trigeminal Nerve

The ophthalmic division of the trigeminal nerve (V1) contains only general somatosensory fibers. These fibers carry pain, touch, and temperature sensations from the cornea, from skin on the surface of the face, and from structures within the superior third of the head, such as sinuses and the nasal cavity. The cell bodies for these fibers are in the trigeminal ganglion. The V1 nerve runs through the cavernous sinus and superior orbital fissure to reach the orbit. Just before entering the orbit, V1 splits into three major branches. (You can remember these branches using the helpful acronym: NFL.)

- The frontal nerve is the most superior nerve in the orbit and will be the first nerve visible when you dissect the orbit from the cranial cavity. It travels between the levator palpebrae superioris muscle and the roof of the orbit. It splits within the orbit to form two branches: the supraorbital and supratrochlear nerves. These branches are sensory to the skin of the upper eyelid, forehead and scalp.
- The lacrimal nerve, also a somatosensory nerve, is the most lateral nerve in the orbit and supplies the lacrimal gland and adjacent conjunctiva and upper eyelid. (Secretion by the lacrimal gland is controlled by parasympathetic fibers of the facial nerve (below).)
The nasociliary nerve, also purely somatosensory, is the deepest branch of V₁. It crosses the optic nerve from lateral to medial and runs through the medial part of the orbit. It has several named branches:

- **Long ciliary nerves**, which travel directly to the back of the eyeball, carry pain, touch, and temperature sensations from the eyeball (including the cornea). If you've made it through a Wisconsin winter, you know that your eyeballs can indeed feel cold!

  - *(Short ciliary nerves are also branches of the nasociliary nerve. They travel from the parasympathetic ciliary ganglion to the back of the eyeball and contain both somatosensory and postganglionic parasympathetic fibers. The somatosensory parts of these nerves carry pain, touch, and temperature sensations from the eyeball. More about the parasympathetics later.)*

- The ciliary ganglion is a parasympathetic ganglion, associated with the oculomotor nerve. Fibers from V₁ will pass through it, but will not synapse there.

- **Ethmoidal** branches carry sensation from the sphenoid, ethmoid and frontal sinuses, the nasal cavity and the skin on the nose.

- **Sensory branches** run between the main nasociliary nerve to the ciliary ganglion.
Corneal (Blink) Reflex

The corneal (blink) reflex is a cranial-nerve mediated reflex. When something touches one of your corneas, you blink (with both eyes). The corneal (or blink) reflex is initiated by a foreign object...
touching the cornea, a sensation carried by long and/or short ciliary branches of the ophthalmic division of the trigeminal nerve (V₁). The motor output (the blink) is stimulated by the facial nerve (VII) via its innervation of the orbicularis oculi, the muscle of facial expression which is responsible for closing the eye.

Here is a video describing the anatomy of the blink reflex:

One or more interactive elements has been excluded from this version of the text. You can view them online here:
https://wisc.pb.unizin.org/mindmotionanatomy/?p=108#oembed-4

This video demonstrates the clinical test for the corneal (blink) reflex:

One or more interactive elements has been excluded from this version of the text. You can view them online here:

**Somatomotor Innervation: Oculomotor (III), Trochlear (IV), and Abducens (VI) Nerves**

Somatomotor fibers to the orbit innervate the extraocular muscles, skeletal muscles which develop from the three preotic somites in the embryo. Recall from your embryology unit that each of the preotic somites is innervated by a different cranial nerve: oculomotor (III), trochlear (IV) or abducens (VI). All three nerves enter the orbit through the superior orbital fissure.
• The oculomotor nerve (III) contains both somatomotor and parasympathetic fibers. The oculomotor nerve originates in the midbrain, travels through the cavernous sinus, and goes through the superior orbital fissure. As it enters the orbit, it travels between the two heads of the lateral rectus muscle and splits into two branches.
  ◦ The superior branch runs between and innervates the levator palpebrae superioris and superior rectus muscles. The superior branch also carries sympathetic fibers (with cell bodies in the superior cervical ganglion) to the superior tarsal muscle, the smooth muscle which keeps the eye open involuntarily.
  ◦ The inferior branch travels inferior to the optic nerve and innervates three muscles: inferior rectus, inferior oblique, and medial rectus. The inferior branch also carries the parasympathetic fibers of the oculomotor nerve (cell bodies in the Edinger–Westphal nucleus). These parasympathetic fibers will synapse in the ciliary ganglion.
• The trochlear nerve (IV) passes through the cavernous sinus and superior orbital fissure to innervate the superior oblique muscle. The trochlear nerve runs superior to the superior oblique muscle in the posterior orbit before piercing the muscle.
• The abducens nerve (VI) passes through the cavernous sinus and superior orbital fissure and toward the lateral rectus muscle. It pierces that muscle on the medial side.
**Autonomic (Visceromotor) Innervation: Oculomotor (III) and Facial (VII) Nerves + Sympathetics**

Visceromotor fibers to the orbit travel on branches of other nerves to reach their targets. Parasympathetic fibers of the oculomotor nerve (III) travel on its inferior branch, synapse in the ciliary ganglion, and then follow branches of V₁ into the eyeball. Parasympathetic fibers from the facial nerve (VII) synapse in the pterygopalatine ganglion and enter the orbit on branches of V₁. Sympathetic fibers travel with blood vessels and/or other nerves to reach their target organs.

**Parasympathetics**

Parasympathetic fibers to the orbit are derived from two cranial nerves and their postsynaptic ganglia.

**Oculomotor Nerve & Ciliary Ganglion: Targets within the Eyeball**

Parasympathetic targets within the eyeball are innervated by parasympathetic fibers which originate from the Edinger-Westphal nucleus in the midbrain and are part of the oculomotor nerve (III). These fibers will innervate two smooth muscles, the pupillary sphincter muscle, which constricts the pupil, and the ciliary muscle, which alters the shape of the lens for accommodation.
The presynaptic parasympathetic fibers of the oculomotor nerve (III) travel on its inferior branch. These fibers synapse in the ciliary ganglion within the orbit. After synapsing, the postganglionic fibers enter the back of the eyeball as part of the **short ciliary nerves** (which also contain general somatosensory fibers from the **nasociliary branch of V₁**) to reach the pupillary sphincter and ciliary muscles. (Remember that all parasympathetic fibers to targets in the head will, at some point, travel with branches of the trigeminal nerve.)

Back to Top

Pupillary Light Reflex

The pupillary light reflex is another cranial nerve-mediated reflex. When a light is shined into either eye, the optic nerve (II) carries sensory information back to the brainstem (the sensory input of the reflex). This results in the constriction of the pupils in both eyes, via parasympathetic output from the oculomotor nerves (III). The pupillary light reflex tests the integrity of both the optic and oculomotor nerves.

Here is a video that outlines the anatomy of the pupillary light reflex. (Left and right are switched on this video, but it makes no difference. Shining a light into one eye causes both pupils to contract.):
Facial Nerve and Pterygopalatine Ganglion: Target outside the Eyeball

The lacrimal gland is the only parasympathetic target in the orbit which is outside of the eyeball. The lacrimal gland, like all glands in the head except the parotid gland, is innervated by parasympathetic fibers from the facial nerve (VII).

Presynaptic parasympathetics to the lacrimal gland originate with cell bodies in the superior salivatory (lacrimal) nucleus in the pons. These fibers take a circuitous and complicated pathway to reach the orbit. From the main facial nerve trunk, these fibers branch off just past the genu to form the greater petrosal nerve, which contains presynaptic parasympathetic fibers to the upper part of the head.
cervical ganglion to form the **nerve of the pterygoid canal**. This nerve travels through the sphenoid bone to end at the **pterygopalatine ganglion**, a postsynaptic parasympathetic ganglion deep within the skull. From there, postsynaptic parasympathetic fibers will travel along branches of V2 to enter the orbit and then join the **lacrimal nerve** (a branch of V1) to reach the lacrimal gland. (Postsynaptic parasympathetics from the pterygopalatine ganglion also distribute to glands of the nasal and oral mucosa, following branches of V2.) As is true elsewhere in the head, parasympathetic stimulation increases secretion by the glands and sympathetic stimulation inhibits secretion.

![Route of postsynaptic parasympathetic fibers from the pterygopalatine ganglion to the lacrimal gland. Modified from Netter Presenter.](http://netterreference.com.ezproxy.library.wisc.edu/content/netter_atlas_6e/?task=home)

**Sympathetics**

The primary sympathetic targets in the orbit are smooth muscles within the eye and eyelid. All preganglionic sympathetic cell bodies are in the lateral horn of the spinal cord at levels T1-L2. These fibers synapse on the postganglionic cell bodies in the superior cervical ganglion. The postsynaptic axons travel as part of the internal carotid plexus into the cavernous sinus. Within the sinus, many fibers leave the artery and join cranial nerves III, IV, V1, V2, and VI to reach
structures within the head. Postsynaptic sympathetic fibers tend to follow other structures (blood vessels and/or other nerves) to reach their target organs.

To Pupillary Dilator Muscle

The postganglionic sympathetic fibers traveling to the pupillary dilator muscle within the eyeball can travel via one of several pathways:

- with sensory branches of the nasociliary nerve (branch of V1) to the ciliary ganglion; they pass through without synapsing and follow the short ciliary nerves to the back of the eyeball.
- directly from the cavernous sinus to the ciliary ganglion (again without synapsing and following the short ciliary nerves to the eyeball).
- follow the long ciliary nerves (branches of the nasociliary nerve), which bypass the ciliary ganglion and go directly to the back of the eyeball.

To Superior Tarsal Muscle

The superior tarsal muscle in the eyelid also receives sympathetic innervation. Sympathetic fibers join the oculomotor nerve within the cavernous sinus and distribute with its superior branch. (The somatomotor fibers of the superior branch of III innervate the superior rectus and levator palpebrae superioris muscles.) Damage to the superior cervical ganglion can result in Horner's syndrome, an ipsilateral loss of sympathetic function in the head. One of the symptoms of this condition is a drooping of the eyelid on the affected side (ptosis) due to loss of function of the superior tarsal muscle, which normally acts to keep the eyelid open (involuntarily).
## Nerves of the Orbit

<table>
<thead>
<tr>
<th>Nerve</th>
<th>Fiber Type(s)</th>
<th>Sensation Carried/Target Organ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optic Nerve (II)^</td>
<td>Special Somatosensory</td>
<td>Vision (light) from retina</td>
</tr>
<tr>
<td>Oculomotor Nerve (III)^</td>
<td>Somatomotor</td>
<td>Superior Rectus, Inferior Rectus, Medial Rectus, Inferior Oblique, Levator Palpebrae Superiors</td>
</tr>
<tr>
<td>Trochlear Nerve (IV)</td>
<td>Somatomotor</td>
<td>Superior Oblique</td>
</tr>
<tr>
<td>Trigeminal Nerve (V)*</td>
<td>General Somatosensory</td>
<td>Pain, touch, &amp; temperature from all structures in orbit, Also from structures in and on the superior 1/3 of the head (including skin of the face)</td>
</tr>
<tr>
<td>Ophthalmic Division (V₁)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abducens Nerve (VI)</td>
<td>Somatomotor</td>
<td>Lateral Rectus</td>
</tr>
<tr>
<td>Facial Nerve (VII)*</td>
<td>Branchiomotor</td>
<td>Orbicularis Oculi</td>
</tr>
<tr>
<td>Sympathetics</td>
<td>Parasympathetic</td>
<td>Lacrimal Gland, via pterygopalatine ganglion</td>
</tr>
<tr>
<td>from superior cervical ganglion</td>
<td>Sympathetic</td>
<td>Pupillary Dilator muscle, Superior Tarsal Muscle</td>
</tr>
</tbody>
</table>

*Part of corneal (blink) reflex
^Part of pupillary light reflex
KNOWLEDGE CHECKS

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://wisc.pb.unizin.org/mindmotionanatomy/?p=108#h5p-28

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https://wisc.pb.unizin.org/mindmotionanatomy/?p=108#h5p-29

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An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://wisc.pb.unizin.org/mindmotionanatomy/?p=108#h5p-32
Ophthalmic Artery

Just after the internal carotid artery enters the middle cranial fossa, the ophthalmic artery branches off of it. The ophthalmic artery enters the orbit through the optic canal, along with the optic nerve, and supplies tissues in and around the orbit. The branches of the artery have similar names to the branches of V1 in the orbit. Four branches of the ophthalmic artery stay within the orbit and four branches leave the orbit.

The **four branches which stay in the orbit** are:

- the **central artery of the retina** that crosses the subarachnoid space, penetrates the optic nerve and continues forward within the optic nerve to supply the retina.
- the **ciliary arteries** which supply the outer layers of the eyeball (sclera and vascular layer).
  - There are anterior, posterior, long and short ciliary arteries. They all pierce the eyeball in various places. We'll call them all ciliary arteries for now.
- the **lacrimal artery** which supplies the lacrimal gland and adjacent conjunctiva and eyelid.
- **muscular branches** to the extraocular muscles.

**Four branches leave the orbit** to supply surrounding tissues.

- The **ethmoidal arteries** supply the ethmoidal sinuses (air cells) and follow the ethmoidal...
branches of $V_1$. There are multiple ethmoidal arteries.

- The **supraorbital artery** follows the supraorbital nerve and exits the skull via the supraorbital foramen (notch) to reach the superficial face.
- The **supratrochlear artery** similarly follows the supratrochlear nerve to the surface of the face.
- The **dorsal nasal artery** is medial to the supratrochlear artery and also supplies the face.

### Arterial Anastomoses between Internal and External Carotid Arteries

All of the branches of the ophthalmic artery which supply the face anastomose with branches of the facial artery on the surface of the face. This connects the vascular territory of the internal carotid artery (which gives rise to the ophthalmic artery) and the external carotid artery (which gives rise to the facial artery).

Additionally, there is an anastomotic connection between a branch of the lacrimal artery (from ophthalmic/internal carotid artery) and a branch of the middle meningeal artery (from maxillary/external carotid artery).

These anastomoses can provide a pathway for infection from the surface of the face into the cranial cavity.

Venous Drainage of the Orbit (& More Anastomoses)

There are several pathways for drainage of venous blood from the orbit. There are two main veins within the orbit, the **superior** and **inferior ophthalmic veins**. They typically drain blood from the orbit posteriorly to the **cavernous sinus** by traveling through the superior orbital fissure. However, there are two other alternatives. The ophthalmic veins can drain anteriorly to the **angular vein** of the superficial face which connects to the facial vein. They can also drain inferiorly into the **pterygoid plexus** in the infratemporal fossa, deep in the face. All of these venous pathways eventually end up in the internal jugular vein.

Because of all of these connections and the fact that these veins have no valves, blood can flow in any direction through this venous system, providing a pathway for the spread of infection between the superficial and deep face, orbit, and cranial cavity.

Multiple pathways of venous drainage from the orbit. Modified from Netter Presenter, [http://netterreference.com.ezproxy.library.wisc.edu/content/netter_atlas_6e/?task=home](http://netterreference.com.ezproxy.library.wisc.edu/content/netter_atlas_6e/?task=home)
Helpful Reference

American Academy of Ophthalmology: Interactive Ophthalmic Figures for Medical Students
I. The Ear and Its Development

The figure below shows a cutaway section of the three divisions of the ear: outer, middle and inner. The outer ear consists of the auricle and the external auditory meatus or canal that ends at the ear drum (tympanic membrane). The air filled middle ear contains three bones, the malleus, incus and stapes that convert airborne to fluid-borne pressure waves. The fluid-filled inner ear is a series of membranous sacs that house the sensory receptors and that are suspended within a bony labyrinth.
As seen in the figures above, the three divisions of the ear develop from separate embryological structures, but function as one unit. A section through the branchial arches shows that the external ear develops from pharyngeal cleft one, and the middle ear and auditory tube from pharyngeal pouch one. The small middle ear bones and their associated muscles arise from either the first branchial arch (malleus, incus and tensor tympani muscle) or second branchial arch (stapes and stapedius muscle).

The figures below illustrate another embryo and a section through the otic placode, which develops into the inner ear structures.
II. External Ear

The external ear collects airborne pressure waves. It consists of the **auricle** and **external auditory meatus**. The ear canal or meatus is not straight, but is slightly S-shaped in adults (not in young children). As a result, the eardrum is viewed with an otoscope after pulling the auricle up, out and back to straighten the canal. Most of the auricle is innervated by the **great auricular nerve** from the cervical plexus and by the **auriculotemporal branch of CN V**. There are minor contributions from **CNs VII and X**.

![Ear Examination](image)

The lateral 1/3 of the external auditory meatus is cartilaginous and has **ceruminous glands** that produce protective, waxy secretions. The medial 2/3 of the wall is bony. The external auditory meatus ends at the **eardrum** or **tympanic membrane**, a translucent membrane that separates it from the middle ear. The eardrum is not exactly vertical; instead, it faces the floor in front of and to the side of you. **Innervation** of the external auditory meatus and tympanic membrane is variable. The major innervation is by the **auriculotemporal branch of CN V**. The posterior portion of the meatus is innervated by branches of **CN X** and to a lesser extent by **CNs VII and IX**. Clinically, the most important sensory contribution is from CN X because examination of the external auditory canal occasionally can elicit a **cough** and/or a **vomit reflex** via the sensory contributions of this nerve. **CN IX** innervates the inner surface of the tympanic membrane. During middle ear infections (otitis media) the drum becomes amber and immobile and a fluid line may be viewed through it.
III. Middle Ear

The middle ear is an air filled space. It is continuous posteriorly with the mastoid air cells and anteriorly with the outside world via the auditory tube that opens into the nasopharynx. This connection permits equalization of air pressure across the tympanic membrane, which is essential for its normal vibration. The auditory tube is normally closed, but when you yawn or swallow, it opens and air exchange with the middle ear equalizes pressure across the tympanic membrane.

The middle ear contains three ossicles that bridge the tympanic membrane to the oval window. These are the smallest bones in the body and they articulate with each other at tiny synovial joints. The malleus (hammer) is attached to the tympanic membrane so that every time the tympanic membrane moves, the malleus moves as well. The vibration passes in series from the malleus to the incus (anvil), to the stapes (stirrup), to an opening in the medial wall of the middle ear, the oval window. The oval window is an opening that leads to the fluid filled inner ear. It is just above the promontory, a prominence of bone that separates the middle ear from the cochlea. A second opening is located just below the promontory. This round window is covered by a
membrane. Every time the stapes pushes in at the oval window, against the fluid of the inner ear, the membrane of the round window bulges out into the middle ear. By linking the tympanic membrane to the inner ear, the ossicles convert airborne pressure waves to fluid-borne pressure waves.

Although they are very small, the middle ear ossicles are similar to other bones. They articulate at synovial joints and movement of those joints can be modified by contraction of muscles, the tensor tympani and stapedius. In this case the muscles are meant to limit the movement of the ossicles to prevent damage to the inner ear. They contract by reflex in response to loud sounds. The belly of the tensor tympani muscle runs in a canal just above the auditory tube; its tendon emerges from the bone and attaches to the malleus. It develops from branchial arch one and is innervated by CN V3. Similarly, the belly of the stapedius muscle is located in a bony canal, but its tendon emerges into the middle ear and inserts on the stapes. It develops from branchial arch two and is innervated by CN VII.

The nerves running through the middle ear include the tympanic nerve, a branch of CN IX that forms the tympanic plexus. It is sensory to the entire middle ear, mastoid air cells and auditory tube. Parasympathetic fibers of the tympanic nerve exit the middle ear and ultimately innervate the parotid gland (Topic IV). CN VII enters the internal acoustic meatus and takes a sharp turn at the geniculate ganglion where it gives off the greater petrosal branch. The main trunk of the facial nerve continues posteriorly in the facial canal along the posterior wall of the middle ear where it gives off the chorda tympani nerve and the nerve to the stapedius (see topic 15-5). The chorda tympani passes through the middle ear cavity between the malleus and incus on its course to the infratemporal fossa (Topic V).

Infections of the upper respiratory tract can migrate to the middle ear via the auditory tube. Infections can also lead to blockage of the tube, causing pain (due to CN IX) and a pressure difference across the eardrum that results in hearing loss. Middle ear infections (otitis media) are also associated with fluid buildup and further hearing loss.

IV. Sensory Innervation of the Middle Ear

The glossopharyngeal nerve is responsible for sensory innervation of the middle ear. After it exits the skull through the jugular foramen, the first branch of the CN IX is the tympanic nerve, which contains both sensory and parasympathetic fibers. The tympanic nerve enters a tiny canal between the jugular foramen and the carotid canal to access the middle ear cavity and form the tympanic plexus in the mucous membrane covering the promontory. The sensory fibers supply the middle ear cavity, mastoid air cells and auditory tube. Sympathetic fibers join the tympanic plexus from the internal carotid plexus through tiny openings in the carotid canal. They innervate the blood vessels in the middle ear. Parasympathetic fibers destined for the parotid gland sort out from the tympanic plexus to form the lesser petrosal nerve, which exits the middle ear through a tiny crevice in the roof of the petrous bone. It runs parallel to the greater petrosal nerve within the middle cranial fossa then exits the foramen ovale to enter the otic ganglion.
V. Facial Nerve

The facial nerve has two roots exiting the brainstem, a branchiomotor root and a sensory and parasympathetic root. They enter the temporal bone through the **internal acoustic meatus** with CN VIII. At the end of the meatus, branchiomotor fibers of CN VII bend sharply at the **genu** and enter the **facial canal**, which travels down the posterior wall of the middle ear cavity to reach the stylomastoid foramen. While traveling through the facial canal, a few branchiomotor fibers branch off to innervate the **stapedius muscle**. The rest of the branchiomotor fibers exit the **stylomastoid foramen** to innervate the **muscles of facial expression**, as well as the **stylohyoid muscle** and the **posterior belly of the digastric muscle**.
At the genu, the geniculate ganglion contains the cell bodies of the special visceral sensory neurons that innervate the taste buds of the anterior 2/3 of the tongue. It also contains some general somatosensory nerve cell bodies that innervate a very small area of the external ear, external auditory meatus and tympanic membrane.

The taste fibers and parasympathetic fibers for the submandibular and sublingual glands, run in the facial canal with the branchiomotor fibers, and then form the chorda tympani branch that enters the middle ear, travels between the malleus and incus, and eventually exits the skull via the petrotympanic fissure. In the infratemporal fossa the chorda tympani nerve joins the lingual branch of the mandibular nerve (V3). Taste fibers go to the anterior 2/3 of the tongue and the parasympathetic fibers synapse on postganglionic cells in the submandibular ganglion, which innervate the submandibular and sublingual glands.

At the genu, some parasympathetic axons form the greater petrosal nerve, which travels to the middle cranial fossa. The greater petrosal nerve joins the deep petrosal nerve that carries sympathetic fibers from the internal carotid plexus. When these two nerves join, the nerve enters the pterygoid canal and is called the nerve of the pterygoid canal. The pterygoid canal opens into the pterygopalatine fossa, where the parasympathetic axons synapse on postganglionic neurons in the pterygopalatine ganglion. Postganglionic parasympathetic fibers from the pterygopalatine ganglion innervate the lacrimal gland and glands in the mucosa of the oral and nasal cavities.

Video: Follow the Facial Nerve Fiber Types though the Skull
3D Model of Facial Nerve in Temporal Bone

V. Inner Ear

The inner ear is a membranous duct (labyrinth) inside a bony canal (labyrinth). The auditory part of this system that houses the receptors (hair cells) for hearing is called the cochlea. The vestibular parts that house the receptors for balance are called the utricle, saccule and semicircular canals. As the stapes pushes in against the fluid of the inner ear at the oval window, the membrane over the round window bulges out into the middle ear.

Components of the Inner Ear
VII. Internal Acoustic Meatus

Cranial nerve VIII leaves the brainstem and enters the internal acoustic meatus (shaded label in figure at right) with cranial nerve VII. The vestibular and auditory branches of CN VIII innervate receptors in their respective areas of the inner ear. The special somatosensory nerve cell bodies are in the **cochlear** and **vestibular ganglia**, which are not dissectible.

Location of the Inner Ear

https://sketchfab.com/models/04bc5ef6fcea4c4cb66003ed2c55a7ef
Cranial Nerves Summary

ELISE DAVIS, PHD AND KAREN KRABENHOFT, PHD

This chapter contains a schematic diagram of each cranial nerve, its axon/fiber composition, locations of cell bodies (within and/or outside the brainstem), nerve pathways, and targets. All twelve cranial nerves are included in this chapter.

A downloadable pdf version of the diagrams in this chapter can be found here: CranialNervesLineDrawingsFINAL

Links to Cranial Nerve Videos (lightboard videos; on SMPH Repository):
  - CN I, II, and VIII
  - CN III, IV, and VI
  - CN V
  - CN VII
  - CN IX
  - CN X
  - CN XI and XII

Cranial Nerves in Phase I

Cranial nerves are covered in Phase 1 across all of the blocks.
<table>
<thead>
<tr>
<th>Cranial Nerve</th>
<th>Associated Primordium</th>
<th>Types &amp; Targets of Motor Fibers</th>
<th>Types &amp; Targets of Sensory Fibers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Olfactory (I)</td>
<td>nasal placode</td>
<td>-</td>
<td>*special viscerosensory: olfactory epithelium (axons of sensory cells are CN I)</td>
</tr>
<tr>
<td>Optic (II)</td>
<td>lens placode</td>
<td>-</td>
<td>*special somatosensory: retina (axons of the ganglion cells of the retina are CN II)</td>
</tr>
<tr>
<td>Oculomotor (III)</td>
<td>first preotic somite</td>
<td>*somatomotor: 5 extraocular muscles *visceromotor: pupillary sphincter &amp; ciliary muscle of the eye</td>
<td>-</td>
</tr>
<tr>
<td>Trochlear (IV)</td>
<td>second preotic somite</td>
<td>*somatomotor: 1 extraocular muscle *branchiomotor: V3 only: muscles of mastication + four small muscles</td>
<td>*general somatosensory: all structures on and in the anterior head (ears forward) including anterior 2/3 of tongue &amp; teeth</td>
</tr>
<tr>
<td>Trigeminal (V)</td>
<td>first branchial arch</td>
<td>*somatomotor: 1 extraocular muscle *branchiomotor: muscles of facial expression + four small muscles</td>
<td>*general somatosensory: small area in/around the external ear *special viscerosensory: taste from the anterior 2/3 of the tongue</td>
</tr>
<tr>
<td>Abducens (VI)</td>
<td>third preotic somite</td>
<td>*somatomotor: 1 extraocular muscle *branchiomotor: muscles of facial expression + four small muscles</td>
<td>-</td>
</tr>
<tr>
<td>Facial (VII)</td>
<td>second branchial arch</td>
<td>*special somatosensory: sensory organs of hearing and balance *general somatosensory: posterior 1/3 of tongue, pharynx, middle ear (tympanic cavity) *general viscerosensory: carotid body &amp; carotid sinus *special viscerosensory: taste from posterior 1/3 of tongue</td>
<td></td>
</tr>
<tr>
<td>Vestibulocochlear (VIII)</td>
<td>otic placode</td>
<td>-</td>
<td>*general somatosensory: larynx, lower pharynx, skin around ear, external acoustic meatus *special viscerosensory: taste from epiglottis</td>
</tr>
<tr>
<td>Glossopharyngeal (IX)</td>
<td>third branchial arch</td>
<td>*branchiomotor: one small muscle in pharynx *visceromotor: parotid gland</td>
<td>-</td>
</tr>
<tr>
<td>Vagus (X)</td>
<td>fourth and sixth branchial arches (+parasympathetics)</td>
<td>*branchiomotor: muscles of pharynx and larynx (&amp; palate) *visceromotor: thoracic organs, foregut &amp; midgut organs</td>
<td>-</td>
</tr>
<tr>
<td>Spinal Accessory (XI)</td>
<td>?? (we do not know this)</td>
<td>*branchiomotor: trapezius, sternocleidomastoid</td>
<td>-</td>
</tr>
</tbody>
</table>
## General Principles for All Cranial Nerves

- Each cranial nerve is associated with one primordium in the embryonic head and neck.
  - This association determines which types of axons are contained in each cranial nerve.
  - Each cranial nerve contains the types of axons needed to innervate all of the structures that are part of its associated embryonic primordium.
  - In the brainstem, specific columns of cells are associated with each type of axon in a
cranial nerve.
  ◦ Link to HFT Development of the Nervous System and Structures of the Head & Neck chapter.

• Cranial nerves are bilateral. There are “rights and lefts” of each cranial nerve.
  ◦ Generally, the right cranial nerve is associated with the right brainstem and the left cranial nerve is associated with the left brainstem. (CN IV is an exception to this.)
• All sympathetic axons in the head originate in the superior cervical ganglion. Sympathetics run with branches of some cranial nerves, but cranial nerves themselves have no sympathetic axons in them.
• Pre-ganglionic parasympathetics in cranial nerves originate in the brainstem. Post-ganglionic parasympathetics in cranial nerves originate in ganglia and always travel with a branch of CN V to reach their targets in the head and neck.
• There are two kinds of ganglia associated with cranial nerves:
  ◦ Sensory ganglia are located just outside the brainstem and contain pseudounipolar sensory cell bodies. There are no synapses in sensory ganglia.
  ◦ Sensory ganglia of cranial nerves are analogous to dorsal root ganglia of spinal nerves.
  ◦ Every cranial nerve that contains sensory axons has at least one sensory ganglion.
• Parasympathetic ganglia are located in the head and contain postsynaptic parasympathetic cell bodies. There are synapses in parasympathetic ganglia. There are four parasympathetic ganglia in the head:
  ◦ for CN III: ciliary ganglion
  ◦ for CN VII: pterygopalatine and submandibular ganglia
  ◦ for CN IX: otic ganglion
  ◦ (Parasympathetics from CN X innervate organs in the thorax and abdomen and synapse in ganglia within the walls of the organs.)

As you approach each cranial nerve, think about what you know about it already.

• Which embryonic primordium does the nerve innervate?
• What are the adult derivatives of the primordium?
• Which functional components (types of axons/fibers) does the nerve include?
• Where are the cell bodies located (for all axon types)?
• Where does the cranial nerve exit the cranial cavity to reach its targets?
Schematic Diagram of the Brainstem

This is a schematic diagram of a cross-section through the brainstem which shows the rough locations of the columns of cells associated with each type of fiber/axons in cranial nerves. Because each cranial nerve has a unique composition, each nerve will only be associated with a subset of these columns of cells at a given level of the brainstem.

In this document, there are color-coded diagrams for each cranial nerve which show the axon/fiber composition, location of cell bodies (within and/or outside brainstem), nerve pathways, and targets.

![Schematic Diagram of Brainstem Nuclei](image)

Cranial Nerve I: Olfactory Nerve

[Link to CN I, II, and VIII Video]
**CN I - Olfactory Nerve**

- Special visceral sensory (sense of smell)

- The olfactory and optic nerves are not associated with the brainstem.
- The olfactory tract and olfactory bulb are located on the ventral surface of the frontal lobe of the brain.

**Cranial Nerve II: Optic Nerve**

[Link to CN I, II, and VIII Video]
Cranial Nerve III: Oculomotor Nerve

- The olfactory and optic nerves are not associated with the brainstem.
- The optic nerves (and optic tracts) are composed of the axons of ganglion cells within the retinas of the eyes.

Cranial Nerve III: Oculomotor Nerve

[Link to CN III, IV, and VI Video]
Cranial Nerve IV: Trochlear Nerve

Somatic motor
(to levator palpebrae superiors, superior/middle/inferior rectus, inferior oblique)

Parasympathetic
(to pupillary constrictor & ciliary muscle of eye)

Symptomatic: run with branches of CN III, but originate in the superior cervical ganglion.
• Targets in the orbit: superior temporal m. and pupillary dilator m.
• All post-ganglionic parasympathetics from CN II travel with a branch of CN V to reach their targets.
  - From the ciliary ganglion into the eyeball on Short ciliary nerves (branches of V₁).

 CN III – Oculomotor Nerve

Ciliary ganglion contains postsynaptic parasympathetic cell bodies (CN II). There are synapses in this ganglion.

Originates from the midbrain

Link to CN III, IV, and VI Video
CN IV – Trochlear Nerve

- Trochlear nerve innervates the contralateral superior oblique muscle.
  - The axons cross the midline as they emerge from the brainstem on the posterior side.
  - The nerve doesn’t really go through the ventricle, but it does exit the brainstem posteriorly.

Cranial Nerve V: Trigeminal Nerve

CN V Video
**V₁-Ophthalmic Division of Trigeminal Nerve**

**CN V₁ – Ophthalmic Nerve**

Parasympathetic and sympathetic fibers travel with V₁ branches:
- **Sympathetics**: run with branches of CN V₁ (other than long ciliary) but originate in the superior cervical ganglion.
  - Target: pupillary dilator m.
- **Postganglionic parasympathetics from CN III**: travel from the ciliary ganglion to their targets with the short ciliary and branches of CN V₁.
  - Targets: ciliary and pupillary constractor muscles
- **Postganglionic parasympathetics from CN VII**: travel from the pterygopalatine ganglion to their target with the inferior labial (branches of CN V₁).
  - Target: lacrimal gland

**V₁-Maxillary Division of Trigeminal Nerve**
**CN V₂ – Maxillary Nerve**

General somatosensory
(from the middle 1/3 of the anterior head, including maxillary sinus, lower nasal cavity, upper teeth)

Parasympathetic and sympathetic fibers travel with V₂ branches.
- Parasympathetics run with branches of CN V₂, but originate in the superior cervical ganglion.
  - Targets: glands, blood vessels in the mucosa of nasal cavity.
- Post-ganglionic sympathetic from CN VII, travel from the pterygopalatine ganglion to their target with the various branches of CN V₂.
  - Targets: glands of nasal and oral mucosa, (also on path to lacrimal gland)

**V₃ – Mandibular Division of Trigeminal Nerve**

General somatosensory
(from the lower 1/3 of the anterior head, including anterior 2/3 of tongue, lower teeth)

Branchiomotor
(to muscles of mastication + 4 small muscles)

Sympathetic, parasympathetic & taste fibers travel with branches of V₃.
- Sympathetics (not shown) run with all branches of CN V₃ but originate in the superior cervical ganglion.
- Post-ganglionic parasympathetics from CN VII, travel from the submandibular ganglion with lingual nerve.
  - Targets: submandibular and sublingual glands.
- Post-ganglionic parasympathetics from CN VII travel from the otic ganglion with the buccal nerve.
  - Target: pterygoid gland
- Taste fibers (special visceral sensory) from CN VII travel with lingual nerve.
  - Targets: taste buds on anterior 2/3 of tongue

Trigeminal ganglion contains pseudounipolar sensory cell bodies. There are no synapses. (Analogous to a dorsal root ganglion)

Pterygopalatine ganglion contains postganglionic parasympathetic cell bodies (CN VII). There are synapses in this ganglion.

Trigeminal ganglion contains pseudounipolar sensory cell bodies. There are no synapses. (Analogous to a dorsal root ganglion)
Cranial Nerve VI: Abducens Nerve

Link to CN III, IV, and VI Video

Cranial Nerve VII: Facial Nerve

Link to CN VII Video
Cranial Nerve VII: Vestibulocochlear Nerve

Link to CN I, II, and VIII Video
Cranial Nerve IX: Glossopharyngeal Nerve

Link to CN IX Video
Cranial Nerve X: Vagus Nerve

Link to CN X Video
Cranial Nerve XI: Spinal Accessory Nerve

Link to CN XI and XII Video
CN XI – Spinal Accessory Nerve

Branchiomotor
(to sternocleidomastoid and trapezius)

CN XI originates from cervical spinal levels C1-C4, not from the brainstem. It is considered a branchiomotor nerve.
- It ascends through the foramen magnum to enter the cranial cavity. Then exits the cranial cavity through the jugular foramen.

Cranial Nerve XII: Hypoglossal Nerve

Link to CN XI and XII Video

CN XII – Hypoglossal Nerve

Somatomotor
(to all tongue muscles except palatoglossus)

Intrinsic & extrinsic tongue muscles EXCEPT palatoglossus m (CN X)
Cranial Nerve Route Videos

Follow along in each of the following videos to draw the routes of the cranial nerves through the skull!

- Cranial Nerves I, II, and VIII
- Cranial Nerves III, IV, and VI
- Cranial Nerve V
- Cranial Nerve VII
- Cranial Nerve IX
- Cranial Nerve X
- Cranial Nerves XI and XII
Embryological Primordia of the Limbs

The limb buds begin forming late in the fourth week of embryological development. They are initially sacs of ectoderm filled with loosely packed mesoderm (mesenchyme) derived from lateral plate mesoderm. The lateral plate mesoderm will differentiate to become the appendicular (limb) skeleton and the blood and lymph vessels of the limbs. The mesoderm and overlying ectoderm interact extensively to form the limbs, but it has been found that the mesoderm is the driving force behind limb development.
The muscles of the limbs are derived from the myotomes of somites. The cells that form the muscles of the limbs come from the hypomere of the myotome. Recall that the muscles that are derived from the hypomere were associated with the ventral rami of spinal nerves very early in development. This relationship is maintained throughout development. See the image below from the Human Family Tree: Early Embryology chapter to review this association.
The dermatomal cells also migrate from the somite into the limbs to form the dermis of the skin of the limbs. In the trunk, the dermatomes are an even repeating pattern. The limbs are a bit more complex, however, and while dermatomes of the limbs still maintain a general cranial to caudal pattern there will be some adjustments due to the complexity of the limbs.


**Limbs Basics**

While the upper and lower limbs of human adults appear strikingly dissimilar, they are both actually built on a similar basic plan. The basic limb plan is evident when looking at the bones of the appendicular (limb) skeleton. Both the upper and lower limbs have a girdle that attaches the limb to the axial skeleton. Both the arm and the thigh have a single, large bone. The forearm and leg have two smaller bones aligned parallel to one another. The wrist and ankle are made up of multiple block-like bones. Finally the hand and foot are made up of multiple bones arranged into five digits each. Among mammals, humans are unique in that we walk bipedally. While our lower limbs are built for stability, our upper limbs are freed up to perform complex, highly mobile
tasks. (Take a look at your nearest furry friend—dog, cat, rat, hamster, elephant—and compare their upper limbs to their lower limbs to help you appreciate the differences between bipedalism and quadrupedalism.)

Movement of the limbs occurs around joints, and oftentimes some movements may seem complex. Luckily, all movements can be broken down into simple movements around three axes (transverse, anterior-posterior and vertical). We will discuss this in depth in Mind & Motion, but for now we will concern ourselves with the movements of flexion and extension around the transverse axis.

Muscles can only pull, they can never push. Due to this feature, muscles must work in pairs on opposite sides of a joint to move that joint. This antagonistic relationship moves the joint around an axis to perform different actions. Around the transverse axis, a joint can be flexed (decreasing the angle between the two bones) or extended (increasing the angle between the two bones).
An easy example is the muscles of the arm. The biceps brachii and brachialis muscles are on the anterior side of the arm and cross the elbow joint to attach to forearm bones. The triceps brachii is on the posterior side of the arm and crosses the elbow joint to attach to the forearm bones. The muscles crossing the anterior side of the elbow flex the elbow joint, and the muscle crossing the posterior side of the elbow extend the elbow joint. To flex the elbow, the anterior muscles contract (pull on the forearm bones). Once the elbow is in full flexion, the triceps must pull on the forearm to extend the elbow joint (the biceps brachii can’t push it back in the opposite direction because muscles can’t push).
Contraction of the biceps brachii and brachialis flexes the elbow.

Contraction of the triceps brachii extends the elbow.

We can extend this example to other muscles in the upper and lower limbs. A group on one side of a joint decrease the angle between two bones at a joint, and we will classify all of those muscles as flexors. Conversely, the group on the opposite side of the joint will increase the angle between two bones at a joint and we will classify those as extensors. This will become important in limb development, because as muscles begin to develop they will already be classified as a flexor or extensor depending on which side of the limb they develop.

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://wisc.pb.unizin.org/mindmotionanatomy/?p=1910#h5p-161
Limb Bud Set-up

The upper limbs first become visible during the fourth week of development as small outgrowths on the flank of the embryo. About 36 hours later, the buds for the lower limbs appear. The base of the upper limb bud is located adjacent to spinal cord levels C5-T1. The base of the lower limb bud is located adjacent to spinal cord levels L2-S3.

As the limbs start to develop, it is important for directional axes to be set up within the limb.

Proximal/Distal

The limbs must develop in a proximal to distal direction, meaning that proximal structures (arm
and thigh) develop before more distal structures (hand and foot). The most proximal part of the limb is the **stylpodium** (arm/thigh), the next segment of the limb is the **zeugopodium** (forearm/leg) and the most distal part of the limb is the **autopodium** (hand/foot).

The ectoderm on the most distal aspect of the limb is thickened and is called the **apical ectodermal ridge** (AER). Interactions between the apical ectodermal ridge and the underlying mesoderm are required for normal limb development to occur. It is also an important structure that drives development of the limb. If the AER is removed or its signalling is disrupted in some way, a limb will not develop. **Amelia** (entire limb), **meromelia** (partial limb), and **adactyly** (lack of digits) are examples of malformations of the limbs due to complete loss or lack of signalling from the AER. Conversely, if the AER is duplicated (as happens in diplopodia) an additional limb will form.

**Anterior/Posterior**

The ventral/anterior side of the limb (palm and plantar sides of the hand and foot, respectively) must be distinct from the dorsal/posterior sides of the limb. The apical ectodermal ridge acts as a boundary between the anterior and posterior sides of the limb.

**Cranial/Caudal**

The cranial side of the limb (thumb side and big toe side) must be distinct from the caudal side of the limb (little finger and little toe). The bud’s distinct upper or cranial margin is called the **preaxial border**, and the lower or caudal margin is called the **postaxial border**. For example, with the adult upper limb in the anatomical position, the preaxial border runs from the tip of the shoulder to the thumb. The postaxial border runs from the base of the axilla (armpit) to the little finger.

The **zone of polarizing activity (ZPA)** is a small area in the distal limb bud that contains cells that produce the molecule sonic hedgehog (shh). Shh performs many action in the embryo, but in the limb exposure to shh determines which side of the limb will be the preaxial or postaxial side of the limb. The thumb develops on the side preaxial side of the limb because it is farther away from the ZPA, and the pinkie develops because it is close to the ZPA. Upregulation of the ZPA can result in the growth of extra digits (polydactyly) on the pinkie side of the limb. Experimental relocation of the ZPA in chicks has shown that if the ZPA is relocated to the opposite side of the limb extra digits will form arranged as a mirror image to the normal digits (for example, pinkie-ring-middle-index-thumb-index-middle-ring-pinkie).
Limb Bud Development

A sagittal cross section of a limb bud (below) shows the position of the marginal vein, a prominent vein that runs immediately beneath the ectoderm of the preaxial border, the apical ectodermal ridge (not illustrated) and the postaxial border. It persists to form veins that are still located in their original pre- and postaxial positions in the adult. In the upper limb, the preaxial vein becomes the cephalic vein in the adult and the postaxial vein becomes the basilic vein in the adult.
The figure above also illustrates a condensation of mesoderm along the longitudinal axis of the limb, which will form the skeletal elements of the limb. The central condensation of mesenchyme is also a landmark that can be used to divide the limb into a preaxial compartment and a postaxial compartment (above or below a horizontal line through the central axis). Note that a vertical line through the central axis separates the limb into anterior and posterior compartments.
The following diagrams below are in the same orientation as the previous two diagrams. The top and bottom of the pictures of the limb buds represent the preaxial and postaxial borders/compartment. Likewise, the left and right borders of the pictures of the limb buds represent the anterior and posterior borders/compartment.

After the axial mesenchyme of the limb bud condenses to form a skeletal element, myogenic cells migrate into the limb from the myotomes of somites and form the preaxial and postaxial muscle masses. At the base of the limb bud, the preaxial muscle mass lies adjacent to spinal cord levels C5, 6, and 7, while the postaxial muscle mass is adjacent to levels C7, 8, and T1. In the lower limb, the preaxial muscle mass is innervated by levels L2-L5 and the postaxial muscle mass is innervated by S1-S3. As they develop, the myofibers within the pre- and postaxial muscle masses are innervated by ventral rami from these respective spinal cord segments. The nerve-muscle connections that are established will persist; the original neurons that innervate the skeletal muscle cell (myofiber) at this early period will stay with that myofiber no matter what migration or change in direction the myofiber might undergo.
Soon after the formation and innervation of the pre- and postaxial muscle masses, each divides into anterior and posterior parts. These portions of the muscle masses come to lie in the presumptive anterior or posterior compartments of the limbs. This division has not only anatomical importance but also functional importance. That is, muscles developing in the posterior compartments function as extensors, while those in the anterior compartment function as flexors of joints of the extremities. Since the muscle fibers have been innervated and bring their nerve supply with them during this splitting, the nerves are also committed to an anterior or posterior compartment and can be called anterior (flexor) or posterior (extensor) division nerves, terms that have both functional and anatomical implications.
The split pre- and postaxial muscle masses merge to form the primordia that will form the adult muscles. The muscle masses are now located entirely in either the anterior or posterior compartment of the limb, and each is formed from a portion of the original pre- and postaxial masses. The anterior or flexor compartment and the posterior or extensor compartments can be demonstrated easily by visualizing a plane that extends from the preaxial border to the postaxial border.
Note that the innervation of muscles of the anterior and posterior compartments is by all segmental levels. However, in each compartment, the muscles nearest the preaxial border tend to be innervated by the highest segmental levels (in the upper limb C5, 6), whereas the muscles closest to the postaxial border tend to be innervated by the lowest segmental levels (in the upper limb C8, T1). The dermatomal sensory innervation of the skin also follows this pattern and is clinically relevant. Dermatomes with the highest segmental innervation (C5, 6) are nearest the preaxial border while the C8 and T1 dermatomes are nearest the postaxial border. This pattern holds for any location along the length of the limb, even though not all segments are represented distally. Notice that C6 is an important dermatome of the thumb.
Changes in ventral dermatome pattern (cutaneous sensory nerve distribution) during limb development

At 4 weeks

Upper limb

C1  C4  C7
C2  C5
C3

Lower limb

L2  L5  S1
L3  L6  S2
L4  L7  S3
S2  S3

At 5 weeks

Upper limb

C1  C4  C7
C2  C5
C3

Postaxial border

Preaxial border

Lower limb

L2  L5  S1
L3  L6  S2
L4  L7  S3
S2  S3

At 7 weeks

Thumb

Preaxial border

Palmar surface

Postaxial border

Big toe

Postaxial border

Palmar surface

At 8 weeks

Dorsal surface

Postaxial border

Big toe

Preaxial border
Limb Compartments and Innervation

While the limb muscles are forming in the anterior and posterior compartments, the girdle bones are forming at the bases of the limbs to serve as their attachment sites. Particular girdle bones become attachment points for either anterior or posterior compartment muscles. Although the association of girdle bones with specific compartments is not important until Mind & Motion, knowing the association can help you understand the overall pattern of the limbs. For example, any muscle originating from the scapula (except for its coracoid process or supraglenoid tubercle) is a posterior compartment muscle and will be innervated by a posterior division nerve from the brachial plexus.

<table>
<thead>
<tr>
<th>Compartment</th>
<th>Pectoral Girdle (Upper Limb)</th>
<th>Pelvic Girdle (Lower Limb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior (flexors)</td>
<td>clavicle</td>
<td>pubis</td>
</tr>
<tr>
<td></td>
<td>coracoid process of scapula</td>
<td>ischium</td>
</tr>
<tr>
<td></td>
<td>supraglenoid tubercle of scapula</td>
<td></td>
</tr>
<tr>
<td>Posterior (extensors)</td>
<td>scapula</td>
<td>ilium</td>
</tr>
</tbody>
</table>

The organization of the brachial and lumbosacral nerve plexuses reflects the segregation of limb muscles into anterior and posterior compartments. As a result, branches from the plexuses innervate muscles either in an anterior or posterior compartment, never both compartments. In the lower extremity, the lumbosacral plexus shows a similar pattern of segregation into anterior and posterior division nerves. The divisions of the lumbosacral plexus are not as obvious as in the brachial plexus, but the overall pattern is the same; each ventral ramus divides into anterior and posterior divisions, and terminal branches of the plexus are comprised entirely of either anterior or posterior division axons.
Terminal Branches of Brachial Plexus

| Anterior division nerves (to flexors) | • musculocutaneous (arm)  
• median (forearm, hand)  
• ulnar (forearm, hand) |
|--------------------------------------|--------------------------|
| Posterior division nerves (to extensors) | • axillary (shoulder)  
• radial (arm, forearm) |

Terminal Branches of Lumbosacral Plexus

| Anterior division nerves (to flexors) | • obturator (thigh)  
• tibial (thigh, leg, foot) |
|--------------------------------------|--------------------------|
| Posterior division nerves (to extensors) | • gluteals (hip)  
• femoral (thigh)  
• fibulars (leg, foot) |

As we have just described, limb development forms functional compartments. Because each compartment is innervated by a specific nerve (with a few exceptions), it is not necessary to memorize the innervations of the individual muscles. Simply learn the nerve that innervates the compartment where the muscle is located. For example, the musculocutaneous nerve innervates all muscles in the anterior compartment of the arm. Therefore, damage to the musculocutaneous nerve would denervate the biceps brachii, brachialis, and the coracobrachialis, the muscles located in that compartment. Below are schematic images of the adult compartments of the limb. In the top image transverse sections of the arm, forearm and hand are shown (anterior is up, posterior is down). In the bottom image transverse sections of the thigh, leg and foot are shown (anterior is up, posterior is down). Note that anterior division nerves are in green and posterior division nerves are in yellow (see below for why this appears to be switched in the lower limb).¹

¹ Netter also color codes images of the brachial plexus and lumbosacral plexus like this.
## Upper Limb Compartmental Innervation

<table>
<thead>
<tr>
<th>Compartment</th>
<th>Nerve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arm</td>
<td>Anterior musculocutaneous</td>
</tr>
<tr>
<td></td>
<td>Posterior radial</td>
</tr>
<tr>
<td>Forearm</td>
<td>Anterior median and ulnar</td>
</tr>
<tr>
<td></td>
<td>Posterior radial</td>
</tr>
<tr>
<td>Hand</td>
<td>Anterior median and ulnar</td>
</tr>
<tr>
<td></td>
<td>Posterior –2</td>
</tr>
</tbody>
</table>

2. The hand does not have a posterior compartment.
3. The thigh and leg have three compartments instead of two, but there are still only two divisions of nerves.

### Lower Limb Compartmental Innervation

<table>
<thead>
<tr>
<th>Compartment</th>
<th>Nerve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thigh</td>
<td></td>
</tr>
<tr>
<td>Anterior</td>
<td>femoral</td>
</tr>
<tr>
<td>Medial</td>
<td>obturator</td>
</tr>
<tr>
<td>Posterior</td>
<td>tibial</td>
</tr>
<tr>
<td>Leg</td>
<td></td>
</tr>
<tr>
<td>Anterior</td>
<td>deep fibular</td>
</tr>
<tr>
<td>Lateral</td>
<td>superficial fibular</td>
</tr>
<tr>
<td>Posterior</td>
<td>tibial</td>
</tr>
<tr>
<td>Foot</td>
<td></td>
</tr>
<tr>
<td>Dorsal</td>
<td>deep fibular</td>
</tr>
<tr>
<td>Plantar</td>
<td>tibial (plantars)</td>
</tr>
</tbody>
</table>
Formation of the Joints and Digits

The individual bones of the skeleton do not start as individual condensations of mesenchyme. Instead a larger condensation of mesenchyme forms, and then the condensations separate where joints should form. Joints form through the process of cavitation: a space forms where a solid structure was. In a single condensation, an interzone forms where the future joint will be located. The cells at the interzone differentiate into cartilage forming cells and there is probably a small amount of programmed cell death (apoptosis) that occurs in the interzone (although this has not been fully elucidated). The cells on either side of the interzone are now physically separated and a space forms between them. The two sides of the joint must mirror each other in shape to be able to move properly, so both sides of the joint must grow simultaneously and interact through cells signaling to be able to form properly. This stage of joint formation, called morphogenesis, is still not well understood.
The digits first become evident in the limb buds when the mesoderm in the distal end of the bud starts to condense into five separate rays. The ZPA is instrumental in determining the personality of each digit (thumb to pinkie). The cells closer to the ZPA (an exposed to shh longer) turn into the pinkie. Cells that are farther away from the ZPA form the thumb.

The limb bud is originally like a paddle with the digits of the hand or foot within the paddle. To separate the digits from one another the cells between them must be removed. To do this the AER at the distal end of the limb bud begins to break up. The islands of AER are associated with the ends of each of the digits, and the areas where the AER regresses are between the digits. Where the AER has regressed the cells begin to undergo apoptosis. Eventually the digits will be completely separate from one another. If apoptosis does not occur properly syndactyly can result.
Rotation of the Lower Limb

In the adult, the innervation of compartments in the upper extremity is very straightforward. Anterior division nerves innervate muscles located in the anterior compartments of the arm, forearm, and hand, and posterior division nerves innervate muscles in the posterior compartments of the arm and forearm. However, development of the lower extremity is more complicated and the innervation pattern seems reversed. For example, the posterior division femoral nerve innervates the quadriceps femoris muscle, which is located in the anterior compartment of the adult thigh. Additionally, the quadriceps femoris muscles extend the knee!!

What accounts for this reversal? Simply put, the lower limb rotates 180° during development and the first year of life.
The lower limb starts out developing exactly like the upper limb with axes and compartments set up anteriorly and posteriorly. However, by the time of birth, the limb has rotated medially so the original anterior compartment lies in a more posterior position. The full 180° of rotation is completed by 8-11 months after birth, so that the posterior compartment of the adult thigh is the original anterior compartment, and the muscles are innervated by anterior division nerves. The rotation places the lower limb in the appropriate position for bipedal standing and weight bearing.
Rotation affects not only the muscles and their nerves, but also the overlying skin. This is apparent in the spiral pattern of both the dermatomes and the location of the greater and lesser saphenous veins. The greater saphenous vein was the original preaxial vein (notice that it is by the big toe), and the lesser saphenous vein was the original postaxial vein.

**Cephalic Vein**

**Greater Saphenous Vein**

**Basilic Vein**

**Lesser Saphenous Vein (on posterior leg)**

Adult veins that are derived from the embryonic marginal veins. The preaxial veins (cephalic and greater saphenous) are on the first digit side of the limbs. The postaxial veins (basilic and lesser saphenous) are on the fifth digit side of the limbs. The lower limb veins maintain their association with their origins throughout the rotation of the lower limb.
Limb Development Timeline
Prenatal Time Scale (Months)

19 days
- Somites in mature gastrula.

1 month
- Somite sclerotome cells migrate around the neural tube.

6 weeks
- Mesenchymal condensation for appendicular skeleton bones.

2 months
- Individual muscles develop.

10 weeks
- Primary centers of ossification expand in diaphyses.

6 weeks
- Mesenchymal precartilage condensations appear for the axial skeleton.

7 weeks
- Segmental elaboration of somite myotomes.
- The limbs rotate to their adult orientations.

3 months
- Cartilage and membrane bones of the skull develop.

Newborn
- Diaphyses ossified; secondary centers of ossification begin to appear.

Birth

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://wisc.pb.unizin.org/mindmotionanatomy/?p=1910#h5p-165
Brachial Plexus and Axilla

ELISE DAVIS, PHD

Sections:

- Note about Upper Limb Terminology
- Axillary Fossa (Axilla)
- What Is The Brachial Plexus?
  - Patterns of Limb Development Result in the Formation of the Brachial Plexus
  - Basic Formation of a Schematic Upper Limb Plexus
- The Organization of the Brachial Plexus
  - Brachial Plexus Diagrams
- Segmental Patterns of Motor Innervation of the Limb Muscles
- Dermatomes Versus Cutaneous Nerves!
- Innervation of the Joints of the Upper Limbs
- Damage/Trauma to the Brachial Plexus
- Cutaneous Veins of the Upper Limb
- Where Is The Brachial Plexus?
- Axillary Artery
- Review Videos
- Image Credits

Note about Upper Limb Terminology

In anatomy, the entire upper extremity from shoulder to fingertips is referred to as the **upper limb**. The section of the upper limb between the shoulder and the elbow is the **arm**. From elbow to wrist is the **forearm**. (It is not correct to call the entire upper limb “the arm.”)
Axillary Fossa (Axilla)

The brachial plexus and all of the structures which supply the upper limb pass through the axilla, or axillary fossa. The axilla is the region of the body which is deep to the skin of the armpit and links the root of the neck to the upper limb. It is a roughly pyramidal space that is surrounded by muscles which move the shoulder joints. The axilla contains the nerves of the brachial plexus, the axillary artery and vein, and extensive lymphatic vessels and nodes, all of which are embedded in a considerable amount of fat.

The boundaries of the axilla are:

- anteriorly: the pectoralis major and minor muscles
- medially: the serratus anterior muscle and the rib cage
- posteriorly: the scapula and the subscapularis, teres major, and latissimus dorsi muscles
- laterally: the shaft of the humerus
- inferiorly: the axillary fascia and skin of the armpit
- superiorly: the clavicle, first rib, and superior border of the scapula
As the axillary artery and vein and the brachial plexus run through this fat-filled space, they are encased in a connective tissue sheath (the **axillary sheath**). Embedded within the adipose tissue of the axilla are extensive lymphatic vessels and lymph nodes. Lymph from the ipsilateral upper limb, as well as the ipsilateral breast, passes through the dense collection of lymph nodes in this region.
A parasagittal (left) and axial (right) section through the axillary fossa, illustrating the axillary artery, axillary vein, and nerves of the brachial plexus traveling through the fossa. The axillary artery and vein and brachial plexus are within the axillary sheath. Left image is adapted from Netter Presenter. Right image is adapted from Schuenke et al., Atlas of Anatomy, Thieme Medical Publishers, 2007.

What Is The Brachial Plexus?

The **brachial plexus** is a network of nerves which innervate the muscles of the upper limb and the skin that overlies them. There is a similar network of nerves which innervates the lower limb (the **lumbosacral plexus**). In these nerve plexuses, nerve fibers (axons) from particular spinal cord segments are sorted and reorganized to form the named nerves which innervate the muscles, skin, and joints of particular regions of the limbs.

As we saw in PPP and BIB, spinal nerves in the thorax and abdomen distribute in a very orderly, segmental fashion (like in an earthworm). The dorsal rami and their branches supply the skin and intrinsic muscles of the back. The ventral rami and their branches supply the skin and muscles of the remainder of the body wall: the intercostal and abdominal wall muscles and the overlying skin. The organization of a typical spinal nerve in the thorax and abdomen is shown below.
In the regions of the limbs, the ventral rami of several spinal nerves weave together in a very specific fashion to form **plexuses**. From these plexuses, specific, named nerves are formed. These individual named nerves innervate the muscles of the limbs and provide for sensory innervation of the joints and skin in the same region. The brachial plexus gives rise to the nerves which innervate the upper limb. It is formed from the **ventral rami of spinal nerves C5, 6, 7, 8, and T1**.

(The lumbosacral plexus that innervates the lower limb is formed from the ventral rami of spinal nerves L2, 3, 4, 5, S1, 2, and 3. There is also a nerve plexus in the cervical region—the cervical plexus—that innervates the skin of the neck and posterior part of the head, as well as some muscles in the neck. It is formed by contributions from the ventral rami of spinal nerves C1, 2, 3, and 4.)
Patterns of Limb Development Result in the Formation of the Brachial Plexus

To understand the anatomy of the brachial plexus, it helps to look at the development of the upper limb in the embryo. Limb development is discussed in detail in another chapter. What follows is a brief discussion of how upper limb development results in the adult morphology and organization of the brachial plexus.

The upper limbs (and brachial plexuses) form during the fifth to eighth weeks of gestation. At the beginning of this period, when the upper limbs are just small paddle-like buds sticking out from the body, axons from the nerve cell bodies in the spinal cord grow into the developing limbs. This initial innervation will persist throughout life even as the limbs elongate and cells within
them migrate and differentiate. As the limbs form and extend away from the body, the innervation that was established early in development is simply dragged along. The changes in the shape and organization of the upper limb in the embryo, following this initial innervation, account for the adult form of the brachial plexus.

(This is similar to the way that the thoracoabdominal diaphragm is innervated. Early in development, the diaphragm forms at cervical levels and is innervated by axons from spinal levels C3, 4, and 5. As the diaphragm migrates inferiorly, it drags its previously established innervation with it. That’s why C3, 4, and 5 keep the diaphragm alive, even through the diaphragm sits at the boundary between the thorax and abdomen.)

The video below illustrates the embryonic development of the limbs.

As the limbs are growing out from the body, the undifferentiated mass of tissue in the limb bud changes into a formed limb with discrete compartments. The first step in the differentiation of the limb occurs with the formation of the bones. The bones form a longitudinal axis which divides the limb into two portions: **preaxial** and **postaxial**. (The humerus forms the long axis of the arm. The radius and ulna form the long axis of the forearm.) To understand this arrangement, use your own upper limbs. First, abduct your upper limb to 90° so that it is parallel to the ground, with the palm facing forward. Then, imagine a horizontal plane bisecting the limb through the long axis.

- The **preaxial** part of the upper limb is superior to the long axis through the embryonic limb. This is the radial (thumb) side of the upper limb.
- The **postaxial** part of the upper limb is inferior to the long axis through the embryonic limb. This is the ulnar (little finger) side of the upper limb.
Division of the developing upper limb into preaxial and postaxial muscle compartments.

From very early in the development of the upper limb, specific spinal cord levels (C5, C6, and C7) innervate the preaxial muscle mass and associated skin. Other levels (C8 and T1) innervate the postaxial muscle mass and associated skin. These relationships will persist even as the developing muscles migrate during development. Throughout life, the preaxial muscle mass will be associated with C5, C6, and C7, and the postaxial muscle mass will be associated with C8 and T1. In addition to establishing connections to specific spinal cord levels, the preaxial and postaxial muscle masses are each associated with a specific cutaneous vein. These cutaneous veins also persist throughout life, within the subcutaneous tissue of the limbs. The preaxial cutaneous vein is the **cephalic vein**; the postaxial cutaneous vein is the **basilic vein**. You will see them in the lab. (More about the cutaneous veins later in this chapter.)

As development of the embryo continues, the preaxial and postaxial muscle masses will each be further differentiated into an **anterior compartment** and a **posterior compartment**, as shown below. To visualize this, keep your upper limb abducted to 90° and then pass a coronal/frontal plane through the length of the limb so that the limb is bisected into anterior and posterior halves. There are muscles that are located anterior to the coronal plane and muscles that are located posterior to the coronal plane.

Generally, muscles in the anterior half of the limb flex the joints that they cross (when they contract, the angle between the bones decreases). By contrast, muscles on the posterior aspect of the limb generally extend the joints that they cross (increasing the angle between the bones.
when they contract). On this basis, we divide the limb into a flexor compartment (or anterior compartment) and an extensor compartment (or posterior compartment). Note that within the anterior (flexor) compartment, there are both preaxial muscles and postaxial muscles. Similarly, there are preaxial and postaxial muscle masses within the posterior (extensor) compartment.

**Limb Development**

**Anterior v. Posterior Compartments**

- **Preaxial**
  - Innervated by C5, C6, & C7
  - *posterior division fibers*

- **Anterior Compartment**
  - Innervated by C5, C6, & C7
  - *anterior division fibers*

- **Postaxial**
  - Innervated by C8 & T1
  - *posterior division fibers*

- **Anterior Compartment**
  - Innervated by C5, C6, & C7
  - *anterior division fibers*

- **Posterior Compartment**
  - Innervated by C8 & T1
  - *anterior division fibers*

Development of anterior and posterior muscle compartments in the upper limb. Notice that there is an anterior preaxial compartment and a posterior preaxial compartment as well as an anterior postaxial compartment and a posterior postaxial compartment.
Nerve fibers (axons) that innervate anterior (flexor) compartment muscles are called **anterior division fibers**. Nerve fibers that innervate posterior (extensor) compartment muscles are called **posterior division fibers**. (Motor neurons in the spinal cord innervate either flexors or extensors. Remember that motor neurons which innervate flexor or extensor muscles are located in specific regions of the ventral horn of the spinal cord.) Each spinal nerve contains both anterior and posterior division fibers. In the brachial plexus, the fibers from spinal levels C5 – T1 are re-sorted. Anterior and posterior division fibers are separated in order to form named nerves which innervate particular regions of the upper limb. For example, preaxial anterior division fibers going to the arm form the musculocutaneous nerve; postaxial anterior division fibers going to the forearm and hand form the ulnar nerve. (Somatosensory and sympathetic axons are similarly sorted in the brachial plexus.)

In summary, from early in development and continuing throughout life, spinal cord segments C5, C6, and C7 innervate the preaxial upper limb and spinal cord segments C8 and T1 innervate the postaxial upper limb.

- Anterior division fibers from C5, C6, and C7 innervate preaxial anterior compartment muscles. Anterior division fibers from C8 and T1 innervate postaxial anterior compartment muscles.
- Posterior division fibers from C5, C6, and C7 innervate preaxial posterior compartment
muscles. Posterior division fibers from C8 and T1 innervate postaxial posterior compartment muscles.

- **Though each spinal nerve contains both anterior and posterior division fibers, individual motor neurons in the spinal cord innervate EITHER flexor (anterior compartment) or extensor (posterior compartment) muscles, not both.** One of the roles of the brachial plexus is to separate the anterior and posterior division fibers which emerge in each spinal nerve. (There is a similar sorting for sensory and sympathetic axons, but it’s easier to visualize with motor neurons.) The significance of this concept will become more apparent in the diagrams of the organization of the brachial plexus in the next two sections of this chapter.

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**KNOWLEDGE CHECKS**

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://wisc.pb.unizin.org/mindmotionanatomy/?p=362#h5p-37

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An interactive H5P element has been excluded from this version of the text. You can view it online here: https://wisc.pb.unizin.org/mindmotionanatomy/?p=362#h5p-38

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**Basic Formation of a Schematic Upper Limb Plexus**

We’ll start with a simplified example which illustrates the formation of a ‘theoretical brachial plexus’ that receives input from the ventral rami of three spinal nerves, X1, X2 and X3.
Each spinal cord level has both flexor neurons (solid lines) and extensor neurons (dashed lines) which give rise to anterior and posterior division fibers, respectively. The axons of both flexor and extensor neurons leave each level of the spinal cord via the ventral rami of spinal nerves (segment 1 in the figure above). (For the real brachial plexus, there are contributions from C5-T1.)

The anterior and posterior division fibers from each spinal level separate within the plexus (segment 2 in the figure above). These components subsequently unite with their counterparts from other spinal levels to form nerves that are comprised of only anterior division (flexor) fiber or posterior division (extensor) fibers (segment 3 in the figure above).

The result of this separation is that all nerves downstream from segment 2 are composed of only anterior division fibers or only posterior division fibers. Every named nerve from the brachial plexus contains either anterior or posterior division fibers, never both.

The result of this sorting-out process is the development of several large, named nerves, named here Flexor Nerve No. 1, Flexor Nerve No. 2, and Extensor Nerve. These named nerves innervate the muscles, joints, and skin of particular regions of the limb. As a result of the interweaving in the plexus:
The Organization of the Brachial Plexus

The basic organization of the brachial plexus is shown in the figures below. Proceeding from proximal to distal, there are several components of the brachial plexus to identify: Roots, Trunks, Divisions, Cords, and Named Nerves. You should understand this organization and you should be able to draw the entire brachial plexus from memory.

- **Roots (5).** The ventral rami of spinal nerves from C5 through T1 are called the roots of the brachial plexus. (Do not confuse these roots with the dorsal and ventral roots or “rootlets” that come off of the spinal cord and form spinal nerves.) Like all ventral rami, the roots of the brachial plexus contain somatomotor, somatosensory, and sympathetic fibers. The roots of the brachial plexus contain both anterior and posterior division fibers (fibers destined for both flexor and extensor compartments).

- **Trunks (3).** The roots of C5 and C6 unite to form the Upper Trunk (or Superior Trunk) of the brachial plexus; the roots of C8 and T1 unite to form the Lower Trunk (or Inferior Trunk). The C7 root does not combine with roots of other spinal nerves; it continues as the Middle Trunk. As with the roots, the trunks contain fibers destined for both flexor and extensor compartments: somatosensory, somatomotor, and sympathetic fibers.

- **Divisions (6).** Next, each of the three trunks divides into an Anterior and a Posterior Division. All divisions contain somatomotor, somatosensory, and sympathetic fibers. Each anterior division contains only anterior division (flexor) fibers; each posterior division contains only posterior division (extensor) fibers. Distal to this point in the plexus, anterior division fibers and posterior division fibers remain segregated.

- **Cords (3).** Each cord contains somatomotor, somatosensory, and sympathetic fibers.
  - **Posterior Cord.** All three of the posterior divisions come together to form the posterior cord, so named because it lies posterior to the axillary artery (and contains only posterior division fibers). The posterior cord contains fibers from all 5 roots of the brachial plexus, C5-T1. All named nerves originating from the posterior cord will contain only posterior division nerve fibers. The nerves which arise from the posterior cord do not necessarily carry fibers from all five roots of the brachial plexus. (There is no pattern to which spinal levels are in which posterior cord nerves; it is just something that must be memorized.)
- **Lateral Cord.** The anterior division fibers from the upper and middle trunks join to form the **lateral cord.** It is located lateral to the axillary artery. The lateral cord contains anterior division fibers from C5, C6, and C7. All nerves arising from the lateral cord will contain only anterior division fibers.

- **Medial Cord.** The anterior division fibers from the lower trunk remain independent and form the **medial cord,** which is medial to the axillary artery. The medial cord contains anterior division fibers from C8 and T1. All nerves arising from the medial cord contain only anterior division fibers.

- **Named nerves.** These nerves arise from the roots, trunks, and cords of the brachial plexus and supply the muscles, joints, and skin of the upper limb. Named nerves contain either posterior division fibers or anterior division fibers, not both. Most named nerves contain somatomotor, somatosensory, and sympathetic fibers, with the exception of 'cutaneous' nerves which contain only somatosensory and sympathetic fibers.

The brachial plexus and its named branches are shown below. There can be individual variations in the contributions of different segments to the named nerves. You are responsible for knowing the “typical” brachial plexus for this class.
Brachial plexus and its branches. Case courtesy of Dr Craig Hacking, Radiopaedia.org. From the case rID: 37612
The brachial plexus, its branches, and the muscle groups innervated by those branches. This diagram will help you understand the composition and targets of each of the branches of the brachial plexus that this course will examine. You should know this chart from memory.

**Back to Top**
Segmental Patterns of Motor Innervation of the Limb Muscles

Within the brachial plexus, there are two organizational patterns that can be clinically relevant. First, there is a ‘top down’ pattern of innervation with respect to joints of the upper limb: **Muscles that move more proximal parts of the limb are innervated by more cranial spinal levels.** For example, most muscles that move the shoulder (glenohumeral) joint are innervated by motor fibers from spinal cord levels C5 and C6, whereas most muscles that move joints in the hand are innervated by motor fibers from spinal cord levels C8 and T1. This is an important concept to keep in mind when evaluating the damage caused by different nerve injuries. Damage to the C5 root of the brachial plexus will affect shoulder function much more than it will affect hand function. Conversely, damage to the T1 root of the brachial plexus will affect hand function much more than it will affect shoulder function.

The second principle is segmental innervation: **Muscles are innervated by neurons in specific segments of the spinal cord.** In general terms, we say that a muscle is innervated by a certain nerve. For example, the biceps brachii muscle is innervated by the musculocutaneous nerve. A quick look at the brachial plexus diagram shows that the musculocutaneous nerve is composed of anterior division fibers from spinal cord levels C5, C6, and C7. In reality, each muscle is usually innervated by fibers from only one or two of the spinal cord levels that are contained within a given named nerve. As an example, biceps brachii is typically innervated by fibers from C5 and C6, but not C7. This pattern is only an average and varies between individuals, but the concept is important to know when working with people who have damage to one or another specific spinal cord segment or spinal nerve.

Dermatomes Versus Cutaneous Nerves!

DERMATOMES

Just as there is precise motor innervation of the muscles of the limbs by specific spinal cord segments, there is also a very precise distribution of sensory fibers from each spinal cord level to specific areas of skin on the limbs. As was introduced in PPP, the **area of skin innervated by fibers from a single spinal cord level (by a pair of spinal nerves) is called a dermatome.** As shown in the figures below, the pattern of dermatomes of the trunk is relatively straightforward. Cutaneous branches of individual spinal nerves supply sensory (and sympathetic) fibers to a uniform band of skin around the trunk that parallels the course of the spinal nerve as it travels around the body. (Remember that there is some overlap from adjacent spinal nerves to each dermatome.)
The elongation and differential growth of the limbs during embryonic development results in a slightly different dermatomal pattern. As shown in the figure below, when the developing limb buds grow out from the lateral body wall, the original, uniform pattern is “stretched” or distorted by the growth and migration of the tissues, resulting in the pattern that is seen in the adult.

Dermatome charts vary a great deal between sources as seen in the two figures below. Notice that Figure A shows the skin over the shoulder as part of the C4 and C5 dermatomes, while Figure B shows the same region as part of the C5 and C6 dermatomes. Diagrams vary — and so do actual humans.
Given that variation, you should not spend time memorizing the standard dermatome charts of the upper limb. However, three dermatomal landmarks on the hand are fairly standard between individuals and can be helpful clinically. (A quick way to test for nerve function is to test for sensation at different places on the skin of the hand with a pin prick test.)

- Thumb: C6 dermatome
- Middle finger: C7 dermatome
- Digit 5 (little finger): C8 dermatome

**CUTANEOUS NERVES**

Innervation of the skin of the upper limb by named, cutaneous nerves follows a fairly stereotypical pattern. **The pattern of innervation by named nerves is different than the dermatomal pattern.** In this course, you are responsible for learning the distribution of the named, cutaneous nerves.
that arise from the brachial plexus, as outlined in the figure below. The pattern can be used clinically to help to determine the site of nerve damage in a patient.

Distribution of the major, named cutaneous nerves of the upper limb. Compare this pattern with the pattern of dermatomes. Named nerves contain fibers from multiple spinal levels; their territory overlaps multiple dermatomes.

Named, cutaneous nerves are branches of the brachial plexus. Remember that the brachial plexus is formed by weaving together spinal nerves from spinal cord levels C5 to T1. Because of this weaving process, most nerves that arise from the brachial plexus, including cutaneous nerves,
carry fibers from more than one spinal cord level. This means that most named, cutaneous nerves will carry axons that distribute to more than one dermatome.

Compare the figures, above and below, to convince yourself that the dermatomal pattern of cutaneous innervation is not the same as the pattern of cutaneous innervation by the named nerves.


Remember that named nerves (both motor and sensory) carry fibers from more than one spinal level. This means that the cutaneous territory of named nerves will span multiple dermatomes. THIS IS A VERY IMPORTANT CONCEPT CLINICALLY because:

- Damage to a nerve root will result in a dermatomal pattern of sensory loss.
- Damage to a named nerve will result in sensory loss which follows the pattern of cutaneous innervation by that nerve, and will span more than one dermatome.

As an example, the figure below shows the cutaneous territory of the median nerve, on the lateral aspect of the palmar side of the hand (figure A). Figure B shows the dermatomes on the palmar aspect of the hand. Together these figures show that the part of the hand that is innervated by
the median nerve sends its sensory fibers back to spinal cord levels C6, C7 and C8 via the median nerve. The cutaneous territory of the median nerve in the hand spans three dermatomes: C6, C7, and C8.

The pattern of dermatomes and the distribution of named, cutaneous nerves are of clinical significance. For example, an individual who damages their median nerve would likely show an area of sensory change consistent with the median nerve’s sensory territory: numbness over the lateral part of the palmar hand (figure A). By contrast, an individual who has a mass impinging on spinal nerve C6 would exhibit sensory deficits consistent with the C6 dermatome: numbness over the thumb and index finger on both the palmar and dorsal hand as well as on the lateral forearm (but normal sensation over the ring finger which is part of the C8 dermatome).

A) Distribution of the sensory component of the median nerve to the skin of the palmar aspect of the hand. B) Dermatomes of the hand. Drawing by Ed Bersu.

Innervation of the Joints of the Upper Limbs

In addition to innervating the muscles and skin, the nerves of the limb plexuses also innervate the joints. The sensory nerves that innervate the joints carry pain sensations, as well as
proprioceptive information about the position of the joints in space. This information is crucial to the production of coordinated movement at the level of the central nervous system. **In general, a joint is innervated by branches from all of the named nerves that supply the muscles which cross that joint** (and which produce movement at the joint). This phenomenon is known as Hilton’s Law.

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**Damage/Trauma to the Brachial Plexus**

A major reason for learning the brachial plexus in detail is to be able to diagnose injuries to it, based on sensory deficits and/or loss or weakening of specific movements. As you learn about the brachial plexus and about upper limb anatomy, think about how damage to different components of the plexus would manifest clinically. Try to diagnose what functional losses or weaknesses of movements might occur. At the beginning, think about what *general* functions would be lost or weakened: flexion or extension or both? Which general group(s) of muscles would be affected? How would cutaneous sensation change with such a deficit?

As you begin to learn and identify the specific muscles and joints in the upper limb, consider *specific* effects of deficits in their innervation. How would damage to a specific nerve manifest in a patient? Which particular muscles would be rendered non-functional? Consider which muscles would be able to compensate for the non-functional ones. How would activities of daily living be affected?

For example, what would happen if the C5 and C6 roots of the brachial plexus are stretched or torn away (avulsed) from the spinal cord, as shown in the injury below? Using the [diagrams of the brachial plexus](#), try to answer the following questions.

1. What *named nerves* would be affected by this injury, either completely or partially?
2. What joints and *muscle groups* would be affected? Flexors? Extensors? Both?
3. Generally speaking, what *losses of movement* might one anticipate in an individual with this injury? (Which movements would become impossible with such an injury?) What *weaknesses* of movement might one anticipate? Which muscles, unaffected by the injury, would be able to *compensate* for the losses?
4. What areas of the limb might exhibit *loss of sensation*?
Increasing the angle between the head and shoulder can stretch, and even sever, the upper part of the brachial plexus. 
Cutaneous Veins of the Upper Limb

The diagrams below show the major cutaneous veins of the upper limb. These superficial veins play an important role in heat exchange, when blood is brought closer to the surface of the body. They are also convenient access points for clinicians. There are no large arteries that accompany these veins. You should be able to identify the following cutaneous veins on your cadaver and on yourself. The pattern and number of these cutaneous veins is somewhat variable between individuals.

- **Cephalic vein** (1, in the figure): the preaxial cutaneous vein of the upper limb. This vein begins on the lateral side of the wrist, travels along the lateral aspect of the forearm and arm, and runs in a groove between the deltoid and pectoralis major muscles at the shoulder (the deltopectoral groove). The cephalic vein empties into the subclavian or axillary vein.
- **Basilic vein** (2, in the figure): the postaxial cutaneous vein of the upper limb. The basilic vein begins on the medial side of the wrist, travels along the medial side of the forearm, and drains into the brachial vein at the middle of the arm.
- **Median cubital vein(s)** (3, in the figure). This is the vein in your cubital fossa (the anterior part of the elbow). (These veins vary quite a bit between individuals. There can be multiple median cubital veins.) Median cubital veins may interconnect with the cephalic and/or basilic veins. These veins are often where blood is drawn.
- **Dorsal venous arch or network** (4, in the figure). These are the veins on the dorsum of your hand. They drain into the cephalic vein on the lateral side of the wrist and into the basilic vein on the medial side of the wrist.
Sketches of cutaneous veins of the upper limb. These veins are highly variable between individuals.
Where is the Brachial Plexus?

The roots of the brachial plexus emerge through the intervertebral foramina into the anterior neck and pass between the anterior and middle scalene muscles. The trunks form at the base of the anterior neck, traveling just superior to the subclavian artery. The entire plexus runs deeps to the clavicle at about the point that the anterior and posterior divisions form. The cords and named nerves form within the axilla and surround the axillary artery. Within the axilla, the cords of the brachial plexus and the axillary artery and vein travel within the dense axillary sheath.

The sections of the brachial plexus located superior to the clavicle (the roots and trunks) are referred to as the **supraclavicular brachial plexus**. The sections of the plexus located inferior to the clavicle (the cords and named nerves) are the **infraclavicular brachial plexus**. The six divisions of the brachial plexus lie just deep to the clavicle.

To get from the anterior neck into the axilla, the brachial plexus (and the axillary artery and vein) pass through the **cervicoaxillary canal**, a somewhat restricted space bounded medially by the neck muscles and first rib, anteriorly by the clavicle and posteriorly by the scapula. This space can become clinically important in cases where a tumor, overdeveloped scalene muscles, or a ‘cervical rib’ reduces the size of the canal, compressing the brachial plexus (or the axillary artery) with potential sensory and motor effects.
Course of the brachial plexus from the anterior neck to the axilla. The axillary artery (not shown) runs between the cords of the brachial plexus. From Agur, Anne, Grant's Atlas of Anatomy, Ninth Edition; 1991, Williams & Wilkins.

Axillary Artery

The axillary artery is continuous with the subclavian artery proximally and the brachial artery distally. (It changes name by region, but is the same tube.) Within the axilla, the axillary artery has extensive branches which supply muscles of the upper limb, as shown in the figure below. You will find these branches in your dissections and are responsible for knowing them.
From proximal to distal, the branches of the axillary artery are:

- **Supreme thoracic artery**: supplies structures in the first and second intercostal spaces
  - This branch is tiny and you may not find it. That’s okay.
- **Thoracoacromial trunk**: a short stump which branches quickly to supply the shoulder area
  - It has many branches which are named by where they go: pectoral, deltoïd, acromial, and
clavicular branches.

- **Lateral thoracic artery**: runs with the long thoracic nerve on the medial wall of the axilla, superficial to the serratus anterior muscle on the thoracic wall.
- **Subscapular artery**: originates from the inferior part of the axillary artery (it travels inferiorly into the axilla). It is generally the largest branch off the axillary artery and immediately bifurcates into two large branches of its own:
  - **Thoracodorsal artery**: runs with the thoracodorsal nerve, crossing the axilla to reach the latissimus dorsi muscle.
  - **Circumflex scapular artery**: travels posteriorly to reach the dorsal surface of the scapula.
- **Anterior and posterior humeral circumflex arteries**: encircle the humeral shaft. The posterior humeral circumflex artery is generally quite a bit larger in diameter and travels to the posterior shoulder with the axillary nerve (through the quadrangular space).

The subclavian/axillary/brachial artery provides the only blood supply to the entire upper limb. A blockage in the artery proximal to the thyrocervical trunk (at the root of the neck) or distal to the subscapular artery (in the distal axilla) would interrupt blood flow to the upper limb. There is no way around a blockage in those regions. However, if there is a blockage in the axillary artery between the thyrocervical trunk and the subscapular artery, there are collateral pathways which can bypass the blockage via the arteries that supply the posterior scapula. (Since arteries do not have valves, blood can flow 'backward' through the arteries, if it needs to.) This is the **scapular arterial anastomosis**.

In the event of a blockage between the thyrocervical trunk and the subscapular artery, blood can flow to the posterior side of the scapula through either the dorsal scapular artery or the suprascapular artery. Within and deep to the muscles on the posterior scapula, branches of those two blood vessels anastomose with branches of the circumflex scapular artery. These will lead ('backwards') to the subscapular artery and then back into the axillary artery to reach the upper limb, as shown in the figure below.
Scapular Arterial Anastomosis

A blockage in the axillary artery between the thyrocervical trunk and subscapular artery can be bypassed through arteries that travel to the posterior surface of the scapula. Inset figure from Netter Presenter; larger figure from Schuenke et al., Atlas of Anatomy, Thieme Medical Publishers, 2007.

Review Videos

The following two videos are excellent white board demonstrations of the brachial plexus and its branches.
An excellent review / overview video:

Image Credits

  https://commons.wikimedia.org/wiki/File%3AUpper_LimbMuscleinnervationcorrected.gif
  Netter Presenter ( http://netterreference.com.ezproxy.library.wisc.edu/content/netter_atlas_6e/?task=home)
Radiopaedia.org. From the case rID: 37612

Back to Top
Joint Structure and Function & Muscle Analysis

MEGHAN COTTER, PHD AND ELISE DAVIS, PHD

**Chapter Sections:**
- Joint Structure
- Movements at Joints
- Classification of Joints by Degree of Movement and by Shape
- How to Analyze Muscle Actions at Joints

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**Joint Structure**

The purpose of these notes is to provide you with some background about the basic structure of joints and the definitions of the specific movements that occur at the joints in the body, including the axes and planes that are associated with the movements. Details about the structures of specific individual joints will be considered as the joints are encountered during dissection.

**Definition of a joint.** A joint is the area where two or more skeletal elements (bone and/or cartilage) come together.

**Classification of joints.** There are a number of ways in which joints can be classified, none of which is perfect. We will concentrate on structural and functional classifications, as listed in the table below. We will classify based on how the skeletal elements are connected and the associated mobility of the joint. The relationships outlined in the table are generally true. As we progress through the course, we will talk about exceptions to these rules.

**Characteristics of Fibrous Joints:**

- Bones are united by dense connective tissue.
- There is no space (joint cavity) between the skeletal elements.
- There is usually little or no movement but there are exceptions!
- There are three major types of fibrous joints:
  - **Sutures.** These are the serrated junctions between bones of the skull. They are
connected by a thin layer of dense, fibrous connective tissue. Examples are the sagittal and coronal sutures. At most sutures, there is no significant movement.

- **Gomphosis.** This is the joint between a tooth and the alveolar bone of its socket. The bone and tooth are joined together by a specialized layer of connective tissue, and there is little or no movement (you hope!).

- **Interosseous membranes.** The radius and ulna, as well as the tibia and fibula, are united by dense connective tissue membranes. At the fibrous joint between the radius and ulna, movement is relatively free; very little movement occurs between the tibia and fibula.

### Characteristics of Cartilaginous Joints:

- Skeletal elements are united by cartilage.
- There is usually no space (joint cavity) between the skeletal elements.
- A slight amount of movement may occur.
- There are two major types of cartilaginous joints:
  - **Hyaline cartilage joints.** The best example is the epiphyseal cartilage plate of long bones, where the diaphysis and epiphysis are united by hyaline cartilage.
  - **Fibrocartilage joints.** Skeletal elements are united by fibrocartilage. There are two major fibrocartilage joints in humans: the pubic symphysis and the intervertebral discs.

### Characteristics of Synovial Joints:

- The skeletal elements are united by a complicated and specialized set of structures (see description below).
- There is a space between the skeletal elements: the *joint space* (or *synovial cavity*).
- These are the joints that one generally associates with free movement, although there are some synovial joints where little or no movement occurs.

The structure of synovial joints maximizes the potential for movement between two bones. There is a joint cavity between the articulating bones that is filled with a lubricating fluid (synovial fluid).
The synovial cavity plus the synovial fluid reduce friction between the articulating surfaces when the bones move.

The above figure shows a generalized synovial joint and illustrates the typical components of such a joint.

- **A joint capsule (articular capsule)** connects the skeletal elements, surrounding the articulating ends of the bones and enclosing a **joint cavity (synovial cavity)**. The joint capsule may limit or prevent unwanted movement at the joint.
- The inner surface of the joint cavity is lined by a **synovial membrane**, a thin, highly vascularized connective tissue membrane which produces **synovial fluid**. Synovial fluid diffuses through the joint space and is crucial for lubrication of the joint surfaces of the bones, ensuring free movement at the joint.
- The articular surfaces of the bones are covered by **articular cartilage**. This is usually made of hyaline cartilage. (In some cases, articular cartilage can be fibrocartilage, rather than hyaline. This is the case in the temporomandibular joint, which is subject to frequent strong forces.)
- Depending on the functional needs of the synovial joint, there can be accessory structures in and/or around the joint cavity.
- **Ligaments** add stability to joints by limiting certain movements. They are **passive stabilizers** (i.e. they work without actively contracting). (Muscles around a joint can act as active stabilizers.)
  - Ligaments prevent movement when they are tight (as opposed to when they are slack). (Try this on yourself and on skeletons in the lab. This is an important point.)
  - Whichever movement puts tension on a ligament is the movement being limited by
that ligament.

- Ligaments are classified by their location relative to the joint capsule/joint cavity.
  - **Intracapsular ligaments** are located within the joint cavity (deep to the joint capsule).
  - **Capsular ligaments** are thickenings of the joint capsule itself.
  - **Extracapsular ligaments** are located external to the joint capsule.
- **Interarticular disks** are fibrocartilaginous disks interposed between the articular surfaces of synovial joints. Important interarticular disks are present in the temporomandibular, sternoclavicular, and knee joints.

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<thead>
<tr>
<th>BY STRUCTURE (How are skeletal elements held together?)</th>
<th>BY MOBILITY (How mobile is the joint?)</th>
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<tbody>
<tr>
<td>Fibrous Joints</td>
<td>Synarthrosis</td>
</tr>
<tr>
<td>By fibrous connective tissue</td>
<td>Little or no movement</td>
</tr>
<tr>
<td>Cartilaginous Joints</td>
<td>Amphiarthrosis</td>
</tr>
<tr>
<td>By cartilage</td>
<td>Slight movement</td>
</tr>
<tr>
<td>Synovial Joints</td>
<td>Diarthrosis</td>
</tr>
<tr>
<td>Specialized structures</td>
<td>Free movement</td>
</tr>
<tr>
<td>(often subdivided by shape of articular surfaces, see below)</td>
<td></td>
</tr>
</tbody>
</table>

**KNOWLEDGE CHECK**

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://wisc.pb.unizin.org/mindmotionanatomy/?p=343#h5p-36
Movements at Joints

In order to standardize the description of movements at different joints in the body, specific names have been assigned to movements around cardinal axes and within specific planes. **Always assume that the body starts in the anatomical position when naming a specific movement.**

There are three cardinal axes, the horizontal/transverse, vertical and anteroposterior axes (which correspond to the x, y, and z axes of geometry, above). Each of these axes is associated with a single plane of movement, as shown below. Think of a wheel spinning around an axle. The axle is the axis and the wheel is the plane of movement. At every joint, bones move around a given axis within a particular plane.

The axes and planes are related as follows:

- movements around the transverse axis are in the sagittal plane,
- movements around the vertical axis are in the horizontal/transverse plane, and
- movements around the anteroposterior axis are in the coronal/frontal plane.
Standard Axes and Movements at Joints

The axes and their associated planes of movement can be superimposed on any joint in the body. At every joint, movements occur around an axis and within a plane. Around each axis, there are two movements possible, as depicted in the figures below. (The most common axis/movement relationships are defined and illustrated below. There are some exceptions to these general patterns; they will be discussed as they are encountered during the course.)

The figures below show each of the three axes of movement superimposed on the glenohumeral (shoulder) joint: the joint between the glenoid fossa of the scapula and the head of the humerus. The glenohumeral joint is the most straightforward joint in the body. It can move around all three axes and its movements are easy to see. Move your own glenohumeral (shoulder) joint to get a sense of these movements, axes and planes.

Movements commonly occurring around the **transverse axis, in the sagittal plane.**
Movement of the GH joint AROUND the transverse axis WITHIN the sagittal plane.

- **Flexion**
  - Decreasing the angle between two skeletal elements.

- **Extension**
  - Increasing the angle between two skeletal elements.

- **Hyperextension**
  - Movement in the direction of extension, beyond the anatomical position.

Movements at glenohumeral joint around transverse axis: flexion and extension. From ExRx.net.
Movements commonly occurring around the **anteroposterior axis, in the coronal/frontal plane.**

- **Abduction**
  - Movement away from the median sagittal plane, or midline, of the body (or other defined midline).

- **Adduction**
  - Movement towards the median sagittal plane, or midline, of the body (or other defined midline).

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Movement of the GH joint AROUND the anterior-posterior axis WITHIN the coronal plane.

Movements at glenohumeral joint around the anteroposterior axis: abduction and adduction.
From ExRx.net.
Movements commonly occurring around the **vertical axis, in the horizontal plane.**

- **Medial (Internal) Rotation**
  - Rotation of a limb segment about its long axis so that the anterior surface faces the midline.

- **Lateral (External) Rotation**
  - Rotation of a limb segment about its long axis so that the anterior surface faces away from the midline.

**For the trunk and head, we talk about rotation to the same or opposite side as the muscle which is contracting.**
Movements at the glenohumeral joint around the vertical axis: medial (internal) rotation and lateral (external) rotation. From ExRx.net.

**KNOWLEDGE CHECK**

An interactive H5P element has been excluded from this version of the text. You can view it online here: [https://wisc.pb.unizin.org/mindmotionanatomy/?p=343#h5p-35](https://wisc.pb.unizin.org/mindmotionanatomy/?p=343#h5p-35)

Specialized Terms for Specific Movements at Some Joints

There are also some specialized terms for movements at particular joints, or sets of joints.

**Movements of the sternoclavicular joint:**

Since the clavicle and scapula are joined together (by the acromioclavicular joint), the scapula and clavicle move together. When movement occurs at the sternoclavicular (SC) joint, both the clavicle and scapula move. Prove this to yourself by performing these movements while grabbing your
Movements of the scapula occur at the sternoclavicular joint.

• **Around AP axis of SC joint:**
  - **Elevation:** Distal ends of clavicle move superiorly. Scapula also moves superiorly along body wall.
  - **Depression:** Distal ends of clavicle move inferiorly. Scapula also moves inferiorly along body wall.

• **Around vertical axis of SC joint:**
  - **Protraction:** Clavicle and scapula rotate anteriorly, as you do when you hunch your shoulders forward. During this movement, your scapula is sliding forward along the ribs/body wall.
  - **Retraction:** Clavicle and scapula rotate posteriorly, as you do when you square your shoulders back. During this movement, your scapula is sliding backward along the ribs/body wall.

• **Around an Oblique axis through the SC joint and the superior scapula:**
  - There is no ‘transverse axis’ of movement for the SC joint; instead, the third axis of movement is oblique.
  - **Upward rotation of the glenoid fossa:** The glenoid fossa of the scapula rotates to point superiorly. This movement is necessary to fully abduct your humerus (to raise your arm over your head, for example).
  - **Downward rotation:** The glenoid fossa of the scapula rotates back to anatomical
Movements of the forearm:

- **Around the vertical axis of the forearm:**
  - **Supination:** Rotation around the vertical axis of the forearm so that the palm of the hand faces anteriorly. This is external/lateral rotation, but has a specific name in the forearm. In the anatomical position ('palms forward'), the forearms are supinated.
  - **Pronation:** Rotation around the vertical axis of the forearm so that the palm of the hand faces posteriorly. This is internal/medial rotation, but has a specific name in the forearm.

Movements of the feet:

- **Around the transverse axis of the ankle:**
  - **Plantar flexion:** Moving the top (dorsum) of the foot away from the anterior surface of the leg, as in pointing your toes.
  - **Dorsiflexion:** Bringing the dorsum of the foot towards the anterior surface of the leg.
- **Around an oblique axis through the ankle and foot:**
  - **Inversion.** Movement of the foot (at the intertarsal joints) so that the sole of the foot faces medially, like you're trying to clap your feet.
  - **Eversion.** Movement of the foot (at the intertarsal joints) so that the sole of the foot faces laterally.
Classification of Joints by Degrees of Movement & by Shape

The three axes are superimposable upon every joint, though not all joints are capable of movement around all three axes. For example, the glenohumeral (shoulder) joint is capable of movement around all three axes, while the humeroulnar (elbow) joint can move around only one axis (transverse) and the wrist joint can move around two axes (transverse and anteroposterior). Degree of movement is another common way of classifying joints.

- **Uniaxial Joints**
  - Permit movement only about a single axis.
  - Examples are the humeroulnar (elbow) joint and ankle (talocrural) joint.

- **Biaxial Joints**
  - Permit movement about two axes.
  - Examples are the wrist and knee joints.

- **Multiaxial Joints**
  - Permit movement about all three axes.
  - Examples are the shoulder and hip joints.

There are six categories of synovial joint by shape. The shape of the bony interaction at a joint plays a large role in determining the range of movement at that joint. The diagram below illustrates the six shapes of synovial joints and their usual functional classifications as well as some examples of joints in the body that fall into these categories.

- **Gliding**, or plane, joints have the potential to move around three axes (multiaxial), but are often limited by ligaments (as in the carpal bones of the wrist).
- **Hinge** joints can move around one axis (uniaxial): generally around a transverse axis (flex and extend, like the elbow).
- **Pivot** joints rotate around a vertical axis (and are uniaxial, like the axis and atlas in the cervical spine or the radius and ulna).
- **Condyloid**, or ellipsoid, joints can move around two axes (biaxial). These joints are basically a ball-and-socket joints in which the ball is oval, rather than round. This limits rotation, as in the wrist joint between the radius and the carpal bones.
- **Saddle** joints can move easily around two axes and can slightly rotate, an small but important movement. We call these multiaxial joints, but others call them biaxial. (They're kind of in between.) The only saddle joint in the body is at the base of the thumb, at the first carpometacarpal joint.
- **Ball-and-socket** joints have the largest range of movement. They are multiaxial. The hip and shoulder (glenohumeral) joints are ball-and-socket joints.
How to Analyze Muscle Actions at Joints

This method for analyzing muscle actions uses a series of steps to determine the **specific movement(s) produced by a muscle at a particular joint**. In these steps, you consider:
• the axis around which the movement is occurring at the joint
• the position of the muscle relative to that axis
• the direction that the muscle pulls

This process can be a little clunky at first, but with practice it will become automatic. The instructions below will take you through the process step-by-step, with guiding questions. The eventual goal is for you to look at a muscle, its location relative to a joint, and its fiber orientation, and be able to see how it will move that joint — without memorizing long lists of actions.

As you do this, take your time and think about the mechanics of the muscles. This is a learning process, and may take some time to sink in. It’s okay to be a little confused at the start. Ask questions to clarify the things that are confusing to you!!!!

*Step to Use to Analyze the Action of Any Muscle*

1. What are the muscle’s attachments? Which is fixed? Which is movable?
   2a. Which joint(s) does the muscle cross? (If more than one joint is crossed by the muscle, analyze each joint separately.)
   2b. Around which axis (or axes) can the joint move? Which planes of movement are associated with the axes? Which movements are possible around these axes?

   Remember that only two movements are possible around each axis.

3. In which direction (or directions) does the muscle pull? (based on the direction of the muscle’s fibers)

   Muscles shorten when they contract and will pull the movable attachment toward the fixed attachment.

4. Where is the muscle located relative to the axis of the joint? Use the movable attachment to determine this orientation.

   A muscle can be located in two directions from an axis. For example, a muscle can be both inferior and anterior to an axis. Both are correct!

5. Which movement is produced by the muscle (around the axis of the given joint)?

   Use the movements possible for the axis in question to narrow your choices to two!

   Then use the direction of pull and the location of the muscle to determine which of the two actions will be caused by the muscle in question.

The next sections will take you through these steps for analyzing the action of a hypothetical muscle around one axis of the glenohumeral joint, giving the answers along the way. Then, you will go through the same series of questions for different axes and muscles on your own (or with a group, if you want to).
Example Analysis: Hypothetical Muscle #1

Step 1: What are the muscle’s attachments?

From https://musculoskeletalkey.com/shoulder-15/ (You don’t need to know these details yet.)
The hypothetical muscle is attached to the superior scapula and the head of the humerus.

Attach your muscle to the bones.

• Proximal attachment: to the superior part of the scapula
• Distal attachment: to the lateral part of head (superior end) of the humerus.

• You will have to know or figure out a muscle's attachments before you can analyze it. It can be approximate.
• Which attachment is fixed? Which is movable?
  ◦ By convention, for muscles of the trunk, the more inferior attachment is the fixed attachment; the more superior attachment is movable.
  ◦ For limb muscles, the more proximal attachment is fixed and the more distal attachment is movable. (We will make this more complicated later, but for now, stick with these conventions.)
  ◦ In this example, the proximal attachment (scapula) is fixed and the distal attachment (humerus) is movable. So, when our hypothetical muscle contracts, the humerus will move.
Step 2a: Which joint(s) does the muscle cross?

The hypothetical muscle is attached to the superior scapula and the head of the humerus.

Look at your muscle. Start at its proximal attachment and follow the muscle distally down the upper limb. Name the joint(s) that the muscle crosses.

- In this case, just one joint is crossed: the shoulder (glenohumeral) joint.
- If, for example, the muscle attached to the scapula proximally and to the radius distally, the muscle would cross two joints: the shoulder and the elbow.

**KEY POINT: A muscle can move any joint that it crosses.**

- Even if the muscles does not have a major action at every joint that it crosses, these minor actions can become important in rehab (to compensate for functional deficits in other muscles).

Step 2b: Around which axis/axes can this joint move?

Around which axis or axes is it possible for the glenohumeral joint to move?

- It is a ball–socket joint and can move around all 3 axes: transverse, anteroposterior (AP), and vertical.
- For this example, we'll start with the AP axis. (We could choose any of the three axes. It doesn't matter which one you start with.)
- Remember that, around each axis, two movements are possible. So, once you've defined an axis, you literally have two choices for possible movements.
• Which two movements are possible around the AP axis? ABduction and ADduction!

**KEY POINT:** When you analyze muscle actions, you’ll need to go axis-by-axis. Define which axis you’re dealing with, then analyze the action of that muscle around that axis. (Choose from the two possibilities.)

Step 3: In which direction (or directions) does the muscle pull?

The hypothetical muscle pulls medially as it shortens, pulling the distal attachment toward the proximal attachment.
**KEY POINT: Muscles shorten when they contract and will pull the movable attachment toward the fixed attachment.**

- The hypothetical muscle here will pull the humeral attachment (movable) toward the scapula (fixed). The pull of the muscle is in the **medial direction** (toward the midline of the body).

Most (real) muscles have an oblique pull. In that case, you need to break the pull into its horizontal and vertical components (vectors!). More on that later.

![Diagram of muscle pull](image)

**Step 4: Where is the muscle located relative to the axis?**

*The AP axis runs through the head of the humerus from anterior to posterior.*

Describe where the muscle is in relation to the AP axis. Look particularly at the movable attachment.
• The hypothetical muscle is **superior to the AP axis**! It is also slightly **lateral to the AP axis**, based on the location of its distal (movable) attachment.

What we have so far:

• A muscle acting at the **glenohumeral joint**.
• We've chosen to analyze its **action around the AP axis**.
• The muscle **pulls in the medial direction** and is **located superior & lateral to the AP axis**.

As you analyze more muscles, it will become clear that some pull/location combinations have greater mechanical advantage than others because they are better positioned to produce movement. In the case of this muscle, the **medial pull of the muscle superior to the AP axis** has the best mechanical advantage to move the humerus and will be far more effective than a medial pull lateral to the AP axis.

Step 5: Which movement is produced by the muscle?

Going back to Step 2b, remember which movements are possible around the AP axis. Only **ABduction or ADduction** occur around the AP axis. Using your props and/or your own body, visualize how the shortening of the muscle will pull the humerus (rotating the head upward) and cause the GH joint to move. Will a medial pull superior to the AP axis of the GH joint move the humerus into **ABduction** or **ADduction**? It will **ABduct** the humerus.

Does this make sense? If yes, keep going through this exercise. If no, review this section again.

Write down your questions and ask them.

Practice this process.

Using the same steps, solidify your understanding of muscle analysis using other axes and other muscles.
1. Two muscles that act around the **AP axis** of the glenohumeral joint

Each of these muscles act around the AP axis of the GH joint. Muscle A is the same as the muscle used in the example above. Muscle B is new.

Go through each of the steps for Muscles A and B.
Solutions:

<table>
<thead>
<tr>
<th></th>
<th>Muscle A</th>
<th>Muscle B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed Attachment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Movable Attachment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direction of Pull</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Position Relative to AP Axis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Movement Produced Around AP Axis</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Posterior View of Right GH Joint**
- *dot* = AP axis
- *arrow* = direction of pull of muscle

Each of these muscles act around the AP axis of the GH joint. Muscle A is the same as the muscle used in the example. Muscle B is new.
Muscles with the same direction of pull, but different positions relative to the AP axis will have opposite actions around the axis.

(You don’t need to know the particular parts of the bones yet. It’s just for reference, in case you already know them.)

**KEY POINT:** Muscles with the same direction of pull, but opposite positions relative to an axis, will have opposite actions around the axis.
2. Two muscles that act around the vertical axis of the shoulder (glenohumeral) joint

<table>
<thead>
<tr>
<th>Horizontal Section through Right GH Joint</th>
</tr>
</thead>
<tbody>
<tr>
<td>• <em>dot</em> = vertical axis</td>
</tr>
<tr>
<td>• <em>arrow</em> = direction of pull of muscle</td>
</tr>
</tbody>
</table>

This is a transverse section through the thorax (rib, vertebral column, scapula, and humerus).

Muscles X and Y act around the vertical axis of the GH joint. These figures depict a horizontal/transverse section through the thorax (through the vertebral column, ribs, scapula, and humerus).

Go through each of the steps for Muscles X and Y.

<table>
<thead>
<tr>
<th></th>
<th>Muscle X</th>
<th>Muscle Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed Attachment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Movable Attachment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direction of Pull</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Position Relative to Vertical Axis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Movement Produced Around Vertical Axis</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Look at the attachment to the humerus!
Solutions:

Muscles X and Y act around the vertical axis of the GH joint. These figures depict a horizontal/transverse section through the thorax (rib, vertebral column, scapula and humerus).

<table>
<thead>
<tr>
<th></th>
<th>Muscle X</th>
<th>Muscle Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed Attachment</td>
<td>Posterior Scapula</td>
<td>Anterior Scapula</td>
</tr>
<tr>
<td>Movable Attachment</td>
<td>Head of Humerus</td>
<td>Head of Humerus</td>
</tr>
<tr>
<td>Direction of Pull</td>
<td>Medial</td>
<td>Medial</td>
</tr>
<tr>
<td>Position Relative to Vertical Axis</td>
<td>Posterior star</td>
<td>Anterior star</td>
</tr>
<tr>
<td>Movement Produced Around Vertical Axis</td>
<td>Lateral (External) Rotation</td>
<td>Medial (Internal) Rotation</td>
</tr>
</tbody>
</table>

Muscles with the same direction of pull, but different positions relative to the vertical axis will have opposite actions around the axis.
SAME KEY POINT: Muscles with the same direction of pull, but opposite positions relative to an axis, will have opposite actions around the axis.

3. Muscles that Act Around the Transverse Axis of the Shoulder (Glenohumeral) Joint

Muscles Q and R act on the transverse axis of the shoulder (GH) joint, as well as on the transverse axis of the elbow.

Go through each of the steps for Muscles Q and R.
These muscles also cross the elbow, with the same pull and position relative to its transverse axis.

• What would the actions of these two muscles be around the transverse axis of the elbow?

Solutions:
Muscles Q and R act on the transverse axis of the shoulder (GH) joint, as well as on the transverse axis of the elbow.

<table>
<thead>
<tr>
<th></th>
<th>Muscle Q</th>
<th>Muscle R</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fixed Attachment</strong></td>
<td>Scapula</td>
<td>Scapula</td>
</tr>
<tr>
<td><strong>Movable Attachment</strong></td>
<td>Anterior Forearm (Radius)</td>
<td>Posterior Forearm (Ulna)</td>
</tr>
<tr>
<td><strong>Direction of Pull</strong></td>
<td>Superior</td>
<td>Superior</td>
</tr>
<tr>
<td><strong>Position Relative to Vertical Axis</strong></td>
<td>Anterior</td>
<td>Posterior</td>
</tr>
<tr>
<td><strong>Movement Produced Around Vertical Axis</strong></td>
<td>Flexion of Humerus*</td>
<td>Extension of Humerus*</td>
</tr>
</tbody>
</table>

These muscles also cross the elbow, with the same pull and position relative to its transverse axis. So Muscle Q also produces flexion of the elbow & Muscle R also produces extension of the elbow.
General Principles

From the three examples in the previous section, some general principles become apparent.

1. At any joint, two muscles with the **same directions of pull** and **opposite positions relative to the axis** will exert opposing movements at that joint.
   1. For example, muscles A & B, above, both pull medially. Muscle A is superior to the AP axis & causes aBduction. Muscle B is inferior to the AP axis & causes aDduction.

2. At any joint, two muscles with **same directions of pull** and **same positions relative to the axis** will exert the same movement at that joint.
   1. For example, muscles B & C, above, both pull medially and are inferior to the AP axis. Both cause aDduction of the humerus.

**Image Credits**

ExRx.net.
I. Joints of the Pectoral Girdle

The pectoral girdle consists of the clavicle and scapula. The only articulation between this girdle and the trunk is at the sternoclavicular joint, a multiaxial joint with a wide range of motion. The clavicle and scapula are constant companions. They meet at the acromioclavicular joint, which allows only a few degrees of gliding motion because of the ligaments that hold them together. Simply stated, the girdle moves as a unit with just a bit of accommodation provided at the acromioclavicular joint.

1. **Sternoclavicular (SC) joint**: This synovial joint lies between the medial end of the clavicle and the sternum. An articular disc divides the cavity into two separate joint cavities. The SC joint is a multiaxial joint, allowing movement in three planes. The specific axes and movements of the SC joint are:
   - Anteroposterior axis – elevation and depression
   - Vertical axis – protraction and retraction
• Oblique axis – medial and lateral rotation

Sternoclavicular Movements

The last set of movements is somewhat complex and requires an explanation. Imagine holes drilled through the sternoclavicular joint and through the scapula near the midpoint of the spine. Insert an axis through these holes. This defines the oblique axis. Now, imagine the girdle rotating about this axis. **Use the inferior angle of the scapula as the reference point to define the direction of rotation.** When the inferior angle moves laterally, the movement is lateral rotation. When the inferior angle moves medially, the movement is medial rotation. The purpose of these movements is to change the position of the glenoid fossa. Lateral rotation causes the glenoid fossa to face more superiorly as when raising the upper limb above the head. Medial rotation causes the glenoid fossa to face laterally as in holding the upper limbs at the sides (in the anatomical position).
fact, the movements can also be called upward and downward rotation if describing the position of the glenoid fossa as the reference point.

Medial Rotation of the SC Joint

Lateral Rotation of the SC Joint

2. Acromioclavicular (AC) joint: This synovial joint is small and weak compared to the SC joint and usually contains an articular disk. Together, the AC and SC joints are often called the “shoulder girdle” joints. The AC joint is necessary because its small amount of gliding allows the pectoral girdle to move smoothly as a unit.

3. Coracoclavicular joint: This fibrous joint, more commonly known as the coracoclavicular ligament, holds the clavicle and scapula together. This ligament prevents independent movements of the clavicle and scapula. A sharp blow to the tip of the shoulder frequently causes a “shoulder separation” at the acromioclavicular joint. After a shoulder separation, the weight of the arm may pull the scapula down, causing the lateral end of the clavicle to appear especially prominent.
II. Glenohumeral (Shoulder) Joint

A. Movements at the Glenohumeral Joint

The shoulder joint is multiaxial. Its capsule is loose to allow great freedom of motion.

The specific axes and movements of the glenohumeral joint are:
- **abduction-adduction** around the anteroposterior axis
- **flexion-extension** occur around the transverse axis
- **medial / lateral rotation** occur around the vertical axis

B. Structure and Support of the Glenohumeral Joint

This joint consists of the head of the humerus articulating with the glenoid fossa of the scapula. A ring of fibrocartilage, the glenoid labrum, surrounds the glenoid fossa and slightly deepens and widens it. The glenoid fossa, including the glenoid labrum, is still only one third the area of the
humeral ball, so only a small proportion of the humeral head is ever in contact with the glenoid socket. Consequently, the structure of the glenohumeral joint does not provide a lot of stability.

The fibrous capsule of the shoulder joint is loose and weak to permit free movement. It has only one extracapsular ligament, the **coracohumeral ligament**, which extends from the coracoid process to the greater tubercle. This ligament strengthens the capsule when the arm is hanging at the side, but is ineffective if the shoulder joint is abducted. Additional support is provided by the **coracoacromial ligament** which forms a horizontal shelf above the glenohumeral joint. This ligament protects the joint when force is transmitted proximally along the humerus. For example, while doing pushups on parallel bars, the head of the humerus is pressed upward with considerable force against this ligament.

Most of the stability of the joint is derived from the musculotendinous cuff or **rotator cuff**, which consists of the tendons of four muscles that attach to the greater and lesser tubercles of the humerus. These are the **supraspinatus** (S), **infraspinatus** (I), and **teres minor** (T) muscles that attach to the greater tubercle and the **subscapularis** (S) muscle that attaches to the lesser tubercle (SITS).

There are two bursae associated with the shoulder joint; they are found outside the capsule. Sometimes only one of these bursae is present, sometimes both are present, and sometimes the two are connected. The **subacromial bursa** is between the rotator cuff and the acromion process and more laterally the **subdeltoid bursa** is between the rotator cuff and the deltoid muscle. These bursae reduce the friction as the muscles contract and move against the adjacent bone or muscle.

Injuries to the shoulder region are quite common. A sudden movement that forces the humerus into abduction and lateral rotation may cause a shoulder dislocation. By placing the cadaver's upper extremity in this position, you will see that the head of the humerus is placed anteriorly and inferiorly. **The inferior portion of the shoulder capsule is not reinforced by the rotator cuff, so capsular tears usually occur here.** The humeral head dislocates beyond the glenoid labrum and usually comes to lie just below the coracoid process. The coracoacromial ligament resists upward dislocation of the humerus.
C. Scapulohumeral Rhythm

Movement of the shoulder region takes place at both the glenohumeral and sternoclavicular joints. When moving through a full range of motion with 180 degrees of shoulder abduction or flexion, approximately 120 degrees of the movement occurs at the glenohumeral joint and 60 degrees of the movement occurs at the sternoclavicular joint. The approximate ratio of 2 degrees of movement at the glenohumeral joint for each 1 degree of movement at the sternoclavicular joint is called **scapulohumeral rhythm**.

Palpate the inferior angle of the scapula as one of your partners raises an arm above his or her head. You will note a shift of almost 90 degrees in the position of the inferior angle. It returns to the resting position when the arm is lowered.
III. Elbow and Radioulnar Joints

A. Movements at the Elbow and Radioulnar Joints

There are really two joints within the capsule at the elbow, but they are conventionally considered to be separate joints, i.e., the elbow joint and the proximal radioulnar joint. The elbow joint is uniaxial, allowing only flexion and extension. The proximal radioulnar joint is uniaxial and functions with the middle and distal radioulnar joints to allow pronation and supination, rotation of the radius around the ulna. The proximal radioulnar joint is considered at this time because the biceps brachii muscle functions here as a supinator due to its insertion into the radial tuberosity. The triceps brachii and brachialis muscles, which attach to the ulna, do not move the radioulnar joints.
B. Joints at the Elbow

The diagram of the elbow joint is a schematic frontal section through the humerus, radius, and ulna showing the humeroulnar, proximal radioulnar, and humeroradial joints. All of these are synovial joints.

1. **Humeroulnar joint.** This is “the” elbow joint. It consists of the pulley-like trochlea of the humerus, which articulates with the C-shaped trochlear notch of the ulna. The upper and lower hooks of the “C” of the trochlear notch are the olecranon and coronoid process, respectively. In full flexion, the coronoid process abuts the coronoid fossa of the humerus, while in full extension, the olecranon abuts the olecranon fossa of the humerus. The humeroulnar joint is **uniaxial**, permitting only flexion and extension of the elbow.

2. **Proximal radioulnar (RU) joint.** This joint is between the circumference of the head of the radius and the radial notch of the ulna. Although this is a **uniaxial** joint, it has an entirely different type of movement than the humeroulnar joint. The proximal RU joint (and the other RU joints) allows the radius to rotate relative to the ulna on an axis that is nearly vertical. These movements are like medial and lateral rotation, but since they are special, they are called **pronation** and **supination**, respectively.

3. **Humeroradial joint.** This joint is between the upper concave surface of the head of the radius and the rounded capitulum of the humerus. There is movement in this joint during both flexion and extension of the elbow and supination and pronation of the RU joints. In flexion and extension, the head of the radius slides up and down against the capitulum, whereas in supination and pronation the head of the radius “rolls” against the capitulum.
C. Middle and Distal Radioulnar Joints

The middle and distal radioulnar joints, with the proximal radioulnar joint, permit supination and pronation. The *middle radioulnar joint* is a syndesmosis formed by the interosseous membrane that joins the radius and ulna. This is the classic example of a fibrous joint that is highly movable. The fibers in the interosseous membrane pass obliquely upward from the ulna to the radius and help to transfer force between the bones. The radius is larger distally and therefore contributes the major weight-bearing surface at the wrist. In contrast, the ulna is larger proximally and therefore contributes the major weight-bearing (force-transmitting) surface at the elbow. Because of the direction of its fibers, the interosseous membrane transmits the forces received by the radius at the wrist joint to the ulna, which then transmits these forces to the humerus at the elbow joint. Imagine that the radius is pushed proximally by a force (leaning on the hand) and it simply drags the ulna along with it via the strong fibers of the interosseous membrane.

The *distal radioulnar joint* is a synovial joint between the distal end of the ulna and the ulnar notch of the radius.
D. Ligaments at the Elbow

The **anular ligament** forms approximately four fifths of a circle attached at both ends to the ulna; the radial notch of the ulna forms the remaining fifth of the circle. This ligament surrounds the head of the radius and prevents its dislocation. The **radial/lateral collateral ligament** is a simple band that attaches the lateral epicondyle and the anular ligament. It limits adduction of the elbow. The **ulnar/medial collateral ligament** is triangular and more complex than the radial collateral ligament. The ulnar collateral ligament is attached to the medial epicondyle, coronoid process, and olecranon. It limits abduction of the elbow. In addition, both the ulnar and radial collateral ligaments prevent hyperextension of the elbow.
The elbow is most frequently dislocated posteriorly, the result of a fall on the hand. Posterior dislocation is commonly accompanied by a fracture of the coronoid process.

The anterior and posterior portions of the joint capsule are relatively weak so that any swelling after injury results in distention at these sites. Muscles and deep fascia cover the anterior portion of the joint so that swelling is usually more prominent posteriorly. Likewise, aspiration of the effusion is usually done posteriorly on either side of the olecranon process.

An all-too-common injury of the elbow is a “pulled elbow.” In children under eight years old, the head of the radius is not fully developed and the anular ligament does not hold it very tightly against the radial notch of the ulna. As a result, a sudden jerk on the arm may cause a subluxation (dislocation) of the head of the radius. The forearm is usually held in pronation after the injury. The reduction of a pulled elbow is accomplished by applying firm pressure on the head of the radius as the forearm is supinated. This maneuver essentially “screws” the radial head back into place.
IV. Wrist Joint

The wrist joint is possibly the most complicated joint in the body including a complex set of articulations between the radius and carpal bones and between the carpal bones themselves. The ulna does not extend far enough distally to contact the carpals directly. Anatomically we will consider two joints at the wrist:

1. The **radiocarpal joint** is between (a) the distal end of the radius, (b) the radioulnar disc that attaches to the styloid process of the ulna, and (c) the proximal row of carpal bones: scaphoid, lunate, and triquetral (but not the pisiform). This is a synovial joint.
2. The **midcarpal joint** is between the proximal and distal rows of carpal bones (again excluding the pisiform), and therefore is between the scaphoid, lunate, and triquetral bones of the proximal row and the trapezium, trapezoid, capitate, and hamate bones of the distal row. This is also a synovial joint.
The radiocarpal and midcarpal joints move together. We do not consider discrete movements at one or the other. The wrist joint is biaxial, permitting movement on the transverse and AP axes. The movements on the transverse axis are flexion and extension; however, these movements are also called palmar flexion and dorsiflexion, respectively. The movements on the AP axis are adduction and abduction, but they are seldom described this way. Instead, adduction is usually called ulnar abduction, ulnar deviation, or ulnar flexion; abduction is usually called radial abduction, radial deviation, or radial flexion. The midcarpal joint is an auxiliary joint that amplifies movements at the wrist, especially during flexion and radial abduction.

Skeletal injuries are quite common at the wrist because we naturally outstretch our hand to break a fall. In these situations we can:
1. Force the wrist into extreme dorsiflexion (hyperextension) and fracture the distal end of the radius—called Colle's fracture.

2. Dislocate the lunate bone. It is the most frequently dislocated carpal bone and it usually dislocates toward the palm, resulting in carpal tunnel syndrome.

3. Fracture the scaphoid bone. Because the scaphoid receives its blood supply from only a restricted area, fractures of this bone often lead to aseptic necrosis of the fragment separated from its blood supply. Aseptic necrosis refers to the death of the isolated fragment without infection.

V. Joints of the Hand

The carpometacarpal joints are all synovial, but those of digits 2-4 permit very little movement. The carpometacarpal joint of digit 5 permits some flexion and lateral rotation during opposition of the little finger and the thumb. The carpometacarpal joint of digit 1 is the highly movable multiaxial joint of the thumb, capable of flexion and extension, medial and lateral rotation, and abduction and adduction.

Because the thumb is rotated 90° relative to the rest of the hand, movements of its joints are rotated 90° to similar movements of the fingers. Use the thumbnail as your reference point when analyzing movements of the thumb joints.
The **metacarpophalangeal** (MP) joints of digits 2–5 are biaxial synovial joints, permitting flexion and extension, and adduction and abduction toward and away from digit 3 (the functional midline of the hand). The MP joint of the thumb is a uniaxial joint, permitting only flexion and extension. The **interphalangeal** joints of all the digits are uniaxial synovial joints, permitting only flexion and extension.

Finger Movements

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An interactive H5P element has been excluded from this version of the text. You can view it online here: https://wisc.pb.unizin.org/mindmotionanatomy/?p=1008#h5p-85
Muscles and Neurovasculature of the Shoulder and Arm

ELISE DAVIS, PHD

Chapter Sections

Muscles that Move the Sternoclavicular Joint
Muscles that Move the Glenohumeral & Elbow Joints
Nerves that Travel through the Arm
Vasculature of the Shoulder and Arm

Muscles that Move the Sternoclavicular Joint

The sternoclavicular (SC) joint is the only joint between the axial skeleton and the upper limb. This joint between the sternum and clavicle is extraordinarily mobile. It is important to remember that the clavicle and the scapula move as a unit. Together the two bones form the pectoral (shoulder) girdle. If the scapula moves, the clavicle moves, and vice versa. They are linked by the relatively immobile acromioclavicular (AC) joint. The primary function of the AC joint is to hold the clavicle and scapula together. All movements of the pectoral girdle (scapula + clavicle) occur at the sternoclavicular joint.

Five muscles attach to the axial skeleton proximally and the clavicle and/or scapula distally. They cross and can move the SC joint. They are the trapezius, levator scapulae, rhomboids, pectoralis minor, and serratus anterior. Each muscle will be discussed below.

Note that the proximal and distal bony attachments are listed for each muscle. This information is included to help you locate the muscles and analyze their actions. The more you know about the muscles' attachments, the better you will understand their functions. However, we will not test you about specific attachments of muscles.

Trapezius

Trapezius should be familiar to you from previous dissections. We reflected it from the upper
back to expose the deeper, intrinsic back muscles. Though it does move the vertebral column, the trapezius is an extrinsic muscle of the back. It has an important role in moving the upper limb. Its movements depend on which of its attachments, proximal or distal, are fixed and which are moving.

As with many large muscles with extensive attachments, specific functions can be assigned to particular parts of trapezius. It can be divided functionally into upper, middle, and lower parts.


_Rotational View of Trapezius. The upper, middle, and lower parts of the muscle are colored differently in this figure. From Anatomography, https://commons.wikimedia.org_
Attachments:

- Proximal: skull base, spinous processes of cervical and thoracic vertebrae
- Distal: lateral third of the clavicle, medial margin of the acromion process, spine of the scapula

Innervation:

- Spinal Accessory nerve (cranial nerve XI).

Actions at the sternoclavicular (SC) joint:

- Elevation of the shoulder girdle (upper fibers)
- Depression of the shoulder girdle (lower fibers)
- Retraction of the shoulder girdle (all parts of the muscle can retract, but the middle portion of the muscle is the most efficient and significant retractor).
- Upward rotation of the glenoid fossa / Lateral rotation of inferior angle (upper and lower parts)
  - Upward rotation of the glenoid fossa is necessary for both full flexion and full abduction of the arm. In order to get your arm 180° above your head, your scapula needs to rotate so that the glenoid fossa moves in the upward direction (and the inferior angle of the scapula moves laterally). (Try it!) Only two muscles can upwardly rotate the glenoid fossa: trapezius and serratus anterior.
Both the upper and lower parts of trapezius (along with serratus anterior) will rotate the glenoid fossa upward. From W. Henry Hollinshead, Anatomy for Surgeons: Volume 3 The Back and Limbs, 3rd Edition;1982, Harper & Row; figure 4-52.

**Upward Rotation of the Glenoid Fossa** is necessary for full abduction and full flexion at the glenohumeral joint. The inferior angle of the scapula moves away from the midline during the motion.
Effects of paralysis or weakness of trapezius:

In the ‘resting’ position, the upper fibers of trapezius act to resist the force of gravity by pulling up on the shoulder girdle (aided by levator scapulae). Paralysis or weakness of trapezius will cause the shoulder to droop.
Rhomboid major and minor

The rhomboid major and minor muscles are hard to differentiate from each other in the cadaver, and you will not be expected to do so. (Rhomboid minor is superior to rhomboid major.) You can just call them ‘the rhomboids.’

Rotational view of rhomboid muscles.
From Anatomography: https://commons.wikimedia.org
Attachments:

- **Proximal:** spinous processes of cervical and thoracic vertebrae
- **Distal:** medial border of the scapula.

Innervation:

- Dorsal scapular nerve

Actions at the sternoclavicular (SC) joint:

- Elevation of the shoulder girdle
- Retraction of the shoulder girdle
- Downward rotation of glenoid fossa / Medial rotation of the inferior angle
  
  - This movement is important in adduction and extension of the arm (i.e. the return to anatomical position), especially when the movements are being resisted. (You adduct your arms against resistance every time you open a tank in the anatomy lab.)


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**Levator scapulae**

This muscle passes nearly vertically between its attachments and its name tells you its primary action: it elevates the scapula.
Attachments:

- **Proximal**: transverse processes of cervical vertebrae
- **Distal**: superior angle of the scapula

Innervation:

- Dorsal scapular nerve
Actions at the sternoclavicular (SC) joint:

- Elevation of shoulder girdle
  - Acts with trapezius to resist the force of gravity on the upper limb.
- Downward rotation of the glenoid fossa / Medial rotation of the inferior angle
- Some retraction (assists rhomboids)

Serratus anterior

Like trapezius, serratus anterior is an especially important muscle for upwardly rotating the glenoid fossa during full abduction and full flexion of the arm, as well as for maintaining the appropriate positioning of the scapula on the posterior thoracic wall. The entire serratus anterior muscle is a strong protractor of the shoulder girdle.
Attachments:

- **Proximal**: external surfaces of ribs 1 through 9, near the midaxillary line
- **Distal**: medial border of the scapula

- *Serratus anterior runs between the ribs and the medial border of the scapula.*

Innervation:

- **Long thoracic nerve**
  - This nerve is located superficial to the muscle and is easy to injure.

Actions at the sternoclavicular (SC) joint:

- **Protraction of the shoulder girdle**
- **Depression of the shoulder girdle** (inferior fibers)
- **Upward rotation of the glenoid fossa** / **Lateral rotation of inferior angle**
  - Because of its critical role in upwardly rotating the glenoid fossa of the scapula, serratus anterior is involved in both full flexion and full abduction of the arm (along with trapezius).

Serratus anterior is a strong protractor of the shoulder girdle. (from ExRx.net)

Inferior fibers of serratus anterior depress the shoulder girdle. From http://giphy.com/gifs/shrug-shrugging-leo-dicaprio-KYNywoibU1PQ4

Serratus anterior is one of only two muscles which rotate the glenoid fossa upward, as is necessary during full abduction of the humerus. (from ExRx.net).

**KNOWLEDGE CHECK**

An interactive H5P element has been excluded from this version of the text. You can view it online here: [https://wisc.pb.unizin.org/mindmotionanatomy/?p=639#h5p-44](https://wisc.pb.unizin.org/mindmotionanatomy/?p=639#h5p-44)
Clinical Correlation

Effects of weakness or paralysis of serratus anterior:

The function of serratus anterior becomes most obvious when the muscle is paralyzed, a very disabling condition. One important function of the muscle is to stabilize the scapula (and the entire shoulder girdle) by holding the scapula against the ribs of the posterior thoracic wall. Loss of function of serratus anterior causes the medial border of the scapula to protrude posteriorly, a condition called "winging" of the scapula. The winging is especially prominent during abduction or flexion of the arm, or when pushing against a wall. Normally, serratus anterior holds the scapula in place during these motions.
Winging of the scapula, posterior view and superior view. From Levangie & Norkin, Joint Structure and Function, A Comprehensive Analysis, Fifth Edition; 2011, F.A. Davis Company; Figure 7-20.
• It would be impossible for an individual to do a push-up with bilateral paralysis of serratus anterior.
• Shoulder joint abduction and flexion would be significantly impaired because of marked weakness in the ability to rotate the glenoid fossa upward.
• With paralysis of both serratus anterior and trapezius, there are marked effects on overall movement and positioning of the shoulder girdle. The ability to fully abduct and flex the arm is almost completely lost.

An illustration depicting an individual with bilateral loss of function of both serratus anterior and trapezius. The person is unable to abduct their arms above their head because of the inability to rotate the scapula. The glenoid fossa begins to face posteriorly because of the inability to hold the scapula in its normal position. Drawing by Ed Bersu.
Pectoralis minor

Pectoralis minor is a small muscle on the anterior chest. You exposed and reflected it in a previous dissection and should return it to its anatomical position.
Attachments:

- **Proximal**: ribs 3, 4 and 5
- **Distal**: coracoid process of the scapula

Innervation:

- Medial and lateral pectoral nerves

Actions at the sternoclavicular (SC) joint:

- Depression of shoulder girdle
- Protraction of shoulder girdle
- Downward rotation of the glenoid fossa / Medial rotation of the inferior angle
Pectoralis minor protracts the shoulder girdle by pulling forward on the coracoid process of the scapula. (from ExRx.net)

Pectoralis minor rotates the glenoid fossa downward by pulling medially on the coracoid process. (from ExRx.net).
Muscles that Move the Sternoclavicular Joint

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Anteroposterior Axis</th>
<th>Vertical Axis</th>
<th>Oblique Axis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trapezius (superior fibers)</td>
<td>elevation</td>
<td>retraction</td>
<td>upward rotation of glenoid fossa</td>
</tr>
<tr>
<td>Trapezius (middle fibers)</td>
<td>n/a</td>
<td>retraction</td>
<td>upward rotation of glenoid fossa (minimal)</td>
</tr>
<tr>
<td>Trapezius (lower fibers)</td>
<td>depression</td>
<td>retraction</td>
<td>upward rotation of glenoid fossa</td>
</tr>
<tr>
<td>Rhomboid Major &amp; Minor</td>
<td>elevation</td>
<td>retraction</td>
<td>downward rotation of glenoid fossa</td>
</tr>
<tr>
<td>Pectoralis Minor</td>
<td>depression</td>
<td>protraction</td>
<td>downward rotation of glenoid fossa</td>
</tr>
<tr>
<td>Levator Scapulae</td>
<td>elevation</td>
<td>retraction (some)</td>
<td>downward rotation of glenoid fossa</td>
</tr>
<tr>
<td>Serratus Anterior</td>
<td>depression</td>
<td>protraction</td>
<td>upward rotation of glenoid fossa</td>
</tr>
</tbody>
</table>

Muscles that Move the Glenohumeral & Elbow Joints

All muscles that cross the glenohumeral joint can move it. Some of these are muscles of the shoulder, attaching proximally to the axial skeleton (sternum and vertebrae), clavicle, and/or scapula and distally to the humerus. These muscles are deltoid, pectoralis major, latissimus dorsi, teres major, and muscles of the ‘rotator cuff’ (supraspinatus, infraspinatus, teres minor, and subscapularis).

Some muscles that move the glenohumeral joint are located in the arm: biceps brachii, triceps...
Muscles of the Shoulder

Deltoid

Deltoid is a large muscle which can produce all movements around all axes of the glenohumeral joint, due to its extensive attachments to the clavicle and scapula. The deltoid is generally divided functionally into three parts: anterior, middle, and posterior. Different regions of this muscle have different actions.

Attachments:

- **Proximal**: entire length of the spine of the scapula, lateral border of the acromion process, and lateral third of the clavicle.
- **Distal**: deltoid tuberosity of the humerus
Innervation:

- Axillary nerve


Actions at the glenohumeral (GH) joint:

Because there are parts of the deltoid on both sides of each of the three axes of rotation, the muscle can produce ALL of the possible movements at the glenohumeral joint, depending on which fibers are activated.

- Abduction (all fibers, except the posterior-inferior fibers)
- Adduction (posterior-inferior fibers only)
- Extension (posterior fibers)
- Flexion (anterior fibers)
- Lateral rotation (posterior fibers)
- Medial rotation (anterior fibers)

Most of deltoid abducts the GH joint. The postero-inferior fibers of deltoid adduct (from ExRx.net).
Anterior fibers of deltoid flex the GH joint. Posterior fibers of the deltoid extend the GH joint. (from ExRx.net).

Anterior fibers of deltoid medially rotate the GH joint. Posterior fibers of deltoid laterally rotate the GH joint. (from ExRx.net).


**Attachments:**

- **Proximal:**
  - medial third of the clavicle ("clavicular component")
  - anterior aspect of the sternum ("sternal component")
  - aponeurosis of the external abdominal oblique muscle/costal cartilages ("abdominal" or "costal" component)
- **Distal:** anterior aspect of the proximal humerus

Innervation:

- Medial and lateral pectoral nerves
Actions at the glenohumeral (GH) joint:

- Flexion
- Medial rotation
- ADduction

  - Think of the pectoralis major as the “hugging muscle“; all three actions of pectoralis major are necessary to hug someone!
Pectoralis major flexes the humerus at the glenohumeral joint. (From ExRx.net)

Pectoralis major medially rotates the humerus at the GH joint. (From ExRx.net)

Pectoralis major adducts the humerus at the GH joint. (From ExRx.net)
Latissimus dorsi

Rotational view of Latissimus Dorsi.

From Anatomography:
https://commons.wikimedia.org
Attachments:

- **Proximal:**
  - spinous processes of thoracic through sacral vertebrae
  - external surfaces of ribs
  - posterior iliac crest
  - inferior angle of the scapula
- **Distal:** anterior aspect of the proximal humerus.

Innervation:

- Thoracodorsal nerve (*also known as middle subscapular nerve*)

Actions at the glenohumeral (GH) joint:

- Medial rotation
- Extension
- Adduction
  - *Think of the latissimus dorsi (and teres major) as the* "**handcuff muscle**"*; all three actions of latissimus dorsi (or teres major) are necessary to put the upper limbs in the handcuff position!*

![Latissimus dorsi medially rotates the glenohumeral joint. (From ExRx.net)](ExRx.net)
Latissimus dorsi extends at the glenohumeral joint. (from ExRx.net)

Latissimus dorsi adducts at the glenohumeral joint. (From ExRx.net)
Teres major

Attachments:

- **Proximal**: posterior scapula along the inferior part of the lateral border
- **Distal**: anterior aspect of the proximal humerus

Innervation:

- Lower subscapular nerve

Actions at the glenohumeral (GH) joint:

- Medial rotation
- Extension
- ADduction

**Actions of teres major are the same as, though less powerful than, those of latissimus dorsi.**
Teres major medially rotates the humerus at the GH joint. (From ExRx.net)

Teres major extends the GH joint. (From ExRx.net)

Teres major adducts at the GH joint. (From ExRx.net)

Rotator cuff

The “rotator cuff” of the glenohumeral joint consists of four muscles which attach to the scapula proximally and the proximal part of the humerus distally: supraspinatus, infraspinatus, teres minor
and subscapularis (SITS). Each of these muscles produces specific movements at the glenohumeral joint as well as small, but important, movements which position the head of the humerus within the glenoid fossa for proper joint mechanics.

The tendons of the rotator cuff muscles blend with the capsule of the glenohumeral joint as they attach to the humerus and reinforce it anteriorly, posteriorly, and superiorly. The inferior part of the joint capsule is not reinforced by the musculotendinous “cuff”. The rotator cuff muscles help to prevent dislocation of the head of the humerus from the glenoid fossa actively, through their contraction, and passively, because they physically hold the head of the humerus in the glenoid fossa.

Shoulder joint dislocations are commonly associated with trauma to, or weakness of, the rotator cuff muscles, most often supraspinatus.

Supraspinatus

Attachments:

- **Proximal**: supraspinous fossa of the scapula
- **Distal**: greater tubercle of the humerus

Innervation:

- Suprascapular nerve
Action at the glenohumeral (GH) joint:

- Abdution, particularly active during the first 15° of abduction

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**Infrapinatus**

**Attachments:**

- Proximal: infraspinous fossa of the scapula
- Distal: greater tubercle of the humerus

**Innervation:**

- Suprascapular nerve

**Action at the glenohumeral (GH) joint:**

- Lateral rotation
Teres minor

Attachments:

- **Proximal**: posterior aspect of the scapula along the middle of the lateral border
- **Distal**: greater tubercle of the humerus

Innervation:

- Axillary nerve

Action at the glenohumeral (GH) joint:

- Lateral rotation
Subscapularis

Attachments:

- **Proximal**: subscapular fossa
- **Distal**: lesser tubercle of the humerus

Innervation:

- Upper and lower subscapular nerves
Subscapularis. From MacKinnon & Morris, Oxford Textbook of Functional Anatomy, Volume 1, Musculoskeletal System; 1986, Oxford University Press; Figure 6.3.3.

Serratus Anterior and Subscapularis Muscles
Action at the glenohumeral (GH) joint:

- Medial rotation

Stabilizing Role of the Rotator Cuff

The shallow glenoid fossa offers only a small degree of articulation for the large head of the humerus and is called a “loose-packed” joint, characterized by high mobility, but low stability. The rotator cuff muscles add stability to the glenohumeral joint. When they contract as a unit, they hold the head of the humerus firmly to the glenoid fossa, an important function in addition to their rotatory functions. Finally, the tendons of the rotator cuff muscles blend with the capsule of the...
glenohumeral joint as they approach their insertions on the humerus, providing reinforcement to the capsule. The figure shows a lateral view of the glenoid fossa, with the head of the humerus removed, to show the positions of the tendons of the rotator cuff.

Attachments of the Rotator Cuff Muscles

Rotator Cuff Tendons
## Muscles of the Shoulder that Move the Glenohumeral Joint

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Transverse Axis</th>
<th>Vertical Axis</th>
<th>Anteroposterior Axis</th>
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</thead>
<tbody>
<tr>
<td>Deltoid (anterior fibers)</td>
<td>flexion</td>
<td>medial rotation</td>
<td>abduction</td>
</tr>
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<td>n/a</td>
<td>abduction</td>
</tr>
<tr>
<td>Deltoid (posterior fibers)</td>
<td>extension</td>
<td>lateral rotation</td>
<td>superior fibers: abduction; inferior fibers: adduction</td>
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<tr>
<td>Pectoralis Major</td>
<td>flexion</td>
<td>medial rotation</td>
<td>adduction</td>
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<tr>
<td>Latissimus Dorsi</td>
<td>extension</td>
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<td>adduction</td>
</tr>
<tr>
<td>Teres Major</td>
<td>extension</td>
<td>medial rotation</td>
<td>adduction</td>
</tr>
<tr>
<td>Supraspinatus</td>
<td>n/a</td>
<td>n/a</td>
<td>abduction (especially to 15 degrees)</td>
</tr>
<tr>
<td>Infraspinatus</td>
<td>n/a</td>
<td>lateral rotation</td>
<td>n/a</td>
</tr>
<tr>
<td>Teres Minor</td>
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<td>n/a</td>
</tr>
<tr>
<td>Subscapularis</td>
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<td>medial rotation</td>
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</table>

**KNOWLEDGE CHECK**

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Muscles of the Arm

Several muscles located in the arm cross the glenohumeral joint and move it. Most also cross the elbow and can move the radioulnar and/or humeroulnar joints. The muscles of the arm are triceps brachii, biceps brachii, coracobrachialis, and brachialis.

Extensors (Posterior Compartment of the Arm)

Triceps brachii, the only muscle in the posterior compartment of the arm, produces movement at the glenohumeral and elbow (humeroulnar) joints.

Triceps Brachii

Attachments:

- Proximal:
- Long head: infraglenoid tuberosity of the scapula
- Lateral head: posterior surface of the humerus, superior to the radial groove
- Medial head: posterior surface of the humerus, inferior to the radial groove

- Distal:
  - All heads attach (via a common tendon) to the olecranon of the ulna

Innervation:

- Radial nerve

Actions at the glenohumeral (GH) joint (long head only):

- Extension
- Adduction

Action of all heads of triceps at the elbow (humeroulnar) joint:

- Extension
Flexors (Anterior Compartment of the Arm)

Three muscles are located in the anterior compartment of the arm: biceps brachii, coracobrachialis and brachialis. Like triceps brachii, biceps brachii produces movement at both the glenohumeral and humeroulnar joints, with both of its heads. Biceps brachii also crosses and moves the radioulnar joints. Coracobrachialis acts only at the glenohumeral joint. Brachialis acts only at the humeroulnar joint.

The three muscles of the anterior compartment of the arm: biceps brachii, coracobrachialis, and brachialis.

Rotational view of biceps brachii. From Anatomography: https://commons.wikimedia.org
Attachments:

- **Proximal:**
  - Long head: supraglenoid tubercle of the scapula
    - The tendon of the long head of the biceps brachii runs up the lateral side of the humerus in the intertubercular (bicipital) groove and passes through the glenohumeral joint to attach to the supraglenoid tubercle.
  - Short head: coracoid process of the scapula (in common with coracobrachialis and pectoralis minor)

- **Distal:**
  - Radial tuberosity of the radius and deep fascia of the medial aspect of the forearm.
    - The fascial attachment forms a strong band, the bicipital aponeurosis.

Innervation:

- Musculocutaneous nerve

Actions at the glenohumeral (GH) joint:

- Flexion (long and short heads)
- Abduction (long head)
- Adduction (short head)
Abduction and adduction of the GH Joint

Action at the elbow (humeroulnar) joint:

- Flexion (long and short heads)

Elbow flexion reduces the angle between the arm and forearm.

Action at the radioulnar joints:

- Supination (long and short heads)

Pronation and supination of the forearm.
Coracobrachialis

Rotational view of coracobrachialis. From Anatomography: https://commons.wikimedia.org

Attachments:

- **Proximal**: coracoid process of the scapula (in common with the short head of biceps brachii and pectoralis minor)
- **Distal**: mid-shaft of the humerus

Innervation:

- Musculocutaneous nerve

Actions at the glenohumeral (GH) joint:

- Flexion
- ADduction

- **Coracobrachialis does not cross or act at the elbow joint.**
Brachialis

Attachments:

- **Proximal:** distal shaft of the anterior humerus
• Distal: ulnar tuberosity

Innervation:

• Musculocutaneous nerve (plus some innervation from the radial nerve)

Action at the elbow (humeroulnar) joint:

• Flexion
  ◦ Brachialis is a really good flexor in all forearm positions and at all speeds. Since it is attached to the ulna, its ability to flex the elbow is unaffected by forearm position (pronation/supination).

Brachialis is the best elbow flexor. It is a good flexor in all shoulder and wrist positions. (From ExRx.net)

**Muscles of the Arm: Actions at Glenohumeral Joint**

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Transverse Axis</th>
<th>Vertical Axis</th>
<th>Anteroposterior Axis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triceps Brachii</td>
<td>extension</td>
<td>n/a</td>
<td>adduction</td>
</tr>
<tr>
<td>Biceps Brachii</td>
<td>flexion</td>
<td>n/a</td>
<td>long head:abduction; short head:adduction</td>
</tr>
<tr>
<td>Coracobrachialis</td>
<td>flexion</td>
<td>n/a</td>
<td>adduction</td>
</tr>
</tbody>
</table>
Muscles of the Arm: Actions at the Elbow Joints

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Transverse Axis</th>
<th>Vertical Axis</th>
</tr>
</thead>
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<tr>
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<td>n/a</td>
</tr>
<tr>
<td>Biceps brachii</td>
<td>flexion</td>
<td>supination</td>
</tr>
<tr>
<td>Brachialis</td>
<td>flexion</td>
<td>n/a</td>
</tr>
</tbody>
</table>
Nerves that Travel through the Arm

Four of the terminal branches of the brachial plexus travel through the length of the arm: the radial, ulnar, median, and musculocutaneous nerves. (The axillary nerve ends in the proximal arm after it innervates the deltoid and teres minor muscles.)

The **musculocutaneous nerve** pierces the coracobrachialis muscle high in the arm and runs between the biceps brachii and brachialis muscles in the anterior compartment of the arm, innervating all three muscles in that compartment. It continues into the forearm as the lateral antebrachial cutaneous nerve. The musculocutaneous nerve innervates no muscles in the forearm.

![Course of the musculocutaneous nerve](image)


The **radial nerve** wraps around the posterior shaft of the humerus, between the lateral and medial heads of triceps brachii, within the radial groove. As it runs through the arm, the radial nerve moves anteriorly, crossing over the lateral epicondyle of the humerus to enter the forearm.

Fractures of the humerus at the level of the radial groove can compress or lacerate the radial nerve. The nerve can also be compressed in this region if a person has had their arm slung over the back of a chair for a long period of time. The result is a forearm that has “fallen asleep.”
The **ulnar nerve** runs through the arm, but does not innervate any arm muscles. It travels superficially around the posterior side of the medial epicondyle of the humerus (the “funny bone”) where it is easily palpated.

The ulnar nerve is especially subject to traumatic injury when it wraps around the medial
epicondyle of the humerus. Arthritis of the elbow joint region that affects the area around the medial epicondyle can also cause compression of the ulnar nerve.

The **median nerve** is the nerve that is least likely to be damaged. It travels through the middle
of the anterior compartment of the arm next to the brachial artery and is fairly protected by surrounding muscles. As it travels through the arm, it does not innervate any muscles. Its targets are in the forearm and hand.
Arteries of Shoulder and Arm: Posterior View

Veins of Shoulder and Arm: Anterior

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Vasculature of the Shoulder and Arm

Branches of the axillary artery which supply the shoulder have been described and dissected previously. As the axillary artery continues distally and crosses the tendon of the teres major muscle, its name changes to the brachial artery. The brachial artery has several branches. The deep brachial artery (profunda brachii) wraps around the shaft of the humerus with the radial nerve to reach the posterior compartment of the arm. Both the brachial and deep brachial arteries have muscular branches that supply the muscles in the arm, with most of the blood to the anterior compartment muscles coming from the brachial artery and most of the blood to the posterior compartment muscles coming from the deep brachial artery. Both of these arteries participate in the collateral circulation around the elbow joint.

The brachial artery typically ends just distal to the elbow by bifurcating to form the radial and ulnar arteries, which supply the forearm and hand.
Review the cutaneous veins that you saw during the skinning of the upper limb. Knowing the locations of the superficial veins is important because they are used frequently for drawing blood and for giving transfusions. Take a few minutes to examine the pattern formed by the cephalic and basilic veins at the antecubital (elbow) region. Although the pattern can vary between individuals, the median cubital vein usually connects the cephalic and basilic veins. The diagram illustrates some common variations.

Demonstration of venous draw from the antecubital fossa.

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Back to Top

KNOWLEDGE CHECKS
I. General Organization of the Forearm

Like the arm, the forearm is divided by connective tissue septa into an anterior, flexor compartment and a posterior, extensor compartment. Each of these compartments has its own blood and nerve supply. The anterior compartment of the forearm contains flexor muscles, the median and ulnar nerves, and the radial and ulnar arteries, as well as the anterior interosseous artery. The posterior compartment of the forearm contains extensor muscles, the radial nerve, and the posterior interosseous artery.

Many of the forearm muscles, which move the joints of the wrist and hand, attach proximally to the distal humerus. The lateral epicondyle of the humerus is considered the ‘common extensor origin.’ The ‘common flexor origin’ is at, and just superior to, the medial epicondyle of the humerus. The forearm extensor muscles and forearm flexor muscles function primarily at the joints of the wrist and hand, but since these muscles do cross the elbow joint, they can weakly flex or extend the elbow. *(Remember that a muscle can move any joint that it crosses.)* These weak or ‘minor’ functions of the forearm muscles can be exploited clinically to compensate for loss of function of the primary movers of the elbow.
II. Naming Forearm (and Hand) Muscles

Muscles throughout the body are named based on many criteria, including their structure, location, function, shape, and attachments. For example, the biceps brachii is a two-bellied muscle in the arm, the levator scapulae elevates the scapula, the rhomboids are shaped like a rhombus and the coracobrachialis attaches to the coracoid process and humerus of the arm. Within the forearm (and hand) muscles are named in a more consistent fashion to reflect their functions. Although the names are long and seemingly ridiculous at first glance, the names provide a lot of information about the location and function of the muscle. As a starting point when naming the muscles, begin with its primary action (flexor, extensor, pronator, supinator), followed by the primary target (carpi, pollicis, digitorum, indicis, digiti minimi), then add any necessary distinguishing terms (radialis, ulnaris, superficialis, profundus, longus, brevis, teres, quadratus) if multiple muscles have similar actions. For example, there are two muscles whose primary action is to flex the wrist joint. One is located more laterally near the radius, while the other is located more medially near the ulna. Their names are flexor carpi radialis and flexor carpi ulnaris. Note that these complex names do not incorporate every possible action of the muscles into their names, but focus on the chief actions.
III. Anterior / Flexor Muscles of the Forearm

As we proceed distally from the shoulder to the hand, keep in mind that the purpose of most upper limb movements is to get the hand into the proper position to grip or manipulate an object. Muscles in the forearm are generally muscles that move the wrist and hand joints, and can act weakly at the elbow.

Most of the muscles of the forearm originate from the humerus and attach distally to bones of the wrist or hand. Muscles of the forearm that act on the hand are called extrinsic hand muscles. They have large muscle bellies in the forearm and long tendons that reach into the hand. By contrast, muscles that attach entirely within the hand are called intrinsic hand muscles. They are responsible for fine, precise movements of the hand and digits. Intrinsic muscles of the hand will be discussed later.

The anterior compartment of the forearm contains the forearm flexor muscles that are innervated by anterior division fibers of the brachial plexus. The muscles of the flexor compartment of the forearm are innervated by the median nerve (mostly) and the ulnar nerve (for 1½ muscles). The muscles of the flexor compartment are organized into four layers.
A. Superficial Flexors (4 Muscles)

Forearm Flexors, Layer One: Superficial Flexors. From Agur, Anne, Grant’s Atlas of Anatomy, Ninth Edition, Williams & Wilkins, 1991. Figure 6-78A.
Superficial Layer of Muscles of the Flexor Forearm.
Actions of Superficial Anterior Forearm Muscles

Wrist Flexion  
Radial Deviation / aBduction  
Ulnar Deviation / aDduction  
Forearm Pronation

1. Pronator Teres

Attachments:

- Proximal: medial epicondyle of the humerus (common flexor tendon)
- Distal: middle of the lateral surface of the radius

Innervation: Median nerve
Pronator teres crosses the proximal radioulnar joint. Note that the median nerve passes between its two heads as the nerve enters the forearm. From Schuenke et al., Atlas of Anatomy, Thieme Medical Publishers, 2007, pp. 344-345.

**Action at the elbow joint (humeroulnar):**

- Flexion (only when the movement is being resisted)

**Action at the radioulnar joints:**

- Pronation

*The pronator teres muscle does not cross the wrist joint*
2. Flexor Carpi Radialis

**Attachments:**

- **Proximal:** medial epicondyle of the humerus (*common flexor tendon*)
- **Distal:** anterior aspect of the base of metacarpal 2
  
  The tendon of flexor carpi radialis passes deep to the flexor retinaculum as it crosses the wrist, but it **does not** travel through the carpal tunnel.

**Innervation:** Median nerve

**Action at the elbow joint (humeroulnar):**

- Weak flexion
  
  This is not a primary function of the muscle.

**Actions at the wrist joint:**

- Flexion
- Abduction

3. Palmaris longus

Palmaris longus is absent in 10% to 15% of individuals. It is an ‘unnecessary’ muscle and can be harvested for tendon repair or replacement, as in repairs of the ulnar collateral ligament of the elbow (“Tommy John Surgery”).

**Attachments:**

- **Proximal:** medial epicondyle of the humerus (*common flexor tendon*)
- **Distal:** palmar aponeurosis

**Innervation:** Median nerve

**Action at the elbow joint (humeroulnar):**

- Weak flexion

**Actions at the wrist joint:**

- Flexion
4. Flexor Carpi Ulnaris

**Attachments**

- **Proximal:** medial epicondyle of the humerus (*common flexor tendon*)
- **Distal:** pisiform bone

**Innervation:** Ulnar nerve

*Action at the elbow joint (humeroulnar):*

- Weak flexion

*Actions at the wrist joint:*

- Flexion
- ADduction

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**Knowledge Check**

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B. Intermediate Layer (One muscle)

1. Flexor Digitorum Superficialis

Flexor digitorum superficialis is a muscle with four bellies, fused together proximally, which ends in four separate tendons (one to each digit 2-5). The four tendons form in the distal forearm, then pass through the carpal tunnel and into the hand. Each tendon attaches to one of the four fingers at the middle phalanx. The tendinous insertion to each phalanx is unique in that the tendon...
splits into medial and lateral branches which attach to the sides of the phalanx. As you’ll see, this split allows the tendons of a deeper muscle, flexor digitorum profundus, to pass between the two branches and attach to the distal phalanges of the four fingers (see figure below).

Forearm Flexors, Layer Two: Flexor Digitorum Superficialis. From Agur, Anne, Grant’s Atlas of Anatomy, Ninth Edition, Williams & Wilkins, 1991; Figure 6-78B.
• **Proximal:**
  - medial epicondyle of the humerus (*common flexor tendon*)
  - upper part of the radius
• **Distal:** sides of the middle phalanges, digits 2 to 5.
  - The tendons of this muscle split over the surfaces of the proximal interphalangeal joints and the tendons of flexor digitorum profundus pass through the openings to reach the distal phalanges.

**Innervation:** Median nerve

**Action at the elbow joint (humeroulnar):**

• Weak flexion

**Action at the wrist joint:**

• Flexion

**Action at the metacarpophalangeal and proximal interphalangeal joints of the fingers:**

• Flexion
  - *(Since flexor digitorum superficialis does not cross the DIP joints, it does not move them.)*

**Neurovascular Plane**

Between Layers 2 and 3 of the flexor forearm muscles is a **neurovascular plane**, containing the main arteries and nerves of the anterior compartment of the forearm: the radial and ulnar arteries and the median and ulnar nerves.
The neurovascular plane between the flexor digitorum superficialis and profundus contains the radial and ulnar arteries as well as the median and ulnar nerves. From Schuenke et al., Atlas of Anatomy, Thieme Medical Publishers, 2007; pp. 346-347.
C. Layer Three: Deep Flexors (Two Muscles)

The muscles found deep to the neurovascular plane do not cross the elbow; their proximal attachments are to the radius, ulna and interosseous membrane.

Forearm Flexors, Layer Three: Deep Flexors. From Agur, Anne, Grant’s Atlas of Anatomy, Ninth Edition, Williams & Wilkins, 1991; Figure 6-78C.
1. Flexor Digitorum Profundus

As with its more superficial counterpart, flexor digitorum profundus has a large, four-part belly in the forearm that forms four separate tendons to the individual digits 2-5. These tendons pass through the carpal tunnel and into the hand in order to attach to the distal phalanges of digits 2-5. To get to the distal phalanx of each finger, the tendon of flexor digitorum profundus passes through the split in the tendon of flexor digitorum superficialis.

The innervation of flexor digitorum profundus is unique. The radial half of the muscle, the two bellies and tendons which attach to digits 2 and 3, is innervated by the median nerve (like most flexor forearm muscles). The ulnar half of the muscle, the two bellies and tendons which attach to digits 4 and 5, is innervated by the ulnar nerve.

**Attachments:**

- **Proximal:** proximal 3/4 of the anterior and medial surfaces of the ulna
- **Distal:** palmar surfaces of the distal phalanges, digits 2 through 5.
  - The tendons pass through the split tendons of flexor digitorum superficialis to reach each distal phalanx.

**Innervation:**

- Lateral half of the muscle: median nerve
- Medial half of the muscle: ulnar nerve

**Action at the wrist joint:**

- Flexion

**Action at the metacarpophalangeal and interphalangeal joints, digits 2-5:**

- Flexion
  - Flexor digitorum profundus is the only muscle which can flex the DIP joints of the fingers

2. Flexor Pollicis Longus

Along with the tendons of the flexor digitorum superficialis and profundus, the tendon of flexor pollicis longus passes through the carpal tunnel as it enters the hand. It attaches to the distal phalanx of the thumb and is the only muscle that flexes the interphalangeal joint of the thumb.

**Attachments:**

- Proximal: proximal 3/4 of the anterior and medial surfaces of the ulna
- Distal: palmar surfaces of the distal phalanges, digits 2 through 5.
- **Proximal**: proximal part of the anterior surface of the radius
- **Distal**: palmar aspect of the base of the distal phalanx of the thumb (digit 1)

**Innervation**: Median nerve

**Actions at the wrist joint:**

- Flexion
- Weak abduction

**Action at the carpometacarpal, metacarpophalangeal and interphalangeal joints of the thumb:**

- Flexion
  - *Flexion of the CMC, MP, and IP joints of the thumb occurs around the AP axis.*

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D. Layer Four – one muscle

1. **Pronator Quadratus**

Pronator quadratus has one job: pronation. It acts solely around the radioulnar joints, pulling the radius medially to cause rotation of the radius around the fixed ulna.
Forearm Flexors, Layer Four: Pronator Quadratus. From Agur, Anne, Grant’s Atlas of Anatomy, Ninth Edition, Williams & Wilkins, 1991; Figure 6-78D.
Attachments:

- **Proximal**: anterior surface of the distal 1/4 of the shaft of the ulna
- **Distal**: anterior surface of the distal 1/4 of the shaft of the radius

**Innervation**: Median nerve (anterior interosseous branch)

**Action at the radioulnar joints**:

- Pronation

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The Flexor Digitorum Muscles

The flexor digitorum superficialis and profundus muscles have an unusual (and beautiful) relationship in the hand. The tendons of flexor digitorum superficialis split over the proximal phalanges of digits 2-5 and attach to the medial and lateral sides of each middle phalanx. The flexor digitorum profundus tendons run deep to those of superficialis and actually pass between the medial and lateral attachments of the superficialis tendons. The tendons of the flexor digitorum profundus then attach to the anterior surface of each distal phalanx of digits 2-5.

For everyday flexion of the fingers, flexor digitorum profundus is the main muscle used. Flexor digitorum superficialis is recruited when more power is needed, or if only PIP joint flexion is required. Based on the distal attachments of each muscle, it should be clear that flexor digitorum profundus is the only muscle capable of causing full hand closure (flexion).

Knowledge Check

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IV. Carpal Tunnel

Structure and Contents

At the wrist, the tendons of the flexor digitorum superficialis and profundus, and flexor pollicis longus muscles, and the median nerve pass through the carpal tunnel to enter the hand. Although its name suggests that the tunnel is constructed by the carpal bones alone, this is an osteofibrous tunnel constructed by the articulated carpal bones and the flexor retinaculum, a band of dense connective tissue that binds the tendons and nerves in place. Repetitive movement of these tendons within the confined carpal tunnel can cause inflammation. Tendonitis in any of the flexor tendons can effectively narrow the carpal tunnel and impinge on the median nerve, causing sensory deficits in the hand (where?). Without treatment, over time, motor deficits will appear in the muscles of the hand that are innervated by the median nerve. Note that the ulnar artery and nerve do not traverse the carpal tunnel, so are not impacted by
Flexor digitorum and flexor pollicis longus tendons and the median nerve pass through the carpal tunnel on their way to the hand. From Schuenke et al., Atlas of Anatomy, Thieme Medical Publishers, 2007; pp. 354-355.
The Gliding Mechanism for Flexor Tendons

For proper functioning of the long flexor muscles that travel through the carpal tunnel and move the digits, it is necessary:

1. to **anchor the flexor tendons to the bones** along their course (preventing 'bowstringing') so that the muscles exert maximum force on their distal attachments to the phalanges, and
2. to **facilitate friction-free gliding** of those tendons along their course, which enables the muscles to act through their full ranges of motion.

To anchor the tendons along their courses from the forearm into the hand, there are fibrous structures which form flexible tunnels through which the tendons run. At the wrist, the **flexor retinaculum**, which completes the carpal tunnel, prevents the nine flexor tendons from popping out from the wrist during flexion. More distally, along each digit are **fibrous digital sheaths**, which keep the tendons closely applied to the bones, while still allowing them to slide (see text below). These fibrous digital sheaths are discontinuous down the length of the digits. The gaps in the sheaths allow for the substantial bending of the fingers that is necessary for full flexion.

In order to allow the tendons to freely glide within the fibrous tunnels, there are specialized...
synovial sheaths surrounding the tendons. A thin layer of synovial fluid fills these membranous sacs and allows friction-free gliding of the tendons. At the wrist, deep to the flexor retinaculum and extending into the palm, the flexor digitorum tendons are surrounded by the ulnar bursa. The flexor pollicis longus tendon sits in its own sheath within the carpal tunnel, the radial bursa (see figure below).

In the digits, the flexor tendons are surrounded by synovial tendon sheaths, long tubes of synovial membrane, which end at the distal part of the middle phalanx. Usually the tendon sheath for digit 5 is continuous with the ulnar bursa and the tendon sheath for digit 1 is continuous with the radial bursa, though this can vary. Typically, the tendons in digits 2–4 are surrounded by individual sheaths which are not connected to the bursae. The tendons are enclosed in the synovial sheaths and the synovial sheaths are surrounded by the fibrous digital sheaths. So the tendons can freely glide within the fibrous tunnels, but are kept closely apposed to the bones in order to maximize their force.

The continuity between the synovial sac of digit 5 and the ulnar bursa creates a continuous open space from the little finger to the distal part of the forearm. This provides a pathway through which infection can spread from the little finger to the wrist. It is a route by which bacteria that enter via a cut on the little finger can, if left untreated, spread across the palm, through the carpal tunnel, to the distal border of the pronator quadratus muscle (where the ulnar bursa ends).
V. Posterior / Extensor Muscles of the Forearm

General organization of posterior forearm muscles

The eleven muscles of the extensor (posterior) compartment of the forearm can be considered in three groups, based on their locations within the compartment: the lateral, medial, and deep groups of extensors. All of these muscles are innervated by the radial nerve. There is a common site of origin for all but the deepest of the extensor muscles. The common extensor origin (or common extensor tendon) is from the lateral epicondyle, and the supracondylar region, of the humerus. The forearm extensors that attach to the humerus act at the elbow joint, albeit weakly. Most of these muscles extend the joints that they cross, passing posterior to the transverse axes. There are some exceptions in the extensor compartment, however, due to the anterior migration of some of these muscles during embryological development. These exceptions are listed here and will be covered throughout this chapter.

- Muscles of the lateral group of extensors pass anterior to the transverse axis of the elbow and are flexors of the elbow.
- Two of the muscles of the deep group of extensors are located just anterior to the transverse axis of the wrist, and will flex that joint.
- In both cases, the muscles will extend the more distal joints that they cross, because they pass posterior to the transverse axes.
• These ‘weird’ muscles are innervated by the radial nerve and can provide important functional compensation for movements that are lost when there is damage to the nerves of the anterior compartment of the forearm.

A. Lateral Group of Extensor Muscles

Brachioradialis, Extensor Carpi Radialis Longus, Extensor Carpi Radialis Brevis

All three of these muscles originate superior to the elbow, from the supracondylar ridge of the humerus. They all pass anterior to the transverse axis of the elbow, and will flex the elbow. Brachioradialis is the anteriormost muscle of this group and is a powerful flexor of the elbow, particularly in the handshake (thumbs-up!) position, which gives it the greatest mechanical advantage. Extensor carpi radialis longus and brevis also flex the elbow, but much more weakly than brachioradialis does.
Lateral group of forearm extensor muscles.
1. Brachioradialis

Extensor Forearm muscles, Superficial Layer. From Agur, Anne, Grant’s Atlas of Anatomy, Ninth Edition, Williams & Wilkins, 1991; Figure 6-102A.
Hammer curl to strengthen brachioradialis.
From exrx.net

Brachioradialis starts its development in the posterior compartment of the forearm, but makes a significant shift anteriorly in the embryo. It retains its innervation from the radial nerve, but, due to its new position, becomes a flexor of the elbow. Brachioradialis forms the bulk of the forearm that faces up when the forearm is in the handshake, or thumbs-up, position. Its greatest mechanical advantage for flexion is in that position. Also, it can both pronate and supinate the forearm to that position. Basically, brachioradialis likes to be in the thumbs-up position, and will pronate from full supination to the thumbs-up position and will supinate from the fully pronated position to the thumbs-up position.

Brachioradialis attaches to the distal radius, so does not cross the wrist and will not move that joint.

**Attachments:**

- **Proximal:** supracondylar ridge of the humerus
- **Distal:** styloid process of the radius

**Innervation:** Radial nerve

**Action at the elbow joint (humeroulnar):**

- Flexion

**Actions at the radioulnar joints:**

- Supination: from full pronation to mid-position (thumbs-up)
- Pronation: from full supination to a mid-position (thumbs-up)

*Brachioradialis does not cross the wrist.*
Extensor carpi muscles. From Agur, Anne, Grant's Atlas of Anatomy, Ninth Edition, Williams & Wilkins, 1991; Figure 6-102A.
2. Extensor Carpi Radialis Longus

**Attachments:**

- **Proximal:** lateral supracondylar ridge of the humerus, just distal to the attachment of brachioradialis
- **Distal:** posterior surface of the base of metacarpal 2

**Innervation:** Radial nerve

**Action at the elbow joint (humeroulnar):**

- Weak flexion
  - Look at an atlas (or the cadavers) to convince yourself of this action. Both extensor carpi radialis longus and brevis are located just anterior to the transverse axis of the elbow joint, along with brachioradialis. The extensor carpi radialis muscles do not have as
much mechanical advantage for elbow flexion as does brachioradialis, and are weak flexors.

**Actions at the wrist joint:**

- Extension
- Abduction
  - *Which other muscles will abduct the wrist?*

3. Extensor Carpi Radialis Brevis

**Attachments:**

- **Proximal:** lateral epicondyle of the humerus (*common extensor origin*)
- **Distal:** posterior surface of the base of metacarpal 3

**Innervation:** Radial nerve

**Action at the elbow joint (humeroulnar):**

- Weak flexion (see description for extensor carpi radialis longus)

**Actions at the wrist joint:**

- Extension
- Abduction

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**B. Medial Group of Extensor Muscles**

Extensor Digitorum, Extensor Digiti Minimi, Extensor Carpi Ulnaris
Extensor digitorum and extensor digiti minimi muscles. From Agur, Anne, Grant’s Atlas of Anatomy, Ninth Edition, Williams & Wilkins, 1991; Figure 6-102C.
Muscles of medial group of forearm extensors.
1. Extensor Digitorum

Like the flexor digitorum muscles, extensor digitorum is a large-bellied muscle with multiple tendons to digits 2–5. The tendons from this and other extensors of the digits are more variable than they are on the flexor side. There can be multiple tendons from extensor digitorum to one digit. Not infrequently, on the dorsum of the hand, there are connections between tendons to adjacent digits. This is one of the reasons that it is harder to independently extend the fingers, compared with flexion.

It is also more difficult, if not impossible, to independently extend the PIP and DIP joints of a particular digit. This is due to the unusual way that the extensor digitorum tendons attach to the digits. Instead of a ‘regular’ tendinous insertion into the bone, the tendons of extensor digitorum expand at the MP joints into a flattened tendinous ‘hood’ over the dorsum of the entire length of the digit, to form a structure called the extensor expansion, or extensor hood. This specialized structure serves to link the PIP and DIP joints in extension. It will be discussed later in this section.

**Attachments:**

- **Proximal:** lateral epicondyle of the humerus (*common extensor origin*)
- **Distal:** posterior surfaces of the middle and distal phalanges of digits 2 through 5, via the extensor expansion (see description below).

**Innervation:** Deep radial nerve

**Action at the elbow joint (humeroulnar):**

- Weak extension

**Action at the wrist joint:**

- Extension

**Action on the carpometacarpal joints:**

- Extension (where possible)
  - Only CMC 4 & 5 really have any potential for movement.

**Action on the metacarpophalangeal joints:**

- Extension
  - *Extensor digitorum* is the **only** muscle that can extend the MP joints.

**Action on the interphalangeal joints:**

- Helps to extend at the interphalangeal joints (in conjunction with the lumbral and
interosseous muscles, intrinsic muscles of the hand)

- *Extensor digitorum cannot extend the digits by itself. It needs the active assistance of the interosseous muscles and lumbricals to overcome the passive tension from the flexor tendons on the palmar side of the digits.*

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**Extensor Expansions**

The distal attachments of the tendons of extensor digitorum are unique. At the metacarpophalangeal joints, the tendons of extensor digitorum expand to form a flattened tendinous expansion (or ‘hood’) over the dorsal surface of the digits (see figure below). This tendinous expansion attaches to the ligaments which surround the joints of the digits: the MP, PIP, and DIP joints. When the extensor digitorum contracts, it pulls on the extensor expansion, tightening the entire sheet of connective tissue that covers the dorsal surface of the digit. Anything that increases the tension on the extensor expansion will extend all of the joints that are covered by the expansion: MP, PIP, and DIP. This structure is the reason that it is very hard to extend just one joint of your fingers at a time. Anything that increases the tension on the extensor expansion to extend one of the IP joints will cause the extensor expansion to pull the other IP joint into extension as well. The extensor expansion is also very important to the function of the lumbricals and interosseous muscles, intrinsic hand muscles which will be discussed in the next section.

*Extensor Expansions. From Agur, Anne, Grant’s Atlas of Anatomy, 9th Edition, Figure 6.100*
2. Extensor Digiti Minimi

The belly of extensor digiti minimi usually blends with the medial side of the belly of extensor digitorum. (Some people think it is just the medial-most part of the extensor digitorum.) This small muscle confers a degree of independence for extension of digit 5 (at least more so than for digits 3 and 4). This small action is important to open the hand widely in preparation for grasping (and for drinking tea).

**Attachments:**

- **Proximal:** lateral epicondyle of the humerus *(common extensor tendon)*
- **Distal:** extensor expansion of digit 5

**Innervation:** Deep radial nerve

**Action at the elbow joint:**

- Weak extension

**Actions at the wrist joint:**

- Extension

![Actions of extensor digiti minimi at the CMC, MP, PIP, and DIP joints. From http://etiquipedia.blogspot.com/2015_08_01_archive.html](http://etiquipedia.blogspot.com/2015_08_01_archive.html)

**Actions at the carpometacarpal joint (CMC 5):**

- Extension (a little)

**Actions at the metacarpophalangeal joint of digit 5:**

- Extension
Action at the interphalangeal joints of digit 5:

• Extension

3. Extensor Carpi Ulnaris

Attachments:

• Proximal: lateral epicondyle of the humerus (common extensor tendon)
• Distal: base of metacarpal 5

Note that the tendon of extensor carpi ulnaris crosses the wrist medial to the head of the ulna. The tendon of extensor digiti minimi passes on the lateral side of the ulnar head.

Innervation: Deep radial nerve

Action at the elbow joint (humeroulnar):

• Weak extension

Actions at the wrist joint:

• Extension
• ADduction
  • Which other muscle adducts the wrist?
C. Deep Extensor Muscles

Supinator, Abductor Pollicis Longus, Extensor Pollicis Brevis, Extensor Pollicis Longus, Extensor Indicis
Deep extensor muscles. From Agur, Anne, Grant’s Atlas of Anatomy, Ninth Edition, Williams & Wilkins, 1991; Figure 6-102C.
1. Supinator

The supinator muscle does one thing: it supinates the forearm at the radioulnar joints. It is located deep in the forearm, wrapped tightly around the proximal end of the radius.

Views of the forearm in the supinated (left) and pronated positions with the supinator, pronator teres, and pronator quadratus muscles labelled. From Netter Presenter.
Attachments:

- Proximal: lateral epicondyle of the humerus and supinator crest of the ulna
- Distal: proximal 1/3 of the anterior border of the radius (adjacent to the attachment of pronator teres)

Innervation: Deep radial nerve

Action at the radioulnar joints:

- Supination

Extrinsic Muscles of the Thumb

The three 'pollicis' muscles of the deep extensors are extrinsic thumb muscles. There is a separate extensor tendon for each joint of the thumb. One important function of these muscles is to return the thumb to the anatomical position from opposition. This movement is called reposition.

As with the other digits, the muscles to the extensor side of the thumb insert onto an extensor expansion, though it is constructed somewhat differently than those for the fingers since there is only one interphalangeal joint of the thumb.
2. Abductor Pollicis Longus

Abductor pollicis longus is attached distally to the anterolateral surface of the base of the first metacarpal. On its way to the first metacarpal, the tendon of the muscle passes anterior to the transverse axis of the wrist. So, abductor pollicis longus is a wrist flexor. It will also abduct the wrist. The muscle's main action is abduction of the first metacarpal at the first CMC joint. It is anterior to the transverse axis of the CMC joint and will pull the thumb into abduction around the transverse axis of the joint. Abductor pollicis longus does not cross the MP joint of the thumb.

**Attachments:**

- **Proximal:** posterior surface of the ulna distal to anconeus and posterior surface of the radius distal to supinator
- **Distal:** anterolateral aspect of the base of metacarpal 1

**Innervation:** Deep radial nerve

**Actions at the wrist joint:**

- Abduction
- Flexion
  - The transverse axis of the wrist joint passes through the anatomical snuffbox. The abductor pollicis longus and extensor pollicis brevis pass anterior to the transverse axis of the wrist.

**Actions at the carpometacarpal joint of the thumb:**

- Abduction
- Extension

*Abductor pollicis longus does not cross the MP joint of the thumb.*

3. Extensor Pollicis Brevis

Like abductor pollicis longus, the tendon of extensor pollicis brevis passes anterior to the transverse axis of the wrist joint, and it is a wrist flexor. It is also an abductor of the wrist, along with the other extrinsic thumb muscles.

**Attachments:**

- **Proximal:** posterior surface of the radius, distal to abductor pollicis longus
- **Distal:** lateral aspect of the base of the proximal phalanx of digit 1

**Innervation:** Deep radial nerve
Actions at the wrist joint:

- Abduction
- Flexion

Actions at the carpometacarpal joint of digit 1:

- Extension
- Abduction

Action at the metacarpophalangeal joint of digit 1:

- Extension

4. Extensor Pollicis Longus

The third extrinsic thumb muscle in the posterior compartment, extensor pollicis longus, is the only muscle to cross the IP joint of the thumb on the extensor side. Unlike the abductor pollicis longus and the extensor pollicis brevis, the extensor pollicis longus crosses the transverse axis of the wrist posteriorly, so that it is an extensor of the wrist joint.

On its way into the hand, the tendon of extensor pollicis longus passes around the dorsal tubercle of the radius. This bony prominence serves as an anatomical pulley, directing the pull of the muscle more medially in order to better effect extension of the thumb around the AP axis (medial pull superior to the axis). The tendon is especially prominent during strong extension of the interphalangeal, metacarpophalangeal and carpometacarpal joints of the thumb.

Attachments:

- Proximal: posterior surface of the ulna, distal to abductor pollicis longus
- Distal: dorsal surface of the distal phalanx of the thumb (extensor expansion)

Innervation: Deep radial nerve

Action at the wrist joint:

- Extension

Actions at the carpometacarpal joint of digit 1:

- Extension
- Adduction
- Lateral rotation
  - Lateral rotation of the thumb is a subtle movement which is necessary to return the thumb
to the anatomical position from the opposed position.

**Action at the metacarpophalangeal and interphalangeal joints of the thumb:**

- Extension

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**Anatomical Snuffbox**

*Surface anatomy of anatomical snuff box. From http://www.wikiradiography.net/page/Scaphoid-Radiography*
On the lateral side of the wrist, the tendons of extensor pollicis longus and brevis and abductor pollicis longus, form a structure referred to as the ‘anatomical snuffbox.’ The snuffbox has no function, but it is a good anatomical landmark.

The anterior boundary of the anatomical snuffbox is formed by the tendons of the abductor pollicis longus and extensor pollicis brevis which run very close together. The tendon of abductor pollicis longus lies slightly anterior to that of extensor pollicis brevis, and is quite a bit larger. The posterior boundary of the anatomical snuffbox is formed by the tendon of extensor pollicis longus.

These tendons enclose a triangular space which is prominent when you forcefully extend your thumb. Within that space is the styloid process of the radius, the radial artery (a pulse point), the scaphoid bone, and the base of the first metacarpal. The transverse axis of the wrist passes through the anatomical snuffbox as well.

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5. Extensor Indicis

One digit has the unique ability to extend independently: digit 2, the index finger. This ability stems from the presence of a unique muscle for that digit. Extensor indicis is deeper than extensor digitorum and it does not cross the elbow. It has a separate belly and a separate tendon to the second digit. The tendon inserts onto the extensor expansion, but the muscle can contract independently from extensor digitorum. This independent action of the index finger is important for the functionality of the hand, generally, and particularly in gripping/grasping and for fine manipulations of objects (pinching).

**Attachments:**

- **Proximal:** posterior surface of the ulna distal to the attachment of extensor pollicis longus
- **Distal:** extensor expansion of digit 2

**Innervation:** Deep radial nerve

**Action at the wrist joint:**

- Extension

**Actions at the metacarpophalangeal joint, digit 2:**

- Extension
- ADduction

**Action at the interphalangeal joints of digit 2:**

- Extension
As on the flexor side of the forearm, there is a band of dense connective tissue on the extensor side which holds the extensor tendons close to the bones of the forearm, preventing bowstringing of the tendons during extension and increasing the mechanical advantage of their contraction. Unlike the flexor retinaculum, which forms a single canal (the carpal tunnel) for all of the tendons which pass deep to it, the extensor retinaculum is bound down to the radius and ulna at intervals and forms six separate canals for groups of tendons. The tendons in each canal are within synovial sheaths which allow them to glide freely. No nerve branches pass deep to the extensor retinaculum, so tendonitis–related neuropathy is not a problem on the extensor side, as it is on the flexor side.
Knowledge Check

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://wisc.pb.unizin.org/mindmotionanatomy/?p=241#h5p-122

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I. Structure of the Hand

The upper limb, from the shoulder through the wrist, moves the hand through space and puts the hand in the correct position for its many intricate functions. These tiny muscles work, in concert with the extrinsic hand muscles of the forearm, to give the hand its incredible ability to move precisely and to grip objects. Think about the finely controlled movements of your thumb and fingers and the role that these movements play in everyday actions that involve grasping and pinching. These critical functions all start with the anatomy of the hand. Bones, connective tissue, muscles, and tendons are organized into a complicated and intricate architecture which gives the hand incredible abilities to move, both grossly and finely.

Start by looking at your own hands. The dorsal and palmar surfaces of the hand are very different, each specialized for particular functions. Dorsally, the skin is loose over the bones and the tendons of the extrinsic extensor muscles; there are no intrinsic muscles in the dorsal hand. The skin on the dorsal side of the hand needs to be able to move freely to allow intricate movements of the fingers and a large range of flexion during grasping. On the palmar side of the hand, the skin is very thick and tightly bound to the underlying connective tissue. This dense tissue on the palm provides a tough surface to resist shearing forces during gripping, as well as to protect the densely packed muscles, tendons, nerves, and vessels deep in the palm.
Fascial Compartments of the Hand

A tough layer of dense connective tissue in the palm, the \textit{palmar aponeurosis}, lies just deep to the skin of the middle of the palm. There are four compartments within the hand that are separated by connective tissue septa which project inwardly from the palmar aponeurosis: the \textit{thenar}, \textit{hypothenar}, \textit{palmar (central)}, and \textit{adductor} compartments. The palmar aponeurosis overlies the palmar (central) compartment of the hand, which houses the tendons of the flexor forearm muscles as they travel to the fingers, the neurovasculature of the hand, and the intrinsic muscles that move the fingers. Flanking the palmar compartment laterally is the thenar compartment and medially is the hypothenar compartment. The adductor compartment is found deep to the thenar compartment and is related to the thumb.

The intrinsic muscles of the hand attach proximally to the carpal bones or within the hand. They do not cross or act at the wrist. There are three anatomical groups of intrinsic hand muscles. The lateral group forms a mass at the base of the thumb, the \textit{thenar muscles}. The medial group of muscles forms a mass at the base of the little finger, the \textit{hypothenar muscles}. The thenar and hypothenar muscle groups each consist of three muscles: an abductor, a flexor, and an opponens muscle. A third muscle group is positioned within and deep to the central compartment of the hand and contains the adductor pollicis, lumbrical, and interosseous muscles.

Functionally, the intrinsic hand muscles are important in fine tuning the gross movements of the digits that are produced by the extrinsic muscles of the hand. In general, the ulnar side of the hand is used for strength (in gripping) and the radial side of the hand (thumb and index finger) is used for coordination and fine manipulation of objects.

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**Knowledge Check**
II. Muscles of the Thumb and Little Finger

The thumb and little finger have sets of intrinsic muscles that produce flexion, abduction, and rotation: the thenar (thumb) and hypothenar (little finger) muscles. These muscles make up the fleshy masses at the bases of the thumb and little finger.

Muscles of the Thumb (Thenar Muscles):

- Abductor Pollicis Brevis (Median Nerve)*
- Flexor Pollicis Brevis (Median Nerve)*
- Opponens Pollicis (Median Nerve)*
- Adductor Pollicis (Ulnar Nerve)
  - moves the thumb, but is not considered a ‘thenar compartment’ muscle (see below).

*These three muscles receive their innervation from the recurrent branch of the median nerve. Look at an atlas to locate this small, but crucially important, little branch. This nerve is located very superficially and is susceptible to injury. What symptoms might you see in an individual if this nerve has been injured?

Muscles of the Little Finger (Hypothenar Muscles):

- Abductor Digiti Minimi (Ulnar Nerve)
- Flexor Digiti Minimi (Ulnar Nerve)
- Opponens Digiti Minimi (Ulnar Nerve)
Thenar Muscles

The thenar muscles move the bones of the thumb, from the first carpometacarpal joint distally. The first CMC joint is very movable. Alone, it is not a very stable base for movements of the thumb. So, the bones of the thumb are stabilized by muscles and tendons arranged like guy wires around a flagpole. Effective pulls by both the extrinsic and intrinsic muscles of the thumb are needed, in every direction around the thumb, to achieve a stable base for movement (much like the rotator cuff muscles stabilize the glenohumeral joint during movements of the shoulder). During most thumb movements, the majority of thumb muscles are active, but the relative contribution of each muscle varies depending on the specific movement being produced.

1. Abductor Pollicis Brevis

This is the most lateral muscle in the thenar compartment. 

**Attachments:**

- **Proximal:** flexor retinaculum and scaphoid bone
- **Distal:** base of the proximal phalanx of the thumb
**Innervation:** Recurrent branch of median nerve

**Action at the carpometacarpal joint of the thumb:**

- Abduction

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2. Flexor Pollicis Brevis

This muscle is located medial to abductor pollicis brevis. It crosses both the CMC and MP joints of the thumb.

**Attachments:**

- **Proximal:** flexor retinaculum and palmar surface of the trapezium
- **Distal:** base of the proximal phalanx of the thumb

**Innervation:** Recurrent branch of median nerve

**Actions at the carpometacarpal joint of the thumb:**

- Flexion

**Action at the metacarpophalangeal joint of the thumb:**

- Flexion

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3. Opponens Pollicis

This is the deepest muscle in the thenar compartment. It attaches along the length of the first metacarpal and has a more horizontal fiber orientation than the other two thenar muscles. (You will need to look deep to the abductor pollicis brevis to see this muscle.) Opposition involves actions around all three axes of the CMC1 joint. During opposition, the tip of the thumb touches the tip of a finger, as it does when you make the ‘OK’ sign. There is a significant (medial) rotational component to opposition. **Opponens pollicis is the only muscle which is capable of medially rotating the thumb.**

**Attachments:**

- **Proximal:** flexor retinaculum and palmar surface of the trapezium
- **Distal:** entire shaft of the first metacarpal

**Innervation:** Recurrent branch of median nerve
Actions at the carpometacarpal joint of the thumb:

- Medial rotation
  - Medial rotation of the thumb at the carpometacarpal joint is a critical component of opposition of the thumb. Opponens pollicis is the only muscle which performs this action.

Adductor Pollicis

*(A muscle of the thumb that is not within the thenar compartment.)*

The adductor pollicis muscle is deep within the hand. You may not see it in its entirety, except in prosected specimens. To identify a major portion of it, abduct and extend the thumb of the cadaver and look for the muscle fibers between the thumb and index finger. The adductor pollicis forms most of the fleshy part of the web between the thumb and index finger when the thumb is abducted.
The adductor pollicis muscle is not considered part of the ‘thenar compartment.’ It is innervated by the ulnar nerve, unlike the other ‘pollicis’ muscles of the hand, and is located in the deep compartment of the hand, along with the interosseous and lumbrical muscles.

This two-headed muscle has two proximal attachments. The transverse head attaches along the shaft of the third metacarpal. The oblique head attaches to the capitate bone and the bases of the second and third metacarpals. The distal attachment of the muscle is to the base of the proximal phalanx of the thumb.

**Attachments:**

- **Proximal attachment (oblique head):** palmar surface of the capitate and bases of metacarpals 2 and 3
- **Proximal attachment (transverse head):** palmar surface of metacarpal 3 along most of its length
- **Distal attachment (both heads):** base of the proximal phalanx.

**Innervation:** Ulnar nerve

**Actions at the carpometacarpal joint of the thumb:**
Opposition of the Thumb

Opposition of the thumb as shown in the video above looks very simple. When you touch the pad of your thumb to the pad of any other finger, you are opposing your thumb. Opposition is a precise sequence of movements at the CMC1 and MP1 joints: some abduction, flexion, medial rotation, and adduction at the CMC1 joint and some flexion at the MP1 joint. The exact order of the movements is not completely agreed upon by anatomists. What is crucial to the movement, however, is the small amount of medial rotation that occurs at the CMC1 joint. This slight rotation turns the pad of the thumb toward the pads of the other fingers. Without it, the best you could do would be to touch the medial side of your thumb to the pads of your fingers when you tried to pinch.

Return of the thumb to the anatomical position is called reposition. It involves CMC1 extension, abduction, adduction, and lateral rotation. The lateral rotation at CMC1 is produced by extensor pollicis longus.

Hypothenar Muscles

The hypothenar muscles have the same names as the thenar muscles do (instead of ‘pollicis’ in the name, it’s ‘digiti minimi’) and have the same functions. They are a mirror image of the thenar muscles (the abductor digiti minimi is located on the medial side of the hand; the abductor pollicis brevis is on the lateral side of the hand)

1. Abductor Digiti Minimi

Abductor digiti minimi is the medial-most muscle of the hypothenar compartment. It abducts the
little finger away from the midline of the hand. (The dorsal interosseous muscles do this for the other fingers.)

**Attachments:**

- **Proximal:** pisiform bone
- **Distal:** base of the proximal phalanx of digit 5

**Innervation:** Ulnar nerve

**Actions at the fifth metacarpophalangeal joint:**

- Abduction

2. Flexor Digiti Minimi

This muscle is just lateral to the abductor digiti minimi.

**Attachments:**

- **Proximal:** hook of the hamate and flexor retinaculum
- **Distal:** base of the proximal phalanx of digit 5

**Innervation:** Ulnar nerve

**Actions at the fifth carpometacarpal joint:**

- Flexion

**Actions at the fifth metacarpophalangeal joint:**

- Flexion

3. Opponens Digiti Minimi

**Attachments:**

- **Proximal:** hook of the hamate and flexor retinaculum
- **Distal:** entire shaft of the fifth metacarpal, ulnar side

**Innervation:** Ulnar nerve

**Action at the fifth carpometacarpal joint:**
• Lateral rotation
  • Lateral rotation of the 5th CMC joint is a crucial component in opposition of the fifth digit to the thumb.

Knowledge Check

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://wisc.pb.unizin.org/mindmotionanatomy/?p=249#h5p-114
There are four tiny intrinsic muscles called lumbrical muscles that are unusual in that both their proximal and distal attachments are to tendons of other muscles. The lumbricals arise from the tendons of flexor digitorum profundus at about the middle of the palm and attach distally to the extensor hoods of the four fingers, on the radial side. (Another set of intrinsic hand muscles, the interossei, attach to the extensor hoods of the fingers as well).

The pattern of innervation of the lumbricals is also unusual. Typically, the lumbral muscles to the second and third digits are innervated by the median nerve, while the lumbral muscles of the fourth and fifth digits are innervated by the ulnar nerve. (This follows the same innervation pattern as flexor digitorum profundus, to which the lumbricals are attached.) There can be
variations in this pattern (e.g., all lumbricals innervated by the median nerve), and there are variations in the structure and presence of the muscles themselves. Despite their small size, these muscles are important to the function of the hand, as will be discussed below.

**Attachments:**

- **Proximal:** tendons of flexor digitorum profundus
- **Distal:** extensor expansions (extensor hoods) of extensor digitorum on the radial sides of digits 2-5

**Innervation:**

- The two lateral lumbrical muscles (to the index and middle fingers) are innervated by the median nerve and the two medial lumbrical muscles (to the ring and little fingers) are innervated by the ulnar nerve.

**Actions at metacarpophalangeal joints:**

- Flexion

**Actions at interphalangeal joints:**

- Extension

These actions, MP flexion combined with IP extension, are performed in concert with the interosseous muscles, via the attachments of both sets of muscles to the extensor expansions. Along with the interosseous muscles, the lumbricals are the primary extensors of the interphalangeal joints.

**B. Interosseous Muscles**

The interosseous muscles are a set of intrinsic muscles positioned between the metacarpal bones. Along with the metacarpals, the interosseous muscles make up the floor of the palmar (central) compartment of the hand. All of the interosseous muscles are innervated by branches of the ulnar nerve.

The interosseous muscles are divided into two groups. There are three palmar interosseous muscles which adduct the fingers. There are four dorsal interosseous muscles which abduct the fingers. The best way to differentiate between the dorsal and palmar interosseous muscles in the cadaver is to visualize what their action would be when they contract. Look at the distal attachment of the muscles. If the muscle attaches to the side of the finger that would pull the digit into abduction, it is a dorsal interosseous muscle; if it attaches to the side of the finger that would
aDduct the digit, it is a palmar interosseous muscle. Remember that the third digit is the midline of the hand and can only be ab ducted.

The interossei attach to the extensor hoods just distal to the MP joints. They flex the digits at the metacarpophalangeal joints and extend the interphalangeal joints through the same mechanism as the lumbricals. These relationships are described below.

Attachments:

- **Dorsal interosseous muscles (four)**
  - Proximal: adjacent metacarpal bones (*bipennate*)
  - Distal: proximal phalanges of all four fingers and their extensor hoods (distal to the MP joints)

- **Palmar interosseous muscles (three)**
  - Proximal: metacarpal bones 2, 4 and 5 (*fusiform*)
  - Distal: proximal phalanges of digits 2, 4 and 5 and their extensor hoods (distal to the MP joints)

**Innervation of all interosseous muscles**: Ulnar nerve
Actions at metacarpophalangeal joints:

- **Actions of all interosseous muscles:**
  - Flexion at metacarpophalangeal joints of digits 2-5
- **Action of dorsal interosseous muscles:**
  - Abduction at metacarpophalangeal joints of digits 2, 3 and 4
- **Action of palmar interosseous muscles:**
  - Adduction at metacarpophalangeal joints of digits 2, 4 and 5

Actions at interphalangeal joints of digits 2-5:

- Extension

The interosseous and lumbral muscles are the **primary extensors of the interphalangeal joints**. They are assisted by the extensor digitorum muscle. Extensor digitorum cannot extend the IP joints by itself.
The actions of the lumbricals and interossei at the MP and IP joints seem paradoxical at first. How can the same muscle flex the MP joints and extend the IP joints? The answer lies in the muscles’ distal attachments to the extensor expansions. Both sets of muscles attach to the extensor expansion just distal to the MP joints. This creates two different relationships to the transverse axes of the MP and the IP joints. At the MP joints, the muscles lie on the palmar (anterior) side of the axis and their superior pull will flex the MP joints. Distal to the MP joints, though, the lumbricals and interossei act through the extensor expansion, which lies posterior to the transverse axes of the IP joints. This means that contraction of these muscles will increase tension on the extensor expansion, causing both the PIP and DIP joints to extend. (Remember: anything that increases the tension on the extensor expansion will extend the IP joints.) These sets of little muscles are absolutely essential to IP extension. Without the lumbricals and interossei, the extensor digitorum alone cannot overcome the resting flexor tension in the digits to pull the IP joints into extension. Officially, the extensor digitorum, despite its name, cannot extend the digits by itself (though it is the only muscle that is capable of extending the MP joints!).
IV. Functional Anatomy of the Hand

Below is a very old-school video which shows the structures of the forearm and hand in a freshly dissected specimen. Not only is the dissection, and the description of the structures, outstanding, but the fresh tissue allows full motion of the limb, so that the function of each muscle in the forearm and hand is demonstrated very clearly. Though it is a very long video (33 minutes), it is well worth your time as a review of both the structure and function of the forearm and hand.

V. Function of the Upper Limb as a Whole

Now that you know all about the joints, muscles, nerves, and arteries of the upper limb, here are a few ways you can put all of the information together into a picture of how the upper limb works as a unit to facilitate hand function. None of this anatomy works in isolation. The action of one muscle will affect the action of others.

With respect to hand function, the upper limb exists to position the hand in space. The position of each of the joints of the upper limb affects grip strength, both through the orientation of the
joints and by changing the length-tension relationships of muscles which cross multiple joints. Use your own body to examine how different joint positions affect grip.

The **shoulder** forms a dynamic base of support. It is a unique joint complex because the ‘base’ itself can be moved to significantly adjust the position of the entire limb in space. This gives our upper limbs an incredible range of motion, as well as huge potential for injury, both acute and chronic. You might not think that shoulder position would affect grip strength, but it does. More shoulder flexion allows more grip strength. (Try it! Who usually drops the baton in a relay?)

The **elbow** changes the distance from the hand to the body. This may seem obvious, but think about how important this action is in almost everything you do with your hand. Adjusting the distance between your body and your hand is crucial. Additionally, grip strength increases with elbow extension.

The **forearm** and its ability to pronate and supinate give the upper limb an added dimension of movement. It adjusts the approach of the hand to an object and, critically, changes the direction that the palm faces, enabling a wide variety of grips and manipulations of objects.

The **wrist** transfers the movements of the forearm to the hand. It also forms, with muscular action, a stable base for the actions of the extrinsic and intrinsic hand muscles. The amount of force that is transmitted through the wrist depends on the wrist position (see figure below). Though the movements of the wrist make relatively small adjustments of the hand in space, these movements are critical for fine movements, for grip, and for controlling the length-tension relationships in muscles which reach from the distal arm and proximal forearm into the hand.

Grasping hand, illustrating the importance of wrist extension in the grip function of the hand. From Agur, Anne, Grant’s Atlas of Anatomy, 12th Edition, Williams & Wilkins.

Grip strength is especially dependent on wrist position. Try gripping an object with your wrist held in extension and compare the strength of grip when your wrist is flexed. A strong grip depends on a wrist held fairly rigid by the forearm extensors. In order for flexor digitorum
superficialis and flexor digitorum profundus to flex the MP and IP joints and make a fist, there must be active, counterbalancing extension of the wrist. Without the active wrist extension, the flexor digitorum muscles would flex the wrist instead of the finger joints. Think about the implications of a radial nerve injury on grip strength and ability.

It could be said that the grasping function is the purpose of the whole upper limb. Grasping involves a synergy between many of the muscles of the limb, both for joint positioning and for direct control of movements. The extrinsic muscles of the hand are responsible for the power of the hand and for positioning the MP and IP joints for the smaller, intrinsic muscles. The intrinsic muscles are responsible for the precision and fine-tuning of the gross movements created by the extrinsic muscles, as well as for stabilizing the joints of the hand. Additionally, in the thumb, the extrinsic muscles are critical for returning the thumb to the anatomical position from opposition (repositioning the thumb), a motion that the intrinsic muscles are incapable of performing.

For our purposes, in this class, we will consider two types of grips. The **power grip** is used to move an object through space, as in swinging a baseball bat. Power grip involves flexion at all joints of the fingers and adduction of the thumb; the palm contacts the object being gripped. In a **precision grip**, an object is held between the fingers or between the fingers and thumb. The thumb is opposed and the palm is not in contact with the object, as in holding a key (a ‘pinch’ grip). Precision grip allows you to manipulate an object and involves finer motor control than the power grip does. In all types of grip, the ulnar side of the hand is responsible for the strength of the grip and the radial side of the hand is responsible for precision of movement. Think about the implications of different nerve injuries on the ability of a person to grip effectively.

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**Knowledge Check**

An interactive H5P element has been excluded from this version of the text. You can view it online here: [https://wisc.ph.unizin.org/mindmotionanatomy/?p=249#p=115](https://wisc.ph.unizin.org/mindmotionanatomy/?p=249#p=115)
I. Blood Supply to the Hand

The hand receives collateral circulation via the radial and ulnar arteries. Both these vessels supply the forearm then continue into the hand where they form arterial arches. The ulnar artery crosses the anterior side of the wrist, immediately superficial to the carpal tunnel, then becomes the superficial palmar arch. The radial artery crosses the posterior side of the wrist, in the floor of the anatomical snuffbox. It continues distally, then passes between the thumb and second digit and forms the deep palmar arch. There are anastomoses between the two palmar arches. This deeper arch has metacarpal branches, while the superficial palmar arch forms common digital arteries, which branch into proper digital arteries. Note that the proper digital arteries (and nerves) run along each side of the finger, not down the midline.
II. Summary of Motor Innervation

Forearm:

The median nerve innervates all of the muscles of the anterior compartment of the forearm except for the flexor carpi ulnaris and ½ of the flexor digitorum profundus, which are innervated by the ulnar nerve.

The radial nerve innervates all of the muscles of the posterior compartment of the forearm.

Hand:

The median nerve innervates 2LOAF and the ulnar nerve innervates all other intrinsic muscles. (2LOAF = radial two Lumbricals, Opponens pollicis, Abductor pollicis brevis and Flexor pollicis brevis.)

The intrinsic muscles of the hand are innervated mainly by segmental levels C8-T1.
**Important spinal cord segmental levels at joints of the upper extremity**
An understanding of the spinal cord levels that are most important for movements of each joint is an important diagnostic tool in discerning peripheral nerve injuries from spinal cord injuries. In the upper limb, spinal cord levels that innervate muscles that move the joints are:

- **Shoulder joint**
  - C5, 6
- **Elbow joint**
  - C6, 7
- **Wrist joint**
  - C7, 8
- **Intrinsic muscles of the hand**
  - C8, T1

**As a general rule, segmental levels C5, 6 innervate any muscle originating from the scapula.**

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**III. Cutaneous Innervation of the Hand**

The typical cutaneous targets of major nerves to the hand are illustrated below.

![Cutaneous Distribution of Major Nerves](image)

There can be considerable variation in the distribution of the cutaneous nerves. Injury to purely cutaneous nerves is rare and usually of little consequence because of the degree of overlap that exists. However, because there is little overlap and variability in the hand, knowing the cutaneous sensory distribution of the radial, median, and ulnar nerves is helpful to quickly check for their integrity, especially in situations when the patient is unable to move.
IV. Nerve Injury

Nerves are usually protected from physical injury along most of their course by passing between the fleshy portions of muscles. However, at some point(s) along their length nearly all major nerves of the upper extremity are vulnerable to injury where they lie in more superficial positions. Injury may also result when nerves are located deep in the extremity where no soft tissue separates them from a bone. In these positions, the nerve is frequently damaged when the bone is fractured. In general, the nerves of the extremities are most vulnerable at or near the joints they cross.

Musculocutaneous nerve: is rarely injured. It is well protected by the biceps brachii muscle.

Radial nerve: The radial nerve reaches the posterior compartment of the arm by spiraling around the humerus. Here, it can be injured by fracture of the midshaft of the humerus or by compression with crutches that are too long for the person using them. It is also vulnerable as it passes near the lateral supracondylar ridge where it might be damaged by a supracondylar fracture of the humerus. The radial nerve is well protected for the remainder of its course. (Note that in the arm, the axillary nerve also spirals around the humerus and can be injured after fracture of the surgical neck). The wrist is a reliable joint to test for loss of radial nerve function. Damage to the radial nerve results in “wrist drop,” or the inability to extend the wrist because of the loss of extensor muscles in the posterior compartment of the forearm. The major disability is the inability to grip firmly, because unless the extended wrist stretches the flexor muscles, they are at a mechanical disadvantage. Try grasping something firmly with the wrist held in flexion so you can appreciate how important wrist extension is to the function of the flexors.

Median nerve: is sometimes injured at the elbow after a supracondylar fracture of the humerus. It is probably most frequently injured at the wrist, where it lies just under the skin and investing fascia at the proximal border of the flexor retinaculum (between the tendons of the palmaris
longus and flexor carpi radialis muscles). It is also subject to pressure injury within the carpal canal. Swelling deep to the flexor retinaculum results in motor deficits and sensations in the hand defining what is commonly called “carpal tunnel syndrome.” Carpal tunnel syndrome is more common in women than in men and can be precipitated by arthritis, inflammation of the synovial tendon sheaths (repetitive action syndrome), or dislocation of the lunate bone. In the hand, which is the most reliable area for diagnosis, median nerve injury is associated with sensory loss in the shaded area. The thenar eminence will exhibit atrophy and the thumb will “derotate” because of loss of the opponens pollicis muscle and come to lie in the same orientation as the fingers (this is not as well illustrated in the diagram). Because of the de-rotated position of the thumb, the deformity is often referred to as “ape hand.”

**Ulnar nerve:** is superficial and against bone at the elbow. Therefore, ulnar nerve damage occurs most frequently with injuries at the elbow, particularly fracture of the medial epicondyle. At the wrist, the ulnar nerve lies superficial to the flexor retinaculum on the radial side of the pisiform bone and it can be injured when the pisiform is fractured (as occurs occasionally in such sports as karate). In the hand, which is the most reliable area for diagnosis, there will be sensory loss in the shaded area on the palmar and dorsal sides. The ring and little fingers are maintained in a position of flexion at the proximal and distal interphalangeal joints, and in extension at the metacarpophalangeal joints. There is hyperextension at all four MP joints, but it is more severe at digits 4 and 5 due to the loss of the interossei. This deformity is often referred to as “claw hand.” Note that the thumb remains in its anatomical position.

![https://s-media-cache-ak0.pinimg.com/736x/c3/f4/fc/c3f4fc3bbc6b70c1c6e9461c3385172–hand-therapy-massage-therapy.jpg](https://s-media-cache-ak0.pinimg.com/736x/c3/f4/fc/c3f4fc3bbc6b70c1c6e9461c3385172–hand-therapy-massage-therapy.jpg)

The following video clearly explains the outcome of median and ulnar nerve lesions.

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One or more interactive elements has been excluded from this version of the text. You can view them online here: [https://wisc.pb.unizin.org/mindmotionanatomy/?p=253#oembed-1](https://wisc.pb.unizin.org/mindmotionanatomy/?p=253#oembed-1)
Fascia and Compartments of the Lower Limb

The muscles of both the upper and lower limbs are surrounded by dense fascial coverings, but they are more pronounced in the lower limb. The fascia of the thigh is called the fascia lata. Two muscles – tensor fascia latae and gluteus maximus – have attachments to this fascia which allow them to exert specific pulls on it. This portion of the fascia lata, called the iliotibial tract or band, will be discussed with the muscles of the hip. The fascia of the leg is called crural fascia. Like the investing fascia of the forearm, called antebrachial fascia, the crural fascia forms the retinacula at the ankle joint that help to maintain the proper positioning of the long tendons extending into the foot. There are also retinacula associated with the knee joint, called patellar retinacula that assist in maintaining the appropriate positioning of the patella and patellar ligament.

The investing fascias are also continuous with some very dense connective tissue sheets called intermuscular septa which separate the various groups of muscles. They extend from the bones to the investing fascia, as occurs also in the upper limb. The septa not only separate different groups of muscles into specific compartments, but they also provide a surface for muscle attachment. The upper limb has two compartments (flexor and extensor), but the lower limb has three compartments. In the thigh, there are anterior, posterior and medial compartment. In the leg there are anterior, posterior and lateral compartments. Just like in the upper limb, the muscles in each of the compartments perform similar actions at the joints they cross.
Please note, when we are talking about anterior and posterior compartments, we are not talking about anterior and posterior division nerves!!! When we are talking about compartments, we are talking about where the compartments are located in an adult standing in anatomical position. Remember that the nerves of the lower limb have been pulled around during limb rotation and now have a position different than during embryonic development. Remember, the femoral nerve is a posterior division nerve, BUT it innervates muscles found in the anterior compartment of the thigh. Likewise, the tibial nerve is an anterior division nerve, but it innervates muscles in the posterior compartment of the leg. Keeping this straight will take a little practice, but keep lining up your thumb with your big toe and you'll get it in no time!
Clinical Correlation

The fascias of the lower limb can cause problems comparable to the problems seen in association with connective tissue entities of the upper limb. One example is **tarsal tunnel syndrome**, which can be compared with carpal tunnel syndrome. Tarsal tunnel syndrome refers to compression of the tibial nerve as it passes beneath the flexor retinaculum on the medial aspect of the ankle joint. This can lead to parasthesia or even anesthesia of the plantar surface of the foot, and problems with movements of the toes.

Another significant problem in the lower limb is **compartment syndrome**. This involves increased tissue pressure in one of the compartments, such as the anterior compartment of the thigh or anterior compartment of the leg. It may be caused by inflammation resulting from trauma to the muscles in the compartment. Because each compartment represents a confined anatomical space, the inflammation can put pressure on the nerves and vessels traveling within or through the compartment. If blood flow is decreased because of vessel compression, there may be ischemia and dysfunction of the muscles included in the specific compartment. Symptoms include pain, muscle weakness, sensory loss, and palpable tenseness in the involved compartment. Ischemia can lead to necrosis resulting in permanent impairment or function. Anterior tibial compartment syndrome (increased pressure in the anterior compartment of the leg) is one of the more common compartment syndromes.

Lumbosacral Plexus

The **lumbosacral plexus** spans from L2-S4 spinal cord levels. It is sometimes broken up into the lumbar and sacral plexuses, but there is no functional significance to this division. The **lumbosacral trunk** (formed by nerve fibers from L4 and L5) serves as a connecting link between the lumbar and sacral portions of the lumbosacral plexus. As in the case of the brachial plexus, the anterior and posterior division fibers – both sensory and motor – separate and segregate into specific named nerves that distribute to muscle groups in the lower limb. Unlike the brachial plexus, the segregation process is more direct. For example, the anterior division fibers from L2-4 simply join together to form the obturator nerve. Posterior division fibers from these levels join to form the femoral nerve. The end result is the development of four major nerves to the thigh, leg and foot, several nerves to the muscles of the hip region, and several cutaneous nerves. Just like in the upper limb, it is possible to generally group the muscles that each nerve innervates (see table below as well as exceptions to that table!)
A The lumbosacral plexus and its branches
Right side, anterior view.
As in the case of the upper limb, one may group muscles according to their nerve supply. However,
as in the upper limb, there are exceptions, e.g., brachioradialis innervated by the radial nerve, but a flexor at the elbow. In the lower limb, the most noticeable exceptions are the following. In each instance, the “variation” can be attributed to the embryonic development of the muscles (ie their rotation went a little too far/not far enough).

- Innervation of pectineus by the obturator and femoral nerves.
- Innervation of adductor magnus by the obturator and tibial nerves.
- Innervation of the short head of biceps femoris by the common fibular nerve.

The **pudendal nerve** is a “non-limb” nerve that is closely related to the sacral component of the plexus with which you should be familiar. It is composed of fibers from S2,3,4. The nerve provides sensory innervation for the perineal region and external genitalia, and motor fibers to the striated skeletal muscle of the external genitalia and the external anal sphincter.

The named nerves listed above all go to skeletal muscles in the lower limb. Additionally, most of them travel to the skin as cutaneous branches. As you go through the groups of muscles in the lower limb and learn their innervation, also refer back to maps of cutaneous innervation. This will be of the utmost importance when we start talking about nerve deficits in the lower limb.
Clinical Correlation

The sciatic nerve deserves special consideration because of the functional importance of this nerve in the lower extremity and because of the practice of using the buttocks for intramuscular injections. The sciatic nerve enters the gluteal region halfway between the posterior superior iliac spine and the ischial tuberosity. From this point, the nerve curves laterally and inferiorly, passes halfway between the greater trochanter and the ischial tuberosity, and continues distally along the posterior midline of the thigh to the top of the popliteal fossa, where it divides into its component parts—the tibial and common peroneal nerves. To avoid damaging the nerve by intramuscular injections (by directly hitting the nerve with the needle, or by injecting substances that are toxic to the nerve in its immediate vicinity), injections should be made in the upper lateral quadrant of the buttock—the so-called “safe area.” The safe area is defined as the area beneath the palm when the thenar eminence and thumb are placed along the iliac crest, with the tip of the thumb touching the anterior superior iliac spine.

Vessels of the Lower Limb

Arteries

The major arteries to the lower limb are the femoral, superior gluteal, inferior gluteal, and obturator arteries. Three of these arteries—obturator, and superior and inferior gluteal arteries—accompany the nerves of the same name. They provide blood to the same muscles and other tissues that receive their innervation from the accompanying nerve. These three arteries are
branches from the internal iliac artery, which is one of the two major terminal branches of the common iliac artery.

The femoral artery is the largest of the four major arteries. It is the continuation of the external iliac artery, the second terminal branch of the common iliac artery. The basic plan of the femoral artery is similar to that of the brachial artery. There are medial and lateral femoral circumflex branches surrounding the proximal region of the femur. The femoral artery also has a deep branch – profunda femoris or deep femoral – which provides a blood supply to the deeply positioned muscles and muscles located in the posterior compartment of the thigh. As in the case of the arteries of the upper limb, the lower limb arteries are positioned on the flexor side of the joints. Thus, the femoral artery is positioned anterior to the hip joint. In order to be on the flexor side of the knee joint, it must be positioned posteriorly. To accomplish this, the artery passes to the posterior aspect of the femur near its distal end through a structure called the adductor hiatus. This is a “hole” in the adductor magnus muscle, near its attachment to the adductor tubercle. This point will be discussed further when the muscles of the thigh are studied.

Posterior to the knee, the artery changes its name to the popliteal artery. From the popliteal artery arise the branches that distribute to the leg and foot: anterior tibial, posterior tibial and fibular. The anterior tibial artery pierces the interosseous membrane between the tibia and fibula and descends through the anterior compartment onto the dorsal aspect of the foot as the dorsalis pedis artery and dorsal arch of the foot. The posterior tibial artery gives off a lateral branch called the fibular artery then continues in the posterior compartment and around the medial malleolus into the foot. Once in the foot, it splits into the lateral and medial plantar arteries that then rejoin to form a plantar arch and give rise to common and proper digital arteries which distribute to the toes. The dorsal and plantar arches anastomose with each other. The formation of the “arches” in the foot is not of the exact same pattern as the formation of the superficial and
deep palmar arterial arches in the hand, but it is reasonable to make a comparison of the vessels in the hand and foot.

The lower limb has extensive collateral circulatory networks at the hip, knee, and ankle joints, and also in the foot via the arterial arches. Collateral circulation around the hip is provided through a structure called the **cruciate anastomosis**. The cruciate anastomosis forms from three branches of the femoral artery (medial femoral circumflex, lateral femoral circumflex, first perforating branch of the profunda femoris) and a branch of the internal iliac artery (inferior gluteal artery). **Geniculate branches** of the popliteal artery provide collateral circulation around the knee. The branches are named for their position with respect to the knee (superior medial geniculate, inferior lateral geniculate, etc).
Veins

The arteries of the lower limb are accompanied by veins of the same name. As in the upper limb, there is also a set of prominent subcutaneous veins. The largest of these are the **greater saphenous vein** that drains into the **femoral vein** in the groin region, and the small or **lesser saphenous vein** that drains into the **popliteal vein** in the **popliteal fossa**. A further point about the positioning of the veins: The great saphenous vein is located along the preaxial margin of the limb and can be compared with the cephalic vein of the upper limb. The lesser/small saphenous vein is positioned along the postaxial margin of the limb and can be compared with the basilic vein of the upper limb. Their positioning is another illustration of the rotation of the lower limb. If you abduct your limb 90° and laterally rotate it by 90°, these vessels will be in the homologous position as the cutaneous vessels in the upper limb.
Adult veins that are derived from the embryonic marginal veins. The preaxial veins (cephalic and greater saphenous) are on the first digit side of the limbs. The postaxial veins (basilic and lesser saphenous) are on the fifth digit side of the limbs. The lower limb veins maintain their association with their origins throughout the rotation of the lower limb. Image adapted from Netter, Atlas of Anatomy, 6th ed, 2014.
While the superficial veins of the lower limb can be large, the majority of the blood from the lower limb travels through deep veins that run within the lower limb compartments. Blood from superficial areas of the limb can be shunted to deeper veins through perforating veins. Recall that the veins of the limbs are valved to prevent backflow of blood (see lecture notes on the cardiovascular system for a discussion of the valves in veins). Another important part of blood flow through the lower limbs is the fascia lata, crural fascia and intermuscular septa creating the lower limb compartments. The compartments do not expand when muscles contract, so each time a muscle contracts it also squeezes the veins within the compartment. This is called the **skeletal muscle pump**. At rest, blood flows through both the superficial and deep veins. During exercise, with the milking action of the muscles on the deep veins, a majority of the blood returns via the deep veins. The blood in the superficial veins flows inward to the deeper veins, via the perforating veins, during exercise. The exact mechanism is due to pressure changes in the deep veins associated with the milking action of the muscles. The skeletal muscle pump, plus negative intrathoracic pressure, are the two major factors which aid in the return of blood from the limbs.
A significant problem the saphenous veins is that they can become **varicose**. A varicose vein is a dilated and tortuous one. Varicose veins are not only painful and/or present a cosmetic problem; they can also lead to nutritive imbalances in the limb due to sluggish circulation and pooling of blood. This can lead to ulcers which do not readily heal.

The basic cause of varicose veins is an overloading of the superficial veins with blood. Because the saphenous veins have no significant support due to their positioning in the subcutaneous tissue, and because they must support a column of blood reaching from the foot to the level of the heart, they are particularly subject to this overfilling and subsequent stretching. Pregnancy may cause varicose veins because of the compression of veins in the pelvis. Individuals who stand for long hours, e.g., surgeons, assembly-line workers, gross anatomists, etc., are also susceptible to developing varicose veins.

The factors that operate to produce varicosities are not well understood. One possible factor is the breakdown of the valves within the superficial veins. Another factor may be the breakdown of valves in small perforating veins that connect the superficial and deep veins. These small veins, called perforating veins or communicating veins, are valved so that they normally conduct blood only to the deep veins from the superficial veins. If the valves in these perforating veins break down, a considerable amount of blood will flow back into the superficial veins.
Lower Limb Joints

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Chapter Sections

Pelvic Girdle
- Sacroiliac Joint
- Pubic Symphysis
- Hip (Iliofemoral) Joint
- Hip Joint Structure
- Hip Joint Movements
- Knee Joint Structure
- Knee Joint Capsule and Ligaments
- Knee Joint Menisci
- Movements at the Knee Joint
- Ankle Joint Structure
- Ankle Joint Movements
- Intertarsal Joints Structure
- Intertarsal Joints Movement
- Foot Arches
- Metatarsalphalangeal and Interphalangeal Joints

Pelvic Girdle

The pelvic girdle is formed by the sacrum and the two girdle bones of the lower limb, called the hip bones, **innominate** bones, or **os coxae**. Each hip bone is formed by three originally separate bones – the **ilium**, **ischium** and **pubis**. They fuse with each other at the cup-shaped **acetabulum**. Complete fusion of the three bones usually occurs around 16 years of age.
Unlike the pectoral girdle that has only a small bony articulation with the axial skeleton at the sternoclavicular joint, the hip bones articulate firmly with the sacrum – a part of the axial skeleton- via the **sacroiliac joints**. Movement at the sacroiliac joints is limited – compare with the movement of the upper limb girdle – and there are no muscles that cross these joints that have a major purpose of producing movement at the sacroiliac joints. Thus, there are no lower limb muscles that can be compared with trapezius, the rhomboids, levator scapula, and serratus anterior. You should recall that the major function of these muscles is to produce movement of the shoulder girdle.

An additional general point about the pelvis worth mentioning is that there are differences between the male and female pelvis. For the most part the differences are mainly those that
contribute to a wider female pelvis and pelvic inlet and outlet. Females tend to have wider subpubic angles, greater sciatic notches and sacra. Female pelves must be wider to accommodate a fetus during labor and delivery.

**Sacroiliac Joint**

The sacroiliac (SI) joints are true synovial joints between the auricular surfaces of the sacrum and the auricular surfaces of the two ilia. The articular surfaces of the SI joint are unique though in that only one of them (the sacral part) is covered with hyaline cartilage. The iliac auricular surface is covered with fibrocartilage. There are a number of strong sacroiliac ligaments that surround the sacroiliac joint capsules making them extremely stable. There is only slight movement at the joints (called **nutation/anterior rotation** and **counternutation/posterior rotation**) around a transverse axis. These small movements are highly dependent on the position of the lumbar spine and hips. For example, the sacrum undergoes counternutation or tilts backward when a person straightens their lumbar lordosis. The sacrum tilts forward when an individual sits or lies down with the lumbar spine in exaggerated lordosis.
There are two prominent ligaments of the pelvic girdle which function to limit unwanted movements of the sacrum. The **sacrotuberous ligament** spans from the posterior surfaces of the lower three sacral vertebrae to the ischial tuberosity. The **sacrospinous ligament** spans from the lower part of the sacrum and coccyx to the spine of the ischium. A major function of these two ligaments is to restrict/limit anterior rotation of the sacrum between the two hip bones during standing. This may occur when someone lands after a jump. In addition, these two ligaments provide an attachment site for several gluteal muscles and they also form boundaries of the greater and lesser sciatic foramina. A number of muscles, nerves and vessels pass through these two foramina. Structures passing through the greater sciatic foramen include the sciatic nerve, superior and inferior gluteal nerves, the pudendal nerve, superior and inferior gluteal arteries, and the piriformis muscle. The tendon of obturator internus and the pudendal nerve pass through the lesser sciatic foramen.
The pubic symphysis is located between the symphylaseal surfaces of the two pubic bones. It is formed by a fibrocartilaginous disc that is similar in its make-up to the intervertebral discs. Occasionally, there is a joint cavity present in the pubic symphysis, in which case the joint is called a “synovial” joint. Recall that it is usually classified as a “symphyseal” joint or amphiarthrosis, like the intervertebral discs. The pubic symphysis is a very stable joint that has transverse ligaments that span its width. The muscles of the abdominal wall also help to stabilize the pubic symphysis when they contract bilaterally.
Hip (Iliofemoral) Joint

Hip Joint Structure

Although the hip and shoulder joints are both of the ball-and-socket variety, the hip joint is different in several respects. The differences are designed to increase the stability of the hip joint. Hence, they tend to decrease the joint’s mobility. For each of the following points, consider the differences between the hip joint and the glenohumeral joint.

The head of the femur forms about two-thirds of a sphere that fits into the deep cavity of the acetabulum where it articulates with the smooth, horse-shoe shaped lunate surface. The acetabulum itself is deepened further by a prominent lip of cartilage at its margin, the acetabular labrum. Compare this structure with the small fraction of a sphere formed by the humeral head and its articulation with the very shallow glenoid fossa. The lunate surface does not cover the entirety of the acetabulum. The non-articular acetabular notch and acetabular fossa make up
about 30% of the acetabulum. A ligament spans the acetabular notch, the transverse acetabular ligament, and helps prevent inferior dislocation of the femur.
The fibrous capsule of the hip joint is strong compared to the loose capsule of the shoulder joint. The ligaments contributing to the hip joint capsule are considered to be the strongest in the body. The fibrous capsule of the hip joint is unique when compared with other ligamentous capsules because the three ligaments making up the most substantial part of the joint capsule. The iliofemoral, ischiofemoral, and pubofemoral have a “circular” orientation and “spiral” around the hip joint. They are tight, or tense, when an individual is standing in the normal anatomical position. They become even more tense/tight, when an individual attempts to hyperextend the joint beyond the anatomical position. Thus, they play a role in limiting hyperextension. When the hip joint is placed in its original “developmental” position – abducted and laterally rotated, each by 90° – the ligaments are relaxed/loose and have a more transverse orientation from the hip bone to the femur. The circular orientation is also a further illustration of the phenomenon of rotation.

![Image from ET Bersu.](image-url)

It is of interest to consider that the tightening of the ligaments when one is standing means that little or no muscular effort is required to maintain that position. It is believed that the iliofemoral ligament – or “Y ligament of Bigelow” – is most important in this function. The fact that the line of gravity of the body is normally positioned slightly posterior to the hip joint transverse axis – producing a bit of “gravitational extension” at the hip – is also a factor in facilitating the tightening of the ligaments during standing.

Another ligament of the hip joint, the round ligament of the head of the femur, is not considered to have any significant function after childhood. This ligament travels between the acetabulum and the fovea (pit) on the femoral head. It carries a small blood vessel that is important to femoral head development during prenatal and early childhood years. This blood supply in adult years is not believed to be significant – see below for the major blood supply to the femoral head – and in cadavers the ligament is usually frayed and detached from the femoral head.
The muscles that cross the hip joint attach some distance from the head – to the trochanters, etc. – instead of close to the head as in the case of the rotator cuff muscles to the greater and lesser humeral tubercles. The anatomical neck of the femur is also quite long, whereas an anatomical neck of the humerus is almost non-existent. These two features provide the muscles with greater leverage in producing movements at the hip joint. With the deep ball-and-socket arrangement, this greater leverage also diminishes the possibility of dislocations of the femoral head. Unfortunately, the powerful motion facilitated by the greater leverage also leaves the long neck more susceptible to being fractured.

The femoral neck is at an angle to the shaft of the femur, and therefore the vertical axis does not run through the shaft of the femur. This angle creates a bending moment between the femoral neck and the shaft that would cause susceptibility to fracture. However, the trabecular bone arrangement of the proximal femur and the muscles that cross the hip joint work together to change how the loads are applied.
Clinical Correlation

A normal femoral neck angle (in the coronal plane) is approximately 125° in adults, and in infancy is approximately 150°. This angle decreases with age. Abnormal femoral neck angle will effect how loads pass through the proximal femur, and will effect the distribution of trabecular bone. **Coxa vara** is a femoral neck angle of less than 120°, and an angle above 135° is termed **coxa valga**.
Torsion of the femoral neck describes the angle between a transverse axis passing through the femoral condyles and an axis passing through the femoral neck. The femoral neck should be slightly anteverted relative to the femoral condyles (the femoral neck points slightly anteriorly). If the angle is greater than 12° the resultant problem is called **coxa anteverta**. This greater angle results in an in-toe position of the foot (toes are pointed toward the midline) to be able to keep the femoral head properly aligned in the acetabulum. Conversely, **coxa retroverta** is a result of a torsion angle less than 12°, and leads to a toed-out gait.
D Rotational deformities of the femoral neck
Right hip joint, superior view.

a. A normal anteverision angle of approximately 12 degree with the foot directed forward.
b. An increased anteverision angle (coxa anteverta).
c. The femoral neck is retroverted (coxa retroverta).

Illustrator: Karl Wesker
The femur has a prominent nutrient foramen at the midpoint of the posterior aspect of the shaft through which a large artery passes. This vessel, along with other smaller vessels that enter foramina along the shaft, provides the shaft with a rich blood supply. While the femoral head receives a good blood supply, it is more susceptible to interruption than the blood supply of the shaft. The main supply to the femoral head are branches from the **medial** and **lateral femoral circumflex arteries** that travel along the femoral neck. They enter the bone through numerous nutrient foramina around the margin of the femoral head. Examine a femoral neck in the laboratory to convince yourself of this fact. The branches to the femoral head travel for some distance along the neck before entering the nutrient foramina. Fractures of the femoral neck can interrupt these arteries. Because there are few, if any, collateral channels connecting these vessels with vessels associated with the shaft of the femur, damage to the circumflex vessels may leave the femoral head with no blood supply at all, resulting in *avascular necrosis* (death) of the bone. Damage to the vessels can occur in fractures of the femoral neck. Individuals in whom this occurs would be candidates for a hip joint prosthesis.
The hip joint is multiaxial and all three sets of cardinal movements occur: flexion and extension,
aB- and aDduction, medial and lateral rotation. Understanding how various muscles produce movements around the transverse and antero-posterior axes is straightforward.

Analysis of muscle function about the vertical axis can be problematic. In the upper limb, the vertical axis is parallel with, and runs through the center of the humeral shaft. For the lower limb, the true vertical axis does not run with the obliquely oriented femoral shaft. Rather, the vertical axis is truly vertical and runs from the femoral head to a point about midway between the femoral condyles. Whether or not a muscle medially or laterally rotates the femur must be determined by considering its relationship to this true axis. This is best illustrated by example. There are several muscles that are positioned medially to the shaft of the femur (medial relationship). With an anterior pull, one would predict that they would produce lateral rotation of the femur. However, these muscles are positioned laterally to the true vertical axis for the hip joint (lateral relationship). With the anteriorly directed pull they will, therefore, produce medial rotation of the femur because of their lateral relationship to the axis. There are some neat tricks that can be performed to illustrate the points (see the hip model in lab). Do not be concerned, however, if the details of these observations are not clear. Based on studies using mechanical means, as well as electromyography, there is still disagreement about the capability of several muscles to produce rotatory movements. It has also been observed that whether or not a specific muscle produces a movement is related to the positioning of the hip joint when the movement is begun – if it is in the neutral (normal anatomical) or flexed position when the rotation is being attempted.
Clinical Correlation

Replacement of joints whose normal functions have been compromised by conditions such as osteoarthritis has been done for many years. Prosthetic devices are being improved continuously.

Hip joint replacement for severe cases of osteoarthritis is one of the more common procedures. A prosthesis called the “Charnley prosthesis” gives a high rate of success – about 95% for unilateral replacement – in terms of restoring good function. The prosthesis consists of a high impact polyethylene cup, placed in the acetabulum, and a stainless steel (or other alloy) femoral component. The friction in this prosthesis is much less than the metal-to-metal prostheses that were used initially. However, it is still approximately 6 times higher than that of a normal hip joint.


At the present time, the major complication of arthroplasty is the loosening of the prosthesis. Another problem is the potential for late sepsis due to colonization of the prosthesis by bacteria. Therefore, all patients who undergo hip replacement should carry a card warning of the need for prophylactic antibiotics when undergoing minor operative procedures such as tooth extraction, etc.

A more recent procedure, called "hip resurfacing", may likely diminish the above arthroplasty procedures.

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://wisc.pb.unizin.org/mindmotionanatomy/?p=1010#oembed-2
Knee Joint Structure

The knee joint is the largest and most complex joint in the body. It must support the weight of the body, and also allow for considerable movement associated with ambulation. To accommodate to both of these functions, the joint has more strong ligaments and other accessory structures than any other joint in the body. The “knee” joint actually consists of two separate synovial joints. It includes articulations between the tibial and femoral condyles (tibiofemoral joint), and between the patella and patellar articular surfaces of the femur (patellofemoral joint).

The bony surfaces of the knee joint are unique in their incongruence with each other. The mismatch of the surfaces contributes to instability of the joint. For example, tibial and femoral articular surfaces are not like the well-fitting concave and convex interlocking surfaces that you see in the elbow. When you look at them in the lab, you'll note that the femoral condyles have a rounded surface while the tibial condyles are relatively flat. This disparity between the skeletal elements contributes to an inherent instability of the joint. Think of the knee almost as being as stable as a ball sitting on a flat surface. It is possible to roll or displace the ball in most any direction along the plane of the flat surface.

Another feature that contributes to the instability is the fact that the femur and tibia come together at an angle, instead of a straight line. The angle between the femur and tibia sometimes is referred to as the bicondylar angle or the q-angle. In males, the femur is angled off the vertical by about 5 to 10°. The angle is greater in females because the femoral heads are a greater distance from each other because of the wider female pelvis. Bony abnormalities and/or other defects can lead to greater or lesser angles between the bones which can effect normal ambulation.
increase in the q-angle of the knee causes the knee to project medially (“knock-kneed”). This is known as **genu valgum**. A decrease in the q-angle of the knee causes the knee to project laterally (“bow-legged). This is called **genu varus**.

(Far left) Normal position of the femur relative to the tibia and leg. The angle between the vertical line and the femur is greater in females than males because of the wider female pelvis. The sketches at the right show a genu valgum (A) deformity and genu varus (B) deformity. Image from ET Bersu.

The angle between the femur and tibia contributes to instability of the patellofemoral joint. The patellofemoral joint is essentially a plane joint, and could possibly move in any direction. The patella is embedded in the tendon of the quadriceps femoris muscles, and this tendon wants to travel along shortest path from A to B (ASIS to tibial tuberosity). This shortest path is lateral to the actual path of the patellofemoral joint, so the patella is at constant risk of lateral displacement. Thankfully, the **lateral condyle of the femur** projects more anteriorly than the medial one and blocks lateral displacement of the patella. Additionally, horizontally oriented muscle fibers of the vastus medialis contract during full extension to prevent lateral displacement of the patella (see Muscles that Move the Knee). **Patellar retinacula** are connective tissue thickenings associated with the patellar ligament. They extend on either side of the patellar ligament and attach to the tibial condyles. The retinacula play a role in helping to maintain the patella and patellar ligament in their appropriate position.
Knee Joint Capsule and Ligaments

The knee joint **fibrous capsule** and **synovial cavity** involves both the tibiofemoral and the patellofemoral joints. The morphology of the capsule and enclosed synovial membrane is complex. The anterior component of the knee joint capsule is formed by the distal portions of the quadriceps femoris muscle and its tendon, the patella, and the patellar ligament. The posterior aspect of the knee joint capsule is reinforced by several ligaments; the **oblique popliteal ligament** is probably the most significant. Inside the fibrous joint capsule is the synovial cavity. An infrapatellar fat pad and the intracapsular ligaments of the knee are not surrounded by the synovial cavity, but are found within the fibrous joint capsule.
The lateral and medial aspects of the joint capsule are reinforced by the lateral and medial collateral ligaments, respectively. Collateral ligaments have been considered with the elbow and wrist joints, and joints of the fingers. They are characteristic of hinge joints. They are positioned on the sides of joints and function to limit or prevent side-to-side movements at the joint (usually abduction and adduction). The medial/tibial collateral ligament is a broad band that extends from the medial epicondyle of the femur (near the adductor tubercle) to the medial surface of the upper end of the tibia. Fibers of the ligament blend with those of the underlying joint capsule. Some fibers also blend with the medial meniscus. A main function of the ligament is to limit abduction of the leg on the femur (and resist valgus defects). The lateral/fibular collateral ligament is a cord-like ligament which runs from the lateral epicondyle of the femur to the head of the fibula. In contrast to the tibial collateral ligament, the fibular collateral ligament does not blend with the lateral aspect of the knee joint capsule, and has no fibers blending with the lateral meniscus. The ligament limits adduction of the leg on the femur. The collateral ligaments have two additional functions, besides limiting side to side movements: both ligaments become taut (tense) in extension and may therefore limit/prevent hyperextension, both ligaments limit rotation when the knee joint is flexed.

(A) anterior, (B) posterior. Image from ET Bersu.

The anterior and posterior cruciate ligaments may be the most famous of the knee ligaments. They are positioned inside the fibrous capsule of the knee joint, but outside of the synovial lining.
membrane. They extend between the tibia and femur and, as their name implies, they cross each other. The anterior cruciate ligament extends from an attachment anterior to the intercondylar eminence of the tibia, the ligament runs upward, backward and laterally to attach to the medial surface of the lateral femoral condyle. The posterior cruciate ligament arises from the posterior intercondylar area of the tibia and extends upward, forward and medially to attach to the lateral side of the medial femoral condyle. Cross your fingers (with your 3rd digit over your 2nd digit) and place them on your knees. This mimics the position of the cruciate ligaments in the knee.

There are at least three functions which are attributed to the cruciate ligaments. Both ligaments are tense/tightened in extreme flexion and extension, and help to stabilize the knee in these positions. The posterior cruciate ligament limits/prevents anterior displacement of the femur on the fixed tibia. Conversely, the anterior cruciate ligament limits/prevents anterior displacement of the tibia on the femur.
Clinical Correlation

The knee joint is the most vulnerable of joints in terms of its susceptibility to injury. Damage to any of the ligaments or other components can cause considerable problems with ambulation. The following are several of the more frequent problems associated with the joint.

- Tears or sprains of the tibial (medial) collateral ligament are one of the most common knee joint injuries. Any strong blow to the outside of the knee which displaces the tibia laterally on the femur can cause the tibial collateral ligament to be torn or stretched. If the force is strong enough, the ligament may be torn completely, or may avulse a portion of the medial epicondyle of the femur. One can confirm such damage to the ligament by (gently!) pulling the tibia laterally, i.e., abducting the tibia on the fixed femur. There will be a greater movement on the injured side than what occurs on the normal side. The appropriate management of a torn ligament includes suturing. There is a tendency for the ligament to become stretched if it is allowed to heal on its own. A stretched or otherwise poorly healed ligament results in an unstable knee.

- The lateral collateral ligament is not as frequently damaged as the medial collateral ligament. A sharp blow medial blow that caused excessive adduction of the knee would cause damage to it, however.

- Trauma to the anterior cruciate ligament is another common knee injury. With the foot planted on the ground, and the knee flexed, rotation at the joint that occurs as a component of the individual's activity may cause the anterior cruciate ligament to tear. The result is considerable instability.

- The posterior cruciate ligament is not as frequently damaged as the anterior cruciate ligament. Damage to the PCL is commonly seen in car accidents when a head-on collision occurs. During the collision, the flexed knees of the individual may collide with the dashboard causing excessive posterior...
Knee Joint Menisci

The **medial** and **lateral meniscus** are crescent-shaped fibrocartilage structures that are positioned between the tibia and femur. They help to adapt the flat tibial and rounded femoral condyles to each other. They are wedge-shaped in cross-section, with the sharp edge at the inner margin. Each meniscus is attached to the tibia by strong fibrous bands, called **coronary ligaments**. There are also ligament-like extensions from the menisci that attach to the femur. Despite these attachments, the menisci move in association with specific knee joint movements. During extension of the knee, the menisci shift slightly anteriorly. During flexion of the knee the menisci shift posteriorly.
The menisci have multiple functions. They play a role in adapting the femoral and tibial condyles to each other when weight is placed on the joint. This allows for the load of the body weight to be dispersed across the entire proximal end of the tibia. They are thought to be important in helping to maintain an even film of synovial fluid across the joint surfaces, thus aiding in lubrication of the knee joint. They play a role in rotation movements at the knee joint.

Recall that the medial collateral ligament is continuous with, or blends with the medial meniscus. This relationship is significant, because tears of the medial collateral ligament may also result in damage to the medial meniscus. If the menisci are damaged or torn, they may be partially or completely removed. The effects of these procedures will vary depending upon the individual and their activities.
The “terrible triad” is an extensive injury of the knee joint that, as classically described, involves three structures: 1) damage to the tibial collateral ligament, 2) damage to the medial meniscus and 3) damage to the anterior cruciate ligament.

Picture the following. A football player is standing on the field with knees slightly flexed. A second player hits the outside of the individual's knee with considerable force – a “clipping” penalty – as illustrated in the sketch below for a “simple” tearing of the tibial collateral ligament. Recall that the tibial collateral ligament and medial meniscus are attached to each other, so that trauma to the ligament could disrupt/tear the medial meniscus. With the knee joint slightly flexed and the feet firmly planted on the ground, the force of the contact would likely push the tibia forward on the femur. Because the anterior cruciate ligament can prevent/limit anterior displacement of the tibia on the femur, the rapid forward movement of the tibia could tear or stretch the ligament.

Since the terrible triad was defined in the 1950s, researchers have found that it may actually be a misnomer. Surveys of traumatic knee injuries have found that damage to the lateral meniscus is more common than damage to the medial meniscus. It is thought that the sudden abduction of the knee crushes the lateral meniscus. Additionally, when a terrible triad occurred (ACL, MCL and MM) there was always damage to the lateral meniscus as well… making it a terrible quadrad (they are still trying to come up with a catchier name).

There are numerous procedures/tests that can be used to determine whether or not a traumatic knee injury has occurred. The following are among the more basic tests. In each instance, one compares the affected and unaffected joint. To test hyperextension of the knee joint, with the knee joint in full extension, an attempt is made to hyperextend the joint. Extension/hyperextension beyond normal would indicate damage to the cruciate ligaments and collateral ligaments. A valgus test tests the MCL. With the knee joint in 30° of flexion, one attempts to separate the medial condyles of the femur and tibia by abducting the leg on the fixed femur. A positive result would suggest a torn tibial collateral ligament. Drawer signs test the cruciate ligaments. An anterior drawer test tests the ACL. The individual is lying on their back with feet flat on the ground and hip joints flexed to 45°. One stabilizes the individual's feet and then pulls the upper portion of the tibia sharply in an anterior direction. Forward movement of the tibia indicates a tear in the anterior cruciate ligament. Posterior movement of the tibia would be indicative of injury or problems with the posterior cruciate ligament.
Movements at the Knee Joint

The knee joint is biaxial. Flexion and extension are the freest movements. They are a bit more complex than a simple hinge motion and involve a certain amount of gliding of the femoral condyles on the tibia. Rotation (medial and lateral) is the other movement. The rotatory movements can be grouped into two categories: “active” and “passive” rotation.

Active rotation at the knee joint occurs when the knee joint is flexed. With the knee joint flexed to 90°, the leg can be rotated through a range of approximately 60 to 70°. Rotation diminishes as the knee approaches full extension and full flexion. The movement occurs primarily via the contraction of the hamstring (posterior thigh) muscles: semitendinosus, semimembranosus, biceps femoris.

Passive rotation involves slight, inevitable rotatory movements of the femur on the fixed tibia (or
vice-versa) during the final stages of full extension at the knee joint. There is a slight amount of medial rotation of the femur on the fixed tibia as the knee joint moves into full extension. The rotation is a component of what is called “locking” of the knee joint. Conversely, there is a slight amount of lateral rotation of the femur on the fixed tibia when beginning to move the knee joint from full extension to a flexed position. This lateral rotation is associated with “unlocking” of the knee joint. No direct, muscular forces are involved in the medial rotation of the femur during the last few degrees of extension. It occurs, in large part, because the femoral and tibial medial condyles are longer than the lateral condyles. To bring the medial condyles into their closest contact, the “passive” rotation must occur.

Why does this “passive rotation” occur? The final stage of extension involves about 15° of medial rotation of the femur on the tibia, when the leg is fixed on the ground. As mentioned, the rotation is due to a difference in lengths of the articular surfaces of the femoral condyles. The medial condyle of the femur is longer than the lateral condyle. As the femoral condyles slide posteriorly on the tibia during extension of the knee, the lateral condyle stops gliding first because it is shorter. Because the medial condyle is a bit longer, it continues to slide posteriorly and the femur rotates medially. At the end of this movement, all ligaments of the knee are tight, and the articulating surfaces of the bones are quite congruent.

As the term “locked” infers, the knee is in its most stable condition during full extension – and at this time, the major ligaments of the knee joint are also most taut. No muscle activity is required to maintain the knee joint in the fully extended position, and the statement can be made that one is “standing on their ligaments.” You should recall that the ligaments of the hip joint – especially the iliofemoral ligament – are also taut when the hip is in the anatomical (extended) position. Therefore, little or no muscle activity is required to maintain the lower limbs in the anatomical position.

Image from ET Bersu.

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Ankle Joint Structure

The **ankle joint**, or **talocrural joint**, is formed by articulations between the medial and lateral malleoli of the tibia and fibula, and the **trochlea** of the talus. The trochlea of the talus is narrow posteriorly and broad anteriorly. The crural potion of the talocrural joint is very stable because the tibia and fibula are firmly articulated with one another. Unlike the radioulnar joints, there should be no movement between the tibia and the fibula. The interosseous membrane between the two bones is very strong, and the tibiofibular joints are **syndesmotic** (a type of fibrous joint) that allow little to no movement.

The **deltoid ligament** extends between the tibia and tarsal bones. It consists of four components that are named on the basis of the bones to which the specific portions attach: anterior and posterior talotibial ligaments, tibiocalcaneal and tibionavicular ligaments. The components are not really separable from each other, and the ligament is called “deltoid” because of the appearance of the four components as they fan out from the medial malleolus to the tarsal bones. A primary function of the ligament is to limit outward movements (eversion) of the entire foot.

The lateral ligaments of the ankle are three in number and extend from the lateral malleolus to the tarsal bones. They are separate and distinct entities when compared with the deltoid ligament and are named on the basis of their attachments: **anterior** and **posterior talofibular ligaments** and
the calcaneofibular ligament. They are not as thick and strong as the medial ligament. Together, they limit inward movements (inversion) of the foot. Forced inversion (with plantarflexion) is the most common ankle sprain, and usually involves damage to the anterior talofibular ligament.

Ankle Joint Movements

The ankle is a uniaxial joint. **Dorsiflexion** and **plantar flexion** occur about a transverse axis that passes through the trochlea of the talus and the two malleoli. Dorsiflexion may be called extension (but very few people use the term) and plantarflexion may be called flexion. The joint is most stable in dorsiflexion when the broad anterior aspect of the trochlea is “wedged” between the lateral and medial malleoli. Since the posterior part of the trochlea is narrow, when it is moved into the anterior part of the talocrural joint (as occurs during plantarflexion), the entire joint becomes unstable. As is typical of uniaxial joints, the ankle joint capsule is thin anteriorly and posteriorly, but is reinforced by strong ligaments on its sides.
Intertarsal Joints Structure

The intertarsal joints are located distal to the ankle between tarsal bones. All of the joints between the bones of the foot are synovial. There are prominent ligaments connecting them. For example, dorsal ligaments connect the tarsal bones on their dorsal aspects, and plantar ligaments connect them on their plantar aspects. Most are named according to the specific bones which they connect.

There are two intertarsal joints that we will be concerned with here. The subtalar joint is between the talus and the calcaneus. The transverse tarsal joint is actually two joints: the talonavicular and the calcaneocuboid joints. The movements between all of these joints are complex (see below).
Tarsal bones: talus (pink), calcaneus (yellow), navicular (red), cuboid (purple), cuneiforms (green). Image from BodyParts3D.
Intertarsal Joint Movements

The movements at the intertarsal joints work together to create very complex movements that are often linked together. Unfortunately, not all texts agree, so keep in mind that when you go to clinic that the orthopedic clinicians and podiatrists may have a more complex definition of foot movements than we will cover here. The movements of the subtalar joints are around an oblique axis, and these are called inversion – where the plantar surface of the foot faces medially and eversion – where the plantar surface of the foot faces laterally.
A detailed perspective of the joints and axes that are involved in inversion and eversion.

Left) Right foot, dorsal aspect, with longitudinal axis for the transverse tarsal joints and transverse axis at talocrural joint

Middle) Oblique axis at the subtalar joint (top) and longitudinal axis at transverse tarsal joints (bottom).

Right) Superior view of the right foot showing both the oblique axes and transverse axes.
Pronation and supination occur about a longitudinal axis that runs from the calcaneus through the second toe. With the talus and calcaneus fixed, the midfoot and forefoot can rotate at the transverse tarsal joints so that the sole of the foot faces medially—supination—or laterally—pronation. The midfoot and forefoot are those components of the foot distal to the talonavicular and calcaneocuboid joints. You may want to look at a skeleton to clarify these points.

Your atlas lumps together inversion/eversion and supination/pronation, and you will see that those muscles that create eversion also perform pronation, while those muscles that create supination also perform inversion. This is perfectly fine for the purposes of this course. It is difficult, if not impossible, to separate out the above movements in a normal foot, and it is most reasonable to consider only inversion and eversion. If you find yourself working with podiatrists or orthopedic surgeons you may also see pronation and supination described as more complex motions that encompass movements at the transverse tarsal, subtalar and talocrural joints.
those cases pronation = dorsiflexion + abduction + eversion, and supination = plantarflexion + adduction + inversion.

A more complex definition of foot movement. The subtalar joint between the talus and calcaneus (talocaneonavicular joint) is represented by the hinge. At this joint, the foot can swing back and forth so the great toe points in a medial direction or lateral direction (adduction and abduction). The midfoot and forefoot skeleton is linked to the hindfoot at the transverse tarsal joints about a longitudinal axis and can “spin” around a longitudinal axis so that the dorsum of the foot faces medially or laterally (eversion and inversion). This combined with dorsiflexion or plantar flexion of the talocrural joint makes up the definition of pronation and supination according to orthopedic texts. Image from ET Bersu.
Foot Arches

If the foot was only a flat platform situated at right angles to the leg, ambulation would probably be restricted to nothing more than a shuffling gait. The arched structure that is formed by the bones and ligaments transforms the foot into a very resilient “organ” that facilitates movement of the limb. There are three arches in the foot: the medial and lateral longitudinal arches and a transverse arch. The arches are arranged in the triangle. They can be appreciated by examining your own foot, the skeleton of a foot, or the footprints around a swimming pool! These bony arches are formed largely as a result of the shapes of the individual tarsal bones themselves. The bones at the “top” of the arches, such as the talus and the 3rd metatarsal, act as key stones to keep the arches elevated.
Ligaments and the plantar aponeurosis also play a major role in maintaining the arches. The plantar calcaneonavicular or spring ligament joins the sustentaculum tali of the calcaneus with the lower surface of the navicular bone. It forms a sling on which the lower surface of the head of the talus rests. By resisting the downward movement of the head of the talus when the foot is weight bearing, this ligament helps to support the highest part of the medial longitudinal arch of the foot. The long plantar ligament is a broad, strong ligament that extends from the calcaneus to the cuboid bone. Additional groups of fibers continue further distally to attach to the bases of the metatarsals. These fibers form the arch through which the tendon of fibularis longus passes from the lateral to the medial aspect of the foot. You will examine this relationship in the laboratory. The entire ligament provides considerable support for the longitudinal arches of the foot. The plantar calcaneocuboid ligament/short plantar ligament is just deep and slightly medial to the long plantar ligament and extends between the calcaneus and cuboid bones. The plantar aponeurosis is not a true bone-to-bone ligament, but can be compared with the palmar aponeurosis in the hand. It stretches between the calcaneus and the phalanges and also contributes to maintaining the longitudinal arches of the foot.
The arches receive some additional support from muscles of the leg whose tendons travel into the foot, especially the fibularis longus and the tibialis posterior. The tendons of these muscles cross the foot, and when the muscles contract, the arches are actively supported. The tendons and ligaments of the foot serve as “elastic recoil” structures that contribute significantly to movement of the limb. In some instances, the principal that the tendons and ligaments can store energy during locomotion has served as a basis for designing running shoes that are more efficient.

One of the more common variations of the arches is a “flat foot”. This refers to one of many conditions where the medial longitudinal arch, especially, is depressed. This may represent a pathological condition, e.g., the result of stretched or torn ligaments, or a congenital defect. In other cases, it just means that a foot is constructed so that it has a low arch when the foot is in its ideal position for the specific individual.

**Clinical Correlation**

Much has been made of barefoot running in the past decade, with many (professional and amateur) athletes transitioning from wearing running shoes with a lot of padding at the heel to shoes with little to no padding. A huge amount of research is ongoing, and unfortunately not all of the claims made by barefoot running shoe companies have been backed up by science. Ultimately, what is important to know is that the thickness of the sole of your shoe will effect how your foot hits the ground when you run (whether this is better for your body or not is still up for debate). In shoes that have a lot of padding at the heel, the runner tends to hit the ground with a heel strike (left). Runners wearing barefoot shoes (or even runner that don’t wear any shoes) tend to hit the ground with a midfoot or forefoot strike. The different foot strike patterns cause loads to be transferred
through your feet, ankles and legs differently (again, whether one is better than the other is still being researched).

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### Metatarsalphalangeal and Interphalangeal Joints

The final joints we will look at (yay!) are the joints that contribute to the toes: the metatarsalphalangeal (MP) and interphalangeal joints (IP). These joints have a very similar make up as in the hands. There are MP joints at every digit. There is one IP joint at the first digit, and there are proximal (PIP) and distal (DIP) interphalangeal joints at digits 2-5. The MP and IP joints all work around the transverse axis to produce flexion and extension. Additionally, the MP joints work around the vertical axis to abduction and adduction. Note: This is different than in the hands! Why is this? In the anatomical position, the feet are at $90^\circ$ to the hands, thus the axis that the MP joints in the foot changes, even though we keep the same movements. Another difference from the hand is that instead of abduction and adduction occurring relative to the 3rd digit, in the foot abduction and adduction occurs relative to the second digit.

https://www.youtube.com/watch?v=3RjR-Fx5AFs

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Image from [http://www.personal.psu.edu/afr3/blogs/sioufa12/2012/10/barefoot-running-5.html](http://www.personal.psu.edu/afr3/blogs/sioufa12/2012/10/barefoot.running-5.html)

Image from [https://youtu.be/EszwYNvvGjQ](https://youtu.be/EszwYNvvGjQ)

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*Back to Top*
As you may have realized by now, learning the many, many, many (many) muscles in the human body can be approached from a number of directions. You can lead with the muscle names, muscle actions or muscle innervations, even the muscle attachments. Here the muscles that move the hip will be presented as anatomical groups first (thankfully, these groups closely match the innervations!), then we will look at the same muscles in terms of the axes they work around.
Muscle Groups

Posterior Abdominal Wall

The **psoas major** is a muscle of the posterior abdominal wall that reaches into the lower limb. (Psoas minor is absent in about 50% of individuals, don’t worry about it too much.) The psoas major has attachments to the bodies of lumbar vertebrae. The **iliacus** muscle is inferior and lateral to the psoas major and is found attached to the iliac fossa (from whence it gets its name). The two muscles join, pass under the inguinal ligament, and attach to the lesser trochanter of the femur as the **iliopsoas** muscle. It is safe to say that iliacus and psoas major are the main flexors of the hip. Loss of function of the muscle makes walking difficult – the leg is brought forward by iliopsoas – as well as climbing stairs, walking up an incline, or sitting up from a reclining position. All of these movements involve hip joint flexion. Sudden strains or pulls on the muscle, such as during athletic activities, may be severe enough to cause avulsion of the lesser trochanter from the femur.

**Quadratus lumborum** is not a muscle associated with the hip joint; however, it is a muscle of the posterior body wall that extends between the last rib and the posterior margin of the iliac crest. It is located just posterior to the psoas major muscle. The muscle can abduct the trunk (vertebral column) when the pelvic attachment of the muscle is fixed, and it can “elevate” the same side of the pelvis when the rib attachment of the muscle is fixed.
All of the posterior abdominal wall muscles are in close proximity and intimately related with the lumbar portion of the lumbosacral plexus. And for the most part they take their innervation from direct branches off of it. The psoas major, minor and quadratus lumborum receive innervation from ventral rami of the lumbosacral plexus (about T12 to L4 –ish). Iliacus, because of its more lateral and inferior position, receives innervation from the femoral nerve.

Superficial Gluteal

Gluteus maximus, gluteus medius, gluteus minimus and the tensor fascia lata muscle are the superficial gluteal muscles. They all attach to the ilium proximally and to the femur distally (gluteus maximus and the TFL also attach to the iliotibial band). Gluteus maximus is the largest muscle in the body and is innervated by the inferior gluteal nerve. Gluteus medius and minimus can be found deep to gluteus maximus and are innervated by the superior gluteal nerve. The TFL muscle is partially embedded in the fascia lata of the thigh (hence the name!) and is also innervated
by the superior gluteal nerve. These muscles can each do multiple actions around axes of the hip, and taken together can be thought of as the “deltoid” of the lower limb.
Deep Gluteal

The deep gluteal muscles run from the innominate bones and sacrum to the discrete areas on the greater trochanter of the femur. These are very small muscles and are often easily remembered through the mnemonic “P-GOGO-Q” to describe their location from superior to inferior. *Piriformis* is the most superior and largest of the muscles. It is also an excellent landmark for the neurovasculature passing from the pelvis to the gluteal region and thigh. The superior gluteal nerve and artery exits the greater sciatic notch superior to the piriformis to reach the superficial gluteal muscles. The inferior gluteal nerve and artery, pudendal nerve and artery and sciatic nerve all exit the greater sciatic notch inferior to the piriformis. The *gemelli* muscles, superior and inferior “twins,” are very small and can be found on either side of the tendon of the *obturator internus* tendon. The *obturator internus* and *externus* muscles both originate from a membrane that covers the obturator foramen. The *quadratus femoris* is a square shaped muscle and the most inferior of the group. Luckily, the innervation of these muscles is pretty straightforward. Every muscle (except obturator externus which is innervated by the obturator nerve), in innervated by a branch of the lumbosacral plexus called a “nerve to (insert muscle name here).” The P-GOGO-Q muscles all run posterior to the femur (and the vertical axis) and therefore are well placed lateral rotators of the hip. However, there are nuances to the angles at which they insert on the femur and can assist with other actions as well.
The anterior thigh contains muscles that cross both the hip and the knee. The large **quadriceps femoris muscle group** contains four muscles, but only one of the four muscles, the **rectus femoris**, crosses the hip and has an action there. The other three act only at the knee (for further discussion of the quadriceps muscles, go to the Muscles that Move the Knee chapter). The rectus femoris attaches to the anterior inferior iliac spine proximally and to the tibial tuberosity with the remaining quadriceps muscles distally.
The sartorius muscle is not part of the quadriceps femoris group. The sartorius is the longest muscle in the body, and has a proximal attachment at the anterior superior iliac spine and a distal attachment on the medial side of the tibial tuberosity. The position of the sartorius, running from superior-lateral to inferior-medial attachment points, is another feature left over from limb rotation. This complicated orientation allows it to do a series of movement that puts the hip and knee in the “tailor’s position” (sartorial refers to tailor, apparently that's how tailors in ye olde times would sit while working). At the hip the sartorius can flex, abduct and laterally rotate the hip. We'll discuss the further actions and testing of the anterior thigh muscles at the knee later.
All of the muscles of the anterior thigh compartment are innervated by the femoral nerve (L2, 3, 4, posterior division). The sartorius muscle can be used a useful landmark to delineate between the L2 and L3 dermatome in the anterior thigh.

**Medial Thigh**

The medial thigh compartment consists of five muscles that originate from the pubis and/or ischium. Most of the medial thigh muscles have a slightly diagonal orientation that allows them to be able to adduct at the hip (this compartment is sometimes called the “adductor compartment”). Three smaller muscles- **pectineus**, **adductor brevis** and **adductor longus**—attach to the pubis proximally and to the posterior surface of the femoral shaft (mostly the linea aspera) distally. They can all flex, adduct and medially rotate at the hip (see below for further discussion of medial rotation of the hip). **Gracilis** is a long, thin muscle (gracile means thin). It can be easily mistaken for sartorius except that its proximal attachment is on the pubis instead of the ilium. The gracilis can do a bit of flexion, but it mainly works as an adductor.
The largest muscle of the medial compartment is the **adductor magnus**. It can be seen anteriorly as well as posteriorly on the cadaver. Adductor magnus lies posterior to adductor longus and brevis. Its proximal attachments are the pubis and ischium (along the ischiopubic ramus) and its distal attachments are the linea aspera and adductor tubercle on the femur. There is a “hole” in the adductor magnus called the **adductor hiatus** that allows the passage of the femoral artery and vein into the popliteal fossa. The adductor magnus can adduct and medially rotate at the hip, but its movements around the transverse axis are more complicated. The proximal attachments of the adductor magnus pass anteriorly (pubis) and posteriorly (ischium) to the transverse axis. This allows the adductor magnus to both flex and extend the hip. The anterior fibers are sometimes called the adductor portion, and the posterior fibers are sometimes called the hamstrings portion of the adductor magnus.
For the most part, the muscles of the medial compartment are innervated by the obturator nerve (L2,3,4, anterior division) as it splits and passes anteriorly and posteriorly to the adductor brevis muscle. There are a couple of exceptions though (of course there are...). The pectineus muscle can sometimes be innervated by the femoral nerve instead of the obturator nerve, and sometimes by both! Since the femoral nerve is a posterior division nerve and the obturator nerve is an anterior division nerve. The pectineus muscle is sometimes accused of not being able to make up its mind. In fact, you may run across texts that include it in the anterior compartment instead of the medial compartment. The adductor magnus muscle also has dual innervations. The anterior fibers are innervated by the obturator nerve, but the posterior fibers are innervated by the tibial nerve. These are both anterior division nerves though so the adductor magnus is firm in its allegiances.

Back to Top
The posterior compartment of the thigh, sometimes called the hamstrings, consists of three muscles that cross the hip and knee. **Semitendinosus** and **semimembranosus** attach to the ischial tuberosity proximally and to the medial tibia distally. They both extend the hip. These two muscles are situated very close to one another and can be confused. Use their names to tell them apart: semitendinosus has a thick, round tendon that attaches to the tibia; semimembranosus has a wide, flat tendon (it looks like a “membrane”) that attaches to the ischial tuberosity. The **biceps femoris** muscle has two heads: a long head that attaches proximally to the ischial tuberosity and a short head that attaches to the linea aspera of the femur (and thus does not cross the hip). Both heads join to attach distally to the head of the fibula. The long head of the biceps femoris extends the hip, but the short head has no action at the hip. When sitting with the knee flexed to 90°, biceps femoris and its tendon can be palpated along the superior, lateral and posterior aspect of the knee joint. The muscle and its tendon can be palpated to its attachment to the lateral side of the head of the fibula. The semitendinosus, semimembranosus and long head of the biceps femoris are all innervated by the tibial nerve. The short head of the biceps femoris is innervated by the common fibular nerve.
Muscle Actions at the Hip

Transverse Axis

Flexion: The muscles that are capable of producing flexion at the hip joint are listed below based on their innervation. The major or primary flexors of the hip are italicized. They are positioned on the anterior and anteromedial aspects of the thigh. All have at least an anterior relationship...
to the transverse axis of the hip joint, and have a proximal pull. Note that gluteus medius can be “split” into anterior and posterior halves, which flex and extend, respectively. Obturator externus, a deep gluteal muscle, is also capable of flexion.

### Transverse Axis: Flexion

<table>
<thead>
<tr>
<th>Muscles innervated by <strong>direct branches from LS plexus</strong></th>
<th>Muscles innervated by the <strong>femoral nerve</strong></th>
<th>Muscles innervated by the <strong>obturator nerve</strong></th>
<th>Muscles innervated by the <strong>superior gluteal nerve</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>-Psoas major</td>
<td>-Iliacus</td>
<td>-Adductor longus</td>
<td>-Gluteus medius (anterior fibers)</td>
</tr>
<tr>
<td></td>
<td>-Rectus femoris</td>
<td>-Adductor brevis</td>
<td>-Gluteus minimus</td>
</tr>
<tr>
<td></td>
<td>-Sartorius</td>
<td>-Pectineus</td>
<td>-Tensor fascia latae</td>
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<tr>
<td></td>
<td></td>
<td>-Gracilis</td>
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<tr>
<td></td>
<td></td>
<td>-Obturator externus</td>
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</tbody>
</table>

*Image from The Hip Joint (http://christineshipjoint.blogspot.com/2014/12/sartorius.html)*

**Extension:** All muscles that extend the hip have a posterior relationship to the transverse axis through the hip joint. Gluteus maximus is the major extensor of the hip, but it is called into action
only in activities involving powerful of extension. Examples include running or climbing up a flight of stairs. The hamstrings – biceps femoris, long head, semitendinosus and semimembranosus – are used in “less rigorous” activities involving extension, such as walking. You can demonstrate this for yourself. First, place your hands on your buttocks and walk in a leisurely fashion. The gluteus maximus muscle remains rather quiet. Again, put your hands on your buttocks and climb up a steep flight of stairs – two at a time – and you will notice that gluteus maximus is quite active! The same occurs when running. If anyone questions you about this behavior, tell them that you are conducting a scientific experiment.

Paralysis of gluteus maximus makes running, walking up a flight of stairs or straightening up from a flexed position extremely difficult. Individuals in whom the muscle is paralyzed also tend to have a characteristic gait. An individual will be seen always to be leaning slightly backward when walking. This occurs because gluteus maximus normally helps to counteract a slight tendency towards flexion at the hip joint during walking. One compensates for the loss of gluteus maximus by leaning backwards.

<table>
<thead>
<tr>
<th>Transverse Axis: Extension</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscles innervated by <strong>superior</strong></td>
</tr>
<tr>
<td>gluteal nerve</td>
</tr>
<tr>
<td>-Gluteus medius (posterior fibers)</td>
</tr>
<tr>
<td>Muscles innervated by <strong>inferior</strong></td>
</tr>
<tr>
<td>gluteal nerve</td>
</tr>
<tr>
<td>-Gluteus maximus</td>
</tr>
<tr>
<td>Muscles innervated by <strong>tibial</strong></td>
</tr>
<tr>
<td>nerve</td>
</tr>
<tr>
<td>-Biceps femoris (long head)</td>
</tr>
<tr>
<td>-Semimembranosus</td>
</tr>
<tr>
<td>-Semitendinosus</td>
</tr>
<tr>
<td>-Hamstrings portion of adductor magnus</td>
</tr>
</tbody>
</table>
Anterior-Posterior Axis

Abduction: The hip joint abductors are listed below. You will note that gluteus maximus has the capability of abducting (superior lateral fibers) and adducting (inferior medial fibers). The major function of hip abduction is to maintain the pelvis in a horizontal position when one or the other leg is raised from the ground (review Muscle Analysis of the Lower Limb if this movement is confusing). This is an action of the muscles that is continuously required in walking and running. With both feet on the ground, the pelvis is balanced evenly on the two lower limbs. The line of the
center of gravity is positioned in between the feet. When the right leg is raised off of the ground, the right side of the pelvis would droop or depress about the AP axis passing through the left hip joint. This occurs because the right half of the pelvis has “lost” its support, and also that there is a shift in the center of gravity. Contraction of the left gluteus medius and minimus muscles prevents the droop/depression from occurring, and the pelvis maintains its more horizontal positioning. The right gluteus medius and minimus muscles will contract when the left leg is lifted off the ground. You can demonstrate the above phenomenon on yourself or another individual by placing your hands on the gluteus medius muscles and then lifting one leg, and then the other, off the ground.

<table>
<thead>
<tr>
<th>Anterior-Posterior Axis: Abduction</th>
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</thead>
<tbody>
<tr>
<td>Muscles innervated by the <strong>superior gluteal nerve</strong></td>
</tr>
<tr>
<td>-Gluteus medius</td>
</tr>
<tr>
<td>-Gluteus minimis</td>
</tr>
<tr>
<td>-Tensor fascia lata</td>
</tr>
<tr>
<td>Muscles innervated by the <strong>inferior gluteal nerve</strong></td>
</tr>
<tr>
<td>-Gluteus maximus (superior lateral fibers)</td>
</tr>
<tr>
<td>Muscles innervated by the <strong>femoral nerve</strong></td>
</tr>
<tr>
<td>-Sartorius</td>
</tr>
</tbody>
</table>
Clinical Correlation

Paralysis of gluteus medius and minimus results in a characteristic gait, called the **Trendelenberg sign**. If the *left* muscles are paralyzed, the *right* side of the pelvis will droop or depress when the *right* leg is lifted off the ground. This is uncomfortable and contributes to several problems in walking. To compensate for the depression of the pelvis, the individual will throw/lean their trunk towards the left side, or away from the side of the raised leg. The “waddling” gait that results from this trunk movement is the Trendelenberg sign. In
Adduction: The most important hip joint adductors are the muscles in the medial compartment of the thigh that are innervated by the obturator nerve. The ability to adduct at the hip joint, with the pelvis fixed, is not involved in many activities, and loss of adduction function would probably not lead to any significant problems in ambulation. The ability to adduct might be especially missed during horseback riding, however. Like the rotators, the adductors are probably more significant in stabilizing the pelvis on the fixed legs. Stand and shift your weight from one leg to another. The adductors are probably playing a significant role in keeping the trunk and limbs stable during the movement.

<table>
<thead>
<tr>
<th>Anterior–Posterior Axis: Adduction</th>
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</thead>
<tbody>
<tr>
<td>Muscles innervated by the <strong>inferior gluteal nerve</strong></td>
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<tr>
<td>-Gluteus maximus (inferior medial portion)</td>
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Vertical Axis

Lateral Rotation: Lateral rotation is a rather straightforward movement to understand with respect to muscle function. With the exception of sartorius, all of the lateral rotators are posterior to the vertical axis of the hip joint. All of the posteriorly positioned muscles have a medial pull. Sartorius is anterior to the vertical axis with a lateral pull. Gluteus medius can be divided into anterior and posterior halves that medially and laterally rotate, respectively. Gluteus maximus is likely the strongest lateral rotator. While not the strongest, the deep gluteal P-GOGO-Q group is
the most efficient lateral rotators. This group of muscles has been called the “rotator cuff” group of muscles of the hip joint.

**Vertical Axis: Lateral Rotation**

<table>
<thead>
<tr>
<th>Muscles innervated by direct branches from the LS plexus</th>
<th>Muscles innervated by obturator nerve</th>
<th>Muscles innervated by superior gluteal nerve</th>
<th>Muscles innervated by inferior gluteal nerve</th>
<th>Muscles innervated by tibial nerve</th>
<th>Muscles innervated by femoral nerve</th>
</tr>
</thead>
<tbody>
<tr>
<td>-Piriformis</td>
<td>-Obturator externus</td>
<td>-Gluteus medius (posterior fibers)</td>
<td>-Gluteus maximus</td>
<td>-Biceps femoris (long head)</td>
<td>-Sartorius</td>
</tr>
<tr>
<td>-Gemellus superior and inferior</td>
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<td></td>
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<tr>
<td>-Obturator internus</td>
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<tr>
<td>-Quadratus femoris</td>
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<tr>
<td>-Psoas major (as iliopsoas)</td>
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</tbody>
</table>

*Image from The Hip Joint (http://christineshipjoint.blogspot.com/2014/12/sartorius.html)*

Medial Rotation: There is considerable argument about the significance of several muscles that are said to produce hip joint medial rotation, based largely on their relationships to the vertical axis of
the hip joint. Gluteus medius, anterior fibers and gluteus minimus are considered to be the most significant medial rotators, with the adductor group coming in as a half-hearted second. Iliopsoas has been championed as both a medial and lateral rotator, based on mechanical analyses. Most electromyographic studies suggest that the muscle does not participate significantly (?) in either movement. There is also debate over whether the adductor group muscles are medial rotators or lateral rotators. We have a model in the lab that makes a convincing argument for medial rotation in an adult standing in anatomical position (check it out and see if you buy it). However, if the individual is rotating the hip while the hip is also flexed, or that individual is a small child, the adductor group can perform lateral rotation of the hip.

<table>
<thead>
<tr>
<th>Vertical Axis: Medial Rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscles innervated by direct LS branches/femoral nerve</td>
</tr>
<tr>
<td>-Iliopsoas (debated)</td>
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</table>
Medial and lateral rotation of the lower limb, with the pelvis fixed, are actually rather insignificant movements. The rotatory muscles are commonly called into action when their femoral attachments are fixed. You can demonstrate this on yourself by simply standing and twisting or rotating “at the hip” first in one direction, and then in the other direction. The rotators are important in both moving and stabilizing the pelvis during such activities.

The rotators – distal/femoral attachments fixed – are also important during walking. For example, when you take a step forward with your right lower limb, there is a slight amount of rotation of the pelvis so that the trunk faces towards the left (left leg fixed on the ground). The reverse occurs when the left leg is advanced. Now, figure out which muscles would be involved in producing this rotation, and on which side of the pelvis they are active!
Hip rotation during walking. Image adapted from ET Bersu.
Muscles that Move the Hip Quick Reference Table
<table>
<thead>
<tr>
<th>Muscle</th>
<th>Proximal Attachment</th>
<th>Distal Attachment</th>
<th>Innervation</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Psoas major</td>
<td>T12-L4 vertebral bodies</td>
<td>Lesser trochanter (as ilio psoas)</td>
<td>Direct branches from LS plexus (T12-L4)</td>
<td>Flexion Rotation</td>
</tr>
<tr>
<td>Iliacus</td>
<td>Iliac fossa</td>
<td>Lesser trochanter (as iliopsoas)</td>
<td>Femoral</td>
<td>Flexion Rotation</td>
</tr>
<tr>
<td>Quadratus lumborum</td>
<td>12th rib, L1-L4 vertebral bodies</td>
<td>Iliac crest</td>
<td>Direct branches from LS plexus (T12-L4)</td>
<td>No movement at hip (elevates ilium)</td>
</tr>
<tr>
<td>Gluteus maximus</td>
<td>Sacrum, ilium, thoracolumbar fascia, sacrotuberous ligament</td>
<td>IT band, gluteal tuberosity</td>
<td>Inferior gluteal</td>
<td>Extension Abduction (lateral fibers)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Extension (posterior fibers)</td>
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<td></td>
<td>Abduction Medial Rotation (anterior fibers)</td>
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<td></td>
<td>Lateral Rotation (posterior fibers)</td>
</tr>
<tr>
<td>Gluteus medius</td>
<td>Ilium</td>
<td>Greater trochanter</td>
<td>Superior gluteal</td>
<td>Flexion Abduction Medial Rotation</td>
</tr>
<tr>
<td>Gluteus minimus</td>
<td>Ilium</td>
<td>Greater trochanter</td>
<td>Superior gluteal</td>
<td>Flexion Abduction Medial Rotation</td>
</tr>
<tr>
<td>Tensor fascia lata</td>
<td>ASIS</td>
<td>IT band</td>
<td>Superior gluteal</td>
<td>Flexion Abduction Medial Rotation</td>
</tr>
<tr>
<td>Piriformis</td>
<td>Sacrum</td>
<td>Greater trochanter</td>
<td>N. to piriformis</td>
<td>Lateral Rotation</td>
</tr>
<tr>
<td>Gemellus superior</td>
<td>Ischial spine</td>
<td>Greater trochanter</td>
<td>N. to gemellus superior</td>
<td>Lateral Rotation</td>
</tr>
<tr>
<td>Gemellus inferior</td>
<td>Ischial tuberosity</td>
<td>Greater trochanter</td>
<td>N. to gemellus inferior</td>
<td>Lateral Rotation</td>
</tr>
<tr>
<td>Obturator internus</td>
<td>Obturator membrane (inner surface)</td>
<td>Greater trochanter</td>
<td>N. to obturator internus</td>
<td>Lateral Rotation</td>
</tr>
<tr>
<td>Muscle</td>
<td>Proximal Attachment</td>
<td>Distal Attachment</td>
<td>Innervation</td>
<td>Action</td>
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</tr>
<tr>
<td>Obturator externus</td>
<td>Obturator membrane (outer surface)</td>
<td>Greater trochanter</td>
<td>Obturator</td>
<td>Flexion Lateral Rotation</td>
</tr>
<tr>
<td>Quadratus femoris</td>
<td>Ischial tuberosity</td>
<td>Intertrochanteric crest</td>
<td>N. to quadratus femoris</td>
<td>Lateral Rotation</td>
</tr>
<tr>
<td>Sartorius</td>
<td>ASIS</td>
<td>Medial tibial tuberosity</td>
<td>Femoral</td>
<td>Flexion Abduction Lateral Rotation</td>
</tr>
<tr>
<td>Rectus femoris</td>
<td>AIIS</td>
<td>Tibial tuberosity</td>
<td>Femoral</td>
<td>Flexion</td>
</tr>
<tr>
<td>Pectineus</td>
<td>Pectin pubis</td>
<td>Pectineal line</td>
<td>Femoral and/or obturator</td>
<td>Flexion Adduction Medial Rotation</td>
</tr>
<tr>
<td>Adductor brevis</td>
<td>Inferior pubic ramus</td>
<td>Linea aspera</td>
<td>Obturator</td>
<td>Flexion Adduction Medial Rotation</td>
</tr>
<tr>
<td>Adductor longus</td>
<td>Superior pubic ramus</td>
<td>Linea aspera</td>
<td>Obturator</td>
<td>Flexion Adduction Medial Rotation</td>
</tr>
<tr>
<td>Adductor magnus</td>
<td>Ischiopubic ramus, ischial tuberosity</td>
<td>Linea aspera, adductor tubercle</td>
<td>Obturator (anterior fibers) and tibial (posterior fibers)</td>
<td>Flexion Extension (posterior fibers) Adduction Medial Rotation</td>
</tr>
<tr>
<td>Gracilis</td>
<td>Inferior pubic ramus</td>
<td>Medial tibial tuberosity</td>
<td>Obturator</td>
<td>Flexion Adduction</td>
</tr>
<tr>
<td>Semitendinosus</td>
<td>Ischial tuberosity</td>
<td>Medial tibial tuberosity</td>
<td>Tibial</td>
<td>Extension Adduction</td>
</tr>
<tr>
<td>Semimembranosus</td>
<td>Ischial tuberosity</td>
<td>Medial tibial plateau</td>
<td>Tibial</td>
<td>Extension Adduction</td>
</tr>
<tr>
<td>Biceps femoris</td>
<td>Ischial tuberosity (long head) Lina aspera (short head)</td>
<td>Head of fibula</td>
<td>Tibial (long head) and common fibular (short head)</td>
<td>Extension (long head) Adduction (long head) Lateral Rotation (long head)</td>
</tr>
</tbody>
</table>
Muscles that move the knee can be found in the anterior, posterior and medial compartments of the thigh as well as three muscles in the posterior compartment of the leg. Many of the muscles that move the knee also cross the hip and were addresses in the chapter on Muscles that Move the Hip. We will not repeat the specifics of those muscles, so please refer back to that for specifics of those muscles. As was the form previously, we will discuss the muscles and then talk about which muscles work around the two axes (transverse and vertical) that go through the knee.

**Muscle Groups**

**Anterior Thigh**

All of the muscles in the anterior compartment of the thigh cross the knee, and all of the anterior compartment muscles are innervated by the femoral nerve. The quadriceps femoris muscle group is made of four different muscles: rectus femoris (which also crosses the hip), vastus medialis, vastus intermedius, and vastus lateralis. The vastus muscles have proximal attachments along the shaft of the femur. The muscles makes up the main mass of the anterior and lateral thigh musculature. Vastus medialis forms a prominent mass on the medial and distal part of the thigh. It is possible to differentiate the different heads of the muscle. In the sitting position with the knee joint in almost complete passive extension, perform isometric contraction of quadriceps while palpating the muscle near the patella.

The quadriceps femoris muscles join together distally and form a single tendon, the quadriceps tendon. The patella is embedded in this tendon. The presence of the patella in the quadriceps tendon increases the lever arm of the quadriceps muscles to create a more efficient pull on the tibia. The portion of the quadriceps tendon between the patella and the tibial tuberosity is technically a ligament (because it is now attaching bone to bone instead of tendon to bone) and is named the patellar ligament.

The quadriceps femoris muscles are generally aligned with the shaft of the femur and have a superior and lateral pull when they move the tibia (this is what the q in q-angle stands for). The lateral part of the pull of the quadriceps can cause the patella to dislocate. However, the inferiormost fibers of the vastus medialis are aligned horizontally. These fibers contract when the knee reaches full extension, and they apply a medial pull on the patella that helps to offset the lateral pull of the rest of the quadriceps femoris muscles.

The sartorius muscle also moves the knee; however, its unique distal attachment, the pes anserinus, causes it to pass posterior to the transverse axis and flexes of the knee. Additionally, this allows the sartorius to medially rotate the knee. These actions at the knee, along with the actions of the sartorius at the knee can place the lower limb into the “tailor’s position.”
**Medial Thigh**

Of the muscles in the medial thigh, only one crosses the knee: **gracilis**. It passes posterior to the transverse axis and medial to the vertical axis, and its distal attachment joins the pes anserinus. It can flex and medially rotate the knee and is innervated by the **obturator nerve**.

**Back to Top**

**Posterior Thigh**

All of the muscles of the posterior compartment of the thigh (**semitendinosus**, **semimembranosus**, both heads of **biceps femoris**) cross the knee and act as the main flexors of the knee. The hamstrings cross two joints which makes them susceptible to injury if they are stretched across both joints. Most hamstrings injuries occur when the hip is flexed and the knee is extended. Conversely, the hamstrings can only contract concentrically so far. Thus when the hip is extended, it is difficult to fully flex the knee and vice versa.
Semitendinosus and semimembranosus attach distally to the tibia and therefore medially rotate the knee (semitendinosus joins the pes anserinus). Biceps femoris attaches distally to the head of the fibula and therefore laterally rotates the knee. In fact, biceps femoris is the only muscle that laterally rotates the tibia on the femur. Recall that semitendinosus, semimembranosus and the long head of the biceps femoris are innervated by the tibial nerve, and the short head of the biceps femoris is innervated by the common fibular nerve.
The sartorius, gracilis and semitendinosus muscles travel from their respective compartments to cross the knee and attach to the tibia through the pes anserinus. Pes anserinus means “goose foot” and refers the shape formed by the three tendons of the muscles.

**Posterior Leg**

**The following muscles are located in the leg and NOT the thigh. However, they are important for movement of the knee, and we will consider them here and in the following chapter.**

The posterior compartment of the leg contains three muscles that cross the knee: gastrocnemius, plantaris and politeus. All three of them are innervated by the tibial nerve. Gastrocnemius is a two headed muscle that attaches proximally to the medial and lateral femoral epicondyles. It is very superficial, easily recognizable and commonly referred to as the calf muscle. Its distal attachment is the large calcaneal tendon. While it does cross the knee, its primary action is in plantarflexion of the ankle. Plantaris passes from the lateral femoral epicondyle to join the calcaneal tendon as well. It is a tiny muscle that is found deep to gastrocnemius. While it will assist the gastrocnemius in its movements, its action is most often described as “negligible”.


The sartorius, gracilis and semitendinosus muscles travel from their respective compartments to cross the knee and attach to the tibia through the pes anserinus. Pes anserinus means “goose foot” and refers the shape formed by the three tendons of the muscles.
The popliteus muscle is the muscle of the posterior leg that has the most significant job at the knee. The popliteus muscle has a distal attachment to the posterior side of the tibia. It passes obliquely to the opposite side of the knee to attach to the lateral femoral epicondyle. Along this route, the popliteus enters the fibrous joint capsule of the knee and passes in between the lateral meniscus and the lateral collateral ligament of the knee. This is the reason why the LCL and the
lateral meniscus do not come in contact with one another! The position of the popliteus muscle is the key to unlocking the knee (literally). When the knee is in the fully extended or “locked” position, the popliteus initiates the lateral rotation of the femur on the fixed tibia (ie medial rotation of the tibia on the femur) that allows for flexion of the knee to proceed. Paralysis of the muscle may result in considerable difficulty in an individual's ability to unlock the knee joint.
Posterior view of a right knee. The posterior thigh muscles, gastrocnemius and plantaris head have been cut and reflected. Note the passage of the popliteus from the tibia to the femur and its entrance into the fibrous joint capsule of the knee.

Back to Top
Muscle Actions at the Knee

Transverse Axis

Flexion: The most significant feature of the flexors is that they all have a posterior relationship to the transverse axis of the knee joint (versus an anterior position as in the upper limb). If the knee is being flexed from the fully extended position, the knee must first be unlocked by lateral rotation of the femur on the tibia or, if the tibia is off the ground, medial rotation of the tibia on the femur. Popliteus, a muscle located in the posterior knee joint region, is a critical muscle initiating this rotatory movement. Popliteus is also an efficient flexor of the knee joint. In less than the fully extended position, flexion is a straightforward movement.

<table>
<thead>
<tr>
<th>Transverse Axis: Flexion</th>
<th>Muscles innervated by the tibial nerve</th>
<th>Muscles innervated by the femoral nerve</th>
<th>Muscles innervated by the obturator nerve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biceps femoris (both heads)</td>
<td>Semitendinosus</td>
<td>Semimembranosus</td>
<td>Popliteus</td>
</tr>
<tr>
<td>Gastrocnemius</td>
<td>Sartorius</td>
<td>Gracilis</td>
<td></td>
</tr>
</tbody>
</table>

Extension: The main extensor of the knee is the quadriceps femoris group. Paralysis/loss of this muscle eliminates one’s ability to extend at the knee. When one is rehabilitating or strengthening this muscle, it is important to utilize the muscle to bring the knee into full extension, or the “locked” position. Failure to rehabilitate the muscle through its full range of motion may lead to an unstable knee because not all of the muscle fibers will be firing.

<table>
<thead>
<tr>
<th>Transverse Axis: Extension</th>
<th>Muscles innervated by the femoral nerve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectus femoris</td>
<td></td>
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<tr>
<td>Vastus medialis</td>
<td></td>
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<tr>
<td>Vastus intermedius</td>
<td></td>
</tr>
<tr>
<td>Vastus lateralis</td>
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</tr>
</tbody>
</table>

The gluteus maximus and tensor fascia lata muscle have been reported to help stabilize the knee in extension through the IT band. “Iliotibial band” syndrome is an irritation of the tract in the region where it attaches to the lateral tibia condyle. There is a bursa between the band and the underlying bone. Runners and other athletes who are making an effort to strengthen the thigh muscles is one group which is susceptible to the condition.
Muscles that flex the knee can also be used to extend the knee from a non-anatomical position. The posterior thigh muscles and gastrocnemius can work together to extend a knee from a flexed position (as when you stand up from sitting). To do this the foot is fixed on the ground.

The dark lines represent the posterior thigh muscles and gastrocnemius. The shaded arrow represents the direction of the movement of the knee in extension from flexed position when the foot is fixed on the ground. Diagram the pulls of the muscles that create this movement. Image from ET Bersu.
Rotation at the knee can be confusing at first. It is important to define whether you are talking about the tibia moving relative to the femur or the femur moving relative to the tibia. The tables below are set up as the tibia moving relative to the femur, but it is important to remember that many of these movements are actually occurring on a fixed tibia. Examples include making a sharp turn while running (“pivoting” while running) and changing directions while skiing. It is important to feel comfortable describing the muscle causing rotation in both instances.

Active rotation at the knee joint can be accomplished only when the knee joint is flexed (ie, when it is not in a fully locked extension). In this position, the collateral ligaments are relaxed and the condyles are in minimal contact with each other. This permits the femur and tibia to rotate on each other. The movement is facilitated by the menisci.

The most apparent muscles which produce rotation are the ones that also flex the joint. These muscles function well in rotation when the joint is flexed to 90°. With the knee flexed to 90°, the muscles are located on the medial or lateral sides of the vertical axis that passes through the length of the tibia.

The rotator *par excellence* of the knee joint is popliteus. The major function of popliteus is to unlock the fully extended knee joint. Sometimes you will hear that the popliteus will laterally rotate the femur on the fixed tibia, or medially rotate the tibia on the fixed femur. Both of these actions would unlock the knee.

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**Vertical Axis: Medial Rotation**

<table>
<thead>
<tr>
<th>Muscles innervated by the <strong>tibial nerve</strong></th>
<th>Muscles innervated by the <strong>obturator nerve</strong></th>
<th>Muscles innervated by the <strong>femoral nerve</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>-Semitendinosus</td>
<td>-Gracilis</td>
<td>-Sartorius</td>
</tr>
<tr>
<td>-Semimembranosus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-Popliteus</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Vertical Axis: Lateral Rotation**

Muscles innervated by the **tibial and common fibular nerve**

- Biceps femoris (both heads)

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[Back to Top](#)
### Muscles that Move the Knee Quick Reference Table

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Proximal Attachment</th>
<th>Distal Attachment</th>
<th>Innervation</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sartorius</td>
<td>ASIS</td>
<td>Medial tibial tuberosity</td>
<td>Femoral</td>
<td>Flexion, Medial rotation</td>
</tr>
<tr>
<td>Rectus femoris</td>
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<td>Tibial tuberosity</td>
<td>Femoral</td>
<td>Extension</td>
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<td>Vastus medialis</td>
<td>Linea aspera, Intertrochanter line</td>
<td>Tibial tuberosity</td>
<td>Femoral</td>
<td>Extension</td>
</tr>
<tr>
<td>Vastus intermedius</td>
<td>Anterior femoral shaft</td>
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<td>Femoral</td>
<td>Extension</td>
</tr>
<tr>
<td>Vastus lateralis</td>
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<td>Tibial tuberosity</td>
<td>Femoral</td>
<td>Extension</td>
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<td>Medial tibial tuberosity</td>
<td>Obturator</td>
<td>Flexion, Medial rotation</td>
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<td>Flexion, Medial rotation</td>
</tr>
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<td>Medial tibial plateau</td>
<td>Tibial</td>
<td>Flexion, Medial rotation</td>
</tr>
<tr>
<td>Biceps femoris</td>
<td>Ischial tuberosity (long head) Linea aspera (short head)</td>
<td>Head of fibula</td>
<td>Tibial (long head) Common fibular (short head)</td>
<td>Flexion, Lateral rotation</td>
</tr>
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<td>Gastrocnemius</td>
<td>Medial and lateral femoral epicondyles</td>
<td>Calcaneal tuberosity</td>
<td>Tibial</td>
<td>Flexion</td>
</tr>
<tr>
<td>Plantaris</td>
<td>Lateral femoral epicondyle</td>
<td>Calcaneal tuberosity</td>
<td>Tibial</td>
<td>Flexion</td>
</tr>
<tr>
<td>Popliteus</td>
<td>Lateral femoral epicondyle</td>
<td>Posterior proximal tibia</td>
<td>Tibial</td>
<td>Flexion, Medial rotation</td>
</tr>
</tbody>
</table>

[Back to Top]
Muscles of the Leg and Foot

MEGHAN COTTER, PHD

Chapter Sections

Muscles that Move the Ankle and Intertarsal Joints

Muscle Groups
- Anterior Leg
- Lateral Leg
- Posterior Leg: Superficial
- Posterior Leg: Deep

Muscle Actions at the Ankle and Intertarsal Joints
- Ankle: Transverse Axis
- Intertarsal Joints: Oblique Axis

Muscles that Move the Ankle and Intertarsal Joints Quick Reference Table

Muscles that Move the Metatarsophalangeal and Interphalangeal Joints

Muscle Groups
- Dorsal Foot
- Plantar Foot

Muscle Actions at the MP and IP Joints
- MP and IP Joints: Transverse Axis
- MP Joints: Vertical Axis

Muscles that Move the Ankle and Intertarsal Joints

As in the past two muscles chapters we will discuss the muscles by compartment, then revisit them in the context of which axes they work around. The muscles of the leg are divided up into three compartments: anterior, lateral and posterior. Some posterior compartment muscles

Muscles of the Leg and Foot | 639
were discussed previously in terms of the knee. Please refer to that chapter for their movements around the knee.

**Muscle Groups**

*Anterior Leg*

The four muscles of the anterior compartment all extend into the foot past the ankle and the intertarsal joints, and they are all innervated by the **deep fibular nerve**. *(Please note: the term “fibular” when referring to muscles and nerves in the leg has gone through a recent transition. You may see the same muscles and nerves sometimes referred to as “peroneal.” These terms can be used interchangeably, but fibular is the more common term) All of the anterior compartment muscle tendons pass deep to **extensor retinaculae** that are thickenings of the crural fascia. The extensor and flexor retinaculae have the same function in the lower limb as they do in the upper limb.

**Tibialis anterior** and **fibularis tertius** run from their respective bones to attach to tarsal and metatarsal bones. They both dorsiflex the ankle, but attach to either side of the oblique axis. Tibialis anterior is medial and therefore inverts, and fibularis tertius is lateral and therefore everts. **Extensor hallucis longus** runs from the leg to the 1st digit. **Extensor digitorum longus** runs a similar route, but splits into four tendons to digits 2-5. The toes have extensor hoods much like those found in the fingers, and the long extensor muscles use those as their attachment points. The long extensors work on all joints from the ankle to the distal interphalangeal joints. They have similar actions as the other two anterior compartment muscles in that they both dorsiflex, and the more medially oriented muscle (extensor hallucis longus) can invert while the more laterally oriented muscle (extensor digitorum longus) can evert.
In the sitting position with the knee flexed, observe and palpate the most medial of the tendons, tibialis anterior, during active ankle joint dorsiflexion and intertarsal joint inversion. It can be
followed to its attachment on the medial side of the foot (medial surface of first cuneiform bone). Lateral to this is the narrower tendon of extensor hallucis longus. Observe and palpate the tendon during metatarsophalangeal joint hyperextension of the big toe. It is more prominent if the interphalangeal joint is held in flexion. The tendon is identifiable at the ankle and may be followed as far as the distal phalanx of the great toe.

Lateral to the tendon of extensor hallucis longus at the ankle joint is the group of tendons of extensor digitorum longus. The individual tendons can be followed to the middle phalanges of the toes and are most prominent during active hyperextension of the metatarsophalangeal joints, with the interphalangeal joints held in flexion. The pulse of the dorsalis pedis artery can be felt between the tendons on tibialis anterior and extensor hallucis longus. Lateral to the tendon of extensor digitorum longus to the fifth digit is the tendon of fibularis tertius. It is not always present, and even when it is, it may be difficult to identify. You should attempt to locate it during active eversion at the intertarsal joints. The contribution of extensor digitorum longus to the fifth digit should be definitely identified. Fibularis tertius is parallel with the proximal part of the extensor tendon and is close to it on the dorsum of the foot.
The lateral leg compartment contains only two muscles, and both are innervated by the superficial fibular nerve. **Fibularis longus** and **fibularis brevis** both have proximal attachments to the fibula. However, after their tendons pass posterior to the lateral malleolus, their distal attachments are quite different. Fibularis brevis has a straightforward attachment to the proximal end of the fifth metatarsal, but fibularis longus travels deep into the foot and crosses it to attach to the medial cuneiform and the first metatarsal. These attachment points make the lateral leg muscles the best evertors of the intertarsal joints. Additionally, fibularis longus contributes to active maintenance of the transverse arch of the foot (see following chapter for further discussion).
Posterior Leg: Superficial

The posterior compartment of the leg can be broken up into two groups of muscles: superficial and deep. All of the posterior leg muscles are innervated by the tibial nerve. The superficial group contains the **gastrocnemius**, **soleus** and **plantaris**. These three muscles together act as the major plantarflexors of the ankle by attaching to the calcaneus through their common distal attachment, the **calcaneal tendon** (aka Achilles tendon). (Note: plantaris’s action is still pretty negligible at the ankle.) As noted before, gastrocnemius and plantaris cross the knee, but soleus has a proximal attachment to the tibia and fibula. Gastrocnemius functions primarily in dynamic situations such as jumping and running. It is composed primarily of fast glycolytic (fast-twitch or Type 2B). Soleus is most active in maintaining posture and in endurance activities such as walking. It is composed largely of slow oxidative (slow-twitch or Type 1 fibers). An individual is unable to run or jump and will have difficulty pushing off with the ankle during walking if gastrocnemius and soleus are paralyzed. Another important function of gastrocnemius and soleus is aiding in venous return through the **skeletal muscle pump**.
There are four muscles in the deep posterior leg muscle group. One, popliteus, was already addressed in Muscles The Move The Knee. The remaining three muscles are found deep to the soleus muscle. Tibialis posterior has the most superior proximal attachment to the tibia and fibula, and a distal attachment on tarsals and metatarsals. Flexor digitorum longus has a more medial proximal attachment to the tibia only. It has four tendons that distribute to distal phalanges of digits 2-5 (see further discussion of this in Muscles That Move The Foot). Lastly, the flexor hallucis longus has a very lateral proximal attachment to the fibula, and a distal attachment to the distal phalanx of the first digit. Flexor hallucis longus is a surprisingly large muscle, but this makes sense when you think of how important flexion of the big toe is for human gait. The final push (and major propulsion) of the stance phase is produced through flexion of the big toe.
The three deep muscles that extend into the foot pass posterior to the medial malleolus deep to the flexor retinaculum. As they pass into the foot, the tendons of flexor digitorum longus and tibialis posterior cross. Likewise, once in the foot, the tendons of flexor hallucis longus and flexor digitorum cross. It is important to note that the tendons at the ankle and in the foot are not in the same order from medial to lateral as the muscle bellies are in the leg.

**Muscle Actions at the Ankle and Intertarsal Joints**

**Ankle: Transverse Axis**

Dorsiflexion: The muscles of the anterior compartment of the leg are the only dorsiflexors of the ankle, and tibialis anterior is the best dorsiflexor of this bunch. All of the other muscles in the leg pass posteriorly to the malleoli, and therefore plantarflex. Dorsiflexion of the foot is important during the gait cycle, and the muscles of the anterior compartment undergo concentric contraction as well as isometric and eccentric contraction during the gait cycle. In the normal gait cycle, for example, the heel is the first part of the foot to hit the ground (called “heel strike”). The remainder of the foot then comes into contact with the ground from the heel to the ball of the foot, in a gradual manner. The dorsiflexors provide for a gradual and smooth placement of the foot on the ground by gradually elongating, or undergoing an eccentric contraction, during this phase of the gait cycle. Furthermore, during the swing phase of the gait cycle, it is important that the toes not drag on the ground. The anterior compartment muscles perform isometric contraction during this phase to keep the toes off the ground.

**Transverse Axis: Dorsiflexion**

Muscles innervated by the **deep fibular nerve**

- Tibialis anterior

- Extensor hallucis longus
  - Extensor digitorum longus
  - Fibularis tertius

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Back to Top
Dorsiflexion against resistance. (Note that you can see her tibialis anterior when she dorsiflexes against the cabinet!). Image from http://www.freyagilmore.uk/category/treatment-explained/
Clinical Correlation

Steppage gait or foot drop is a characteristic gait that occurs with paralysis of the ankle joint dorsiflexors. Because the individual is not able to dorsiflex at the ankle when walking, he/she will compensate for the deficit by flexing at hip to a greater degree than normal. The front of the foot also tends to contact the ground with a greater-than-normal force because of the loss of the eccentric function of the anterior compartment muscles. Try “practicing” the gait yourself! The condition can occur as a result of trauma or injury to the common fibular nerve. The deep fibular branch of the nerve innervates the dorsiflexor muscles. (The superficial fibular nerve, the second branch of the common fibular nerve, innervates fibularis longus and brevis.) The common fibular nerve curves around the head of the fibula – it is “exposed” much as the ulnar nerve is exposed at the medial epicondyle of the humerus – before it divides into its superficial and deep branches. Blows to the lateral aspect of the knee, such as occur in football, or a cast around the proximal leg which is too tight, are common culprits in damage to the nerve. It would be a good exercise to palpate the common fibular nerve just distal to the fibular head, and to consider other functions that might be affected by loss of the common fibular nerve.

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Plantarflexion: As noted above the remaining muscles that cross the ankle can act in plantarflexion; however, how effective of plantarflexors they are is variable. The best plantarflexors are gastrocnemius and soleus. If gastrocnemius and soleus are paralyzed, it is still possible to walk (with a bit of difficulty), but running and jumping become all but impossible.

**Transverse Axis: Plantarflexion**

Muscles innervated by the **tibial nerve**  
- Gastrocnemius
  - Soleus
    - Flexor digitorum longus
    - Flexor hallucis longus
    - Tibialis posterior
    - Plantaris (?)

Muscles innervated by the **superficial fibular nerve**  
- Fibularis longus
- Fibularis brevis
**Intertarsal Joints: Oblique Axis**

Inversion: A muscle that is an efficient inverter will adduct and laterally rotate at the subtalar joints and transverse tarsal joints. This creates inversion of the foot around an oblique axis. Tibialis anterior and tibialis posterior are the best inverters, and it is likely that the other muscles cannot compensate for the loss of these two.

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**Oblique Axis: Inversion**

<table>
<thead>
<tr>
<th>Muscles innervated by the deep fibular nerve</th>
<th>Muscles innervated by the tibial nerve</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Tibialis anterior</td>
<td>- Tibialis posterior</td>
</tr>
<tr>
<td>- Extensor hallucis longus</td>
<td>- Flexor digitorum longus</td>
</tr>
<tr>
<td></td>
<td>- Flexor hallucis longus</td>
</tr>
</tbody>
</table>

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Eversion: A muscle that is an efficient everter will abduct and medially rotate at the subtalar. The combination of these actions creates eversion around an oblique axis. The muscles of the lateral compartment are the best everters.

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**Intertarsal Joints: Oblique Axis**

Inversion: A muscle that is an efficient inverter will adduct and laterally rotate at the subtalar joints and transverse tarsal joints. This creates inversion of the foot around an oblique axis. Tibialis anterior and tibialis posterior are the best inverters, and it is likely that the other muscles cannot compensate for the loss of these two.

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**Oblique Axis: Inversion**

<table>
<thead>
<tr>
<th>Muscles innervated by the deep fibular nerve</th>
<th>Muscles innervated by the tibial nerve</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Tibialis anterior</td>
<td>- Tibialis posterior</td>
</tr>
<tr>
<td>- Extensor hallucis longus</td>
<td>- Flexor digitorum longus</td>
</tr>
<tr>
<td></td>
<td>- Flexor hallucis longus</td>
</tr>
</tbody>
</table>

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Eversion: A muscle that is an efficient everter will abduct and medially rotate at the subtalar. The combination of these actions creates eversion around an oblique axis. The muscles of the lateral compartment are the best everters.
Oblique Axis: Eversion

Muscles innervated by the **superficial fibular nerve**
- Fibularis longus
- Fibularis brevis

Muscles innervated by the **deep fibular nerve**
- Extensor digitorum longus
- Fibularis tertius

---

**Clinical Correlation**

Tendon transfer is a procedure where a tendon, or part of a tendon, of a functioning muscle is detached from its normal attachment site and relocated to a new insertion or attachment site so that the muscle performs a new or different function. Tendon transfers are done mainly in cases where there are neuromuscular imbalances. The procedures are especially common with muscles acting at the ankle or intertarsal joints, but are done at other joints of the lower and upper limbs. In any tendon transfer, it is important to consider how the new position of the tendon will affect overall movement at the joint. If an individual has weakened or paralyzed fibularis muscles so that the ability to evert the foot is weakened or lost, the result is a marked abnormality in gait, a symptomatic inverted (varus) position of the foot (because of the unopposed pull of the inverter muscles) and other problems, such as bunions. The Split Tibialis Anterior Tendon Transfer (STATT) procedure for may improve this problem. The procedure involves transferring a portion of the tibialis anterior tendon from its medial (normal) attachment to the first cuneiform to the lateral aspect of the foot and attaching it to the cuboid or fifth metatarsal. Tibialis anterior is the best intertarsal joint inverter, and now the laterally attached portion of it is used to provide some ability to evert. The diagrams below illustrate some general features of the STATT surgical procedure.
STATT technique. A. Stippled lines show placement of incisions. B and C. The tendon of tibialis anterior is split and a portion is detached from its cuneiform and first metatarsal attachment. D. The cut portion of the tendon is tunneled to the lateral portion of the foot where it will be attached in the region of the fifth metatarsal and cuboid bone. Image from ET Bersu.
### Muscles that Move the Ankle And Intertarsal Joints Quick Reference Table

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Proximal Attachment</th>
<th>Distal Attachment</th>
<th>Innervation</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tibialis anterior</td>
<td>Proximal tibia and interosseous membrane</td>
<td>Medial cuneiform, 1st metatarsal</td>
<td>Deep fibular</td>
<td>Dorsiflexion Inversion</td>
</tr>
<tr>
<td>Extensor hallucis longus</td>
<td>Fibular shaft, interosseous membrane</td>
<td>Distal phalanx of 1st digit (extensor hood)</td>
<td>Deep fibular</td>
<td>Dorsiflexion Inversion</td>
</tr>
<tr>
<td>Extensor digitorum longus</td>
<td>Proximal tibia, fibula and interosseous membrane</td>
<td>Distal phalanges of 2nd-5th digits (extensor hoods)</td>
<td>Deep fibular</td>
<td>Dorsiflexion Eversion</td>
</tr>
<tr>
<td>Fibularis tertius</td>
<td>Distal fibula</td>
<td>5th metatarsal</td>
<td>Deep fibular</td>
<td>Dorsiflexion Eversion</td>
</tr>
<tr>
<td>Fibularis longus</td>
<td>Proximal fibula</td>
<td>Medial cuneiform, 1st metatarsal</td>
<td>Superficial fibular</td>
<td>Plantarflexion Eversion</td>
</tr>
<tr>
<td>Fibularis brevis</td>
<td>Distal fibula</td>
<td>5th metatarsal</td>
<td>Superficial fibular</td>
<td>Plantarflexion Eversion</td>
</tr>
<tr>
<td>Gastrocnemius</td>
<td>Medial and lateral femoral epicondyles</td>
<td>Calcaneal tuberosity</td>
<td>Tibial</td>
<td>Plantarflexion</td>
</tr>
<tr>
<td>Plantaris</td>
<td>Lateral femoral epicondyle</td>
<td>Calcaneal tuberosity</td>
<td>Tibial</td>
<td>Plantarflexion</td>
</tr>
<tr>
<td>Soleus</td>
<td>Head of fibula, soleal line of tibia</td>
<td>Calcaneal tuberosity</td>
<td>Tibial</td>
<td>Plantarflexion</td>
</tr>
<tr>
<td>Tibialis posterior</td>
<td>Proximal tibia, fibula and interosseous membrane</td>
<td>Navicular, all cuneiforms, 2nd-4th metatarsals</td>
<td>Tibial</td>
<td>Plantarflexion Inversion</td>
</tr>
<tr>
<td>Flexor digitorum longus</td>
<td>Tibial shaft</td>
<td>Distal phalanges of 2nd-5th digits</td>
<td>Tibial</td>
<td>Plantarflexion Inversion</td>
</tr>
<tr>
<td>Flexor hallucis longus</td>
<td>Distal tibia and interosseus membrane</td>
<td>Distal phalanx of 1st digit</td>
<td>Tibial</td>
<td>Plantarflexion Inversion</td>
</tr>
</tbody>
</table>

### Muscles that Move the Metatarsophalangeal and Interphalangeal Joints

Some of the muscles that are located in the leg extend into the foot to move the toes. Their
attachments and innervation were described in detail in the previous muscles chapter. In this chapter, we will talk about them more in terms of how their tendons interact with tendons of intrinsic muscles of the foot.

While you read this chapter, go back and review the comparable structures in the hand. The hand and foot are constructed on a very similar plan with respect to similar sets of intrinsic muscles and their innervation, and a similar pattern of blood vessels. Considerable attention is given to learning about the intrinsic muscles and their innervation and function in the hand. Details about the foot usually get ignored. Why? It is likely because of ways in which we use our hands. We don't use our feet in the same way – e.g., we don't use our feet to feed ourselves, play an instrument (a master pipe organist might be an exception), or grasp things that we want.

But we do use our feet to ambulate from one spot to another. In walking, the intrinsic muscles of the feet are believed to play a crucial role in transforming the foot into a rigid structure, and several of the muscles are also important in helping to maintain the arches of the foot. You can demonstrate this to yourself. First, stand up with your feet planted flat on the surface and simply “roll” your feet back and forth across the floor. You'll note that the feet are rather pliant. Now, stand on your toes. The foot becomes transformed into a highly rigid structure. While the pull of the tendons from the muscles in the leg contribute to this rigidity and stability, the intrinsic muscles of the foot also play a crucial role.

Muscle Groups

Dorsal Foot

There are no muscles found on the dorsal surface of the hand, but there are two in the foot! The extensor hallucis brevis and the extensor digitorum brevis have proximal attachments to the calcaneus. Their dorsal attachments merge with the extensor hoods on the first digit (meeting up with extensor hallucis longus) and the second through fourth digits (meeting up with extensor digitorum longus). These small muscles are found deep to the tendons of the long extensor muscles of the toes. Similarly to the long extensors of the toes, the muscles of the dorsal foot are innervated by the deep fibular nerve.
As stated before, the muscles of the foot have many similarities with the muscles of the hand; however, they are not perfect matches. For example, there are no opponens muscles in the foot, nor do we talk about a thenar or hypothenar eminence in the foot. One of the easier ways of
identifying the muscles in the foot is to organize the foot into layers from superficial to deep. (The other nice thing about the plantar foot muscles is that they tell you exactly what they do!). The most superficial structure of the foot is the **plantar aponeurosis**. Much like the palmar aponeurosis it is triangular shaped. It is affixed to the calcaneus posteriorly and to the head of the first and fifth metatarsals anteriorly.

The most superficial layer of plantar muscles contains the **abductor hallucis, abductor digiti minimi** and **flexor digitorum brevis**. Abductor hallucis has a large muscle belly and tendon and can be found on the medial plantar side of the foot. Abductor digiti minimi is similar but is found on the lateral side of the foot. Flexor digitorum brevis sits in the midline of the foot with a proximal attachment to the calcaneus. It divides into four tendons that split and attach to the intermediate phalanges of digits 2-5. This split allows the passage of the four tendons of the flexor digitorum longus to pass to the distal phalanges of digits 2-5. Compare this arrangement to flexor digitorum superficialis and flexor digitorum profundus in the upper limb.

Deep to this layer can be found the tendon of the **flexor hallucis longus** and the tendons of **flexor digitorum longus**. Two muscle groups are directly associated with the tendons of flexor digitorum longus. **Lumbricals** originate from the tendons of flexor digitorum longus and pass anteriorly to the extensor hoods (compare this to the lumbricals in the hand). The second muscle associated with flexor digitorum longus tendon does not have a functional equivalent in the hand. This muscle, called **quadratus plantae**, has a proximal attachment to the calcaneus and a distal attachment to the tendon of the flexor digitorum longus prior to its division into four separate tendons. This unique muscle serves to redirect the pull of the flexor digitorum longus tendon from an oblique pull to a posterior pull.
The plantar aponeurosis has been removed and the two most superficial layers of plantar foot muscles are shown. Image adapted from Gilroy, Atlas of Anatomy, 2nd ed, 2012.

Removal of the previous layers will reveal the 7-shaped adductor hallucis (much like the adductor pollicis) and the flexor hallucis brevis and flexor digiti minimi brevis (there’s no flexor digiti minimi longus...the brevis is superfluous). Flexor hallucis brevis has two heads and often have sesamoid bones embedded in them. These sesamoid bones not only increase the mechanical advantage of the flexor hallucis brevis muscles, but they also assist with load distribution across the head of the first metatarsal. Examine the head of a first metatarsal and locate the grooves in the bone associated with these two sesamoid bones. Lastly, the deepest muscles are the plantar and dorsal interossei.

Innervation of the plantar muscles of the foot is not as straightforward as those in the hand. The medial plantar nerve innervates abductor hallucis, flexor digitorum brevis, the medial head of flexor hallucis brevis and the first lumbrical. The remaining muscles in the plantar foot are innervated by the lateral plantar nerve.
The muscles and tendons found in the two most superficial layers of plantar foot muscle have been removed and the third and fourth layers are shown. Image adapted from Gilroy, Atlas of Anatomy, 2nd ed, 2012.

Muscle Actions

MP and IP Joints: Transverse Axis

Flexion: Flexion of the digits of the hand is very similar to the digits in the foot. Muscles on the plantar surface of the foot can produce flexion of the MP and IP joints. Flexor hallucis longus flexes both the IP and MP joint of the first digit. Flexor hallucis brevis flexes only the MP joint.
The MP joints of digits 2-5 are flexed by flexor digitorum longus, flexor digitorum brevis and the lumbricals. Flexor digitorum longus can flex the DIP and PIP joints, but flexor digitorum brevis can only flex the PIP joints. Flexor digiti minimi brevis flexes the MP joint of digit 5.

### Transverse Axis: Flexion

<table>
<thead>
<tr>
<th>Muscles innervated by the tibial nerve</th>
<th>Muscles innervated by the medial plantar branch of the tibial nerve</th>
<th>Muscles innervated by the lateral plantar branch of the tibial nerve</th>
</tr>
</thead>
<tbody>
<tr>
<td>-flexor hallucis longus (MP and IP)</td>
<td>-flexor hallucis brevis, medial head (MP)</td>
<td>-flexor hallucis brevis, lateral head (MP)</td>
</tr>
<tr>
<td>-flexor digitorum longus (MP and IP)</td>
<td>-flexor digitorum brevis (MP and PIP)</td>
<td>-flexor digiti minimi brevis (MP)</td>
</tr>
<tr>
<td></td>
<td>-1st lumbrical (MP)</td>
<td>-2nd-4th lumbricals (MP)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-plantar interossei (MP)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-dorsal interossei (MP)</td>
</tr>
</tbody>
</table>

Extension: Muscles running to the extensor hoods of the toes create extension of the MP and IP joints. In the first digit, extensor hallucis longus and brevis are responsible for extension. In digits 2–5, extensor digitorum longus, extensor digitorum brevis create extension (note that often times there are no extensor tendons running to the fifth digit). Finally, the lumbricals also attach to the extensor hoods, so just like in the hand, they can perform extension at the IP joints of digits 2-5 (while flexing the MP joints of digits 2-5).

### Transverse Axis: Extension

<table>
<thead>
<tr>
<th>Muscles innervated by the deep fibular nerve</th>
<th>Muscles innervated by the medial plantar branch of the tibial nerve</th>
<th>Muscles innervated by the lateral plantar branch of the tibial nerve</th>
</tr>
</thead>
<tbody>
<tr>
<td>-extensor hallucis longus (MP and IP)</td>
<td>-1st lumbrical (IP)</td>
<td>-2nd-4th lumbricals (IP)</td>
</tr>
<tr>
<td>-extensor digitorum longus (MP and IP)</td>
<td></td>
<td>-plantar interossei (IP)</td>
</tr>
<tr>
<td>-extensor hallucis brevis (MP and IP)</td>
<td></td>
<td>-dorsal interossei (IP)</td>
</tr>
<tr>
<td>-extensor digitorum brevis (MP and IP)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**MP Joints: Vertical Axis**

Abduction: Recall that in the foot abduction and adduction occur around the vertical axis relative to the second digit (in the hand they occur around the AP axis relative to the third digit). The first and fifth digits have their own respective abductors: abductor hallucis and abductor digiti minimi. Digits 2-4 are abducted by the dorsal interossei (the mnemonic DAB applies to the foot and the hand).
**Vertical Axis: ABduction**

<table>
<thead>
<tr>
<th>Muscles innervated by the medial plantar branch of the tibial nerve</th>
<th>Muscles innervated by the lateral plantar branch of the tibial nerve</th>
</tr>
</thead>
<tbody>
<tr>
<td>- abductor hallucis</td>
<td>- abductor digiti minimi</td>
</tr>
<tr>
<td>- 1st lumbrical</td>
<td>- dorsal interossei</td>
</tr>
</tbody>
</table>

Adduction: The adductor hallucis adducts the MP joint of the first digit. The plantar interossei adduct the third through fifth digits (PAD) with some nominal help from the lumbricals. Recall that as the midline structure of the foot, the second digit can only be abducted.

**Vertical Axis: ADduction**

<table>
<thead>
<tr>
<th>Muscles innervated by the lateral plantar branch of the tibial nerve</th>
</tr>
</thead>
<tbody>
<tr>
<td>- adductor hallucis</td>
</tr>
<tr>
<td>- plantar interossei</td>
</tr>
</tbody>
</table>

**Muscles that Move the Metatarsal and Interphalangeal Joints Quick Reference Table**
<table>
<thead>
<tr>
<th>Muscle</th>
<th>Proximal Attachment</th>
<th>Distal Attachment</th>
<th>Innervation</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extensor hallucis longus</td>
<td>Fibular shaft, interosseous membrane</td>
<td>Distal phalanx of 1st digit (extensor hood)</td>
<td>Deep fibular</td>
<td>Extension (MP and IP)</td>
</tr>
<tr>
<td>Extensor digitorum longus</td>
<td>Proximal tibia, fibula and interosseous membrane</td>
<td>Distal phalanges of 2nd-5th digits (extensor hoods)</td>
<td>Deep fibular</td>
<td>Extension (MP and IP)</td>
</tr>
<tr>
<td>Extensor hallucis brevis</td>
<td>Calcaneus</td>
<td>Distal phalanx of 1st digit (extensor hood)</td>
<td>Deep fibular</td>
<td>Extension (MP and IP)</td>
</tr>
<tr>
<td>Extensor digitorum brevis</td>
<td>Calcaneus</td>
<td>Distal phalanges of 2nd-4th digits (extensor hoods)</td>
<td>Deep fibular</td>
<td>Extension (MP and IP)</td>
</tr>
<tr>
<td>Flexor hallucis longus</td>
<td>Distal tibia and interosseous membrane</td>
<td>Distal phalanx of 1st digit</td>
<td>Tibial</td>
<td>Flexion (MP and IP)</td>
</tr>
<tr>
<td>Flexor digitorum longus</td>
<td>Tibial shaft</td>
<td>Distal phalanges of 2nd-5th digits</td>
<td>Tibial</td>
<td>Flexion (MP and IP)</td>
</tr>
<tr>
<td>Abductor hallucis</td>
<td>Calcaneus</td>
<td>Proximal phalanx of 1st digit</td>
<td>Medial plantar</td>
<td>Abduction (MP only)</td>
</tr>
<tr>
<td>Flexor digitorum brevis</td>
<td>Calcaneus</td>
<td>Intermediate phalanges 2nd-5th digits</td>
<td>Medial plantar</td>
<td>Flexion (MP and PIP only)</td>
</tr>
<tr>
<td>Abductor digiti minimi</td>
<td>Calcaneus</td>
<td>Proximal phalanx of 5th digit</td>
<td>Lateral plantar</td>
<td>Abduction (MP only)</td>
</tr>
<tr>
<td>Lumbricals</td>
<td>Tendons of flexor digitorum longus</td>
<td>Distal phalanges of 2nd-5th digits (extensor hoods)</td>
<td>Medial plantar (1st lumbrical), lateral plantar (2nd-4th lumbrical)</td>
<td>Redirects pull of flexor digitorum longus</td>
</tr>
<tr>
<td>Quadratus plantae</td>
<td>Calcaneus</td>
<td>Tendon of flexor digitorum longus</td>
<td>Lateral plantar</td>
<td>Flexion (MP)</td>
</tr>
<tr>
<td>Flexor hallucis brevis</td>
<td>Cuboid, medial cuneiform</td>
<td>Proximal phalanx of 1st digit</td>
<td>Medial plantar (medial head), lateral plantar (lateral head)</td>
<td>Flexion (MP only)</td>
</tr>
<tr>
<td>Adductor hallucis</td>
<td>2nd-4th metatarsal bases (oblique head), 3rd-5th metatarsal heads (transverse head)</td>
<td>Proximal phalanx of 1st digit</td>
<td>Lateral plantar</td>
<td>Adduction (MP only)</td>
</tr>
<tr>
<td>Muscle</td>
<td>Proximal Attachment</td>
<td>Distal Attachment</td>
<td>Innervation</td>
<td>Action</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>---------------------------</td>
<td>--------------------------------------------------------</td>
<td>------------------</td>
<td>---------------------------------------------</td>
</tr>
<tr>
<td>Flexor digiti minimi brevis</td>
<td>Proximal 5th metatarsal</td>
<td>Proximal phalanx of 5th digit</td>
<td>Lateral plantar</td>
<td>Flexion (MP only)</td>
</tr>
<tr>
<td>Dorsal interossei</td>
<td>1st-5th metatarsals</td>
<td>Extensor hoods: medial side of 2nd toe (1st dorsal interosseus), lateral side of 2nd-4th toe (2nd-4th interosseus)</td>
<td>Lateral plantar</td>
<td>Flexion (MP) Extension (IP) Abduction away from 2nd digit (MP)</td>
</tr>
<tr>
<td>Plantar interossei</td>
<td>3rd-5th metatarsals</td>
<td>Extensor hoods: medial side of 3rd-5th toes</td>
<td>Lateral plantar</td>
<td>Flexion (MP) Extension (IP) Adduction toward 2nd digit (MP)</td>
</tr>
</tbody>
</table>

Back to Top
Links to Online Anatomy Resources

Please let us know if you find any other useful online resources. We will add them to this page.

UW SMPH Hosted Resources

You will need to use your NetID to access these resources

UW SMPH Learning Repository: Anatomy

- Index of all Phase 1 Anatomy content (dissections, ELOs, etc)

UW SMPH Ebling Library

- Extensive collection of online resources available through the SMPH Ebling Library.
- Ebling Library Anatomy Resources Homepage
- Recommended:
  - Netter's Atlas
  - Gray's Atlas of Anatomy
  - Human Anatomy, Color Atlas and Textbook
- Index of all Anatomy Textbooks available from Ebling

Anatomy Apps

All the following apps are considered supplemental. Some apps are free and some must be purchased. Not all apps work on all types of operating systems.

Thumbroll

- General medial app, has a section with anatomy dissections.

Complete Anatomy from 3D4Medical

- Animated 3D anatomy models.

Anatomage App for iPad
• 3D cadaver dissection.

Visible Body Human Anatomy Atlas

• Animated 3D anatomy models.

Visual Anatomy

• Animated 3D anatomy models.

Open Access Textbooks, Atlases, and Image Collections

OpenStax Anatomy and Physiology Textbook

• An open-source (free!) anatomy textbook to use if you need an anatomy reference

KenHub

• Nice images of muscles, nerves, and arteries in isolation around the bones. Structure names are in Latin, but it’s okay. You'll recognize them.

Anatomography

• Huge collection of anatomy gifs showing musculoskeletal structures in 3D.

Michigan BlueLink Images

• Huge collection of labeled and unlabeled images. Quizzes and practice practicals as well.

Anatomy Guy

• Dissection videos and tutorials

You Tube Channels

Anatomy Zone

• Short animated 3D anatomy videos.
Armando Hasudungan

- Short white board diagram videos (much more than just anatomy on this channel).

The Noted Anatomist

- Short anatomy video tutorials.

Neuroanatomy Focused Resources

University of British Columbia Neuroanatomy

- Tutorials, images, dissections, quizzes. This site HAS IT ALL! Very highly recommended!

The Neurosurgical Atlas: Neuroanatomy

- Tons of unlabeled and labeled neuroanatomy images, and step by step dissections.

Arteries/Nerves/Dermatomes/Cutaneous Innervation/ Muscles/Bones (LUMEN)

- Figures for each; good for testing yourself.

Musculoskeletal Focused Resources

ExRx.net

- Videos of Joint Movements and Muscle Actions

University of Washington Radiology Muscle Atlas

- Individual muscles are depicted; this is the atlas linked to in the lab instructions.

Animated Muscle Actions

- Basic movements shown in animated form.
**Muscle&Motion YouTube Channel**

- Great videos showing muscle actions.

**Mind Map of Upper Limb Innervation**

- Nice illustration of a graphic representation of the innervation of muscles in the upper limb.