HKIN 110: HUMAN ANATOMY I FOR KINESIOLOGY



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TABLE OF CONTENTS

Licensing

1: Introduction to Anatomy

- 1.1: Defining Anatomy
- 1.2: Mapping the Body
  - 1.2A: Anatomical Position
  - 1.2B: Directional Terms
  - 1.2C: Regional Terms and Axes
  - 1.2D: Body Planes and Sections
  - 1.2E: Body Cavities
  - 1.2F: Abdominopelvic Regions
  - 1.2G: Interactions of Skeletal Muscles, Their Fascicle Arrangement, and Their Lever Systems
  - 1.2H: Naming Skeletal Muscle

2: The Skeletal System

- 2.1: Introduction
- 2.2: The Functions of the Skeletal System
- 2.3: The Axial Skeleton
- 2.4: The Appendicular Skeleton
- 2.5: Bone Classification
- 2.6: Bone Structure
- 2.7: Cartilage
  - 2.7A: Structure, Type, and Location of Cartilage
  - 2.7B: Cartilage Growth
- 2.8: Joints
  - 2.8A: Classification of Joints
  - 2.8B: Fibrous Joints
  - 2.8C: Cartilaginous Joints
  - 2.8D: Synovial Joints
  - 2.8E: Types of Body Movements
  - 2.8F: Anatomy of Selected Synovial Joints
- 2.9: Bone Formation and Development
- 2.10: Fractures - Bone Repair

3: The Nervous System

- 3.1: Basic Structures and Function of the Nervous System
- 3.2: Nervous Tissue
- 3.3: Spinal Nerves
  - 3.3A: Overview of the Spinal Nerves
  - 3.3B: Branches of Spinal Nerves
  - 3.3C: Plexuses
  - 3.3D: Intercostal Nerves
  - 3.3E: Dermatomes
  - 3.3F: Function and Physiology of the Spinal Nerves
- 3.4: The Central Nervous System

- 3.4A: The Cranial Nerve Exam
- 3.5: Circulation and the Central Nervous System

4: Head, Neck, Spine and Abdominal Core

- 4.1: The Skull
- 4.2: The Vertebral Column
- 4.3: Axial Muscles of the Head, Neck, and Back

5: Thorax, Hip and Pelvis

- 5.1: The Thoracic Cage
- 5.2: The Pelvic Girdle and Pelvis

6: Bones, Joints and Muscles of the Pelvic Girdle and Lower Limb

- 6.1: Bones of the Lower Limb
- 6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs

7: Bones, Joint and Muscles of the Pectoral Girdle and Upper Limb

- 7.1: The Pectoral Girdle
- 7.2: Bones of the Upper Limb
- 7.3: Axial Muscles of the Abdominal Wall and Thorax
- 7.4: Muscles of the Pectoral Girdle and Upper Limbs

Index

Glossary

Detailed Licensing

Licensing

*A detailed breakdown of this resource's licensing can be found in **Back Matter/Detailed Licensing**.*

CHAPTER OVERVIEW

1: Introduction to Anatomy

1.1: Defining Anatomy

1.2: Mapping the Body

1.2A: Anatomical Position

1.2B: Directional Terms

1.2C: Regional Terms and Axes

1.2D: Body Planes and Sections

1.2E: Body Cavities

1.2F: Abdominopelvic Regions

1.2G: Interactions of Skeletal Muscles, Their Fascicle Arrangement, and Their Lever Systems

1.2H: Naming Skeletal Muscle

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1.1: Defining Anatomy

Human anatomy is the study of the structure of the human body.

Learning Objectives

- Define the two major subtypes of anatomy

Key Points

- Gross anatomy is subdivided into surface anatomy (the external body), regional anatomy (specific regions of the body), and systemic anatomy (specific organ systems).
- Microscopic anatomy is subdivided into cytology (the study of cells) and histology (the study of tissues).
- Anatomy is closely related to physiology (study of function), biochemistry (chemical processes of living things), comparative anatomy (similarities and differences between species), and embryology (development of embryos).
- Knowledge of anatomy is needed to understand human biology and medicine.

Key Terms

- **anatomy**: The study of the body structure of animals.
- **surface Anatomy**: The study of anatomical landmarks that can be identified by observing the surface of the body. Sometimes called superficial anatomy.
- **microscopic anatomy**: The study of minute anatomical structures on a microscopic scale, including cells (cytology) and tissues (histology).
- **Gross (or macroscopic) anatomy**: The study of anatomical features visible to the naked eye, such as internal organs and external features.
- **embryology**: The science of the development of an embryo from the fertilization of the ovum to the fetal stage.
- **dissection**: The process of disassembling an organism to determine its internal structure and understand the functions and relationships of its components.

Defining Anatomy

Anatomy describes the structure and location of the different components of an organism to provide a framework for understanding. Human anatomy studies the way that every part of a human, from molecules to bones, interacts to form a functional whole.



Rembrant's "The Anatomy Lesson of Dr. Nicolaes Tulp": Human anatomy is the study of the structure of the human body, from the microscopic to the macroscopic.

There are two major types of anatomy. Gross (macroscopic) anatomy is the study of anatomical structures that can be seen by the naked eye, such as the external and internal bodily organs. Microscopic anatomy is the study of tiny anatomical structures such as tissues and cells.

Gross Anatomy

Gross anatomy can be further subdivided into three different fields:

- Surface anatomy (or superficial anatomy) is the study of external anatomical features without dissection.
- Regional anatomy focuses on specific external and internal regions of the body (such as the head or chest) and how different systems work together in that region.
- Systemic anatomy focuses on the anatomy of different organ systems, such as the respiratory or nervous system.

Regional anatomy is widely used in modern teaching because it is easier to apply to a clinical setting than systemic anatomy. The major anatomy textbook, Gray's Anatomy, has recently been reorganized from a systems format to a regional format to reflect this preference. Surface anatomy is also widely used to gauge the position and structure of deeper organs, tissues, and systems.

Microscopic Anatomy

Within microscopic anatomy, two topics of study are of great importance:

- Cytology, the study of the structure and function of cells
- Histology, the study of the organization and details of biological tissues

The human body has many layers of organization. Biological systems consist of organs that consist of tissues, and tissue in turn is made up of cells and connective tissue. Microscopic anatomy allows one to focus on these tissues and cells.

History of Anatomy

The history of anatomy has been an evolving understanding of organs and structures in the body. Beginning in Ancient Greece and developing through the Middle Ages and the Renaissance, methods of studying anatomy have advanced dramatically. This field has moved from examination of animals and cadavers through invasive dissection to the technologically complex techniques developed in the 20th century, such as non-invasive imaging and radiology.

Generally, medical and biology students learn about the human body from anatomical models, skeletons, textbooks, diagrams, photographs, lectures, and tutorials. Medical and dental students also learn through the dissection and inspection of cadavers. A thorough working knowledge of anatomy is required for all medical professionals, especially surgeons and doctors working in diagnostic specialties such as radiology.

Anatomy and Physiology

Physiology is the study of how the components of the body function, and biochemistry is the study of the chemistry of living structures. Together with anatomy, these are the three primary disciplines within the field of human biology. Anatomy provides information about structure, location, and organization of different parts of the body that is needed to truly understand physiology. Together, anatomy and physiology explain the structure and function of the different components of the human body to describe what it is and how it works.

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SECTION OVERVIEW

1.2: Mapping the Body

1.2A: Anatomical Position

1.2B: Directional Terms

1.2C: Regional Terms and Axes

1.2D: Body Planes and Sections

1.2E: Body Cavities

1.2F: Abdominopelvic Regions

1.2G: Interactions of Skeletal Muscles, Their Fascicle Arrangement, and Their Lever Systems

1.2H: Naming Skeletal Muscle

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1.2A: Anatomical Position

When an organism is in its standard anatomical position, positional descriptive terms are used to indicate regions and features.

Learning Objectives

- Describe the standard position in human anatomy

Key Points

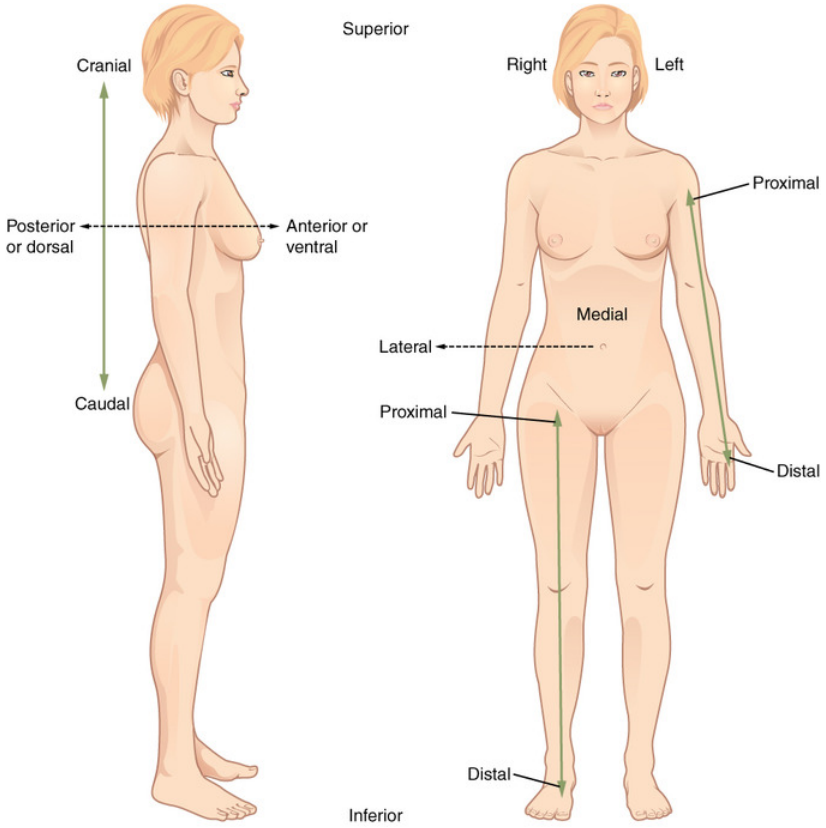
- In standard anatomical position, the limbs are placed similarly to the supine position imposed on cadavers during autopsy.
- The anatomical position of the skull is the Frankfurt plane. In this position, the lower margins of the orbitals (eye sockets), the lower margin of the orbits, and the upper margins of the ear canals (poria) lie in the same horizontal plane.
- Because animals can change orientation with respect to their environments and appendages can change position with respect to the body, positional descriptive terms refer to the organism only in its standard anatomical position to prevent confusion.

Key Terms

- **appendage**: A limb of the body.
- **supine**: Lying on its back, reclined.
- **anatomical position**: The standard position in which the body is standing with feet together, arms to the side, and head, eyes, and palms facing forward.

The Need for Standardization

Standard anatomical position is the body orientation used when describing an organism's anatomy. Standardization is necessary to avoid confusion since most organisms can take on many different positions that may change the relative placement of organs. All descriptions refer to the organism in its standard anatomical position, even when the organism's appendages are in another position. Thus, the standard anatomical position provides a "gold standard" when comparing the anatomy of different members of the same species.



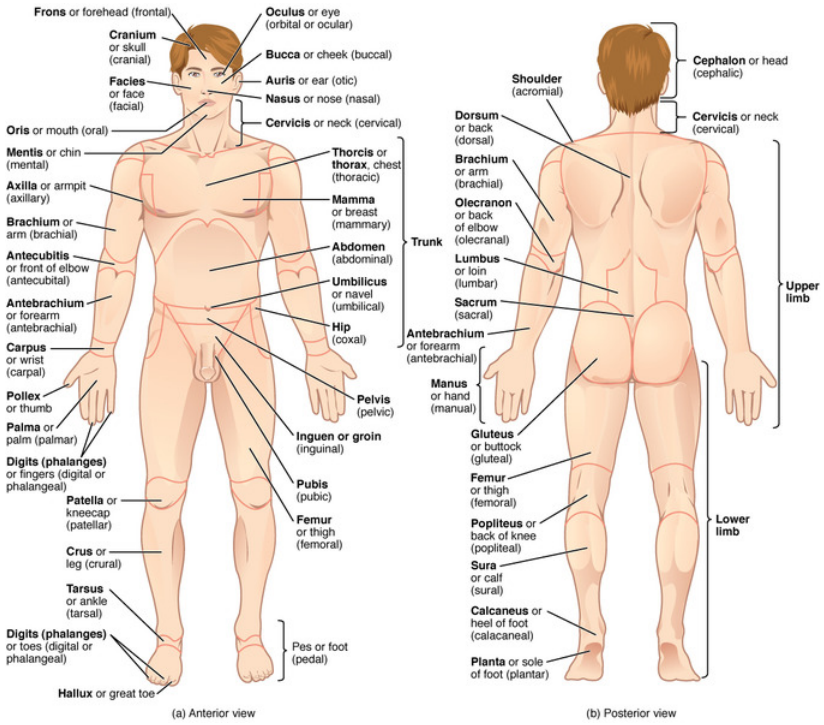
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Relative location in the anatomical position: Many terms are used to describe relative location on the body. Cranial refers to features closer to the head, while caudal refers to features closer to the feet. The front of the body is referred to as anterior or ventral, while the back is referred to as posterior or dorsal. Proximal and distal describe relative position on the limbs. Proximal refers to a feature that is closer to the torso, while distal refers to a feature that is closer to the fingers/toes. Medial and lateral refer to position relative to the midline, which is a vertical line drawn through the center of the forehead, down through the belly button to the floor. Medial indicates a feature is closer to this line, while lateral indicates features further from this line.

Standard Anatomical Position in Humans

The standard anatomical position is agreed upon by the international medical community. In this position, a person is standing upright with the lower limbs together or slightly apart, feet flat on the floor and facing forward, upper limbs at the sides with the palms facing forward and thumbs pointing away from the body, and head and eyes directed straight ahead. In addition, the arms are usually placed slightly apart from the body so that the hands do not touch the sides. The positions of the limbs, particularly the arms, have important implications for directional terms in those appendages.

The basis for the standard anatomical position in humans comes from the supine position used for examining human cadavers during autopsies. Dissection of cadavers was one of the primary ways humans learned about anatomy throughout history, which has tremendously influenced the ways by which anatomical knowledge has developed into the scientific field of today.



Standard anatomical position: The regions of the body in standard anatomical position, in which the body is erect.

In humans, the standard anatomical position of the skull is called the Frankfurt plane. In this position, the orbitales (eye sockets), lower margins of the orbits, and the poria (ear canal upper margins) all lie in the same horizontal plane. This orientation represents the position of the skull if the subject were standing upright and looking straight ahead.

It is important to note that all anatomical descriptions are based on the standard anatomical position unless otherwise stated.

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1.2B: Directional Terms

Positional terms give precise descriptions of anatomical relationships and allow for consistency when referencing anatomical positions.

Learning Objectives

- Identify the anatomical terms that define the human body in space

Key Points

- Descriptions of directional terms include: a) superior (head) and inferior (caudal), b) anterior and posterior, c) lateral and medial, d) deep and superficial, e) proximal and distal, and f) dorsal and ventral.
- Directional terms provide comparison of anatomical position by comparing the locations of different structures in the body.

Key Terms

- **directional terms**: Directional terms are words used to describe the location of an anatomical structure by comparing its position to other structures within the body or within the orientation of the body itself.

Navigating Anatomy with Language

Directional terms provide precise descriptions of a structure's location. They allow a description of anatomical position by comparing location relative to other structures or within the rest of the body. Standard anatomical terms for direction include:

- *Superior and inferior (cranial and caudal)* are used when referring to parts of the body which are toward an end of the body. Superior structures are toward the head (cranial) while inferior (caudal) structures are toward the feet. Examples include the superior and inferior vena cava, which carry deoxygenated blood away from the head (superior) and from the lower body (inferior) to the heart.
- *Anterior and posterior* are sometimes used in place of superior and inferior, respectively. These words are used more often for animal anatomy and rarely and only with very specific meaning in human anatomy. Anterior refers to the side of the structure facing up in the standard anatomical position while posterior refers to the bottom side. For example, the pituitary gland has an anterior and posterior side, each of which secretes different types of hormones.
- *Dorsal and ventral* are sometimes used in place of anterior and posterior, respectively. Dorsal means the back side or upper side, while ventral means the frontal or lower side. These are mostly used with animal anatomy, but can be used in human anatomy as long as they are describing the side of an appendage. One example is the dorsal fin in fish, found on the upper side of the fish's body.
- *Lateral* is used to describe anything closer to the sides of the body (toward the arms, in the standard anatomical position), while*medial* is used to describe anything toward the middle of the body. In general, many structures of the human body are bilateral and symmetrical with the middle of the body, such as the lungs or the arms.
- *Deep* refers to structures closer to the interior center of the body. For example, bones in an appendage are located deeper than the muscles. *Superficial* is used to describe structures that are closer to the exterior surface of the body. For example, the outer layers of skin are superficial to deeper layers of skin.
- *Proximal and Distal* describe one point relative to another. Proximal refers to a point closer to the reference point while distal refers to a point farther away. When describing appendages, the proximal end of the appendage connects the appendage to the body, while the distal end is away from the body.

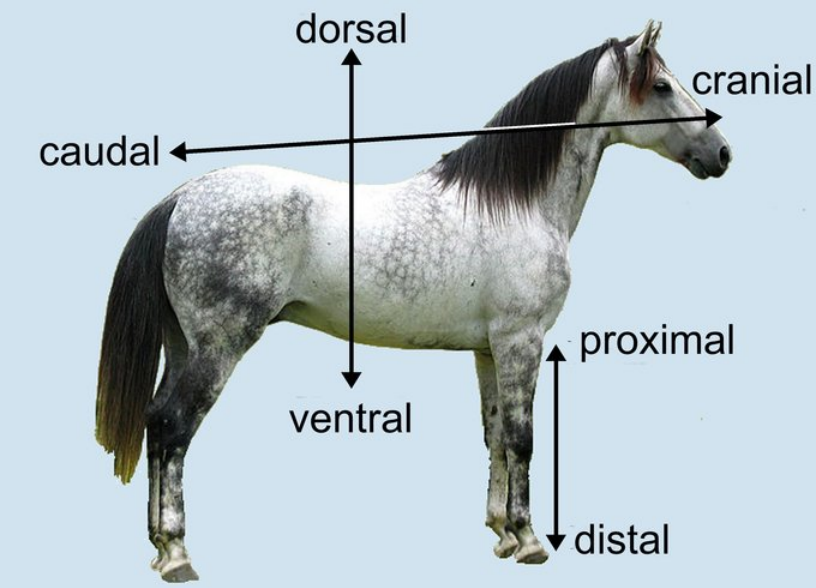


Diagram of anatomical terms: Directional axes in a tetrapod.

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1.2C: Regional Terms and Axes

Regional directional terms include anterior and posterior, dorsal and ventral, and lateral and medial.

Learning Objectives

- Describe how axes give direction, detail, and location when describing a region of the body

Key Points

- Regional terms describe the different parts of the body by the structures and functions of a specific region. The most basic regional terms are the axial and appendicular regions.
- Axes use directional terms to describe the location and orientation of a specific region.
- The directional term lateral is used to describe structures divided by a left-to-right axis.

Key Terms

- **ventral**: On the front side of the human body or the corresponding surface of an animal, usually the lower surface.
- **posterior**: Nearer the caudal end of the body in quadrupeds or the dorsal end in bipeds.
- **axis**: A line between two points that is used to give direction to an anatomical region.

Regional Terms in Anatomy

Regional terms describe anatomy by dividing the parts of the body into different regions that contain structures that are involved in similar functions. Two primary terms are used to describe the main regions of the body:

- *The Axial Region* makes up the main axis of the human body and includes the head, neck, chest, and trunk.
- *The Appendicular Region* makes up the parts of the human body that connect to the axial region. This includes the limbs and appendages.

These are the two basic categories of regional terms; however, many other terms are used to describe smaller regions within the axial and appendicular regions. For example, the brachial region consists of the arm as a part of the appendicular region, while the abdominal region consists of the abdomen as a smaller part of the axial region.

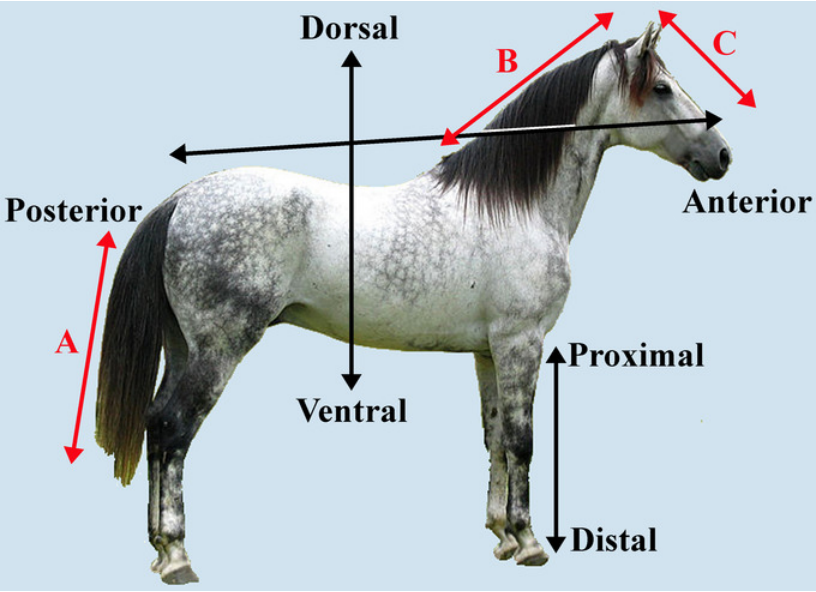
The abdominal region is subdivided into even smaller regions based on different functions of groups of organs and tissues in that region. If a person is experiencing pain in one part of the abdominal region, then the smaller regional divisions can help determine the organs involved in the problem to better treat symptoms.

Axes Describe Relative Positions

Another method for describing region An axis uses a straight line between two parts of the body to describe a region of the body with linear direction. For example, blood can be said to flow
in a proximal or distal direction through a region marked by that axis. The X, Y, and Z axes of the Cartesian coordinate system are used describe the specific location of an axis in standard anatomical position.

Many types of axes can give regional direction. Any pair of corresponding directional terms can be combined to form an axis (such as proximal-distal for an appendage).

- *The Dorsoventral axis (DV axis)* is formed by the connection of the dorsal and ventral points of a region. The region between the belly (ventral) and back (dorsal) is often described by a DV axis.
- *The Anterioposterior axis (AP axis)* is the axis formed by the connection of the anterior (top) and posterior (bottom) ends of a region. The AP axis of a region is by definition perpendicular to the DV axis and vice-versa.
- *The Left-to-right axis* is the axis connecting the left and right hand sides of a region. It is used to describe the lateral sides of a region, which in humans are often symmetrical around the center of the body. It is perpendicular to both the DV and AP axes.



Different Directional AP Axes in Three Body Segments of a Horse: Axis (A) (in red) shows the AP axis of the tail, (B) shows the AP axis of the neck, and (C) shows the AP axis of the head.

Axes give more clarity and detail for describing the location of an anatomical region. They are commonly used in both zoology and human anatomy, and can be paired with body planes to give even more detail to anatomical direction, region, and location.

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1.2D: Body Planes and Sections

There are three basic reference planes used in anatomy: the sagittal plane, the coronal plane, and the transverse plane.

Learning Objectives

- Identify the three basic anatomical reference planes

Key Points

- A coronal or frontal plane divides the body into dorsal and ventral (back and front, or posterior and anterior) portions.
- A transverse plane, also known as an axial plane or cross-section, divides the body into cranial and caudal (head and tail) portions.
- A sagittal plane divides the body into sinister and dexter (left and right) portions.
- Body planes have several uses within the anatomy field, including in medical imaging, descriptions of body motion, and embryology.

Key Terms

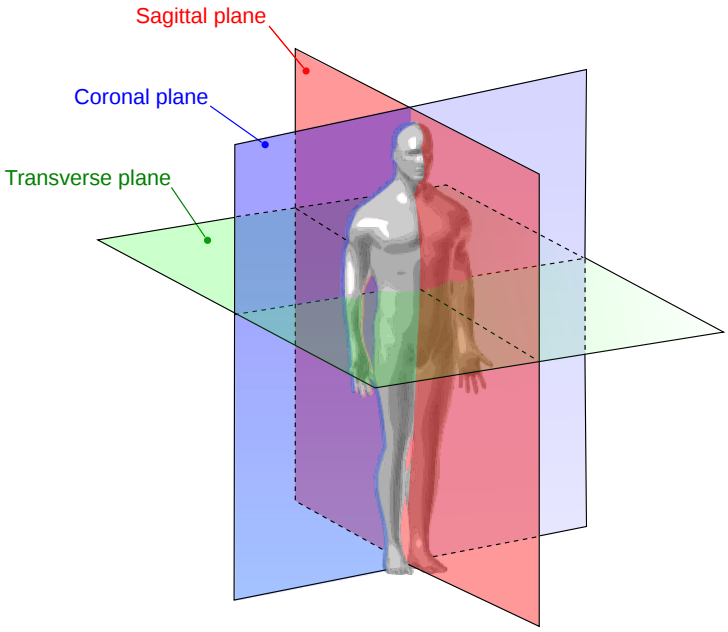
- **coronal plane**: Any vertical plane that divides the body into anterior and posterior (belly and back) sections.
- **transverse plane**: Any plane that divides the body into superior and inferior parts, roughly perpendicular to the spine.
- **sagittal plane**: Any imaginary plane parallel to the median plane.

What Are Body Planes?

Body planes are hypothetical geometric planes used to divide the body into sections. They are commonly used in both human and zoological anatomy to describe the location or direction of bodily structures. Reference planes are the standard planes used in anatomical terminology and include:

- *The sagittal plane (lateral or Y-Z plane)* divides the body into sinister and dexter (left and right) sides. The midsagittal (median) plane is in the midline through the center of the body, and all other sagittal planes are parallel to it.
- *The coronal plane (frontal or Y-X plane)* divides the body into dorsal and ventral (back and front) portions. It also separates the anterior and posterior portions.
- *The transverse plane (axial or X-Z plane)* divides the body into superior and inferior (head and tail) portions. It is typically a horizontal plane through the center of the body and is parallel to the ground.

While these are the major reference planes of the body, other planes are commonly used in relation to these three. A longitudinal plane is any plane perpendicular to the transverse plane, while parasaggital planes are parallel to the saggital plane.
The coronal plane, the sagittal plane, and the parasaggital planes are examples of longitudinal
planes.



Anatomical Planes in a Human: There are three basic planes in zoological anatomy: sagittal, coronal, and transverse. A human in the anatomical position, can be described using a coordinate system with the Z-axis going from front to back, the X-axis going from left to right, and the Y-axis going from up to down.

Applications of Body Planes

Medical imaging techniques such as sonography, CT scans, MRI scans, or PET scans are one of the primary applications of body planes. By imaging a patient in standard anatomical position, a radiologist can build an X-Y-Z axis around the patient to apply body planes to the images. The planes can then be used to identify and locate the positions of the patient's internal organs. Individual organs can also be divided by planes to help identify smaller structures within that organ.

Body planes are used to describe anatomical motion in the X-Y-Z coordinate system that the body moves through. An anatomist could model a limb's range of motion by measuring which planes the limb can move through and how far it is able to travel.

Anatomical change during embryological development is also described and measured with body planes. For example, during human embryonic development the coronal plane is horizontal, but becomes vertical as the embryo develops into a fetus. In comparative embryology, body planes provide a basis for comparing the ways in which different types of organisms develop anatomically within the womb.

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1.2E: Body Cavities

Vertebrates have fluid-filled spaces called body cavities that contain the organs.

Learning Objectives

- Describe the major cavities of the human body

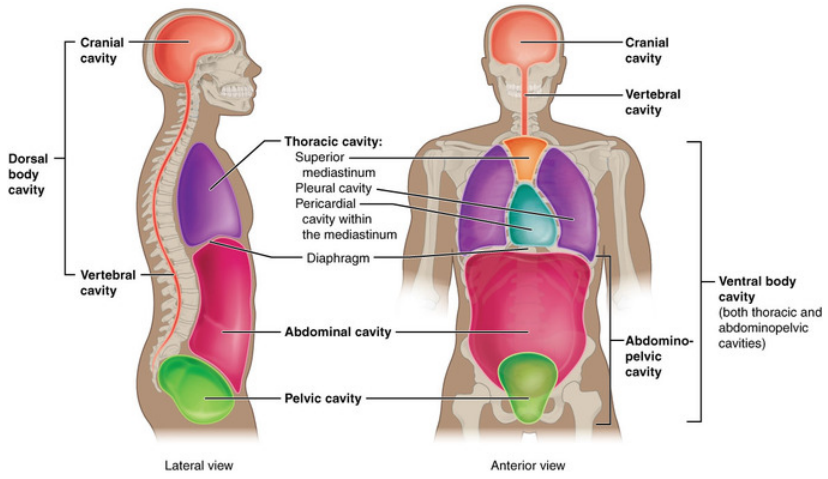
Key Points

- The dorsal cavity contains the primary organs of the nervous system, including the brain and spinal cord.
- The diaphragm is a sheet of muscle that separates the thoracic cavity from the abdominal cavity.
- Special membrane tissues surround the body cavities, such as the meninges of the dorsal cavity and the mesothelium of the ventral cavity.
- The mesothelium consists of the pleura of the lungs, the pericardium of the heart, and the peritoneum of the abdominopelvic cavity.

Key Terms

- **abdominoplevic cavity**: The ventral body chamber that contains the abdominal cavity (primarily digestive system) and the pelvic cavity (primarily reproductive system).
- **dorsal cavity**: The cavity in the back of the body that contains the cranial and vertebral cavities, which house the brain and spinal cord respectively.
- **Thoracic Cavity**: The ventral body chamber that contains the pericardial cavity (the heart) and the pleural cavity (the lungs).

By the broadest definition, a body cavity is any fluid-filled space in a multicellular organism. However, the term usually refers to the space where internal organs develop, located between the skin and the outer lining of the gut cavity."The human body cavity," normally refers to the ventral body cavity because it is by far the largest one in volume. Blood vessels are not considered cavities but may be held within cavities. Most cavities provide room for the organs to adjust to changes in the organism's position. They usually contains protective membranes and sometimes bones that protect the organs.



Anatomical terminology for body cavities: Humans have multiple body cavities, including the cranial cavity, the vertebral cavity, the thoracic cavity (containing the pericardial cavity and the pleural cavity), the abdominal cavity, and the pelvic cavity. In mammals, the diaphragm separates the thoracic cavity from the abdominal cavity.

Dorsal

The dorsal cavity is a continuous cavity located on the dorsal side of the body. It houses the organs of the upper central nervous system, including the brain and the spinal cord. The meninges is a multi-layered membrane within the dorsal cavity that envelops and protects the brain and spinal cord.

Cranial

The cranial cavity is the anterior portion of the dorsal cavity consisting of the space inside the skull. This cavity contains the brain, the meninges of the brain, and cerebrospinal fluid.

Vertebral

The vertebral cavity is the posterior portion of the dorsal cavity and contains the structures within the vertebral column. These include the spinal cord, the meninges of the spinal cord, and the fluid-filled spaces between them. This is the most narrow of all body cavities, sometimes described as threadlike.

Ventral

The ventral cavity, the interior space in the front of the body, contains many different organ systems. The organs within the ventral cavity are also called viscera. The ventral cavity has anterior and posterior portions divided by the diaphragm, a sheet of skeletal muscle found beneath the lungs.

Thoracic

The thoracic cavity is the anterior ventral body cavity found within the rib cage in the torso. It houses the primary organs of the cardiovascular and respiratory systems, such as the heart and lungs, but also includes organs from other systems, such as the esophagus and the thymus gland. The thoracic cavity is lined by two types of mesothelium, a type of membrane tissue that lines the ventral cavity: the pleura lining of the lungs, and the pericadium lining of the heart.

Abdominopelvic

The abdominoplevic cavity is the posterior ventral body cavity found beneath the thoracic cavity and diaphragm. It is generally divided into the abdominal and pelvic cavities. The abdominal cavity is not contained within bone and houses many organs of the digestive and renal systems, as well as some organs of the endocrine system, such as the adrenal glands. The pelvic cavity is contained within the pelvis and houses the bladder and reproductive system. The abdominopelvic cavity is lined by a type of mesothelium called the peritoneum.

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1.2F: Abdominopelvic Regions

The abdomen is subdivided into four quadrants and nine areas.

Learning Objectives

- Distinguish among the abdominopelvic regions of the body

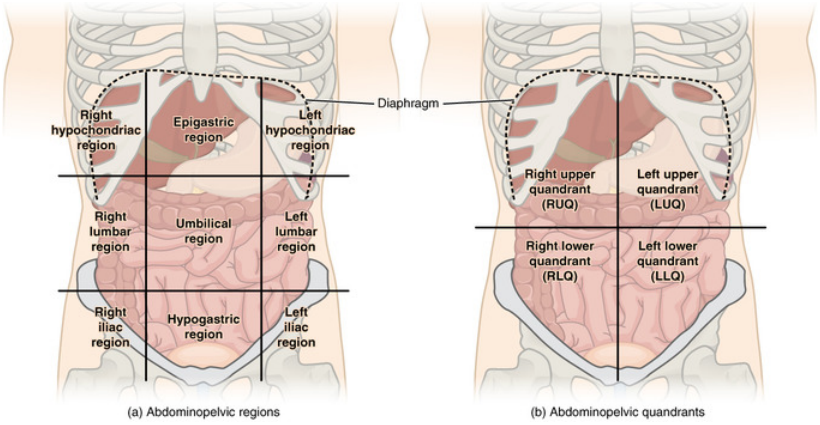
Key Points

- The abdominopelvic cavity can be subdivided into four quadrants and nine areas.
  The quadrants are labeled by location: the right upper, right lower, left upper, and left lower quadrants.
- The nine regions are smaller than the four abdominopelvic quadrants and include the right hypochondriac, right lumbar, right illiac, epigastric, umbilical, hypogastric (or pubic), left hypochondriac, left lumbar, and left illiac divisions.
- The perineum is sometimes considered to be the tenth division.
- The purpose of the abdominal divisions is to describe regional anatomy in the abdomen, and to help clinicians determine which organ and tissues are involved in a disease based on which regions experience pain.

Key Terms

- **left upper quadrant**: The left upper quadrant is the location of the left portion of the liver, the larger portion of the stomach, the pancreas, left kidney, spleen, portions of the transverse and descending colon, and parts of the small intestine.
- **Right upper quadrant**: The right upper quadrant contains the right portion of the liver, gallbladder, right kidney, a small portion of the stomach, portions of the ascending and transverse colon, and parts of the small intestine.
- **left lower quadrant**: The left lower quadrant houses the majority of the small intestine, some of the large intestine, the left female reproductive organs, and the left ureter.
- **nine divisions**: An alternate system for dividing the abdominopelvic cavity into regions.
- **right lower quadrant**: In the right lower quadrant sits the cecum, appendix, part of the small intestines, the right female reproductive organs, and the right ureter.

Anatomists and medical personnel divide the abdominopelvic cavity into smaller regions to facilitate study and discussion. These divisions are often used to categorize the individual abdominal organs by their location and function and are used by clinicians to help diagnose the source of abdominal pain and determine appropriate treatment. The most common divisions for the abdominopelvic region are the four quadrants and nine regions.



Abdominal nine divisions (a) and quadrant regions (b): The abdomen is subdivided into four quadrants and nine areas.

Abdominal Four Quadrants

The abdominopelvic region can be divided into four quadrants. These quadrants are defined by the intersection of the sagittal plane with the umbilical plane (the transverse plane through the navel). Clinicians use these regions to determine the organs and tissues that may be causing pain or discomfort in that region.

Right Upper Quadrant

The right upper quadrant contains the right portion of the liver, the gallbladder, right kidney, a small portion of the stomach, the duodenum, the head of the pancreas, portions of the ascending and transverse colon, and parts of small intestine. Pain in this region is associated with infection and inflammation in the gallbladder and liver or peptic ulcers in the stomach.

Left Upper Quadrant

The left upper quadrant is the location of the left portion of the liver, part of the stomach, the pancreas, left kidney, spleen, portions of the transverse and descending colon, and parts of the small intestine. Pain in this region is associated with malrotation of the intestine and colon.

Right Lower Quadrant

In the right lower quadrant sits the cecum, appendix, part of the small intestines, the right half of the female reproductive system, and the right ureter. Pain in this region is most commonly associated with appendicitis.

Left Lower Quadrant

The left lower quadrant houses the majority of the small intestine, some of the large intestine, the left half of the female reproductive system, and the left ureter. Pain in this region is generally associated with colitis (inflammation of the large intestine) as well as pelvic inflammatory disease and ovarian cysts in females.

Abdominal Nine Divisions

The nine divisions of the abdominopelvic region are smaller than the four quadrants, allowing for a more detailed discussion. These divisions are marked by two parasagittal and two transverse planes centered around the navel. Most organs are part of multiple regions, including the gallbladder, duodenum, stomach, kidneys, spleen, small intestine and colon. The perineum (the area beneath the hypogastric region at the bottom of the pelvic cavity) is sometimes considered to be a tenth division in this system.

Right Hypochondriac

The right hypochondriac region contains the right portion of the liver, the gallbladder, the right kidney, and parts of the small intestine.

Left Hypochondriac

The left hypochondriac region contains part of the spleen, the left kidney, part of the stomach, the pancreas, and parts of the colon.

Epigastric

The epigastric (above stomach) region contains the majority of the stomach, part of the liver, part of the pancreas, part of the duodenum, part of the spleen, and the adrenal glands. This region pushes out when the diaphragm contracts during breathing.

Right Lumbar

The right lumbar region consists of the gallbladder, the right kidney, part of the liver, and the ascending colon.

Left Lumbar

The left lumbar region consists of the descending colon, the left kidney, and part of the spleen.

Umbilical

The umbilical region contains the umbilicus (navel), and many parts of the small intestine, such as part of the duodenum, the jejunum, and the illeum. It also contains the transverse colon (the section between the ascending and descending colons) and the bottom portions of both the left and right kidney.

Right Iliac

The right iliac region contains the appendix, cecum, and the right iliac fossa. It is also commonly referred to as the right inguinal region. Pain in this area is generally associated with appendicitis.

Left Iliac

The left illiac region contains part of the descending colon, the sigmoid colon, and the left illiac fossa. It is also commonly called the left inguinal region.

Hypogastric

The hypogastric region (below the stomach) contains the organs around the pubic bone. These include bladder, part of the sigmoid colon, the anus, and many organs of the reproductive system, such as the uterus and ovaries in females and the prostate in males.

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1.2G: Interactions of Skeletal Muscles, Their Fascicle Arrangement, and Their Lever Systems

Learning Objectives

- Compare and contrast agonist and antagonist muscles
- Describe how fascicles are arranged within a skeletal muscle
- Explain the major events of a skeletal muscle contraction within a muscle in generating force

To move the skeleton, the tension created by the contraction of the fibers in most skeletal muscles is transferred to the tendons. The tendons are strong bands of dense, regular connective tissue that connect muscles to bones. The bone connection is why this muscle tissue is called skeletal muscle.

Interactions of Skeletal Muscles in the Body

To pull on a bone, that is, to change the angle at its synovial joint, which essentially moves the skeleton, a skeletal muscle must also be attached to a fixed part of the skeleton. The moveable end of the muscle that attaches to the bone being pulled is called the muscle's **insertion**, and the end of the muscle attached to a fixed (stabilized) bone is called the **origin**. During forearm **flexion**—bending the elbow—the brachioradialis assists the brachialis.

Although a number of muscles may be involved in an action, the principal muscle involved is called the **prime mover**, or **agonist**. To lift a cup, a muscle called the biceps brachii is actually the prime mover; however, because it can be assisted by the brachialis, the brachialis is called a **synergist** in this action (Figure 1.2G.1). A synergist can also be a **fixator** that stabilizes the bone that is the attachment for the prime mover's origin.

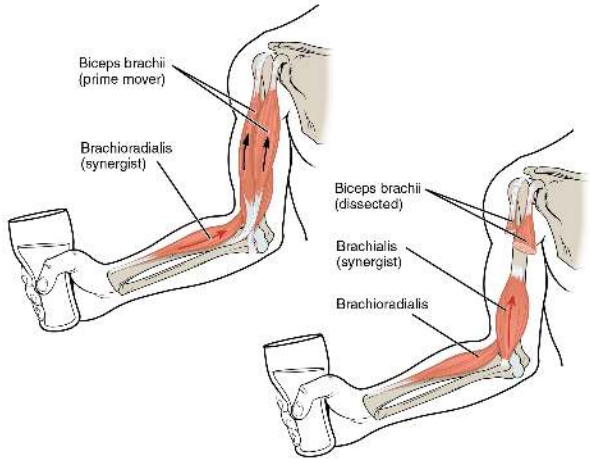


Figure 1.2G.1: Prime Movers and Synergists. The biceps brachii flex the lower arm. The brachoradialis, in the forearm, and brachialis, located deep to the biceps in the upper arm, are both synergists that aid in this motion.

A muscle with the opposite action of the prime mover is called an **antagonist**. Antagonists play two important roles in muscle function: (1) they maintain body or limb position, such as holding the arm out or standing erect; and (2) they control rapid movement, as in shadow boxing without landing a punch or the ability to check the motion of a limb.

For example, to extend the knee, a group of four muscles called the quadriceps femoris in the anterior compartment of the thigh are activated (and would be called the agonists of knee extension). However, to flex the knee joint, an opposite or antagonistic set of muscles called the hamstrings is activated.

As you can see, these terms would also be reversed for the opposing action. If you consider the first action as the knee bending, the hamstrings would be called the agonists and the quadriceps femoris would then be called the antagonists. See Table 1.2G.1 for a list of some agonists and antagonists.

Table 1.2G.1

Agonist and Antagonist Skeletal Muscle Pairs

Agonist and Antagonist Skeletal Muscle Pairs	Antagonist	Movement
Agonist	Antagonist	Movement
Biceps brachii: in the anterior compartment of the arm	Triceps brachii: in the posterior compartment of the arm	The biceps brachii flexes the forearm, whereas the triceps brachii extends it.
Hamstrings: group of three muscles in the posterior compartment of the thigh	Quadriceps femoris: group of four muscles in the anterior compartment of the thigh	The hamstrings flex the leg, whereas the quadriceps femoris extend it.
Flexor digitorum superficialis and flexor digitorum profundus: in the anterior compartment of the forearm	Extensor digitorum: in the posterior compartment of the forearm	The flexor digitorum superficialis and flexor digitorum profundus flex the fingers and the hand at the wrist, whereas the extensor digitorum extends the fingers and the hand at the wrist.

There are also skeletal muscles that do not pull against the skeleton for movements. For example, there are the muscles that produce facial expressions. The insertions and origins of facial muscles are in the skin, so that certain individual muscles contract to form a smile or frown, form sounds or words, and raise the eyebrows. There also are skeletal muscles in the tongue, and the external urinary and anal sphincters that allow for voluntary regulation of urination and defecation, respectively. In addition, the diaphragm contracts and relaxes to change the volume of the pleural cavities but it does not move the skeleton to do this.

EVERYDAY CONNECTIONS

Exercise and Stretching

When exercising, it is important to first warm up the muscles. Stretching pulls on the muscle fibers and it also results in an increased blood flow to the muscles being worked. Without a proper warm-up, it is possible that you may either damage some of the muscle fibers or pull a tendon. A pulled tendon, regardless of location, results in pain, swelling, and diminished function; if it is moderate to severe, the injury could immobilize you for an extended period.

Recall the discussion about muscles crossing joints to create movement. Most of the joints you use during exercise are synovial joints, which have synovial fluid in the joint space between two bones. Exercise and stretching may also have a beneficial effect on synovial joints. Synovial fluid is a thin, but viscous film with the consistency of egg whites. When you first get up and start moving, your joints feel stiff for a number of reasons. After proper stretching and warm-up, the synovial fluid may become less viscous, allowing for better joint function.

Patterns of Fascicle Organization

Skeletal muscle is enclosed in connective tissue scaffolding at three levels. Each muscle fiber (cell) is covered by endomysium and the entire muscle is covered by epimysium. When a group of muscle fibers is "bundled" as a unit within the whole muscle by an additional covering of a connective tissue called perimysium, that bundled group of muscle fibers is called a **fascicle**. Fascicle arrangement by perimysia is correlated to the force generated by a muscle; it also affects the range of motion of the muscle. Based on the patterns of fascicle arrangement, skeletal muscles can be classified in several ways. What follows are the most common fascicle arrangements.

Parallel muscles have fascicles that are arranged in the same direction as the long axis of the muscle (Figure $1.2G.2$). The majority of skeletal muscles in the body have this type of organization. Some parallel muscles are flat sheets that expand at the ends to make broad attachments. Other parallel muscles are rotund with tendons at one or both ends. Muscles that seem to be plump have a large mass of tissue located in the middle of the muscle, between the insertion and the origin, which is known as the central body. A more common name for this muscle is **belly**. When a muscle contracts, the contractile fibers shorten it to an even larger bulge. For example, extend and then flex your biceps brachii muscle; the large, middle section is the belly (Figure $1.2G.3$). When a parallel muscle has a central, large belly that is spindle-shaped, meaning it tapers as it extends to its origin and insertion, it sometimes is called **fusiform**.



Figure 1.2G.3: Biceps Brachii Muscle Contraction. The large mass at the center of a muscle is called the belly. Tendons emerge from both ends of the belly and connect the muscle to the bones, allowing the skeleton to move. The tendons of the bicep connect to the upper arm and the forearm. (credit: Victoria Garcia)

Circular muscles are also called sphincters (see Figure 1.2G.2). When they relax, the sphincters' concentrically arranged bundles of muscle fibers increase the size of the opening, and when they contract, the size of the opening shrinks to the point of closure. The orbicularis oris muscle is a circular muscle that goes around the mouth. When it contracts, the oral opening becomes smaller, as when puckering the lips for whistling. Another example is the orbicularis oculi, one of which surrounds each eye. Consider, for example, the names of the two orbicularis muscles (orbicularis oris and oribicularis oculi), where part of the first name of both muscles is the same. The first part of orbicularis, orb (orb = "circular"), is a reference to a round or circular structure; it may also make one think of orbit, such as the moon's path around the earth. The word oris (oris = "oral") refers to the oral cavity, or the mouth. The word oculi (ocular = "eye") refers to the eye.

There are other muscles throughout the body named by their shape or location. The deltoid is a large, triangular-shaped muscle that covers the shoulder. It is so-named because the Greek letter delta looks like a triangle. The rectus abdomis (rector = "straight") is the straight muscle in the anterior wall of the abdomen, while the rectus femoris is the straight muscle in the anterior compartment of the thigh.

When a muscle has a widespread expansion over a sizable area, but then the fascicles come to a single, common attachment point, the muscle is called **convergent**. The attachment point for a convergent muscle could be a tendon, an aponeurosis (a flat, broad tendon), or a raphe (a very slender tendon). The large muscle on the chest, the pectoralis major, is an example of a convergent muscle because it converges on the greater tubercle of the humerus via a tendon. The temporalis muscle of the cranium is another.

Pennate muscles (penna = "feathers") blend into a tendon that runs through the central region of the muscle for its whole length, somewhat like the quill of a feather with the muscle arranged similar to the feathers. Due to this design, the muscle fibers in a pennate muscle can only pull at an angle, and as a result, contracting pennate muscles do not move their tendons very far. However, because a pennate muscle generally can hold more muscle fibers within it, it can produce relatively more tension for its size. There are three subtypes of pennate muscles.

In a **unipennate** muscle, the fascicles are located on one side of the tendon. The extensor digitorum of the forearm is an example of a unipennate muscle. A **bipennate** muscle has fascicles on both sides of the tendon. In some pennate muscles, the muscle fibers wrap around the tendon, sometimes forming individual fascicles in the process. This arrangement is referred to as **multipennate**. A common example is the deltoid muscle of the shoulder, which covers the shoulder but has a single tendon that inserts on the deltoid tuberosity of the humerus.

Because of fascicles, a portion of a multipennate muscle like the deltoid can be stimulated by the nervous system to change the direction of the pull. For example, when the deltoid muscle contracts, the arm abducts (moves away from midline in the sagittal plane), but when only the anterior fascicle is stimulated, the arm will **abduct** and flex (move anteriorly at the shoulder joint).

The Lever System of Muscle and Bone Interactions

Skeletal muscles do not work by themselves. Muscles are arranged in pairs based on their functions. For muscles attached to the bones of the skeleton, the connection determines the force, speed, and range of movement. These characteristics depend on each other and can explain the general organization of the muscular and skeletal systems.

The skeleton and muscles act together to move the body. Have you ever used the back of a hammer to remove a nail from wood? The handle acts as a lever and the head of the hammer acts as a fulcrum, the fixed point that the force is applied to when you pull back or push down on the handle. The effort applied to this system is the pulling or pushing on the handle to remove the nail, which is the load, or "resistance" to the movement of the handle in the system. Our musculoskeletal system works in a similar manner,

with bones being stiff levers and the articular endings of the bones—encased in synovial joints—acting as fulcrums. The load would be an object being lifted or any resistance to a movement (your head is a load when you are lifting it), and the effort, or applied force, comes from contracting skeletal muscle.

Chapter Review

Skeletal muscles each have an origin and an insertion. The end of the muscle that attaches to the bone being pulled is called the muscle's insertion and the end of the muscle attached to a fixed, or stabilized, bone is called the origin. The muscle primarily responsible for a movement is called the prime mover, and muscles that assist in this action are called synergists. A synergist that makes the insertion site more stable is called a fixator. Meanwhile, a muscle with the opposite action of the prime mover is called an antagonist. Several factors contribute to the force generated by a skeletal muscle. One is the arrangement of the fascicles in the skeletal muscle. Fascicles can be parallel, circular, convergent, pennate, fusiform, or triangular. Each arrangement has its own range of motion and ability to do work.

Review Questions

Q. Which of the following is unique to the muscles of facial expression?

A. They all originate from the scalp musculature.

B. They insert onto the cartilage found around the face.

C. They only insert onto the facial bones.

D. They insert into the skin.

Answer; D

Q. Which of the following helps an agonist work?

A. a synergist

B. a fixator

C. an insertion

D. an antagonist

Answer: A

Q. Which of the following statements is correct about what happens during flexion?

A. The angle between bones is increased.

B. The angle between bones is decreased.

C. The bone moves away from the body.

D. The bone moves toward the center of the body.

Answer: B

Q. Which is moved the *least* during muscle contraction?

A. the origin

B. the insertion

C. the ligaments

D. the joints

Answer: A

Q. Which muscle has a convergent pattern of fascicles?

A. biceps brachii

B. gluteus maximus

C. pectoralis major

D. rectus femoris

Answer: C

Q. A muscle that has a pattern of fascicles running along the long axis of the muscle has which of the following fascicle arrangements?

A. circular

B. pennate

C. parallel

D. rectus

Answer: C

Q. Which arrangement *best* describes a bipennate muscle?

A. The muscle fibers feed in on an angle to a long tendon from both sides.

B. The muscle fibers feed in on an angle to a long tendon from all directions.

C. The muscle fibers feed in on an angle to a long tendon from one side.

D. The muscle fibers on one side of a tendon feed into it at a certain angle and muscle fibers on the other side of the tendon feed into it at the opposite angle.

Answer: A

Critical Thinking Questions

Q. What effect does fascicle arrangement have on a muscle's action?

A. Fascicle arrangements determine what type of movement a muscle can make. For instance, circular muscles act as sphincters, closing orifices.

Q. Movements of the body occur at joints. Describe how muscles are arranged around the joints of the body.

A. Muscles work in pairs to facilitate movement of the bones around the joints. Agonists are the prime movers while antagonists oppose or resist the movements of the agonists. Synergists assist the agonists, and fixators stabilize a muscle's origin.

Q. Explain how a synergist assists an agonist by being a fixator.

A. Agonists are the prime movers while antagonists oppose or resist the movements of the agonists. Synergists assist the agonists, and fixators stabilize a muscle's origin.

Glossary

abduct

move away from midline in the sagittal plane

agonist

(also, prime mover) muscle whose contraction is responsible for producing a particular motion

antagonist
muscle that opposes the action of an agonist

belly
bulky central body of a muscle

bipennate
pennate muscle that has fascicles that are located on both sides of the tendon

circular
(also, sphincter) fascicles that are concentrically arranged around an opening

convergent
fascicles that extend over a broad area and converge on a common attachment site

fascicle
muscle fibers bundled by perimysium into a unit

fixator
synergist that assists an agonist by preventing or reducing movement at another joint, thereby stabilizing the origin of the agonist

flexion
movement that decreases the angle of a joint

fusiform
muscle that has fascicles that are spindle-shaped to create large bellies

insertion
end of a skeletal muscle that is attached to the structure (usually a bone) that is moved when the muscle contracts

multipennate
pennate muscle that has a tendon branching within it

origin
end of a skeletal muscle that is attached to another structure (usually a bone) in a fixed position

parallel
fascicles that extend in the same direction as the long axis of the muscle

pennate
fascicles that are arranged differently based on their angles to the tendon

prime mover
(also, agonist) principle muscle involved in an action

synergist
muscle whose contraction helps a prime mover in an action

unipennate
pennate muscle that has fascicles located on one side of the tendon

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1.2H: Naming Skeletal Muscle

Learning Objectives

- Describe the criteria used to name skeletal muscles
- Explain how understanding the muscle names helps describe shapes, location, and actions of various muscles

The Greeks and Romans conducted the first studies done on the human body in Western culture. The educated class of subsequent societies studied Latin and Greek, and therefore the early pioneers of anatomy continued to apply Latin and Greek terminology or roots when they named the skeletal muscles. The large number of muscles in the body and unfamiliar words can make learning the names of the muscles in the body seem daunting, but understanding the etymology can help. Etymology is the study of how the root of a particular word entered a language and how the use of the word evolved over time. Taking the time to learn the root of the words is crucial to understanding the vocabulary of anatomy and physiology. When you understand the names of muscles it will help you remember where the muscles are located and what they do (Figure 1.2H.1, Figure 1.2H.2, and Table 1.2H.1). Pronunciation of words and terms will take a bit of time to master, but after you have some basic information; the correct names and pronunciations will become easier.

Example	Word	Latin Root 1	Latin Root 2	Meaning	Translation
abductor digiti minimi	abductor	ab = away from	duct = to move	a muscle that moves away from	A muscle that moves the little finger or toe away
	digiti	digitus = digit		refers to a finger or toe	
	minimi	minimus = mini, tiny		little	
adductor digiti minimi	adductor	ad = to, toward	duct = to move	a muscle that moves towards	A muscle that moves the little finger or toe toward
	digiti	digitus = digit		refers to a finger or toe	
	minimi	minimus = mini, tiny		little	

Figure 1.2H.2: Understanding a Muscle Name from the Latin.

Table 1.2H.1: Mnemonic Device for Latin Roots

Example	Latin or Greek Translation	Mnemonic Device
ad	to; toward	ADvance toward your goal
ab	away from	n/a
sub	under	SUBmarines move under water.
ductor	something that moves	A conDUCTOR makes a train move.
anti	against	If you are antisocial, you are against engaging in social activities.
epi	on top of	n/a
apo	to the side of	n/a
longissimus	longest	“Longissimus” is longer than the word “long.”
longus	long	long
brevis	short	brief
maximus	large	max

Example	Latin or Greek Translation	Mnemonic Device
medius	medium	“Medius” and “medium” both begin with “med.”
minimus	tiny; little	mini
rectus	straight	To RECTify a situation is to straighten it out.
multi	many	If something is MULTIcolored, it has many colors.
uni	one	A UNIcorn has one horn.
bi/di	two	If a ring is DIcast, it is made of two metals.
tri	three	TRIple the amount of money is three times as much.
quad	four	QUADruplets are four children born at one birth.
externus	outside	EXternal
internus	inside	INternal

Anatomists name the skeletal muscles according to a number of criteria, each of which describes the muscle in some way. These include naming the muscle after its shape, its size compared to other muscles in the area, its location in the body or the location of its attachments to the skeleton, how many origins it has, or its action.

The skeletal muscle’s anatomical location or its relationship to a particular bone often determines its name. For example, the frontalis muscle is located on top of the frontal bone of the skull. Similarly, the shapes of some muscles are very distinctive and the names, such as orbicularis, reflect the shape. For the buttocks, the size of the muscles influences the names: gluteus **maximus** (largest), gluteus **medius** (medium), and the gluteus **minimus** (smallest). Names were given to indicate length—**brevis** (short), **longus** (long)—and to identify position relative to the midline: **lateralis** (to the outside away from the midline), and **medialis** (toward the midline). The direction of the muscle fibers and fascicles are used to describe muscles relative to the midline, such as the **rectus** (straight) abdominis, or the **oblique** (at an angle) muscles of the abdomen.

Some muscle names indicate the number of muscles in a group. One example of this is the quadriceps, a group of four muscles located on the anterior (front) thigh. Other muscle names can provide information as to how many origins a particular muscle has, such as the biceps brachii. The prefix **bi** indicates that the muscle has two origins and **tri** indicates three origins.

The location of a muscle’s attachment can also appear in its name. When the name of a muscle is based on the attachments, the origin is always named first. For instance, the sternocleidomastoid muscle of the neck has a dual origin on the sternum (sterno) and clavicle (cleido), and it inserts on the mastoid process of the temporal bone. The last feature by which to name a muscle is its action. When muscles are named for the movement they produce, one can find action words in their name. Some examples are **flexor** (decreases the angle at the joint), **extensor** (increases the angle at the joint), **abductor** (moves the bone away from the midline), or **adductor** (moves the bone toward the midline).

Chapter Review

Muscle names are based on many characteristics. The location of a muscle in the body is important. Some muscles are named based on their size and location, such as the gluteal muscles of the buttocks. Other muscle names can indicate the location in the body or bones with which the muscle is associated, such as the tibialis anterior. The shapes of some muscles are distinctive; for example, the direction of the muscle fibers is used to describe muscles of the body midline. The origin and/or insertion can also be features used to name a muscle; examples are the biceps brachii, triceps brachii, and the pectoralis major.

Review Questions

Q. The location of a muscle’s insertion and origin can determine _____.

A. action

B. the force of contraction

C. muscle name

D. the load a muscle can carry

Answer: A

Q. Where is the temporalis muscle located?

A. on the forehead

B. in the neck

C. on the side of the head

D. on the chin

Answer: C

Q. Which muscle name does *not* make sense?

A. extensor digitorum

B. gluteus minimus

C. biceps femoris

D. extensor minimus longus

Answer: D

Q. Which of the following terms would be used in the name of a muscle that moves the leg away from the body?

A. flexor

B. adductor

C. extensor

D. abductor

Answer: D

Critical Thinking Questions

Q. Describe the different criteria that contribute to how skeletal muscles are named.

A. In anatomy and physiology, many word roots are Latin or Greek. Portions, or roots, of the word give us clues about the function, shape, action, or location of a muscle.

Glossary

abductor
moves the bone away from the midline

adductor
moves the bone toward the midline

bi
two

brevis

short

extensor
muscle that increases the angle at the joint

flexor
muscle that decreases the angle at the joint

lateralis
to the outside

longus
long

maximus
largest

medialis
to the inside

medius
medium

minimus
smallest

oblique
at an angle

rectus
straight

tri
three

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CHAPTER OVERVIEW

2: The Skeletal System

- 2.1: Introduction
- 2.2: The Functions of the Skeletal System
- 2.3: The Axial Skeleton
- 2.4: The Appendicular Skeleton
- 2.5: Bone Classification
- 2.6: Bone Structure
- 2.7: Cartilage
  - 2.7A: Structure, Type, and Location of Cartilage
  - 2.7B: Cartilage Growth
- 2.8: Joints
  - 2.8A: Classification of Joints
  - 2.8B: Fibrous Joints
  - 2.8C: Cartilaginous Joints
  - 2.8D: Synovial Joints
  - 2.8E: Types of Body Movements
  - 2.8F: Anatomy of Selected Synovial Joints
- 2.9: Bone Formation and Development
- 2.10: Fractures - Bone Repair

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2.1: Introduction

Chapter Objectives:

After studying this chapter, you will be able to:

- List and descrive the functions of bones
- Describe the classes of bones
- Discuss the process of bone formation and development
- Explain how bone repairs itself after a fracture
- Discuss the effect of exercise, nutrition, and hormones on bone tissues
- Describe how an imbalance of calcium can affect bone tissue

Bones make good fossils. While the soft tissue of a once living organism will decay and fall away over time, bone tissue will, under the right conditions, undergo a process of mineralization, effectively turning the bone to stone. A well-preserved fossil skeleton can give us a good sense of the size and shape of an organism, just as your skeleton helps to define your size and shape. Unlike a fossil skeleton, however, your skeleton is a structure of living tissue that grows, repairs, and renews itself. The bones within it are dynamic and complex organs that serve a number of important functions, including some necessary to maintain homeostasis.



Figure 2.1.1: Child Looking at Bones. *Bone is a living tissue. Unlike the bones of a fossil made inert by a process of mineralization, a child's bones will continue to grow and develop while contributing to the support and function of other body systems. (credit: James Emery)*

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2.2: The Functions of the Skeletal System

Learning Objectives

- Define bone, cartilage, and the skeletal system
- List and describe the functions of the skeletal system

Bone, or **osseous tissue**, is a hard, dense connective tissue that forms most of the adult skeleton, the support structure of the body. In the areas of the skeleton where bones move (for example, the ribcage and joints), **cartilage**, a semi-rigid form of connective tissue, provides flexibility and smooth surfaces for movement. The **skeletal system** is the body system composed of bones and cartilage and performs the following critical functions for the human body:

- supports the body
- facilitates movement
- protects internal organs
- produces blood cells
- stores and releases minerals and fat

Support, Movement, and Protection

The most apparent functions of the skeletal system are the gross functions—those visible by observation. Simply by looking at a person, you can see how the bones support, facilitate movement, and protect the human body.

Just as the steel beams of a building provide a scaffold to support its weight, the bones and cartilage of your skeletal system compose the scaffold that supports the rest of your body. Without the skeletal system, you would be a limp mass of organs, muscle, and skin.

Bones also facilitate movement by serving as points of attachment for your muscles. While some bones only serve as a support for the muscles, others also transmit the forces produced when your muscles contract. From a mechanical point of view, bones act as levers and joints serve as fulcrums (Figure 2.2.1). Unless a muscle spans a joint and contracts, a bone is not going to move. For information on the interaction of the skeletal and muscular systems, that is, the musculoskeletal system, seek additional content.



Figure 2.2.1: Bones Support Movement.Bones act as levers when muscles span a joint and contract. (credit: Benjamin J. DeLong)

Bones also protect internal organs from injury by covering or surrounding them. For example, your ribs protect your lungs and heart, the bones of your vertebral column (spine) protect your spinal cord, and the bones of your cranium (skull) protect your brain (Figure 2.2.2).

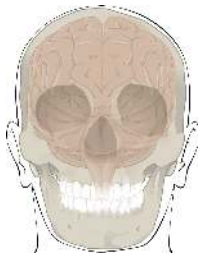


Figure 2.2.2: Bones Protect Brain.The cranium completely surrounds and protects the brain from non-traumatic injury.

CAREER CONNECTION: Orthopedist

An **orthopedist** is a doctor who specializes in diagnosing and treating disorders and injuries related to the musculoskeletal system. Some orthopedic problems can be treated with medications, exercises, braces, and other devices, but others may be best treated with surgery (Figure 2.2.3).

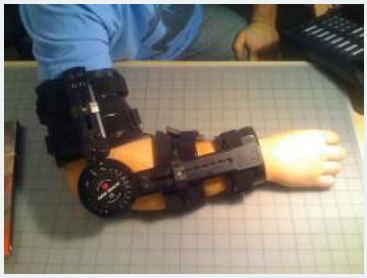


Figure 2.2.3: Arm Brace.An orthopedist will sometimes prescribe the use of a brace that reinforces the underlying bone structure it is being used to support. (credit: Juhan Sonin).

While the origin of the word “orthopedics” (ortho- = “straight”; paed- = “child”), literally means “straightening of the child,” orthopedists can have patients who range from pediatric to geriatric. In recent years, orthopedists have even performed prenatal surgery to correct spina bifida, a congenital defect in which the neural canal in the spine of the fetus fails to close completely during embryologic development.

Orthopedists commonly treat bone and joint injuries but they also treat other bone conditions including curvature of the spine. Lateral curvatures (scoliosis) can be severe enough to slip under the shoulder blade (scapula) forcing it up as a hump. Spinal curvatures can also be excessive dorsoventrally (kyphosis) causing a hunch back and thoracic compression. These curvatures often appear in preteens as the result of poor posture, abnormal growth, or indeterminate causes. Mostly, they are readily treated by orthopedists. As people age, accumulated spinal column injuries and diseases like osteoporosis can also lead to curvatures of the spine, hence the stooping you sometimes see in the elderly.

Some orthopedists sub-specialize in sports medicine, which addresses both simple injuries, such as a sprained ankle, and complex injuries, such as a torn rotator cuff in the shoulder. Treatment can range from exercise to surgery.

Mineral Storage, Energy Storage, and Hematopoiesis

On a metabolic level, bone tissue performs several critical functions. For one, the bone matrix acts as a reservoir for a number of minerals important to the functioning of the body, especially calcium, and potassium. These minerals, incorporated into bone tissue, can be released back into the bloodstream to maintain levels needed to support physiological processes. Calcium ions, for example, are essential for muscle contractions and controlling the flow of other ions involved in the transmission of nerve impulses.

Bone also serves as a site for fat storage and blood cell production. The softer connective tissue that fills the interior of most bone is referred to as bone marrow (Figure 2.2.4). There are two types of bone marrow: yellow marrow and red marrow. **Yellow marrow** contains adipose tissue; the triglycerides stored in the adipocytes of the tissue can serve as a source of energy. **Red marrow** is where **hematopoiesis**—the production of blood cells—takes place. Red blood cells, white blood cells, and platelets are all produced in the red marrow.

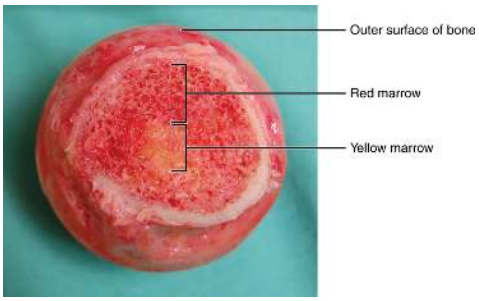


Figure 2.2.4: Head of Femur Showing Red and Yellow Marrow.The head of the femur contains both yellow and red marrow. Yellow marrow stores fat. Red marrow is responsible for hematopoiesis. (credit: modification of work by “stevenfruitsmaak”/Wikimedia Commons)

Chapter Review

The major functions of the bones are body support, facilitation of movement, protection of internal organs, storage of minerals and fat, and hematopoiesis. Together, the muscular system and skeletal system are known as the musculoskeletal system.

Review Questions

Q. Which function of the skeletal system would be especially important if you were in a car accident?

A. storage of minerals

B. protection of internal organs

C. facilitation of movement

D. fat storage

Answer: B

Q. Bone tissue can be described as _____.

A. dead calcified tissue

B. cartilage

C. the skeletal system

D. dense, hard connective tissue

Answer: D

Q. Without red marrow, bones would not be able to _____.

A. store phosphate

B. store calcium

C. make blood cells

D. move like levers

Answer: C

Q. Yellow marrow has been identified as _____.

A. an area of fat storage

B. a point of attachment for muscles

C. the hard portion of bone

D. the cause of kyphosis

Answer: A

Q. Which of the following can be found in areas of movement?

A. hematopoiesis

B. cartilage

C. yellow marrow

D. red marrow

Answer: B

Q. The skeletal system is made of _____.

A. muscles and tendons

B. bones and cartilage

C. vitreous humor

D. minerals and fat

Answer: B

Critical Thinking Questions

The skeletal system is composed of bone and cartilage and has many functions. Choose three of these functions and discuss what features of the skeletal system allow it to accomplish these functions.

Answer:

It supports the body. The rigid, yet flexible skeleton acts as a framework to support the other organs of the body.

It facilitates movement. The movable joints allow the skeleton to change shape and positions; that is, move.

It protects internal organs. Parts of the skeleton enclose or partly enclose various organs of the body including our brain, ears, heart, and lungs. Any trauma to these organs has to be mediated through the skeletal system.

It produces blood cells. The central cavity of long bones is filled with marrow. The red marrow is responsible for forming red and white blood cells.

It stores and releases minerals and fat. The mineral component of bone, in addition to providing hardness to bone, provides a mineral reservoir that can be tapped as needed. Additionally, the yellow marrow, which is found in the central cavity of long bones along with red marrow, serves as a storage site for fat.

Glossary

bone
hard, dense connective tissue that forms the structural elements of the skeleton

cartilage
semi-rigid connective tissue found on the skeleton in areas where flexibility and smooth surfaces support movement

hematopoiesis
production of blood cells, which occurs in the red marrow of the bones

orthopedist
doctor who specializes in diagnosing and treating musculoskeletal disorders and injuries

osseous tissue
bone tissue; a hard, dense connective tissue that forms the structural elements of the skeleton

red marrow
connective tissue in the interior cavity of a bone where hematopoiesis takes place

skeletal system
organ system composed of bones and cartilage that provides for movement, support, and protection

yellow marrow
connective tissue in the interior cavity of a bone where fat is stored

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2.3: The Axial Skeleton

The axial skeleton functions to support and protect the organs of the dorsal and ventral cavities and serves as a surface for the attachment of muscles and parts of the appendicular skeleton.

Learning Objectives

- List the components of the axial skeleton

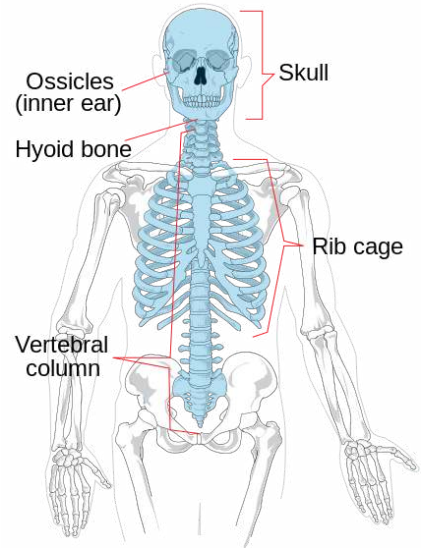
Key Points

- The axial skeleton is the part of the skeleton that consists of the bones of the head and trunk of a vertebrate animal, including humans.
- The primary divisions of the skeleton system are the head, thorax, and vertebral column.
- The human cranium supports the structures of the face and forms the brain cavity.
- The rib cage functions as protection for the vital organs of the chest such as the heart and lungs.
- The cervical vertebrae make up the junction between the vertebral column and the cranium, and the bone makes up the junction between the vertebral column and the pelvic bones.

Key Terms

- **flat bones**: Thin bones (although often curved) that serve as points of attachment for muscles and protect internal organs (examples, cranium, sternum).
- **cranial vault**: The space in the skull occupied by the brain.
- **sutures**: Fibrous joints that are only found in the cranium.

The axial skeleton is the part of the skeleton that consists of the bones of the head and trunk of a vertebrate animal, including humans.



Axial skeleton: Image depicting the human skeleton with the axial skeleton.

The word axial is from the word axis, and refers to how the bones of the axial skeleton are located along the central axis of the body.

The axial skeleton functions to support and protect the organs of the dorsal and ventral cavities. It also serves as a surface for the attachment of muscles and parts of the appendicular skeleton.

The human's axial skeleton is composed of 80 bones and is the central core of the body. The primary divisions of the skeleton system are:

- Head, including the bones of the skull (cranium), face, auditory ossicles, and hyoid bone.

- Thorax, including the rib cage and sternum.
- Vertebral column.

Bones of the Head

Skull (Cranium)

The human cranium consists of the flat bones of the cranium and includes the facial bones. The cranium protects the brain that is contained in the cranial vault. The cranium is formed from eight bones connected by sutures.

Fourteen facial bones form the lower front part of the cranium. Important facial bones include the lower jaw or mandible, the upper jaw or maxilla, the zygomatic or cheek bone, and the nasal bone.

The immature cranium has separate plates to allow the flexibility needed for a newborn to pass through the birth canal and pelvis.

These plates fuse as the skull matures (except the mandible). The human cranium supports the structures of the face and forms the brain cavity.

Ossicle

The ossicles (also called auditory ossicles) consist of three bones (malleus, incus, and stapes) that are the smallest in the body. These are located in the middle ear and serve to transmit sounds from the air to the fluid-filled labyrinth.

Hyoid Bone

The hyoid bone is a horseshoe-shaped bone situated in the anterior midline of the neck between the chin and the thyroid cartilage. It provides attachment to the muscles of the floor of the mouth, the tongue above, larynx below, and the epiglottis and pharynx behind.

Rib Cage

The rib cage is composed of 25 bones that include the 12 pairs of ribs plus the sternum. It functions as protection for the vital organs of the chest, such as the heart and lungs. The rounded ends are attached at joints to the thoracic vertebrae posteriorly and the flattened ends come together at the sternum anteriorly.

The first seven pairs of ribs attach to the sternum with costal cartilage and are known as true ribs. Thelength of each rib pair increases from number one to seven. After rib seven, the size begins to decrease. The 8th through 10th ribs have noncostal cartilage that connects them to the ribs above.

The last two ribs are called floating ribs because they do not attach to the sternum or to other ribs.

Vertebral Column

There are normally thirty-three vertebrae in the human vertebral column. The upper twenty-four articulate and are unfused, the lower nine are fused. The fused vertebrae are the five in the sacrum and four in the coccyx.

The articulating vertebrae are named according regions:

- Cervical vertebrae (seven vertebrae).
- Thoracic (twelve vertebrae).
- Lumbar (five vertebrae).

The first and second cervical vertebrae are the atlas and axis, respectively, on which the head rests. The cervical vertebrae make up the junction between the vertebral column and the cranium, and the bone makes up the junction between the vertebral column and the pelvic bones.

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2.4: The Appendicular Skeleton

The appendicular skeleton includes the skeletal elements within the limbs, as well as supporting pectoral and pelvic girdles.

Learning Objectives

- List the components of the appendicular skeleton

Key Points

- The appendicular skeleton comprises 126 bones and is involved in locomotion and manipulation of objects in the environment.
- The bones of the appendicular skeleton are divided into two groups: the bones that are located within the limbs themselves, and the girdle bones that attach the limbs to the axial skeleton.
- The bones of the pectoral girdle anchor the upper limb to the thoracic cage of the axial skeleton.
- The pelvic girdle is formed by a single bone and serves as the attachment point for each lower limb.

Key Terms

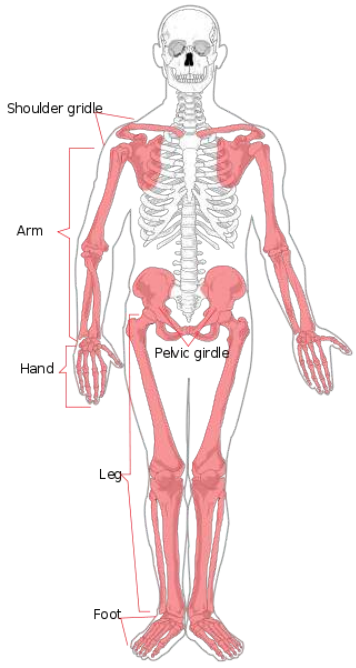
- **Girdle**: A group of bones that connect the appendages to the axial skeleton.
- **phalanges**: The digital bones of the hands and feet (singular, phalanx).
- **appendages**: The parts of the body that extend from the axial trunk.

The appendicular skeleton of vertebrates, including humans, consists of the bones that support and compose the appendages (for example, the arms and legs of humans). The word appendicular is the adjective of the noun appendage.

The appendicular skeleton includes the skeletal elements within the limbs, as well as supporting the pectoral and pelvic girdles.

The appendicular skeleton comprises 126 bones and is involved in locomotion and manipulation of objects in the environment. It is unfused, allowing for greater range of motion.

Divisions of the Appendicular Skeleton



A diagram of the apendicular skeleton: Image depicting the human skeleton with the appendicular skeleton colored red.

The appendicular skeleton is divided into six major regions:

1. The pectoral girdles consist of 4 bones: The left and right clavicle (2) and the scapula (2).

2. The upper arms and forearms are made up of 6 bones: The left and right humerus (upper arm, 2), the ulna (2), and the radius (forearm, 2).
3. The hands have 54 bones: The left and right carpals (wrist, 16), metacarpals (10), proximal phalanges (10), intermediate phalanges (8), and the distal phalanges (10).
4. The pelvis has 2 bones: The left and right hip bone (2).
5. The thighs and legs have 8 bones: The left and right femur (thigh, 2), patella (knee, 2), tibia (2) and fibula (leg, 2).
6. The feet and ankles have 52 bones: The left and right tarsals (ankle, 14), metatarsals (10), proximal phalanges (10), intermediate phalanges (8), and distal phalanges (10).

Pectoral Girdle

The bones of the pectoral girdle consist of two bones (scapula and clavicle) and anchor the upper limb to the thoracic cage of the axial skeleton.

The three regions of the upper limb are: arm (humerus), forearm (ulna medially and radius laterally), and the hand.

The base of the hand contains eight bones (carpal bones), and the palm is formed by five bones (metacarpal bones). The fingers and thumb contain a total of 14 bones, called phalanges.

Pelvic Girdle

The pelvic girdle is formed by a single bone, the hip or coxal bone, and serves as the attachment point for each lower limb. Each hip bone is joined to the axial skeleton by its attachment to the sacrum of the vertebral column. The right and left hip bones attach to each other anteriorly.

The lower limb contains 30 bones and is divided into three regions, the thigh, leg, and foot. These consist of the femur, patella, tibia, fibula, tarsal bones, metatarsal bones, and phalanges.

- The femur is the single bone of the thigh.
- The patella (kneecap) articulates with the distal femur.
- The tibia is located on the medial side of the leg,
- The fibula is the thin bone of the lateral leg.

The bones of the foot are divided into three groups, the tarsal bones, metatarsal bones, and phalanges of the foot.

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2.5: Bone Classification

Learning Objectives

- Classify bones according to their shapes
- Describe the function of each category of bones

The 206 bones that compose the adult skeleton are divided into five categories based on their shapes (Figure 2.5.1). Their shapes and their functions are related such that each categorical shape of bone has a distinct function.

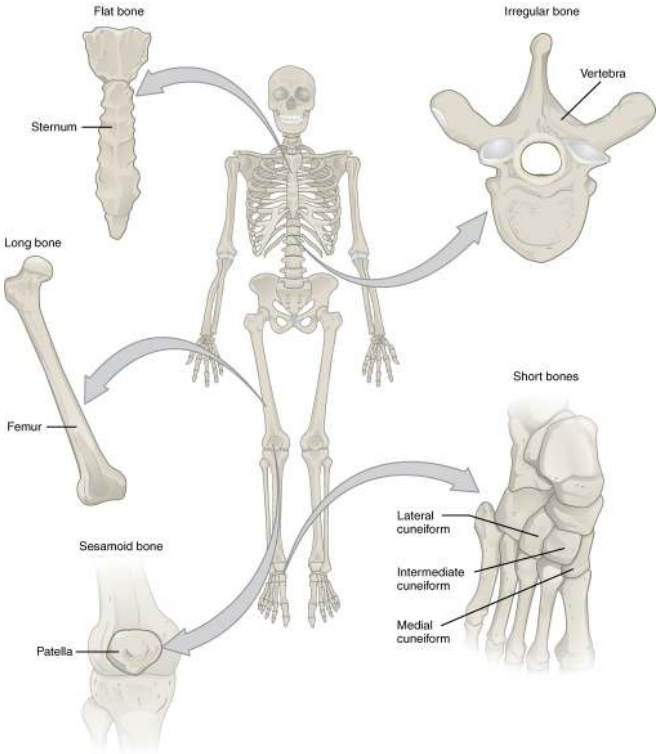


Figure 2.5.1: Classifications of Bones.Bones are classified according to their shape.

Long Bones

A **long bone** is one that is cylindrical in shape, being longer than it is wide. Keep in mind, however, that the term describes the shape of a bone, not its size. Long bones are found in the arms (humerus, ulna, radius) and legs (femur, tibia, fibula), as well as in the fingers (metacarpals, phalanges) and toes (metatarsals, phalanges). Long bones function as levers; they move when muscles contract.

Short Bones

A **short bone** is one that is cube-like in shape, being approximately equal in length, width, and thickness. The only short bones in the human skeleton are in the carpals of the wrists and the tarsals of the ankles. Short bones provide stability and support as well as some limited motion.

Flat Bones

The term "**flat bone**" is somewhat of a misnomer because, although a flat bone is typically thin, it is also often curved. Examples include the cranial (skull) bones, the scapulae (shoulder blades), the sternum (breastbone), and the ribs. Flat bones serve as points of attachment for muscles and often protect internal organs.

Irregular Bones

An **irregular bone** is one that does not have any easily characterized shape and therefore does not fit any other classification. These bones tend to have more complex shapes, like the vertebrae that support the spinal cord and protect it from compressive forces. Many facial bones, particularly the ones containing sinuses, are classified as irregular bones.

Sesamoid Bones

A **sesamoid bone** is a small, round bone that, as the name suggests, is shaped like a sesame seed. These bones form in tendons (the sheaths of tissue that connect bones to muscles) where a great deal of pressure is generated in a joint. The sesamoid bones protect tendons by helping them overcome compressive forces. Sesamoid bones vary in number and placement from person to person but are typically found in tendons associated with the feet, hands, and knees. The patellae (singular = patella) are the only sesamoid bones found in common with every person. Table 2.5.1 reviews bone classifications with their associated features, functions, and examples.

Table 2.5.1: Bone Classifications

Bone classification	Features	Function(s)	Examples
Long	Cylinder-like shape, longer than it is wide	Leverage	Femur, tibia, fibula, metatarsals, humerus, ulna, radius, metacarpals, phalanges
Short	Cube-like shape, approximately equal in length, width, and thickness	Provide stability, support, while allowing for some motion	Carpals, tarsals
Flat	Thin and curved	Points of attachment for muscles; protectors of internal organs	Sternum, ribs, scapulae, cranial bones
Irregular	Complex shape	Protect internal organs	Vertebrae, facial bones
Sesamoid	Small and round; embedded in tendons	Protect tendons from compressive forces	Patellae

Chapter Review

Bones can be classified according to their shapes. Long bones, such as the femur, are longer than they are wide. Short bones, such as the carpals, are approximately equal in length, width, and thickness. Flat bones are thin, but are often curved, such as the ribs. Irregular bones such as those of the face have no characteristic shape. Sesamoid bones, such as the patellae, are small and round, and are located in tendons.

Review Questions

Q. Most of the bones of the arms and hands are long bones; however, the bones in the wrist are categorized as _____.

A. flat bones

B. short bones

C. sesamoid bones

D. irregular bones

Answer: B

Q. Sesamoid bones are found embedded in _____.

A. joints

B. muscles

C. ligaments

D. tendons

Answer: D

Q. Bones that surround the spinal cord are classified as _____ bones.

A. irregular

B. sesamoid

C. flat

D. short

Answer: A

Q. Which category of bone is among the most numerous in the skeleton?

A. long bone

B. sesamoid bone

C. short bone

D. flat bone

Answer: A

Q. Long bones enable body movement by acting as a _____.

A. counterweight

B. resistive force

C. lever

D. fulcrum

Answer: C

Critical Thinking Questions

Q. What are the structural and functional differences between a tarsal and a metatarsal?

A. Structurally, a tarsal is a short bone, meaning its length, width, and thickness are about equal, while a metatarsal is a long bone whose length is greater than its width. Functionally, the tarsal provides limited motion, while the metatarsal acts as a lever.

Q. What are the structural and functional differences between the femur and the patella?

A. Structurally, the femur is a long bone, meaning its length is greater than its width, while the patella, a sesamoid bone, is small and round. Functionally, the femur acts as a lever, while the patella protects the patellar tendon from compressive forces.

Glossary

flat bone

thin and curved bone; serves as a point of attachment for muscles and protects internal organs

irregular bone

bone of complex shape; protects internal organs from compressive forces

long bone

cylinder-shaped bone that is longer than it is wide; functions as a lever

sesamoid bone

small, round bone embedded in a tendon; protects the tendon from compressive forces

short bone

cube-shaped bone that is approximately equal in length, width, and thickness; provides limited motion

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2.6: Bone Structure

Learning Objectives

- Identify the anatomical features of a bone
- Define and list examples of bone markings
- Describe the histology of bone tissue
- Compare and contrast compact and spongy bone
- Identify the structures that compose compact and spongy bone
- Describe how bones are nourished and innervated

Bone tissue (osseous tissue) differs greatly from other tissues in the body. Bone is hard and many of its functions depend on that characteristic hardness. Later discussions in this chapter will show that bone is also dynamic in that its shape adjusts to accommodate stresses. This section will examine the gross anatomy of bone first and then move on to its histology.

Gross Anatomy of Bone

The structure of a long bone allows for the best visualization of all of the parts of a bone (Figure 2.6.1). A long bone has two parts: the **diaphysis** and the **epiphysis**. The diaphysis is the tubular shaft that runs between the proximal and distal ends of the bone. The hollow region in the diaphysis is called the **medullary cavity**, which is filled with yellow marrow. The walls of the diaphysis are composed of dense and hard **compact bone**.

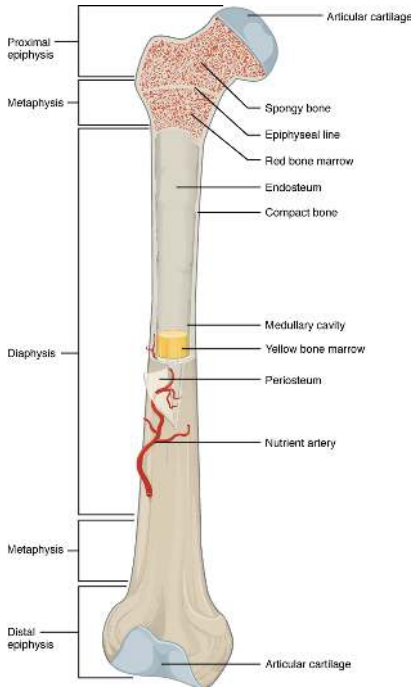


Figure 2.6.1: Anatomy of a Long Bone.A typical long bone shows the gross anatomical characteristics of bone.

The wider section at each end of the bone is called the epiphysis (plural = epiphyses), which is filled with spongy bone. Red marrow fills the spaces in the spongy bone. Each epiphysis meets the diaphysis at the metaphysis, the narrow area that contains the **epiphyseal plate** (growth plate), a layer of hyaline (transparent) cartilage in a growing bone. When the bone stops growing in early adulthood (approximately 18–21 years), the cartilage is replaced by osseous tissue and the epiphyseal plate becomes an epiphyseal line.

The medullary cavity has a delicate membranous lining called the **endosteum** (end- = “inside”; oste- = “bone”), where bone growth, repair, and remodeling occur. The outer surface of the bone is covered with a fibrous membrane called the **periosteum** (peri- = “around” or “surrounding”). The periosteum contains blood vessels, nerves, and lymphatic vessels that nourish compact bone. Tendons and ligaments also attach to bones at the periosteum. The periosteum covers the entire outer surface except where the epiphyses meet other bones to form joints (Figure 2.6.2). In this region, the epiphyses are covered with **articular cartilage**, a thin layer of cartilage that reduces friction and acts as a shock absorber.

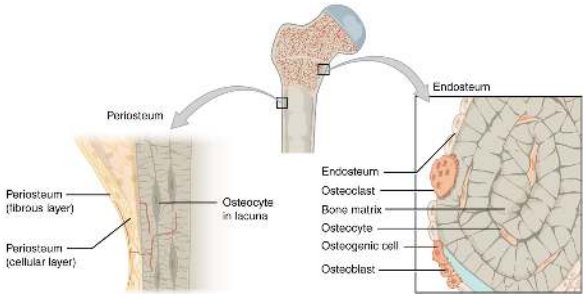


Figure 2.6.2: Periosteum and Endosteum.The periosteum forms the outer surface of bone, and the endosteum lines the medullary cavity.

Flat bones, like those of the cranium, consist of a layer of **diploë** (spongy bone), lined on either side by a layer of compact bone (Figure \Pageindex3). The two layers of compact bone and the interior spongy bone work together to protect the internal organs. If the outer layer of a cranial bone fractures, the brain is still protected by the intact inner layer.

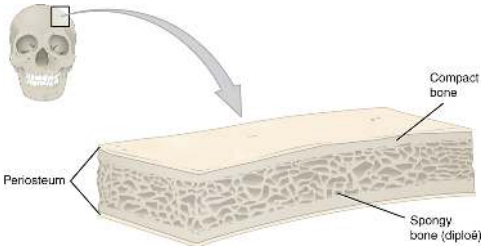


Figure 2.6.3: Anatomy of a Flat Bone.This cross-section of a flat bone shows the spongy bone (diploë) lined on either side by a layer of compact bone.

Bone Markings

The surface features of bones vary considerably, depending on the function and location in the body. Table 2.6.1 describes the bone markings, which are illustrated in (Figure 2.6.4). There are three general classes of bone markings: (1) articulations, (2) projections, and (3) holes. As the name implies, an **articulation** is where two bone surfaces come together (articulus = "joint"). These surfaces tend to conform to one another, such as one being rounded and the other cupped, to facilitate the function of the articulation. A **projection** is an area of a bone that projects above the surface of the bone. These are the attachment points for tendons and ligaments. In general, their size and shape is an indication of the forces exerted through the attachment to the bone. A **hole** is an opening or groove in the bone that allows blood vessels and nerves to enter the bone. As with the other markings, their size and shape reflect the size of the vessels and nerves that penetrate the bone at these points.

Table 2.6.1

Bone Markings		
Marking	Description	Example
Articulations	Where two bones meet	Knee joint
Head	Prominent rounded surface	Head of femur
Facet	Flat surface	Vertebrae
Condyle	Rounded surface	Occipital condyles
Projections	Raised markings	Spinous process of the vertebrae
Protuberance	Protruding	Chin
Process	Prominence feature	Transverse process of vertebra
Spine	Sharp process	Ischial spine
Tubercle	Small, rounded process	Tubercle of humerus
Tuberosity	Rough surface	Deltoid tuberosity
Line	Slight, elongated ridge	Temporal lines of the parietal bones
Crest	Ridge	Iliac crest
Holes	Holes and depressions	Foramen (holes through which blood vessels can pass through)
Fossa	Elongated basin	Mandibular fossa

Bone Markings		
Marking	Description	Example
Fovea	Small pit	Fovea capitis on the head of the femur
Sulcus	Groove	Sigmoid sulcus of the temporal bones
Canal	Passage in bone	Auditory canal
Fissure	Slit through bone	Auricular fissure
Foramen	Hole through bone	Foramen magnum in the occipital bone
Meatus	Opening into canal	External auditory meatus
Sinus	Air-filled space in bone	Nasal sinus

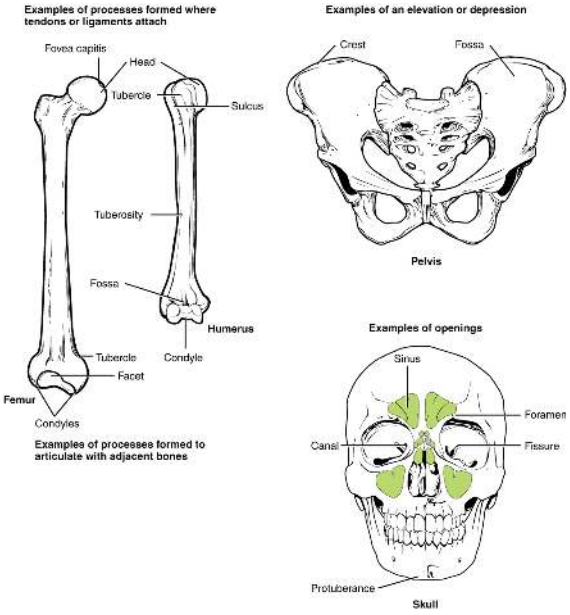


Figure 2.6.4: Bone Features.The surface features of bones depend on their function, location, attachment of ligaments and tendons, or the penetration of blood vessels and nerves.

Bone Cells and Tissue

Bone contains a relatively small number of cells entrenched in a matrix of collagen fibers that provide a surface for inorganic salt crystals to adhere. These salt crystals form when calcium phosphate and calcium carbonate combine to create hydroxyapatite, which incorporates other inorganic salts like magnesium hydroxide, fluoride, and sulfate as it crystallizes, or calcifies, on the collagen fibers. The hydroxyapatite crystals give bones their hardness and strength, while the collagen fibers give them flexibility so that they are not brittle.

Although bone cells compose a small amount of the bone volume, they are crucial to the function of bones. Four types of cells are found within bone tissue: osteoblasts, osteocytes, osteogenic cells, and osteoclasts (Figure 2.6.5).

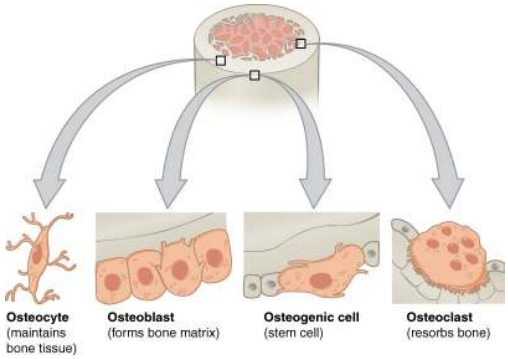


Figure 2.6.5: Bone Cells.Four types of cells are found within bone tissue. Osteogenic cells are undifferentiated and develop into osteoblasts. When osteoblasts get trapped within the calcified matrix, their structure and function changes, and they become osteocytes. Osteoclasts develop from monocytes and macrophages and differ in appearance from other bone cells.

The **osteoblast** is the bone cell responsible for forming new bone and is found in the growing portions of bone, including the periosteum and endosteum. Osteoblasts, which do not divide, synthesize and secrete the collagen matrix and calcium salts. As the secreted matrix surrounding the osteoblast calcifies, the osteoblast become trapped within it; as a result, it changes in structure and becomes an **osteocyte**, the primary cell of mature bone and the most common type of bone cell. Each osteocyte is located in a space called a **lacuna** and is surrounded by bone tissue. Osteocytes maintain the mineral concentration of the matrix via the secretion of enzymes. Like osteoblasts, osteocytes lack mitotic activity. They can communicate with each other and receive nutrients via long cytoplasmic processes that extend through **canaliculi** (singular = canaliculus), channels within the bone matrix.

If osteoblasts and osteocytes are incapable of mitosis, then how are they replenished when old ones die? The answer lies in the properties of a third category of bone cells—the **osteogenic cell**. These osteogenic cells are undifferentiated with high mitotic activity and they are the only bone cells that divide. Immature osteogenic cells are found in the deep layers of the periosteum and the marrow. They differentiate and develop into osteoblasts.

The dynamic nature of bone means that new tissue is constantly formed, and old, injured, or unnecessary bone is dissolved for repair or for calcium release. The cell responsible for bone resorption, or breakdown, is the **osteoclast**. They are found on bone surfaces, are multinucleated, and originate from monocytes and macrophages, two types of white blood cells, not from osteogenic cells. Osteoclasts are continually breaking down old bone while osteoblasts are continually forming new bone. The ongoing balance between osteoblasts and osteoclasts is responsible for the constant but subtle reshaping of bone. Table 2.6.2 reviews the bone cells, their functions, and locations.

Table 2.6.2

Bone Cells		
Cell type	Function	Location
Osteogenic cells	Develop into osteoblasts	Deep layers of the periosteum and the marrow
Osteoblasts	Bone formation	Growing portions of bone, including periosteum and endosteum
Osteocytes	Maintain mineral concentration of matrix	Entrapped in matrix
Osteoclasts	Bone resorption	Bone surfaces and at sites of old, injured, or unneeded bone

Compact and Spongy Bone

The differences between compact and spongy bone are best explored via their histology. Most bones contain compact and spongy osseous tissue, but their distribution and concentration vary based on the bone's overall function. Compact bone is dense so that it can withstand compressive forces, while spongy (cancellous) bone has open spaces and supports shifts in weight distribution.

Compact Bone

Compact bone is the denser, stronger of the two types of bone tissue (Figure 2.6.6). It can be found under the periosteum and in the diaphyses of long bones, where it provides support and protection.

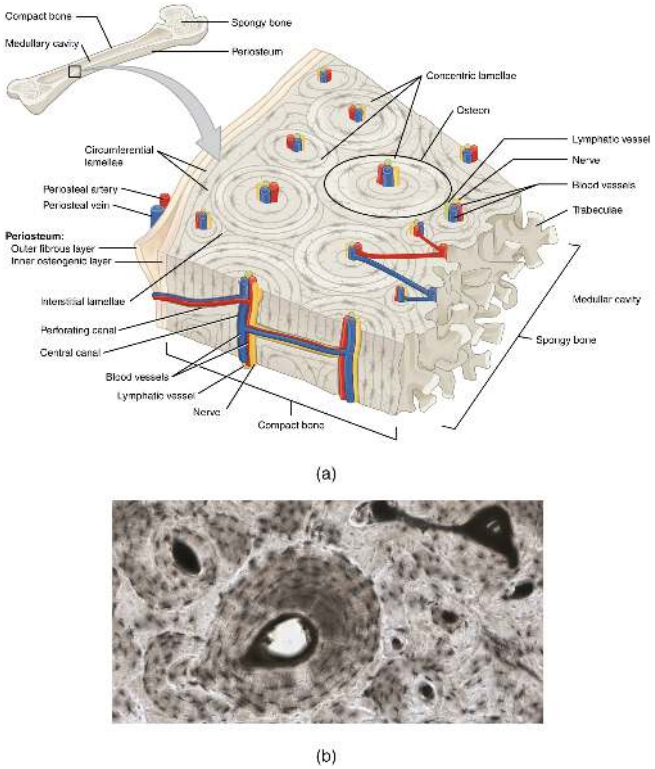


Figure 2.6.6: Diagram of Compact Bone.(a) This cross-sectional view of compact bone shows the basic structural unit, the osteon. (b) In this micrograph of the osteon, you can clearly see the concentric lamellae and central canals. LM × 40. (Micrograph provided by the Regents of University of Michigan Medical School © 2012)

The microscopic structural unit of compact bone is called an **osteon**, or Haversian system. Each osteon is composed of concentric rings of calcified matrix called lamellae (singular = lamella). Running down the center of each osteon is the **central canal**, or Haversian canal, which contains blood vessels, nerves, and lymphatic vessels. These vessels and nerves branch off at right angles through a **perforating canal**, also known as Volkmann's canals, to extend to the periosteum and endosteum.

The osteocytes are located inside spaces called lacunae (singular = lacuna), found at the borders of adjacent lamellae. As described earlier, canaliculi connect with the canaliculi of other lacunae and eventually with the central canal. This system allows nutrients to be transported to the osteocytes and wastes to be removed from them.

Spongy (Cancellous) Bone

Like compact bone, **spongy bone**, also known as cancellous bone, contains osteocytes housed in lacunae, but they are not arranged in concentric circles. Instead, the lacunae and osteocytes are found in a lattice-like network of matrix spikes called **trabeculae** (singular = trabecula) (Figure 2.6.7). The trabeculae may appear to be a random network, but each trabecula forms along lines of stress to provide strength to the bone. The spaces of the trabeculated network provide balance to the dense and heavy compact bone by making bones lighter so that muscles can move them more easily. In addition, the spaces in some spongy bones contain red marrow, protected by the trabeculae, where hematopoiesis occurs.

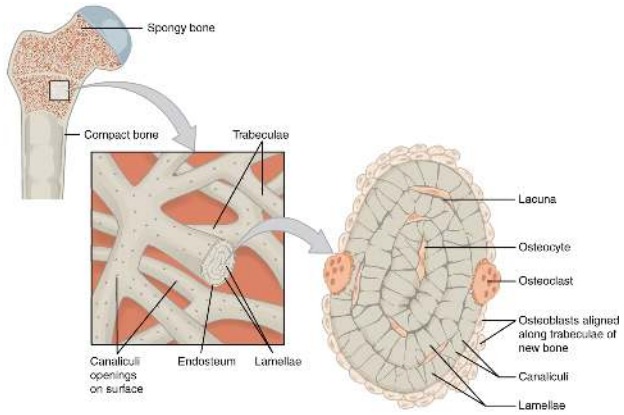


Figure 2.6.7: Diagram of Spongy Bone.Spongy bone is composed of trabeculae that contain the osteocytes. Red marrow fills the spaces in some bones.

AGING AND THE...

Skeletal System: Paget's Disease

Paget's disease usually occurs in adults over age 40. It is a disorder of the bone remodeling process that begins with overactive osteoclasts. This means more bone is resorbed than is laid down. The osteoblasts try to compensate but the new bone they lay down is weak and brittle and therefore prone to fracture.

While some people with Paget's disease have no symptoms, others experience pain, bone fractures, and bone deformities (Figure 2.6.8). Bones of the pelvis, skull, spine, and legs are the most commonly affected. When occurring in the skull, Paget's disease can cause headaches and hearing loss.

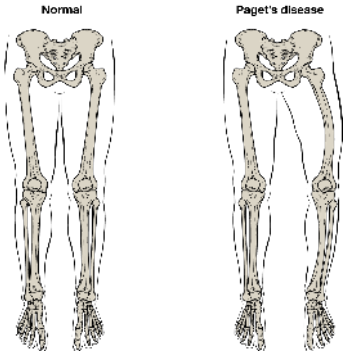


Figure 2.6.8: Paget's Disease.Normal leg bones are relatively straight, but those affected by Paget's disease are porous and curved.

What causes the osteoclasts to become overactive? The answer is still unknown, but hereditary factors seem to play a role. Some scientists believe Paget's disease is due to an as-yet-unidentified virus.

Paget's disease is diagnosed via imaging studies and lab tests. X-rays may show bone deformities or areas of bone resorption. Bone scans are also useful. In these studies, a dye containing a radioactive ion is injected into the body. Areas of bone resorption have an affinity for the ion, so they will light up on the scan if the ions are absorbed. In addition, blood levels of an enzyme called alkaline phosphatase are typically elevated in people with Paget's disease.

Bisphosphonates, drugs that decrease the activity of osteoclasts, are often used in the treatment of Paget's disease. However, in a small percentage of cases, bisphosphonates themselves have been linked to an increased risk of fractures because the old bone that is left after bisphosphonates are administered becomes worn out and brittle. Still, most doctors feel that the benefits of bisphosphonates more than outweigh the risk; the medical professional has to weigh the benefits and risks on a case-by-case basis. Bisphosphonate treatment can reduce the overall risk of deformities or fractures, which in turn reduces the risk of surgical repair and its associated risks and complications.

Blood and Nerve Supply

The spongy bone and medullary cavity receive nourishment from arteries that pass through the compact bone. The arteries enter through the **nutrient foramen** (plural = foramina), small openings in the diaphysis (Figure 2.6.9). The osteocytes in spongy bone are nourished by blood vessels of the periosteum that penetrate spongy bone and blood that circulates in the marrow cavities. As the blood passes through the marrow cavities, it is collected by veins, which then pass out of the bone through the foramina.

In addition to the blood vessels, nerves follow the same paths into the bone where they tend to concentrate in the more metabolically active regions of the bone. The nerves sense pain, and it appears the nerves also play roles in regulating blood supplies and in bone growth, hence their concentrations in metabolically active sites of the bone.

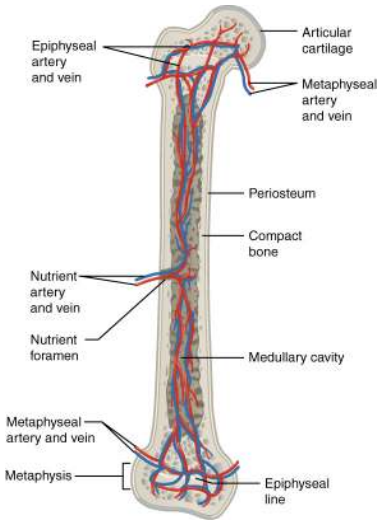
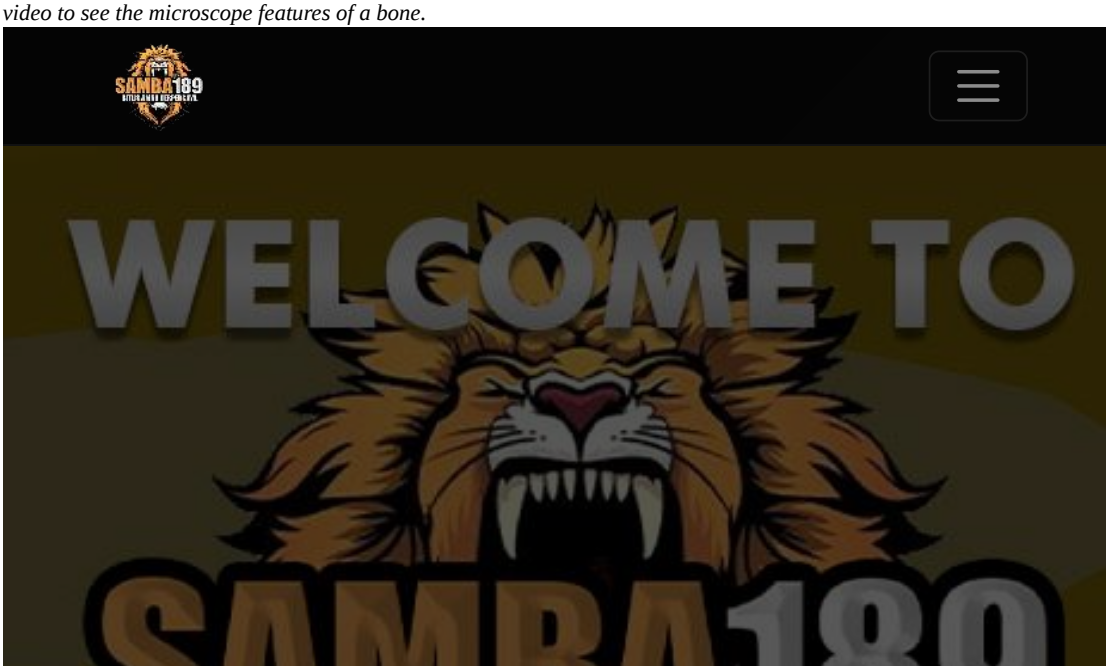


Figure 2.6.9: Diagram of Blood and Nerve Supply to Bone.Blood vessels and nerves enter the bone through the nutrient foramen.

QR Code representing a URL

Watch this video to see the microscope features of a bone.



Chapter Review

A hollow medullary cavity filled with yellow marrow runs the length of the diaphysis of a long bone. The walls of the diaphysis are compact bone. The epiphyses, which are wider sections at each end of a long bone, are filled with spongy bone and red marrow. The epiphyseal plate, a layer of hyaline cartilage, is replaced by osseous tissue as the organ grows in length. The medullary cavity has a delicate membranous lining called the endosteum. The outer surface of bone, except in regions covered with articular cartilage, is covered with a fibrous membrane called the periosteum. Flat bones consist of two layers of compact bone surrounding a layer of spongy bone. Bone markings depend on the function and location of bones. Articulations are places where two bones meet. Projections stick out from the surface of the bone and provide attachment points for tendons and ligaments. Holes are openings or depressions in the bones.

Bone matrix consists of collagen fibers and organic ground substance, primarily hydroxyapatite formed from calcium salts. Osteogenic cells develop into osteoblasts. Osteoblasts are cells that make new bone. They become osteocytes, the cells of mature bone, when they get trapped in the matrix. Osteoclasts engage in bone resorption. Compact bone is dense and composed of osteons, while spongy bone is less dense and made up of trabeculae. Blood vessels and nerves enter the bone through the nutrient foramina to nourish and innervate bones.

Review Questions

Q. Which of the following occurs in the spongy bone of the epiphysis?

A. bone growth

B. bone remodeling

C. hematopoiesis

D. shock absorption

Answer: C

Q. The diaphysis contains _____.

A. the metaphysis

B. fat stores

C. spongy bone

D. compact bone

Answer: B

Q. The fibrous membrane covering the outer surface of the bone is the _____.

A. periosteum

B. epiphysis

C. endosteum

D. diaphysis

Answer: A

Q. Which of the following are incapable of undergoing mitosis?

A. osteoblasts and osteoclasts

B. osteocytes and osteoclasts

C. osteoblasts and osteocytes

D. osteogenic cells and osteoclasts

Answer: C

Q. Which cells do not originate from osteogenic cells?

A. osteoblasts

B. osteoclasts

C. osteocytes

D. osteoprogenitor cells

Answer: D

Q. Which of the following are found in compact bone and cancellous bone?

A. Haversian systems

B. Haversian canals

C. lamellae

D. lacunae

Answer: C

Q. Which of the following are *only* found in cancellous bone?

A. canaliculi

B. Volkmann’s canals

C. trabeculae

D. calcium salts

> Answer: C

Q. The area of a bone where the nutrient foramen passes forms what kind of bone marking?

A. a hole

B. a facet

C. a canal

D. a fissure

> Answer: A

Critical Thinking Questions

Q. If the articular cartilage at the end of one of your long bones were to degenerate, what symptoms do you think you would experience? Why?

> A. If the articular cartilage at the end of one of your long bones were to deteriorate, which is actually what happens in osteoarthritis, you would experience joint pain at the end of that bone and limitation of motion at that joint because there would be no cartilage to reduce friction between adjacent bones and there would be no cartilage to act as a shock absorber.

Q. In what ways is the structural makeup of compact and spongy bone well suited to their respective functions?

> A. The densely packed concentric rings of matrix in compact bone are ideal for resisting compressive forces, which is the function of compact bone. The open spaces of the trabeculated network of spongy bone allow spongy bone to support shifts in weight distribution, which is the function of spongy bone.

Glossary

articular cartilage
thin layer of cartilage covering an epiphysis; reduces friction and acts as a shock absorber

articulation
where two bone surfaces meet

canaliculi
(singular = canaliculus) channels within the bone matrix that house one of an osteocyte’s many cytoplasmic extensions that it uses to communicate and receive nutrients

central canal
longitudinal channel in the center of each osteon; contains blood vessels, nerves, and lymphatic vessels; also known as the Haversian canal

compact bone
dense osseous tissue that can withstand compressive forces

diaphysis
tubular shaft that runs between the proximal and distal ends of a long bone

diploë
layer of spongy bone, that is sandwiched between two the layers of compact bone found in flat bones

endosteum
delicate membranous lining of a bone’s medullary cavity

epiphyseal plate
(also, growth plate) sheet of hyaline cartilage in the metaphysis of an immature bone; replaced by bone tissue as the organ grows in length

epiphysis
wide section at each end of a long bone; filled with spongy bone and red marrow

hole
opening or depression in a bone

lacunae
(singular = lacuna) spaces in a bone that house an osteocyte

medullary cavity
hollow region of the diaphysis; filled with yellow marrow

nutrient foramen
small opening in the middle of the external surface of the diaphysis, through which an artery enters the bone to provide nourishment

osteoblast
cell responsible for forming new bone

osteoclast
cell responsible for resorbing bone

osteocyte
primary cell in mature bone; responsible for maintaining the matrix

osteogenic cell
undifferentiated cell with high mitotic activity; the only bone cells that divide; they differentiate and develop into osteoblasts

osteon
(also, Haversian system) basic structural unit of compact bone; made of concentric layers of calcified matrix

perforating canal
(also, Volkmann's canal) channel that branches off from the central canal and houses vessels and nerves that extend to the periosteum and endosteum

periosteum
fibrous membrane covering the outer surface of bone and continuous with ligaments

projection
bone markings where part of the surface sticks out above the rest of the surface, where tendons and ligaments attach

spongy bone
(also, cancellous bone) trabeculated osseous tissue that supports shifts in weight distribution

trabeculae
(singular = trabecula) spikes or sections of the lattice-like matrix in spongy bone

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SECTION OVERVIEW

2.7: Cartilage

2.7A: Structure, Type, and Location of Cartilage

2.7B: Cartilage Growth

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2.7A: Structure, Type, and Location of Cartilage

Cartilage is an avascular, flexible connective tissue located throughout the body that provides support and cushioning for adjacent tissues.

LEARNING OBJECTIVE

Differentiate among the types of cartilage

Key Takeaways

Key Points

- Cartilage is a flexible connective tissue that differs from bone in several ways; it is avascular and its microarchitecture is less organized than bone.
- Cartilage is not innervated and therefore relies on diffusion to obtain nutrients. This causes it to heal very slowly.
- The main cell types in cartilage are chondrocytes, the ground substance is chondroitin sulfate, and the fibrous sheath is called perichondrium.
- There are three types of cartilage: hyaline, fibrous, and elastic cartilage.
- Hyaline cartilage is the most widespread type and resembles glass. In the embryo, bone begins as hyaline cartilage and later ossifies.
- Fibrous cartilage has many collagen fibers and is found in the intervertebral discs and pubic symphysis.
- Elastic cartilage is springy, yellow, and elastic and is found in the internal support of the external ear and in the epiglottis.

Key Terms

chondroitin sulfate: An important structural component of cartilage that provides much of its resistance to compression.

connective tissue: A type of tissue found in animals whose main function is to bind other tissue systems (such as muscle to skin) or organs. It consists of the following three elements: cells, fibers, and a ground substance (or extracellular matrix).

hyaline cartilage: A type of cartilage found on many joint surfaces; it contains no nerves or blood vessels, and its structure is relatively simple.

temporal mandibular joint: A joint of the jaw that connects it to the temporal bones of the skull.

Chondrocytes: Cells that form and maintain the cartilage.

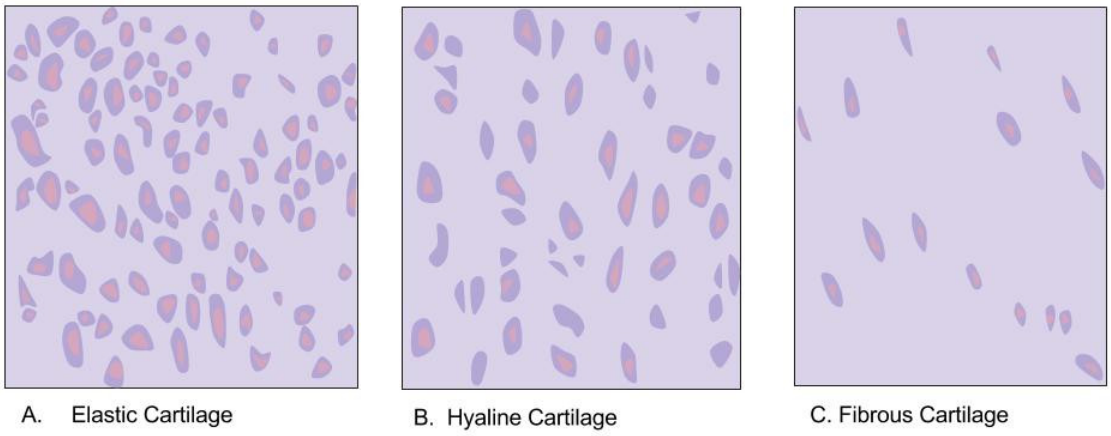
What is Cartilage?

Cartilage is a flexible connective tissue that differs from bone in several ways. For one, the primary cell types are chondrocytes as opposed to osteocytes. Chondrocytes are first chondroblast cells that produce the collagen extracellular matrix (ECM) and then get caught in the matrix. They lie in spaces called lacunae with up to eight chondrocytes located in each.

Chondrocytes rely on diffusion to obtain nutrients as, unlike bone, cartilage is avascular, meaning there are no vessels to carry blood to cartilage tissue. This lack of blood supply causes cartilage to heal very slowly compared with bone.

The base substance of cartilage is chondroitin sulfate, and the microarchitecture is substantially less organized than in bone. The cartilage fibrous sheath is called the perichondrium. The division of cells within cartilage occurs very slowly, and thus growth in cartilage is usually not based on an increase in size or mass of the cartilage itself.

Articular cartilage function is dependent on the molecular composition of its ECM, which consists mainly of proteoglycans and collagens. The remodeling of cartilage is predominantly affected by changes and rearrangements of the collagen matrix, which responds to tensile and compressive forces experienced by the cartilage.



Cartilage types: Images of microscopic views of the different types of cartilage: elastic, hyaline, and fibrous. Elastic cartilage has the most ECM; hyaline a middle amount; and fibrous cartilage has the least amount of ECM.

Types of Cartilage

There are three major types of cartilage: hyaline cartilage, fibrocartilage, and elastic cartilage.

Hyaline Cartilage

Hyaline cartilage is the most widespread cartilage type and, in adults, it forms the articular surfaces of long bones, the rib tips, the rings of the trachea, and parts of the skull. This type of cartilage is predominately collagen (yet with few collagen fibers), and its name refers to its glassy appearance.

In the embryo, bones form first as hyaline cartilage before ossifying as development progresses. Hyaline cartilage is covered externally by a fibrous membrane, called the perichondrium, except at the articular ends of bones; it also occurs under the skin (for instance, ears and nose).

Hyaline cartilage is found on many joint surfaces. It contains no nerves or blood vessels, and its structure is relatively simple.

If a thin slice of cartilage is examined under the microscope, it will be found to consist of cells of a rounded or bluntly angular form, lying in groups of two or more in a granular or almost homogeneous matrix. These cells have generally straight outlines where they are in contact with each other, with the rest of their circumference rounded.

They consist of translucent protoplasm in which fine interlacing filaments and minute granules are sometimes present. Embedded in this are one or two round nuclei with the usual intranuclear network.

Fibrocartilage

Fibrous cartilage has lots of collagen fibers (Type I and Type II), and it tends to grade into dense tendon and ligament tissue. White fibrocartilage consists of a mixture of white fibrous tissue and cartilaginous tissue in various proportions.

It owes its flexibility and toughness to the fibrous tissue, and its elasticity to the cartilaginous tissue. It is the only type of cartilage that contains type I collagen in addition to the normal type II.

Fibrocartilage is found in the pubic symphysis, the annulus fibrosus of intervertebral discs, menisci, and the temporal mandibular joint.

Elastic Cartilage

Elastic or yellow cartilage contains elastic fiber networks and collagen fibers. The principal protein is elastin.

Elastic cartilage is histologically similar to hyaline cartilage but contains many yellow elastic fibers lying in a solid matrix. These fibers form bundles that appear dark under a microscope. They give elastic cartilage great flexibility so it can withstand repeated bending.

Chondrocytes lie between the fibers. Elastic cartilage is found in the epiglottis (part of the larynx) and the pinnae (the external ear flaps of many mammals, including humans).

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2.7B: Cartilage Growth

Chondrification is the process by which cartilage is formed from condensed mesenchyme tissue.

LEARNING OBJECTIVE

Describe cartilage growth and repair

Key Takeaways

Key Points

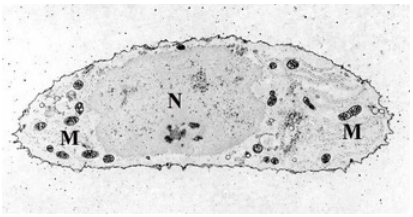
- The division of cells within cartilage occurs very slowly.
- Articular cartilage function is dependent on the molecular composition of its extracellular matrix (ECM).
- The remodeling of cartilage is predominantly affected by changes and rearrangements of the collagen matrix in response to forces experienced by the cartilage.
- Cartilage growth mainly refers to matrix deposition, but can include both growth and remodeling of the extracellular matrix.

Key Terms

- **collagen matrix**: The most abundant protein in the human body and accounts for 90% of bone matrix protein content.
- **mesenchyme**: Undifferentiated cells of the early embryo are able to develop into the different tisue types, including bone and cartilage.
- **chondrocyte**: A cell that makes up the tissue of cartilage.
- **chondrification**: The process by which cartilage is formed from condensed mesenchyme tissue.

Formation

Chondrification (also known as chondrogenesis) is the process by which cartilage is formed from condensed mesenchyme tissue.



A chondrocyte: A chondrocyte, stained for calcium, showing its nucleus (N) and mitochondria (M).

Mesenchyme tissue differentiates into chondroblasts and begins secreting the molecules that form the extracellular matrix (ECM). Mesenchymal stem cells (MSCs) are undifferentiated, meaning they can give rise to different cell types. Under the appropriate conditions and at sites of cartilage formation, they are referred to as chondrogenic cells.

During cartilage formation, undifferentiated MSCs are highly proliferative and form dense aggregates of chondrogenic cells at the center of chondrification. These condrogenic cells then differentiate to chondroblasts, which will then synthesize the cartilage ECM.



Cartilage: Hyaline cartilage showing chondrocytes and organelles, lacunae and matrix.

The extracellular matrix consists of ground substance (proteoglycans and glycosaminoglycans) and associated fibers, such as collagen. The chondroblasts then trap themselves in lacunae, small spaces that are no longer in contact with the newly created matrix and contain extracellular fluid. The chondroblast is now a chondrocyte, which is usually inactive but can still secrete and degrade the matrix depending on the conditions.

Growth

The majority of body cartilage is synthesized from chondroblasts that are largely inactive at later developmental stages compared to earlier years (pre-pubescence). The division of cells within cartilage occurs very slowly.

Therefore, growth in cartilage is usually not based on an increase in size or mass of the cartilage itself. Remodeling of cartilage is predominantly affected by changes and rearrangements of the collagen matrix, which responds to tensile and compressive forces experienced by the cartilage. Cartilage growth thus mainly refers to matrix deposition, but can include both growth and remodeling of the ECM.

Early in fetal development, the greater part of the skeleton is cartilaginous. This temporary cartilage is gradually replaced by bone (endochondral ossification), a process that ends at puberty. In contrast, the cartilage in the joints remains permanently unossified during life.

Repair

Once damaged, cartilage has limited repair capabilities because chondrocytes are bound in lacunae and cannot migrate to damaged areas. Also, because cartilage does not have a blood supply, the deposition of new matrix is slow.

Damaged hyaline cartilage is usually replaced by fibrocartilage scar tissue. Over the last few years, surgeons and scientists have elaborated a series of cartilage repair procedures that help to postpone the need for joint replacement.

These include marrow stimulation techniques, including surgeries, stem cell injections, and grafting of cartilage into damaged areas.

However, due to the extremely slow growth of cartilage and its avascular properties, regeneration and growth of cartilage post-injury is still very slow.

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SECTION OVERVIEW

2.8: Joints

2.8A: Classification of Joints

2.8B: Fibrous Joints

2.8C: Cartilaginous Joints

2.8D: Synovial Joints

2.8E: Types of Body Movements

2.8F: Anatomy of Selected Synovial Joints

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2.8A: Classification of Joints

Learning Objectives

- Distinguish between the functional and structural classifications for joints
- Describe the three functional types of joints and give an example of each
- List the three types of diarthrodial joints

A **joint**, also called an **articulation**, is any place where adjacent bones or bone and cartilage come together (articulate with each other) to form a connection. Joints are classified both structurally and functionally. Structural classifications of joints take into account whether the adjacent bones are strongly anchored to each other by fibrous connective tissue or cartilage, or whether the adjacent bones articulate with each other within a fluid-filled space called a **joint cavity**. Functional classifications describe the degree of movement available between the bones, ranging from immobile, to slightly mobile, to freely moveable joints. The amount of movement available at a particular joint of the body is related to the functional requirements for that joint. Thus immobile or slightly moveable joints serve to protect internal organs, give stability to the body, and allow for limited body movement. In contrast, freely moveable joints allow for much more extensive movements of the body and limbs.

Structural Classification of Joints

The structural classification of joints is based on whether the articulating surfaces of the adjacent bones are directly connected by fibrous connective tissue or cartilage, or whether the articulating surfaces contact each other within a fluid-filled joint cavity. These differences serve to divide the joints of the body into three structural classifications. A **fibrous joint** is where the adjacent bones are united by fibrous connective tissue. At a **cartilaginous joint**, the bones are joined by hyaline cartilage or fibrocartilage. At a synovial joint, the articulating surfaces of the bones are not directly connected, but instead come into contact with each other within a joint cavity that is filled with a lubricating fluid. **Synovial joints** allow for free movement between the bones and are the most common joints of the body.

Functional Classification of Joints

The functional classification of joints is determined by the amount of mobility found between the adjacent bones. Joints are thus functionally classified as a synarthrosis or immobile joint, an amphiarthrosis or slightly moveable joint, or as a diarthrosis, which is a freely moveable joint (arthroun = “to fasten by a joint”). Depending on their location, fibrous joints may be functionally classified as a synarthrosis (immobile joint) or an amphiarthrosis (slightly mobile joint). Cartilaginous joints are also functionally classified as either a synarthrosis or an amphiarthrosis joint. All synovial joints are functionally classified as a diarthrosis joint.

Synarthrosis

An immobile or nearly immobile joint is called a **synarthrosis**. The immobile nature of these joints provide for a strong union between the articulating bones. This is important at locations where the bones provide protection for internal organs. Examples include sutures, the fibrous joints between the bones of the skull that surround and protect the brain (Figure 2.8A.1), and the manubriosternal joint, the cartilaginous joint that unites the manubrium and body of the sternum for protection of the heart.

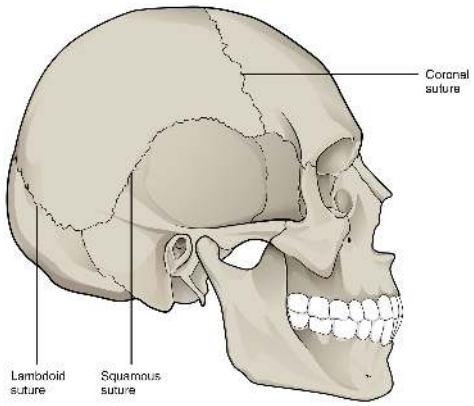


Figure 2.8A.1: Suture Joints of Skull. The suture joints of the skull are an example of a synarthrosis, an immobile or essentially immobile joint.

Amphiarthrosis

An **amphiarthrosis** is a joint that has limited mobility. An example of this type of joint is the cartilaginous joint that unites the bodies of adjacent vertebrae. Filling the gap between the vertebrae is a thick pad of fibrocartilage called an intervertebral disc (Figure 2.8A.2). Each intervertebral disc strongly unites the vertebrae but still allows for a limited amount of movement between them. However, the small movements available between adjacent vertebrae can sum together along the length of the vertebral column to provide for large ranges of body movements.

Another example of an amphiarthrosis is the pubic symphysis of the pelvis. This is a cartilaginous joint in which the pubic regions of the right and left hip bones are strongly anchored to each other by fibrocartilage. This joint normally has very little mobility. The strength of the pubic symphysis is important in conferring weight-bearing stability to the pelvis.

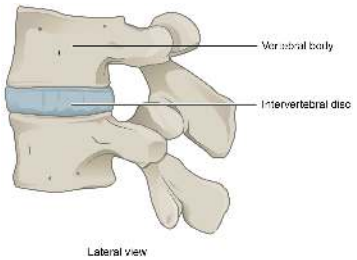


Figure 2.8A.2: Intervertebral Disc. An intervertebral disc unites the bodies of adjacent vertebrae within the vertebral column. Each disc allows for limited movement between the vertebrae and thus functionally forms an amphiarthrosis type of joint. Intervertebral discs are made of fibrocartilage and thereby structurally form a symphysis type of cartilaginous joint.

Diarthrosis

A freely mobile joint is classified as a **diarthrosis**. These types of joints include all synovial joints of the body, which provide the majority of body movements. Most diarthrotic joints are found in the appendicular skeleton and thus give the limbs a wide range of motion. These joints are divided into three categories, based on the number of axes of motion provided by each. An axis in anatomy is described as the movements in reference to the three anatomical planes: transverse, frontal, and sagittal. Thus, diarthroses are classified as uniaxial (for movement in one plane), biaxial (for movement in two planes), or multiaxial joints (for movement in all three anatomical planes).

A **uniaxial joint** only allows for a motion in a single plane (around a single axis). The elbow joint, which only allows for bending or straightening, is an example of a uniaxial joint. A **biaxial joint** allows for motions within two planes. An example of a biaxial joint is a metacarpophalangeal joint (knuckle joint) of the hand. The joint allows for movement along one axis to produce bending or straightening of the finger, and movement along a second axis, which allows for spreading of the fingers away from each other and bringing them together. A joint that allows for the several directions of movement is called a **multiaxial joint** (polyaxial or triaxial joint). This type of diarthrotic joint allows for movement along three axes (Figure 2.8A.3). The shoulder and hip joints are multiaxial joints. They allow the upper or lower limb to move in an anterior-posterior direction and a medial-lateral direction. In addition, the limb can also be rotated around its long axis. This third movement results in rotation of the limb so that its anterior surface is moved either toward or away from the midline of the body.

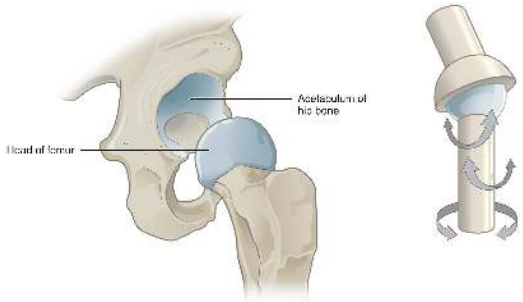


Figure 2.8A.3: Multiaxial Joint. A multiaxial joint, such as the hip joint, allows for three types of movement: anterior-posterior, medial-lateral, and rotational.

Chapter Review

Structural classifications of the body joints are based on how the bones are held together and articulate with each other. At fibrous joints, the adjacent bones are directly united to each other by fibrous connective tissue. Similarly, at a cartilaginous joint, the

adjacent bones are united by cartilage. In contrast, at a synovial joint, the articulating bone surfaces are not directly united to each other, but come together within a fluid-filled joint cavity.

The functional classification of body joints is based on the degree of movement found at each joint. A synarthrosis is a joint that is essentially immobile. This type of joint provides for a strong connection between the adjacent bones, which serves to protect internal structures such as the brain or heart. Examples include the fibrous joints of the skull sutures and the cartilaginous manubriosternal joint. A joint that allows for limited movement is an amphiarthrosis. An example is the pubic symphysis of the pelvis, the cartilaginous joint that strongly unites the right and left hip bones of the pelvis. The cartilaginous joints in which vertebrae are united by intervertebral discs provide for small movements between the adjacent vertebrae and are also an amphiarthrosis type of joint. Thus, based on their movement ability, both fibrous and cartilaginous joints are functionally classified as a synarthrosis or amphiarthrosis.

The most common type of joint is the diarthrosis, which is a freely moveable joint. All synovial joints are functionally classified as diarthroses. A uniaxial diarthrosis, such as the elbow, is a joint that only allows for movement within a single anatomical plane. Joints that allow for movements in two planes are biaxial joints, such as the metacarpophalangeal joints of the fingers. A multiaxial joint, such as the shoulder or hip joint, allows for three planes of motions.

Review Questions

Q. The joint between adjacent vertebrae that includes an invertebral disc is classified as which type of joint?

A. diarthrosis

B. multiaxial

C. amphiarthrosis

D. synarthrosis

Answer: C

Q. Which of these joints is classified as a synarthrosis?

A. the pubic symphysis

B. the manubriosternal joint

C. an invertebral disc

D. the shoulder joint

Answer: B

Q. Which of these joints is classified as a biaxial diarthrosis?

A. the metacarpophalangeal joint

B. the hip joint

C. the elbow joint

D. the pubic symphysis

Answer: A

Q. Synovial joints _____.

A. may be functionally classified as a synarthrosis

B. are joints where the bones are connected to each other by hyaline cartilage

C. may be functionally classified as a amphiarthrosis

D. are joints where the bones articulate with each other within a fluid-filled joint cavity

Answer: D

Critical Thinking Questions

Q. Define how joints are classified based on function. Describe and give an example for each functional type of joint.

A. Functional classification of joints is based on the degree of mobility exhibited by the joint. A synarthrosis is an immobile or nearly immobile joint. An example is the manubriosternal joint or the joints between the skull bones surrounding the brain. An amphiarthrosis is a slightly moveable joint, such as the pubic symphysis or an intervertebral cartilaginous joint. A diarthrosis is a freely moveable joint. These are subdivided into three categories. A uniaxial diarthrosis allows movement within a single anatomical plane or axis of motion. The elbow joint is an example. A biaxial diarthrosis, such as the metacarpophalangeal joint, allows for movement along two planes or axes. The hip and shoulder joints are examples of a multiaxial diarthrosis. These allow movements along three planes or axes.

Q. Explain the reasons for why joints differ in their degree of mobility.

A. The functional needs of joints vary and thus joints differ in their degree of mobility. A synarthrosis, which is an immobile joint, serves to strongly connect bones thus protecting internal organs such as the heart or brain. A slightly moveable amphiarthrosis provides for small movements, which in the vertebral column can add together to yield a much larger overall movement. The freedom of movement provided by a diarthrosis can allow for large movements, such as is seen with most joints of the limbs.

Glossary

amphiarthrosis
slightly mobile joint

articulation
joint of the body

biaxial joint
type of diarthrosis; a joint that allows for movements within two planes (two axes)

cartilaginous joint
joint at which the bones are united by hyaline cartilage (synchondrosis) or fibrocartilage (symphysis)

diarthrosis
freely mobile joint

fibrous joint
joint where the articulating areas of the adjacent bones are connected by fibrous connective tissue

joint
site at which two or more bones or bone and cartilage come together (articulate)

joint cavity
space enclosed by the articular capsule of a synovial joint that is filled with synovial fluid and contains the articulating surfaces of the adjacent bones

multiaxial joint
type of diarthrosis; a joint that allows for movements within three planes (three axes)

synarthrosis
immobile or nearly immobile joint

synovial joint
joint at which the articulating surfaces of the bones are located within a joint cavity formed by an articular capsule

uniaxial joint

type of diarthrosis; joint that allows for motion within only one plane (one axis)

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2.8B: Fibrous Joints

Learning Objectives

- Describe the structural features of fibrous joints
- Distinguish between a suture, syndesmosis, and gomphosis
- Give an example of each type of fibrous joint

At a fibrous joint, the adjacent bones are directly connected to each other by fibrous connective tissue, and thus the bones do not have a joint cavity between them (Figure 2.8B.1). The gap between the bones may be narrow or wide. There are three types of fibrous joints. A suture is the narrow fibrous joint found between most bones of the skull. At a syndesmosis joint, the bones are more widely separated but are held together by a narrow band of fibrous connective tissue called a **ligament** or a wide sheet of connective tissue called an interosseous membrane. This type of fibrous joint is found between the shaft regions of the long bones in the forearm and in the leg. Lastly, a gomphosis is the narrow fibrous joint between the roots of a tooth and the bony socket in the jaw into which the tooth fits.

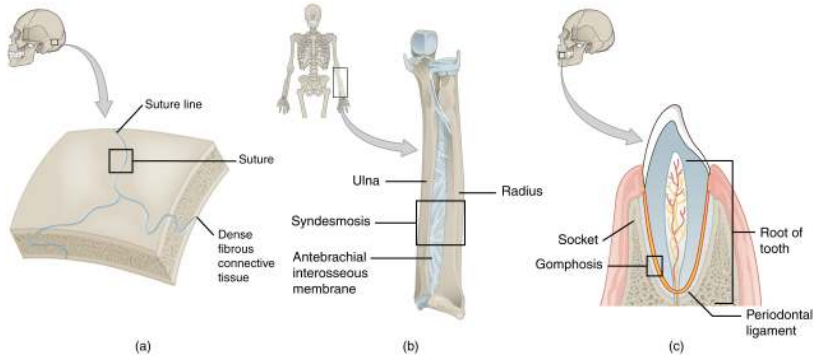


Figure 2.8B.1: Fibrous Joints. Fibrous joints form strong connections between bones. (a) Sutures join most bones of the skull. (b) An interosseous membrane forms a syndesmosis between the radius and ulna bones of the forearm. (c) A gomphosis is a specialized fibrous joint that anchors a tooth to its socket in the jaw.

Suture

All the bones of the skull, except for the mandible, are joined to each other by a fibrous joint called a **suture**. The fibrous connective tissue found at a suture ("to bind or sew") strongly unites the adjacent skull bones and thus helps to protect the brain and form the face. In adults, the skull bones are closely opposed and fibrous connective tissue fills the narrow gap between the bones. The suture is frequently convoluted, forming a tight union that prevents most movement between the bones. (See Figure 2.8B.1.a) Thus, skull sutures are functionally classified as a synarthrosis, although some sutures may allow for slight movements between the cranial bones.

In newborns and infants, the areas of connective tissue between the bones are much wider, especially in those areas on the top and sides of the skull that will become the sagittal, coronal, squamous, and lambdoid sutures. These broad areas of connective tissue are called **fontanelles** (Figure 2.8B.2). During birth, the fontanelles provide flexibility to the skull, allowing the bones to push closer together or to overlap slightly, thus aiding movement of the infant's head through the birth canal. After birth, these expanded regions of connective tissue allow for rapid growth of the skull and enlargement of the brain. The fontanelles greatly decrease in width during the first year after birth as the skull bones enlarge. When the connective tissue between the adjacent bones is reduced to a narrow layer, these fibrous joints are now called sutures. At some sutures, the connective tissue will ossify and be converted into bone, causing the adjacent bones to fuse to each other. This fusion between bones is called a **synostosis** ("joined by bone"). Examples of synostosis fusions between cranial bones are found both early and late in life. At the time of birth, the frontal and maxillary bones consist of right and left halves joined together by sutures, which disappear by the eighth year as the halves fuse together to form a single bone. Late in life, the sagittal, coronal, and lambdoid sutures of the skull will begin to ossify and fuse, causing the suture line to gradually disappear.

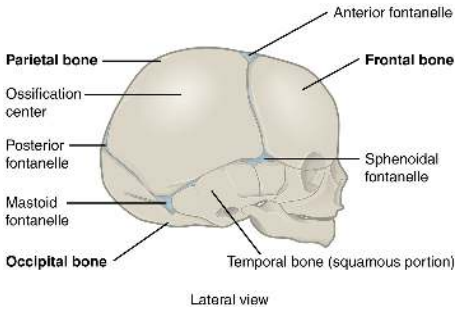


Figure 2.8B.2: The Newborn Skull. The fontanelles of a newborn's skull are broad areas of fibrous connective tissue that form fibrous joints between the bones of the skull.

Syndesmosis

A **syndesmosis** ("fastened with a band") is a type of fibrous joint in which two parallel bones are united to each other by fibrous connective tissue. The gap between the bones may be narrow, with the bones joined by ligaments, or the gap may be wide and filled in by a broad sheet of connective tissue called an **interosseous membrane**.

In the forearm, the wide gap between the shaft portions of the radius and ulna bones are strongly united by an interosseous membrane (see Figure9.2.1.b). Similarly, in the leg, the shafts of the tibia and fibula are also united by an interosseous membrane. In addition, at the distal tibiofibular joint, the articulating surfaces of the bones lack cartilage and the narrow gap between the bones is anchored by fibrous connective tissue and ligaments on both the anterior and posterior aspects of the joint. Together, the interosseous membrane and these ligaments form the tibiofibular syndesmosis.

The syndesmoses found in the forearm and leg serve to unite parallel bones and prevent their separation. However, a syndesmosis does not prevent all movement between the bones, and thus this type of fibrous joint is functionally classified as an amphiarthrosis. In the leg, the syndesmosis between the tibia and fibula strongly unites the bones, allows for little movement, and firmly locks the talus bone in place between the tibia and fibula at the ankle joint. This provides strength and stability to the leg and ankle, which are important during weight bearing. In the forearm, the interosseous membrane is flexible enough to allow for rotation of the radius bone during forearm movements. Thus in contrast to the stability provided by the tibiofibular syndesmosis, the flexibility of the antebrachial interosseous membrane allows for the much greater mobility of the forearm.

The interosseous membranes of the leg and forearm also provide areas for muscle attachment. Damage to a syndesmotic joint, which usually results from a fracture of the bone with an accompanying tear of the interosseous membrane, will produce pain, loss of stability of the bones, and may damage the muscles attached to the interosseous membrane. If the fracture site is not properly immobilized with a cast or splint, contractile activity by these muscles can cause improper alignment of the broken bones during healing.

Gomphosis

A **gomphosis** ("fastened with bolts") is the specialized fibrous joint that anchors the root of a tooth into its bony socket within the maxillary bone (upper jaw) or mandible bone (lower jaw) of the skull. A gomphosis is also known as a peg-and-socket joint. Spanning between the bony walls of the socket and the root of the tooth are numerous short bands of dense connective tissue, each of which is called a **periodontal ligament** (see Figure9.2.1.c). Due to the immobility of a gomphosis, this type of joint is functionally classified as a synarthrosis.

Chapter Review

Fibrous joints are where adjacent bones are strongly united by fibrous connective tissue. The gap filled by connective tissue may be narrow or wide. The three types of fibrous joints are sutures, gomphoses, and syndesmoses. A suture is the narrow fibrous joint that unites most bones of the skull. At a gomphosis, the root of a tooth is anchored across a narrow gap by periodontal ligaments to the walls of its socket in the bony jaw. A syndesmosis is the type of fibrous joint found between parallel bones. The gap between the bones may be wide and filled with a fibrous interosseous membrane, or it may narrow with ligaments spanning between the bones. Syndesmoses are found between the bones of the forearm (radius and ulna) and the leg (tibia and fibula). Fibrous joints strongly unite adjacent bones and thus serve to provide protection for internal organs, strength to body regions, or weight-bearing stability.

Review Questions

Q. Which type of fibrous joint connects the tibia and fibula?

A. syndesmosis

B. symphysis

C. suture

D. gomphosis

Answer: A

Q. An example of a wide fibrous joint is _____.

A. the interosseous membrane of the forearm

B. a gomphosis

C. a suture joint

D. a synostosis

Answer: A

Q. A gomphosis _____.

A. is formed by an interosseous membrane

B. connects the tibia and fibula bones of the leg

C . contains a joint cavity

D. anchors a tooth to the jaw

Answer: D

Q. A syndesmosis is _____.

A. a narrow fibrous joint

B. the type of joint that unites bones of the skull

C. a fibrous joint that unites parallel bones

D. the type of joint that anchors the teeth in the jaws

Answer: C

Critical Thinking Questions

Q. Distinguish between a narrow and wide fibrous joint and give an example of each.

A. Narrow fibrous joints are found at a suture, gomphosis, or syndesmosis. A suture is the fibrous joint that joins the bones of the skull to each other (except the mandible). A gomphosis is the fibrous joint that anchors each tooth to its bony socket within the upper or lower jaw. The tooth is connected to the bony jaw by periodontal ligaments. A narrow syndesmosis is found at the distal tibiofibular joint where the bones are united by fibrous connective tissue and ligaments. A syndesmosis can also form a wide fibrous joint where the shafts of two parallel bones are connected by a broad interosseous membrane. The radius and ulna bones of the forearm and the tibia and fibula bones of the leg are united by interosseous membranes.

Q. The periodontal ligaments are made of collagen fibers and are responsible for connecting the roots of the teeth to the jaws. Describe how scurvy, a disease that inhibits collagen production, can affect the teeth.

A. The teeth are anchored into their sockets within the bony jaws by the periodontal ligaments. This is a gomphosis type of fibrous joint. In scurvy, collagen production is inhibited and the periodontal ligaments become weak. This will cause the teeth to become loose or even to fall out.

Glossary

fontanelles
expanded areas of fibrous connective tissue that separate the braincase bones of the skull prior to birth and during the first year after birth

gomphosis
type of fibrous joint in which the root of a tooth is anchored into its bony jaw socket by strong periodontal ligaments

interosseous membrane
wide sheet of fibrous connective tissue that fills the gap between two parallel bones, forming a syndesmosis; found between the radius and ulna of the forearm and between the tibia and fibula of the leg

ligament
strong band of dense connective tissue spanning between bones

periodontal ligament
band of dense connective tissue that anchors the root of a tooth into the bony jaw socket

suture
fibrous joint that connects the bones of the skull (except the mandible); an immobile joint (synarthrosis)

syndesmosis
type of fibrous joint in which two separated, parallel bones are connected by an interosseous membrane

synostosis
site at which adjacent bones or bony components have fused together

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2.8C: Cartilaginous Joints

Learning Objectives

- Describe the structural features of cartilaginous joints
- Distinguish between a synchondrosis and symphysis
- Give an example of each type of cartilaginous joint

As the name indicates, at a cartilaginous joint, the adjacent bones are united by cartilage, a tough but flexible type of connective tissue. These types of joints lack a joint cavity and involve bones that are joined together by either hyaline cartilage or fibrocartilage (Figure 2.8C.1). There are two types of cartilaginous joints. A synchondrosis is a cartilaginous joint where the bones are joined by hyaline cartilage. Also classified as a synchondrosis are places where bone is united to a cartilage structure, such as between the anterior end of a rib and the costal cartilage of the thoracic cage. The second type of cartilaginous joint is a symphysis, where the bones are joined by fibrocartilage.

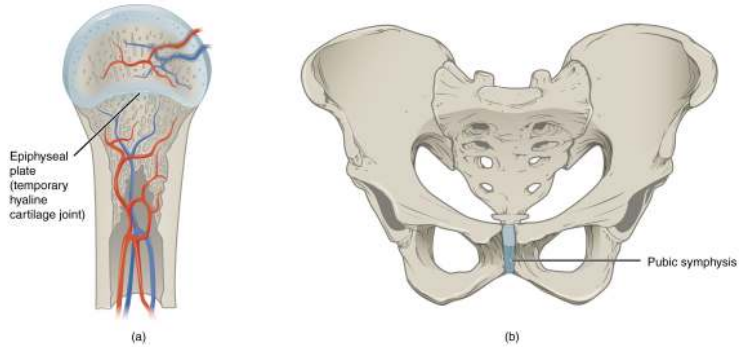


Figure 2.8C.1: Cartiliginous Joints. At cartilaginous joints, bones are united by hyaline cartilage to form a synchondrosis or by fibrocartilage to form a symphysis. (a) The hyaline cartilage of the epiphyseal plate (growth plate) forms a synchondrosis that unites the shaft (diaphysis) and end (epiphysis) of a long bone and allows the bone to grow in length. (b) The pubic portions of the right and left hip bones of the pelvis are joined together by fibrocartilage, forming the pubic symphysis.

Synchondrosis

A **synchondrosis** ("joined by cartilage") is a cartilaginous joint where bones are joined together by hyaline cartilage, or where bone is united to hyaline cartilage. A synchondrosis may be temporary or permanent. A temporary synchondrosis is the epiphyseal plate (growth plate) of a growing long bone. The epiphyseal plate is the region of growing hyaline cartilage that unites the diaphysis (shaft) of the bone to the epiphysis (end of the bone). Bone lengthening involves growth of the epiphyseal plate cartilage and its replacement by bone, which adds to the diaphysis. For many years during childhood growth, the rates of cartilage growth and bone formation are equal and thus the epiphyseal plate does not change in overall thickness as the bone lengthens. During the late teens and early 20s, growth of the cartilage slows and eventually stops. The epiphyseal plate is then completely replaced by bone, and the diaphysis and epiphysis portions of the bone fuse together to form a single adult bone. This fusion of the diaphysis and epiphysis is a synostosis. Once this occurs, bone lengthening ceases. For this reason, the epiphyseal plate is considered to be a temporary synchondrosis. Because cartilage is softer than bone tissue, injury to a growing long bone can damage the epiphyseal plate cartilage, thus stopping bone growth and preventing additional bone lengthening.

Growing layers of cartilage also form synchondroses that join together the ilium, ischium, and pubic portions of the hip bone during childhood and adolescence. When body growth stops, the cartilage disappears and is replaced by bone, forming synostoses and fusing the bony components together into the single hip bone of the adult. Similarly, synostoses unite the sacral vertebrae that fuse together to form the adult sacrum.

QR Code representing a URL

Visit this website to view a radiograph (X-ray image) of a child's hand and wrist. The growing bones of child have an epiphyseal plate that forms a synchondrosis between the shaft and end of a long bone. Being less dense than bone, the area of epiphyseal cartilage is seen on this radiograph as the dark epiphyseal gaps located near the ends of the long bones, including the radius, ulna, metacarpal, and phalanx bones. Which of the bones in this image do not show an epiphyseal plate (epiphyseal gap)?

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Examples of permanent synchondroses are found in the thoracic cage. One example is the first sternocostal joint, where the first rib is anchored to the manubrium by its costal cartilage. (The articulations of the remaining costal cartilages to the sternum are all synovial joints.) Additional synchondroses are formed where the anterior end of the other 11 ribs is joined to its costal cartilage. Unlike the temporary synchondroses of the epiphyseal plate, these permanent synchondroses retain their hyaline cartilage and thus do not ossify with age. Due to the lack of movement between the bone and cartilage, both temporary and permanent synchondroses are functionally classified as a synarthrosis.

Symphysis

A cartilaginous joint where the bones are joined by fibrocartilage is called a **symphysis** (“growing together”). Fibrocartilage is very strong because it contains numerous bundles of thick collagen fibers, thus giving it a much greater ability to resist pulling and bending forces when compared with hyaline cartilage. This gives symphyses the ability to strongly unite the adjacent bones, but can still allow for limited movement to occur. Thus, a symphysis is functionally classified as an amphiarthrosis.

The gap separating the bones at a symphysis may be narrow or wide. Examples in which the gap between the bones is narrow include the pubic symphysis and the manubriosternal joint. At the pubic symphysis, the pubic portions of the right and left hip bones of the pelvis are joined together by fibrocartilage across a narrow gap. Similarly, at the manubriosternal joint, fibrocartilage unites the manubrium and body portions of the sternum.

The intervertebral symphysis is a wide symphysis located between the bodies of adjacent vertebrae of the vertebral column. Here a thick pad of fibrocartilage called an intervertebral disc strongly unites the adjacent vertebrae by filling the gap between them. The width of the intervertebral symphysis is important because it allows for small movements between the adjacent vertebrae. In addition, the thick intervertebral disc provides cushioning between the vertebrae, which is important when carrying heavy objects or during high-impact activities such as running or jumping.

Chapter Review

There are two types of cartilaginous joints. A synchondrosis is formed when the adjacent bones are united by hyaline cartilage. A temporary synchondrosis is formed by the epiphyseal plate of a growing long bone, which is lost when the epiphyseal plate ossifies as the bone reaches maturity. The synchondrosis is thus replaced by a synostosis. Permanent synchondroses that do not ossify are found at the first sternocostal joint and between the anterior ends of the bony ribs and the junction with their costal cartilage. A symphysis is where the bones are joined by fibrocartilage and the gap between the bones may be narrow or wide. A narrow

symphysis is found at the manubriosternal joint and at the pubic symphysis. A wide symphysis is the intervertebral symphysis in which the bodies of adjacent vertebrae are united by an intervertebral disc.

Interactive Link Questions

Go to this website to view a radiograph (X-ray image) of a child's hand and wrist. The growing bones of child have an epiphyseal plate that forms a synchondrosis between the shaft and end of a long bone. Being less dense than bone, the area of epiphyseal cartilage is seen on this radiograph as the dark epiphyseal gaps located near the ends of the long bones, including the radius, ulna, metacarpal, and phalanx bones. Which of the bones in this image do not show an epiphyseal plate (epiphyseal gap)?

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Answer: Although they are still growing, the carpal bones of the wrist area do not show an epiphyseal plate. Instead of elongating, these bones grow in diameter by adding new bone to their surfaces.

Review Questions

Q. A cartilaginous joint _____.

A. has a joint cavity

B. is called a symphysis when the bones are united by fibrocartilage

C. anchors the teeth to the jaws

D. is formed by a wide sheet of fibrous connective tissue

Answer: B

Q. A synchondrosis is _____.

A. found at the pubic symphysis

B. where bones are connected together with fibrocartilage

C. a type of fibrous joint

D. found at the first sternocostal joint of the thoracic cage

Answer: D

Q. Which of the following are joined by a symphysis?

A. adjacent vertebrae

B. the first rib and the sternum

C . the end and shaft of a long bone

D. the radius and ulna bones

> Answer: A

Q. The epiphyseal plate of a growing long bone in a child is classified as a _____.

A. synchondrosis

B. synostosis

C. symphysis

D. syndesmosis

> Answer: A

Critical Thinking Questions

Q. Describe the two types of cartilaginous joints and give examples of each.

> A. Cartilaginous joints are where the adjacent bones are joined by cartilage. At a synchondrosis, the bones are united by hyaline cartilage. The epiphyseal plate of growing long bones and the first sternocostal joint that unites the first rib to the sternum are examples of synchondroses. At a symphysis, the bones are joined by fibrocartilage, which is strong and flexible. Symphysis joints include the intervertebral symphysis between adjacent vertebrae and the pubic symphysis that joins the pubic portions of the right and left hip bones.

Q. Both functional and structural classifications can be used to describe an individual joint. Define the first sternocostal joint and the pubic symphysis using both functional and structural characteristics.

> A. The first sternocostal joint is a synchondrosis type of cartilaginous joint in which hyaline cartilage unites the first rib to the manubrium of the sternum. This forms an immobile (synarthrosis) type of joint. The pubic symphysis is a slightly mobile (amphiarthrosis) cartilaginous joint, where the pubic portions of the right and left hip bones are united by fibrocartilage, thus forming a symphysis.

Glossary

symphysis
type of cartilaginous joint where the bones are joined by fibrocartilage

synchondrosis
type of cartilaginous joint where the bones are joined by hyaline cartilage

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2.8D: Synovial Joints

Learning Objectives

- Describe the structural features of a synovial joint
- Discuss the function of additional structures associated with synovial joints
- List the six types of synovial joints and give an example of each

Synovial joints are the most common type of joint in the body (Figure 2.8*D*.1). A key structural characteristic for a synovial joint that is not seen at fibrous or cartilaginous joints is the presence of a joint cavity. This fluid-filled space is the site at which the articulating surfaces of the bones contact each other. Also unlike fibrous or cartilaginous joints, the articulating bone surfaces at a synovial joint are not directly connected to each other with fibrous connective tissue or cartilage. This gives the bones of a synovial joint the ability to move smoothly against each other, allowing for increased joint mobility.

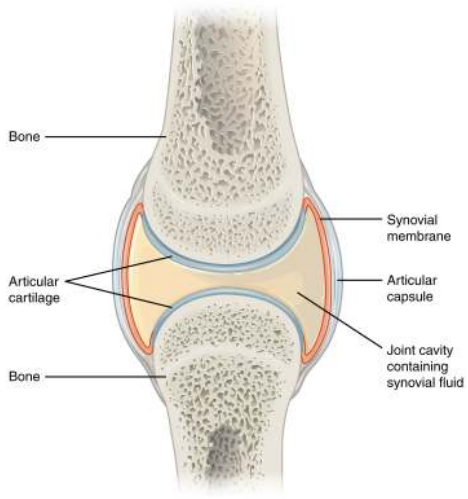


Figure 2.8*D*.1: Synovial Joints. Synovial joints allow for smooth movements between the adjacent bones. The joint is surrounded by an articular capsule that defines a joint cavity filled with synovial fluid. The articulating surfaces of the bones are covered by a thin layer of articular cartilage. Ligaments support the joint by holding the bones together and resisting excess or abnormal joint motions.

Structural Features of Synovial Joints

Synovial joints are characterized by the presence of a joint cavity. The walls of this space are formed by the **articular capsule**, a fibrous connective tissue structure that is attached to each bone just outside the area of the bone's articulating surface. The bones of the joint articulate with each other within the joint cavity.

Friction between the bones at a synovial joint is prevented by the presence of the **articular cartilage**, a thin layer of hyaline cartilage that covers the entire articulating surface of each bone. However, unlike at a cartilaginous joint, the articular cartilages of each bone are not continuous with each other. Instead, the articular cartilage acts like a Teflon® coating over the bone surface, allowing the articulating bones to move smoothly against each other without damaging the underlying bone tissue. Lining the inner surface of the articular capsule is a thin **synovial membrane**. The cells of this membrane secrete **synovial fluid** (synovia = "a thick fluid"), a thick, slimy fluid that provides lubrication to further reduce friction between the bones of the joint. This fluid also provides nourishment to the articular cartilage, which does not contain blood vessels. The ability of the bones to move smoothly against each other within the joint cavity, and the freedom of joint movement this provides, means that each synovial joint is functionally classified as a diarthrosis.

Outside of their articulating surfaces, the bones are connected together by ligaments, which are strong bands of fibrous connective tissue. These strengthen and support the joint by anchoring the bones together and preventing their separation. Ligaments allow for normal movements at a joint, but limit the range of these motions, thus preventing excessive or abnormal joint movements. Ligaments are classified based on their relationship to the fibrous articular capsule. An **extrinsic ligament** is located outside of the articular capsule, an **intrinsic ligament** is fused to or incorporated into the wall of the articular capsule, and an **intracapsular ligament** is located inside of the articular capsule.

At many synovial joints, additional support is provided by the muscles and their tendons that act across the joint. A **tendon** is the dense connective tissue structure that attaches a muscle to bone. As forces acting on a joint increase, the body will automatically increase the overall strength of contraction of the muscles crossing that joint, thus allowing the muscle and its tendon to serve as a "dynamic ligament" to resist forces and support the joint. This type of indirect support by muscles is very important at the shoulder joint, for example, where the ligaments are relatively weak.

Additional Structures Associated with Synovial Joints

A few synovial joints of the body have a fibrocartilage structure located between the articulating bones. This is called an **articular disc**, which is generally small and oval-shaped, or a **meniscus**, which is larger and C-shaped. These structures can serve several functions, depending on the specific joint. In some places, an articular disc may act to strongly unite the bones of the joint to each other. Examples of this include the articular discs found at the sternoclavicular joint or between the distal ends of the radius and ulna bones. At other synovial joints, the disc can provide shock absorption and cushioning between the bones, which is the function of each meniscus within the knee joint. Finally, an articular disc can serve to smooth the movements between the articulating bones, as seen at the temporomandibular joint. Some synovial joints also have a fat pad, which can serve as a cushion between the bones.

Additional structures located outside of a synovial joint serve to prevent friction between the bones of the joint and the overlying muscle tendons or skin. A **bursa** (plural = bursae) is a thin connective tissue sac filled with lubricating liquid. They are located in regions where skin, ligaments, muscles, or muscle tendons can rub against each other, usually near a body joint (Figure 2.8*D*.2). Bursae reduce friction by separating the adjacent structures, preventing them from rubbing directly against each other. Bursae are classified by their location. A **subcutaneous bursa** is located between the skin and an underlying bone. It allows skin to move smoothly over the bone. Examples include the prepatellar bursa located over the kneecap and the olecranon bursa at the tip of the elbow. A **submuscular bursa** is found between a muscle and an underlying bone, or between adjacent muscles. These prevent rubbing of the muscle during movements. A large submuscular bursa, the trochanteric bursa, is found at the lateral hip, between the greater trochanter of the femur and the overlying gluteus maximus muscle. A **subtendinous bursa** is found between a tendon and a bone. Examples include the subacromial bursa that protects the tendon of shoulder muscle as it passes under the acromion of the scapula, and the suprapatellar bursa that separates the tendon of the large anterior thigh muscle from the distal femur just above the knee.

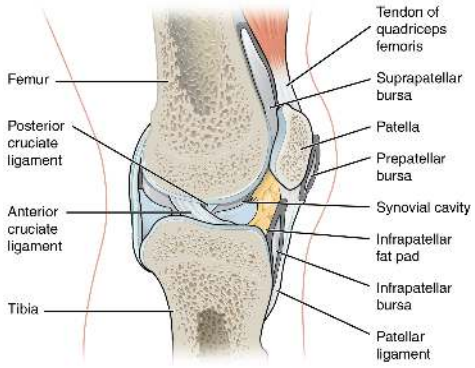


Figure 2.8*D*.2***: Bursae.*** *Bursae are fluid-filled sacs that serve to prevent friction between skin, muscle, or tendon and an underlying bone. Three major bursae and a fat pad are part of the complex joint that unites the femur and tibia of the leg.*

A **tendon sheath** is similar in structure to a bursa, but smaller. It is a connective tissue sac that surrounds a muscle tendon at places where the tendon crosses a joint. It contains a lubricating fluid that allows for smooth motions of the tendon during muscle contraction and joint movements.

HOMEOSTATIC IMBALANCES

Bursitis

Bursitis is the inflammation of a bursa near a joint. This will cause pain, swelling, or tenderness of the bursa and surrounding area, and may also result in joint stiffness. Bursitis is most commonly associated with the bursae found at or near the shoulder, hip, knee, or elbow joints. At the shoulder, subacromial bursitis may occur in the bursa that separates the acromion of the scapula from the tendon of a shoulder muscle as it passes deep to the acromion. In the hip region,

trochanteric bursitis can occur in the bursa that overlies the greater trochanter of the femur, just below the lateral side of the hip. Ischial bursitis occurs in the bursa that separates the skin from the ischial tuberosity of the pelvis, the bony structure that is weight bearing when sitting. At the knee, inflammation and swelling of the bursa located between the skin and patella bone is prepatellar bursitis ("housemaid's knee"), a condition more commonly seen today in roofers or floor and carpet installers who do not use knee pads. At the elbow, olecranon bursitis is inflammation of the bursa between the skin and olecranon process of the ulna. The olecranon forms the bony tip of the elbow, and bursitis here is also known as "student's elbow."

Bursitis can be either acute (lasting only a few days) or chronic. It can arise from muscle overuse, trauma, excessive or prolonged pressure on the skin, rheumatoid arthritis, gout, or infection of the joint. Repeated acute episodes of bursitis can result in a chronic condition. Treatments for the disorder include antibiotics if the bursitis is caused by an infection, or anti-inflammatory agents, such as nonsteroidal anti-inflammatory drugs (NSAIDs) or corticosteroids if the bursitis is due to trauma or overuse. Chronic bursitis may require that fluid be drained, but additional surgery is usually not required.

Types of Synovial Joints

Synovial joints are subdivided based on the shapes of the articulating surfaces of the bones that form each joint. The six types of synovial joints are pivot, hinge, condyloid, saddle, plane, and ball-and socket-joints (Figure 2.8D.3).

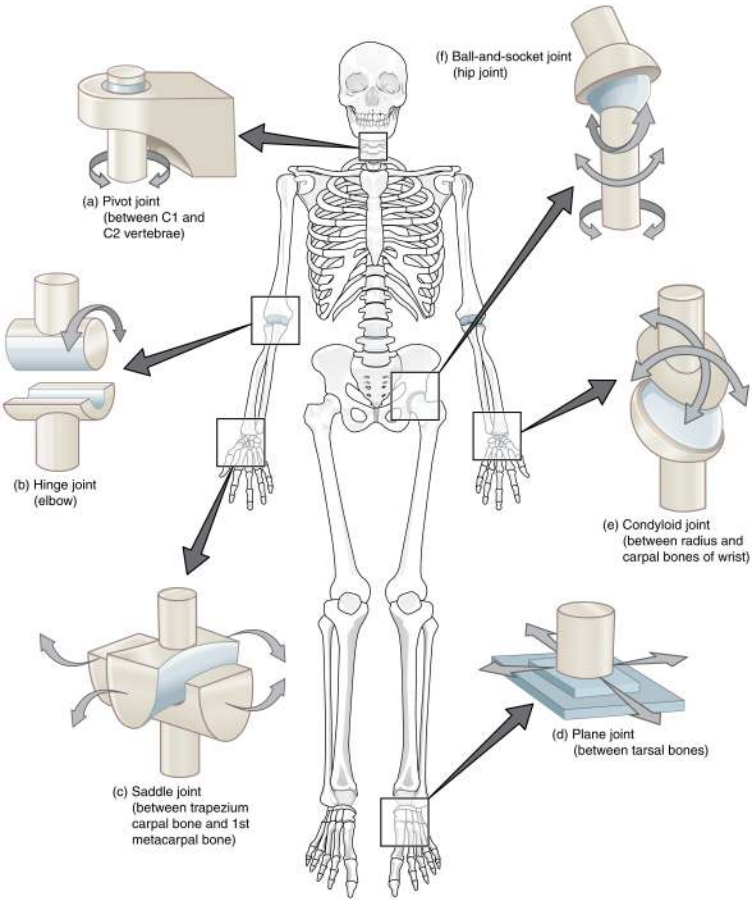


Figure 2.8D.3: Types of Synovial Joints. The six types of synovial joints allow the body to move in a variety of ways. (a) Pivot joints allow for rotation around an axis, such as between the first and second cervical vertebrae, which allows for side-to-side rotation of the head. (b) The hinge joint of the elbow works like a door hinge. (c) The articulation between the trapezium carpal bone and the first metacarpal bone at the base of the thumb is a saddle joint. (d) Plane joints, such as those between the tarsal bones of the foot, allow for limited gliding movements between bones. (e) The radiocarpal joint of the wrist is a condyloid joint. (f) The hip and shoulder joints are the only ball-and-socket joints of the body.

Pivot Joint

At a **pivot joint**, a rounded portion of a bone is enclosed within a ring formed partially by the articulation with another bone and partially by a ligament (see Figure 2.8D.3.a). The bone rotates within this ring. Since the rotation is around a single axis, pivot

joints are functionally classified as a uniaxial diarthrosis type of joint. An example of a pivot joint is the atlantoaxial joint, found between the C1 (atlas) and C2 (axis) vertebrae. Here, the upward projecting dens of the axis articulates with the inner aspect of the atlas, where it is held in place by a ligament. Rotation at this joint allows you to turn your head from side to side. A second pivot joint is found at the **proximal radioulnar joint**. Here, the head of the radius is largely encircled by a ligament that holds it in place as it articulates with the radial notch of the ulna. Rotation of the radius allows for forearm movements.

Hinge Joint

In a **hinge joint**, the convex end of one bone articulates with the concave end of the adjoining bone (see Figure9.4.3.b). This type of joint allows only for bending and straightening motions along a single axis, and thus hinge joints are functionally classified as uniaxial joints. A good example is the elbow joint, with the articulation between the trochlea of the humerus and the trochlear notch of the ulna. Other hinge joints of the body include the knee, ankle, and interphalangeal joints between the phalanx bones of the fingers and toes.

Condyloid Joint

At a **condyloid joint** (ellipsoid joint), the shallow depression at the end of one bone articulates with a rounded structure from an adjacent bone or bones (see Figure9.4.3.e). The knuckle (metacarpophalangeal) joints of the hand between the distal end of a metacarpal bone and the proximal phalanx bone are condyloid joints. Another example is the radiocarpal joint of the wrist, between the shallow depression at the distal end of the radius bone and the rounded scaphoid, lunate, and triquetrum carpal bones. In this case, the articulation area has a more oval (elliptical) shape. Functionally, condyloid joints are biaxial joints that allow for two planes of movement. One movement involves the bending and straightening of the fingers or the anterior-posterior movements of the hand. The second movement is a side-to-side movement, which allows you to spread your fingers apart and bring them together, or to move your hand in a medial-going or lateral-going direction.

Saddle Joint

At a **saddle joint**, both of the articulating surfaces for the bones have a saddle shape, which is concave in one direction and convex in the other (see Figure9.4.3.c). This allows the two bones to fit together like a rider sitting on a saddle. Saddle joints are functionally classified as biaxial joints. The primary example is the first carpometacarpal joint, between the trapezium (a carpal bone) and the first metacarpal bone at the base of the thumb. This joint provides the thumb the ability to move away from the palm of the hand along two planes. Thus, the thumb can move within the same plane as the palm of the hand, or it can jut out anteriorly, perpendicular to the palm. This movement of the first carpometacarpal joint is what gives humans their distinctive “opposable” thumbs. The sternoclavicular joint is also classified as a saddle joint.

Plane Joint

At a **plane joint** (gliding joint), the articulating surfaces of the bones are flat or slightly curved and of approximately the same size, which allows the bones to slide against each other (see Figure9.4.3.d). The motion at this type of joint is usually small and tightly constrained by surrounding ligaments. Based only on their shape, plane joints can allow multiple movements, including rotation. Thus plane joints can be functionally classified as a multiaxial joint. However, not all of these movements are available to every plane joint due to limitations placed on it by ligaments or neighboring bones. Thus, depending upon the specific joint of the body, a plane joint may exhibit only a single type of movement or several movements. Plane joints are found between the carpal bones (intercarpal joints) of the wrist or tarsal bones (intertarsal joints) of the foot, between the clavicle and acromion of the scapula (acromioclavicular joint), and between the superior and inferior articular processes of adjacent vertebrae (zygapophysial joints).

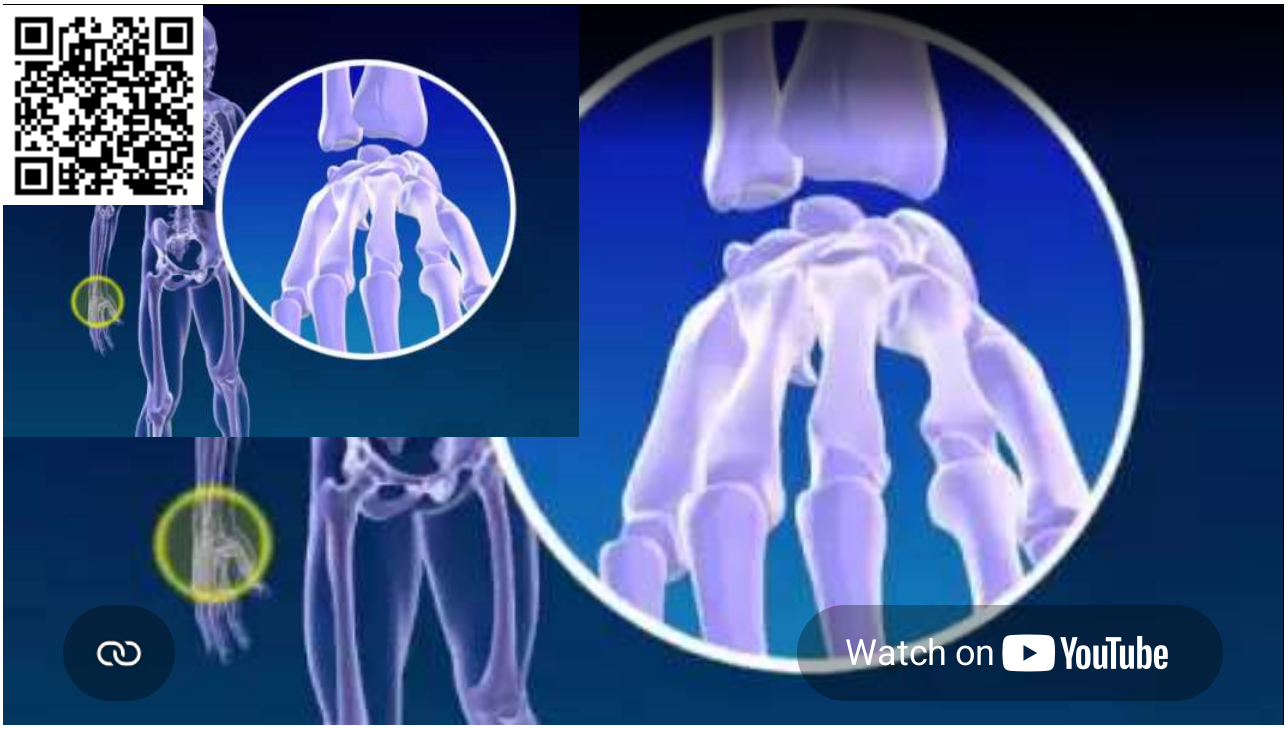
Ball-and-Socket Joint

The joint with the greatest range of motion is the **ball-and-socket joint**. At these joints, the rounded head of one bone (the ball) fits into the concave articulation (the socket) of the adjacent bone (see Figure9.4.3.f). The hip joint and the glenohumeral (shoulder) joint are the only ball-and-socket joints of the body. At the hip joint, the head of the femur articulates with the acetabulum of the hip bone, and at the shoulder joint, the head of the humerus articulates with the glenoid cavity of the scapula.

Ball-and-socket joints are classified functionally as multiaxial joints. The femur and the humerus are able to move in both anterior-posterior and medial-lateral directions and they can also rotate around their long axis. The shallow socket formed by the glenoid cavity allows the shoulder joint an extensive range of motion. In contrast, the deep socket of the acetabulum and the strong supporting ligaments of the hip joint serve to constrain movements of the femur, reflecting the need for stability and weight-bearing ability at the hip.

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Watch this video to see an animation of synovial joints in action. Synovial joints are places where bones articulate with each other inside of a joint cavity. The different types of synovial joints are the ball-and-socket joint (shoulder joint), hinge joint (knee), pivot joint (atlantoaxial joint, between C1 and C2 vertebrae of the neck), condyloid joint (radiocarpal joint of the wrist), saddle joint (first carpometacarpal joint, between the trapezium carpal bone and the first metacarpal bone, at the base of the thumb), and plane joint (facet joints of vertebral column, between superior and inferior articular processes). Which type of synovial joint allows for the widest range of motion?



AGING AND THE...

Joints

Arthritis is a common disorder of synovial joints that involves inflammation of the joint. This often results in significant joint pain, along with swelling, stiffness, and reduced joint mobility. There are more than 100 different forms of arthritis. Arthritis may arise from aging, damage to the articular cartilage, autoimmune diseases, bacterial or viral infections, or unknown (probably genetic) causes.

The most common type of arthritis is osteoarthritis, which is associated with aging and “wear and tear” of the articular cartilage (Figure $2.8D.4$). Risk factors that may lead to osteoarthritis later in life include injury to a joint; jobs that involve physical labor; sports with running, twisting, or throwing actions; and being overweight. These factors put stress on the articular cartilage that covers the surfaces of bones at synovial joints, causing the cartilage to gradually become thinner. As the articular cartilage layer wears down, more pressure is placed on the bones. The joint responds by increasing production of the lubricating synovial fluid, but this can lead to swelling of the joint cavity, causing pain and joint stiffness as the articular capsule is stretched. The bone tissue underlying the damaged articular cartilage also responds by thickening, producing irregularities and causing the articulating surface of the bone to become rough or bumpy. Joint movement then results in pain and inflammation. In its early stages, symptoms of osteoarthritis may be reduced by mild activity that “warms up” the joint, but the symptoms may worsen following exercise. In individuals with more advanced osteoarthritis, the affected joints can become more painful and therefore are difficult to use effectively, resulting in increased immobility. There is no cure for osteoarthritis, but several treatments can help alleviate the pain. Treatments may include lifestyle changes, such as weight loss and low-impact exercise, and over-the-counter or prescription medications that help to alleviate the pain and inflammation. For severe cases, joint replacement surgery (arthroplasty) may be required.

Joint replacement is a very invasive procedure, so other treatments are always tried before surgery. However arthroplasty can provide relief from chronic pain and can enhance mobility within a few months following the surgery. This type of surgery involves replacing the articular surfaces of the bones with prosthesis (artificial components). For example, in hip arthroplasty, the worn or damaged parts of the hip joint, including the head and neck of the femur and the acetabulum of the pelvis, are removed and replaced with artificial joint components. The replacement head for the femur consists of a rounded ball attached to the end of a shaft that is inserted inside the diaphysis of the femur. The acetabulum of the pelvis is reshaped and a replacement socket is fitted into its place. The parts, which are always built in advance of the surgery, are sometimes custom made to produce the best possible fit for a patient.

Gout is a form of arthritis that results from the deposition of uric acid crystals within a body joint. Usually only one or a few joints are affected, such as the big toe, knee, or ankle. The attack may only last a few days, but may return to the same or another joint. Gout occurs when the body makes too much uric acid or the kidneys do not properly excrete it. A diet with excessive fructose has been implicated in raising the chances of a susceptible individual developing gout.

Other forms of arthritis are associated with various autoimmune diseases, bacterial infections of the joint, or unknown genetic causes. Autoimmune diseases, including rheumatoid arthritis, scleroderma, or systemic lupus erythematosus, produce arthritis because the immune system of the body attacks the body joints. In rheumatoid arthritis, the joint capsule and synovial membrane become inflamed. As the disease progresses, the articular cartilage is severely damaged or destroyed, resulting in joint deformation, loss of movement, and severe disability. The most commonly involved joints are the hands, feet, and cervical spine, with corresponding joints on both sides of the body usually affected, though not always to the same extent. Rheumatoid arthritis is also associated with lung fibrosis, vasculitis (inflammation of blood vessels), coronary heart disease, and premature mortality. With no known cure, treatments are aimed at alleviating symptoms. Exercise, anti-inflammatory and pain medications, various specific disease-modifying anti-rheumatic drugs, or surgery are used to treat rheumatoid arthritis.

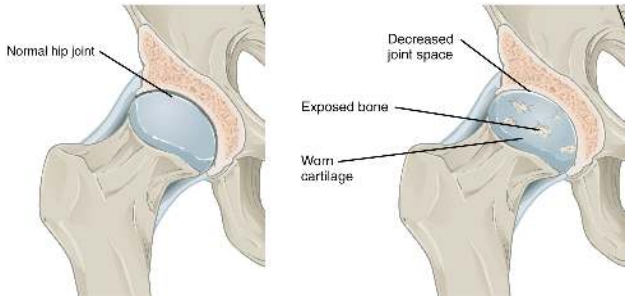


Figure 2.8*D*.4: Osteoarthritis. Osteoarthritis of a synovial joint results from aging or prolonged joint wear and tear. These cause erosion and loss of the articular cartilage covering the surfaces of the bones, resulting in inflammation that causes joint stiffness and pain.

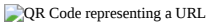
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Visit this website to learn about a patient who arrives at the hospital with joint pain and weakness in his legs. What caused this patient's weakness?

https://med.libretexts.org/@go/page/52925



Watch this animation to observe hip replacement surgery (total hip arthroplasty), which can be used to alleviate the pain and loss of joint mobility associated with osteoarthritis of the hip joint. What is the most common cause of hip disability?



Watch this video to learn about the symptoms and treatments for rheumatoid arthritis. Which system of the body malfunctions in rheumatoid arthritis and what does this cause?

Chapter Review

Synovial joints are the most common type of joints in the body. They are characterized by the presence of a joint cavity, inside of which the bones of the joint articulate with each other. The articulating surfaces of the bones at a synovial joint are not directly connected to each other by connective tissue or cartilage, which allows the bones to move freely against each other. The walls of the joint cavity are formed by the articular capsule. Friction between the bones is reduced by a thin layer of articular cartilage covering the surfaces of the bones, and by a lubricating synovial fluid, which is secreted by the synovial membrane.

Synovial joints are strengthened by the presence of ligaments, which hold the bones together and resist excessive or abnormal movements of the joint. Ligaments are classified as extrinsic ligaments if they are located outside of the articular capsule, intrinsic ligaments if they are fused to the wall of the articular capsule, or intracapsular ligaments if they are located inside the articular capsule. Some synovial joints also have an articular disc (meniscus), which can provide padding between the bones, smooth their movements, or strongly join the bones together to strengthen the joint. Muscles and their tendons acting across a joint can also increase their contractile strength when needed, thus providing indirect support for the joint.

Bursae contain a lubricating fluid that serves to reduce friction between structures. Subcutaneous bursae prevent friction between the skin and an underlying bone, submuscular bursae protect muscles from rubbing against a bone or another muscle, and a subtendinous bursa prevents friction between bone and a muscle tendon. Tendon sheaths contain a lubricating fluid and surround tendons to allow for smooth movement of the tendon as it crosses a joint.

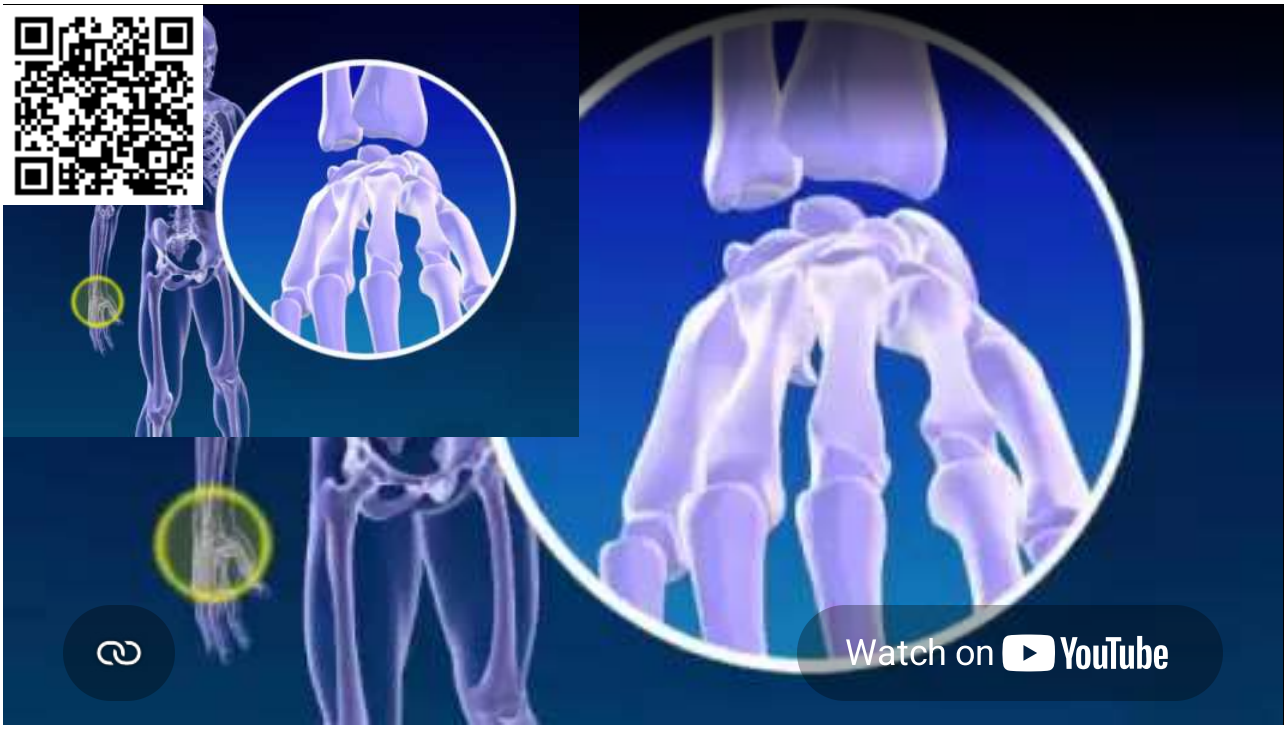
Based on the shape of the articulating bone surfaces and the types of movement allowed, synovial joints are classified into six types. At a pivot joint, one bone is held within a ring by a ligament and its articulation with a second bone. Pivot joints only allow for rotation around a single axis. These are found at the articulation between the C1 (atlas) and the dens of the C2 (axis) vertebrae, which provides the side-to-side rotation of the head, or at the proximal radioulnar joint between the head of the radius and the radial notch of the ulna, which allows for rotation of the radius during forearm movements. Hinge joints, such as at the elbow, knee, ankle, or interphalangeal joints between phalanx bones of the fingers and toes, allow only for bending and straightening of the joint. Pivot and hinge joints are functionally classified as uniaxial joints.

Condyloid joints are found where the shallow depression of one bone receives a rounded bony area formed by one or two bones. Condyloid joints are found at the base of the fingers (metacarpophalangeal joints) and at the wrist (radiocarpal joint). At a saddle joint, the articulating bones fit together like a rider and a saddle. An example is the first carpometacarpal joint located at the base of the thumb. Both condyloid and saddle joints are functionally classified as biaxial joints.

Plane joints are formed between the small, flattened surfaces of adjacent bones. These joints allow the bones to slide or rotate against each other, but the range of motion is usually slight and tightly limited by ligaments or surrounding bones. This type of joint is found between the articular processes of adjacent vertebrae, at the acromioclavicular joint, or at the intercarpal joints of the hand and intertarsal joints of the foot. Ball-and-socket joints, in which the rounded head of a bone fits into a large depression or socket, are found at the shoulder and hip joints. Both plane and ball-and-sockets joints are classified functionally as multiaxial joints. However, ball-and-socket joints allow for large movements, while the motions between bones at a plane joint are small.

Interactive Link Questions

Watch this video to see an animation of synovial joints in action. Synovial joints are places where bones articulate with each other inside of a joint cavity. The different types of synovial joints are the ball-and-socket joint (shoulder joint), hinge joint (knee), pivot joint (atlantoaxial joint, between C1 and C2 vertebrae of the neck), condyloid joint (radiocarpal joint of the wrist), saddle joint (first carpometacarpal joint, between the trapezium carpal bone and the first metacarpal bone, at the base of the thumb), and plane joint (facet joints of vertebral column, between superior and inferior articular processes). Which type of synovial joint allows for the widest ranges of motion?



Answer: Ball-and-socket joint.

Visit this website to read about a patient who arrives at the hospital with joint pain and weakness in his legs. What caused this patient's weakness?

Answer: Gout is due to the accumulation of uric acid crystals in the body. Usually these accumulate within joints, causing joint pain. This patient also had crystals that accumulated in the space next to his spinal cord, thus compressing the spinal cord and causing muscle weakness.

Watch this animation to observe hip replacement surgery (total hip arthroplasty), which can be used to alleviate the pain and loss of joint mobility associated with osteoarthritis of the hip joint. What is the most common cause of hip disability?

Answer: The most common cause of hip disability is osteoarthritis, a chronic disease in which the articular cartilage of the joint wears away, resulting in severe hip pain and stiffness.

Watch this video to learn about the symptoms and treatments for rheumatoid arthritis. Which system of the body malfunctions in rheumatoid arthritis and what does this cause?

Answer: The immune system malfunctions and attacks healthy cells in the lining of your joints. This causes inflammation and pain in the joints and surrounding tissues.

Review Questions

Q. Which type of joint provides the greatest range of motion?

A. ball-and-socket

B. hinge

C. condyloid

D. plane

Answer: A

Q. Which type of joint allows for only uniaxial movement?

A. saddle joint

B. hinge joint

C. condyloid joint

D. ball-and-socket joint

Answer: B

Q. Which of the following is a type of synovial joint?

A. a synostosis

B. a suture

C. a plane joint

D. a synchondrosis

Answer: C

Q. A bursa _____.

A. surrounds a tendon at the point where the tendon crosses a joint

B. secretes the lubricating fluid for a synovial joint

C. prevents friction between skin and bone, or a muscle tendon and bone

D. is the strong band of connective tissue that holds bones together at a synovial joint

Answer: C

Q. At synovial joints, _____.

A. the articulating ends of the bones are directly connected by fibrous connective tissue

B. the ends of the bones are enclosed within a space called a subcutaneous bursa

C. intrinsic ligaments are located entirely inside of the articular capsule

D. the joint cavity is filled with a thick, lubricating fluid

Answer: D

Q. At a synovial joint, the synovial membrane _____.

A. forms the fibrous connective walls of the joint cavity

B. is the layer of cartilage that covers the articulating surfaces of the bones

C. forms the intracapsular ligaments

D. secretes the lubricating synovial fluid

Answer: D

Q. Condyloid joints _____.

A. are a type of ball-and-socket joint

B. include the radiocarpal joint

C. are a uniaxial diarthrosis joint

D. are found at the proximal radioulnar joint

Answer: B

Q. A meniscus is _____.

A. a fibrocartilage pad that provides padding between bones

B. a fluid-filled space that prevents friction between a muscle tendon and underlying bone

C. the articular cartilage that covers the ends of a bone at a synovial joint

D. the lubricating fluid within a synovial joint

Answer: A

Critical Thinking Questions

Q. Describe the characteristic structures found at all synovial joints.

A. All synovial joints have a joint cavity filled with synovial fluid that is the site at which the bones of the joint articulate with each other. The articulating surfaces of the bones are covered by articular cartilage, a thin layer of hyaline cartilage. The walls of the joint cavity are formed by the connective tissue of the articular capsule. The synovial membrane lines the interior surface of the joint cavity and secretes the synovial fluid. Synovial joints are directly supported by ligaments, which span between the bones of the joint. These may be located outside of the articular capsule (extrinsic ligaments), incorporated or fused to the wall of the articular capsule (intrinsic ligaments), or found inside of the articular capsule (intracapsular ligaments). Ligaments hold the bones together and also serve to resist or prevent excessive or abnormal movements of the joint.

Q. Describe the structures that provide direct and indirect support for a synovial joint.

A. Direct support for a synovial joint is provided by ligaments that strongly unite the bones of the joint and serve to resist excessive or abnormal movements. Some joints, such as the sternoclavicular joint, have an articular disc that is attached to both bones, where it provides direct support by holding the bones together. Indirect joint support is provided by the muscles and their tendons that act across a joint. Muscles will increase their contractile force to help support the joint by resisting forces acting on it.

Glossary

articular capsule
connective tissue structure that encloses the joint cavity of a synovial joint

articular cartilage
thin layer of hyaline cartilage that covers the articulating surfaces of bones at a synovial joint

articular disc
meniscus; a fibrocartilage structure found between the bones of some synovial joints; provides padding or smooths movements between the bones; strongly unites the bones together

ball-and-socket joint
synovial joint formed between the spherical end of one bone (the ball) that fits into the depression of a second bone (the socket); found at the hip and shoulder joints; functionally classified as a multiaxial joint

bursa
connective tissue sac containing lubricating fluid that prevents friction between adjacent structures, such as skin and bone, tendons and bone, or between muscles

condyloid joint
synovial joint in which the shallow depression at the end of one bone receives a rounded end from a second bone or a rounded structure formed by two bones; found at the metacarpophalangeal joints of the fingers or the radiocarpal joint of the wrist; functionally classified as a biaxial joint

extrinsic ligament
ligament located outside of the articular capsule of a synovial joint

hinge joint
synovial joint at which the convex surface of one bone articulates with the concave surface of a second bone; includes the elbow, knee, ankle, and interphalangeal joints; functionally classified as a uniaxial joint

intracapsular ligament
ligament that is located within the articular capsule of a synovial joint

intrinsic ligament
ligament that is fused to or incorporated into the wall of the articular capsule of a synovial joint

meniscus
articular disc

pivot joint
synovial joint at which the rounded portion of a bone rotates within a ring formed by a ligament and an articulating bone; functionally classified as uniaxial joint

plane joint
synovial joint formed between the flattened articulating surfaces of adjacent bones; functionally classified as a multiaxial joint

proximal radioulnar joint
articulation between head of radius and radial notch of ulna; uniaxial pivot joint that allows for rotation of radius during pronation/supination of forearm

saddle joint
synovial joint in which the articulating ends of both bones are convex and concave in shape, such as at the first carpometacarpal joint at the base of the thumb; functionally classified as a biaxial joint

subcutaneous bursa
bursa that prevents friction between skin and an underlying bone

submuscular bursa
bursa that prevents friction between bone and a muscle or between adjacent muscles

subtendinous bursa
bursa that prevents friction between bone and a muscle tendon

synovial fluid
thick, lubricating fluid that fills the interior of a synovial joint

synovial membrane
thin layer that lines the inner surface of the joint cavity at a synovial joint; produces the synovial fluid

tendon
dense connective tissue structure that anchors a muscle to bone

tendon sheath
connective tissue that surrounds a tendon at places where the tendon crosses a joint; contains a lubricating fluid to prevent friction and allow smooth movements of the tendon

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2.8E: Types of Body Movements

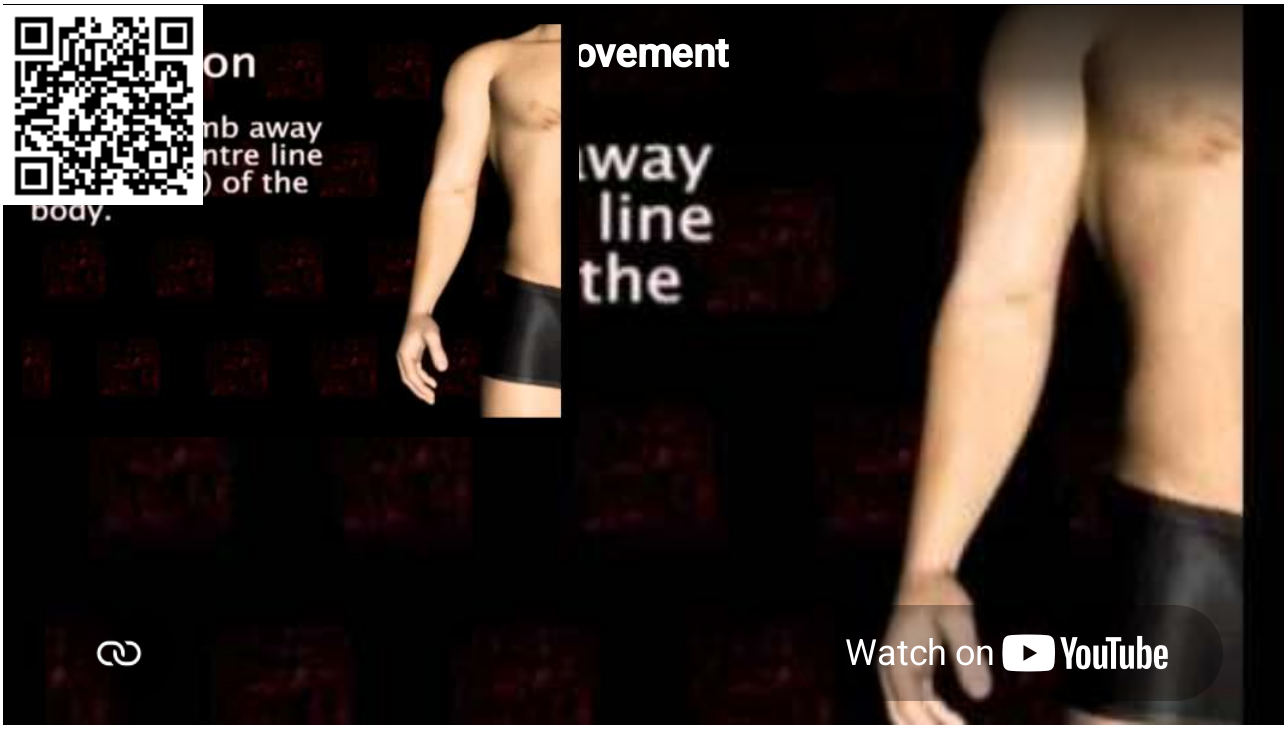
Learning Objectives

- Define the different types of body movements
- Identify the joints that allow for these motions

Synovial joints allow the body a tremendous range of movements. Each movement at a synovial joint results from the contraction or relaxation of the muscles that are attached to the bones on either side of the articulation. The type of movement that can be produced at a synovial joint is determined by its structural type. While the ball-and-socket joint gives the greatest range of movement at an individual joint, in other regions of the body, several joints may work together to produce a particular movement. Overall, each type of synovial joint is necessary to provide the body with its great flexibility and mobility. There are many types of movement that can occur at synovial joints (Table). Movement types are generally paired, with one being the opposite of the other. Body movements are always described in relation to the anatomical position of the body: upright stance, with upper limbs to the side of body and palms facing forward. Refer to Figure $2.8E.1$ as you go through this section.

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Watch this video to learn about anatomical motions. What motions involve increasing or decreasing the angle of the foot at the ankle?



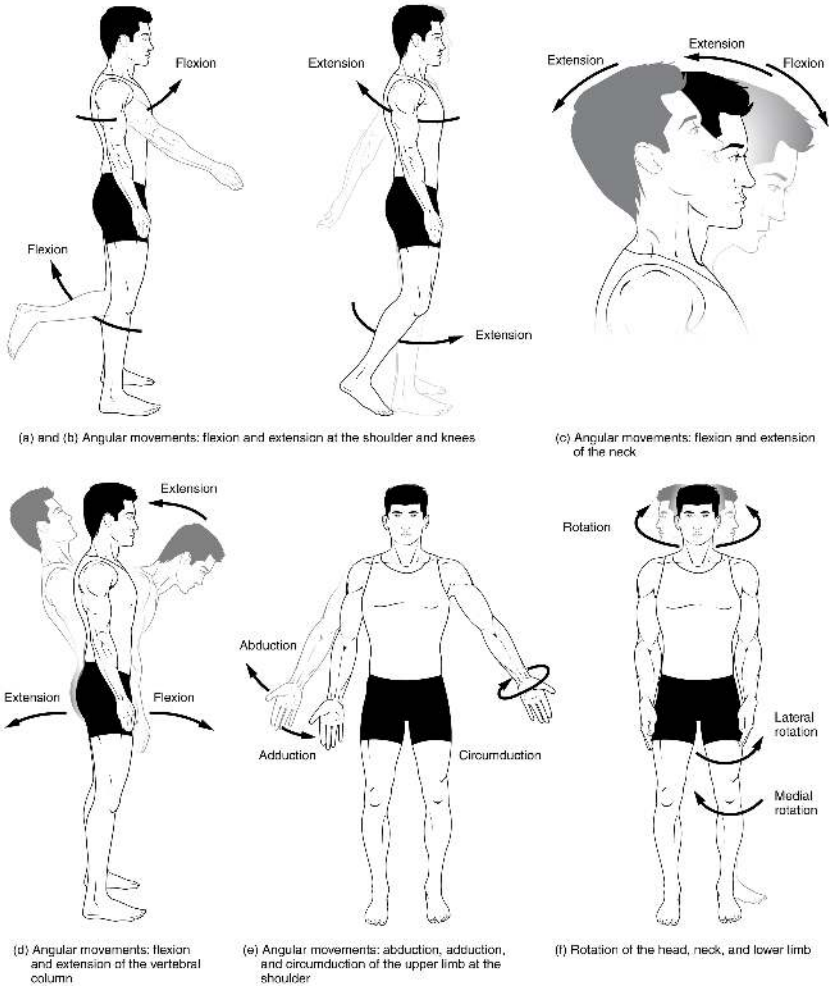


Figure 2.8*E*.1***: Movements of the Body, Part 1.*** *Synovial joints give the body many ways in which to move. (a)–(b) Flexion and extension motions are in the sagittal (anterior–posterior) plane of motion. These movements take place at the shoulder, hip, elbow, knee, wrist, metacarpophalangeal, metatarsophalangeal, and interphalangeal joints. (c)–(d) Anterior bending of the head or vertebral column is flexion, while any posterior-going movement is extension. (e) Abduction and adduction are motions of the limbs, hand, fingers, or toes in the coronal (medial–lateral) plane of movement. Moving the limb or hand laterally away from the body, or spreading the fingers or toes, is abduction. Adduction brings the limb or hand toward or across the midline of the body, or brings the fingers or toes together. Circumduction is the movement of the limb, hand, or fingers in a circular pattern, using the sequential combination of flexion, adduction, extension, and abduction motions. Adduction/abduction and circumduction take place at the shoulder, hip, wrist, metacarpophalangeal, and metatarsophalangeal joints. (f) Turning of the head side to side or twisting of the body is rotation. Medial and lateral rotation of the upper limb at the shoulder or lower limb at the hip involves turning the anterior surface of the limb toward the midline of the body (medial or internal rotation) or away from the midline (lateral or external rotation).*

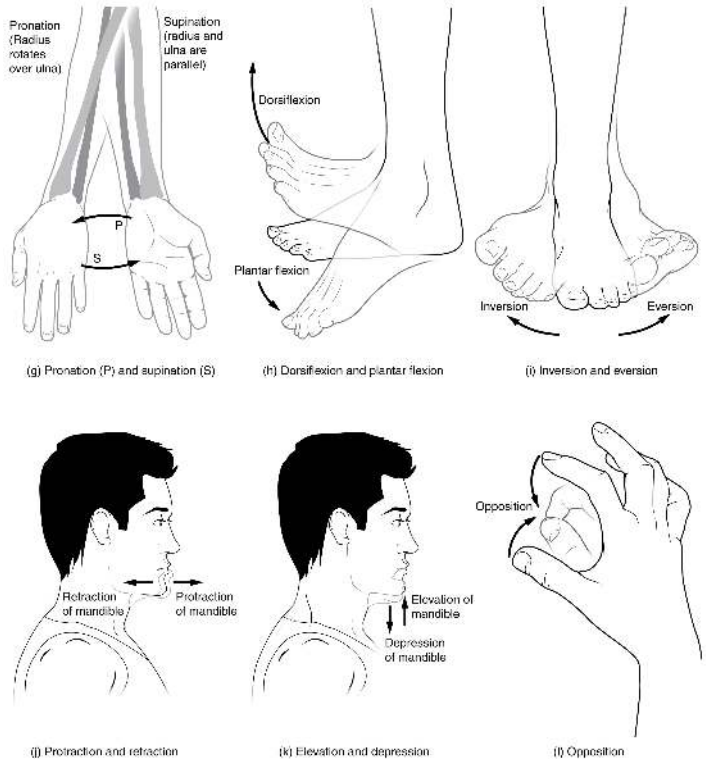


Figure $2.8E.2$***: Movements of the Body, Part 2.*** *(g) Supination of the forearm turns the hand to the palm forward position in which the radius and ulna are parallel, while forearm pronation turns the hand to the palm backward position in which the radius crosses over the ulna to form an "X." (h) Dorsiflexion of the foot at the ankle joint moves the top of the foot toward the leg, while plantar flexion lifts the heel and points the toes. (i) Eversion of the foot moves the bottom (sole) of the foot away from the midline of the body, while foot inversion faces the sole toward the midline. (j) Protraction of the mandible pushes the chin forward, and retraction pulls the chin back. (k) Depression of the mandible opens the mouth, while elevation closes it. (l) Opposition of the thumb brings the tip of the thumb into contact with the tip of the fingers of the same hand and reposition brings the thumb back next to the index finger.*

Flexion and Extension

Flexion and **extension** are movements that take place within the sagittal plane and involve anterior or posterior movements of the body or limbs. For the vertebral column, flexion (anterior flexion) is an anterior (forward) bending of the neck or body, while extension involves a posterior-directed motion, such as straightening from a flexed position or bending backward. **Lateral flexion** is the bending of the neck or body toward the right or left side. These movements of the vertebral column involve both the symphysis joint formed by each intervertebral disc, as well as the plane type of synovial joint formed between the inferior articular processes of one vertebra and the superior articular processes of the next lower vertebra.

In the limbs, flexion decreases the angle between the bones (bending of the joint), while extension increases the angle and straightens the joint. For the upper limb, all anterior-going motions are flexion and all posterior-going motions are extension. These include anterior-posterior movements of the arm at the shoulder, the forearm at the elbow, the hand at the wrist, and the fingers at the metacarpophalangeal and interphalangeal joints. For the thumb, extension moves the thumb away from the palm of the hand, within the same plane as the palm, while flexion brings the thumb back against the index finger or into the palm. These motions take place at the first carpometacarpal joint. In the lower limb, bringing the thigh forward and upward is flexion at the hip joint, while any posterior-going motion of the thigh is extension. Note that extension of the thigh beyond the anatomical (standing) position is greatly limited by the ligaments that support the hip joint. Knee flexion is the bending of the knee to bring the foot toward the posterior thigh, and extension is the straightening of the knee. Flexion and extension movements are seen at the hinge, condyloid, saddle, and ball-and-socket joints of the limbs (see Figure $2.8E.1$.a-d).

Hyperextension is the abnormal or excessive extension of a joint beyond its normal range of motion, thus resulting in injury. Similarly, **hyperflexion** is excessive flexion at a joint. Hyperextension injuries are common at hinge joints such as the knee or

elbow. In cases of “whiplash” in which the head is suddenly moved backward and then forward, a patient may experience both hyperextension and hyperflexion of the cervical region.

Abduction and Adduction

Abduction and **adduction** motions occur within the coronal plane and involve medial-lateral motions of the limbs, fingers, toes, or thumb. Abduction moves the limb laterally away from the midline of the body, while adduction is the opposing movement that brings the limb toward the body or across the midline. For example, abduction is raising the arm at the shoulder joint, moving it laterally away from the body, while adduction brings the arm down to the side of the body. Similarly, abduction and adduction at the wrist moves the hand away from or toward the midline of the body. Spreading the fingers or toes apart is also abduction, while bringing the fingers or toes together is adduction. For the thumb, abduction is the anterior movement that brings the thumb to a 90° perpendicular position, pointing straight out from the palm. Adduction moves the thumb back to the anatomical position, next to the index finger. Abduction and adduction movements are seen at condyloid, saddle, and ball-and-socket joints (see Figure9.5.1.e).

Circumduction

Circumduction is the movement of a body region in a circular manner, in which one end of the body region being moved stays relatively stationary while the other end describes a circle. It involves the sequential combination of flexion, adduction, extension, and abduction at a joint. This type of motion is found at biaxial condyloid and saddle joints, and at multiaxial ball-and-sockets joints (see Figure9.5.1.e).

Rotation

Rotation can occur within the vertebral column, at a pivot joint, or at a ball-and-socket joint. Rotation of the neck or body is the twisting movement produced by the summation of the small rotational movements available between adjacent vertebrae. At a pivot joint, one bone rotates in relation to another bone. This is a uniaxial joint, and thus rotation is the only motion allowed at a pivot joint. For example, at the atlantoaxial joint, the first cervical (C1) vertebra (atlas) rotates around the dens, the upward projection from the second cervical (C2) vertebra (axis). This allows the head to rotate from side to side as when shaking the head “no.” The proximal radioulnar joint is a pivot joint formed by the head of the radius and its articulation with the ulna. This joint allows for the radius to rotate along its length during pronation and supination movements of the forearm.

Rotation can also occur at the ball-and-socket joints of the shoulder and hip. Here, the humerus and femur rotate around their long axis, which moves the anterior surface of the arm or thigh either toward or away from the midline of the body. Movement that brings the anterior surface of the limb toward the midline of the body is called **medial (internal) rotation**. Conversely, rotation of the limb so that the anterior surface moves away from the midline is **lateral (external) rotation** (see Figure9.5.1.f). Be sure to distinguish medial and lateral rotation, which can only occur at the multiaxial shoulder and hip joints, from circumduction, which can occur at either biaxial or multiaxial joints.

Supination and Pronation

Supination and pronation are movements of the forearm. In the anatomical position, the upper limb is held next to the body with the palm facing forward. This is the **supinated position** of the forearm. In this position, the radius and ulna are parallel to each other. When the palm of the hand faces backward, the forearm is in the **pronated position**, and the radius and ulna form an X-shape.

Supination and pronation are the movements of the forearm that go between these two positions. **Pronation** is the motion that moves the forearm from the supinated (anatomical) position to the pronated (palm backward) position. This motion is produced by rotation of the radius at the proximal radioulnar joint, accompanied by movement of the radius at the distal radioulnar joint. The proximal radioulnar joint is a pivot joint that allows for rotation of the head of the radius. Because of the slight curvature of the shaft of the radius, this rotation causes the distal end of the radius to cross over the distal ulna at the distal radioulnar joint. This crossing over brings the radius and ulna into an X-shape position. **Supination** is the opposite motion, in which rotation of the radius returns the bones to their parallel positions and moves the palm to the anterior facing (supinated) position. It helps to remember that supination is the motion you use when scooping up soup with a spoon (see Figure $2.8E.2$.g).

Dorsiflexion and Plantar Flexion

Dorsiflexion and **plantar flexion** are movements at the ankle joint, which is a hinge joint. Lifting the front of the foot, so that the top of the foot moves toward the anterior leg is dorsiflexion, while lifting the heel of the foot from the ground or pointing the toes downward is plantar flexion. These are the only movements available at the ankle joint (see Figure $2.8E.2$.h).

Inversion and Eversion

Inversion and eversion are complex movements that involve the multiple plane joints among the tarsal bones of the posterior foot (intertarsal joints) and thus are not motions that take place at the ankle joint. **Inversion** is the turning of the foot to angle the bottom of the foot toward the midline, while **eversion** turns the bottom of the foot away from the midline. The foot has a greater range of inversion than eversion motion. These are important motions that help to stabilize the foot when walking or running on an uneven surface and aid in the quick side-to-side changes in direction used during active sports such as basketball, racquetball, or soccer (see Figure $2.8E.2$.i).

Protraction and Retraction

Protraction and **retraction** are anterior-posterior movements of the scapula or mandible. Protraction of the scapula occurs when the shoulder is moved forward, as when pushing against something or throwing a ball. Retraction is the opposite motion, with the scapula being pulled posteriorly and medially, toward the vertebral column. For the mandible, protraction occurs when the lower jaw is pushed forward, to stick out the chin, while retraction pulls the lower jaw backward. (See Figure $2.8E.2$.j).

Depression and Elevation

Depression and **elevation** are downward and upward movements of the scapula or mandible. The upward movement of the scapula and shoulder is elevation, while a downward movement is depression. These movements are used to shrug your shoulders. Similarly, elevation of the mandible is the upward movement of the lower jaw used to close the mouth or bite on something, and depression is the downward movement that produces opening of the mouth (see Figure $2.8E.2$.k).

Excursion

Excursion is the side to side movement of the mandible. **Lateral excursion** moves the mandible away from the midline, toward either the right or left side. **Medial excursion** returns the mandible to its resting position at the midline.

Superior Rotation and Inferior Rotation

Superior and inferior rotation are movements of the scapula and are defined by the direction of movement of the glenoid cavity. These motions involve rotation of the scapula around a point inferior to the scapular spine and are produced by combinations of muscles acting on the scapula. During **superior rotation**, the glenoid cavity moves upward as the medial end of the scapular spine moves downward. This is a very important motion that contributes to upper limb abduction. Without superior rotation of the scapula, the greater tubercle of the humerus would hit the acromion of the scapula, thus preventing any abduction of the arm above shoulder height. Superior rotation of the scapula is thus required for full abduction of the upper limb. Superior rotation is also used without arm abduction when carrying a heavy load with your hand or on your shoulder. You can feel this rotation when you pick up a load, such as a heavy book bag and carry it on only one shoulder. To increase its weight-bearing support for the bag, the shoulder lifts as the scapula superiorly rotates. **Inferior rotation** occurs during limb adduction and involves the downward motion of the glenoid cavity with upward movement of the medial end of the scapular spine.

Opposition and Reposition

Opposition is the thumb movement that brings the tip of the thumb in contact with the tip of a finger. This movement is produced at the first carpometacarpal joint, which is a saddle joint formed between the trapezium carpal bone and the first metacarpal bone. Thumb opposition is produced by a combination of flexion and abduction of the thumb at this joint. Returning the thumb to its anatomical position next to the index finger is called **reposition** (see Figure $2.8E.2$.l).

Table $2.8E.1$

Movements of the Joints		
Type of Joint	Movement	Example
Pivot	Uniaxial joint; allows rotational movement	Atlantoaxial joint (C1–C2 vertebrae articulation); proximal radioulnar joint
Hinge	Uniaxial joint; allows flexion/extension movements	Knee; elbow; ankle; interphalangeal joints of fingers and toes

Movements of the Joints		
Type of Joint	Movement	Example
Condyloid	Biaxial joint; allows flexion/extension, abduction/adduction, and circumduction movements	Metacarpophalangeal (knuckle) joints of fingers; radiocarpal joint of wrist; metatarsophalangeal joints for toes
Saddle	Biaxial joint; allows flexion/extension, abduction/adduction, and circumduction movements	First carpometacarpal joint of the thumb; sternoclavicular joint
Plane	Multiaxial joint; allows inversion and eversion of foot, or flexion, extension, and lateral flexion of the vertebral column	Intertarsal joints of foot; superior-inferior articular process articulations between vertebrae
Ball-and-socket	Multiaxial joint; allows flexion/extension, abduction/adduction, circumduction, and medial/lateral rotation movements	Shoulder and hip joints

Chapter Review

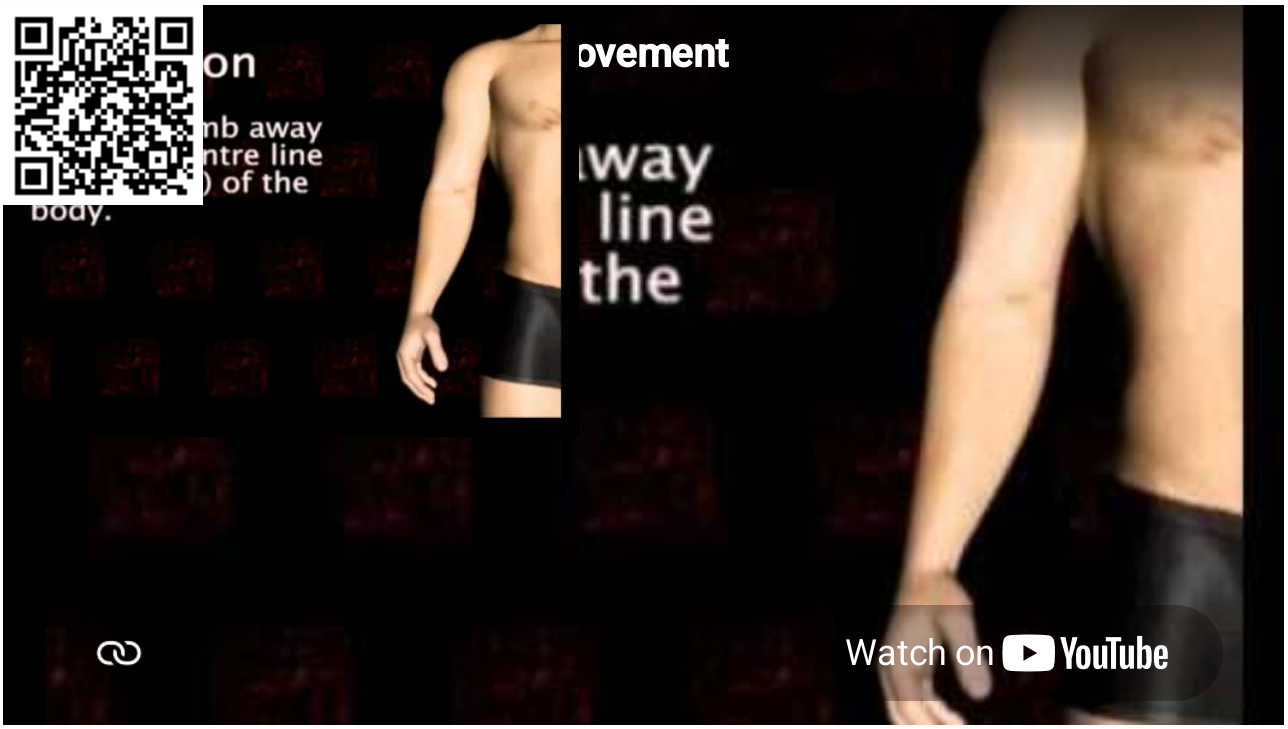
The variety of movements provided by the different types of synovial joints allows for a large range of body motions and gives you tremendous mobility. These movements allow you to flex or extend your body or limbs, medially rotate and adduct your arms and flex your elbows to hold a heavy object against your chest, raise your arms above your head, rotate or shake your head, and bend to touch the toes (with or without bending your knees).

Each of the different structural types of synovial joints also allow for specific motions. The atlantoaxial pivot joint provides side-to-side rotation of the head, while the proximal radioulnar articulation allows for rotation of the radius during pronation and supination of the forearm. Hinge joints, such as at the knee and elbow, allow only for flexion and extension. Similarly, the hinge joint of the ankle only allows for dorsiflexion and plantar flexion of the foot.

Condyloid and saddle joints are biaxial. These allow for flexion and extension, and abduction and adduction. The sequential combination of flexion, adduction, extension, and abduction produces circumduction. Multiaxial plane joints provide for only small motions, but these can add together over several adjacent joints to produce body movement, such as inversion and eversion of the foot. Similarly, plane joints allow for flexion, extension, and lateral flexion movements of the vertebral column. The multiaxial ball and socket joints allow for flexion-extension, abduction-adduction, and circumduction. In addition, these also allow for medial (internal) and lateral (external) rotation. Ball-and-socket joints have the greatest range of motion of all synovial joints.

Interactive Link Questions

Watch this video to learn about anatomical motions. What motions involve increasing or decreasing the angle of the foot at the ankle?



Answer: Dorsiflexion of the foot at the ankle decreases the angle of the ankle joint, while plantar flexion increases the angle of the ankle joint.

Chapter Review

Q. The joints between the articular processes of adjacent vertebrae can contribute to which movement?

A. lateral flexion

B. circumduction

C. dorsiflexion

D. abduction

Answer: A

Q. Which motion moves the bottom of the foot away from the midline of the body?

A. elevation

B. dorsiflexion

C. eversion

D. plantar flexion

Answer: C

Q. Movement of a body region in a circular movement at a condyloid joint is what type of motion?

A. rotation

B. elevation

C. abduction

D. circumduction

Answer: D

Q. Supination is the motion that moves the _____.

A. hand from the palm backward position to the palm forward position

B. foot so that the bottom of the foot faces the midline of the body

C. hand from the palm forward position to the palm backward position

D. scapula in an upward direction

Answer: A

Q. Movement at the shoulder joint that moves the upper limb laterally away from the body is called _____.

A. elevation

B. eversion

C. abduction

D. lateral rotation

Answer: C

Critical Thinking Questions

Q. Briefly define the types of joint movements available at a ball-and-socket joint.

A. Ball-and-socket joints are multiaxial joints that allow for flexion and extension, abduction and adduction, circumduction, and medial and lateral rotation.

Q. Discuss the joints involved and movements required for you to cross your arms together in front of your chest.

A. To cross your arms, you need to use both your shoulder and elbow joints. At the shoulder, the arm would need to flex and medially rotate. At the elbow, the forearm would need to be flexed.

Glossary

abduction
movement in the coronal plane that moves a limb laterally away from the body; spreading of the fingers

adduction
movement in the coronal plane that moves a limb medially toward or across the midline of the body; bringing fingers together

circumduction
circular motion of the arm, thigh, hand, thumb, or finger that is produced by the sequential combination of flexion, abduction, extension, and adduction

depression
downward (inferior) motion of the scapula or mandible

dorsiflexion
movement at the ankle that brings the top of the foot toward the anterior leg

elevation
upward (superior) motion of the scapula or mandible

eversion
foot movement involving the intertarsal joints of the foot in which the bottom of the foot is turned laterally, away from the midline

extension
movement in the sagittal plane that increases the angle of a joint (straightens the joint); motion involving posterior bending of the vertebral column or returning to the upright position from a flexed position

flexion
movement in the sagittal plane that decreases the angle of a joint (bends the joint); motion involving anterior bending of the vertebral column

hyperextension
excessive extension of joint, beyond the normal range of movement

hyperflexion
excessive flexion of joint, beyond the normal range of movement

inferior rotation
movement of the scapula during upper limb adduction in which the glenoid cavity of the scapula moves in a downward direction as the medial end of the scapular spine moves in an upward direction

inversion
foot movement involving the intertarsal joints of the foot in which the bottom of the foot is turned toward the midline

lateral excursion
side-to-side movement of the mandible away from the midline, toward either the right or left side

lateral flexion
bending of the neck or body toward the right or left side

lateral (external) rotation
movement of the arm at the shoulder joint or the thigh at the hip joint that moves the anterior surface of the limb away from the midline of the body

medial excursion
side-to-side movement that returns the mandible to the midline

medial (internal) rotation
movement of the arm at the shoulder joint or the thigh at the hip joint that brings the anterior surface of the limb toward the midline of the body

opposition
thumb movement that brings the tip of the thumb in contact with the tip of a finger

plantar flexion
foot movement at the ankle in which the heel is lifted off of the ground

pronated position
forearm position in which the palm faces backward

pronation
forearm motion that moves the palm of the hand from the palm forward to the palm backward position

protraction
anterior motion of the scapula or mandible

reposition
movement of the thumb from opposition back to the anatomical position (next to index finger)

retraction

posterior motion of the scapula or mandible

rotation

movement of a bone around a central axis (atlantoaxial joint) or around its long axis (proximal radioulnar joint; shoulder or hip joint); twisting of the vertebral column resulting from the summation of small motions between adjacent vertebrae

superior rotation

movement of the scapula during upper limb abduction in which the glenoid cavity of the scapula moves in an upward direction as the medial end of the scapular spine moves in a downward direction

supinated position

forearm position in which the palm faces anteriorly (anatomical position)

supination

forearm motion that moves the palm of the hand from the palm backward to the palm forward position

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2.8F: Anatomy of Selected Synovial Joints

Learning Objectives

- Describe the bones that articulate together to form selected synovial joints
- Discuss the movements available at each joint
- Describe the structures that support and prevent excess movements at each joint

Each synovial joint of the body is specialized to perform certain movements. The movements that are allowed are determined by the structural classification for each joint. For example, a multiaxial ball-and-socket joint has much more mobility than a uniaxial hinge joint. However, the ligaments and muscles that support a joint may place restrictions on the total range of motion available. Thus, the ball-and-socket joint of the shoulder has little in the way of ligament support, which gives the shoulder a very large range of motion. In contrast, movements at the hip joint are restricted by strong ligaments, which reduce its range of motion but confer stability during standing and weight bearing.

This section will examine the anatomy of selected synovial joints of the body. Anatomical names for most joints are derived from the names of the bones that articulate at that joint, although some joints, such as the elbow, hip, and knee joints are exceptions to this general naming scheme.

Articulations of the Vertebral Column

In addition to being held together by the intervertebral discs, adjacent vertebrae also articulate with each other at synovial joints formed between the superior and inferior articular processes called **zygapophysial joints** (facet joints) (see [link]). These are plane joints that provide for only limited motions between the vertebrae. The orientation of the articular processes at these joints varies in different regions of the vertebral column and serves to determine the types of motions available in each vertebral region. The cervical and lumbar regions have the greatest ranges of motions.

In the neck, the articular processes of cervical vertebrae are flattened and generally face upward or downward. This orientation provides the cervical vertebral column with extensive ranges of motion for flexion, extension, lateral flexion, and rotation. In the thoracic region, the downward projecting and overlapping spinous processes, along with the attached thoracic cage, greatly limit flexion, extension, and lateral flexion. However, the flattened and vertically positioned thoracic articular processes allow for the greatest range of rotation within the vertebral column. The lumbar region allows for considerable extension, flexion, and lateral flexion, but the orientation of the articular processes largely prohibits rotation.

The articulations formed between the skull, the atlas (C1 vertebra), and the axis (C2 vertebra) differ from the articulations in other vertebral areas and play important roles in movement of the head. The **atlanto-occipital joint** is formed by the articulations between the superior articular processes of the atlas and the occipital condyles on the base of the skull. This articulation has a pronounced U-shaped curvature, oriented along the anterior-posterior axis. This allows the skull to rock forward and backward, producing flexion and extension of the head. This moves the head up and down, as when shaking your head "yes."

The **atlantoaxial joint**, between the atlas and axis, consists of three articulations. The paired superior articular processes of the axis articulate with the inferior articular processes of the atlas. These articulating surfaces are relatively flat and oriented horizontally. The third articulation is the pivot joint formed between the dens, which projects upward from the body of the axis, and the inner aspect of the anterior arch of the atlas (Figure 2.8F.1). A strong ligament passes posterior to the dens to hold it in position against the anterior arch. These articulations allow the atlas to rotate on top of the axis, moving the head toward the right or left, as when shaking your head "no."

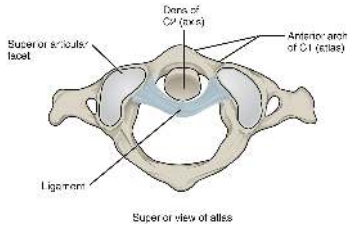


Figure 2.8F.1: Atlantoaxial Joint. The atlantoaxial joint is a pivot type of joint between the dens portion of the axis (C2 vertebra) and the anterior arch of the atlas (C1 vertebra), with the dens held in place by a ligament.

Temporomandibular Joint

The **temporomandibular joint (TMJ)** is the joint that allows for opening (mandibular depression) and closing (mandibular elevation) of the mouth, as well as side-to-side and protraction/retraction motions of the lower jaw. This joint involves the articulation between the mandibular fossa and articular tubercle of the temporal bone, with the condyle (head) of the mandible. Located between these bony structures, filling the gap between the skull and mandible, is a flexible articular disc (Figure 2.8F.2). This disc serves to smooth the movements between the temporal bone and mandibular condyle.

Movement at the TMJ during opening and closing of the mouth involves both gliding and hinge motions of the mandible. With the mouth closed, the mandibular condyle and articular disc are located within the mandibular fossa of the temporal bone. During opening of the mouth, the mandible hinges downward and at the same time is pulled anteriorly, causing both the condyle and the articular disc to glide forward from the mandibular fossa onto the downward projecting articular tubercle. The net result is a forward and downward motion of the condyle and mandibular depression. The temporomandibular joint is supported by an extrinsic ligament that anchors the mandible to the skull. This ligament spans the distance between the base of the skull and the lingula on the medial side of the mandibular ramus.

Dislocation of the TMJ may occur when opening the mouth too wide (such as when taking a large bite) or following a blow to the jaw, resulting in the mandibular condyle moving beyond (anterior to) the articular tubercle. In this case, the individual would not be able to close his or her mouth. Temporomandibular joint disorder is a painful condition that may arise due to arthritis, wearing of the articular cartilage covering the bony surfaces of the joint, muscle fatigue from overuse or grinding of the teeth, damage to the articular disc within the joint, or jaw injury. Temporomandibular joint disorders can also cause headache, difficulty chewing, or even the inability to move the jaw (lock jaw). Pharmacologic agents for pain or other therapies, including bite guards, are used as treatments.

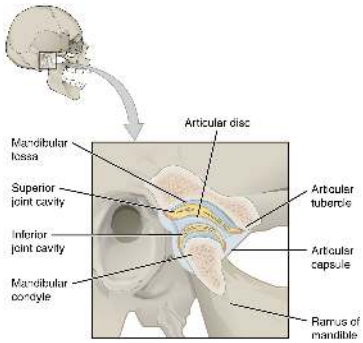
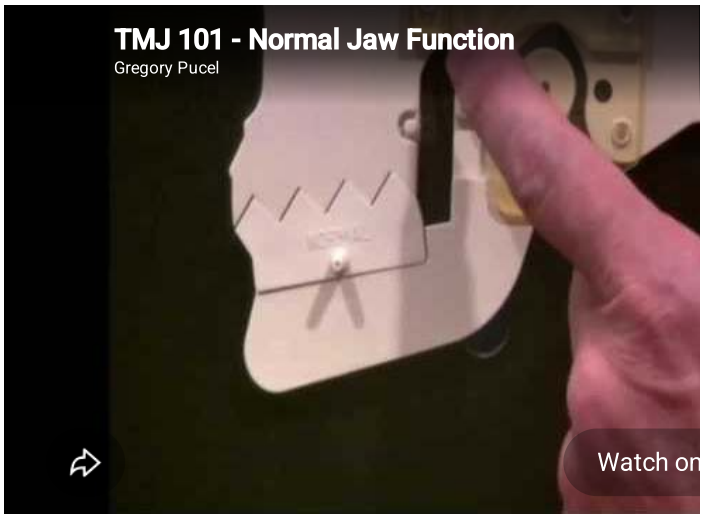


Figure 2.8F.2: Temporomandibular Joint. The temporomandibular joint is the articulation between the temporal bone of the skull and the condyle of the mandible, with an articular disc located between these bones. During depression of the mandible (opening of the mouth), the mandibular condyle moves both forward and hinges downward as it travels from the mandibular fossa onto the articular tubercle.

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Watch this video to learn about TMJ. Opening of the mouth requires the combination of two motions at the temporomandibular joint, an anterior gliding motion of the articular disc and mandible and the downward hinging of the mandible. What is the initial movement of the mandible during opening and how much mouth opening does this produce?



Shoulder Joint

The shoulder joint is called the **glenohumeral joint**. This is a ball-and-socket joint formed by the articulation between the head of the humerus and the glenoid cavity of the scapula (Figure 2.8F.3). This joint has the largest range of motion of any joint in the body. However, this freedom of movement is due to the lack of structural support and thus the enhanced mobility is offset by a loss of stability.

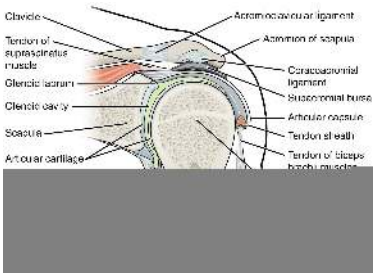


Figure 2.8F.3: Glenohumeral Joint. The glenohumeral (shoulder) joint is a ball-and-socket joint that provides the widest range of motions. It has a loose articular capsule and is supported by ligaments and the rotator cuff muscles.

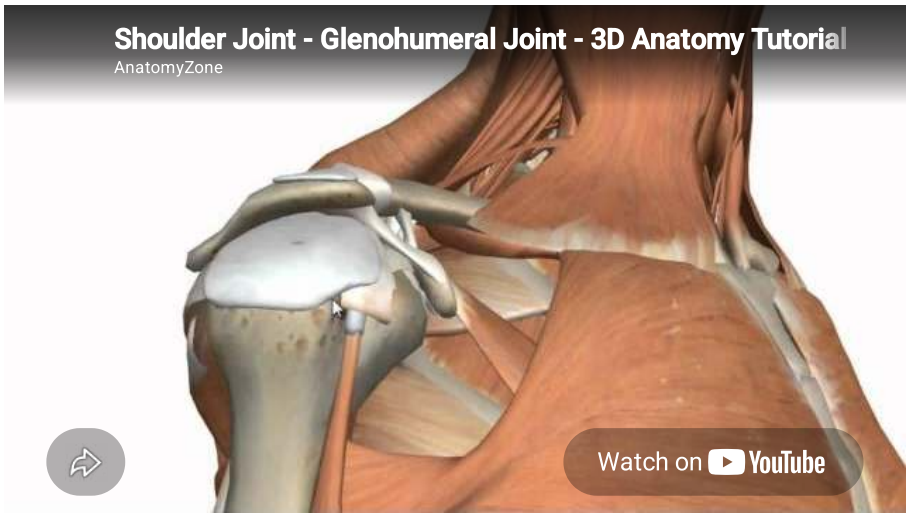
The large range of motions at the shoulder joint is provided by the articulation of the large, rounded humeral head with the small and shallow glenoid cavity, which is only about one third of the size of the humeral head. The socket formed by the glenoid cavity is deepened slightly by a small lip of fibrocartilage called the **glenoid labrum**, which extends around the outer margin of the cavity. The articular capsule that surrounds the glenohumeral joint is relatively thin and loose to allow for large motions of the upper limb. Some structural support for the joint is provided by thickenings of the articular capsule wall that form weak intrinsic ligaments. These include the **coracohumeral ligament**, running from the coracoid process of the scapula to the anterior humerus, and three ligaments, each called a **glenohumeral ligament**, located on the anterior side of the articular capsule. These ligaments help to strengthen the superior and anterior capsule walls.

However, the primary support for the shoulder joint is provided by muscles crossing the joint, particularly the four rotator cuff muscles. These muscles (supraspinatus, infraspinatus, teres minor, and subscapularis) arise from the scapula and attach to the greater or lesser tubercles of the humerus. As these muscles cross the shoulder joint, their tendons encircle the head of the humerus and become fused to the anterior, superior, and posterior walls of the articular capsule. The thickening of the capsule formed by the fusion of these four muscle tendons is called the **rotator cuff**. Two bursae, the **subacromial bursa** and the **subscapular bursa**, help to prevent friction between the rotator cuff muscle tendons and the scapula as these tendons cross the glenohumeral joint. In addition to their individual actions of moving the upper limb, the rotator cuff muscles also serve to hold the head of the humerus in position within the glenoid cavity. By constantly adjusting their strength of contraction to resist forces acting on the shoulder, these muscles serve as “dynamic ligaments” and thus provide the primary structural support for the glenohumeral joint.

Injuries to the shoulder joint are common. Repetitive use of the upper limb, particularly in abduction such as during throwing, swimming, or racquet sports, may lead to acute or chronic inflammation of the bursa or muscle tendons, a tear of the glenoid labrum, or degeneration or tears of the rotator cuff. Because the humeral head is strongly supported by muscles and ligaments around its anterior, superior, and posterior aspects, most dislocations of the humerus occur in an inferior direction. This can occur when force is applied to the humerus when the upper limb is fully abducted, as when diving to catch a baseball and landing on your hand or elbow. Inflammatory responses to any shoulder injury can lead to the formation of scar tissue between the articular capsule and surrounding structures, thus reducing shoulder mobility, a condition called adhesive capsulitis (“frozen shoulder”).

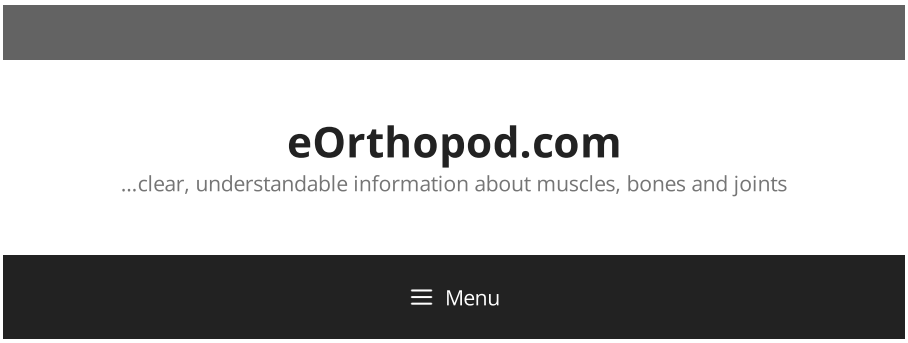
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Watch this video for a tutorial on the anatomy of the shoulder joint. What movements are available at the shoulder joint?



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Watch this video to learn more about the anatomy of the shoulder joint, including bones, joints, muscles, nerves, and blood vessels. What is the shape of the glenoid labrum in cross-section, and what is the importance of this shape?



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Elbow Joint

The **elbow joint** is a uniaxial hinge joint formed by the **humeroulnar joint**, the articulation between the trochlea of the humerus and the trochlear notch of the ulna. Also associated with the elbow are the **humeroradial joint** and the proximal radioulnar joint. All three of these joints are enclosed within a single articular capsule (Figure $2.8F.4$).

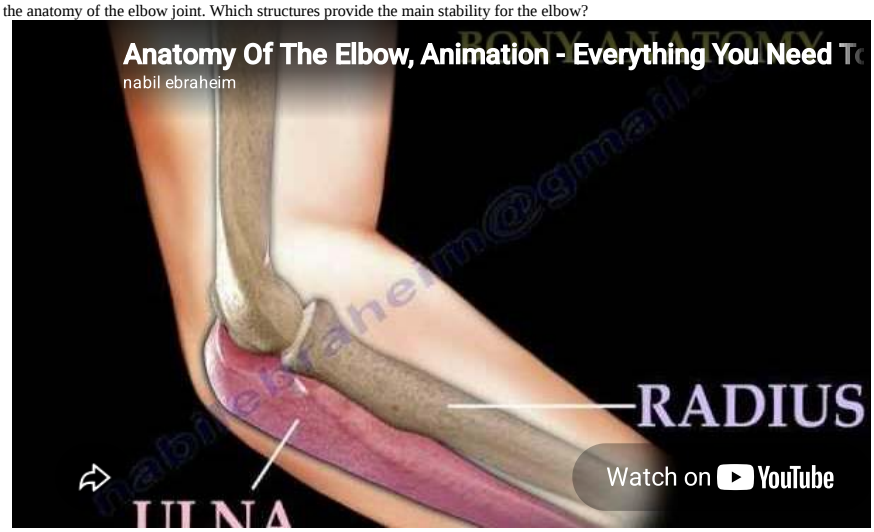
The articular capsule of the elbow is thin on its anterior and posterior aspects, but is thickened along its outside margins by strong intrinsic ligaments. These ligaments prevent side-to-side movements and hyperextension. On the medial side is the triangular **ulnar collateral ligament**. This arises from the medial epicondyle of the humerus and attaches to the medial side of the proximal ulna. The strongest part of this ligament is the anterior portion, which resists hyperextension of the elbow. The ulnar collateral ligament may be injured by frequent, forceful extensions of the forearm, as is seen in baseball pitchers. Reconstructive surgical repair of this ligament is referred to as Tommy John surgery, named for the former major league pitcher who was the first person to have this treatment.

The lateral side of the elbow is supported by the **radial collateral ligament**. This arises from the lateral epicondyle of the humerus and then blends into the lateral side of the annular ligament. The **annular ligament** encircles the head of the radius. This ligament supports the head of the radius as it articulates with the radial notch of the ulna at the proximal radioulnar joint. This is a pivot joint that allows for rotation of the radius during supination and pronation of the forearm.



Figure 2.8F.4: Elbow Joint. (a) The elbow is a hinge joint that allows only for flexion and extension of the forearm. (b) It is supported by the ulnar and radial collateral ligaments. (c) The annular ligament supports the head of the radius at the proximal radioulnar joint, the pivot joint that allows for rotation of the radius.

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Watch this animation to learn more about the anatomy of the elbow joint. Which structures provide the main stability for the elbow?



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Watch this video to learn more about the anatomy of the elbow joint, including bones, joints, muscles, nerves, and blood vessels. What are the functions of the articular cartilage?

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Hip Joint

The hip joint is a multiaxial ball-and-socket joint between the head of the femur and the acetabulum of the hip bone (Figure 2.8F.5). The hip carries the weight of the body and thus requires strength and stability during standing and walking. For these reasons, its range of motion is more limited than at the shoulder joint.

The acetabulum is the socket portion of the hip joint. This space is deep and has a large articulation area for the femoral head, thus giving stability and weight bearing ability to the joint. The acetabulum is further deepened by the **acetabular labrum**, a fibrocartilage lip attached to the outer margin of the acetabulum. The surrounding articular capsule is strong, with several thickened areas forming intrinsic ligaments. These ligaments arise from the hip bone, at the margins of the acetabulum, and attach to the femur at the base of the neck. The ligaments are the **iliofemoral ligament**, **pubofemoral ligament**, and **ischiofemoral ligament**, all of which spiral around the head and neck of the femur. The ligaments are tightened by extension at the hip, thus pulling the head of the femur tightly into the acetabulum when in the upright, standing position. Very little additional extension of the thigh is permitted beyond this vertical position. These ligaments thus stabilize the hip joint and allow you to maintain an upright standing position with only minimal muscle contraction. Inside of the articular capsule, the **ligament of the head of the femur** (ligamentum teres) spans between the acetabulum and femoral head. This intracapsular ligament is normally slack and does not provide any significant joint support, but it does provide a pathway for an important artery that supplies the head of the femur.

The hip is prone to osteoarthritis, and thus was the first joint for which a replacement prosthesis was developed. A common injury in elderly individuals, particularly those with weakened bones due to osteoporosis, is a “broken hip,” which is actually a fracture of the femoral neck. This may result from a fall, or it may cause the fall. This can happen as one lower limb is taking a step and all of the body weight is placed on the other limb, causing the femoral neck to break and producing a fall. Any accompanying disruption of the blood supply to the femoral neck or head can lead to necrosis of these areas, resulting in bone and cartilage death. Femoral fractures usually require surgical treatment, after which the patient will need mobility assistance for a prolonged period, either from family members or in a long-term care facility. Consequentially, the associated health care costs of “broken hips” are substantial. In addition, hip fractures are associated with increased rates of morbidity (incidences of disease) and mortality (death). Surgery for a hip fracture followed by prolonged bed rest may lead to life-threatening complications, including pneumonia, infection of pressure ulcers (bedsores), and thrombophlebitis (deep vein thrombosis; blood clot formation) that can result in a pulmonary embolism (blood clot within the lung).

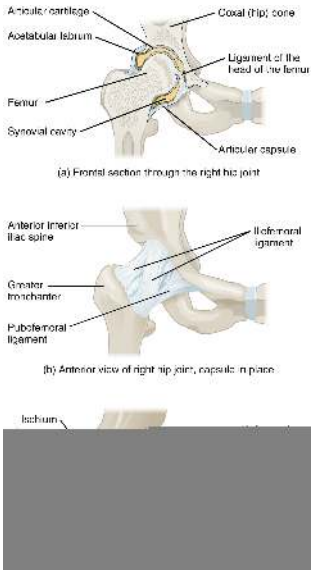
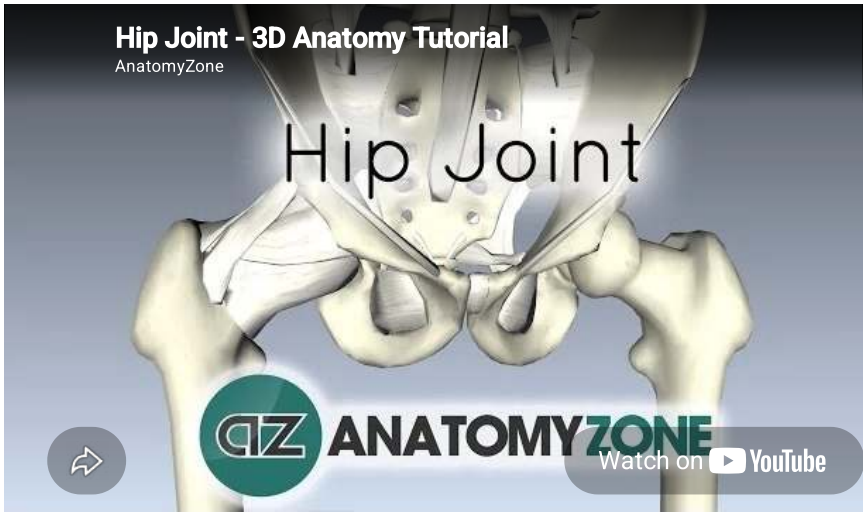


Figure 2.8*F*.5: Hip Joint. (a) The ball-and-socket joint of the hip is a multiaxial joint that provides both stability and a wide range of motion. (b–c) When standing, the supporting ligaments are tight, pulling the head of the femur into the acetabulum.

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Watch this video for a tutorial on the anatomy of the hip joint. What is a possible consequence following a fracture of the femoral neck within the capsule of the hip joint?



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Watch this video to learn more about the anatomy of the hip joint, including bones, joints, muscles, nerves, and blood vessels. Where is the articular cartilage thickest within the hip joint?

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Knee Joint

The knee joint is the largest joint of the body (Figure 2.8F.6). It actually consists of three articulations. The **femoropatellar joint** is found between the patella and the distal femur. The **medial tibiofemoral joint** and **lateral tibiofemoral joint** are located between the medial and lateral condyles of the femur and the medial and lateral condyles of the tibia. All of these articulations are enclosed within a single articular capsule. The knee functions as a hinge joint, allowing flexion and extension of the leg. This action is generated by both rolling and gliding motions of the femur on the tibia. In addition, some rotation of the leg is available when the knee is flexed, but not when extended. The knee is well constructed for weight bearing in its extended position, but is vulnerable to injuries associated with hyperextension, twisting, or blows to the medial or lateral side of the joint, particularly while weight bearing.

At the femoropatellar joint, the patella slides vertically within a groove on the distal femur. The patella is a sesamoid bone incorporated into the tendon of the quadriceps femoris muscle, the large muscle of the anterior thigh. The patella serves to protect the quadriceps tendon from friction against the distal femur. Continuing from the patella to the anterior tibia just below the knee is the **patellar ligament**. Acting via the patella and patellar ligament, the quadriceps femoris is a powerful muscle that acts to extend the leg at the knee. It also serves as a "dynamic ligament" to provide very important support and stabilization for the knee joint.

The medial and lateral tibiofemoral joints are the articulations between the rounded condyles of the femur and the relatively flat condyles of the tibia. During flexion and extension motions, the condyles of the femur both roll and glide over the surfaces of the tibia. The rolling action produces flexion or extension, while the gliding action serves to maintain the femoral condyles centered over the tibial condyles, thus ensuring maximal bony, weight-bearing support for the femur in all knee positions. As the knee comes into full extension, the femur undergoes a slight medial rotation in relation to tibia. The rotation results because the lateral condyle of the femur is slightly smaller than the medial condyle. Thus, the lateral condyle finishes its rolling motion first, followed by the medial condyle. The resulting small medial rotation of the femur serves to "lock" the knee into its fully extended and most stable position. Flexion of the knee is initiated by a slight lateral rotation of the femur on the tibia, which "unlocks" the knee. This lateral rotation motion is produced by the popliteus muscle of the posterior leg.

Located between the articulating surfaces of the femur and tibia are two articular discs, the **medial meniscus** and **lateral meniscus** (see Figure9.6.6.b). Each is a C-shaped fibrocartilage structure that is thin along its inside margin and thick along the outer margin. They are attached to their tibial condyles, but do not attach to the femur. While both menisci are free to move during knee motions, the medial meniscus shows less movement because it is anchored at its outer margin to the articular capsule and tibial collateral ligament. The menisci provide padding between the bones and help to fill the gap between the round femoral condyles and flattened tibial condyles. Some areas of each meniscus lack an arterial blood supply and thus these areas heal poorly if damaged.

The knee joint has multiple ligaments that provide support, particularly in the extended position (see Figure9.6.6.c). Outside of the articular capsule, located at the sides of the knee, are two extrinsic ligaments. The **fibular collateral ligament** (lateral collateral ligament) is on the lateral side and spans from the lateral epicondyle of the femur to the head of the fibula. The **tibial collateral ligament** (medial collateral ligament) of the medial knee runs from the medial epicondyle of the femur to the medial tibia. As it crosses the knee, the tibial collateral ligament is firmly attached on its deep side to the articular capsule and to the medial meniscus, an important factor when considering knee injuries. In the fully extended knee position, both collateral ligaments are taut (tight), thus serving to stabilize and support the extended knee and preventing side-to-side or rotational motions between the femur and tibia.

The articular capsule of the posterior knee is thickened by intrinsic ligaments that help to resist knee hyperextension. Inside the knee are two intracapsular ligaments, the **anterior cruciate ligament** and **posterior cruciate ligament**. These ligaments are anchored inferiorly to the tibia at the intercondylar eminence, the roughened area between the tibial condyles. The cruciate ligaments are named for whether they are attached anteriorly or posteriorly to this tibial region. Each ligament runs diagonally upward to attach to the inner aspect of a femoral condyle. The cruciate ligaments are named for the X-shape formed as they pass each other (cruciate means "cross"). The posterior cruciate ligament is the stronger ligament. It serves to support the knee when it is flexed and weight bearing, as when walking downhill. In this position, the posterior cruciate ligament prevents the femur from sliding anteriorly off the top of the tibia. The anterior cruciate ligament becomes tight when the knee is extended, and thus resists hyperextension.

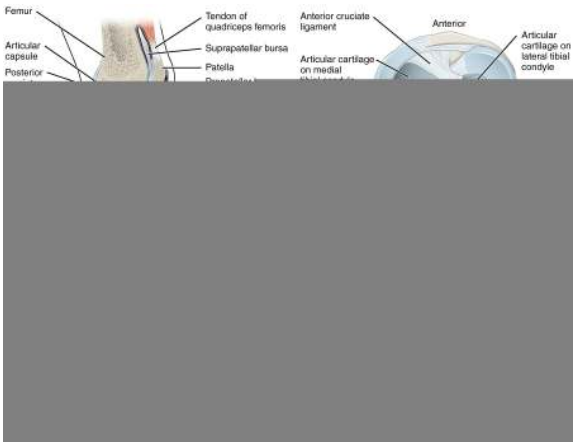


Figure 2.8F.6: Knee Joint. (a) The knee joint is the largest joint of the body. (b)–(c) It is supported by the tibial and fibular collateral ligaments located on the sides of the knee outside of the articular capsule, and the anterior and posterior cruciate ligaments found inside the capsule. The medial and lateral menisci provide padding and support between the femoral condyles and tibial condyles.

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Watch this video to learn more about the flexion and extension of the knee, as the femur both rolls and glides on the tibia to maintain stable contact between the bones in all knee positions. The patella glides along a groove on the anterior side of the distal femur. The collateral ligaments on the sides of the knee become tight in the fully extended position to help stabilize the knee. The posterior cruciate ligament supports the knee when flexed and the anterior cruciate ligament becomes tight when the knee comes into full extension to resist hyperextension. What are the ligaments that support the knee joint?



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Watch this video to learn more about the anatomy of the knee joint, including bones, joints, muscles, nerves, and blood vessels. Which ligament of the knee keeps the tibia from sliding too far forward in relation to the femur and which ligament keeps the tibia from sliding too far backward?

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Joints

Injuries to the knee are common. Since this joint is primarily supported by muscles and ligaments, injuries to any of these structures will result in pain or knee instability. Injury to the posterior cruciate ligament occurs when the knee is flexed and the tibia is driven posteriorly, such as falling and landing on the tibial tuberosity or hitting the tibia on the

dashboard when not wearing a seatbelt during an automobile accident. More commonly, injuries occur when forces are applied to the extended knee, particularly when the foot is planted and unable to move. Anterior cruciate ligament injuries can result with a forceful blow to the anterior knee, producing hyperextension, or when a runner makes a quick change of direction that produces both twisting and hyperextension of the knee.

A worse combination of injuries can occur with a hit to the lateral side of the extended knee (Figure 2.8F.7). A moderate blow to the lateral knee will cause the medial side of the joint to open, resulting in stretching or damage to the tibial collateral ligament. Because the medial meniscus is attached to the tibial collateral ligament, a stronger blow can tear the ligament and also damage the medial meniscus. This is one reason that the medial meniscus is 20 times more likely to be injured than the lateral meniscus. A powerful blow to the lateral knee produces a "terrible triad" injury, in which there is a sequential injury to the tibial collateral ligament, medial meniscus, and anterior cruciate ligament.

Arthroscopic surgery has greatly improved the surgical treatment of knee injuries and reduced subsequent recovery times. This procedure involves a small incision and the insertion into the joint of an arthroscope, a pencil-thin instrument that allows for visualization of the joint interior. Small surgical instruments are also inserted via additional incisions. These tools allow a surgeon to remove or repair a torn meniscus or to reconstruct a ruptured cruciate ligament. The current method for anterior cruciate ligament replacement involves using a portion of the patellar ligament. Holes are drilled into the cruciate ligament attachment points on the tibia and femur, and the patellar ligament graft, with small areas of attached bone still intact at each end, is inserted into these holes. The bone-to-bone sites at each end of the graft heal rapidly and strongly, thus enabling a rapid recovery.



Figure 2.8F.7: Knee Injury. A strong blow to the lateral side of the extended knee will cause three injuries, in sequence: tearing of the tibial collateral ligament, damage to the medial meniscus, and rupture of the anterior cruciate ligament.

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Watch this video to learn more about different knee injuries and diagnostic testing of the knee. What are the most common causes of anterior cruciate ligament injury?



Ankle and Foot Joints

The ankle is formed by the **talocrural joint** (Figure 2.8F.8). It consists of the articulations between the talus bone of the foot and the distal ends of the tibia and fibula of the leg (crural = "leg"). The superior aspect of the talus bone is square-shaped and has three areas of articulation. The top of the talus articulates with the inferior tibia. This is the portion of the ankle joint that carries the body weight between the leg and foot. The sides of the talus are firmly held in position by the articulations with the medial malleolus of the tibia and the lateral malleolus of the fibula, which prevent any side-to-side motion of the talus. The ankle is thus a uniaxial hinge joint that allows only for dorsiflexion and plantar flexion of the foot.

Additional joints between the tarsal bones of the posterior foot allow for the movements of foot inversion and eversion. Most important for these movements is the **subtalar joint**, located between the talus and calcaneus bones. The joints between the talus and navicular bones and the calcaneus and cuboid bones are also important contributors to these movements. All of the joints between tarsal bones are plane joints. Together, the small motions that take place at these joints all contribute to the production of inversion and eversion foot motions.

Like the hinge joints of the elbow and knee, the talocrural joint of the ankle is supported by several strong ligaments located on the sides of the joint. These ligaments extend from the medial malleolus of the tibia or lateral malleolus of the fibula and anchor to the talus and calcaneus bones. Since they are located on the sides of the ankle joint, they allow for dorsiflexion and plantar flexion of the foot. They also prevent abnormal side-to-side and twisting movements of the talus and calcaneus bones during eversion and inversion of the foot. On the medial side is the broad **deltoid ligament**. The deltoid ligament supports the ankle joint and also resists excessive eversion of the foot. The lateral side of the ankle has several smaller ligaments. These include the **anterior talofibular ligament** and the **posterior talofibular ligament**, both of which span between the talus bone and the lateral malleolus of the fibula, and the **calcaneofibular ligament**, located between the calcaneus bone and fibula. These ligaments support the ankle and also resist excess inversion of the foot.



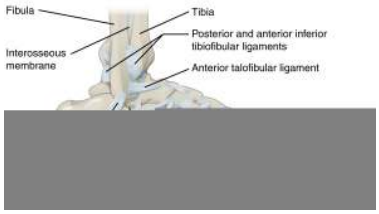


Figure 2.8*F*.8: Ankle Joint. The talocrural (ankle) joint is a uniaxial hinge joint that only allows for dorsiflexion or plantar flexion of the foot. Movements at the subtalar joint, between the talus and calcaneus bones, combined with motions at other intertarsal joints, enables eversion/inversion movements of the foot. Ligaments that unite the medial or lateral malleolus with the talus and calcaneus bones serve to support the talocrural joint and to resist excess eversion or inversion of the foot.

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Watch this video for a tutorial on the anatomy of the ankle joint. What are the three ligaments found on the lateral side of the ankle joint?



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Watch this video to learn more about the anatomy of the ankle joint, including bones, joints, muscles, nerves, and blood vessels. Which type of joint used in woodworking does the ankle joint resemble?

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Joints

The ankle is the most frequently injured joint in the body, with the most common injury being an inversion ankle sprain. A sprain is the stretching or tearing of the supporting ligaments. Excess inversion causes the talus bone to tilt laterally, thus damaging the ligaments on the lateral side of the ankle. The anterior talofibular ligament is most commonly injured, followed by the calcaneofibular ligament. In severe inversion injuries, the forceful lateral movement of the talus not only ruptures the lateral ankle ligaments, but also fractures the distal fibula.

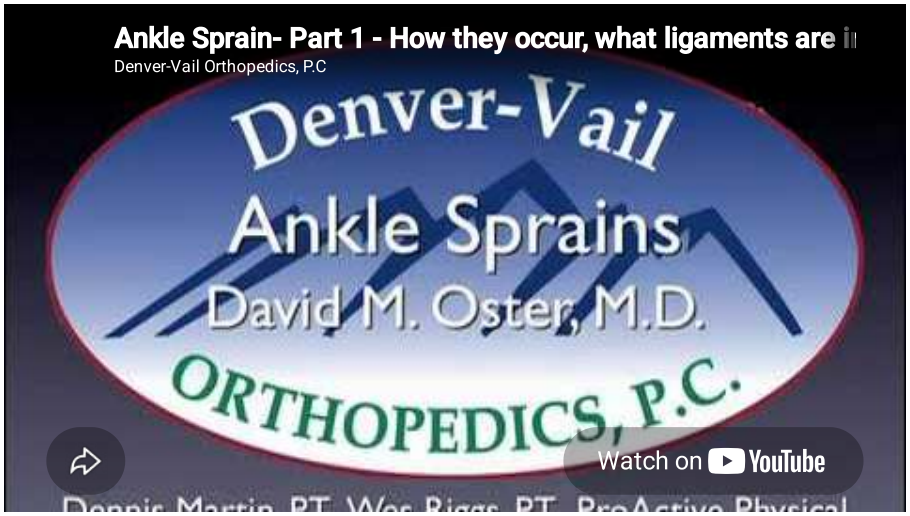
Less common are eversion sprains of the ankle, which involve stretching of the deltoid ligament on the medial side of the ankle. Forcible eversion of the foot, for example, with an awkward landing from a jump or when a football player has a foot planted and is hit on the lateral ankle, can result in a Pott's fracture and dislocation of the ankle joint. In this injury, the very strong deltoid ligament does not tear, but instead shears off the medial malleolus of the tibia. This frees the talus, which moves laterally and fractures the distal fibula. In extreme cases, the posterior margin of the tibia may also be sheared off.

Above the ankle, the distal ends of the tibia and fibula are united by a strong syndesmosis formed by the interosseous membrane and ligaments at the distal tibiofibular joint. These connections prevent separation between the distal ends of the tibia and fibula and maintain the talus locked into position between the medial malleolus and lateral malleolus. Injuries that produce a lateral twisting of the leg on top of the planted foot can result in stretching or tearing of the tibiofibular ligaments, producing a syndesmotic ankle sprain or "high ankle sprain."

Most ankle sprains can be treated using the RICE technique: Rest, Ice, Compression, and Elevation. Reducing joint mobility using a brace or cast may be required for a period of time. More severe injuries involving ligament tears or bone fractures may require surgery.

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Watch this video to learn more about the ligaments of the ankle joint, ankle sprains, and treatment. During an inversion ankle sprain injury, all three ligaments that resist excessive inversion of the foot may be injured. What is the sequence in which these three ligaments are injured?



Chapter Review

Although synovial joints share many common features, each joint of the body is specialized for certain movements and activities. The joints of the upper limb provide for large ranges of motion, which give the upper limb great mobility, thus enabling actions such as the throwing of a ball or typing on a keyboard. The joints of the lower limb are more robust, giving them greater strength and the stability needed to support the body weight during running, jumping, or kicking activities.

The joints of the vertebral column include the symphysis joints formed by each intervertebral disc and the plane synovial joints between the superior and inferior articular processes of adjacent vertebrae. Each of these joints provide for limited motions, but these sum together to produce flexion, extension, lateral flexion, and rotation of the neck and body. The range of motions available in each region of the vertebral column varies, with all of these motions available in the cervical region. Only rotation is allowed in the thoracic region, while the lumbar region has considerable extension, flexion, and lateral flexion, but rotation is prevented. The atlanto-occipital joint allows for flexion and extension of the head, while the atlantoaxial joint is a pivot joint that provides for rotation of the head.

The temporomandibular joint is the articulation between the condyle of the mandible and the mandibular fossa and articular tubercle of the skull temporal bone. An articular disc is located between the bony components of this joint. A combination of gliding and hinge motions of the mandibular condyle allows for elevation/depression, protraction/retraction, and side-to-side motions of the lower jaw.

The glenohumeral (shoulder) joint is a multiaxial ball-and-socket joint that provides flexion/extension, abduction/adduction, circumduction, and medial/lateral rotation of the humerus. The head of the humerus articulates with the glenoid cavity of the scapula. The glenoid labrum extends around the margin of the glenoid cavity. Intrinsic ligaments, including the coracohumeral ligament and glenohumeral ligaments, provide some support for the shoulder joint. However, the primary support comes from muscles crossing the joint whose tendons form the rotator cuff. These muscle tendons are protected from friction against the scapula by the subacromial bursa and subscapular bursa.

The elbow is a uniaxial hinge joint that allows for flexion/extension of the forearm. It includes the humeroulnar joint and the humeroradial joint. The medial elbow is supported by the ulnar collateral ligament and the radial collateral ligament supports the lateral side. These ligaments prevent side-to-side movements and resist hyperextension of the elbow. The proximal radioulnar joint is a pivot joint that allows for rotation of the radius during pronation/supination of the forearm. The annular ligament surrounds the head of the radius to hold it in place at this joint.

The hip joint is a ball-and-socket joint whose motions are more restricted than at the shoulder to provide greater stability during weight bearing. The hip joint is the articulation between the head of the femur and the acetabulum of the hip bone. The acetabulum is deepened by the acetabular labrum. The iliofemoral, pubofemoral, and ischiofemoral ligaments strongly support the hip joint in the upright, standing position. The ligament of the head of the femur provides little support but carries an important artery that supplies the femur.

The knee includes three articulations. The femoropatellar joint is between the patella and distal femur. The patella, a sesamoid bone incorporated into the tendon of the quadriceps femoris muscle of the anterior thigh, serves to protect this tendon from rubbing against the distal femur during knee movements. The medial and lateral tibiofemoral joints, between the condyles of the femur and condyles of the tibia, are modified hinge joints that allow for knee extension and flexion. During these movements, the condyles of the femur both roll and glide over the surface of the tibia. As the knee comes into full extension, a slight medial rotation of the femur serves to "lock" the knee into its most stable, weight-bearing position. The reverse motion, a small lateral rotation of the femur, is required to initiate knee flexion. When the knee is flexed, some rotation of the leg is available.

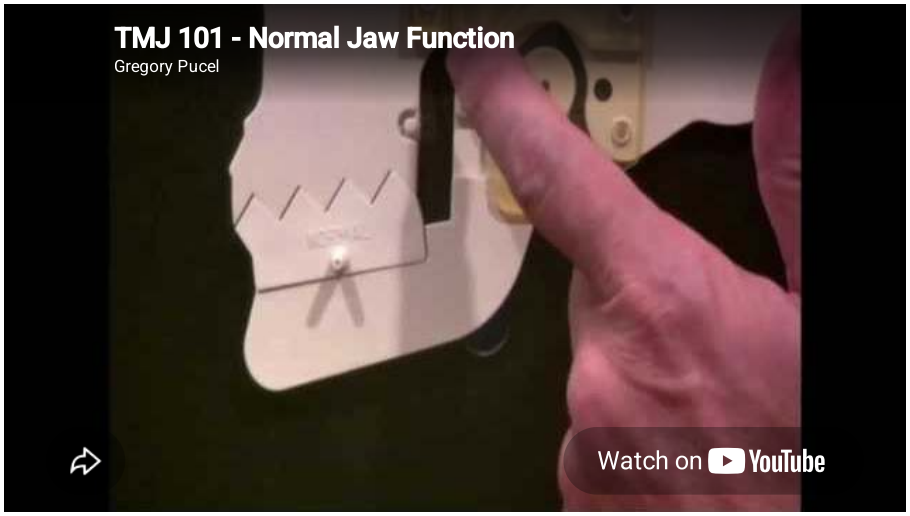
Two extrinsic ligaments, the tibial collateral ligament on the medial side and the fibular collateral ligament on the lateral side, serve to resist hyperextension or rotation of the extended knee joint. Two intracapsular ligaments, the anterior cruciate ligament and posterior cruciate ligament, span between the tibia and the inner aspects of the femoral condyles. The anterior cruciate ligament resists hyperextension of the knee, while the posterior cruciate ligament prevents anterior sliding of the femur, thus supporting the knee when it is flexed and weight bearing. The medial and lateral menisci, located between the femoral and tibial condyles, are articular discs that provide padding and improve the fit between the bones.

The talocrural joint forms the ankle. It consists of the articulation between the talus bone and the medial malleolus of the tibia, the distal end of the tibia, and the lateral malleolus of the fibula. This is a uniaxial hinge joint that allows only dorsiflexion and plantar flexion of the foot. Gliding motions at the subtalar and intertarsal joints of the foot allow for inversion/eversion

of the foot. The ankle joint is supported on the medial side by the deltoid ligament, which prevents side-to-side motions of the talus at the talocrural joint and resists excessive eversion of the foot. The lateral ankle is supported by the anterior and posterior talofibular ligaments and the calcaneofibular ligament. These support the ankle joint and also resist excess inversion of the foot. An inversion ankle sprain, a common injury, will result in injury to one or more of these lateral ankle ligaments.

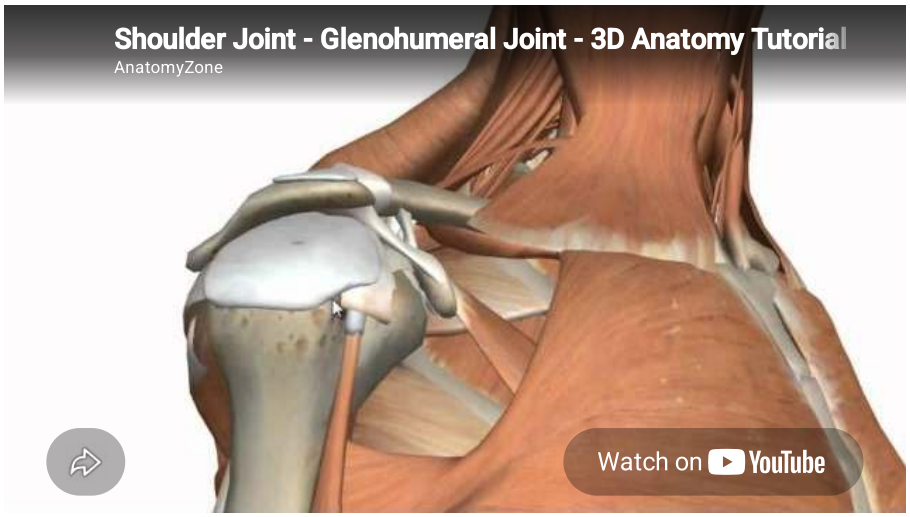
Interactive Link Questions

Watch this video to learn about TMJ. Opening of the mouth requires the combination of two motions at the temporomandibular joint, an anterior gliding motion of the articular disc and mandible and the downward hinging of the mandible. What is the initial movement of the mandible during opening and how much mouth opening does this produce?



Answer: The first motion is rotation (hinging) of the mandible, but this only produces about 20 mm (0.78 in) of mouth opening.

Watch this video for a tutorial on the anatomy of the shoulder joint. What movements are available at the shoulder joint?



Answer: The shoulder joint is a ball-and-socket joint that allows for flexion-extension, abduction-adduction, medial rotation, lateral rotation, and circumduction of the humerus.

Watch this video to learn about the anatomy of the shoulder joint, including bones, joints, muscles, nerves, and blood vessels. What is the shape of the glenoid labrum in cross-section, and what is the importance of this shape?

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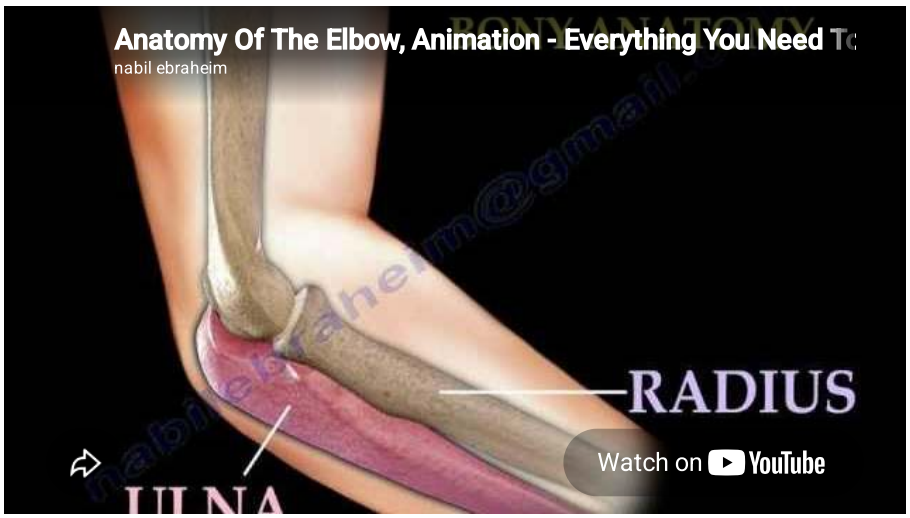
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Answer: The glenoid labrum is wedge-shaped in cross-section. This is important because it creates an elevated rim around the glenoid cavity, which creates a deeper socket for the head of the humerus to fit into.

Watch this animation to learn more about the anatomy of the elbow joint. What structures provide the main stability for the elbow?



Answer: The structures that stabilize the elbow include the coronoid process, the radial (lateral) collateral ligament, and the anterior portion of the ulnar (medial) collateral ligament.

Watch this video to learn more about the anatomy of the elbow joint, including bones, joints, muscles, nerves, and blood vessels. What are the functions of the articular cartilage?

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Answer: The articular cartilage functions to absorb shock and to provide an extremely smooth surface that makes movement between bones easy, without damaging the bones.

Watch this video for a tutorial on the anatomy of the hip joint. What is a possible consequence following a fracture of the femoral neck within the capsule of the hip joint?



Answer: An intracapsular fracture of the neck of the femur can result in disruption of the arterial blood supply to the head of the femur, which may lead to avascular necrosis of the femoral head.

Watch this video to learn more about the anatomy of the hip joint, including bones, joints, muscles, nerves, and blood vessels. Where is the articular cartilage thickest within the hip joint?

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Answer: The articular cartilage is thickest in the upper and back part of the acetabulum, the socket portion of the hip joint. These regions receive most of the force from the head of the femur during walking and running.

Watch this video to learn more about the flexion and extension of the knee, as the femur both rolls and glides on the tibia to maintain stable contact between the bones in all knee positions. The patella glides along a groove on the anterior side of the distal femur. The collateral ligaments on the sides of the knee become tight in the fully extended position to help stabilize the knee. The posterior cruciate ligament supports the knee when flexed and the anterior cruciate ligament becomes tight when the knee comes into full extension to resist hyperextension. What are the ligaments that support the knee joint?





Answer: There are five ligaments associated with the knee joint. The tibial collateral ligament is located on the medial side of the knee and the fibular collateral ligament is located on the lateral side. The anterior and posterior cruciate ligaments are located inside the knee joint.

Watch this video to learn more about the anatomy of the knee joint, including bones, joints, muscles, nerves, and blood vessels. Which ligament of the knee keeps the tibia from sliding too far forward in relation to the femur and which ligament keeps the tibia from sliding too far backward?

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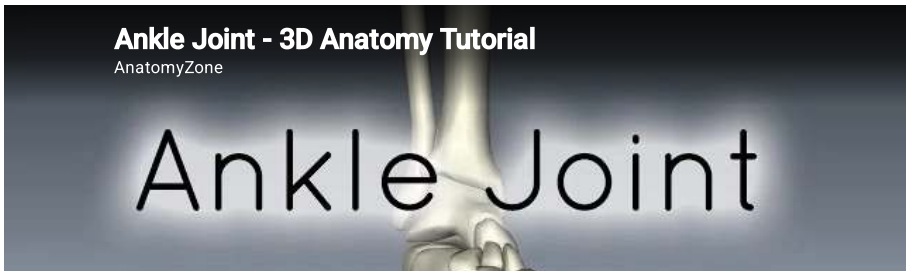
Answer: The anterior cruciate ligament prevents the tibia from sliding too far forward in relation to the femur and the posterior cruciate ligament keeps the tibia from sliding too far backward.

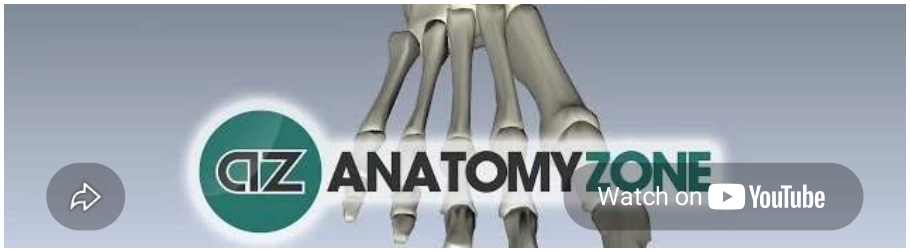
Watch this video to learn more about different knee injuries and diagnostic testing of the knee. What are the most causes of anterior cruciate ligament injury?



Answer: The anterior cruciate ligament (ACL) is most commonly injured when traumatic force is applied to the knee during a twisting motion or when side standing or landing from a jump.

Watch this video for a tutorial on the anatomy of the ankle joint. What are the three ligaments found on the lateral side of the ankle joint?





Answer: The ligaments of the lateral ankle are the anterior and posterior talofibular ligaments and the calcaneofibular ligament. These ligaments support the ankle joint and resist excess inversion of the foot.

Watch this video to learn more about the anatomy of the ankle joint, including bones, joints, muscles, nerves, and blood vessels. The ankle joint resembles what type of joint used in woodworking?

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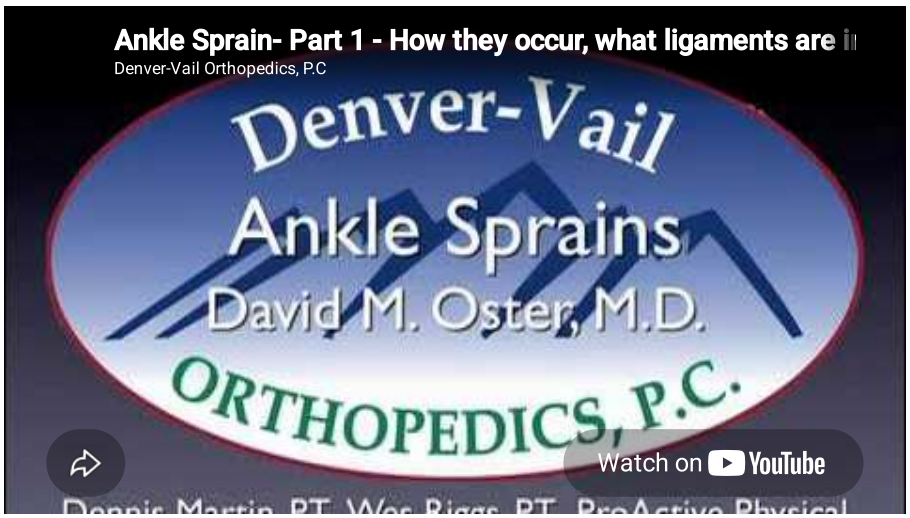
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Answer: Because of the square shape of the ankle joint, it has been compared to a mortise-and-tendon type of joint.

Watch this video to learn about the ligaments of the ankle joint, ankle sprains, and treatment. During an inversion ankle sprain injury, all three ligaments that resist excessive inversion of the foot may be injured. What is the sequence in which these three ligaments are injured?



Answer: QAn inversion ankle sprain may injure all three ligaments located on the lateral side of the ankle. The sequence of injury would be the anterior talofibular ligament first, followed by the calcaneofibular ligament second, and finally, the posterior talofibular ligament third.

Review Questions

Q. The primary support for the glenohumeral joint is provided by the _____.

A. coracohumeral ligament

B. glenoid labrum

C. rotator cuff muscles

D. subacromial bursa

Answer: C

Q. The proximal radioulnar joint _____.

A. is supported by the annular ligament

B. contains an articular disc that strongly unites the bones

C. is supported by the ulnar collateral ligament

D. is a hinge joint that allows for flexion/extension of the forearm

Answer: A

Q. Which statement is true concerning the knee joint?

A. The lateral meniscus is an intrinsic ligament located on the lateral side of the knee joint.

B. Hyperextension is resisted by the posterior cruciate ligament.

C. The anterior cruciate ligament supports the knee when it is flexed and weight bearing.

D. The medial meniscus is attached to the tibial collateral ligament.

Answer: D

Q. The ankle joint _____.

A. is also called the subtalar joint

B. allows for gliding movements that produce inversion/eversion of the foot

C. is a uniaxial hinge joint

D. is supported by the tibial collateral ligament on the lateral side

Answer: C

Q. Which region of the vertebral column has the *greatest* range of motion for rotation?

A. cervical

B. thoracic

C. lumbar

D. sacral

Answer: B

Critical Thinking Questions

Q. Discuss the structures that contribute to support of the shoulder joint.

A. The shoulder joint allows for a large range of motion. The primary support for the shoulder joint is provided by the four rotator cuff muscles. These muscles serve as “dynamic ligaments” and thus can modulate their strengths of contraction as needed to hold the head of the humerus in position at the glenoid fossa. Additional but weaker support comes from the coracohumeral ligament, an intrinsic ligament that supports the superior aspect of the shoulder joint, and the glenohumeral ligaments, which are intrinsic ligaments that support the anterior side of the joint.

Q. Describe the sequence of injuries that may occur if the extended, weight-bearing knee receives a very strong blow to the lateral side of the knee.

A. A strong blow to the lateral side of the extended knee will cause the medial side of the knee joint to open, resulting in a sequence of three injuries. First will be damage to the tibial collateral ligament. Since the medial meniscus is attached to the tibial collateral ligament, the meniscus is also injured. The third structure injured would be the anterior cruciate ligament.

Glossary

acetabular labrum
lip of fibrocartilage that surrounds outer margin of the acetabulum on the hip bone

annular ligament
intrinsic ligament of the elbow articular capsule that surrounds and supports the head of the radius at the proximal radioulnar joint

anterior cruciate ligament
intracapsular ligament of the knee; extends from anterior, superior surface of the tibia to the inner aspect of the lateral condyle of the femur; resists hyperextension of knee

anterior talofibular ligament
intrinsic ligament located on the lateral side of the ankle joint, between talus bone and lateral malleolus of fibula; supports talus at the talocrural joint and resists excess inversion of the foot

atlantoaxial joint
series of three articulations between the atlas (C1) vertebra and the axis (C2) vertebra, consisting of the joints between the inferior articular processes of C1 and the superior articular processes of C2, and the articulation between the dens of C2 and the anterior arch of C1

atlanto-occipital joint
articulation between the occipital condyles of the skull and the superior articular processes of the atlas (C1 vertebra)

calcaneofibular ligament
intrinsic ligament located on the lateral side of the ankle joint, between the calcaneus bone and lateral malleolus of the fibula; supports the talus bone at the ankle joint and resists excess inversion of the foot

coracohumeral ligament
intrinsic ligament of the shoulder joint; runs from the coracoid process of the scapula to the anterior humerus

deltoid ligament
broad intrinsic ligament located on the medial side of the ankle joint; supports the talus at the talocrural joint and resists excess eversion of the foot

elbow joint
humeroulnar joint

femoropatellar joint
portion of the knee joint consisting of the articulation between the distal femur and the patella

fibular collateral ligament
extrinsic ligament of the knee joint that spans from the lateral epicondyle of the femur to the head of the fibula; resists hyperextension and rotation of the extended knee

glenohumeral joint
shoulder joint; articulation between the glenoid cavity of the scapula and head of the humerus; multiaxial ball-and-socket joint that allows for flexion/extension, abduction/adduction, circumduction, and medial/lateral rotation of the humerus

glenohumeral ligament
one of the three intrinsic ligaments of the shoulder joint that strengthen the anterior articular capsule

glenoid labrum
lip of fibrocartilage located around the outside margin of the glenoid cavity of the scapula

humeroradial joint
articulation between the capitulum of the humerus and head of the radius

humeroulnar joint
articulation between the trochlea of humerus and the trochlear notch of the ulna; uniaxial hinge joint that allows for flexion/extension of the forearm

iliofemoral ligament
intrinsic ligament spanning from the ilium of the hip bone to the femur, on the superior-anterior aspect of the hip joint

ischiofemoral ligament
intrinsic ligament spanning from the ischium of the hip bone to the femur, on the posterior aspect of the hip joint

lateral meniscus
C-shaped fibrocartilage articular disc located at the knee, between the lateral condyle of the femur and the lateral condyle of the tibia

lateral tibiofemoral joint
portion of the knee consisting of the articulation between the lateral condyle of the tibia and the lateral condyle of the femur; allows for flexion/extension at the knee

ligament of the head of the femur
intracapsular ligament that runs from the acetabulum of the hip bone to the head of the femur

medial meniscus
C-shaped fibrocartilage articular disc located at the knee, between the medial condyle of the femur and medial condyle of the tibia

medial tibiofemoral joint
portion of the knee consisting of the articulation between the medial condyle of the tibia and the medial condyle of the femur; allows for flexion/extension at the knee

patellar ligament
ligament spanning from the patella to the anterior tibia; serves as the final attachment for the quadriceps femoris muscle

posterior cruciate ligament
intracapsular ligament of the knee; extends from the posterior, superior surface of the tibia to the inner aspect of the medial condyle of the femur; prevents anterior displacement of the femur when the knee is flexed and weight bearing

posterior talofibular ligament
intrinsic ligament located on the lateral side of the ankle joint, between the talus bone and lateral malleolus of the fibula; supports the talus at the talocrural joint and resists excess inversion of the foot

pubofemoral ligament
intrinsic ligament spanning from the pubis of the hip bone to the femur, on the anterior-inferior aspect of the hip joint

radial collateral ligament
intrinsic ligament on the lateral side of the elbow joint; runs from the lateral epicondyle of humerus to merge with the annular ligament

rotator cuff
strong connective tissue structure formed by the fusion of four rotator cuff muscle tendons to the articular capsule of the shoulder joint; surrounds and supports superior, anterior, lateral, and posterior sides of the humeral head

subacromial bursa
bursa that protects the supraspinatus muscle tendon and superior end of the humerus from rubbing against the acromion of the scapula

subscapular bursa
bursa that prevents rubbing of the subscapularis muscle tendon against the scapula

subtalar joint
articulation between the talus and calcaneus bones of the foot; allows motions that contribute to inversion/eversion of the foot

talocrural joint
ankle joint; articulation between the talus bone of the foot and medial malleolus of the tibia, distal tibia, and lateral malleolus of the fibula; a uniaxial hinge joint that allows only for dorsiflexion and plantar flexion of the foot

temporomandibular joint (TMJ)
articulation between the condyle of the mandible and the mandibular fossa and articular tubercle of the temporal bone of the skull; allows for depression/elevation (opening/closing of mouth), protraction/retraction, and side-to-side motions of the mandible

tibial collateral ligament
extrinsic ligament of knee joint that spans from the medial epicondyle of the femur to the medial tibia; resists hyperextension and rotation of extended knee

ulnar collateral ligament
intrinsic ligament on the medial side of the elbow joint; spans from the medial epicondyle of the humerus to the medial ulna

zygapophysial joints
facet joints; plane joints between the superior and inferior articular processes of adjacent vertebrae that provide for only limited motions between the vertebrae

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2.9: Bone Formation and Development

Learning Objectives

- Explain the function of cartilage
- List the steps of intramembranous ossification
- List the steps of endochondral ossification
- Explain the growth activity at the epiphyseal plate
- Compare and contrast the processes of modeling and remodeling

In the early stages of embryonic development, the embryo's skeleton consists of fibrous membranes and hyaline cartilage. By the sixth or seventh week of embryonic life, the actual process of bone development, **ossification** (osteogenesis), begins. There are two osteogenic pathways—intramembranous ossification and endochondral ossification—but bone is the same regardless of the pathway that produces it.

Cartilage Templates

Bone is a replacement tissue; that is, it uses a model tissue on which to lay down its mineral matrix. For skeletal development, the most common template is cartilage. During fetal development, a framework is laid down that determines where bones will form. This framework is a flexible, semi-solid matrix produced by chondroblasts and consists of hyaluronic acid, chondroitin sulfate, collagen fibers, and water. As the matrix surrounds and isolates chondroblasts, they are called chondrocytes. Unlike most connective tissues, cartilage is avascular, meaning that it has no blood vessels supplying nutrients and removing metabolic wastes. All of these functions are carried on by diffusion through the matrix. This is why damaged cartilage does not repair itself as readily as most tissues do.

Throughout fetal development and into childhood growth and development, bone forms on the cartilaginous matrix. By the time a fetus is born, most of the cartilage has been replaced with bone. Some additional cartilage will be replaced throughout childhood, and some cartilage remains in the adult skeleton.

Intramembranous Ossification

During **intramembranous ossification**, compact and spongy bone develops directly from sheets of mesenchymal (undifferentiated) connective tissue. The flat bones of the face, most of the cranial bones, and the clavicles (collarbones) are formed via intramembranous ossification.

The process begins when mesenchymal cells in the embryonic skeleton gather together and begin to differentiate into specialized cells (Figure 2.9.1.*a*). Some of these cells will differentiate into capillaries, while others will become osteogenic cells and then osteoblasts. Although they will ultimately be spread out by the formation of bone tissue, early osteoblasts appear in a cluster called an **ossification center**.

The osteoblasts secrete **osteoid**, uncalcified matrix, which calcifies (hardens) within a few days as mineral salts are deposited on it, thereby entrapping the osteoblasts within. Once entrapped, the osteoblasts become osteocytes (Figure 2.9.1.*b*). As osteoblasts transform into osteocytes, osteogenic cells in the surrounding connective tissue differentiate into new osteoblasts.

Osteoid (unmineralized bone matrix) secreted around the capillaries results in a trabecular matrix, while osteoblasts on the surface of the spongy bone become the periosteum (Figure 2.9.1.*c*). The periosteum then creates a protective layer of compact bone superficial to the trabecular bone. The trabecular bone crowds nearby blood vessels, which eventually condense into red marrow (Figure 2.9.1.*d*).

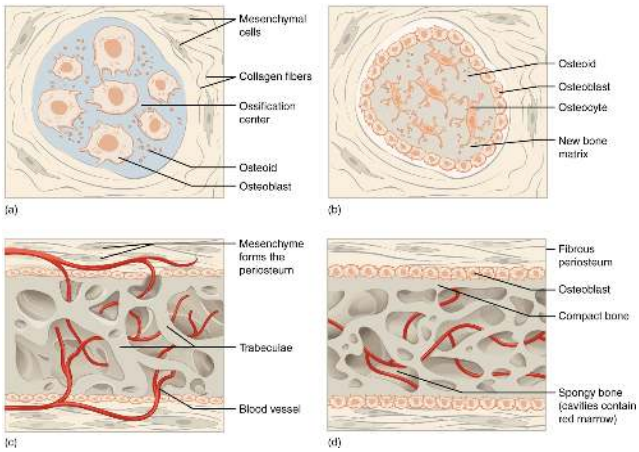


Figure 2.9.1: Intramembranous Ossification. Intramembranous ossification follows four steps. (a) Mesenchymal cells group into clusters, and ossification centers form. (b) Secreted osteoid traps osteoblasts, which then become osteocytes. (c) Trabecular matrix and periosteum form. (d) Compact bone develops superficial to the trabecular bone, and crowded blood vessels condense into red marrow.

Intramembranous ossification begins *in utero* during fetal development and continues on into adolescence. At birth, the skull and clavicles are not fully ossified nor are the sutures of the skull closed. This allows the skull and shoulders to deform during passage through the birth canal. The last bones to ossify via intramembranous ossification are the flat bones of the face, which reach their adult size at the end of the adolescent growth spurt.

Endochondral Ossification

In **endochondral ossification**, bone develops by *replacing* hyaline cartilage. Cartilage does not become bone. Instead, cartilage serves as a template to be completely replaced by new bone. Endochondral ossification takes much longer than intramembranous ossification. Bones at the base of the skull and long bones form via endochondral ossification.

In a long bone, for example, at about 6 to 8 weeks after conception, some of the mesenchymal cells differentiate into chondrocytes (cartilage cells) that form the cartilaginous skeletal precursor of the bones (Figure 2.9.2.*a*). Soon after, the **perichondrium**, a membrane that covers the cartilage, appears Figure 2.9.2.*b*).

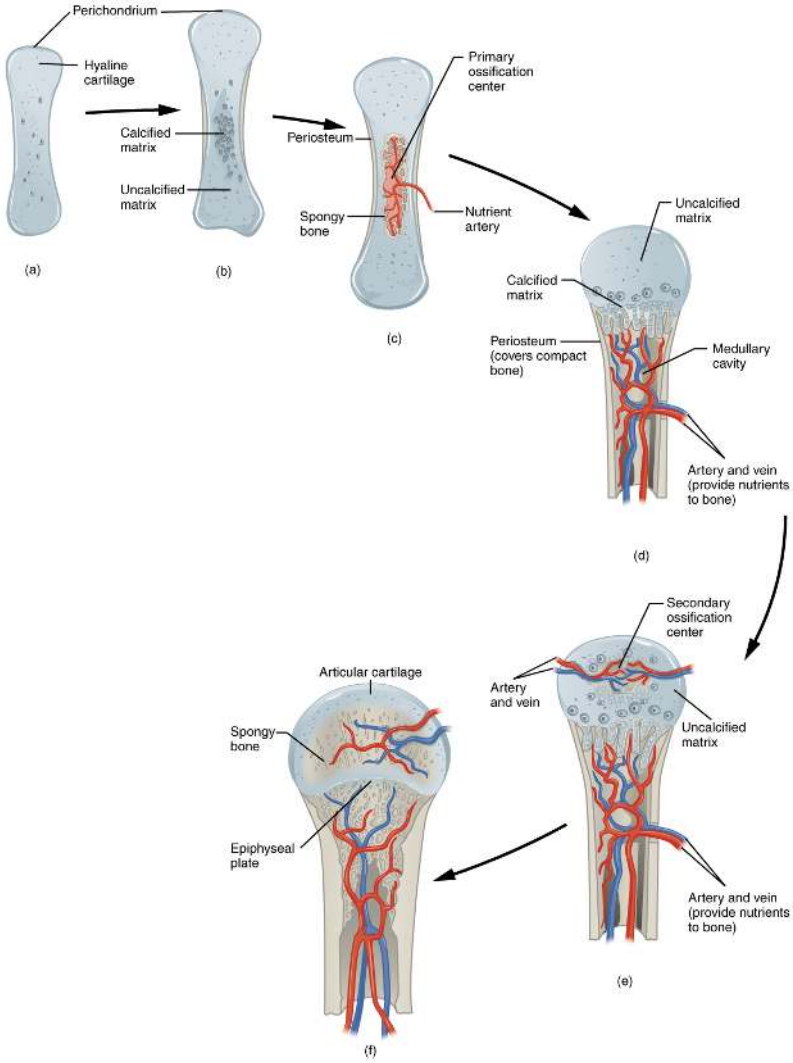


Figure 2.9.2: Endochondral Ossification.Endochondral ossification follows five steps. (a) Mesenchymal cells differentiate into chondrocytes. (b) The cartilage model of the future bony skeleton and the perichondrium form. (c) Capillaries penetrate cartilage. Perichondrium transforms into periosteum. Periosteal collar develops. Primary ossification center develops. (d) Cartilage and chondrocytes continue to grow at ends of the bone. (e) Secondary ossification centers develop. (f) Cartilage remains at epiphyseal (growth) plate and at joint surface as articular cartilage.

As more matrix is produced, the chondrocytes in the center of the cartilaginous model grow in size. As the matrix calcifies, nutrients can no longer reach the chondrocytes. This results in their death and the disintegration of the surrounding cartilage. Blood vessels invade the resulting spaces, not only enlarging the cavities but also carrying osteogenic cells with them, many of which will become osteoblasts. These enlarging spaces eventually combine to become the medullary cavity.

As the cartilage grows, capillaries penetrate it. This penetration initiates the transformation of the perichondrium into the bone-producing periosteum. Here, the osteoblasts form a periosteal collar of compact bone around the cartilage of the diaphysis. By the second or third month of fetal life, bone cell development and ossification ramps up and creates the **primary ossification center**, a region deep in the periosteal collar where ossification begins (Figure 2.9.2.*c*).

While these deep changes are occurring, chondrocytes and cartilage continue to grow at the ends of the bone (the future epiphyses), which increases the bone's length at the same time bone is replacing cartilage in the diaphyses. By the time the fetal skeleton is fully formed, cartilage only remains at the joint surface as articular cartilage and between the diaphysis and epiphysis as the epiphyseal plate, the latter of which is responsible for the

longitudinal growth of bones. After birth, this same sequence of events (matrix mineralization, death of chondrocytes, invasion of blood vessels from the periosteum, and seeding with osteogenic cells that become osteoblasts) occurs in the epiphyseal regions, and each of these centers of activity is referred to as a **secondary ossification center** (Figure 2.9.2.*e*).

How Bones Grow in Length

The epiphyseal plate is the area of growth in a long bone. It is a layer of hyaline cartilage where ossification occurs in immature bones. On the epiphyseal side of the epiphyseal plate, cartilage is formed. On the diaphyseal side, cartilage is ossified, and the diaphysis grows in length. The epiphyseal plate is composed of four zones of cells and activity (Figure 2.9.3). The **reserve zone** is the region closest to the epiphyseal end of the plate and contains small chondrocytes within the matrix. These chondrocytes do not participate in bone growth but secure the epiphyseal plate to the osseous tissue of the epiphysis.

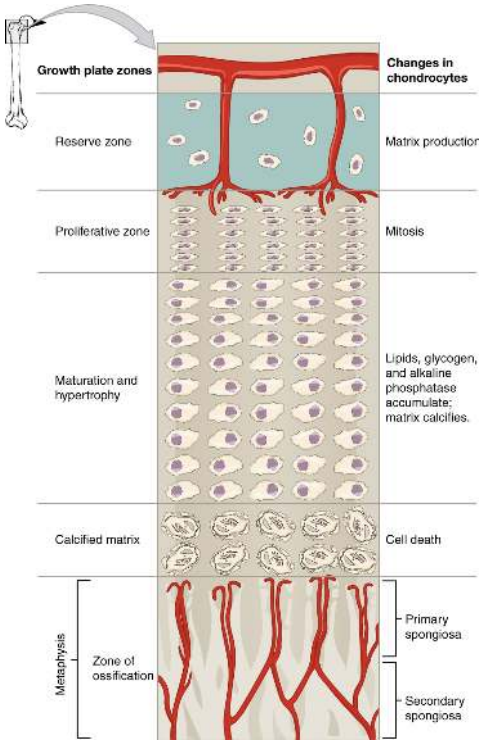


Figure 2.9.3: Longitudinal Bone Growth.The epiphyseal plate is responsible for longitudinal bone growth.

The **proliferative zone** is the next layer toward the diaphysis and contains stacks of slightly larger chondrocytes. It makes new chondrocytes (via mitosis) to replace those that die at the diaphyseal end of the plate. Chondrocytes in the next layer, the **zone of maturation and hypertrophy**, are older and larger than those in the proliferative zone. The more mature cells are situated closer to the diaphyseal end of the plate. The longitudinal growth of bone is a result of cellular division in the proliferative zone and the maturation of cells in the zone of maturation and hypertrophy.

Most of the chondrocytes in the **zone of calcified matrix**, the zone closest to the diaphysis, are dead because the matrix around them has calcified. Capillaries and osteoblasts from the diaphysis penetrate this zone, and the osteoblasts secrete bone tissue on the remaining calcified cartilage. Thus, the zone of calcified matrix connects the epiphyseal plate to the diaphysis. A bone grows in length when osseous tissue is added to the diaphysis.

Bones continue to grow in length until early adulthood. The rate of growth is controlled by hormones, which will be discussed later. When the chondrocytes in the epiphyseal plate cease their proliferation and bone replaces the cartilage, longitudinal growth stops. All that remains of the epiphyseal plate is the **epiphyseal line** (Figure 2.9.4).

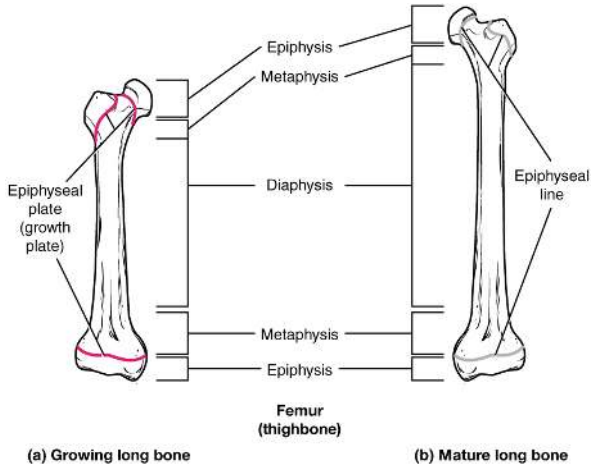


Figure 2.9.4: Progression from Epiphyseal Plate to Epiphyseal Line.As a bone matures, the epiphyseal plate progresses to an epiphyseal line. (a) Epiphyseal plates are visible in a growing bone. (b) Epiphyseal lines are the remnants of epiphyseal plates in a mature bone.

How Bones Grow in Diameter

While bones are increasing in length, they are also increasing in diameter; growth in diameter can continue even after longitudinal growth ceases. This is called appositional growth. Osteoclasts resorb old bone that lines the medullary cavity, while osteoblasts, via intramembranous ossification, produce new bone tissue beneath the periosteum. The erosion of old bone along the medullary cavity and the deposition of new bone beneath the periosteum not only increase the diameter of the diaphysis but also increase the diameter of the medullary cavity. This process is called **modeling**.

Bone Remodeling

The process in which matrix is resorbed on one surface of a bone and deposited on another is known as bone modeling. Modeling primarily takes place during a bone's growth. However, in adult life, bone undergoes **remodeling**, in which resorption of old or damaged bone takes place on the same surface where osteoblasts lay new bone to replace that which is resorbed. Injury, exercise, and other activities lead to remodeling. Those influences are discussed later in the chapter, but even without injury or exercise, about 5 to 10 percent of the skeleton is remodeled annually just by destroying old bone and renewing it with fresh bone.

DISEASES OF THE... Skeletal System

Osteogenesis imperfecta (OI) is a genetic disease in which bones do not form properly and therefore are fragile and break easily. It is also called *brittle bone disease*. The disease is present from birth and affects a person throughout life.

The genetic mutation that causes OI affects the body's production of collagen, one of the critical components of bone matrix. The severity of the disease can range from mild to severe. Those with the most severe forms of the disease sustain many more fractures than those with a mild form. Frequent and multiple fractures typically lead to bone deformities and short stature. Bowing of the long bones and curvature of the spine are also common in people afflicted with OI. Curvature of the spine makes breathing difficult because the lungs are compressed.

Because collagen is such an important structural protein in many parts of the body, people with OI may also experience fragile skin, weak muscles, loose joints, easy bruising, frequent nosebleeds, brittle teeth, blue sclera, and hearing loss. There is no known cure for OI. Treatment focuses on helping the person retain as much independence as possible while minimizing fractures and maximizing mobility. Toward that end, safe exercises, like swimming, in which the body is less likely to experience collisions or compressive forces, are recommended. Braces to support legs, ankles, knees, and wrists are used as needed. Canes, walkers, or wheelchairs can also help compensate for weaknesses.

When bones do break, casts, splints, or wraps are used. In some cases, metal rods may be surgically implanted into the long bones of the arms and legs. Research is currently being conducted on using bisphosphonates to treat OI. Smoking and being overweight are especially risky in people with OI, since smoking is known to weaken bones, and extra body weight puts additional stress on the bones.

QR Code representing a URL



Watch this video to see how a bone grows

Chapter Review

All bone formation is a replacement process. Embryos develop a cartilaginous skeleton and various membranes. During development, these are replaced by bone during the ossification process. In intramembranous ossification, bone develops directly from sheets of mesenchymal connective tissue. In endochondral ossification, bone develops by replacing hyaline cartilage. Activity in the epiphyseal plate enables bones to grow in length. Modeling allows bones to grow in diameter. Remodeling occurs as bone is resorbed and replaced by new bone. Osteogenesis imperfecta is a genetic disease in which collagen production is altered, resulting in fragile, brittle bones.

Review Questions

Q. Why is cartilage slow to heal?

A. because it eventually develops into bone

B. because it is semi-solid and flexible

C. because it does not have a blood supply

D. because endochondral ossification replaces all cartilage with bone

Answer: C

Q. Why are osteocytes spread out in bone tissue?

A. They develop from mesenchymal cells.

B. They are surrounded by osteoid.

C. They travel through the capillaries.

D. Formation of osteoid spreads out the osteoblasts that formed the ossification centers.

Answer: D

Q. In endochondral ossification, what happens to the chondrocytes?

A. They develop into osteocytes.

B. They die in the calcified matrix that surrounds them and form the medullary cavity.

C. They grow and form the periosteum.

D. They group together to form the primary ossification center.

Answer: B

Q. Which of the following bones is (are) formed by intramembranous ossification?

A. the metatarsals

B. the femur

C. the ribs

D. the flat bones of the cranium

Answer: D

Q. Bones grow in length due to activity in the _____.

A. epiphyseal plate

B. perichondrium

C. periosteum

D. medullary cavity

Answer: A

Q. Bones grow in diameter due to bone formation _____.

A. in the medullary cavity

B. beneath the periosteum

C. in the epiphyseal plate

D. within the metaphysis

Answer: B

Q. Which of the following represents the correct sequence of zones in the epiphyseal plate?

A. proliferation, reserved, maturation, calcification

B. maturation, proliferation, reserved, calcification

C. calcification, maturation, proliferation, reserved

D. calcification, reserved, proliferation, maturation

Answer: C

Critical Thinking Questions

Q. In what ways do intramembranous and endochondral ossification differ?

A. In intramembranous ossification, bone develops directly from sheets of mesenchymal connective tissue, but in endochondral ossification, bone develops by replacing hyaline cartilage. Intramembranous ossification is complete by the end of the adolescent growth spurt, while endochondral ossification lasts into young adulthood. The flat bones of the face, most of the cranial bones, and a good deal of the clavicles (collarbones) are formed via intramembranous ossification, while bones at the base of the skull and the long bones form via endochondral ossification.

Q. Considering how a long bone develops, what are the similarities and differences between a primary and a secondary ossification center?

A. A single primary ossification center is present, during endochondral ossification, deep in the periosteal collar. Like the primary ossification center, secondary ossification centers are present during endochondral ossification, but they form later, and there are two of them, one in each epiphysis.

Glossary

endochondral ossification
process in which bone forms by replacing hyaline cartilage

epiphyseal line
completely ossified remnant of the epiphyseal plate

intramembranous ossification

process by which bone forms directly from mesenchymal tissue

modeling
process, during bone growth, by which bone is resorbed on one surface of a bone and deposited on another

ossification
(also, osteogenesis) bone formation

ossification center
cluster of osteoblasts found in the early stages of intramembranous ossification

osteoid
uncalcified bone matrix secreted by osteoblasts

perichondrium
membrane that covers cartilage

primary ossification center
region, deep in the periosteal collar, where bone development starts during endochondral ossification

proliferative zone
region of the epiphyseal plate that makes new chondrocytes to replace those that die at the diaphyseal end of the plate and contributes to longitudinal growth of the epiphyseal plate

remodeling
process by which osteoclasts resorb old or damaged bone at the same time as and on the same surface where osteoblasts form new bone to replace that which is resorbed

reserve zone
region of the epiphyseal plate that anchors the plate to the osseous tissue of the epiphysis

secondary ossification center
region of bone development in the epiphyses

zone of calcified matrix
region of the epiphyseal plate closest to the diaphyseal end; functions to connect the epiphyseal plate to the diaphysis

zone of maturation and hypertrophy
region of the epiphyseal plate where chondrocytes from the proliferative zone grow and mature and contribute to the longitudinal growth of the epiphyseal plate

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2.10: Fractures - Bone Repair

Learning Objectives

- Differentiate among the different types of fractures
- Describe the steps involved in bone repair

A **fracture** is a broken bone. It will heal whether or not a physician resets it in its anatomical position. If the bone is not reset correctly, the healing process will keep the bone in its deformed position. When a broken bone is manipulated and set into its natural position without surgery, the procedure is called a **closed reduction**. **Open reduction** requires surgery to expose the fracture and reset the bone. While some fractures can be minor, others are quite severe and result in grave complications. For example, a fractured diaphysis of the femur has the potential to release fat globules into the bloodstream. These can become lodged in the capillary beds of the lungs, leading to respiratory distress and if not treated quickly, death.

Types of Fractures

Fractures are classified by their complexity, location, and other features (Figure 2.10.1). Table 2.10.1 outlines common types of fractures. Some fractures may be described using more than one term because it may have the features of more than one type (e.g., an open transverse fracture).

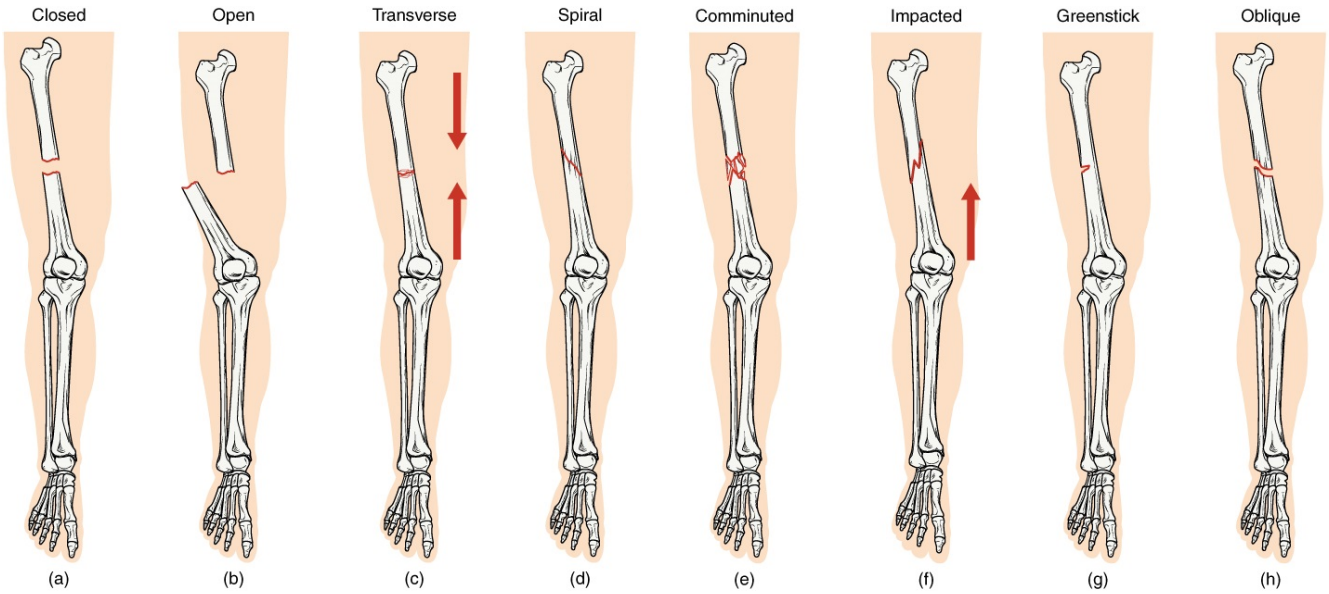


***Figure** 2.10.1**:** Types of Fractures. Compare healthy bone with different types of fractures: (a) closed fracture, (b) open fracture, (c) transverse fracture, (d) spiral fracture, (e) comminuted fracture, (f) impacted fracture, (g) greenstick fracture, and (h) oblique fracture.*

Table 2.10.1: Types of Fractures

Type of fracture	Description
Transverse	Occurs straight across the long axis of the bone
Oblique	Occurs at an angle that is not 90 degrees
Spiral	Bone segments are pulled apart as a result of a twisting motion
Comminuted	Several breaks result in many small pieces between two large segments
Impacted	One fragment is driven into the other, usually as a result of compression

Type of fracture	Description
Greenstick	A partial fracture in which only one side of the bone is broken
Open (or compound)	A fracture in which at least one end of the broken bone tears through the skin; carries a high risk of infection
Closed (or simple)	A fracture in which the skin remains intact

Bone Repair

When a bone breaks, blood flows from any vessel torn by the fracture. These vessels could be in the periosteum, osteons, and/or medullary cavity. The blood begins to clot, and about six to eight hours after the fracture, the clotting blood has formed a **fracture hematoma** (Figure 2.10.2.a). The disruption of blood flow to the bone results in the death of bone cells around the fracture.

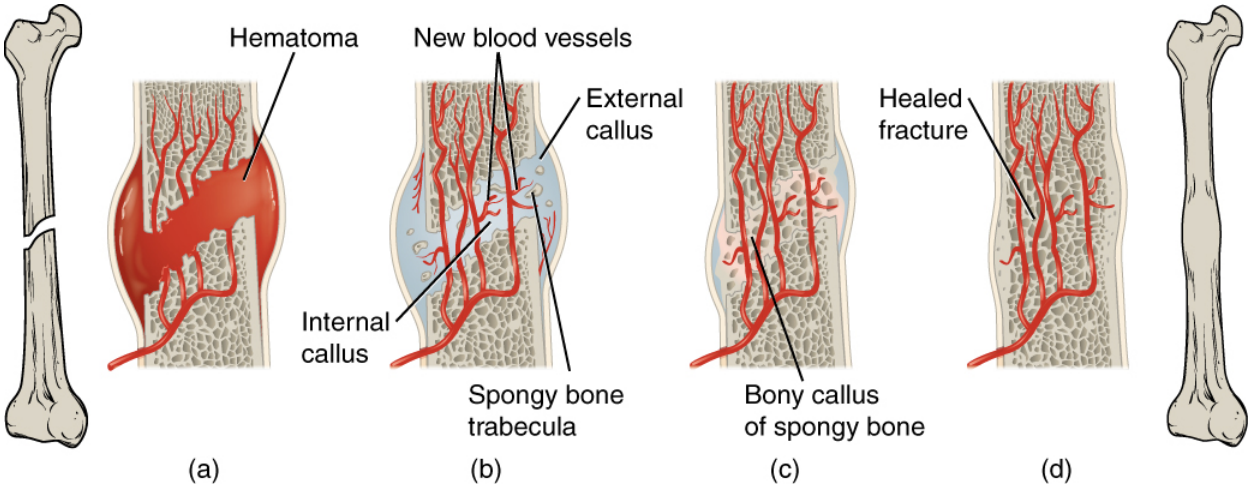


Figure 2.10.2: Stages in Fracture Repair. The healing of a bone fracture follows a series of progressive steps: (a) A fracture hematoma forms. (b) Internal and external calli form. (c) Cartilage of the calli is replaced by trabecular bone. (d) Remodeling occurs.

Within about 48 hours after the fracture, chondrocytes from the endosteum have created an **internal callus** (plural = calli) by secreting a fibrocartilaginous matrix between the two ends of the broken bone, while the periosteal chondrocytes and osteoblasts create an **external callus** of hyaline cartilage and bone, respectively, around the outside of the break (Figure 2.10.2.b). This stabilizes the fracture.

Over the next several weeks, osteoclasts resorb the dead bone; osteogenic cells become active, divide, and differentiate into osteoblasts. The cartilage in the calli is replaced by trabecular bone via endochondral ossification (Figure 2.10.2.c).

Eventually, the internal and external calli unite, compact bone replaces spongy bone at the outer margins of the fracture, and healing is complete. A slight swelling may remain on the outer surface of the bone, but quite often, that region undergoes remodeling (Figure 2.10.2.d), and no external evidence of the fracture remains.

Visit this website to review different types of fractures and then take a short self-assessment quiz.

Chapter Review

Fractured bones may be repaired by closed reduction or open reduction. Fractures are classified by their complexity, location, and other features. Common types of fractures are transverse, oblique, spiral, comminuted, impacted, greenstick, open (or compound), and closed (or simple). Healing of fractures begins with the formation of a hematoma, followed by internal and external calli. Osteoclasts resorb dead bone, while osteoblasts create new bone that replaces the cartilage in the calli. The calli eventually unite, remodeling occurs, and healing is complete.

Review Questions

Q. A fracture can be both _____.

A. open and closed

B. open and transverse

C. transverse and greenstick

D. greenstick and comminuted

Answer: B

Q. How can a fractured diaphysis release fat globules into the bloodstream?

A. The bone pierces fat stores in the skin.

B. The yellow marrow in the diaphysis is exposed and damaged.

C. The injury triggers the body to release fat from healthy bones.

D. The red marrow in the fractured bone releases fat to heal the fracture.

Answer: B

Q. In a compound fracture, _____.

A. the break occurs at an angle to the bone

B. the broken bone does not tear the skin

C. one fragment of broken bone is compressed into the other

D. broken bone pierces the skin

Answer: D

Q. The internal and external calli are replaced by _____.

A. hyaline cartilage

B. trabecular bone

C. osteogenic cells

D. osteoclasts

Answer: B

Q. The first type of bone to form during fracture repair is _____ bone.

A. compact

B. lamellar

C. spongy

D. dense

Answer: C

Critical Thinking Questions

Q. What is the difference between closed reduction and open reduction? In what type of fracture would closed reduction most likely occur? In what type of fracture would open reduction most likely occur?

A. In closed reduction, the broken ends of a fractured bone can be reset without surgery. Open reduction requires surgery to return the broken ends of the bone to their correct anatomical position. A partial fracture would likely require closed reduction. A compound fracture would require open reduction.

Q. In terms of origin and composition, what are the differences between an internal callus and an external callus?

A. The internal callus is produced by cells in the endosteum and is composed of a fibrocartilaginous matrix. The external callus is produced by cells in the periosteum and consists of hyaline cartilage and bone.

Glossary

closed reduction
manual manipulation of a broken bone to set it into its natural position without surgery

external callus
collar of hyaline cartilage and bone that forms around the outside of a fracture

fracture
broken bone

fracture hematoma
blood clot that forms at the site of a broken bone

internal callus
fibrocartilaginous matrix, in the endosteal region, between the two ends of a broken bone

open reduction
surgical exposure of a bone to reset a fracture

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CHAPTER OVERVIEW

3: The Nervous System

3.1: Basic Structures and Function of the Nervous System
3.2: Nervous Tissue
3.3: Spinal Nerves
3.3A: Overview of the Spinal Nerves
3.3B: Branches of Spinal Nerves
3.3C: Plexuses
3.3D: Intercostal Nerves
3.3E: Dermatomes
3.3F: Function and Physiology of the Spinal Nerves
3.4: The Central Nervous System
3.4A: The Cranial Nerve Exam
3.5: Circulation and the Central Nervous System

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3.1: Basic Structures and Function of the Nervous System

Learning Objectives

- Identify the anatomical and functional divisions of the nervous system
- Relate the functional and structural differences between gray matter and white matter structures of the nervous system to the structure of neurons
- List the basic functions of the nervous system

The picture you have in your mind of the nervous system probably includes the **brain**, the nervous tissue contained within the cranium, and the **spinal cord**, the extension of nervous tissue within the vertebral column. That suggests it is made of two organs—and you may not even think of the spinal cord as an organ—but the nervous system is a very complex structure. Within the brain, many different and separate regions are responsible for many different and separate functions. It is as if the nervous system is composed of many organs that all look similar and can only be differentiated using tools such as the microscope or electrophysiology. In comparison, it is easy to see that the stomach is different than the esophagus or the liver, so you can imagine the digestive system as a collection of specific organs.

The Central and Peripheral Nervous Systems

The nervous system can be divided into two major regions: the central and peripheral nervous systems. The **central nervous system (CNS)** is the brain and spinal cord, and the **peripheral nervous system (PNS)** is everything else (Figure 3.1.1). The brain is contained within the cranial cavity of the skull, and the spinal cord is contained within the vertebral cavity of the vertebral column. It is a bit of an oversimplification to say that the CNS is what is inside these two cavities and the peripheral nervous system is outside of them, but that is one way to start to think about it. In actuality, there are some elements of the peripheral nervous system that are within the cranial or vertebral cavities. The peripheral nervous system is so named because it is on the periphery—meaning beyond the brain and spinal cord. Depending on different aspects of the nervous system, the dividing line between central and peripheral is not necessarily universal.

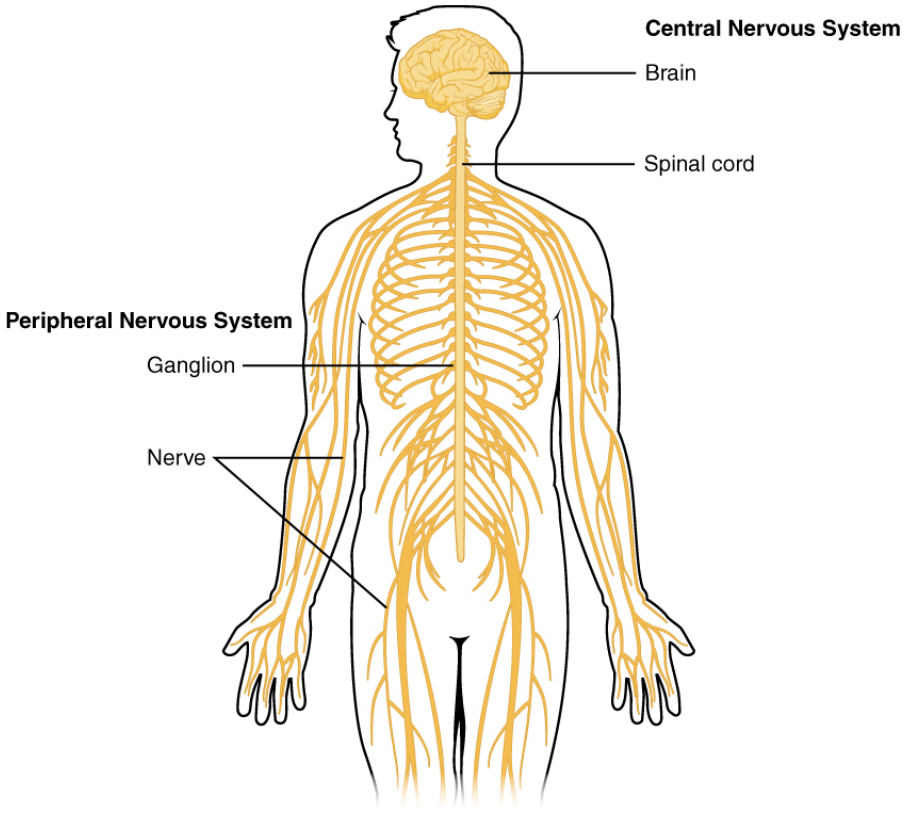


***Figure** 3.1.1**: Central and Peripheral Nervous System.** The structures of the PNS are referred to as ganglia and nerves, which can be seen as distinct structures. The equivalent structures in the CNS are not obvious from this overall perspective and are best examined in prepared tissue under the microscope.*

Nervous tissue, present in both the CNS and PNS, contains two basic types of cells: neurons and glial cells. A **glial cell** is one of a variety of cells that provide a framework of tissue that supports the neurons and their activities. The **neuron** is the more functionally important of the two, in terms of the communicative function of the nervous system. To describe the functional divisions of the nervous system, it is important to understand the structure of a neuron. Neurons are cells and therefore have a **soma**, or cell body, but they also have extensions of the cell; each extension is generally

referred to as a **process**. There is one important process that every neuron has called an **axon**, which is the fiber that connects a neuron with its target. Another type of process that branches off from the soma is the **dendrite**. Dendrites are responsible for receiving most of the input from other neurons. Looking at nervous tissue, there are regions that predominantly contain cell bodies and regions that are largely composed of just axons. These two regions within nervous system structures are often referred to as **gray matter** (the regions with many cell bodies and dendrites) or **white matter** (the regions with many axons). Figure 3.1.2 demonstrates the appearance of these regions in the brain and spinal cord. The colors ascribed to these regions are what would be seen in "fresh," or unstained, nervous tissue. Gray matter is not necessarily gray. It can be pinkish because of blood content, or even slightly tan, depending on how long the tissue has been preserved. But white matter is white because axons are insulated by a lipid-rich substance called **myelin**. Lipids can appear as white ("fatty") material, much like the fat on a raw piece of chicken or beef. Actually, gray matter may have that color ascribed to it because next to the white matter, it is just darker—hence, gray.

The distinction between gray matter and white matter is most often applied to central nervous tissue, which has large regions that can be seen with the unaided eye. When looking at peripheral structures, often a microscope is used and the tissue is stained with artificial colors. That is not to say that central nervous tissue cannot be stained and viewed under a microscope, but unstained tissue is most likely from the CNS—for example, a frontal section of the brain or cross section of the spinal cord.

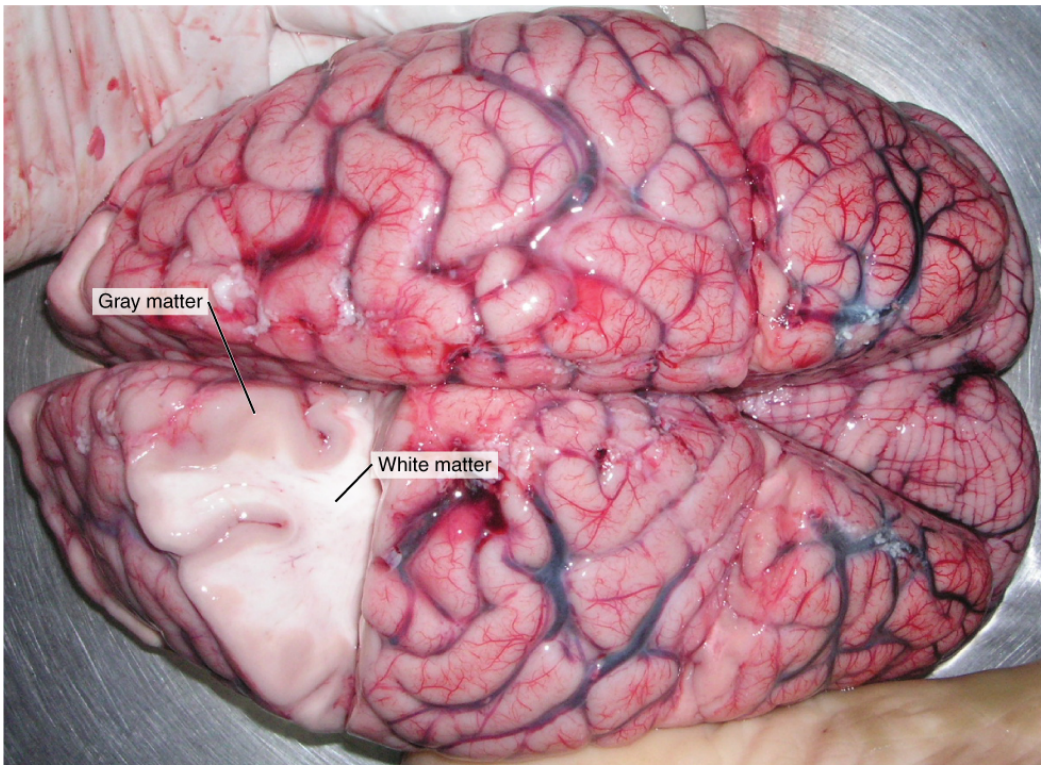


***Figure** 3.1.2**: Gray Matter and White Matter.** A brain removed during an autopsy, with a partial section removed, shows white matter surrounded by gray matter. Gray matter makes up the outer cortex of the brain. (credit: modification of work by "Suseno"/Wikimedia Commons)*

Regardless of the appearance of stained or unstained tissue, the cell bodies of neurons or axons can be located in discrete anatomical structures that need to be named. Those names are specific to whether the structure is central or peripheral. A localized collection of neuron cell bodies in the CNS is referred to as a **nucleus**. In the PNS, a cluster of neuron cell bodies is referred to as a **ganglion**. Figure 3.1.3 indicates how the term nucleus has a few different meanings within anatomy and physiology. It is the center of an atom, where protons and neutrons are found; it is the center of a cell, where the DNA is found; and it is a center of some function in the CNS. There is also a potentially confusing use of the word ganglion (plural = ganglia) that has a historical explanation. In the central nervous system, there is a group of nuclei that are connected together and were once called the basal ganglia before "ganglion" became accepted as a description for a peripheral structure. Some sources refer to this group of nuclei as the "basal nuclei" to avoid confusion.

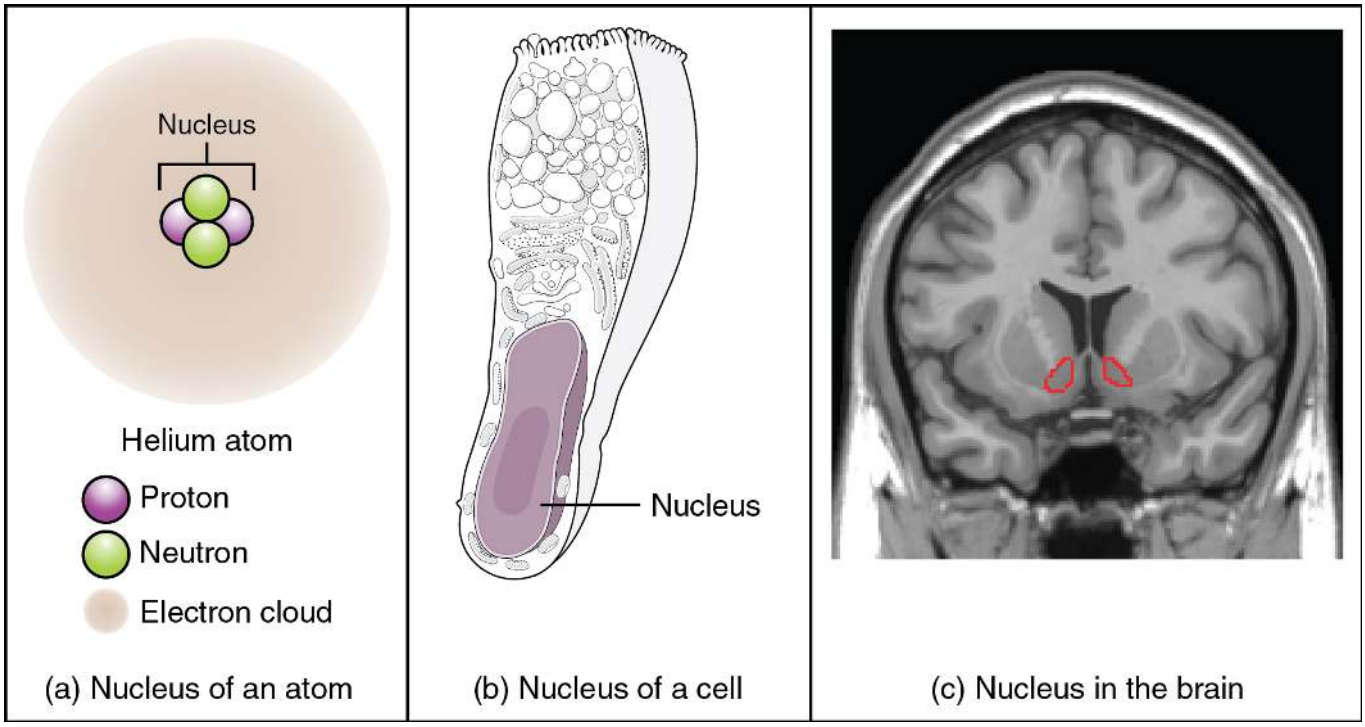


Figure 3.1.3: What Is a Nucleus? (a) The nucleus of an atom contains its protons and neutrons. (b) The nucleus of a cell is the organelle that contains DNA. (c) A nucleus in the CNS is a localized center of function with the cell bodies of several neurons, shown here circled in red. (credit c: "Was a bee"/Wikimedia Commons)

Terminology applied to bundles of axons also differs depending on location. A bundle of axons, or fibers, found in the CNS is called a **tract** whereas the same thing in the PNS would be called a **nerve**. There is an important point to make about these terms, which is that they can both be used to refer to the same bundle of axons. When those axons are in the PNS, the term is nerve, but if they are CNS, the term is tract. The most obvious example of this is the axons that project from the retina into the brain. Those axons are called the optic nerve as they leave the eye, but when they are inside the cranium, they are referred to as the optic tract. There is a specific place where the name changes, which is the optic chiasm, but they are still the same axons (Figure 3.1.4). A similar situation outside of science can be described for some roads. Imagine a road called "Broad Street" in a town called "Anyville." The road leaves Anyville and goes to the next town over, called "Hometown." When the road crosses the line between the two towns and is in Hometown, its name changes to "Main Street." That is the idea behind the naming of the retinal axons. In the PNS, they are called the optic nerve, and in the CNS, they are the optic tract. Table 3.1.1 helps to clarify which of these terms apply to the central or peripheral nervous systems.

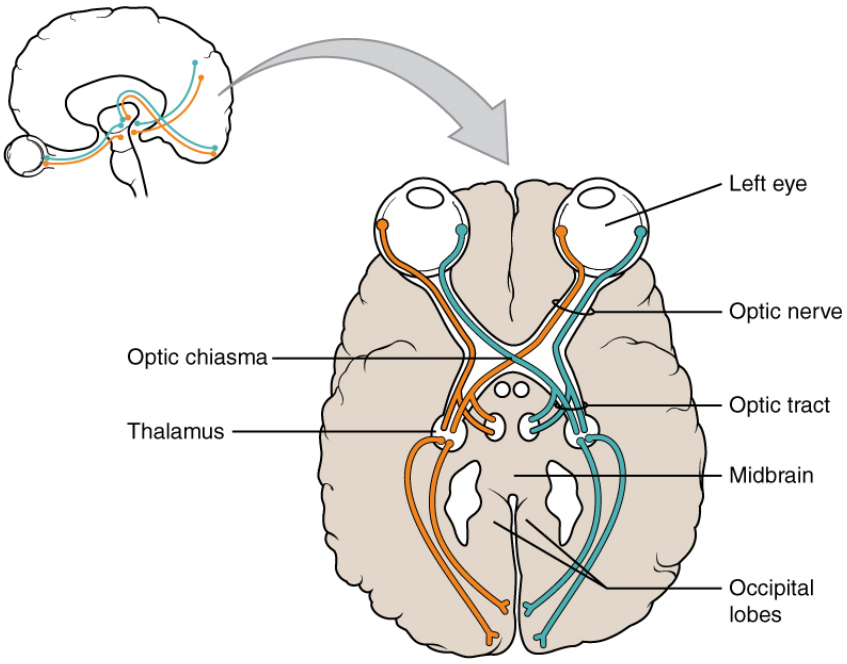


***Figure** 3.1.4**: Optic Nerve Versus Optic Tract.** This drawing of the connections of the eye to the brain shows the optic nerve extending from the eye to the chiasm, where the structure continues as the optic tract. The same axons extend from the eye to the brain through these two bundles of fibers, but the chiasm represents the border between peripheral and central.*

magnetic resonance imaging

In 2003, the Nobel Prize in Physiology or Medicine was awarded to Paul C. Lauterbur and Sir Peter Mansfield for discoveries related to magnetic resonance imaging (MRI). This is a tool to see the structures of the body (not just the nervous system) that depends on magnetic fields associated with certain atomic nuclei. The utility of this technique in the nervous system is that fat tissue and water appear as different shades between black and white. Because white matter is fatty (from myelin) and gray matter is not, they can be easily distinguished in MRI images. Visit the Nobel Prize web site to play an interactive game that demonstrates the use of this technology and compares it with other types of imaging technologies. Also, the results from an MRI session are compared with images obtained from X-ray or computed tomography. How do the imaging techniques shown in this game indicate the separation of white and gray matter compared with the freshly dissected tissue shown earlier?

Table 3.1.1: Structures of the CNS and PNS

	CNS	PNS
Group of Neuron Cell Bodies (i.e., gray matter)	Nucleus	Ganglion
Bundle of Axons (i.e., white matter)	Tract	Nerve

Functional Divisions of the Nervous System

The nervous system can also be divided on the basis of its functions, but anatomical divisions and functional divisions are different. The CNS and the PNS both contribute to the same functions, but those functions can be attributed to different regions of the brain (such as the cerebral cortex or the hypothalamus) or to different ganglia in the periphery. The problem with trying to fit functional differences into anatomical divisions is that sometimes the same structure can be part of several functions. For example, the optic nerve carries signals from the retina that are either used for the conscious perception of visual stimuli, which takes place in the cerebral cortex, or for the reflexive responses of smooth muscle tissue that are processed through the hypothalamus.

There are two ways to consider how the nervous system is divided functionally. First, the basic functions of the nervous system are sensation, integration, and response. Secondly, control of the body can be somatic or autonomic—divisions that are largely defined by the structures that are involved in the response. There is also a region of the peripheral nervous system that is called the enteric nervous system that is responsible for a specific set of the functions within the realm of autonomic control related to gastrointestinal functions.

Basic Functions

The nervous system is involved in receiving information about the environment around us (sensation) and generating responses to that information (motor responses). The nervous system can be divided into regions that are responsible for **sensation** (sensory functions) and for the **response** (motor functions). But there is a third function that needs to be included. Sensory input needs to be integrated with other sensations, as well as with memories, emotional state, or learning (cognition). Some regions of the nervous system are termed **integration** or association areas. The process of integration combines sensory perceptions and higher cognitive functions such as memories, learning, and emotion to produce a response.

Sensation. The first major function of the nervous system is sensation—receiving information about the environment to gain input about what is happening outside the body (or, sometimes, within the body). The sensory functions of the nervous system register the presence of a change from homeostasis or a particular event in the environment, known as a **stimulus**. The senses we think of most are the “big five”: taste, smell, touch, sight, and hearing. The stimuli for taste and smell are both chemical substances (molecules, compounds, ions, etc.), touch is physical or mechanical stimuli that interact with the skin, sight is light stimuli, and hearing is the perception of sound, which is a physical stimulus similar to some aspects of touch. There are actually more senses than just those, but that list represents the major senses. Those five are all senses that receive stimuli from the outside world, and of which there is conscious perception. Additional sensory stimuli might be from the internal environment (inside the body), such as the stretch of an organ wall or the concentration of certain ions in the blood.

Response. The nervous system produces a response on the basis of the stimuli perceived by sensory structures. An obvious response would be the movement of muscles, such as withdrawing a hand from a hot stove, but there are broader uses of the term. The nervous system can cause the contraction of all three types of muscle tissue. For example, skeletal muscle contracts to move the skeleton, cardiac muscle is influenced as heart rate increases during exercise, and smooth muscle contracts as the digestive system moves food along the digestive tract. Responses also include the neural control of glands in the body as well, such as the production and secretion of sweat by the eccrine and merocrine sweat glands found in the skin to lower body temperature.

Responses can be divided into those that are voluntary or conscious (contraction of skeletal muscle) and those that are involuntary (contraction of smooth muscles, regulation of cardiac muscle, activation of glands). Voluntary responses are governed by the somatic nervous system and involuntary responses are governed by the autonomic nervous system, which are discussed in the next section.

Integration. Stimuli that are received by sensory structures are communicated to the nervous system where that information is processed. This is called integration. Stimuli are compared with, or integrated with, other stimuli, memories of previous stimuli, or the state of a person at a particular time. This leads to the specific response that will be generated. Seeing a baseball pitched to a batter will not automatically cause the batter to swing. The trajectory of the ball and its speed will need to be considered. Maybe the count is three balls and one strike, and the batter wants to let this pitch go by in the hope of getting a walk to first base. Or maybe the batter's team is so far ahead, it would be fun to just swing away.

Controlling the Body

The nervous system can be divided into two parts mostly on the basis of a functional difference in responses. The **somatic nervous system (SNS)** is responsible for conscious perception and voluntary motor responses. Voluntary motor response means the contraction of skeletal muscle, but those contractions are not always voluntary in the sense that you have to want to perform them. Some somatic motor responses are reflexes, and often happen without a conscious decision to perform them. If your friend jumps out from behind a corner and yells "Boo!" you will be startled and you might scream or leap back. You didn't decide to do that, and you may not have wanted to give your friend a reason to laugh at your expense, but it is a reflex involving skeletal muscle contractions. Other motor responses become automatic (in other words, unconscious) as a person learns motor skills (referred to as "habit learning" or "procedural memory").

The **autonomic nervous system (ANS)** is responsible for involuntary control of the body, usually for the sake of homeostasis (regulation of the internal environment). Sensory input for autonomic functions can be from sensory structures tuned to external or internal environmental stimuli. The motor output extends to smooth and cardiac muscle as well as glandular tissue. The role of the autonomic system is to regulate the organ systems of the body, which usually means to control homeostasis. Sweat glands, for example, are controlled by the autonomic system. When you are hot, sweating helps cool your body down. That is a homeostatic mechanism. But when you are nervous, you might start sweating also. That is not homeostatic, it is the physiological response to an emotional state.

There is another division of the nervous system that describes functional responses. The **enteric nervous system (ENS)** is responsible for controlling the smooth muscle and glandular tissue in your digestive system. It is a large part of the PNS, and is not dependent on the CNS. It is sometimes valid, however, to consider the enteric system to be a part of the autonomic system because the neural structures that make up the enteric system are a component of the autonomic output that regulates digestion. There are some differences between the two, but for our purposes here there will be a good bit of overlap. See Figure 3.1.5 for examples of where these divisions of the nervous system can be found.

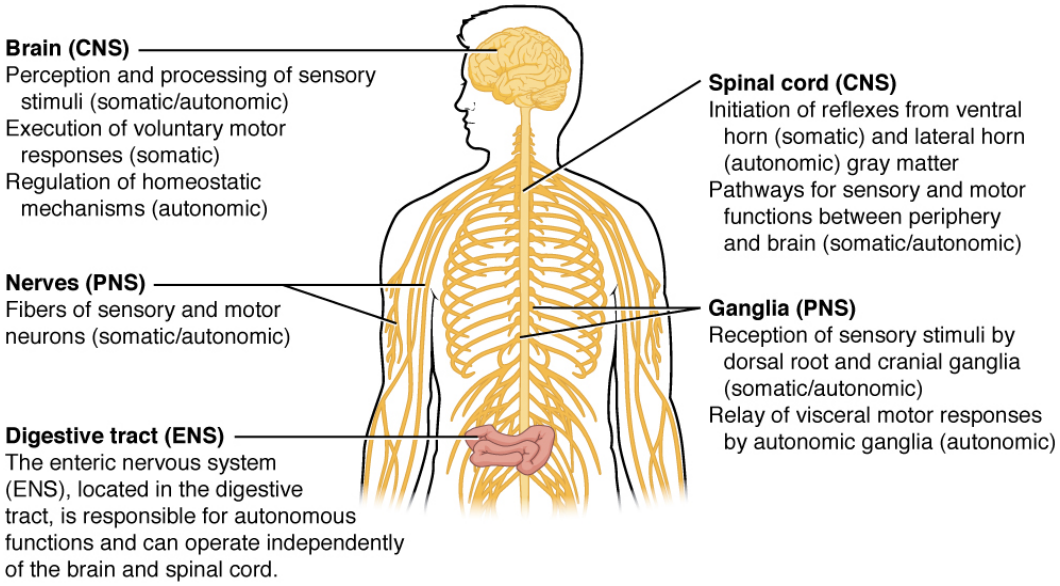


***Figure** 3.1.5**: Somatic, Autonomic, and Enteric Structures of the Nervous System.** Somatic structures include the spinal nerves, both motor and sensory fibers, as well as the sensory ganglia (posterior root ganglia and cranial nerve ganglia). Autonomic structures are found in the nerves also, but include the sympathetic and parasympathetic ganglia. The enteric nervous system includes the nervous tissue within the organs of the digestive tract.*

> Visit this site to read about a woman that notices that her daughter is having trouble walking up the stairs. This leads to the discovery of a hereditary condition that affects the brain and spinal cord. The electromyography and MRI tests indicated deficiencies in the spinal cord and cerebellum, both of which are responsible for controlling coordinated movements. To what functional division of the nervous system would these structures belong?

EVERYDAY CONNECTION: How Much of Your Brain Do You Use?

Have you ever heard the claim that humans only use 10 percent of their brains? Maybe you have seen an advertisement on a website saying that there is a secret to unlocking the full potential of your mind—as if there were 90 percent of your brain sitting idle, just waiting for you to use it. If you see an ad like that, don't click. It isn't true.

An easy way to see how much of the brain a person uses is to take measurements of brain activity while performing a task. An example of this kind of measurement is functional magnetic resonance imaging (fMRI), which generates a map of the most active areas and can be generated and presented in three dimensions (Figure 3.1.6). This procedure is different from the standard MRI technique because it is measuring changes in the tissue in time with an experimental condition or event.

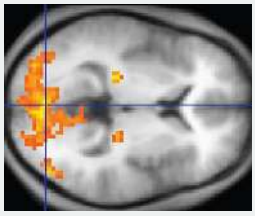


***Figure** 3.1.6**: fMRI.** This fMRI shows activation of the visual cortex in response to visual stimuli. (credit: "Superborsuk"/Wikimedia Commons)*

The underlying assumption is that active nervous tissue will have greater blood flow. By having the subject perform a visual task, activity all over the brain can be measured. Consider this possible experiment: the subject is told to look at a screen with a black dot in the middle (a fixation point). A photograph of a face is projected on the screen away from the center. The subject has to look at the photograph and decipher what it is. The subject has been instructed to push a button if the photograph is of someone they recognize. The photograph might be of a celebrity, so the subject would press the button, or it might be of a random person unknown to the subject, so the subject would not press the button.

In this task, visual sensory areas would be active, integrating areas would be active, motor areas responsible for moving the eyes would be active, and motor areas for pressing the button with a finger would be active. Those areas are distributed all around the brain and the fMRI images would show activity in more than just 10 percent of the brain (some evidence suggests that about 80 percent of the brain is using energy—based on blood flow to the tissue—during well-defined tasks similar to the one suggested above). This task does not even include all of the functions the brain performs. There is no language response, the body is mostly lying still in the MRI machine, and it does not consider the autonomic functions that would be ongoing in the background.

Chapter Review

The nervous system can be separated into divisions on the basis of anatomy and physiology. The anatomical divisions are the central and peripheral nervous systems. The CNS is the brain and spinal cord. The PNS is everything else. Functionally, the nervous system can be divided into those regions that are responsible for sensation, those that are responsible for integration, and those that are responsible for generating responses. All of these functional areas are found in both the central and peripheral anatomy.

Considering the anatomical regions of the nervous system, there are specific names for the structures within each division. A localized collection of neuron cell bodies is referred to as a nucleus in the CNS and as a ganglion in the PNS. A bundle of axons is referred to as a tract in the CNS and as a nerve in the PNS. Whereas nuclei and ganglia are specifically in the central or peripheral divisions, axons can cross the boundary between the two. A single axon can be part of a nerve and a tract. The name for that specific structure depends on its location.

Nervous tissue can also be described as gray matter and white matter on the basis of its appearance in unstained tissue. These descriptions are more often used in the CNS. Gray matter is where nuclei are found and white matter is where tracts are found. In the PNS, ganglia are basically gray matter and nerves are white matter.

The nervous system can also be divided on the basis of how it controls the body. The somatic nervous system (SNS) is responsible for functions that result in moving skeletal muscles. Any sensory or integrative functions that result in the movement of skeletal muscle would be considered somatic. The autonomic nervous system (ANS) is responsible for functions that affect cardiac or smooth muscle tissue, or that cause glands to produce their secretions. Autonomic functions are distributed between central and peripheral regions of the nervous system. The sensations that lead to autonomic functions can be the same sensations that are part of initiating somatic responses. Somatic and autonomic integrative functions may overlap as well.

A special division of the nervous system is the enteric nervous system, which is responsible for controlling the digestive organs. Parts of the autonomic nervous system overlap with the enteric nervous system. The enteric nervous system is exclusively found in the periphery because it is the nervous tissue in the organs of the digestive system.

Interactive Link Questions

In 2003, the Nobel Prize in Physiology or Medicine was awarded to Paul C. Lauterbur and Sir Peter Mansfield for discoveries related to magnetic resonance imaging (MRI). This is a tool to see the structures of the body (not just the nervous system) that depends on magnetic fields associated with certain atomic nuclei. The utility of this technique in the nervous system is that fat tissue and water appear as different shades between black

and white. Because white matter is fatty (from myelin) and gray matter is not, they can be easily distinguished in MRI images. Visit the Nobel Prize website to play an interactive game that demonstrates the use of this technology and compares it with other types of imaging technologies. Also, the results from an MRI session are compared with images obtained from x-ray or computed tomography. How do the imaging techniques shown in this game indicate the separation of white and gray matter compared with the freshly dissected tissue shown earlier?

THE NOBEL PRIZE

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Answer: MRI uses the relative amount of water in tissue to distinguish different areas, so gray and white matter in the nervous system can be seen clearly in these images.

Visit this site to read about a woman that notices that her daughter is having trouble walking up the stairs. This leads to the discovery of a hereditary condition that affects the brain and spinal cord. The electromyography and MRI tests indicated deficiencies in the spinal cord and cerebellum, both of which are responsible for controlling coordinated movements. To what functional division of the nervous system would these structures belong?

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Published: April 13, 2012



Diagnosis

Creeping Weakness

By LISA SANDERS, M.D.

THE PRESENTING PROBLEM

An odd way of climbing stairs leads to the discovery of an illness.

A Strange Climb

A STRANGE CLIMB

“You need to see a doctor,” the woman
she insisted. “I’m worried.” Her daught
visiting, and when the mother happened
by how odd this simple, everyday actio
rocked from side to side as she moved u
entire body to bring up each leg. Her m
wrong.

Answer: They are part of the somatic nervous system, which is responsible for voluntary movements such as walking or climbing the stairs.

Review Questions

Q. Which of the following cavities contains a component of the central nervous system?

A. abdominal

B. pelvic

C. cranial

D. thoracic

Answer: C

Q. Which structure predominates in the white matter of the brain?

A. myelinated axons

B. neuronal cell bodies

C. ganglia of the parasympathetic nerves

D. bundles of dendrites from the enteric nervous system

Answer: A

Q. Which part of a neuron transmits an electrical signal to a target cell?

A. dendrites

B. soma

C. cell body

D. axon

Answer: D

Q. Which term describes a bundle of axons in the peripheral nervous system?

A. nucleus

B. ganglion

C. tract

D. nerve

Answer: D

Q. Which functional division of the nervous system would be responsible for the physiological changes seen during exercise (e.g., increased heart rate and sweating)?

A. somatic

B. autonomic

C. enteric

D. central

Answer: B

Critical Thinking Questions

Q. What responses are generated by the nervous system when you run on a treadmill? Include an example of each type of tissue that is under nervous system control.

A. Running on a treadmill involves contraction of the skeletal muscles in the legs, increase in contraction of the cardiac muscle of the heart, and the production and secretion of sweat in the skin to stay cool.

Q. When eating food, what anatomical and functional divisions of the nervous system are involved in the perceptual experience?

A. The sensation of taste associated with eating is sensed by nerves in the periphery that are involved in sensory and somatic functions.

References

Kramer, PD. Listening to prozac. 1st ed. New York (NY): Penguin Books; 1993.

Glossary

autonomic nervous system (ANS)
functional division of the nervous system that is responsible for homeostatic reflexes that coordinate control of cardiac and smooth muscle, as well as glandular tissue

axon
single process of the neuron that carries an electrical signal (action potential) away from the cell body toward a target cell

brain
the large organ of the central nervous system composed of white and gray matter, contained within the cranium and continuous with the spinal cord

central nervous system (CNS)
anatomical division of the nervous system located within the cranial and vertebral cavities, namely the brain and spinal cord

dendrite
one of many branchlike processes that extends from the neuron cell body and functions as a contact for incoming signals (synapses) from other neurons or sensory cells

enteric nervous system (ENS)
neural tissue associated with the digestive system that is responsible for nervous control through autonomic connections

ganglion
localized collection of neuron cell bodies in the peripheral nervous system

glial cell
one of the various types of neural tissue cells responsible for maintenance of the tissue, and largely responsible for supporting neurons

gray matter
regions of the nervous system containing cell bodies of neurons with few or no myelinated axons; actually may be more pink or tan in color, but called gray in contrast to white matter

integration
nervous system function that combines sensory perceptions and higher cognitive functions (memories, learning, emotion, etc.) to produce a response

myelin
lipid-rich insulating substance surrounding the axons of many neurons, allowing for faster transmission of electrical signals

nerve
cord-like bundle of axons located in the peripheral nervous system that transmits sensory input and response output to and from the central nervous system

neuron
neural tissue cell that is primarily responsible for generating and propagating electrical signals into, within, and out of the nervous system

nucleus
in the nervous system, a localized collection of neuron cell bodies that are functionally related; a “center” of neural function

peripheral nervous system (PNS)
anatomical division of the nervous system that is largely outside the cranial and vertebral cavities, namely all parts except the brain and spinal cord

process
in cells, an extension of a cell body; in the case of neurons, this includes the axon and dendrites

response
nervous system function that causes a target tissue (muscle or gland) to produce an event as a consequence to stimuli

sensation
nervous system function that receives information from the environment and translates it into the electrical signals of nervous tissue

soma
in neurons, that portion of the cell that contains the nucleus; the cell body, as opposed to the cell processes (axons and dendrites)

somatic nervous system (SNS)
functional division of the nervous system that is concerned with conscious perception, voluntary movement, and skeletal muscle reflexes

spinal cord
organ of the central nervous system found within the vertebral cavity and connected with the periphery through spinal nerves; mediates reflex behaviors

stimulus
an event in the external or internal environment that registers as activity in a sensory neuron

tract
bundle of axons in the central nervous system having the same function and point of origin

white matter
regions of the nervous system containing mostly myelinated axons, making the tissue appear white because of the high lipid content of myelin

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3.2: Nervous Tissue

Learning Objectives

- Describe the basic structure of a neuron
- Identify the different types of neurons on the basis of polarity
- List the glial cells of the CNS and describe their function
- List the glial cells of the PNS and describe their function

Nervous tissue is composed of two types of cells, neurons and glial cells. Neurons are the primary type of cell that most anyone associates with the nervous system. They are responsible for the computation and communication that the nervous system provides. They are electrically active and release chemical signals to target cells. Glial cells, or glia, are known to play a supporting role for nervous tissue. Ongoing research pursues an expanded role that glial cells might play in signaling, but neurons are still considered the basis of this function. Neurons are important, but without glial support they would not be able to perform their function.

Neurons

Neurons are the cells considered to be the basis of nervous tissue. They are responsible for the electrical signals that communicate information about sensations, and that produce movements in response to those stimuli, along with inducing thought processes within the brain. An important part of the function of neurons is in their structure, or shape. The three-dimensional shape of these cells makes the immense numbers of connections within the nervous system possible.

Parts of a Neuron

As you learned in the first section, the main part of a neuron is the cell body, which is also known as the soma (soma = "body"). The cell body contains the nucleus and most of the major organelles. But what makes neurons special is that they have many extensions of their cell membranes, which are generally referred to as processes. Neurons are usually described as having one, and only one, axon—a fiber that emerges from the cell body and projects to target cells. That single axon can branch repeatedly to communicate with many target cells. It is the axon that propagates the nerve impulse, which is communicated to one or more cells. The other processes of the neuron are dendrites, which receive information from other neurons at specialized areas of contact called **synapses**. The dendrites are usually highly branched processes, providing locations for other neurons to communicate with the cell body. Information flows through a neuron from the dendrites, across the cell body, and down the axon. This gives the neuron a polarity—meaning that information flows in this one direction. Figure 3.2.1 shows the relationship of these parts to one another.

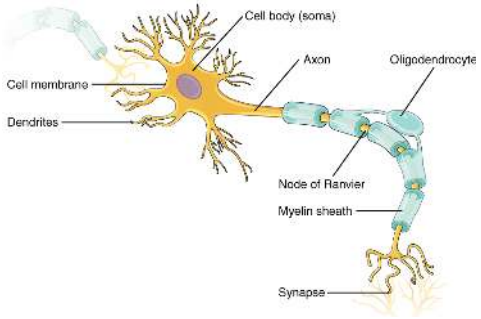


Figure 3.2.1: Parts of a Neuron. The major parts of the neuron are labeled on a multipolar neuron from the CNS.

Where the axon emerges from the cell body, there is a special region referred to as the **axon hillock**. This is a tapering of the cell body toward the axon fiber. Within the axon hillock, the cytoplasm changes to a solution of limited components called **axoplasm**. Because the axon hillock represents the beginning of the axon, it is also referred to as the **initial segment**.

Many axons are wrapped by an insulating substance called myelin, which is actually made from glial cells. Myelin acts as insulation much like the plastic or rubber that is used to insulate electrical wires. A key difference between myelin and the insulation on a wire is that there are gaps in the myelin covering of an axon. Each gap is called a **node of Ranvier** and is important to the way that electrical signals travel down the axon. The length of the axon between each gap, which is wrapped in myelin, is referred to as an **axon segment**. At the end of the axon is the **axon terminal**, where there are usually several branches extending toward the target cell, each of which ends in an enlargement called a **synaptic end bulb**. These bulbs are what make the connection with the target cell at the synapse.

QR Code representing a URL

Visit this site to learn about how nervous tissue is composed of neurons and glial cells. Neurons are dynamic cells with the ability to make a vast number of connections, to respond incredibly quickly to stimuli, and to initiate movements on the basis of those stimuli. They are the focus of intense research because failures in physiology can lead to devastating illnesses. Why are neurons only found in animals? Based on what this article says about neuron function, why wouldn't they be helpful for plants or microorganisms?

Types of Neurons

There are many neurons in the nervous system—a number in the trillions. And there are many different types of neurons. They can be classified by many different criteria. The first way to classify them is by the number of processes attached to the cell body. Using the standard model of neurons, one of these processes is the axon, and the rest are dendrites. Because information flows through the neuron from dendrites or cell bodies toward the axon, these names are based on the neuron's polarity (Figure 3.2.2).

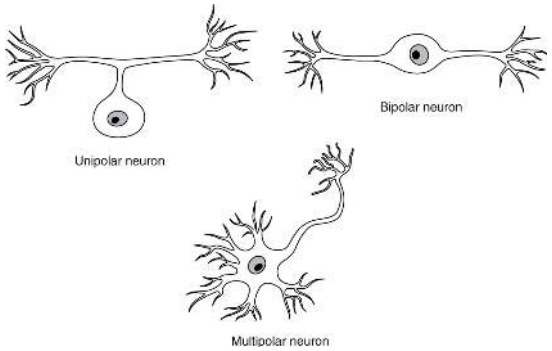


Figure 3.2.2: Neuron Classification by Shape. Unipolar cells have one process that includes both the axon and dendrite. Bipolar cells have two processes, the axon and a dendrite. Multipolar cells have more than two processes, the axon and two or more dendrites.

Unipolar cells have only one process emerging from the cell. True unipolar cells are only found in invertebrate animals, so the unipolar cells in humans are more appropriately called “pseudo-unipolar” cells. Invertebrate unipolar cells do not have dendrites. Human unipolar cells have an axon that emerges from the cell body, but it splits so that the axon can extend along a very long distance. At one end of the axon are dendrites, and at the other end, the axon forms synaptic connections with a target. Unipolar cells are exclusively sensory neurons and have two unique characteristics. First, their dendrites are receiving sensory information, sometimes directly from the stimulus itself. Secondly, the cell bodies of unipolar neurons are always found in ganglia. Sensory reception is a peripheral function (those dendrites are in the periphery, perhaps in the skin) so the cell body is in the periphery, though closer to the CNS in a ganglion. The axon projects from the dendrite endings, past the cell body in a ganglion, and into the central nervous system.

Bipolar cells have two processes, which extend from each end of the cell body, opposite to each other. One is the axon and one the dendrite. Bipolar cells are not very common. They are found mainly in the olfactory epithelium (where smell stimuli are sensed), and as part of the retina.

Multipolar neurons are all of the neurons that are not unipolar or bipolar. They have one axon and two or more dendrites (usually many more). With the exception of the unipolar sensory ganglion cells, and the two specific bipolar cells mentioned above, all other neurons are multipolar. Some cutting edge research suggests that certain neurons in the CNS do not conform to the standard model of “one, and only one” axon. Some sources describe a fourth type of neuron, called an anaxonic neuron. The name suggests that it has no axon (an- = “without”), but this is not accurate. Anaxonic neurons are very small, and if you look through a microscope at the standard resolution used in histology (approximately 400X to 1000X total magnification), you will not be able to distinguish any process specifically as an axon or a dendrite. Any of those processes can function as an

axon depending on the conditions at any given time. Nevertheless, even if they cannot be easily seen, and one specific process is definitively the axon, these neurons have multiple processes and are therefore multipolar.

Neurons can also be classified on the basis of where they are found, who found them, what they do, or even what chemicals they use to communicate with each other. Some neurons referred to in this section on the nervous system are named on the basis of those sorts of classifications (Figure 3.2.3). For example, a multipolar neuron that has a very important role to play in a part of the brain called the cerebellum is known as a Purkinje (commonly pronounced per-KIN-gee) cell. It is named after the anatomist who discovered it (Jan Evangilista Purkinje, 1787–1869).

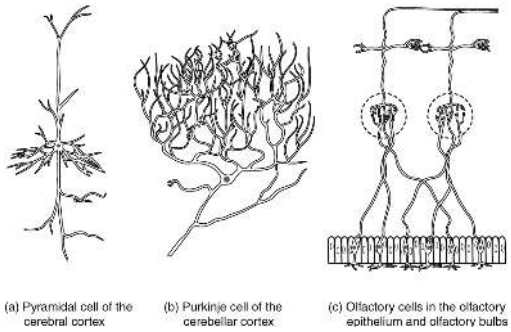


Figure 3.2.3: Other Neuron Classifications. Three examples of neurons that are classified on the basis of other criteria. (a) The pyramidal cell is a multipolar cell with a cell body that is shaped something like a pyramid. (b) The Purkinje cell in the cerebellum was named after the scientist who originally described it. (c) Olfactory neurons are named for the functional group with which they belong.

Glial Cells

Glial cells, or neuroglia or simply glia, are the other type of cell found in nervous tissue. They are considered to be supporting cells, and many functions are directed at helping neurons complete their function for communication. The name glia comes from the Greek word that means “glue,” and was coined by the German pathologist Rudolph Virchow, who wrote in 1856: “This connective substance, which is in the brain, the spinal cord, and the special sense nerves, is a kind of glue (neuroglia) in which the nervous elements are planted.” Today, research into nervous tissue has shown that there are many deeper roles that these cells play. And research may find much more about them in the future.

There are six types of glial cells. Four of them are found in the CNS and two are found in the PNS. Table 3.2.1 outlines some common characteristics and functions.

Table 3.2.1: Glial Cell Types by Location and Basic Function

CNS glia	PNS glia	Basic function
Astrocyte	Satellite cell	Support
Oligodendrocyte	Schwann cell	Insulation, myelination
Microglia	-	Immune surveillance and phagocytosis
Ependymal cell	-	Creating CSF

Glial Cells of the CNS

One cell providing support to neurons of the CNS is the **astrocyte**, so named because it appears to be star-shaped under the microscope (astro- = “star”). Astrocytes have many processes extending from their main cell body (not axons or dendrites like neurons, just cell extensions). Those processes extend to interact with neurons, blood vessels, or the connective tissue covering the CNS that is called the pia mater (Figure 3.2.4). Generally, they are supporting cells for the neurons in the central nervous system. Some ways in which they support neurons in the central nervous system are by maintaining the concentration of chemicals in the extracellular space, removing excess signaling molecules, reacting to tissue damage, and contributing to the **blood-brain barrier (BBB)**. The blood-brain barrier is a physiological barrier that keeps many substances that circulate in the rest of the body from getting into the central nervous system, restricting what can cross from circulating blood into the CNS. Nutrient molecules, such as glucose or amino acids, can pass through the BBB, but other molecules cannot. This actually causes problems with drug delivery to the CNS. Pharmaceutical companies are challenged to design drugs that can cross the BBB as well as have an effect on the nervous system.

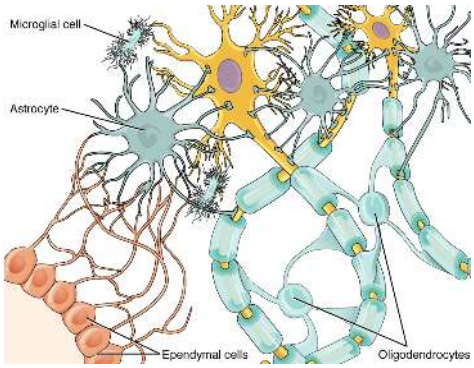


Figure 3.2.4: Glial Cells of the CNS. The CNS has astrocytes, oligodendrocytes, microglia, and ependymal cells that support the neurons of the CNS in several ways.

Like a few other parts of the body, the brain has a privileged blood supply. Very little can pass through by diffusion. Most substances that cross the wall of a blood vessel into the CNS must do so through an active transport process. Because of this, only specific types of molecules can enter the CNS. Glucose—the primary energy source—is allowed, as are amino acids. Water and some other small particles, like gases and ions, can enter. But most everything else cannot, including white blood cells, which are one of the body's main lines of defense. While this barrier protects the CNS from exposure to toxic or pathogenic substances, it also keeps out the cells that could protect the brain and spinal cord from disease and damage. The BBB also makes it harder for pharmaceuticals to be developed that can affect the nervous system. Aside from finding efficacious substances, the means of delivery is also crucial.

Also found in CNS tissue is the **oligodendrocyte**, sometimes called just "oligo," which is the glial cell type that insulates axons in the CNS. The name means "cell of a few branches" (oligo- = "few"; dendro- = "branches"; -cyte = "cell"). There are a few processes that extend from the cell body. Each one reaches out and surrounds an axon to insulate it in myelin. One oligodendrocyte will provide the myelin for multiple axon segments, either for the same axon or for separate axons. The function of myelin will be discussed below.

Microglia are, as the name implies, smaller than most of the other glial cells. Ongoing research into these cells, although not entirely conclusive, suggests that they may originate as white blood cells, called macrophages, that become part of the CNS during early development. While their origin is not conclusively determined, their function is related to what macrophages do in the rest of the body. When macrophages encounter diseased or damaged cells in the rest of the body, they ingest and digest those cells or the pathogens that cause disease. Microglia are the cells in the CNS that can do this in normal, healthy tissue, and they are therefore also referred to as CNS-resident macrophages.

The **ependymal cell** is a glial cell that filters blood to make **cerebrospinal fluid (CSF)**, the fluid that circulates through the CNS. Because of the privileged blood supply inherent in the BBB, the extracellular space in nervous tissue does not easily exchange components with the blood. Ependymal cells line each **ventricle**, one of four central cavities that are remnants of the hollow center of the neural tube formed during the embryonic development of the brain. The **choroid plexus** is a specialized structure in the ventricles where ependymal cells come in contact with blood vessels and filter and absorb components of the blood to produce cerebrospinal fluid. Because of this, ependymal cells can be considered a component of the BBB, or a place where the BBB breaks down. These glial cells appear similar to epithelial cells, making a single layer of cells with little intracellular space and tight connections between adjacent cells. They also have cilia on their apical surface to help move the CSF through the ventricular space. The relationship of these glial cells to the structure of the CNS is seen in Figure 3.2.4.

Glial Cells of the PNS

One of the two types of glial cells found in the PNS is the **satellite cell**. Satellite cells are found in sensory and autonomic ganglia, where they surround the cell bodies of neurons. This accounts for the name, based on their appearance under the microscope. They provide support, performing similar functions in the periphery as astrocytes do in the CNS—except, of course, for establishing the BBB.

The second type of glial cell is the **Schwann cell**, which insulate axons with myelin in the periphery. Schwann cells are different than oligodendrocytes, in that a Schwann cell wraps around a portion of only one axon segment and no others. Oligodendrocytes have processes that reach out to multiple axon segments, whereas the entire Schwann cell surrounds just one axon segment. The nucleus and cytoplasm of the Schwann cell are on the edge of the myelin sheath. The relationship of these two types of glial cells to ganglia and nerves in the PNS is seen in Figure 3.2.5.

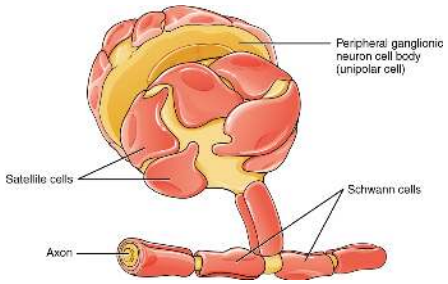


FIgure 12.2.5: Glial Cells of the PNS. *The PNS has satellite cells and Schwann cells.*

Myelin

The insulation for axons in the nervous system is provided by glial cells, oligodendrocytes in the CNS, and Schwann cells in the PNS. Whereas the manner in which either cell is associated with the axon segment, or segments, that it insulates is different, the means of myelinating an axon segment is mostly the same in the two situations. Myelin is a lipid-rich sheath that surrounds the axon and by doing so creates a **myelin sheath** that facilitates the transmission of electrical signals along the axon. The lipids are essentially the phospholipids of the glial cell membrane. Myelin, however, is more than just the membrane of the glial cell. It also includes important proteins that are integral to that membrane. Some of the proteins help to hold the layers of the glial cell membrane closely together.

The appearance of the myelin sheath can be thought of as similar to the pastry wrapped around a hot dog for “pigs in a blanket” or a similar food. The glial cell is wrapped around the axon several times with little to no cytoplasm between the glial cell layers. For oligodendrocytes, the rest of the cell is separate from the myelin sheath as a cell process extends back toward the cell body. A few other processes provide the same insulation for other axon segments in the area. For Schwann cells, the outermost layer of the cell membrane contains cytoplasm and the nucleus of the cell as a bulge on one side of the myelin sheath. During development, the glial cell is loosely or incompletely wrapped around the axon (Figure 3.2.6.a). The edges of this loose enclosure extend toward each other, and one end tucks under the other. The inner edge wraps around the axon, creating several layers, and the other edge closes around the outside so that the axon is completely enclosed.

QR Code representing a URL

View the University of Michigan WebScope at virtualslides.med.umich.edu/H...ml?listview=1& to see an electron micrograph of a cross-section of a myelinated nerve fiber. The axon contains microtubules and neurofilaments that are bounded by a plasma membrane known as the axolemma. Outside the plasma membrane of the axon is the myelin sheath, which is composed of the tightly wrapped plasma membrane of a Schwann cell. What aspects of the cells in this image react with the stain to make them a deep, dark, black color, such as the multiple layers that are the myelin sheath?

Myelin sheaths can extend for one or two millimeters, depending on the diameter of the axon. Axon diameters can be as small as 1 to 20 micrometers. Because a micrometer is 1/1000 of a millimeter, this means that the length of a myelin sheath can be 100–1000 times the diameter of the axon. Figure 3.2.1, Figure 3.2.4, and Figure 3.2.5 show the myelin sheath surrounding an axon segment, but are not to scale. If the myelin sheath were drawn to scale, the neuron would have to be immense—possibly covering an entire wall of the room in which you are sitting.

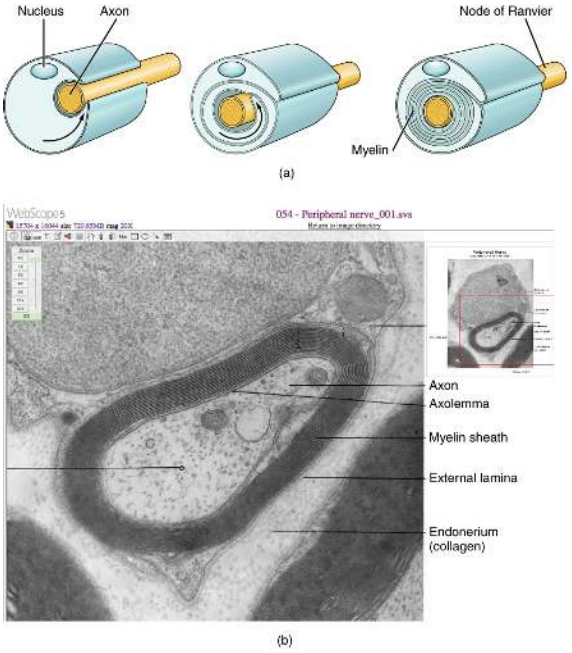


Figure 3.2.6: The Process of Myelination. Myelinating glia wrap several layers of cell membrane around the cell membrane of an axon segment. A single Schwann cell insulates a segment of a peripheral nerve, whereas in the CNS, an oligodendrocyte may provide insulation for a few separate axon segments. EM × 1,460,000. (Micrograph provided by the Regents of University of Michigan Medical School © 2012)

DISORDERS OF THE...

Nervous Tissue

Several diseases can result from the demyelination of axons. The causes of these diseases are not the same; some have genetic causes, some are caused by pathogens, and others are the result of autoimmune disorders. Though the causes are varied, the results are largely similar. The myelin insulation of axons is compromised, making electrical signaling slower.

Multiple sclerosis (MS) is one such disease. It is an example of an autoimmune disease. The antibodies produced by lymphocytes (a type of white blood cell) mark myelin as something that should not be in the body. This causes inflammation and the destruction of the myelin in the central nervous system. As the insulation around the axons is destroyed by the disease, scarring becomes obvious. This is where the name of

the disease comes from; sclerosis means hardening of tissue, which is what a scar is. Multiple scars are found in the white matter of the brain and spinal cord. The symptoms of MS include both somatic and autonomic deficits. Control of the musculature is compromised, as is control of organs such as the bladder.

Guillain-Barré (pronounced gee-YAN bah-RAY) syndrome is an example of a demyelinating disease of the peripheral nervous system. It is also the result of an autoimmune reaction, but the inflammation is in peripheral nerves. Sensory symptoms or motor deficits are common, and autonomic failures can lead to changes in the heart rhythm or a drop in blood pressure, especially when standing, which causes dizziness.

Chapter Review

Nervous tissue contains two major cell types, neurons and glial cells. Neurons are the cells responsible for communication through electrical signals. Glial cells are supporting cells, maintaining the environment around the neurons.

Neurons are polarized cells, based on the flow of electrical signals along their membrane. Signals are received at the dendrites, are passed along the cell body, and propagate along the axon towards the target, which may be another neuron, muscle tissue, or a gland. Many axons are insulated by a lipid-rich substance called myelin. Specific types of glial cells provide this insulation.

Several types of glial cells are found in the nervous system, and they can be categorized by the anatomical division in which they are found. In the CNS, astrocytes, oligodendrocytes, microglia, and ependymal cells are found. Astrocytes are important for maintaining the chemical environment around the neuron and are crucial for regulating the blood-brain barrier. Oligodendrocytes are the myelinating glia in the CNS. Microglia act as phagocytes and play a role in immune surveillance. Ependymal cells are responsible for filtering the blood to produce cerebrospinal fluid, which is a circulatory fluid that performs some of the functions of blood in the brain and spinal cord because of the BBB. In the PNS, satellite cells are supporting cells for the neurons, and Schwann cells insulate peripheral axons.

Interactive Link Questions

Visit this site to learn about how nervous tissue is composed of neurons and glial cells. The neurons are dynamic cells with the ability to make a vast number of connections and to respond incredibly quickly to stimuli and to initiate movements based on those stimuli. They are the focus of intense research as failures in physiology can lead to devastating illnesses. Why are neurons only found in animals? Based on what this article says about neuron function, why wouldn't they be helpful for plants or microorganisms?

> Answer: Neurons enable thought, perception, and movement. Plants do not move, so they do not need this type of tissue. Microorganisms are too small to have a nervous system. Many are single-celled, and therefore have organelles for perception and movement.

View the University of Michigan WebScope at virtualslides.med.umich.edu/H...ml?listview=1& to see an electron micrograph of a cross-section of a myelinated nerve fiber. The axon contains microtubules and neurofilaments, bounded by a plasma membrane known as the axolemma. Outside the plasma membrane of the axon is the myelin sheath, which is composed of the tightly wrapped plasma membrane of a Schwann cell. What aspects of the cells in this image react with the stain that makes them the deep, dark, black color, such as the multiple layers that are the myelin sheath?

> Answer: Lipid membranes, such as the cell membrane and organelle membranes.

Review Questions

Q. What type of glial cell provides myelin for the axons in a tract?

A. oligodendrocyte

B. astrocyte

C. Schwann cell

D. satellite cell

Answer: A

Q. Which part of a neuron contains the nucleus?

A. dendrite

B. soma

C. axon

D. synaptic end bulb

Answer: B

Q. Which of the following substances is least able to cross the blood-brain barrier?

A. water

B. sodium ions

C. glucose

D. white blood cells

Answer: D

Q. What type of glial cell is the resident macrophage behind the blood-brain barrier?

A. microglia

B. astrocyte

C. Schwann cell

D. satellite cell

Answer: A

Q. What two types of macromolecules are the main components of myelin?

A. carbohydrates and lipids

B. proteins and nucleic acids

C. lipids and proteins

D. carbohydrates and nucleic acids

Answer: C

Critical Thinking Questions

Q. Multiple sclerosis is a demyelinating disease affecting the central nervous system. What type of cell would be the most likely target of this disease? Why?

A. The disease would target oligodendrocytes. In the CNS, oligodendrocytes provide the myelin for axons.

Q. Which type of neuron, based on its shape, is best suited for relaying information directly from one neuron to another? Explain why.

A. Bipolar cells, because they have one dendrite that receives input and one axon that provides output, would be a direct relay between two other cells.

Glossary

astrocyte
glial cell type of the CNS that provides support for neurons and maintains the blood-brain barrier

axon hillock
tapering of the neuron cell body that gives rise to the axon

axon segment
single stretch of the axon insulated by myelin and bounded by nodes of Ranvier at either end (except for the first, which is after the initial segment, and the last, which is followed by the axon terminal)

axon terminal
end of the axon, where there are usually several branches extending toward the target cell

axoplasm
cytoplasm of an axon, which is different in composition than the cytoplasm of the neuronal cell body

bipolar
shape of a neuron with two processes extending from the neuron cell body—the axon and one dendrite

blood-brain barrier (BBB)
physiological barrier between the circulatory system and the central nervous system that establishes a privileged blood supply, restricting the flow of substances into the CNS

cerebrospinal fluid (CSF)
circulatory medium within the CNS that is produced by ependymal cells in the choroid plexus filtering the blood

choroid plexus
specialized structure containing ependymal cells that line blood capillaries and filter blood to produce CSF in the four ventricles of the brain

ependymal cell
glial cell type in the CNS responsible for producing cerebrospinal fluid

initial segment
first part of the axon as it emerges from the axon hillock, where the electrical signals known as action potentials are generated

microglia
glial cell type in the CNS that serves as the resident component of the immune system

multipolar
shape of a neuron that has multiple processes—the axon and two or more dendrites

myelin sheath
lipid-rich layer of insulation that surrounds an axon, formed by oligodendrocytes in the CNS and Schwann cells in the PNS; facilitates the transmission of electrical signals

node of Ranvier
gap between two myelinated regions of an axon, allowing for strengthening of the electrical signal as it propagates down the axon

oligodendrocyte
glial cell type in the CNS that provides the myelin insulation for axons in tracts

satellite cell
glial cell type in the PNS that provides support for neurons in the ganglia

Schwann cell
glial cell type in the PNS that provides the myelin insulation for axons in nerves

synapse
narrow junction across which a chemical signal passes from neuron to the next, initiating a new electrical signal in the target cell

synaptic end bulb

swelling at the end of an axon where neurotransmitter molecules are released onto a target cell across a synapse

unipolar

shape of a neuron which has only one process that includes both the axon and dendrite

ventricle

central cavity within the brain where CSF is produced and circulates

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SECTION OVERVIEW

3.3: Spinal Nerves

3.3A: Overview of the Spinal Nerves

3.3B: Branches of Spinal Nerves

3.3C: Plexuses

3.3D: Intercostal Nerves

3.3E: Dermatomes

3.3F: Function and Physiology of the Spinal Nerves

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3.3A: Overview of the Spinal Nerves

Spinal nerves, a part of the peripheral nervous system (PNS), are mixed nerves that send motor, sensory, and autonomic signals between the CNS and the body.

Learning Objectives

- Describe spinal nerves of the peripheral nervous system

Key Points

- Afferent sensory axons bring sensory information from the body to the spinal cord and brain; they travel through the dorsal roots of the spinal cord.
- Efferent motor axons bring motor information from the brain to the body; they travel through the ventral roots of the spinal cord.
- All spinal nerves—except the first pair—emerge from the spinal column through an opening between vertebrae, called an intervertebral foramen.
- The spinal nerves are typically labeled by their location in the body: thoracic, lumbar, or sacral.

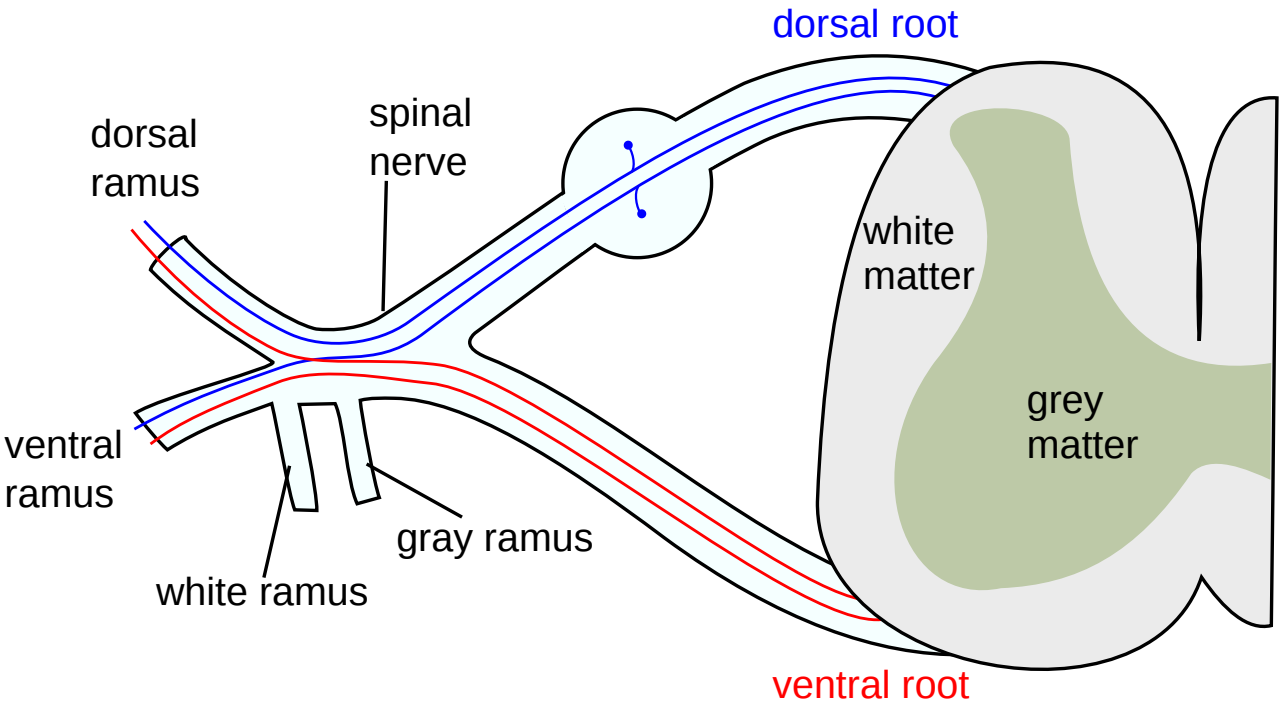
Key Terms

- **ventral root**: Also called the anterior root, it is the efferent motor root of a spinal nerve.
- **autonomic**: Acting or occurring involuntarily, without conscious control.
- **dorsal root**: Also known as the posterior root, the afferent sensory root of a spinal nerve.
- **intervertebral foramen**: The foramen allows for the passage of the spinal nerve root, dorsal root ganglion, the spinal artery of the segmental artery, the communicating veins between the internal and external plexuses, recurrent meningeal (sinu-vertebral) nerves, and transforaminal ligaments.

Spinal Nerve Anatomy

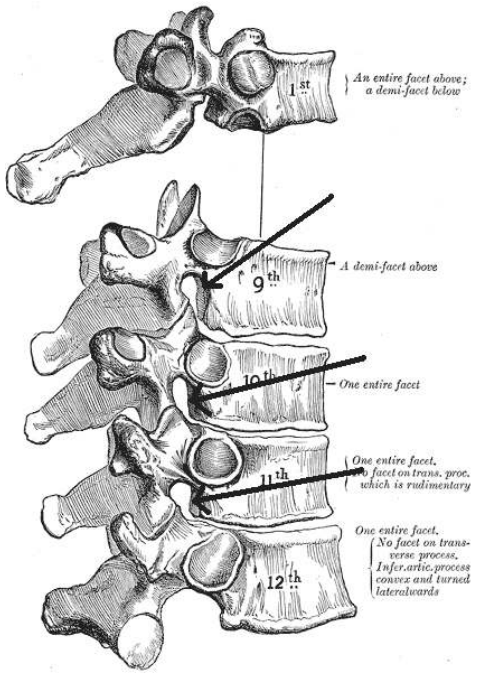
The term spinal nerve generally refers to a mixed spinal nerve that carries motor, sensory, and autonomic signals between the spinal cord and the body.

Humans have 31 left–right pairs of spinal nerves, each roughly corresponding to a segment of the vertebral column: eight cervical spinal nerve pairs (C1–C8), 12 thoracic pairs (T1–T12), five lumbar pairs (L1–L5), five sacral pairs (S1–S5), and one coccygeal pair. The spinal nerves are part of the peripheral nervous system (PNS).



A spinal nerve: Spinal nerves arise from a combination of nerve fibers from the dorsal and ventral roots of the spinal cord.

Location



Intervertebral foramina: Intervertebral foramina are indicated by arrows.

Each spinal nerve is formed by the combination of nerve fibers from the dorsal and ventral roots of the spinal cord. The dorsal roots carry afferent sensory axons, while the ventral roots carry efferent motor axons.

The spinal nerve emerges from the spinal column through an opening (intervertebral foramen) between adjacent vertebrae.

This is true for all spinal nerves except for the first spinal nerve pair, which emerges between the occipital bone and the atlas (the first vertebra). Thus the cervical nerves are numbered by the vertebra below, except C8, which exists below C7 and above T1.

The thoracic, lumbar, and sacral nerves are then numbered by the vertebra above. In the case of a lumbarized S1 vertebra (i.e., L6) or a sacralized L5 vertebra, the nerves are typically still counted to L5 and the next nerve is S1.

Spinal Nerve Innervation

Outside the vertebral column, the nerve divides into branches. The dorsal ramus contains nerves that serve the dorsal portions of the trunk; it carries visceral motor, somatic motor, and somatic sensory information to and from the skin and muscles of the back (epaxial muscles).

The ventral ramus contains nerves that serve the remaining ventral parts of the trunk and the upper and lower limbs (hypaxial muscles); they carry visceral motor, somatic motor, and sensory information to and from the ventrolateral body surface, structures in the body wall, and the limbs.

The meningeal branches (recurrent meningeal or sinuvertebral nerves) branch from the spinal nerve and re-enter the intervertebral foramen to serve the ligaments, dura, blood vessels, intervertebral discs, facet joints, and periosteum of the vertebrae.

The rami communicantes contain autonomic nerves that serve visceral functions, such as carrying visceral motor and sensory information to and from the visceral organs.

Cervical Nerves

The posterior distribution of the cervical nerves includes the suboccipital nerve (C1), the greater occipital nerve (C2), and the third occipital nerve (C3). The anterior distribution includes the cervical plexus (C1–C4) and brachial plexus (C5–T1).

The muscles innervated by the cervical nerves are the sternohyoid, sternothyroid, and omohyoid muscles.

A loop of nerves called ansa cervicalis is also part of the cervical plexus.

Thoracic Nerves

Thoracic nerve branches exit the spine and go directly to the paravertebral ganglia of the autonomic nervous system, where they are involved in the functions of organs and glands in the head, neck, thorax, and abdomen.

Anterior Divisions

The intercostal nerves come from thoracic nerves T1–T11, and run between the ribs. The subcostal nerve comes from nerve T12, and runs below the twelfth rib.

Posterior Divisions

The medial branches (ramus medialis) of the posterior branches of the upper six thoracic nerves run between the semispinalis dorsi and multifidus, which they supply.

They then pierce the rhomboid and trapezius muscles, and reach the skin by the sides of the spinous processes. This branch is called the medial cutaneous ramus.

The medial branches of the lower six thoracic nerves are distributed chiefly to the multifidus and longissimus dorsi, occasionally they give off filaments to the skin near the middle line. This sensitive branch is called the posterior cutaneous ramus.

Lumbar Nerves

The lumbar nerves are divided into posterior and anterior divisions.

Posterior Divisions

The medial branches of the posterior divisions of the lumbar nerves run close to the articular processes of the vertebrae and end in the multifidus muscle. The lateral branches supply the erector spinae muscles.

Anterior Divisions

The anterior divisions of the lumbar nerves (rami anteriores) consist of long, slender branches that accompany the lumbar arteries around the sides of the vertebral bodies, beneath the psoas major.

The first and second, and sometimes the third and fourth, lumbar nerves are each connected with the lumbar part of the sympathetic trunk by a white ramus communicans.

The nerves pass obliquely outward behind the psoas major, or between its fasciculi, distributing filaments to it and the quadratus lumborum.

The first three and the greater part of the fourth are connected by anastomotic loops and form the lumbar plexus.

The smaller part of the fourth joins with the fifth to form the lumbosacral trunk, which assists in the formation of the sacral plexus. The fourth nerve is named the furcal nerve, from the fact that it is subdivided between the two plexuses.

Sacral Nerves

There are five paired sacral nerves, half of them arising through the sacrum on the left side and the other half on the right side. Each nerve emerges in two divisions: one division through the anterior sacral foramina and the other division through the posterior sacral foramina.

The sacral nerves have both afferent and efferent fibers, thus they are responsible for part of the sensory perception and the movements of the lower extremities of the human body.

The pudendal nerve and parasympathetic fibers arise from S2, S3, and S4. They supply the descending colon and rectum, urinary bladder, and genital organs. These pathways have both afferent and efferent fibers.

Coccygeal Nerve

The coccygeal nerve is the 31st pair of spinal nerves and arises from the conus medullaris. Its anterior root helps form the coccygeal plexus.

Function

Spinal nerve motor functions are summarized in the table below.

Actions of the spinal nerves	
Level	Motor Function
C1–C6	Neck flexors
C1–T1	Neck extensors
C3, C4, C5	Supply diaphragm (mostly C4)
C5, C6	Move shoulder, raise arm (deltoid); flex elbow (biceps)
C6	Externally rotate (supinate) the arm
C6, C7	Extend the elbow and wrist (triceps and wrist extensors); pronate wrist
C7, C8	Flex wrist; supply small muscles of the hand
T1–T6	Intercostals and trunk above the waist
T7–L1	Abdominal muscles
L1–L4	Flex thigh
L2, L3, L4	Adduct thigh; extend leg at the knee (quadriceps femoris)
L4, L5, S1	Abduct thigh; flex leg at the knee (hamstrings); dorsiflex foot (tibialis anterior); extend toes
L5, S1, S2	Extend leg at the hip (gluteus maximus); plantar flex foot and flex toes

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3.3B: Branches of Spinal Nerves

The spinal nerves branch into the dorsal ramus, ventral ramus, the meningeal branches, and the rami communicantes.

Learning Objectives

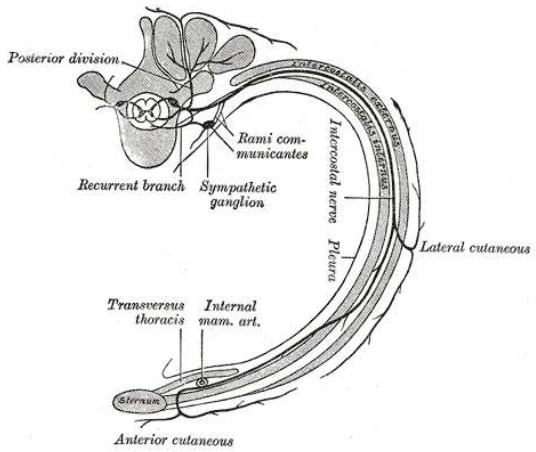
- Describe branches of the peripheral nervous system

Key Points

- The dorsal and ventral rami contain nerves that provide visceral motor, somatic motor, and sensory information, with the dorsal ramus feeding the dorsal trunk (skin and muscles of the back), and the ventral ramus feeding the ventral trunk and limbs through the ventrolateral surface.
- The meningeal branches supply nerve function to the vertebrae themselves, including the ligaments, dura, blood vessels, intervertebral discs, facet joints, and periosteum.
- The rami communicantes contain autonomic nerves that carry visceral motor and sensory information to and from the visceral organs.

Key Terms

- **nerve plexus**: A branching network of intersecting nerves.
- **dorsal ramus**: The posterior (or dorsal) branches (or divisions) of the spinal nerves are, as a rule, smaller than the anterior divisions. They are also referred to as the dorsal rami. They are directed backwards and—with the exceptions of those of the first cervical, the fourth and fifth sacral, and the coccygeal—divide into medial and lateral branches for the supply of the muscles and skin of the posterior part of the trunk.
- **meningeal branches**: Also known as recurrent meningeal nerves, sinuvertebral nerves, or recurrent nerves of Luschka, these are a number of small nerves that branch from the spinal nerve (or the posterior ramus) near the origin of the anterior and posterior rami. They then re-enter the intervertebral foramen, and innervate the facet joints, the annulus fibrosus of the intervertebral disk, and the ligaments and periosteum of the spinal canal, carrying pain sensation.



Course and branches of thoracic spinal nerve: This diagram depicts the course and branches of a typical thoracic spinal nerve. The posterior division (dorsal ramus) is labeled at the top right.

Outside the vertebral column, the spinal nerves divide into branches.

- The dorsal ramus: Contains nerves that serve the dorsal portions of the trunk carrying visceral motor, somatic motor, and sensory information to and from the skin and muscles of the back.
- The ventral ramus: Contains nerves that serve the remaining ventral parts of the trunk and the upper and lower limbs carrying visceral motor, somatic motor, and sensory information to and from the ventrolateral body surface, structures in the body wall, and the limbs.
- Some ventral rami merge with adjacent ventral rami to form a nerve plexus, a network of interconnecting nerves. Nerves emerging from a plexus contain fibers from various spinal nerves, which are now carried together to some target location. Major

plexuses include the cervical, brachial, lumbar, and sacral plexuses.

- The meningeal branches (recurrent meningeal or sinuvertebral nerves): These branch from the spinal nerve and re-enter the intervertebral foramen to serve the ligaments, dura, blood vessels, intervertebral discs, facet joints, and periosteum of the vertebrae.
- The rami communicantes: Contain autonomic nerves that carry visceral motor and sensory information to and from the visceral organs.

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3.3C: Plexuses

A nerve plexus is a network of intersecting nerves that serve the same part of the body.

Learning Objectives

- Describe nerve plexuses in the peripheral nervous system

Key Points

- Nerve plexuses throughout the body tend to be named after the area in which the plexus occurs and the organs, limbs, and tissues it serves. Examples include the cervical, brachial, lumbar, sacral, celiac, and coccygeal plexuses.
- Auerbach's plexus, which serves the gastrointestinal tract, is named after the first person to describe this plexus, Leopold Auerbach, rather than the area of the body it serves.
- The brachial plexus serves the chest, shoulders, arms and hands and is formed by the ventral rami of C5, C8, and T1 spinal nerves, and the lower and upper halves of the C4 and T2 spinal nerves.

Key Terms

- **nerve plexus**: A network of intersecting nerves.
- **brachial plexus**: A network of nerve fibers, running from the spine, formed by the ventral rami of the lower four cervical and first thoracic nerve roots (C5–C8, T1). It proceeds through the neck, the axilla (armpit region), and into the arm. It also supplies the brachium, the antebrachium, and the hand.
- **coccygeal plexus**: A plexus of nerves near the coccyx bone.
- **Autonomic**: A division of the peripheral nervous system that influences the function of internal organs.

A nerve plexus is a network of intersecting nerves; multiple nerve plexuses exist in the body. Nerve plexuses are composed of afferent and efferent fibers that arise from the merging of the anterior rami of spinal nerves and blood vessels.

There are five spinal nerve plexuses—except in the thoracic region—as well as other forms of autonomic plexuses, many of which are a part of the enteric nervous system.

Spinal Plexuses

Cervical Plexus—Serves the Head, Neck and Shoulders

The cervical plexus is formed by the ventral rami of the upper four cervical nerves and the upper part of fifth cervical ventral ramus. The network of rami is located deep within the neck.

Brachial Plexus—Serves the Chest, Shoulders, Arms and Hands

The brachial plexus is formed by the ventral rami of C5–C8 and the T1 spinal nerves, and lower and upper halves of the C4 and T2 spinal nerves. The plexus extends toward the armpit (axilla).

Lumbar Plexus—Serves the Back, Abdomen, Groin, Thighs, Knees, and Calves

The lumbar plexus is formed by the ventral rami of L1–L5 spinal nerves with a contribution of T12 form the lumbar plexus. This plexus lies within the psoas major muscle.

Sacral Plexus—Serves the Pelvis, Buttocks, Genitals, Thighs, Calves, and Feet

The sacral plexus is formed by the ventral rami of L4-S3, with parts of the L4 and S4 spinal nerves. It is located on the posterior wall of the pelvic cavity.

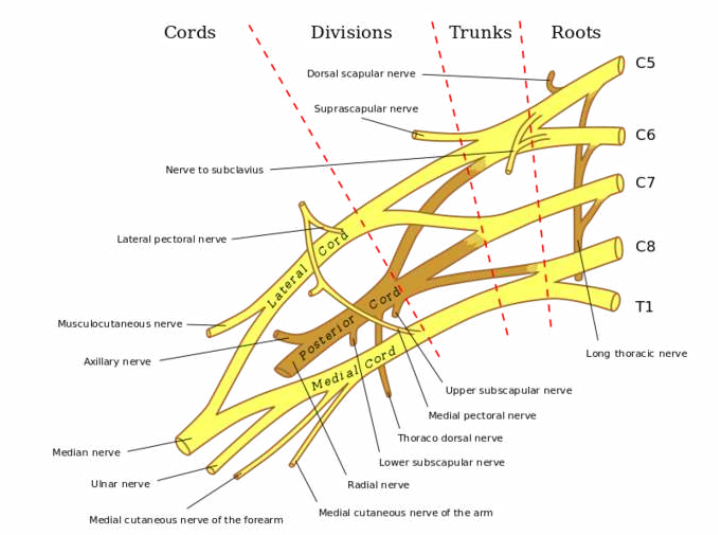
Coccygeal Plexus—Serves a Small Region over the Coccyx

The coccygeal plexus serves a small region over the coccyx and originates from S4, S5, and Co1 spinal nerves. It is interconnected with the lower part of sacral plexus.

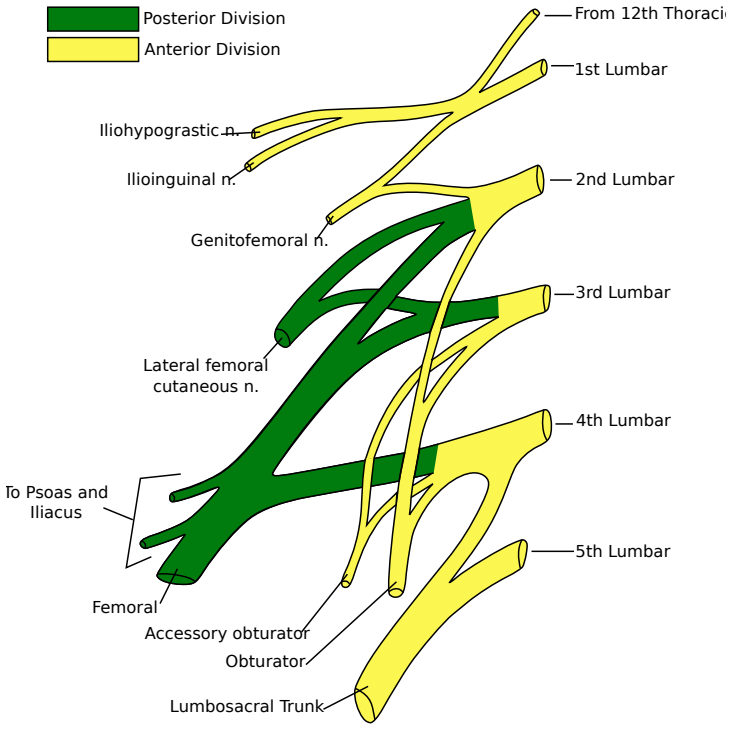
In addition, the celiac plexus serves the internal organs, and Auerbach's plexus serves the gastrointestinal tract.

Autonomic Plexuses

- Celiac plexus (solar plexus)—Serves internal organs.
- Auerbach's plexus—Serves the gastrointestinal tract.
- Meissner's plexus (submucosal plexus)—Serves the gastrointestinal tract.



Brachial plexus: Cervical (C5–C8) and thoracic (T1) nerves comprise the brachial plexus, which is a nerve plexus that provides sensory and motor function to the shoulders and upper limbs.



Lumbar plexus: The lumbar plexus is comprised of the ventral rami of the lumbar spinal nerves (L1–L5) and a contribution from thoracic nerve (T12). The posterior (green) and anterior (yellow) divisions of the lumbar plexus are shown in the diagram.

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3.3D: Intercostal Nerves

The anterior divisions of the thoracic spinal nerves (T1–T11) are called the intercostal nerves.

Learning Objectives

- Describe the function of intercostal nerves

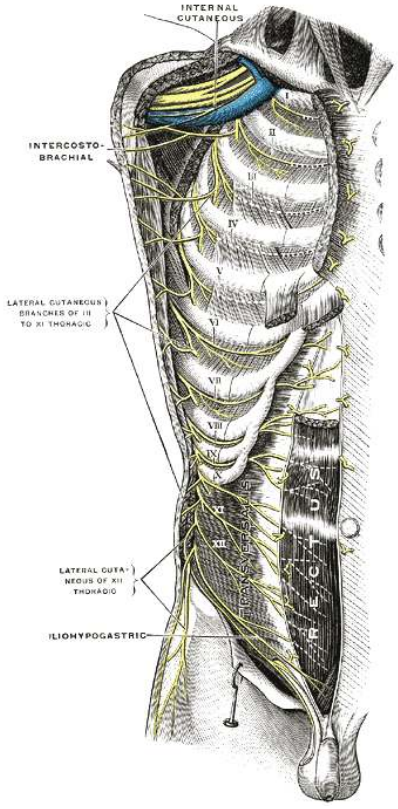
Key Points

- The intercostal nerves are part of the somatic nervous system. This enables them to control the contraction of muscles, as well as provide specific sensory information regarding the skin and parietal pleura.
- Intercostal nerves connect to the appropriate ganglion in the sympathetic trunk through rami communicantes and serve the thoracic pleura and the abdominal peritoneum.
- Unlike most other anterior divisions of spinal nerves, the intercostal nerves do not form a plexus.

Key Terms

- **thoracic spinal nerves**: The spinal nerves emerging from the thoracic vertebrae. Branches also exit the spine and go directly to the sympathetic chain ganglia of the autonomic nervous system where they are involved in the functions of organs and glands in the head, neck, thorax, and abdomen.
- **sympathetic trunk**: Also called the sympathetic chain or gangliated cord, these are a paired bundle of nerve fibers that run from the base of the skull to the coccyx.
- **abdominal peritoneum**: The serous membrane that forms the lining of the abdominal cavity. It covers most of the intra-abdominal organs. It is composed of a layer of mesothelium supported by a thin layer of connective tissue. The peritoneum supports the abdominal organs and serves as a conduit for their blood and lymph vessels and nerves.

The intercostal nerves are part of the somatic nervous system and arise from anterior divisions (rami anteriores, ventral divisions) of the thoracic spinal nerves T1 to T11. The intercostal nerves are distributed chiefly to the thoracic pleura and abdominal peritoneum.



Intercostal nerves: An image of the intercostal brachial nerves.

They differ from the anterior divisions of the other spinal nerves in that each pursues an independent course without plexus formation.

First Thoracic Nerve

The anterior division of the first thoracic nerve divides into two branches:

1. The larger branch leaves the thorax in front of the neck of the first rib and enters the brachial plexus.
2. The other smaller branch, the first intercostal nerve, runs along the first intercostal space and ends on the front of the chest as the first anterior cutaneous branch of the thorax.

The Upper Thoracic Nerves (2nd–6th)

These are limited in their distribution to the parietes (wall) of the thorax. The anterior divisions of the second, third, fourth, fifth, and sixth thoracic nerves, and the small branch from the first thoracic, are confined to the walls of the thorax and are named thoracic intercostal nerves.

Near the sternum, they cross in front of the internal mammary artery and transversus thoracis muscle, pierce the intercostales interni, the anterior intercostal membranes, and pectoralis major, and supply the integument of the front of the thorax and over the mamma, forming the anterior cutaneous branches of the thorax.

The branch from the second nerve unites with the anterior supraclavicular nerves of the cervical plexus.

The Lower Thoracic Nerves (7th–12th)

The seventh intercostal nerve terminates at the xyphoid process, at the lower end of the sternum.

The anterior divisions of the seventh, eighth, ninth, tenth, and eleventh thoracic intercostal nerves are continued anteriorly from the intercostal spaces into the abdominal wall; hence they are named thoraco-abdominal nerves or thoracicoabdominal intercostal nerves.

The tenth intercostal nerve terminates at the umbilicus.

The twelfth (subcostal) thoracic nerve is distributed to the abdominal wall and groin.

Unlike the nerves from the autonomic nervous system that innervate the visceral pleura of the thoracic cavity, the intercostal nerves arise from the somatic nervous system. This enables them to control the contraction of muscles, as well as provide specific sensory information regarding the skin and parietal pleura.

This explains why damage to the internal wall of the thoracic cavity can be felt as a sharp pain localized in the injured region. Damage to the visceral pleura is experienced as an unlocalized ache.

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3.3E: Dermatomes

A dermatome is an area of skin that is supplied by a single spinal nerve, and a myotome is a group of muscles that a single spinal nerve root innervates.

Learning Objectives

- Describe dermatomes and how they relate to the peripheral nervous system

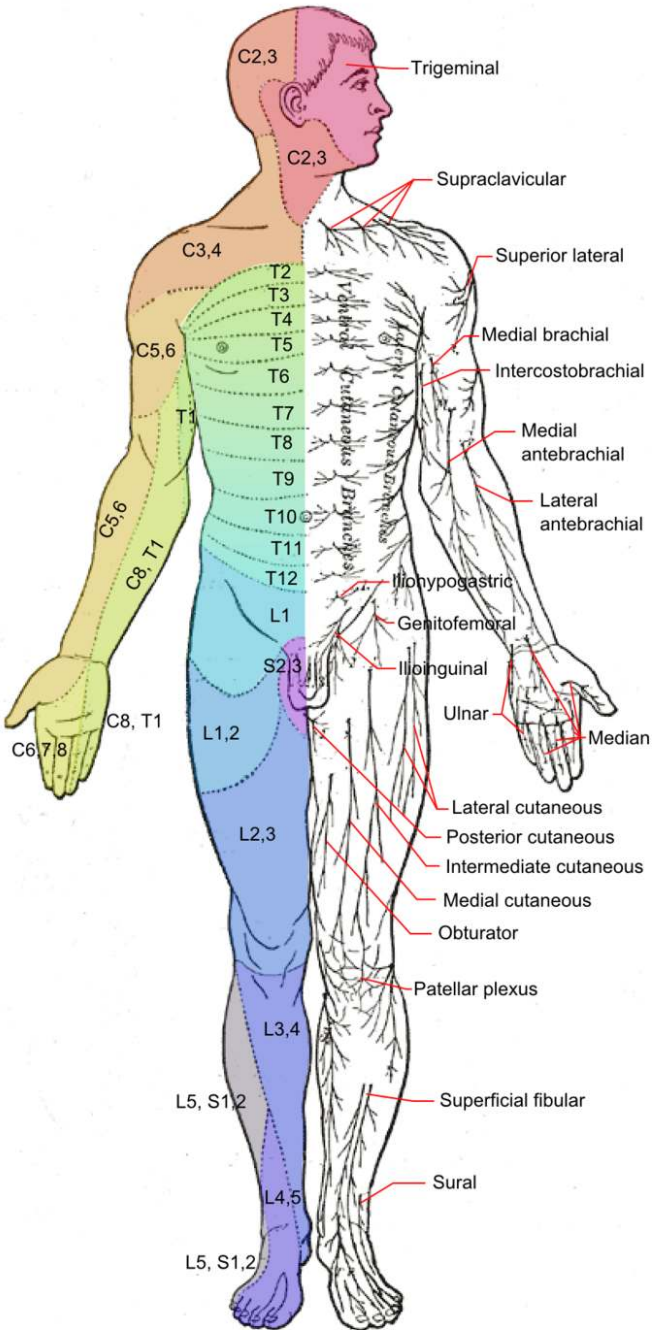
Key Points

- There are eight cervical nerves, twelve thoracic nerves, five lumbar nerves and five sacral nerves. Each of these nerves relays sensation, including pain, from a particular region of skin to the brain.
- Along the thorax and abdomen, the dermatomes are like a stack of discs, with each section supplied by a different spinal nerve. The pattern is different along the arms and the legs. The dermatomes run longitudinally along the limbs, so that each half of the limb has a different dermatome.
- Dermatomes have clinical significance, especially in the diagnosis of certain diseases. Symptoms that follow a dermatome, such as pain or a rash, may indicate a pathology that involves the related nerve root. Examples include dysfunction of the spine or a viral infection.

Key Terms

- **shingles**: Also known as herpes zoster, shingles is an acute viral inflammation of the sensory ganglia of spinal and cranial nerves associated with a vesicular eruption and neuralgic pains and caused by reactivation of the poxvirus causing chicken pox.
- **chickenpox**: A common childhood disease caused by the varicella-zoster virus.

A dermatome is an area of skin that is supplied by a single spinal nerve. There are eight cervical nerves, twelve thoracic nerves, five lumbar nerves and five sacral nerves. Each of these nerves relays sensation, including pain, from a particular region of the skin to the brain.



Dermatomes: Dermatomes are areas of skin supplied by sensory neurons that arise from a spinal nerve ganglion. Dermatomes and the associated major cutaneous nerves are shown here in a ventral view.

Along the thorax and abdomen, the dermatomes are like a stack of discs, with each section supplied by a different spinal nerve. Along the arms and the legs, the pattern is different. The dermatomes run longitudinally along the limbs, so that each half of the limb has a different dermatome.

Although the general pattern is similar in all people, the precise areas of innervation are as unique to an individual as fingerprints.

Dermatomes have clinical significance, especially in the diagnosis of certain diseases. Symptoms that follow a dermatome, such as pain or a rash, may indicate a pathology that involves the related nerve root. Examples include dysfunction of the spine or a viral infection.

Viruses that remain dormant in nerve ganglia, such as the varicella zoster virus that causes both chickenpox and shingles, often cause either pain, rash, or both in a pattern defined by a dermatome.



Shingles rash: The shingles rash appears across a dermatome. In this patient, one of the dermatomes in the arm is affected, restricting the rash to the length of the back of the arm.

Shingles is one of the only diseases that causes a rash in a dermatomal pattern, and as such, this is its defining symptom. The rash of shingles is almost always restricted to a specific dermatome, such as on the chest, leg, or arm caused by the residual varicella zoster virus infection of the nerve that supplies that area of skin. Shingles typically appears years or decades after recovery from chickenpox.

Mytome

A myotome is the group of muscles that a single spinal nerve root innervates. The myotome is the motor equivalent of a dermatome.

The myotome distributions of the upper and lower extremities are listed below:

- C1/C2: Neck flexion / extension
- C3: Neck lateral flexion
- C4: Shoulder elevation
- C5: Shoulder abduction
- C6: Elbow flexion/wrist extension
- C7: Elbow extension/wrist flexion
- C8: Finger flexion
- T1: Finger abduction
- L2: Hip flexion
- L3: Knee extension
- L4: Ankle dorsi-flexion
- L5: Great toe extension
- S1: Ankle plantar flexion/ankle eversion/hip extension
- S2: Knee flexion
- S3–S4: Anal reflex

The testing of myotomes provides the clinician with information about the level in the spine where a lesion may be present. During testing, the clinician looks for muscle weakness of a particular group of muscles. Results may indicate lesions to the spinal cord nerve root, or intervertebral disc herniation that presses on the spinal nerve roots.

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3.3F: Function and Physiology of the Spinal Nerves

Spinal nerves connect the brain and spinal cord to the limbs and organs of the body.

Learning Objectives

- Describe the function and physiology of the spinal nerves

Key Points

- Spinal nerves, considered part of the peripheral nervous system, generally refer to mixed spinal nerves, which carry motor, sensory, and autonomic information between the brain and spinal cord and the rest of the body.
- The cervical spinal nerves innervate the muscles and provide sensation for the head, neck, and diaphragm, as well as the upper limbs and back.
- The lumbar, sacral, and coccygeal nerves combine to form the lumbosacral plexus.
- The spinal cord can be divided into the lateral, posterior, and medial cord, each segment of which gives rise to specific nerves and serves specific areas of the body.
- The somatic nervous system is responsible for voluntary body movements, receiving information from afferent fibers and contracting muscles with efferent fibers.
- The autonomic nervous system involves the visceral organs and regulates involuntary movements or unconscious actions.
- The sympathetic nervous system is responsible for the fight or flight reaction under stressful conditions, while the parasympathetic nervous system conserves energy after high stress situations or during rest and digesting.
- The primary neurotransmitters of the peripheral nervous system (PNS) are acetylcholine and noradrenaline, though other neurotransmitters are also present. Acetylcholine acts on two sets of receptors, muscarinic and nicotinic cholinergic receptors.

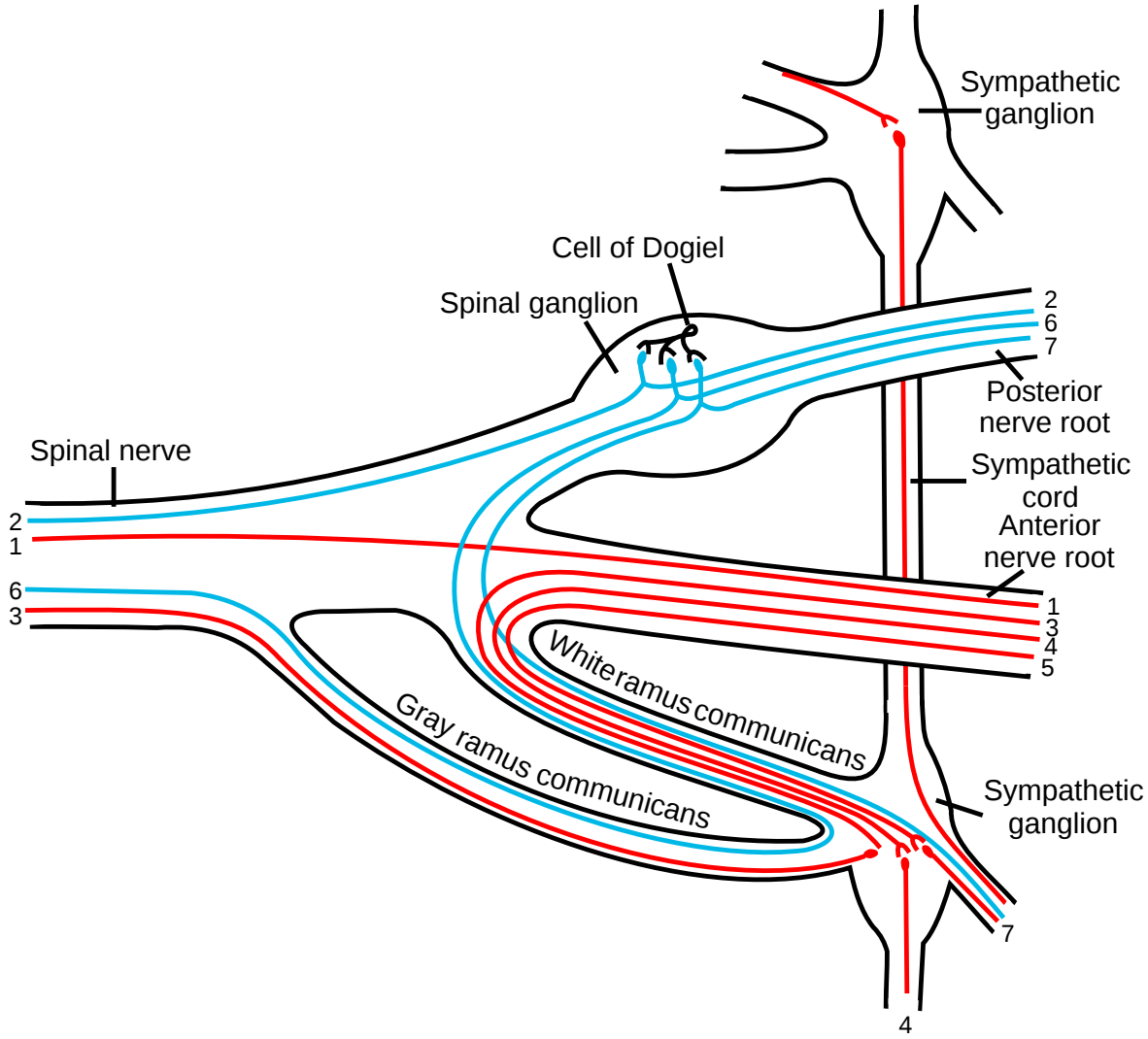
Key Terms

- **nicotinic**: Excitatory acetylcholine receptors.
- **mixed spinal nerve**: A nerve that carries motor, sensory, and autonomic signals between the spinal cord and the body.
- **peripheral nervous system**: The nerves and ganglia outside of the brain and spinal cord.
- **muscarinic**: Acetylcholine receptors
  that can be both excitatory and inhibitory.

Review of Peripheral Nervous System Structure

The peripheral nervous system (PNS) consists of the nerves and ganglia outside of the brain and spinal cord. The main function of the PNS is to connect the central nervous system (CNS) to the limbs and organs.

Unlike the CNS, the PNS is not protected by the bones of the spine and skull, or by the blood –brain barrier, leaving it exposed to toxins and mechanical injuries. The peripheral nervous system is divided into the somatic nervous system and the autonomic nervous system.



Spinal nerve: This diagram indicates the formation of a typical spinal nerve from the dorsal and ventral roots. Numbers indicate the types of nerve fibers: 1 somatic efferent, 2 somatic afferent, 3–5 sympathetic efferent, 6–7 sympathetic afferent.

The peripheral nervous system includes 12 cranial nerves and 31 pairs of spinal nerves that provide communication from the CNS to the rest of the body by nerve impulses to regulate the functions of the human body. The term spinal nerve generally refers to a mixed spinal nerve, which carries motor, sensory, and autonomic signals between the spinal cord and the body.

Spinal Nerve Correspondences

Each pair of spinal nerves roughly correspond to a segment of the vertebral column: 8 cervical spinal nerve pairs (C1–C8), 12 thoracic pairs (T1–T12), 5 lumbar pairs (L1–L5), 5 sacral pairs (S1–S5), and 1 coccygeal pair.

- The first 4 cervical spinal nerves, C1 through C4, split and recombine to produce a variety of nerves that subserve the neck and back of the head.
- The spinal nerve C1 (suboccipital nerve) provides motor innervation to muscles at the base of the skull.
- C2 and C3 form many of the nerves of the neck, and provides both sensory and motor control. These include the greater occipital nerve that provides sensation to the back of the head, the lesser occipital nerve that provides sensation to the area behind the ears, the greater auricular nerve, and the lesser auricular nerve.
- The phrenic nerve arises from nerve roots C3, C4, and C5. It innervates the diaphragm to enable breathing. If the spinal cord is transected above C3, then spontaneous breathing is not possible.
- The last four cervical spinal nerves, C5 through C8, and the first thoracic spinal nerve, T1, combine to form the brachial plexus, or plexus brachialis, a tangled array of nerves, splitting, combining and recombining to form the nerves that subserve the upper

limb region and upper back. Although the brachial plexus may appear tangled, it is highly organized and predictable with little variation among people.

Lumbosacral Plexus

The anterior divisions of the lumbar, sacral, and coccygeal nerves form the lumbosacral plexus, the first lumbar nerve being frequently joined by a branch from the twelfth thoracic. For descriptive purposes, this plexus is usually divided into three parts: lumbar plexus, sacral plexus, and pudendal plexus.

Autonomic Nervous System Function (ANS)

The sympathetic division typically functions in actions that need quick responses. The parasympathetic division functions with actions that do not require immediate reaction.

The sympathetic system is often considered the fight or flight system, while the parasympathetic system is often considered the rest and digest or feed and breed system.

Some typical actions of the sympathetic and parasympathetic systems are listed below.

Sympathetic Nervous System

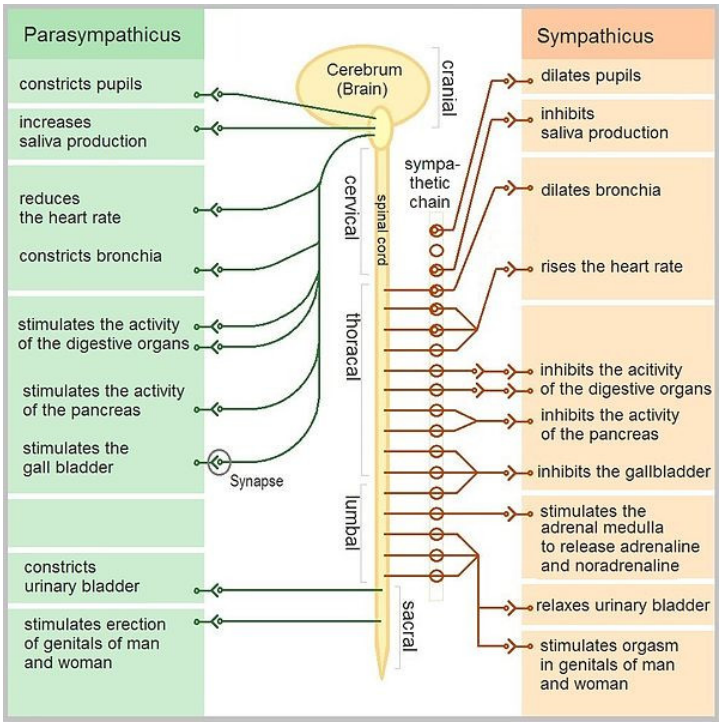
- Diverts blood flow away from the gastrointestinal (GI) tract and skin via vasoconstriction.
- Enhances blood flow to skeletal muscles and the lungs.
- Dilates bronchioles of the lung by circulating epinephrine to allow for greater alveolar oxygen exchange.
- Increases the heart rate and contractility of cardiac muscle for enhanced blood flow to skeletal muscles.
- Dilates pupils and relaxes the ciliary muscle to the lens for far vision.
- Provides vasodilation for the coronary vessels of the heart.
- Constricts all the intestinal sphincters and the urinary sphincter.
- Inhibits peristalsis.
- Stimulates orgasm.

Parasympathetic Nervous System

- Dilates blood vessels that lead to the GI tract to increase blood flow; this is important following food consumption due to the greater metabolic demands placed on the body by the gut.
- Constricts the bronchiolar diameter when the need for oxygen has diminished.
- Manages heart control via dedicated cardiac branches of the vagus and thoracic spinal accessory nerves.
- Constricts the pupil and contracts the ciliary muscles to facilitate accommodation for closer vision.
- Stimulates salivary gland secretion and accelerates peristalsis to mediate the digestion of food.
- PNS nerves are involved in the erection of genital tissues via the pelvic splanchnic nerves 2–4. They are also responsible for stimulating sexual arousal.

Neurotransmitters

- Acetylcholine is the preganglionic neurotransmitter for both divisions of the ANS, as well as the postganglionic neurotransmitter of parasympathetic neurons.
- Nerves that release acetylcholine are said to be cholinergic. In the parasympathetic system, ganglionic neurons use acetylcholine as a neurotransmitter to stimulate muscarinic receptors.
- At the adrenal medulla, there is no postsynaptic neuron. Instead the presynaptic neuron releases acetylcholine to act on nicotinic receptors.
- Stimulation of the adrenal medulla releases adrenaline (epinephrine) into the bloodstream, which acts on adrenoceptors, producing a widespread increase in sympathetic activity.



Autonomic nervous sytem: The functions of the parasympathetic and sympathetic nervous systems are detailed.

Somatic Nervous System Function (SoNS)

The somatic nervous system consists of afferent and efferent nerves and is associated with the voluntary control of skeletal muscle movements. The afferent nerves are responsible for relaying sensations from the body to the central nervous system (CNS), while the efferent nerves are responsible for sending out commands from the CNS to the body to stimulate muscle contraction.

Upper motor neurons release acetylcholine. Acetylcholine is released from the axon terminal knobs of alpha motor neurons and received by postsynaptic receptors (nicotinic acetylcholine receptors) of muscles, thereby relaying the stimulus to contract muscle fibers.

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3.4: The Central Nervous System

Learning Objectives

- Name the major regions of the adult brain
- Describe the connections between the cerebrum and brain stem through the diencephalon, and from those regions into the spinal cord
- Recognize the complex connections within the subcortical structures of the basal nuclei
- Explain the arrangement of gray and white matter in the spinal cord

The brain and the spinal cord are the central nervous system, and they represent the main organs of the nervous system. The spinal cord is a single structure, whereas the adult brain is described in terms of four major regions: the cerebrum, the diencephalon, the brain stem, and the cerebellum. A person's conscious experiences are based on neural activity in the brain. The regulation of homeostasis is governed by a specialized region in the brain. The coordination of reflexes depends on the integration of sensory and motor pathways in the spinal cord.

The Cerebrum

The iconic gray mantle of the human brain, which appears to make up most of the mass of the brain, is the **cerebrum** (Figure 3.4.1). The wrinkled portion is the **cerebral cortex**, and the rest of the structure is beneath that outer covering. There is a large separation between the two sides of the cerebrum called the **longitudinal fissure**. It separates the cerebrum into two distinct halves, a right and left **cerebral hemisphere**. Deep within the cerebrum, the white matter of the **corpus callosum** provides the major pathway for communication between the two hemispheres of the cerebral cortex.

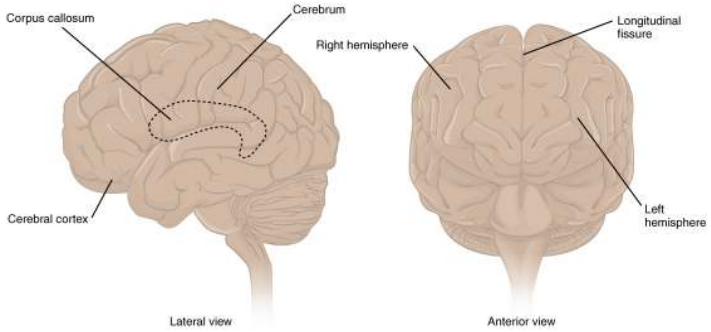


Figure 3.4.1: The Cerebrum. The cerebrum is a large component of the CNS in humans, and the most obvious aspect of it is the folded surface called the cerebral cortex.

Many of the higher neurological functions, such as memory, emotion, and consciousness, are the result of cerebral function. The complexity of the cerebrum is different across vertebrate species. The cerebrum of the most primitive vertebrates is not much more than the connection for the sense of smell. In mammals, the cerebrum comprises the outer gray matter that is the cortex (from the Latin word meaning "bark of a tree") and several deep nuclei that belong to three important functional groups. The **basal nuclei** are responsible for cognitive processing, the most important function being that associated with planning movements. The **basal forebrain** contains nuclei that are important in learning and memory. The **limbic cortex** is the region of the cerebral cortex that is part of the **limbic system**, a collection of structures involved in emotion, memory, and behavior.

Cerebral Cortex

The cerebrum is covered by a continuous layer of gray matter that wraps around either side of the forebrain—the cerebral cortex. This thin, extensive region of wrinkled gray matter is responsible for the higher functions of the nervous system. A **gyrus** (plural = gyri) is the ridge of one of those wrinkles, and a **sulcus** (plural = sulci) is the groove between two gyri. The pattern of these folds of tissue indicates specific regions of the cerebral cortex.

The head is limited by the size of the birth canal, and the brain must fit inside the cranial cavity of the skull. Extensive folding in the cerebral cortex enables more gray matter to fit into this limited space. If the gray matter of the cortex were peeled off of the cerebrum and laid out flat, its surface area would be roughly equal to one square meter.

The folding of the cortex maximizes the amount of gray matter in the cranial cavity. During embryonic development, as the telencephalon expands within the skull, the brain goes through a regular course of growth that results in everyone's brain having a similar pattern of folds. The surface of the brain can be mapped on the basis of the locations of large gyri and sulci. Using these landmarks, the cortex can be separated into four major regions, or lobes (Figure 3.4.2). The **lateral sulcus** that separates the **temporal lobe** from the other regions is one such landmark. Superior to the lateral sulcus are the **parietal lobe** and **frontal lobe**, which are separated from each other by the **central sulcus**. The posterior region of the cortex is the **occipital lobe**, which has no obvious anatomical border between it and the parietal or temporal lobes on the lateral surface of the brain. From the medial surface, an obvious landmark separating the parietal and occipital lobes is called the **parieto-occipital sulcus**. The fact that there is no obvious anatomical border between these lobes is consistent with the functions of these regions being interrelated.

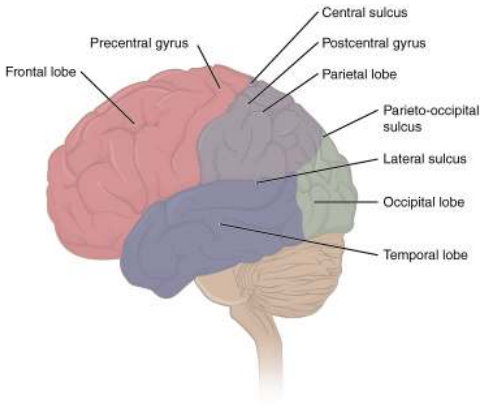


Figure 3.4.2: Lobes of the Cerebral Cortex. The cerebral cortex is divided into four lobes. Extensive folding increases the surface area available for cerebral functions.

Different regions of the cerebral cortex can be associated with particular functions, a concept known as localization of function. In the early 1900s, a German neuroscientist named Korbinian Brodmann performed an extensive study of the microscopic anatomy—the cytoarchitecture—of the cerebral cortex and divided the cortex into 52 separate regions on the basis of the histology of the cortex. His work resulted in a system of classification known as **Brodmann's areas**, which is still used today to describe the anatomical distinctions within the cortex (Figure 3.4.3). The results from Brodmann's work on the anatomy align very well with the functional differences within the cortex. Areas 17 and 18 in the occipital lobe are responsible for primary visual perception. That visual information is complex, so it is processed in the temporal and parietal lobes as well.

The temporal lobe is associated with primary auditory sensation, known as Brodmann's areas 41 and 42 in the superior temporal lobe. Because regions of the temporal lobe are part of the limbic system, memory is an important function associated with that lobe. Memory is essentially a sensory function; memories are recalled sensations such as the smell of Mom's baking or the sound of a barking dog. Even memories of movement are really the memory of sensory feedback from those movements, such as stretching muscles or the movement of the skin around a joint. Structures in the temporal lobe are responsible for establishing long-term memory, but the ultimate location of those memories is usually in the region in which the sensory perception was processed.

The main sensation associated with the parietal lobe is **somatosensation**, meaning the general sensations associated with the body. Posterior to the central sulcus is the **postcentral gyrus**, the primary somatosensory cortex, which is identified as Brodmann's areas 1, 2, and 3. All of the tactile senses are processed in this area, including touch, pressure, tickle, pain, itch, and vibration, as well as more general senses of the body such as **proprioception** and **kinesthesia**, which are the senses of body position and movement, respectively.

Anterior to the central sulcus is the frontal lobe, which is primarily associated with motor functions. The **precentral gyrus** is the primary motor cortex. Cells from this region of the cerebral cortex are the upper motor neurons that instruct cells in the spinal cord to move skeletal muscles. Anterior to this region are a few areas that are associated with planned movements. The **premotor area** is responsible for thinking of a movement to be made. The **frontal eye fields** are important in eliciting eye movements and in attending to visual stimuli. **Broca's area** is responsible for the production of language, or controlling movements responsible for speech; in the vast majority of people, it is located only on the left side. Anterior to these regions is the **prefrontal lobe**, which serves cognitive functions that can be the basis of personality, short-term memory, and consciousness. The prefrontal lobotomy is an outdated mode of treatment for personality disorders (psychiatric conditions) that profoundly affected the personality of the patient.

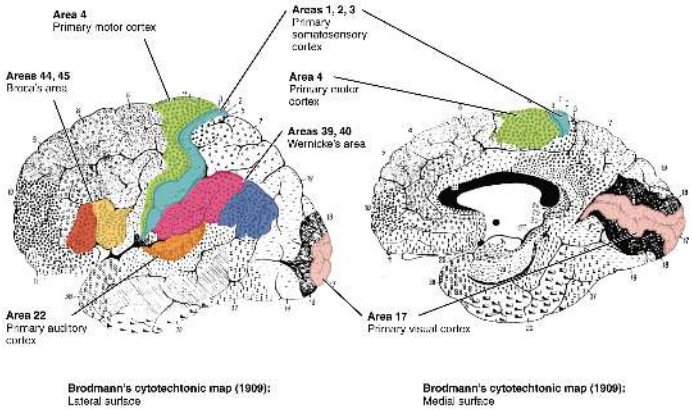


Figure 3.4.3: Brodmann's Areas of the Cerebral Cortex. Brodmann mapping of functionally distinct regions of the cortex was based on its cytoarchitecture at a microscopic level.

Subcortical structures

Beneath the cerebral cortex are sets of nuclei known as **subcortical nuclei** that augment cortical processes. The nuclei of the basal forebrain serve as the primary location for acetylcholine production, which modulates the overall activity of the cortex, possibly leading to greater attention to sensory stimuli. Alzheimer's disease is associated with a loss of neurons in the basal forebrain. The **hippocampus** and **amygdala** are medial-lobe structures that, along with the adjacent cortex, are involved in long-term memory formation and emotional responses. The basal nuclei are a set of nuclei in the cerebrum responsible for comparing cortical processing with the general state of activity in the nervous system to influence the likelihood of movement taking place. For example, while a student is sitting in a classroom listening to a lecture, the basal nuclei will keep the urge to jump up and scream from actually happening. (The basal nuclei are also referred to as the basal ganglia, although that is potentially confusing because the term ganglia is typically used for peripheral structures.)

The major structures of the basal nuclei that control movement are the **caudate**, **putamen**, and **globus pallidus**, which are located deep in the cerebrum. The caudate is a long nucleus that follows the basic C-shape of the cerebrum from the frontal lobe, through the parietal and occipital lobes, into the temporal lobe. The putamen is mostly deep in the anterior regions of the frontal and parietal lobes. Together, the caudate and putamen are called the **striatum**. The globus pallidus is a layered nucleus that lies just medial to the putamen; they are called the lenticular nuclei because they look like curved pieces fitting together like lenses. The globus pallidus has two subdivisions, the external and internal segments, which are lateral and medial, respectively. These nuclei are depicted in a frontal section of the brain in Figure 3.4.4.

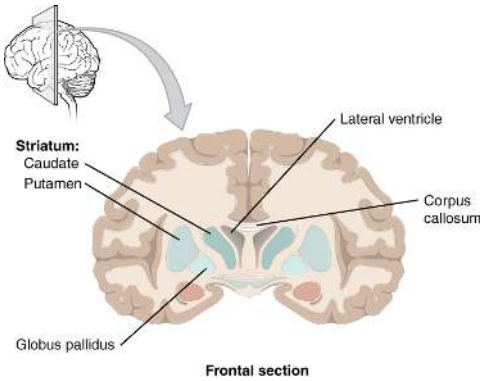


Figure 3.4.4: Frontal Section of Cerebral Cortex and Basal Nuclei. The major components of the basal nuclei, shown in a frontal section of the brain, are the caudate (just lateral to the lateral ventricle), the putamen (inferior to the caudate and separated by the large white-matter structure called the internal capsule), and the globus pallidus (medial to the putamen).

The basal nuclei in the cerebrum are connected with a few more nuclei in the brain stem that together act as a functional group that forms a motor pathway. Two streams of information processing take place in the basal nuclei. All input to the basal nuclei is from the cortex into the striatum (Figure 3.4.5). The **direct pathway** is the projection of axons from the striatum to the globus pallidus internal segment (GPi) and the **substantia nigra pars reticulata (SNr)**. The GPi/SNr then projects to the thalamus, which projects back to the cortex. The **indirect pathway** is the projection of axons from the striatum to the globus pallidus external segment (GPe), then to the subthalamic nucleus (STN), and finally to GPi/SNr. The two streams both target the GPi/SNr, but one has a

direct projection and the other goes through a few intervening nuclei. The direct pathway causes the **disinhibition** of the thalamus (inhibition of one cell on a target cell that then inhibits the first cell), whereas the indirect pathway causes, or reinforces, the normal inhibition of the thalamus. The thalamus then can either excite the cortex (as a result of the direct pathway) or fail to excite the cortex (as a result of the indirect pathway).

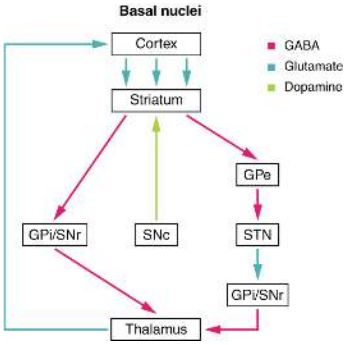


Figure 3.4.5: Connections of Basal Nuclei. Input to the basal nuclei is from the cerebral cortex, which is an excitatory connection releasing glutamate as a neurotransmitter. This input is to the striatum, or the caudate and putamen. In the direct pathway, the striatum projects to the internal segment of the globus pallidus and the substantia nigra pars reticulata (GPi/SNr). This is an inhibitory pathway, in which GABA is released at the synapse, and the target cells are hyperpolarized and less likely to fire. The output from the basal nuclei is to the thalamus, which is an inhibitory projection using GABA. The switch between the two pathways is the substantia nigra pars compacta, which projects to the striatum and releases the neurotransmitter dopamine. Dopamine receptors are either excitatory (D1-type receptors) or inhibitory (D2-type receptors). The direct pathway is activated by dopamine, and the indirect pathway is inhibited by dopamine. When the substantia nigra pars compacta is firing, it signals to the basal nuclei that the body is in an active state, and movement will be more likely. When the substantia nigra pars compacta is silent, the body is in a passive state, and movement is inhibited. To illustrate this situation, while a student is sitting listening to a lecture, the substantia nigra pars compacta would be silent and the student less likely to get up and walk around. Likewise, while the professor is lecturing, and walking around at the front of the classroom, the professor's substantia nigra pars compacta would be active, in keeping with his or her activity level.

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Watch this video to learn about the basal nuclei (also known as the basal ganglia), which have two pathways that process information within the cerebrum. As shown in this video, the direct pathway is the shorter pathway through the system that results in increased activity in the cerebral cortex and increased motor activity. The direct pathway is described as resulting in "disinhibition" of the thalamus. What does disinhibition mean? What are the two neurons doing individually to cause this?

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Watch this video to learn about the basal nuclei (also known as the basal ganglia), which have two pathways that process information within the cerebrum. As shown in this video, the indirect pathway is the longer pathway through the system that results in decreased activity in the cerebral cortex, and therefore less motor activity. The indirect pathway has an extra couple of connections in it, including disinhibition of the subthalamic nucleus. What is the end result on the thalamus, and therefore on movement initiated by the cerebral cortex?

EVERYDAY CONNECTIONS

The Myth of Left Brain/Right Brain

There is a persistent myth that people are "right-brained" or "left-brained," which is an oversimplification of an important concept about the cerebral hemispheres. There is some lateralization of function, in which the left side of the brain is devoted to language function and the right side is devoted to spatial and nonverbal reasoning. Whereas these functions are predominantly associated with those sides of the brain, there is no monopoly by either side on these functions. Many pervasive functions, such as language, are distributed globally around the cerebrum.

Some of the support for this misconception has come from studies of split brains. A drastic way to deal with a rare and devastating neurological condition (intractable epilepsy) is to separate the two hemispheres of the brain. After sectioning the corpus callosum, a split-brained patient will have trouble producing verbal responses on the basis of sensory information processed on the right side of the cerebrum, leading to the idea that the left side is responsible for language function.

However, there are well-documented cases of language functions lost from damage to the right side of the brain. The deficits seen in damage to the left side of the brain are classified as aphasia, a loss of speech function; damage on the right side can affect the use of language. Right-side damage can result in a loss of ability to understand figurative aspects of speech, such as jokes, irony, or metaphors. Nonverbal aspects of speech can be affected by damage to the right side, such as

facial expression or body language, and right-side damage can lead to a “flat affect” in speech, or a loss of emotional expression in speech—sounding like a robot when talking.

The Diencephalon

The diencephalon is the one region of the adult brain that retains its name from embryologic development. The etymology of the word diencephalon translates to “through brain.” It is the connection between the cerebrum and the rest of the nervous system, with one exception. The rest of the brain, the spinal cord, and the PNS all send information to the cerebrum through the diencephalon. Output from the cerebrum passes through the diencephalon. The single exception is the system associated with **olfaction**, or the sense of smell, which connects directly with the cerebrum. In the earliest vertebrate species, the cerebrum was not much more than olfactory bulbs that received peripheral information about the chemical environment (to call it smell in these organisms is imprecise because they lived in the ocean).

The diencephalon is deep beneath the cerebrum and constitutes the walls of the third ventricle. The diencephalon can be described as any region of the brain with “thalamus” in its name. The two major regions of the diencephalon are the thalamus itself and the hypothalamus (Figure 3.4.6). There are other structures, such as the **epithalamus**, which contains the pineal gland, or the **subthalamus**, which includes the subthalamic nucleus that is part of the basal nuclei.

Thalamus

The **thalamus** is a collection of nuclei that relay information between the cerebral cortex and the periphery, spinal cord, or brain stem. All sensory information, except for the sense of smell, passes through the thalamus before processing by the cortex. Axons from the peripheral sensory organs, or intermediate nuclei, synapse in the thalamus, and thalamic neurons project directly to the cerebrum. It is a requisite synapse in any sensory pathway, except for olfaction. The thalamus does not just pass the information on, it also processes that information. For example, the portion of the thalamus that receives visual information will influence what visual stimuli are important, or what receives attention.

The cerebrum also sends information down to the thalamus, which usually communicates motor commands. This involves interactions with the cerebellum and other nuclei in the brain stem. The cerebrum interacts with the basal nuclei, which involves connections with the thalamus. The primary output of the basal nuclei is to the thalamus, which relays that output to the cerebral cortex. The cortex also sends information to the thalamus that will then influence the effects of the basal nuclei.

Hypothalamus

Inferior and slightly anterior to the thalamus is the **hypothalamus**, the other major region of the diencephalon. The hypothalamus is a collection of nuclei that are largely involved in regulating homeostasis. The hypothalamus is the executive region in charge of the autonomic nervous system and the endocrine system through its regulation of the anterior pituitary gland. Other parts of the hypothalamus are involved in memory and emotion as part of the limbic system.

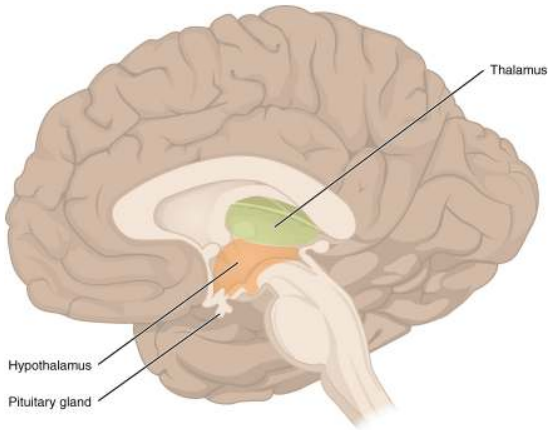


Figure 3.4.6: The Diencephalon. The diencephalon is composed primarily of the thalamus and hypothalamus, which together define the walls of the third ventricle. The thalami are two elongated, ovoid structures on either side of the midline that make contact in the middle. The hypothalamus is inferior and anterior to the thalamus, culminating in a sharp angle to which the pituitary gland is attached.

Brain Stem

The midbrain and hindbrain (composed of the pons and the medulla) are collectively referred to as the brain stem (Figure 3.4.7). The structure emerges from the ventral surface of the forebrain as a tapering cone that connects the brain to the spinal cord. Attached to the brain stem, but considered a separate region of the adult brain, is the cerebellum. The midbrain coordinates sensory representations of the visual, auditory, and somatosensory perceptual spaces. The pons is the main connection with the cerebellum. The pons and the medulla regulate several crucial functions, including the cardiovascular and respiratory systems and rates.

The cranial nerves connect through the brain stem and provide the brain with the sensory input and motor output associated with the head and neck, including most of the special senses. The major ascending and descending pathways between the spinal cord and brain, specifically the cerebrum, pass through the brain stem.

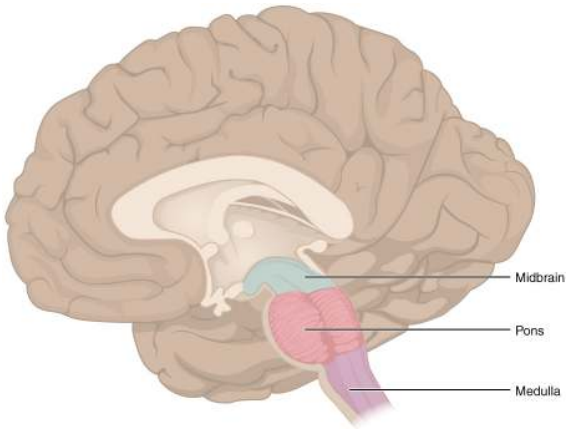


Figure 3.4.7: The Brain Stem. The brain stem comprises three regions: the midbrain, the pons, and the medulla.

Midbrain

One of the original regions of the embryonic brain, the midbrain is a small region between the thalamus and pons. It is separated into the **tectum** and **tegmentum**, from the Latin words for roof and floor, respectively. The cerebral aqueduct passes through the center of the midbrain, such that these regions are the roof and floor of that canal.

The tectum is composed of four bumps known as the colliculi (singular = colliculus), which means “little hill” in Latin. The **inferior colliculus** is the inferior pair of these enlargements and is part of the auditory brain stem pathway. Neurons of the inferior colliculus project to the thalamus, which then sends auditory information to the cerebrum for the conscious perception of sound. The **superior colliculus** is the superior pair and combines sensory information about visual space, auditory space, and somatosensory space. Activity in the superior colliculus is related to orienting the eyes to a sound or touch stimulus. If you are walking along the sidewalk on campus and you hear chirping, the superior colliculus coordinates that information with your awareness of the visual location of the tree right above you. That is the correlation of auditory and visual maps. If you suddenly feel something wet fall on your head, your superior colliculus integrates that with the auditory and visual maps and you know that the chirping bird just relieved itself on you. You want to look up to see the culprit, but do not.

The tegmentum is continuous with the gray matter of the rest of the brain stem. Throughout the midbrain, pons, and medulla, the tegmentum contains the nuclei that receive and send information through the cranial nerves, as well as regions that regulate important functions such as those of the cardiovascular and respiratory systems.

Pons

The word pons comes from the Latin word for bridge. It is visible on the anterior surface of the brain stem as the thick bundle of white matter attached to the cerebellum. The pons is the main connection between the cerebellum and the brain stem. The bridge-like white matter is only the anterior surface of the pons; the gray matter beneath that is a continuation of the tegmentum from the midbrain. Gray matter in the tegmentum region of the pons contains neurons receiving descending input from the forebrain that is sent to the cerebellum.

Medulla

The medulla is the region known as the myelencephalon in the embryonic brain. The initial portion of the name, “myel,” refers to the significant white matter found in this region—especially on its exterior, which is continuous with the white matter of the spinal

cord. The tegmentum of the midbrain and pons continues into the medulla because this gray matter is responsible for processing cranial nerve information. A diffuse region of gray matter throughout the brain stem, known as the **reticular formation**, is related to sleep and wakefulness, such as general brain activity and attention.

The Cerebellum

The **cerebellum**, as the name suggests, is the "little brain." It is covered in gyri and sulci like the cerebrum, and looks like a miniature version of that part of the brain (Figure 3.4.8). The cerebellum is largely responsible for comparing information from the cerebrum with sensory feedback from the periphery through the spinal cord. It accounts for approximately 10 percent of the mass of the brain.

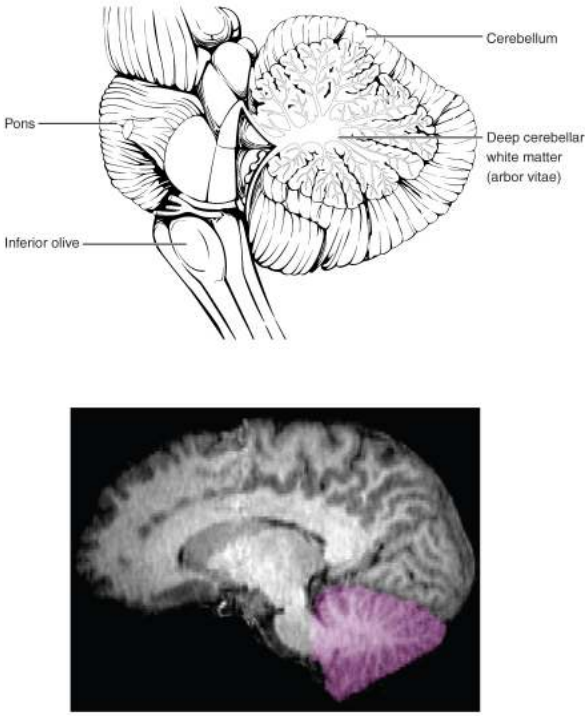


Figure 3.4.8: The Cerebellum. The cerebellum is situated on the posterior surface of the brain stem. Descending input from the cerebellum enters through the large white matter structure of the pons. Ascending input from the periphery and spinal cord enters through the fibers of the inferior olive. Output goes to the midbrain, which sends a descending signal to the spinal cord.

Descending fibers from the cerebrum have branches that connect to neurons in the pons. Those neurons project into the cerebellum, providing a copy of motor commands sent to the spinal cord. Sensory information from the periphery, which enters through spinal or cranial nerves, is copied to a nucleus in the medulla known as the **inferior olive**. Fibers from this nucleus enter the cerebellum and are compared with the descending commands from the cerebrum. If the primary motor cortex of the frontal lobe sends a command down to the spinal cord to initiate walking, a copy of that instruction is sent to the cerebellum. Sensory feedback from the muscles and joints, proprioceptive information about the movements of walking, and sensations of balance are sent to the cerebellum through the inferior olive and the cerebellum compares them. If walking is not coordinated, perhaps because the ground is uneven or a strong wind is blowing, then the cerebellum sends out a corrective command to compensate for the difference between the original cortical command and the sensory feedback. The output of the cerebellum is into the midbrain, which then sends a descending input to the spinal cord to correct the messages going to skeletal muscles.

The Spinal Cord

The description of the CNS is concentrated on the structures of the brain, but the spinal cord is another major organ of the system. Whereas the brain develops out of expansions of the neural tube into primary and then secondary vesicles, the spinal cord maintains the tube structure and is only specialized into certain regions. As the spinal cord continues to develop in the newborn, anatomical features mark its surface. The anterior midline is marked by the **anterior median fissure**, and the posterior midline is marked by the **posterior median sulcus**. Axons enter the posterior side through the **dorsal (posterior) nerve root**, which marks the **posterolateral sulcus** on either side. The axons emerging from the anterior side do so through the **ventral (anterior) nerve root**. Note that it is common to see the terms dorsal (dorsal = "back") and ventral (ventral = "belly") used interchangeably with

posterior and anterior, particularly in reference to nerves and the structures of the spinal cord. You should learn to be comfortable with both.

On the whole, the posterior regions are responsible for sensory functions and the anterior regions are associated with motor functions. This comes from the initial development of the spinal cord, which is divided into the **basal plate** and the **alar plate**. The basal plate is closest to the ventral midline of the neural tube, which will become the anterior face of the spinal cord and gives rise to motor neurons. The alar plate is on the dorsal side of the neural tube and gives rise to neurons that will receive sensory input from the periphery.

The length of the spinal cord is divided into regions that correspond to the regions of the vertebral column. The name of a spinal cord region corresponds to the level at which spinal nerves pass through the intervertebral foramina. Immediately adjacent to the brain stem is the cervical region, followed by the thoracic, then the lumbar, and finally the sacral region. The spinal cord is not the full length of the vertebral column because the spinal cord does not grow significantly longer after the first or second year, but the skeleton continues to grow. The nerves that emerge from the spinal cord pass through the intervertebral formina at the respective levels. As the vertebral column grows, these nerves grow with it and result in a long bundle of nerves that resembles a horse's tail and is named the **cauda equina**. The sacral spinal cord is at the level of the upper lumbar vertebral bones. The spinal nerves extend from their various levels to the proper level of the vertebral column.

Gray Horns

In cross-section, the gray matter of the spinal cord has the appearance of an ink-blot test, with the spread of the gray matter on one side replicated on the other—a shape reminiscent of a bulbous capital "H." As shown in Figure 3.4.9, the gray matter is subdivided into regions that are referred to as horns. The **posterior horn** is responsible for sensory processing. The **anterior horn** sends out motor signals to the skeletal muscles. The **lateral horn**, which is only found in the thoracic, upper lumbar, and sacral regions, is the central component of the sympathetic division of the autonomic nervous system.

Some of the largest neurons of the spinal cord are the multipolar motor neurons in the anterior horn. The fibers that cause contraction of skeletal muscles are the axons of these neurons. The motor neuron that causes contraction of the big toe, for example, is located in the sacral spinal cord. The axon that has to reach all the way to the belly of that muscle may be a meter in length. The neuronal cell body that maintains that long fiber must be quite large, possibly several hundred micrometers in diameter, making it one of the largest cells in the body.

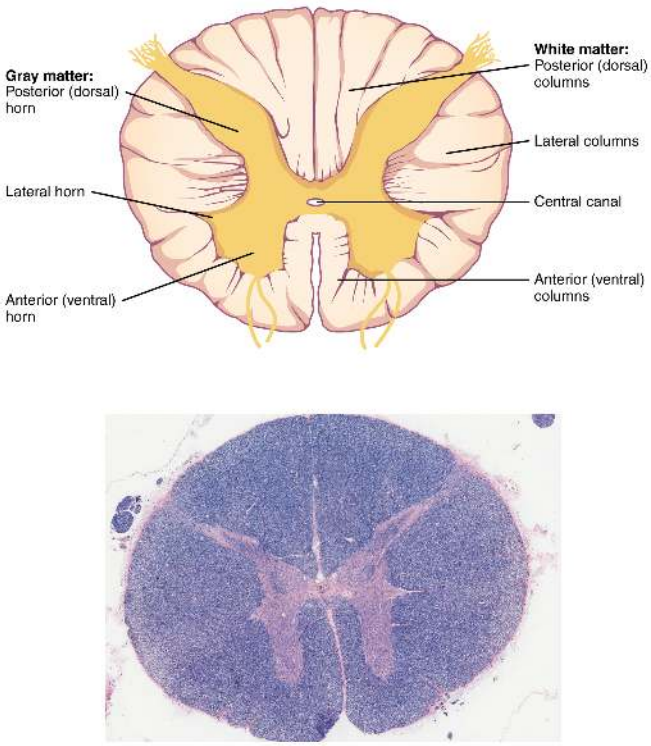


Figure 3.4.9: Cross-section of Spinal Cord. The cross-section of a thoracic spinal cord segment shows the posterior, anterior, and lateral horns of gray matter, as well as the posterior, anterior, and lateral columns of white matter. LM × 40. (Micrograph provided by the Regents of University of Michigan Medical School © 2012)

White Columns

Just as the gray matter is separated into horns, the white matter of the spinal cord is separated into columns. **Ascending tracts** of nervous system fibers in these columns carry sensory information up to the brain, whereas **descending tracts** carry motor commands from the brain. Looking at the spinal cord longitudinally, the columns extend along its length as continuous bands of white matter. Between the two posterior horns of gray matter are the **posterior columns**. Between the two anterior horns, and bounded by the axons of motor neurons emerging from that gray matter area, are the **anterior columns**. The white matter on either side of the spinal cord, between the posterior horn and the axons of the anterior horn neurons, are the **lateral columns**. The posterior columns are composed of axons of ascending tracts. The anterior and lateral columns are composed of many different groups of axons of both ascending and descending tracts—the latter carrying motor commands down from the brain to the spinal cord to control output to the periphery.

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Watch this video to learn about the gray matter of the spinal cord that receives input from fibers of the dorsal (posterior) root and sends information out through the fibers of the ventral (anterior) root. As discussed in this video, these connections represent the interactions of the CNS with peripheral structures for both sensory and motor functions. The cervical and lumbar spinal cords have enlargements as a result of larger populations of neurons. What are these enlargements responsible for?

DISORDERS OF THE...

Basal Nuclei

Parkinson's disease is a disorder of the basal nuclei, specifically of the substantia nigra, that demonstrates the effects of the direct and indirect pathways. Parkinson's disease is the result of neurons in the substantia nigra pars compacta dying. These neurons release dopamine into the striatum. Without that modulatory influence, the basal nuclei are stuck in the indirect pathway, without the direct pathway being activated. The direct pathway is responsible for increasing cortical movement commands. The increased activity of the indirect pathway results in the hypokinetic disorder of Parkinson's disease.

Parkinson's disease is neurodegenerative, meaning that neurons die that cannot be replaced, so there is no cure for the disorder. Treatments for Parkinson's disease are aimed at increasing dopamine levels in the striatum. Currently, the most

common way of doing that is by providing the amino acid L-DOPA, which is a precursor to the neurotransmitter dopamine and can cross the blood-brain barrier. With levels of the precursor elevated, the remaining cells of the substantia nigra pars compacta can make more neurotransmitter and have a greater effect. Unfortunately, the patient will become less responsive to L-DOPA treatment as time progresses, and it can cause increased dopamine levels elsewhere in the brain, which are associated with psychosis or schizophrenia.

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Visit this site for a thorough explanation of Parkinson's disease.

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Compared with the nearest evolutionary relative, the chimpanzee, the human has a brain that is huge. At a point in the past, a common ancestor gave rise to the two species of humans and chimpanzees. That evolutionary history is long and is still an area of intense study. But something happened to increase the size of the human brain relative to the chimpanzee. Read this article in which the author explores the current understanding of why this happened.

According to one hypothesis about the expansion of brain size, what tissue might have been sacrificed so energy was available to grow our larger brain? Based on what you know about that tissue and nervous tissue, why would there be a trade-off between them in terms of energy use?

Chapter Review

The adult brain is separated into four major regions: the cerebrum, the diencephalon, the brain stem, and the cerebellum. The cerebrum is the largest portion and contains the cerebral cortex and subcortical nuclei. It is divided into two halves by the longitudinal fissure.

The cortex is separated into the frontal, parietal, temporal, and occipital lobes. The frontal lobe is responsible for motor functions, from planning movements through executing commands to be sent to the spinal cord and periphery. The most anterior portion of the frontal lobe is the prefrontal cortex, which is associated with aspects of personality through its influence on motor responses in decision-making.

The other lobes are responsible for sensory functions. The parietal lobe is where somatosensation is processed. The occipital lobe is where visual processing begins, although the other parts of the brain can contribute to visual function. The temporal lobe contains the cortical area for auditory processing, but also has regions crucial for memory formation.

Nuclei beneath the cerebral cortex, known as the subcortical nuclei, are responsible for augmenting cortical functions. The basal nuclei receive input from cortical areas and compare it with the general state of the individual through the activity of a dopamine-releasing nucleus. The output influences the activity of part of the thalamus that can then increase or decrease cortical activity that often results in changes to motor commands. The basal forebrain is responsible for modulating cortical activity in attention and memory. The limbic system includes deep cerebral nuclei that are responsible for emotion and memory.

The diencephalon includes the thalamus and the hypothalamus, along with some other structures. The thalamus is a relay between the cerebrum and the rest of the nervous system. The hypothalamus coordinates homeostatic functions through the autonomic and endocrine systems.

The brain stem is composed of the midbrain, pons, and medulla. It controls the head and neck region of the body through the cranial nerves. There are control centers in the brain stem that regulate the cardiovascular and respiratory systems.

The cerebellum is connected to the brain stem, primarily at the pons, where it receives a copy of the descending input from the cerebrum to the spinal cord. It can compare this with sensory feedback input through the medulla and send output through the midbrain that can correct motor commands for coordination.

Interactive Link Questions

Watch this video to learn about the basal nuclei (also known as the basal ganglia), which have two pathways that process information within the cerebrum. As shown in this video, the direct pathway is the shorter pathway through the system that results in increased activity in the cerebral cortex and increased motor activity. The direct pathway is described as resulting in "disinhibition" of the thalamus. What does disinhibition mean? What are the two neurons doing individually to cause this?

Answer: Both cells are inhibitory. The first cell inhibits the second one. Therefore, the second cell can no longer inhibit its target. This is disinhibition of that target across two synapses.

Watch this video to learn about the basal nuclei (also known as the basal ganglia), which have two pathways that process information within the cerebrum. As shown in this video, the indirect pathway is the longer pathway through the system that results in decreased activity in the cerebral cortex, and therefore less motor activity. The indirect pathway has an extra couple of connections in it, including disinhibition of the subthalamic nucleus. What is the end result on the thalamus, and therefore on movement initiated by the cerebral cortex?

Answer: By disinhibiting the subthalamic nucleus, the indirect pathway increases excitation of the globus pallidus internal segment. That, in turn, inhibits the thalamus, which is the opposite effect of the direct pathway that disinhibits the thalamus.

Watch this video to learn about the gray matter of the spinal cord that receives input from fibers of the dorsal (posterior) root and sends information out through the fibers of the ventral (anterior) root. As discussed in this video, these connections represent the interactions of the CNS with peripheral structures for both sensory and motor functions. The cervical and lumbar spinal cords have enlargements as a result of larger populations of neurons. What are these enlargements responsible for?

Answer: There are more motor neurons in the anterior horns that are responsible for movement in the limbs. The cervical enlargement is for the arms, and the lumbar enlargement is for the legs.

Compared with the nearest evolutionary relative, the chimpanzee, the human has a brain that is huge. At a point in the past, a common ancestor gave rise to the two species of humans and chimpanzees. That evolutionary history is long and is still an area of intense study. But something happened to increase the size of the human brain relative to the chimpanzee. Read this article in which the author explores the current understanding of why this happened.

According to one hypothesis about the expansion of brain size, what tissue might have been sacrificed so energy was available to grow our larger brain? Based on what you know about that tissue and nervous tissue, why would there be a trade-off between them in terms of energy use?

Answer: Energy is needed for the brain to develop and perform higher cognitive functions. That energy is not available for the muscle tissues to develop and function. The hypothesis suggests that humans have larger brains and less muscle mass, and chimpanzees have the smaller brains but more muscle mass.

Review Questions

Q. Which lobe of the cerebral cortex is responsible for generating motor commands?

A. temporal

B. parietal

C. occipital

D. frontal

Answer: D

Q. What region of the diencephalon coordinates homeostasis?

A. thalamus

B. epithalamus

C. hypothalamus

D. subthalamus

Answer: C

Q. What level of the brain stem is the major input to the cerebellum?

A. midbrain

B. pons

C. medulla

D. spinal cord

Answer: B

Q. What region of the spinal cord contains motor neurons that direct the movement of skeletal muscles?

A. anterior horn

B. posterior horn

C. lateral horn

D. alar plate

Answer: A

Q. Brodmann's areas map different regions of the _____ to particular functions.

A. cerebellum

B. cerebral cortex

C. basal forebrain

D. corpus callosum

Answer: B

Critical Thinking Questions

Q. Damage to specific regions of the cerebral cortex, such as through a stroke, can result in specific losses of function. What functions would likely be lost by a stroke in the temporal lobe?

A. The temporal lobe has sensory functions associated with hearing and vision, as well as being important for memory. A stroke in the temporal lobe can result in specific sensory deficits in these systems (known as agnosias) or losses in memory.

Q. Why do the anatomical inputs to the cerebellum suggest that it can compare motor commands and sensory feedback?

A. A copy of descending input from the cerebrum to the spinal cord, through the pons, and sensory feedback from the spinal cord and special senses like balance, through the medulla, both go to the cerebellum. It can therefore send output through the midbrain that will correct spinal cord control of skeletal muscle movements.

Glossary

alar plate
developmental region of the spinal cord that gives rise to the posterior horn of the gray matter

amygdala
nucleus deep in the temporal lobe of the cerebrum that is related to memory and emotional behavior

anterior column
white matter between the anterior horns of the spinal cord composed of many different groups of axons of both ascending and descending tracts

anterior horn
gray matter of the spinal cord containing multipolar motor neurons, sometimes referred to as the ventral horn

anterior median fissure
deep midline feature of the anterior spinal cord, marking the separation between the right and left sides of the cord

ascending tract
central nervous system fibers carrying sensory information from the spinal cord or periphery to the brain

basal forebrain
nuclei of the cerebrum related to modulation of sensory stimuli and attention through broad projections to the cerebral cortex, loss of which is related to Alzheimer's disease

basal nuclei
nuclei of the cerebrum (with a few components in the upper brain stem and diencephalon) that are responsible for assessing cortical movement commands and comparing them with the general state of the individual through broad modulatory activity of dopamine neurons; largely related to motor functions, as evidenced through the symptoms of Parkinson's and Huntington's diseases

basal plate
developmental region of the spinal cord that gives rise to the lateral and anterior horns of gray matter

Broca's area
region of the frontal lobe associated with the motor commands necessary for speech production and located only in the cerebral hemisphere responsible for language production, which is the left side in approximately 95 percent of the population

Brodmann's areas
mapping of regions of the cerebral cortex based on microscopic anatomy that relates specific areas to functional differences, as described by Brodmann in the early 1900s

cauda equina
bundle of spinal nerve roots that descend from the lower spinal cord below the first lumbar vertebra and lie within the vertebral cavity; has the appearance of a horse's tail

caudate
nucleus deep in the cerebrum that is part of the basal nuclei; along with the putamen, it is part of the striatum

central sulcus
surface landmark of the cerebral cortex that marks the boundary between the frontal and parietal lobes

cerebral cortex
outer gray matter covering the forebrain, marked by wrinkles and folds known as gyri and sulci

cerebrum
region of the adult brain that develops from the telencephalon and is responsible for higher neurological functions such as memory, emotion, and consciousness

cerebellum
region of the adult brain connected primarily to the pons that developed from the metencephalon (along with the pons) and is largely responsible for comparing information from the cerebrum with sensory feedback from the periphery through the spinal cord

cerebral hemisphere
one half of the bilaterally symmetrical cerebrum

corpus callosum
large white matter structure that connects the right and left cerebral hemispheres

descending tract
central nervous system fibers carrying motor commands from the brain to the spinal cord or periphery

direct pathway
connections within the basal nuclei from the striatum to the globus pallidus internal segment and substantia nigra pars reticulata that disinhibit the thalamus to increase cortical control of movement

disinhibition
disynaptic connection in which the first synapse inhibits the second cell, which then stops inhibiting the final target

dorsal (posterior) nerve root
axons entering the posterior horn of the spinal cord

epithalamus
region of the diecephalon containing the pineal gland

frontal eye field
region of the frontal lobe associated with motor commands to orient the eyes toward an object of visual attention

frontal lobe
region of the cerebral cortex directly beneath the frontal bone of the cranium

globus pallidus
nuclei deep in the cerebrum that are part of the basal nuclei and can be divided into the internal and external segments

gyrus
ridge formed by convolutions on the surface of the cerebrum or cerebellum

hippocampus
gray matter deep in the temporal lobe that is very important for long-term memory formation

hypothalamus
major region of the diencephalon that is responsible for coordinating autonomic and endocrine control of homeostasis

indirect pathway
connections within the basal nuclei from the striatum through the globus pallidus external segment and subthalamic nucleus to the globus pallidus internal segment/substantia nigra pars compacta that result in inhibition of the thalamus to decrease cortical control of movement

inferior colliculus
half of the midbrain tectum that is part of the brain stem auditory pathway

inferior olive
nucleus in the medulla that is involved in processing information related to motor control

kinesthesia
general sensory perception of movement of the body

lateral column
white matter of the spinal cord between the posterior horn on one side and the axons from the anterior horn on the same side; composed of many different groups of axons, of both ascending and descending tracts, carrying motor commands to and from the brain

lateral horn
region of the spinal cord gray matter in the thoracic, upper lumbar, and sacral regions that is the central component of the sympathetic division of the autonomic nervous system

lateral sulcus
surface landmark of the cerebral cortex that marks the boundary between the temporal lobe and the frontal and parietal lobes

limbic cortex
collection of structures of the cerebral cortex that are involved in emotion, memory, and behavior and are part of the larger limbic system

limbic system
structures at the edge (limit) of the boundary between the forebrain and hindbrain that are most associated with emotional behavior and memory formation

longitudinal fissure
large separation along the midline between the two cerebral hemispheres

occipital lobe
region of the cerebral cortex directly beneath the occipital bone of the cranium

olfaction
special sense responsible for smell, which has a unique, direct connection to the cerebrum

parietal lobe
region of the cerebral cortex directly beneath the parietal bone of the cranium

parieto-occipital sulcus
groove in the cerebral cortex representing the border between the parietal and occipital cortices

postcentral gyrus
ridge just posterior to the central sulcus, in the parietal lobe, where somatosensory processing initially takes place in the cerebrum

posterior columns
white matter of the spinal cord that lies between the posterior horns of the gray matter, sometimes referred to as the dorsal column; composed of axons of ascending tracts that carry sensory information up to the brain

posterior horn
gray matter region of the spinal cord in which sensory input arrives, sometimes referred to as the dorsal horn

posterior median sulcus
midline feature of the posterior spinal cord, marking the separation between right and left sides of the cord

posterolateral sulcus
feature of the posterior spinal cord marking the entry of posterior nerve roots and the separation between the posterior and lateral columns of the white matter

precentral gyrus
primary motor cortex located in the frontal lobe of the cerebral cortex

prefrontal lobe
specific region of the frontal lobe anterior to the more specific motor function areas, which can be related to the early planning of movements and intentions to the point of being personality-type functions

premotor area
region of the frontal lobe responsible for planning movements that will be executed through the primary motor cortex

proprioception
general sensory perceptions providing information about location and movement of body parts; the “sense of the self”

putamen
nucleus deep in the cerebrum that is part of the basal nuclei; along with the caudate, it is part of the striatum

reticular formation
diffuse region of gray matter throughout the brain stem that regulates sleep, wakefulness, and states of consciousness

somatosensation
general senses related to the body, usually thought of as the senses of touch, which would include pain, temperature, and proprioception

striatum
the caudate and putamen collectively, as part of the basal nuclei, which receive input from the cerebral cortex

subcortical nucleus
all the nuclei beneath the cerebral cortex, including the basal nuclei and the basal forebrain

substantia nigra pars compacta
nuclei within the basal nuclei that release dopamine to modulate the function of the striatum; part of the motor pathway

substantia nigra pars reticulata
nuclei within the basal nuclei that serve as an output center of the nuclei; part of the motor pathway

subthalamus
nucleus within the basal nuclei that is part of the indirect pathway

sulcus
groove formed by convolutions in the surface of the cerebral cortex

superior colliculus
half of the midbrain tectum that is responsible for aligning visual, auditory, and somatosensory spatial perceptions

tectum
region of the midbrain, thought of as the roof of the cerebral aqueduct, which is subdivided into the inferior and superior colliculi

tegmentum
region of the midbrain, thought of as the floor of the cerebral aqueduct, which continues into the pons and medulla as the floor of the fourth ventricle

temporal lobe
region of the cerebral cortex directly beneath the temporal bone of the cranium

thalamus
major region of the diencephalon that is responsible for relaying information between the cerebrum and the hindbrain, spinal cord, and periphery

Contributors and Attributions

ventral (anterior) nerve root

axons emerging from the anterior or lateral horns of the spinal cord

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3.4A: The Cranial Nerve Exam

Learning Objectives

- Describe the functional grouping of cranial nerves
- Match the regions of the forebrain and brain stem that are connected to each cranial nerve
- Suggest diagnoses that would explain certain losses of function in the cranial nerves
- Relate cranial nerve deficits to damage of adjacent, unrelated structures

The twelve cranial nerves are typically covered in introductory anatomy courses, and memorizing their names is facilitated by numerous mnemonics developed by students over the years of this practice. But knowing the names of the nerves in order often leaves much to be desired in understanding what the nerves do. The nerves can be categorized by functions, and subtests of the cranial nerve exam can clarify these functional groupings.

Three of the nerves are strictly responsible for special senses whereas four others contain fibers for special and general senses. Three nerves are connected to the extraocular muscles resulting in the control of gaze. Four nerves connect to muscles of the face, oral cavity, and pharynx, controlling facial expressions, mastication, swallowing, and speech. Four nerves make up the cranial component of the parasympathetic nervous system responsible for pupillary constriction, salivation, and the regulation of the organs of the thoracic and upper abdominal cavities. Finally, one nerve controls the muscles of the neck, assisting with spinal control of the movement of the head and neck.

The cranial nerve exam allows directed tests of forebrain and brain stem structures. The twelve cranial nerves serve the head and neck. The vagus nerve (cranial nerve X) has autonomic functions in the thoracic and superior abdominal cavities. The special senses are served through the cranial nerves, as well as the general senses of the head and neck. The movement of the eyes, face, tongue, throat, and neck are all under the control of cranial nerves. Preganglionic parasympathetic nerve fibers that control pupillary size, salivary glands, and the thoracic and upper abdominal viscera are found in four of the nerves. Tests of these functions can provide insight into damage to specific regions of the brain stem and may uncover deficits in adjacent regions.

Sensory Nerves

The olfactory, optic, and vestibulocochlear nerves (cranial nerves I, II, and VIII) are dedicated to four of the special senses: smell, vision, equilibrium, and hearing, respectively. Taste sensation is relayed to the brain stem through fibers of the facial and glossopharyngeal nerves. The trigeminal nerve is a mixed nerve that carries the general somatic senses from the head, similar to those coming through spinal nerves from the rest of the body.

Testing smell is straightforward, as common smells are presented to one nostril at a time. The patient should be able to recognize the smell of coffee or mint, indicating the proper functioning of the olfactory system. Loss of the sense of smell is called anosmia and can be lost following blunt trauma to the head or through aging. The short axons of the first cranial nerve regenerate on a regular basis. The neurons in the olfactory epithelium have a limited life span, and new cells grow to replace the ones that die off. The axons from these neurons grow back into the CNS by following the existing axons—representing one of the few examples of such growth in the mature nervous system. If all of the fibers are sheared when the brain moves within the cranium, such as in a motor vehicle accident, then no axons can find their way back to the olfactory bulb to re-establish connections. If the nerve is not completely severed, the anosmia may be temporary as new neurons can eventually reconnect.

Olfaction is not the pre-eminent sense, but its loss can be quite detrimental. The enjoyment of food is largely based on our sense of smell. Anosmia means that food will not seem to have the same taste, though the gustatory sense is intact, and food will often be described as being bland. However, the taste of food can be improved by adding ingredients (e.g., salt) that stimulate the gustatory sense.

Testing vision relies on the tests that are common in an optometry office. The **Snellen chart** (Figure $3.4A.1$) demonstrates visual acuity by presenting standard Roman letters in a variety of sizes. The result of this test is a rough generalization of the acuity of a person based on the normal accepted acuity, such that a letter that subtends a visual angle of 5 minutes of an arc at 20 feet can be seen. To have 20/60 vision, for example, means that the smallest letters that a person can see at a 20-foot distance could be seen by a person with normal acuity from 60 feet away. Testing the extent of the visual field means that the examiner can establish the boundaries of peripheral vision as simply as holding their hands out to either side and asking the patient when the fingers are no longer visible without moving the eyes to track them. If it is necessary, further tests can establish the perceptions in the visual fields. Physical inspection of the optic disk, or where the optic nerve emerges from the eye, can be accomplished by looking through the pupil with an ophthalmoscope.

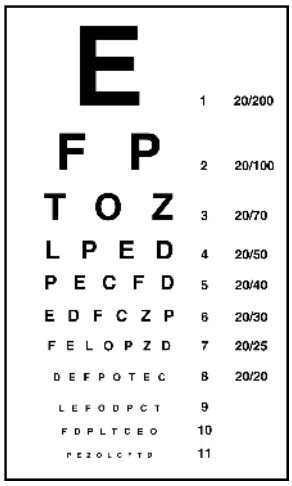


Figure 3.4A.1: The Snellen Chart. The Snellen chart for visual acuity presents a limited number of Roman letters in lines of decreasing size. The line with letters that subtend 5 minutes of an arc from 20 feet represents the smallest letters that a person with normal acuity should be able to read at that distance. The different sizes of letters in the other lines represent rough approximations of what a person of normal acuity can read at different distances. For example, the line that represents 20/200 vision would have larger letters so that they are legible to the person with normal acuity at 200 feet.

The optic nerves from both sides enter the cranium through the respective optic canals and meet at the optic chiasm at which fibers sort such that the two halves of the visual field are processed by the opposite sides of the brain. Deficits in visual field perception often suggest damage along the length of the optic pathway between the orbit and the diencephalon. For example, loss of peripheral vision may be the result of a pituitary tumor pressing on the optic chiasm (Figure 3.4A.2). The pituitary, seated in the sella turcica of the sphenoid bone, is directly inferior to the optic chiasm. The axons that decussate in the chiasm are from the medial retinae of either eye, and therefore carry information from the peripheral visual field.

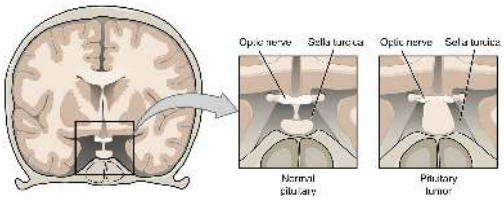


Figure 3.4A.2: Pituitary Tumor. The pituitary gland is located in the sella turcica of the sphenoid bone within the cranial floor, placing it immediately inferior to the optic chiasm. If the pituitary gland develops a tumor, it can press against the fibers crossing in the chiasm. Those fibers are conveying peripheral visual information to the opposite side of the brain, so the patient will experience “tunnel vision”—meaning that only the central visual field will be perceived.

The vestibulocochlear nerve (CN VIII) carries both equilibrium and auditory sensations from the inner ear to the medulla. Though the two senses are not directly related, anatomy is mirrored in the two systems. Problems with balance, such as vertigo, and deficits in hearing may both point to problems with the inner ear. Within the petrous region of the temporal bone is the bony labyrinth of the inner ear. The vestibule is the portion for equilibrium, composed of the utricle, saccule, and the three semicircular canals. The cochlea is responsible for transducing sound waves into a neural signal. The sensory nerves from these two structures travel side-by-side as the vestibulocochlear nerve, though they are really separate divisions. They both emerge from the inner ear, pass through the internal auditory meatus, and synapse in nuclei of the superior medulla. Though they are part of distinct sensory systems, the vestibular nuclei and the cochlear nuclei are close neighbors with adjacent inputs. Deficits in one or both systems could occur from damage that encompasses structures close to both. Damage to structures near the two nuclei can result in deficits to one or both systems.

Balance or hearing deficits may be the result of damage to the middle or inner ear structures. Ménière's disease is a disorder that can affect both equilibrium and audition in a variety of ways. The patient can suffer from vertigo, a low-frequency ringing in the ears, or a loss of hearing. From patient to patient, the exact presentation of the disease can be different. Additionally, within a single patient, the symptoms and signs may change as the disease progresses. Use of the neurological exam subtests for the vestibulocochlear nerve illuminates the changes a patient may go through. The disease appears to be the result of accumulation, or over-production, of fluid in the inner ear, in either the vestibule or cochlea.

Tests of equilibrium are important for coordination and gait and are related to other aspects of the neurological exam. The vestibulo-ocular reflex involves the cranial nerves for gaze control. Balance and equilibrium, as tested by the Romberg test, are part of spinal and cerebellar processes and involved in those components of the neurological exam, as discussed later.

Hearing is tested by using a tuning fork in a couple of different ways. The **Rinne test** involves using a tuning fork to distinguish between **conductive hearing** and **sensorineural hearing**. Conductive hearing relies on vibrations being conducted through the ossicles of the middle ear. Sensorineural hearing is the transmission of sound stimuli through the neural components of the inner ear and cranial nerve. A vibrating tuning fork is placed on the mastoid process and the patient indicates when the sound produced from this is no longer present. Then the fork is immediately moved to just next to the ear canal so the sound travels through the air. If the sound is not heard through the ear, meaning the sound is conducted better through the

temporal bone than through the ossicles, a conductive hearing deficit is present. The **Weber test** also uses a tuning fork to differentiate between conductive versus sensorineural hearing loss. In this test, the tuning fork is placed at the top of the skull, and the sound of the tuning fork reaches both inner ears by travelling through bone. In a healthy patient, the sound would appear equally loud in both ears. With unilateral conductive hearing loss, however, the tuning fork sounds louder in the ear with hearing loss. This is because the sound of the tuning fork has to compete with background noise coming from the outer ear, but in conductive hearing loss, the background noise is blocked in the damaged ear, allowing the tuning fork to sound relatively louder in that ear. With unilateral sensorineural hearing loss, however, damage to the cochlea or associated nervous tissue means that the tuning fork sounds quieter in that ear.

The trigeminal system of the head and neck is the equivalent of the ascending spinal cord systems of the dorsal column and the spinothalamic pathways. Somatosensation of the face is conveyed along the nerve to enter the brain stem at the level of the pons. Synapses of those axons, however, are distributed across nuclei found throughout the brain stem. The mesencephalic nucleus processes proprioceptive information of the face, which is the movement and position of facial muscles. It is the sensory component of the **jaw-jerk reflex**, a stretch reflex of the masseter muscle. The chief nucleus, located in the pons, receives information about light touch as well as proprioceptive information about the mandible, which are both relayed to the thalamus and, ultimately, to the postcentral gyrus of the parietal lobe. The spinal trigeminal nucleus, located in the medulla, receives information about crude touch, pain, and temperature to be relayed to the thalamus and cortex. Essentially, the projection through the chief nucleus is analogous to the dorsal column pathway for the body, and the projection through the spinal trigeminal nucleus is analogous to the spinothalamic pathway.

Subtests for the sensory component of the trigeminal system are the same as those for the sensory exam targeting the spinal nerves. The primary sensory subtest for the trigeminal system is sensory discrimination. A cotton-tipped applicator, which is cotton attached to the end of a thin wooden stick, can be used easily for this. The wood of the applicator can be snapped so that a pointed end is opposite the soft cotton-tipped end. The cotton end provides a touch stimulus, while the pointed end provides a painful, or sharp, stimulus. While the patient's eyes are closed, the examiner touches the two ends of the applicator to the patient's face, alternating randomly between them. The patient must identify whether the stimulus is sharp or dull. These stimuli are processed by the trigeminal system separately. Contact with the cotton tip of the applicator is a light touch, relayed by the chief nucleus, but contact with the pointed end of the applicator is a painful stimulus relayed by the spinal trigeminal nucleus. Failure to discriminate these stimuli can localize problems within the brain stem. If a patient cannot recognize a painful stimulus, that might indicate damage to the spinal trigeminal nucleus in the medulla. The medulla also contains important regions that regulate the cardiovascular, respiratory, and digestive systems, as well as being the pathway for ascending and descending tracts between the brain and spinal cord. Damage, such as a stroke, that results in changes in sensory discrimination may indicate these unrelated regions are affected as well.

Gaze Control

The three nerves that control the extraocular muscles are the oculomotor, trochlear, and abducens nerves, which are the third, fourth, and sixth cranial nerves. As the name suggests, the abducens nerve is responsible for abducting the eye, which it controls through contraction of the lateral rectus muscle. The trochlear nerve controls the superior oblique muscle to rotate the eye along its axis in the orbit medially, which is called **intorsion**, and is a component of focusing the eyes on an object close to the face. The oculomotor nerve controls all the other extraocular muscles, as well as a muscle of the upper eyelid. Movements of the two eyes need to be coordinated to locate and track visual stimuli accurately. When moving the eyes to locate an object in the horizontal plane, or to track movement horizontally in the visual field, the lateral rectus muscle of one eye and medial rectus muscle of the other eye are both active. The lateral rectus is controlled by neurons of the abducens nucleus in the superior medulla, whereas the medial rectus is controlled by neurons in the oculomotor nucleus of the midbrain.

Coordinated movement of both eyes through different nuclei requires integrated processing through the brain stem. In the midbrain, the superior colliculus integrates visual stimuli with motor responses to initiate eye movements. The **paramedian pontine reticular formation (PPRF)** will initiate a rapid eye movement, or **saccade**, to bring the eyes to bear on a visual stimulus quickly. These areas are connected to the oculomotor, trochlear, and abducens nuclei by the **medial longitudinal fasciculus (MLF)** that runs through the majority of the brain stem. The MLF allows for **conjugate gaze**, or the movement of the eyes in the same direction, during horizontal movements that require the lateral and medial rectus muscles. Control of conjugate gaze strictly in the vertical direction is contained within the oculomotor complex. To elevate the eyes, the oculomotor nerve on either side stimulates the contraction of both superior rectus muscles; to depress the eyes, the oculomotor nerve on either side stimulates the contraction of both inferior rectus muscles.

Purely vertical movements of the eyes are not very common. Movements are often at an angle, so some horizontal components are necessary, adding the medial and lateral rectus muscles to the movement. The rapid movement of the eyes used to locate and direct the fovea onto visual stimuli is called a saccade. Notice that the paths that are traced in Figure 3.4A.3 are not strictly vertical. The movements between the nose and the mouth are closest, but still have a slant to them. Also, the superior and inferior rectus muscles are not perfectly oriented with the line of sight. The origin for both muscles is medial to their insertions, so elevation and depression may require the lateral rectus muscles to compensate for the slight adduction inherent in the contraction of those muscles, requiring MLF activity as well.



Figure 3.4A.3: Saccadic Eye Movements. Saccades are rapid, conjugate movements of the eyes to survey a complicated visual stimulus, or to follow a moving visual stimulus. This image represents the shifts in gaze typical of a person studying a face. Notice the concentration of gaze on the major features of the face and the large number of paths traced between the eyes or around the mouth.

Testing eye movement is simply a matter of having the patient track the tip of a pen as it is passed through the visual field. This may appear similar to testing visual field deficits related to the optic nerve, but the difference is that the patient is asked to not move the eyes while the examiner moves a stimulus into the peripheral visual field. Here, the extent of movement is the point of the test. The examiner is watching for conjugate movements representing proper function of the related nuclei and the MLF. Failure of one eye to abduct while the other adducts in a horizontal movement is referred to as **internuclear ophthalmoplegia**. When this occurs, the patient will experience **diplopia**, or double vision, as the two eyes are temporarily pointed at different stimuli. Diplopia is not restricted to failure of the lateral rectus, because any of the extraocular muscles may fail to move one eye in perfect conjugation with the other.

The final aspect of testing eye movements is to move the tip of the pen in toward the patient's face. As visual stimuli move closer to the face, the two medial recti muscles cause the eyes to move in the one nonconjugate movement that is part of gaze control. When the two eyes move to look at something closer to the face, they both adduct, which is referred to as **convergence**. To keep the stimulus in focus, the eye also needs to change the shape of the lens, which is controlled through the parasympathetic fibers of the oculomotor nerve. The change in focal power of the eye is referred to as **accommodation**. Accommodation ability changes with age; focusing on nearer objects, such as the written text of a book or on a computer screen, may require corrective lenses later in life. Coordination of the skeletal muscles for convergence and coordination of the smooth muscles of the ciliary body for accommodation are referred to as the **accommodation–convergence reflex**.

A crucial function of the cranial nerves is to keep visual stimuli centered on the fovea of the retina. The **vestibulo-ocular reflex (VOR)** coordinates all of the components (Figure 3.4A.4), both sensory and motor, that make this possible. If the head rotates in one direction—for example, to the right—the horizontal pair of semicircular canals in the inner ear indicate the movement by increased activity on the right and decreased activity on the left. The information is sent to the abducens nuclei and oculomotor nuclei on either side to coordinate the lateral and medial rectus muscles. The left lateral rectus and right medial rectus muscles will contract, rotating the eyes in the opposite direction of the head, while nuclei controlling the right lateral rectus and left medial rectus muscles will be inhibited to reduce antagonism of the contracting muscles. These actions stabilize the visual field by compensating for the head rotation with opposite rotation of the eyes in the orbits. Deficits in the VOR may be related to vestibular damage, such as in Ménière's disease, or from dorsal brain stem damage that would affect the eye movement nuclei or their connections through the MLF.

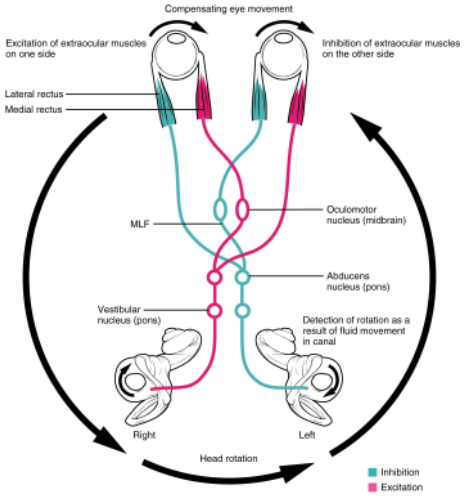


Figure 3.4A.4: Vestibulo-ocular Reflex. If the head is turned in one direction, the coordination of that movement with the fixation of the eyes on a visual stimulus involves a circuit that ties the vestibular sense with the eye movement nuclei through the MLF.

Nerves of the Face and Oral Cavity

An iconic part of a doctor's visit is the inspection of the oral cavity and pharynx, suggested by the directive to "open your mouth and say 'ah.'" This is followed by inspection, with the aid of a tongue depressor, of the back of the mouth, or the opening of the oral cavity into the pharynx known as the **fauces**. Whereas this portion of a medical exam inspects for signs of infection, such as in tonsillitis, it is also the means to test the functions of the cranial nerves that are associated with the oral cavity.

The facial and glossopharyngeal nerves convey gustatory stimulation to the brain. Testing this is as simple as introducing salty, sour, bitter, or sweet stimuli to either side of the tongue. The patient should respond to the taste stimulus before retracting the tongue into the mouth. Stimuli applied to specific locations on the tongue will dissolve into the saliva and may stimulate taste buds connected to either the left or right of the nerves, masking any lateral deficits. Along with taste, the glossopharyngeal nerve relays general sensations from the pharyngeal walls. These sensations, along with certain taste stimuli, can stimulate the gag reflex. If the examiner moves the tongue depressor to contact the lateral wall of the fauces, this should elicit the gag reflex. Stimulation of either side of the fauces should elicit an equivalent response. The motor response, through contraction of the muscles of the pharynx, is mediated through the vagus nerve. Normally, the vagus nerve is considered autonomic in nature. The vagus nerve directly stimulates the contraction of skeletal muscles in the pharynx and larynx to contribute to the swallowing and speech functions. Further testing of vagus motor function has the patient repeating consonant sounds that require movement of the muscles around the fauces. The patient is asked to say "lah-kah-pah" or a similar set of alternating sounds while the examiner observes the movements of the soft palate and arches between the palate and tongue.

The facial and glossopharyngeal nerves are also responsible for the initiation of salivation. Neurons in the salivary nuclei of the medulla project through these two nerves as preganglionic fibers, and synapse in ganglia located in the head. The parasympathetic fibers of the facial nerve synapse in the pterygopalatine ganglion, which projects to the submandibular gland and sublingual gland. The parasympathetic fibers of the glossopharyngeal nerve synapse in the otic ganglion, which projects to the parotid gland. Salivation in response to food in the oral cavity is based on a visceral reflex arc within the facial or glossopharyngeal nerves. Other stimuli that stimulate salivation are coordinated through the hypothalamus, such as the smell and sight of food.

The hypoglossal nerve is the motor nerve that controls the muscles of the tongue, except for the palatoglossus muscle, which is controlled by the vagus nerve. There are two sets of muscles of the tongue. The **extrinsic muscles of the tongue** are connected to other structures, whereas the **intrinsic muscles of the tongue** are completely contained within the lingual tissues. While examining the oral cavity, movement of the tongue will indicate whether hypoglossal function is impaired. The test for hypoglossal function is the "stick out your tongue" part of the exam. The genioglossus muscle is responsible for protrusion of the tongue. If the hypoglossal nerves on both sides are working properly, then the tongue will stick straight out. If the nerve on one side has a deficit, the tongue will stick out to that side—pointing to the side with damage. Loss of function of the tongue can interfere with speech and swallowing. Additionally, because the location of the hypoglossal nerve and nucleus is near the cardiovascular center, inspiratory and expiratory areas for respiration, and the vagus nuclei that regulate digestive functions, a tongue that protrudes incorrectly can suggest damage in adjacent structures that have nothing to do with controlling the tongue.

QR Code representing a URL

Watch this short video to see an examination of the facial nerve using some simple tests. The facial nerve controls the muscles of facial expression. Severe deficits will be obvious in watching someone use those muscles for normal control. One side of the face might not move like the other side. But directed tests, especially for contraction against resistance, require a formal testing of the muscles. The muscles of the upper and lower face need to be tested. The strength test in this video involves the patient squeezing her eyes shut and the examiner trying to pry her eyes open. Why does the examiner ask her to try a second time?



Motor Nerves of the Neck

The accessory nerve, also referred to as the spinal accessory nerve, innervates the sternocleidomastoid and trapezius muscles (Figure 3.4A.5). When both the sternocleidomastoids contract, the head flexes forward; individually, they cause rotation to the opposite side. The trapezius can act as an antagonist, causing extension and hyperextension of the neck. These two superficial muscles are important for changing the position of the head. Both muscles also receive input from cervical spinal nerves. Along with the spinal accessory nerve, these nerves contribute to elevating the scapula and clavicle through the trapezius, which is tested by asking the patient to shrug both shoulders, and watching for asymmetry. For the sternocleidomastoid, those spinal nerves are primarily sensory projections, whereas the trapezius also has lateral insertions to the clavicle and scapula, and receives motor input from the spinal cord. Calling the nerve the spinal accessory nerve suggests that it is aiding the spinal nerves. Though that is not precisely how the name originated, it does help make the association between the function of this nerve in controlling these muscles and the role these muscles play in movements of the trunk or shoulders.

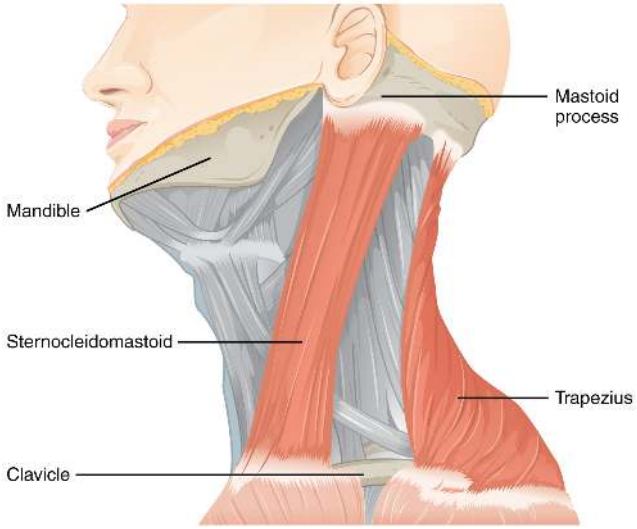


***Figure** 3.4A.5**: Muscles Controlled by the Accessory Nerve.** The accessory nerve innervates the sternocleidomastoid and trapezius muscles, both of which attach to the head and to the trunk and shoulders. They can act as antagonists in head flexion and extension, and as synergists in lateral flexion toward the shoulder.*

To test these muscles, the patient is asked to flex and extend the neck or shrug the shoulders against resistance, testing the strength of the muscles. Lateral flexion of the neck toward the shoulder tests both at the same time. Any difference on one side versus the other would suggest damage on the weaker side. These strength tests are common for the skeletal muscles controlled by spinal nerves and are a significant component of the motor exam. Deficits associated with the accessory nerve may have an effect on orienting the head, as described with the VOR.

HOMEOSTATIC IMBALANCES: The Pupillary Light Response

The autonomic control of pupillary size in response to a bright light involves the sensory input of the optic nerve and the parasympathetic motor output of the oculomotor nerve. When light hits the retina, specialized photosensitive ganglion cells send a signal along the optic nerve to the pretectal nucleus in the superior midbrain. A neuron from this nucleus projects to the Eddinger–Westphal nuclei in the oculomotor complex in both sides of the midbrain. Neurons in this nucleus give rise to the preganglionic parasympathetic fibers that project through the oculomotor nerve to the ciliary ganglion in the posterior orbit. The postganglionic parasympathetic fibers from the ganglion project to the iris, where they release acetylcholine onto circular fibers that constrict the pupil to reduce the amount of light hitting the retina. The sympathetic nervous system is responsible for dilating the pupil when light levels are low.

Shining light in one eye will elicit constriction of both pupils. The efferent limb of the pupillary light reflex is bilateral. Light shined in one eye causes a constriction of that pupil, as well as constriction of the contralateral pupil. Shining a penlight in the eye of a patient is a very artificial situation, as both eyes are normally exposed to the same light sources. Testing this reflex can illustrate whether the optic nerve or the oculomotor nerve is damaged. If shining the light in one eye results in no changes in pupillary size but shining light in the opposite eye elicits a normal, bilateral response, the damage is associated with the optic nerve on the nonresponsive side. If light in either eye elicits a response in only one eye, the problem is with the oculomotor system.

If light in the right eye only causes the left pupil to constrict, the direct reflex is lost and the consensual reflex is intact, which means that the right oculomotor nerve (or Eddinger–Westphal nucleus) is damaged. Damage to the right oculomotor connections will be evident when light is shined in the left eye. In that case, the direct reflex is intact but the consensual reflex is lost, meaning that the left pupil will constrict while the right does not.

The Cranial Nerve Exam

The cranial nerves can be separated into four major groups associated with the subtests of the cranial nerve exam. First are the sensory nerves, then the nerves that control eye movement, the nerves of the oral cavity and superior pharynx, and the nerve that controls movements of the neck.

The olfactory, optic, and vestibulocochlear nerves are strictly sensory nerves for smell, sight, and balance and hearing, whereas the trigeminal, facial, and glossopharyngeal nerves carry somatosensation of the face, and taste—separated between the anterior two-thirds of the tongue and the posterior one-third. Special senses are tested by presenting the particular stimuli to each receptive organ. General senses can be tested through sensory discrimination of touch versus painful stimuli.

The oculomotor, trochlear, and abducens nerves control the extraocular muscles and are connected by the medial longitudinal fasciculus to coordinate gaze. Testing conjugate gaze is as simple as having the patient follow a visual target, like a pen tip, through the visual field ending with an approach toward the face to test convergence and accommodation. Along with the vestibular functions of the eighth nerve, the vestibulo-ocular reflex stabilizes gaze during head movements by coordinating equilibrium sensations with the eye movement systems.

The trigeminal nerve controls the muscles of chewing, which are tested for stretch reflexes. Motor functions of the facial nerve are usually obvious if facial expressions are compromised, but can be tested by having the patient raise their eyebrows, smile, and frown. Movements of the tongue, soft palate, or superior pharynx can be observed directly while the patient swallows, while the gag reflex is elicited, or while the patient says repetitive consonant sounds. The motor control of the gag reflex is largely controlled by fibers in the vagus nerve and constitutes a test of that nerve because the parasympathetic functions of that nerve are involved in visceral regulation, such as regulating the heartbeat and digestion.

Movement of the head and neck using the sternocleidomastoid and trapezius muscles is controlled by the accessory nerve. Flexing of the neck and strength testing of those muscles reviews the function of that nerve.

Interactive Link Questions

Watch this short video to see an examination of the facial nerve using some simple tests. The facial nerve controls the muscles of facial expression. Severe deficits will be obvious in watching someone use those muscles for normal control. One side of the face might not move like the other side. But directed tests, especially for contraction against resistance, require a formal testing of the muscles. The muscles of the upper and lower face need to be tested. The strength test in this video involves the patient squeezing her eyes shut and the examiner trying to pry her eyes open. Why does the examiner ask her to try a second time?



Answer: She has just demonstrated voluntary control by closing her eyes, but when he provides the resistance that she needs to hold tight against, she has already relaxed the muscles enough for him to pull them open. She needs to squeeze them tighter to demonstrate the strength she has in the orbicular oculi.

Review Questions

Q. Without olfactory sensation to complement gustatory stimuli, food will taste bland unless it is seasoned with which substance?

A. salt

B. thyme

C. garlic

D. olive oil

Answer: A

Q. Which of the following cranial nerves is *not* part of the VOR?

A. optic

B. oculomotor

C. abducens

D. vestibulocochlear

Answer: A

Q. Which nerve is responsible for controlling the muscles that result in the gag reflex?

A. trigeminal

B. facial

C. glossopharyngeal

D. vagus

Answer: D

Q. Which nerve is responsible for taste, as well as salivation, in the anterior oral cavity?

A. facial

B. glossopharyngeal

C. vagus

D. hypoglossal

Answer: A

Q. Which of the following nerves controls movements of the neck?

A. oculomotor

B. vestibulocochlear

C. spinal accessory

D. hypoglossal

Answer: C

Critical Thinking Questions

Q. As a person ages, their ability to focus on near objects (accommodation) changes. If a person is already myopic (near-sighted), why would corrective lenses not be necessary to read a book or computer screen?

A. If the person already has problems focusing on far objects, and wears corrective lenses to see farther objects, then as accommodation changes, focusing on a reading surface might still be in their naturally near-sighted range.

Q. When a patient flexes their neck, the head tips to the right side. Also, their tongue sticks out slightly to the left when they try to stick it straight out. Where is the damage to the brain stem most likely located?

A. The medulla is where the accessory nerve, which controls the sternocleidomastoid muscle, and the hypoglossal nerve, which controls the genioglossus muscle, are both located. The weakness of the left side of the neck, and the tendency of the tongue to point to that side, both show that the damage is on the left side of the brain stem.

Glossary

accommodation

in vision, a change in the ability of the eye to focus on objects at different distances

accommodation–convergence reflex
coordination of somatic control of the medial rectus muscles of either eye with the parasympathetic control of the ciliary bodies to maintain focus while the eyes converge on visual stimuli near to the face

conductive hearing
hearing dependent on the conduction of vibrations of the tympanic membrane through the ossicles of the middle ear

conjugate gaze
coordinated movement of the two eyes simultaneously in the same direction

convergence
in vision, the movement of the eyes so that they are both pointed at the same point in space, which increases for stimuli that are closer to the subject

diplopia
double vision resulting from a failure in conjugate gaze

extrinsic muscles of the tongue
muscles that are connected to other structures, such as the hyoid bone or the mandible, and control the position of the tongue

fauces
opening from the oral cavity into the pharynx

internuclear ophthalmoplegia
deficit of conjugate lateral gaze because the lateral rectus muscle of one eye does not contract resulting from damage to the abducens nerve or the MLF

intorsion
medial rotation of the eye around its axis

intrinsic muscles of the tongue
muscles that originate out of, and insert into, other tissues within the tongue and control the shape of the tongue

jaw-jerk reflex
stretch reflex of the masseter muscle

medial longitudinal fasciculus (MLF)
fiber pathway that connects structures involved in the control of eye and head position, from the superior colliculus to the vestibular nuclei and cerebellum

paramedian pontine reticular formation (PPRF)
region of the brain stem adjacent to the motor nuclei for gaze control that coordinates rapid, conjugate eye movements

Rinne test
use of a tuning fork to test conductive hearing loss versus sensorineural hearing loss

saccade
small, rapid movement of the eyes used to locate and direct the fovea onto visual stimuli

sensorineural hearing
hearing dependent on the transduction and propagation of auditory information through the neural components of the peripheral auditory structures

Snellen chart
standardized arrangement of letters in decreasing size presented to a subject at a distance of 20 feet to test visual acuity

vestibulo-ocular reflex (VOR)
reflex based on connections between the vestibular system and the cranial nerves of eye movements that ensures that images are stabilized on the retina as the head and body move

Weber test
use of a tuning fork to test the laterality of hearing loss by placing it at several locations on the midline of the skull

Contributors and Attributions

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3.5: Circulation and the Central Nervous System

Learning Objectives

- Describe the vessels that supply the CNS with blood
- Name the components of the ventricular system and the regions of the brain in which each is located
- Explain the production of cerebrospinal fluid and its flow through the ventricles
- Explain how a disruption in circulation would result in a stroke

The CNS is crucial to the operation of the body, and any compromise in the brain and spinal cord can lead to severe difficulties. The CNS has a privileged blood supply, as suggested by the blood-brain barrier. The function of the tissue in the CNS is crucial to the survival of the organism, so the contents of the blood cannot simply pass into the central nervous tissue. To protect this region from the toxins and pathogens that may be traveling through the blood stream, there is strict control over what can move out of the general systems and into the brain and spinal cord. Because of this privilege, the CNS needs specialized structures for the maintenance of circulation. This begins with a unique arrangement of blood vessels carrying fresh blood into the CNS. Beyond the supply of blood, the CNS filters that blood into cerebrospinal fluid (CSF), which is then circulated through the cavities of the brain and spinal cord called ventricles.

Blood Supply to the Brain

A lack of oxygen to the CNS can be devastating, and the cardiovascular system has specific regulatory reflexes to ensure that the blood supply is not interrupted. There are multiple routes for blood to get into the CNS, with specializations to protect that blood supply and to maximize the ability of the brain to get an uninterrupted perfusion.

Arterial Supply

The major artery carrying recently oxygenated blood away from the heart is the aorta. The very first branches off the aorta supply the heart with nutrients and oxygen. The next branches give rise to the **common carotid arteries**, which further branch into the **internal carotid arteries**. The external carotid arteries supply blood to the tissues on the surface of the cranium. The bases of the common carotids contain stretch receptors that immediately respond to the drop in blood pressure upon standing. The **orthostatic reflex** is a reaction to this change in body position, so that blood pressure is maintained against the increasing effect of gravity (orthostatic means “standing up”). Heart rate increases—a reflex of the sympathetic division of the autonomic nervous system—and this raises blood pressure.

The internal carotid artery enters the cranium through the **carotid canal** in the temporal bone. A second set of vessels that supply the CNS are the **vertebral arteries**, which are protected as they pass through the neck region by the transverse foramina of the cervical vertebrae. The vertebral arteries enter the cranium through the **foramen magnum** of the occipital bone. Branches off the left and right vertebral arteries merge into the **anterior spinal artery** supplying the anterior aspect of the spinal cord, found along the anterior median fissure. The two vertebral arteries then merge into the **basilar artery**, which gives rise to branches to the brain stem and cerebellum. The left and right internal carotid arteries and branches of the basilar artery all become the **circle of Willis**, a confluence of arteries that can maintain perfusion of the brain even if narrowing or a blockage limits flow through one part (Figure 3.5.1).

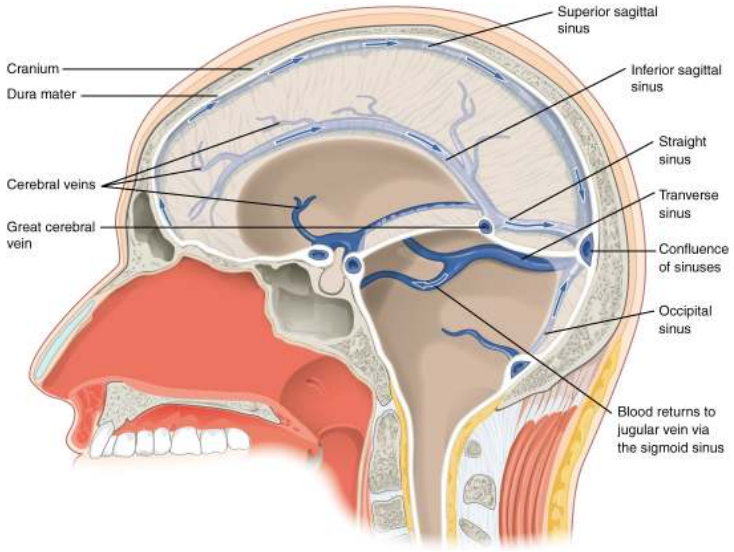


Figure 3.5.2: Dural Sinuses and Veins. Blood drains from the brain through a series of sinuses that connect to the jugular veins.

Protective Coverings of the Brain and Spinal Cord

The outer surface of the CNS is covered by a series of membranes composed of connective tissue called the **meninges**, which protect the brain. The **dura mater** is a thick fibrous layer and a strong protective sheath over the entire brain and spinal cord. It is anchored to the inner surface of the cranium and vertebral cavity. The **arachnoid mater** is a membrane of thin fibrous tissue that forms a loose sac around the CNS. Beneath the arachnoid is a thin, filamentous mesh called the **arachnoid trabeculae**, which looks like a spider web, giving this layer its name. Directly adjacent to the surface of the CNS is the **pia mater**, a thin fibrous membrane that follows the convolutions of gyri and sulci in the cerebral cortex and fits into other grooves and indentations (Figure 3.5.3).

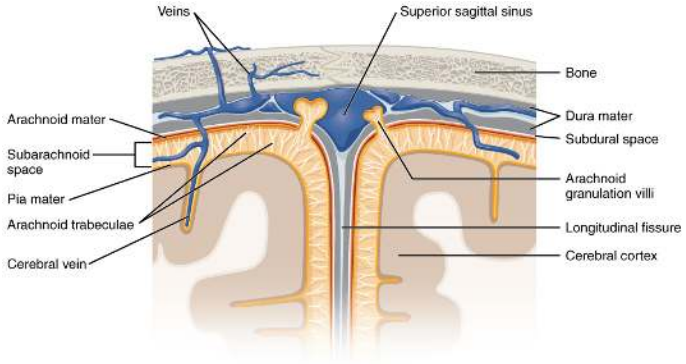


Figure 3.5.3: Meningeal Layers of Superior Sagittal Sinus. The layers of the meninges in the longitudinal fissure of the superior sagittal sinus are shown, with the dura mater adjacent to the inner surface of the cranium, the pia mater adjacent to the surface of the brain, and the arachnoid and subarachnoid space between them. An arachnoid villus is shown emerging into the dural sinus to allow CSF to filter back into the blood for drainage.

Dura Mater

Like a thick cap covering the brain, the dura mater is a tough outer covering. The name comes from the Latin for “tough mother” to represent its physically protective role. It encloses the entire CNS and the major blood vessels that enter the cranium and vertebral cavity. It is directly attached to the inner surface of the bones of the cranium and to the very end of the vertebral cavity.

There are infoldings of the dura that fit into large crevasses of the brain. Two infoldings go through the midline separations of the cerebrum and cerebellum; one forms a shelf-like tent between the occipital lobes of the cerebrum and the cerebellum, and the other surrounds the pituitary gland. The dura also surrounds and supports the venous sinuses.

Arachnoid Mater

The middle layer of the meninges is the arachnoid, named for the spider-web–like trabeculae between it and the pia mater. The arachnoid defines a sac-like enclosure around the CNS. The trabeculae are found in the **subarachnoid space**, which is filled with circulating CSF. The arachnoid emerges into the dural sinuses as the **arachnoid granulations**, where the CSF is filtered back into the blood for drainage from the nervous system.

The subarachnoid space is filled with circulating CSF, which also provides a liquid cushion to the brain and spinal cord. Similar to clinical blood work, a sample of CSF can be withdrawn to find chemical evidence of neuropathology or metabolic traces of the biochemical functions of nervous tissue.

Pia Mater

The outer surface of the CNS is covered in the thin fibrous membrane of the pia mater. It is thought to have a continuous layer of cells providing a fluid-impermeable membrane. The name pia mater comes from the Latin for “tender mother,” suggesting the thin membrane is a gentle covering for the brain. The pia extends into every convolution of the CNS, lining the inside of the sulci in the cerebral and cerebellar cortices. At the end of the spinal cord, a thin filament extends from the inferior end of CNS at the upper lumbar region of the vertebral column to the sacral end of the vertebral column. Because the spinal cord does not extend through the lower lumbar region of the vertebral column, a needle can be inserted through the dura and arachnoid layers to withdraw CSF. This procedure is called a **lumbar puncture** and avoids the risk of damaging the central tissue of the spinal cord. Blood vessels that are nourishing the central nervous tissue are between the pia mater and the nervous tissue.

DISORDERS OF THE...

Meninges

Meningitis is an inflammation of the meninges, the three layers of fibrous membrane that surround the CNS. Meningitis can be caused by infection by bacteria or viruses. The particular pathogens are not special to meningitis; it is just an inflammation of that specific set of tissues from what might be a broader infection. Bacterial meningitis can be caused by Streptococcus, Staphylococcus, or the tuberculosis pathogen, among many others. Viral meningitis is usually the result of common enteroviruses (such as those that cause intestinal disorders), but may be the result of the herpes virus or West Nile virus. Bacterial meningitis tends to be more severe.

The symptoms associated with meningitis can be fever, chills, nausea, vomiting, light sensitivity, soreness of the neck, or severe headache. More important are the neurological symptoms, such as changes in mental state (confusion, memory deficits, and other dementia-type symptoms). A serious risk of meningitis can be damage to peripheral structures because of the nerves that pass through the meninges. Hearing loss is a common result of meningitis.

The primary test for meningitis is a lumbar puncture. A needle inserted into the lumbar region of the spinal column through the dura mater and arachnoid membrane into the subarachnoid space can be used to withdraw the fluid for chemical testing. Fatality occurs in 5 to 40 percent of children and 20 to 50 percent of adults with bacterial meningitis. Treatment of bacterial meningitis is through antibiotics, but viral meningitis cannot be treated with antibiotics because viruses do not respond to that type of drug. Fortunately, the viral forms are milder.



Watch this video that describes the procedure known as the lumbar puncture, a medical procedure used to sample the CSF. Because of the anatomy of the CNS, it is a relative safe location to insert a needle. Why is the lumbar puncture performed in the lower lumbar area of the vertebral column?

The Ventricular System

Cerebrospinal fluid (CSF) circulates throughout and around the CNS. In other tissues, water and small molecules are filtered through capillaries as the major contributor to the interstitial fluid. In the brain, CSF is produced in special structures to perfuse through the nervous tissue of the CNS and is continuous with the interstitial fluid. Specifically, CSF circulates to remove metabolic wastes from the interstitial fluids of nervous tissues and return them to the blood stream. The **ventricles** are the open spaces within the brain where CSF circulates. In some of these spaces, CSF is produced by filtering of the blood that is performed by a specialized membrane known as a choroid plexus. The CSF circulates through all of the ventricles to eventually emerge into the subarachnoid space where it will be reabsorbed into the blood.

The Ventricles

There are four ventricles within the brain, all of which developed from the original hollow space within the neural tube, the **central canal**. The first two are named the **lateral ventricles** and are deep within the cerebrum. These ventricles are connected to the **third ventricle** by two openings called the **interventricular foramina**. The third ventricle is the space between the left and right sides of the diencephalon, which opens into the **cerebral aqueduct** that passes through the midbrain. The aqueduct opens into the **fourth ventricle**, which is the space between the cerebellum and the pons and upper medulla (Figure 3.5.4).

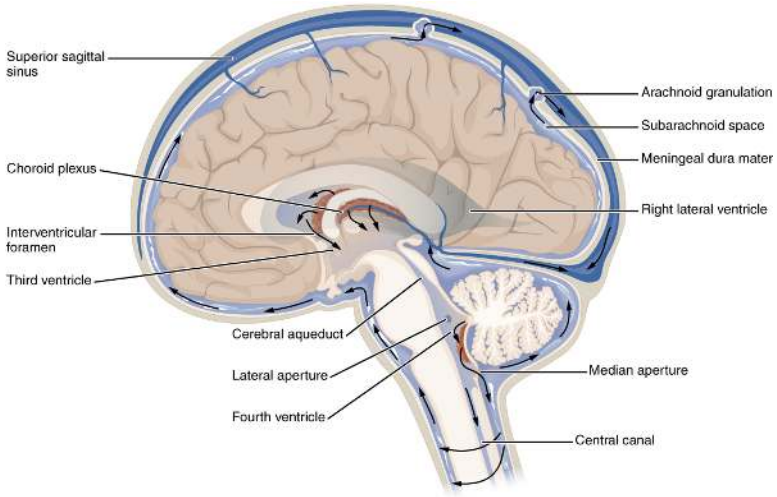


Figure 3.5.4: Cerebrospinal Fluid Circulation. The choroid plexus in the four ventricles produce CSF, which is circulated through the ventricular system and then enters the subarachnoid space through the median and lateral apertures. The CSF is then reabsorbed into the blood at the arachnoid granulations, where the arachnoid membrane emerges into the dural sinuses.

As the telencephalon enlarges and grows into the cranial cavity, it is limited by the space within the skull. The telencephalon is the most anterior region of what was the neural tube, but cannot grow past the limit of the frontal bone of the skull. Because the cerebrum fits into this space, it takes on a C-shaped formation, through the frontal, parietal, occipital, and finally temporal regions. The space within the telencephalon is stretched into this same C-shape. The two ventricles are in the left and right sides, and were at one time referred to as the first and second ventricles. The interventricular foramina connect the frontal region of the lateral ventricles with the third ventricle.

The third ventricle is the space bounded by the medial walls of the hypothalamus and thalamus. The two thalami touch in the center in most brains as the massa intermedia, which is surrounded by the third ventricle. The cerebral aqueduct opens just inferior to the epithalamus and passes through the midbrain. The tectum and tegmentum of the midbrain are the roof and floor of the cerebral aqueduct, respectively. The aqueduct opens up into the fourth ventricle. The floor of the fourth ventricle is the dorsal surface of the pons and upper medulla (that gray matter making a continuation of the tegmentum of the midbrain). The fourth ventricle then narrows into the central canal of the spinal cord.

The ventricular system opens up to the subarachnoid space from the fourth ventricle. The single **median aperture** and the pair of **lateral apertures** connect to the subarachnoid space so that CSF can flow through the ventricles and around the outside of the CNS. Cerebrospinal fluid is produced within the ventricles by a type of specialized membrane called a **choroid plexus**. Ependymal cells (one of the types of glial cells described in the introduction to the nervous system) surround blood capillaries and filter the blood to make CSF. The fluid is a clear solution with a limited amount of the constituents of blood. It is essentially water, small molecules, and electrolytes. Oxygen and carbon dioxide are dissolved into the CSF, as they are in blood, and can diffuse between the fluid and the nervous tissue.

Cerebrospinal Fluid Circulation

The choroid plexuses are found in all four ventricles. Observed in dissection, they appear as soft, fuzzy structures that may still be pink, depending on how well the circulatory system is cleared in preparation of the tissue. The CSF is produced from components extracted from the blood, so its flow out of the ventricles is tied to the pulse of cardiovascular circulation.

From the lateral ventricles, the CSF flows into the third ventricle, where more CSF is produced, and then through the cerebral aqueduct into the fourth ventricle where even more CSF is produced. A very small amount of CSF is filtered at any one of the plexuses, for a total of about 500 milliliters daily, but it is continuously made and pulses through the ventricular system, keeping

the fluid moving. From the fourth ventricle, CSF can continue down the central canal of the spinal cord, but this is essentially a cul-de-sac, so more of the fluid leaves the ventricular system and moves into the subarachnoid space through the median and lateral apertures.

Within the subarachnoid space, the CSF flows around all of the CNS, providing two important functions. As with elsewhere in its circulation, the CSF picks up metabolic wastes from the nervous tissue and moves it out of the CNS. It also acts as a liquid cushion for the brain and spinal cord. By surrounding the entire system in the subarachnoid space, it provides a thin buffer around the organs within the strong, protective dura mater. The arachnoid granulations are outpocketings of the arachnoid membrane into the dural sinuses so that CSF can be reabsorbed into the blood, along with the metabolic wastes. From the dural sinuses, blood drains out of the head and neck through the jugular veins, along with the rest of the circulation for blood, to be reoxygenated by the lungs and wastes to be filtered out by the kidneys (Table 3.5.1).

QR Code representing a URL

Watch this animation that shows the flow of CSF through the brain and spinal cord, and how it originates from the ventricles and then spreads into the space within the meninges, where the fluids then move into the venous sinuses to return to the cardiovascular circulation. What are the structures that produce CSF and where are they found? How are the structures indicated in this animation?

Table 3.5.1

Components of CSF Circulation

	Lateral ventricles	Third ventricle	Cerebral aqueduct	Fourth ventricle	Central canal	Subarachnoid space
Location in CNS	Cerebrum	Diencephalon	Midbrain	Between pons/upper medulla and cerebellum	Spinal cord	External to entire CNS
Blood vessel structure	Choroid plexus	Choroid plexus	None	Choroid plexus	None	Arachnoid granulations

DISORDERS OF THE...

Central Nervous System

The supply of blood to the brain is crucial to its ability to perform many functions. Without a steady supply of oxygen, and to a lesser extent glucose, the nervous tissue in the brain cannot keep up its extensive electrical activity. These nutrients get into the brain through the blood, and if blood flow is interrupted, neurological function is compromised.

The common name for a disruption of blood supply to the brain is a stroke. It is caused by a blockage to an artery in the brain. The blockage is from some type of embolus: a blood clot, a fat embolus, or an air bubble. When the blood cannot travel through the artery, the surrounding tissue that is deprived starves and dies. Strokes will often result in the loss of very specific functions. A stroke in the lateral medulla, for example, can cause a loss in the ability to swallow. Sometimes, seemingly unrelated functions will be lost because they are dependent on structures in the same region. Along with the swallowing in the previous example, a stroke in that region could affect sensory functions from the face or extremities because important white matter pathways also pass through the lateral medulla. Loss of blood flow to specific regions of the cortex can lead to the loss of specific higher functions, from the ability to recognize faces to the ability to move a particular region of the body. Severe or limited memory loss can be the result of a temporal lobe stroke.

Related to strokes are transient ischemic attacks (TIAs), which can also be called “mini-strokes.” These are events in which a physical blockage may be temporary, cutting off the blood supply and oxygen to a region, but not to the extent that it causes cell death in that region. While the neurons in that area are recovering from the event, neurological function may be lost. Function can return if the area is able to recover from the event.

Recovery from a stroke (or TIA) is strongly dependent on the speed of treatment. Often, the person who is present and notices something is wrong must then make a decision. The mnemonic FAST helps people remember what to look for when someone is dealing with sudden losses of neurological function. If someone complains of feeling “funny,” check these

things quickly: Look at the person's face. Does he or she have problems moving Face muscles and making regular facial expressions? Ask the person to raise his or her Arms above the head. Can the person lift one arm but not the other? Has the person's Speech changed? Is he or she slurring words or having trouble saying things? If any of these things have happened, then it is Time to call for help.

Sometimes, treatment with blood-thinning drugs can alleviate the problem, and recovery is possible. If the tissue is damaged, the amazing thing about the nervous system is that it is adaptable. With physical, occupational, and speech therapy, victims of strokes can recover, or more accurately relearn, functions.

Chapter Review

The CNS has a privileged blood supply established by the blood-brain barrier. Establishing this barrier are anatomical structures that help to protect and isolate the CNS. The arterial blood to the brain comes from the internal carotid and vertebral arteries, which both contribute to the unique circle of Willis that provides constant perfusion of the brain even if one of the blood vessels is blocked or narrowed. That blood is eventually filtered to make a separate medium, the CSF, that circulates within the spaces of the brain and then into the surrounding space defined by the meninges, the protective covering of the brain and spinal cord.

The blood that nourishes the brain and spinal cord is behind the glial-cell–enforced blood-brain barrier, which limits the exchange of material from blood vessels with the interstitial fluid of the nervous tissue. Thus, metabolic wastes are collected in cerebrospinal fluid that circulates through the CNS. This fluid is produced by filtering blood at the choroid plexuses in the four ventricles of the brain. It then circulates through the ventricles and into the subarachnoid space, between the pia mater and the arachnoid mater. From the arachnoid granulations, CSF is reabsorbed into the blood, removing the waste from the privileged central nervous tissue.

The blood, now with the reabsorbed CSF, drains out of the cranium through the dural sinuses. The dura mater is the tough outer covering of the CNS, which is anchored to the inner surface of the cranial and vertebral cavities. It surrounds the venous space known as the dural sinuses, which connect to the jugular veins, where blood drains from the head and neck.

Interactive Link Questions

Watch this animation to see how blood flows to the brain and passes through the circle of Willis before being distributed through the cerebrum. The circle of Willis is a specialized arrangement of arteries that ensure constant perfusion of the cerebrum even in the event of a blockage of one of the arteries in the circle. The animation shows the normal direction of flow through the circle of Willis to the middle cerebral artery. Where would the blood come from if there were a blockage just posterior to the middle cerebral artery on the left?

> Answer: If blood could not get to the middle cerebral artery through the posterior circulation, the blood would flow around the circle of Willis to reach that artery from an anterior vessel. Blood flow would just reverse within the circle.

Watch this video that describes the procedure known as the lumbar puncture, a medical procedure used to sample the CSF. Because of the anatomy of the CNS, it is a relative safe location to insert a needle. Why is the lumbar puncture performed in the lower lumbar area of the vertebral column?

> Answer: The spinal cord ends in the upper lumbar area of the vertebral column, so a needle inserted lower than that will not damage the nervous tissue of the CNS.

Watch this animation that shows the flow of CSF through the brain and spinal cord, and how it originates from the ventricles and then spreads into the space within the meninges, where the fluids then move into the venous sinuses to return to the cardiovascular circulation. What are the structures that produce CSF and where are they found? How are the structures indicated in this animation?

> Answer: The choroid plexuses of the ventricles make CSF. As shown, there is a little of the blue color appearing in each ventricle that is joined by the color flowing from the other ventricles.

Review Questions

Q. What blood vessel enters the cranium to supply the brain with fresh, oxygenated blood?

A. common carotid artery

B. jugular vein

C. internal carotid artery

D. aorta

Answer: C

Q. Which layer of the meninges surrounds and supports the sinuses that form the route through which blood drains from the CNS?

A. dura mater

B. arachnoid mater

C. subarachnoid

D. pia mater

Answer: A

Q. What type of glial cell is responsible for filtering blood to produce CSF at the choroid plexus?

A. ependymal cell

B. astrocyte

C. oligodendrocyte

D. Schwann cell

Answer: A

Q. Which portion of the ventricular system is found within the diencephalon?

A. lateral ventricles

B. third ventricle

C. cerebral aqueduct

D. fourth ventricle

Answer: B

Q. What condition causes a stroke?

A. inflammation of meninges

B. lumbar puncture

C. infection of cerebral spinal fluid

D. disruption of blood to the brain

Answer: D

Critical Thinking Questions

Q. Why can the circle of Willis maintain perfusion of the brain even if there is a blockage in one part of the structure?

A. The structure is a circular connection of blood vessels, so that blood coming up from one of the arteries can flow in either direction around the circle and avoid any blockage or narrowing of the blood vessels.

Q. Meningitis is an inflammation of the meninges that can have severe effects on neurological function. Why is infection of this structure potentially so dangerous?

A. The nerves that connect the periphery to the CNS pass through these layers of tissue and can be damaged by that inflammation, causing a loss of important neurological functions.

Glossary

anterior spinal artery
blood vessel from the merged branches of the vertebral arteries that runs along the anterior surface of the spinal cord

arachnoid granulation
outpocket of the arachnoid membrane into the dural sinuses that allows for reabsorption of CSF into the blood

arachnoid mater
middle layer of the meninges named for the spider-web–like trabeculae that extend between it and the pia mater

arachnoid trabeculae
filaments between the arachnoid and pia mater within the subarachnoid space

basilar artery
blood vessel from the merged vertebral arteries that runs along the dorsal surface of the brain stem

carotid canal
opening in the temporal bone through which the internal carotid artery enters the cranium

central canal
hollow space within the spinal cord that is the remnant of the center of the neural tube

cerebral aqueduct
connection of the ventricular system between the third and fourth ventricles located in the midbrain

choroid plexus
specialized structures containing ependymal cells lining blood capillaries that filter blood to produce CSF in the four ventricles of the brain

circle of Willis
unique anatomical arrangement of blood vessels around the base of the brain that maintains perfusion of blood into the brain even if one component of the structure is blocked or narrowed

common carotid artery
blood vessel that branches off the aorta (or the brachiocephalic artery on the right) and supplies blood to the head and neck

dura mater
tough, fibrous, outer layer of the meninges that is attached to the inner surface of the cranium and vertebral column and surrounds the entire CNS

dural sinus
any of the venous structures surrounding the brain, enclosed within the dura mater, which drain blood from the CNS to the common venous return of the jugular veins

foramen magnum
large opening in the occipital bone of the skull through which the spinal cord emerges and the vertebral arteries enter the cranium

fourth ventricle
the portion of the ventricular system that is in the region of the brain stem and opens into the subarachnoid space through the median and lateral apertures

internal carotid artery
branch from the common carotid artery that enters the cranium and supplies blood to the brain

interventricular foramina
openings between the lateral ventricles and third ventricle allowing for the passage of CSF

jugular veins
blood vessels that return “used” blood from the head and neck

lateral apertures
pair of openings from the fourth ventricle to the subarachnoid space on either side and between the medulla and cerebellum

lateral ventricles
portions of the ventricular system that are in the region of the cerebrum

lumbar puncture
procedure used to withdraw CSF from the lower lumbar region of the vertebral column that avoids the risk of damaging CNS tissue because the spinal cord ends at the upper lumbar vertebrae

median aperture
singular opening from the fourth ventricle into the subarachnoid space at the midline between the medulla and cerebellum

meninges
protective outer coverings of the CNS composed of connective tissue

occipital sinuses
dural sinuses along the edge of the occipital lobes of the cerebrum

orthostatic reflex
sympathetic function that maintains blood pressure when standing to offset the increased effect of gravity

pia mater
thin, innermost membrane of the meninges that directly covers the surface of the CNS

sigmoid sinuses
dural sinuses that drain directly into the jugular veins

straight sinus
dural sinus that drains blood from the deep center of the brain to collect with the other sinuses

subarachnoid space
space between the arachnoid mater and pia mater that contains CSF and the fibrous connections of the arachnoid trabeculae

superior sagittal sinus
dural sinus that runs along the top of the longitudinal fissure and drains blood from the majority of the outer cerebrum

third ventricle
portion of the ventricular system that is in the region of the diencephalon

transverse sinuses
dural sinuses that drain along either side of the occipital–cerebellar space

ventricles
remnants of the hollow center of the neural tube that are spaces for cerebrospinal fluid to circulate through the brain

Contributors and Attributions

vertebral arteries

arteries that ascend along either side of the vertebral column through the transverse foramina of the cervical vertebrae and enter the cranium through the foramen magnum

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CHAPTER OVERVIEW

4: Head, Neck, Spine and Abdominal Core

4.1: The Skull

4.2: The Vertebral Column

4.3: Axial Muscles of the Head, Neck, and Back

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4.1: The Skull

Learning Objectives

- List and identify the bones of the brain case and face
- Locate the major suture lines of the skull and name the bones associated with each
- Locate and define the boundaries of the anterior, middle, and posterior cranial fossae, the temporal fossa, and infratemporal fossa
- Define the paranasal sinuses and identify the location of each
- Name the bones that make up the walls of the orbit and identify the openings associated with the orbit
- Identify the bones and structures that form the nasal septum and nasal conchae, and locate the hyoid bone
- Identify the bony openings of the skull

The **cranium** (skull) is the skeletal structure of the head that supports the face and protects the brain. It is subdivided into the **facial bones** and the **brain case**, or cranial vault (Figure 4.1.1). The facial bones underlie the facial structures, form the nasal cavity, enclose the eyeballs, and support the teeth of the upper and lower jaws. The rounded brain case surrounds and protects the brain and houses the middle and inner ear structures.

In the adult, the skull consists of 22 individual bones, 21 of which are immobile and united into a single unit. The 22nd bone is the **mandible** (lower jaw), which is the only moveable bone of the skull.

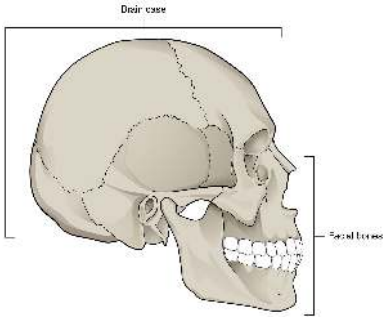
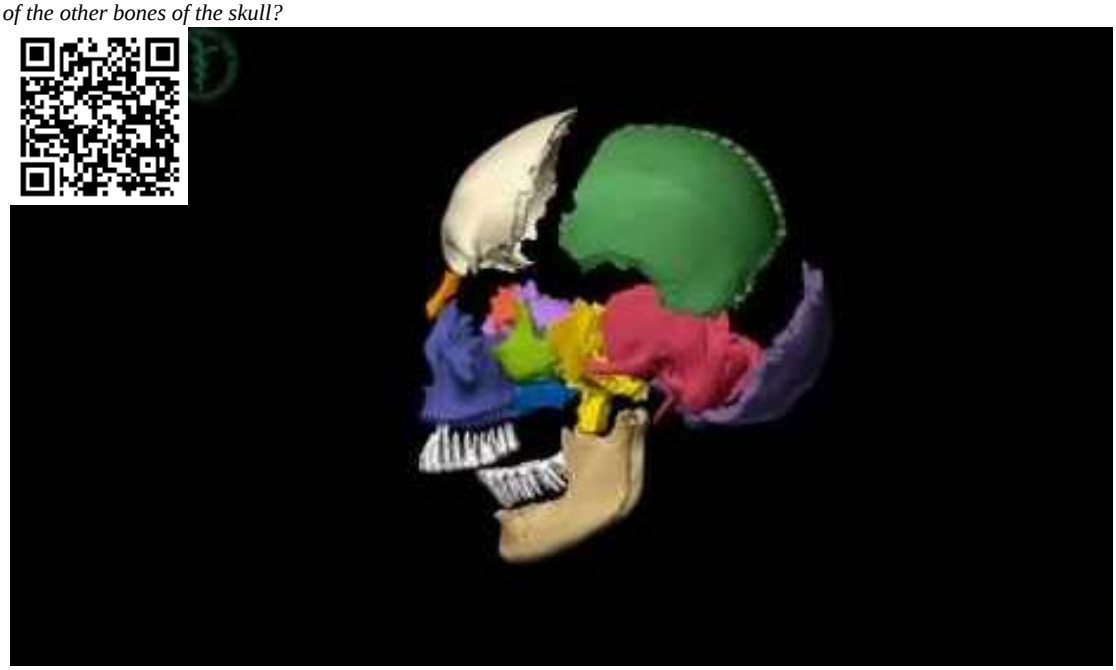


Figure 4.1.1: Parts of the Skull. The skull consists of the rounded brain case that houses the brain and the facial bones that form the upper and lower jaws, nose, orbits, and other facial structures.

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Watch this video to view a rotating and exploded skull, with color-coded bones. Which bone (yellow) is centrally located and joins with most of the other bones of the skull?



Anterior View of Skull

The anterior skull consists of the facial bones and provides the bony support for the eyes and structures of the face. This view of the skull is dominated by the openings of the orbits and the nasal cavity. Also seen are the upper and lower jaws, with their respective teeth (Figure 4.1.2).

The **orbit** is the bony socket that houses the eyeball and muscles that move the eyeball or open the upper eyelid. The upper margin of the anterior orbit is the **supraorbital margin**. Located near the midpoint of the supraorbital margin is a small opening called the **supraorbital foramen**. This provides for passage of a sensory nerve to the skin of the forehead. Below the orbit is the **infraorbital foramen**, which is the point of emergence for a sensory nerve that supplies the anterior face below the orbit.

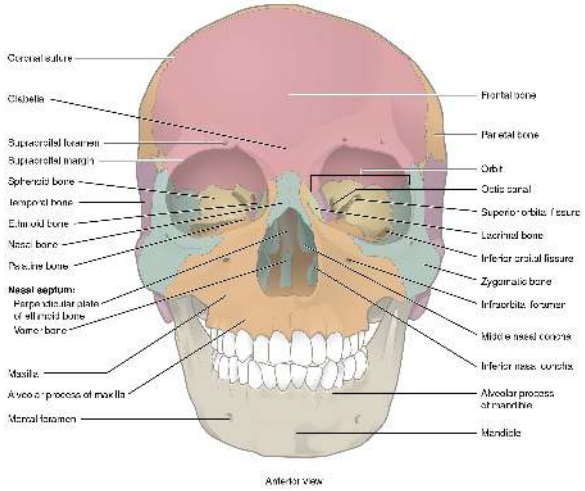


Figure 4.1.2: Anterior View of Skull. An anterior view of the skull shows the bones that form the forehead, orbits (eye sockets), nasal cavity, nasal septum, and upper and lower jaws.

Inside the nasal area of the skull, the **nasal cavity** is divided into halves by the **nasal septum**. The upper portion of the nasal septum is formed by the **perpendicular plate of the ethmoid bone** and the lower portion is the **vomer bone**. Each side of the nasal cavity is triangular in shape, with a broad inferior space that narrows superiorly. When looking into the nasal cavity from the front of the skull, two bony plates are seen projecting from each lateral wall. The larger of these is the **inferior nasal concha**, an independent bone of the skull. Located just above the inferior concha is the **middle nasal concha**, which is part of the ethmoid bone. A third bony plate, also part of the ethmoid bone, is the **superior nasal concha**. It is much smaller and out of sight, above the middle concha. The superior nasal concha is located just lateral to the perpendicular plate, in the upper nasal cavity.

Lateral View of Skull

A view of the lateral skull is dominated by the large, rounded brain case above and the upper and lower jaws with their teeth below (Figure 4.1.3). Separating these areas is the bridge of bone called the zygomatic arch. The **zygomatic arch** is the bony arch on the side of skull that spans from the area of the cheek to just above the ear canal. It is formed by the junction of two bony processes: a short anterior component, the **temporal process of the zygomatic bone** (the cheekbone) and a longer posterior portion, the **zygomatic process of the temporal bone**, extending forward from the temporal bone. Thus the temporal process (anteriorly) and the zygomatic process (posteriorly) join together, like the two ends of a drawbridge, to form the zygomatic arch. One of the major muscles that pulls the mandible upward during biting and chewing arises from the zygomatic arch.

On the lateral side of the brain case, above the level of the zygomatic arch, is a shallow space called the **temporal fossa**. Below the level of the zygomatic arch and deep to the vertical portion of the mandible is another space called the **infratemporal fossa**. Both the temporal fossa and infratemporal fossa contain muscles that act on the mandible during chewing.

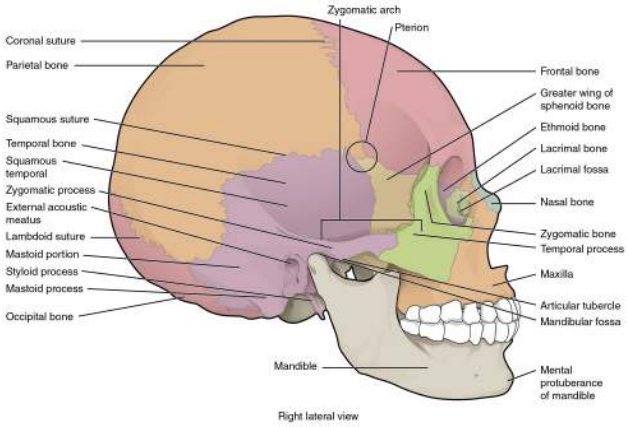


Figure 4.1.3: Lateral View of Skull. The lateral skull shows the large rounded brain case, zygomatic arch, and the upper and lower jaws. The zygomatic arch is formed jointly by the zygomatic process of the temporal bone and the temporal process of the zygomatic bone. The shallow space above the zygomatic arch is the temporal fossa. The space inferior to the zygomatic arch and deep to the posterior mandible is the infratemporal fossa.

Bones of the Brain Case

The brain case contains and protects the brain. The interior space that is almost completely occupied by the brain is called the **cranial cavity**. This cavity is bounded superiorly by the rounded top of the skull, which is called the **calvaria** (skullcap), and the lateral and posterior sides of the skull. The bones that form the top and sides of the brain case are usually referred to as the "flat" bones of the skull.

The floor of the brain case is referred to as the base of the skull. This is a complex area that varies in depth and has numerous openings for the passage of cranial nerves, blood vessels, and the spinal cord. Inside the skull, the base is subdivided into three large spaces, called the **anterior cranial fossa**, **middle cranial fossa**, and **posterior cranial fossa** (fossa = "trench or ditch") (Figure 4.1.4). From anterior to posterior, the fossae increase in depth. The shape and depth of each fossa corresponds to the shape and size of the brain region that each houses. The boundaries and openings of the cranial fossae (singular = fossa) will be described in a later section.

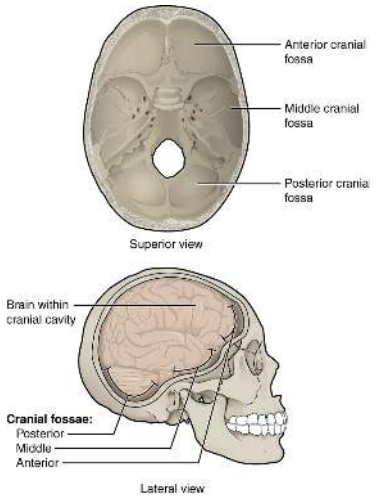


Figure 4.1.4: Cranial Fossae. The bones of the brain case surround and protect the brain, which occupies the cranial cavity. The base of the brain case, which forms the floor of cranial cavity, is subdivided into the shallow anterior cranial fossa, the middle cranial fossa, and the deep posterior cranial fossa.

The brain case consists of eight bones. These include the paired parietal and temporal bones, plus the unpaired frontal, occipital, sphenoid, and ethmoid bones.

Parietal Bone

The **parietal bone** forms most of the upper lateral side of the skull (see Figure 4.1.3). These are paired bones, with the right and left parietal bones joining together at the top of the skull. Each parietal bone is also bounded anteriorly by the frontal bone, inferiorly by the temporal bone, and posteriorly by the occipital bone.

Temporal Bone

The **temporal bone** forms the lower lateral side of the skull (see Figure 4.1.3). Common wisdom has it that the temporal bone (temporal = "time") is so named because this area of the head (the temple) is where hair typically first turns gray, indicating the passage of time.

The temporal bone is subdivided into several regions (Figure 4.1.5). The flattened, upper portion is the squamous portion of the temporal bone. Below this area and projecting anteriorly is the zygomatic process of the temporal bone, which forms the posterior portion of the zygomatic arch. Posteriorly is the mastoid portion of the temporal bone. Projecting inferiorly from this region is a large prominence, the mastoid process, which serves as a muscle attachment site. The **mastoid process** can easily be felt on the side of the head just behind your earlobe. On the interior of the skull, the petrous portion of each temporal bone forms the prominent, diagonally oriented **petrous ridge** in the floor of the cranial cavity. Located inside each petrous ridge are small cavities that house the structures of the middle and inner ears.

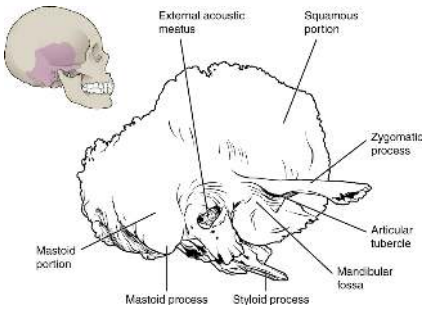


Figure 4.1.5: Temporal Bone.A lateral view of the isolated temporal bone shows the squamous, mastoid, and zygomatic portions of the temporal bone.

Important landmarks of the temporal bone, as shown in Figure 4.1.6, include the following:

- **External acoustic meatus** (ear canal)—This is the large opening on the lateral side of the skull that is associated with the ear.
- **Internal acoustic meatus**—This opening is located inside the cranial cavity, on the medial side of the petrous ridge. It connects to the middle and inner ear cavities of the temporal bone.
- **Mandibular fossa**—This is the deep, oval-shaped depression located on the external base of the skull, just in front of the external acoustic meatus. The mandible (lower jaw) joins with the skull at this site as part of the temporomandibular joint, which allows for movements of the mandible during opening and closing of the mouth.
- **Articular tubercle**—The smooth ridge located immediately anterior to the mandibular fossa. Both the articular tubercle and mandibular fossa contribute to the temporomandibular joint, the joint that provides for movements between the temporal bone of the skull and the mandible.
- **Styloid process**—Posterior to the mandibular fossa on the external base of the skull is an elongated, downward bony projection called the styloid process, so named because of its resemblance to a stylus (a pen or writing tool). This structure serves as an attachment site for several small muscles and for a ligament that supports the hyoid bone of the neck. (See also Figure 4.1.5)
- **Stylomastoid foramen**—This small opening is located between the styloid process and mastoid process. This is the point of exit for the cranial nerve that supplies the facial muscles.
- **Carotid canal**—The carotid canal is a zig-zag shaped tunnel that provides passage through the base of the skull for one of the major arteries that supplies the brain. Its entrance is located on the outside base of the skull, anteromedial to the styloid process. The canal then runs anteromedially within the bony base of the skull, and then turns upward to its exit in the floor of the middle cranial cavity, above the foramen lacerum.

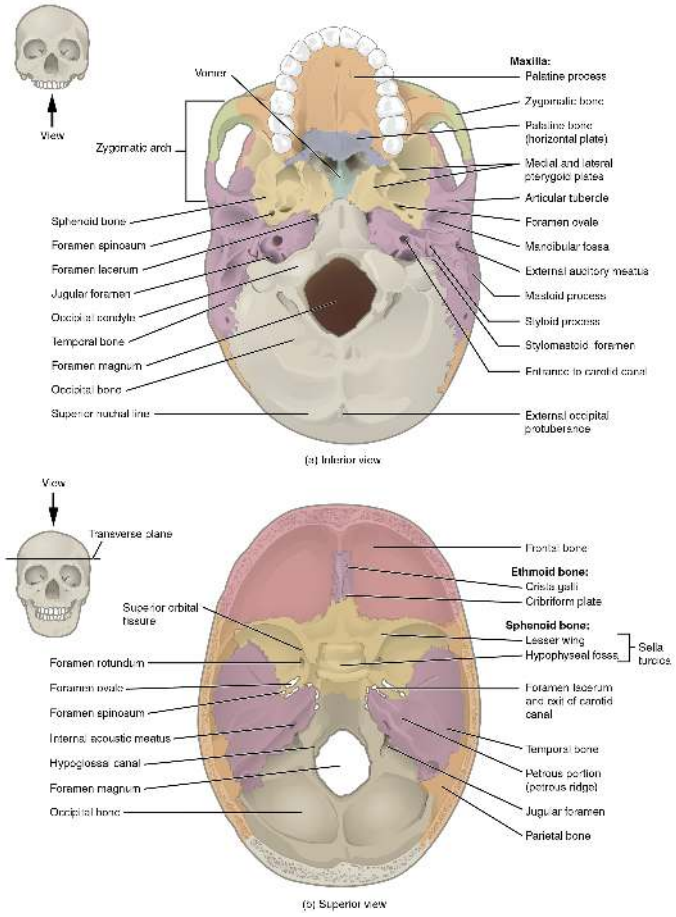


Figure 4.1.6: External and Internal Views of Base of Skull. (a) The hard palate is formed anteriorly by the palatine processes of the maxilla bones and posteriorly by the horizontal plate of the palatine bones. (b) The complex floor of the cranial cavity is formed by the frontal, ethmoid, sphenoid, temporal, and occipital bones. The lesser wing of the sphenoid bone separates the anterior and middle cranial fossae. The petrous ridge (petrous portion of temporal bone) separates the middle and posterior cranial fossae.

Frontal Bone

The **frontal bone** is the single bone that forms the forehead. At its anterior midline, between the eyebrows, there is a slight depression called the **glabella** (see Figure 4.1.3). The frontal bone also forms the supraorbital margin of the orbit. Near the middle of this margin, is the supraorbital foramen, the opening that provides passage for a sensory nerve to the forehead. The frontal bone is thickened just above each supraorbital margin, forming rounded brow ridges. These are located just behind your eyebrows and vary in size among individuals, although they are generally larger in males. Inside the cranial cavity, the frontal bone extends posteriorly. This flattened region forms both the roof of the orbit below and the floor of the anterior cranial cavity above (see Figure 4.1.6.*b*).

Occipital Bone

The **occipital bone** is the single bone that forms the posterior skull and posterior base of the cranial cavity (Figure 4.1.7; see also Figure 4.1.6). On its outside surface, at the posterior midline, is a small protrusion called the **external occipital protuberance**, which serves as an attachment site for a ligament of the posterior neck. Lateral to either side of this bump is a **superior nuchal line** (nuchal = "nape" or "posterior neck"). The nuchal lines represent the most superior point at which muscles of the neck attach to the skull, with only the scalp covering the skull above these lines. On the base of the skull, the occipital bone contains the large opening of the **foramen magnum**, which allows for passage of the spinal cord as it exits the skull. On either side of the foramen magnum is an oval-shaped **occipital condyle**. These condyles form joints with the first cervical vertebra and thus support the skull on top of the vertebral column.

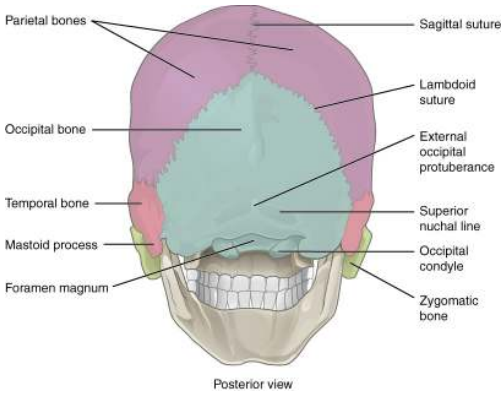


Figure 4.1.7: Posterior View of Skull. This view of the posterior skull shows attachment sites for muscles and joints that support the skull.

Sphenoid Bone

The **sphenoid bone** is a single, complex bone of the central skull (Figure 4.1.8). It serves as a "keystone" bone, because it joins with almost every other bone of the skull. The sphenoid forms much of the base of the central skull (see Figure 4.1.6) and also extends laterally to contribute to the sides of the skull (see Figure 4.1.3). Inside the cranial cavity, the right and left lesser wings of the sphenoid bone, which resemble the wings of a flying bird, form the lip of a prominent ridge that marks the boundary between the anterior and middle cranial fossae. The **sella turcica** ("Turkish saddle") is located at the midline of the middle cranial fossa. This bony region of the sphenoid bone is named for its resemblance to the horse saddles used by the Ottoman Turks, with a high back and a tall front. The rounded depression in the floor of the sella turcica is the **hypophyseal (pituitary) fossa**, which houses the pea-sized pituitary (hypophyseal) gland. The **greater wings of the sphenoid bone** extend laterally to either side away from the sella turcica, where they form the anterior floor of the middle cranial fossa. The greater wing is best seen on the outside of the lateral skull, where it forms a rectangular area immediately anterior to the squamous portion of the temporal bone.

On the inferior aspect of the skull, each half of the sphenoid bone forms two thin, vertically oriented bony plates. These are the **medial pterygoid plate** and **lateral pterygoid plate** (pterygoid = "wing-shaped"). The right and left medial pterygoid plates form the posterior, lateral walls of the nasal cavity. The somewhat larger lateral pterygoid plates serve as attachment sites for chewing muscles that fill the infratemporal space and act on the mandible.

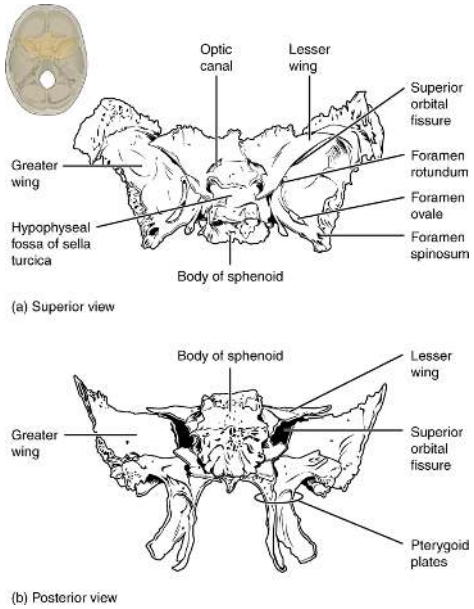


Figure 4.1.8: Sphenoid Bone. Shown in isolation in (a) superior and (b) posterior views, the sphenoid bone is a single midline bone that forms the anterior walls and floor of the middle cranial fossa. It has a pair of lesser wings and a pair of greater wings. The sella turcica surrounds the hypophyseal fossa. Projecting downward are the medial and lateral pterygoid plates. The sphenoid has multiple openings for the passage of nerves and blood vessels, including the optic canal, superior orbital fissure, foramen rotundum, foramen ovale, and foramen spinosum.

Ethmoid Bone

The **ethmoid bone** is a single, midline bone that forms the roof and lateral walls of the upper nasal cavity, the upper portion of the nasal septum, and contributes to the medial wall of the orbit (Figure 4.1.9 and Figure 4.1.10). On the interior of the skull, the ethmoid also forms a portion of the floor of the anterior cranial cavity (see Figure 4.1.6.*b*).

Within the nasal cavity, the perpendicular plate of the ethmoid bone forms the upper portion of the nasal septum. The ethmoid bone also forms the lateral walls of the upper nasal cavity. Extending from each lateral wall are the superior nasal concha and middle nasal concha, which are thin, curved projections that extend into the nasal cavity (Figure 4.1.11).

In the cranial cavity, the ethmoid bone forms a small area at the midline in the floor of the anterior cranial fossa. This region also forms the narrow roof of the underlying nasal cavity. This portion of the ethmoid bone consists of two parts, the crista galli and cribriform plates. The **crista galli** ("rooster's comb or crest") is a small upward bony projection located at the midline. It functions as an anterior attachment point for one of the covering layers of the brain. To either side of the crista galli is the **cribriform plate** (cribrum = "sieve"), a small, flattened area with numerous small openings termed olfactory foramina. Small nerve branches from the olfactory areas of the nasal cavity pass through these openings to enter the brain.

The lateral portions of the ethmoid bone are located between the orbit and upper nasal cavity, and thus form the lateral nasal cavity wall and a portion of the medial orbit wall. Located inside this portion of the ethmoid bone are several small, air-filled spaces that are part of the paranasal sinus system of the skull.

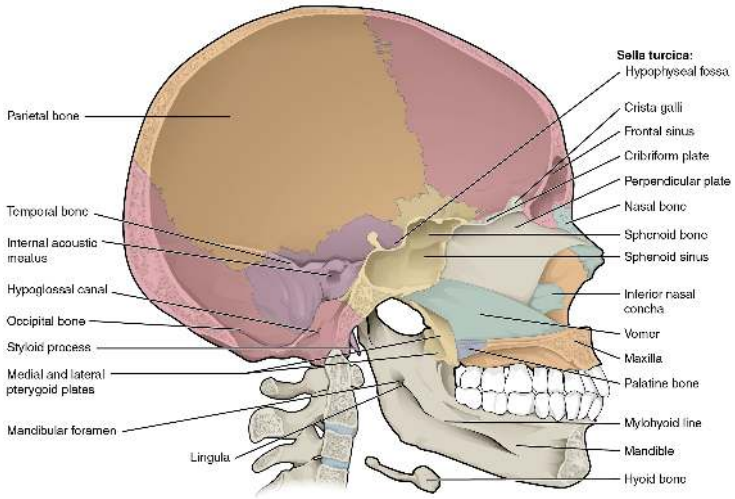


Figure 4.1.9: Sagittal Section of Skull. This midline view of the sagittally sectioned skull shows the nasal septum.

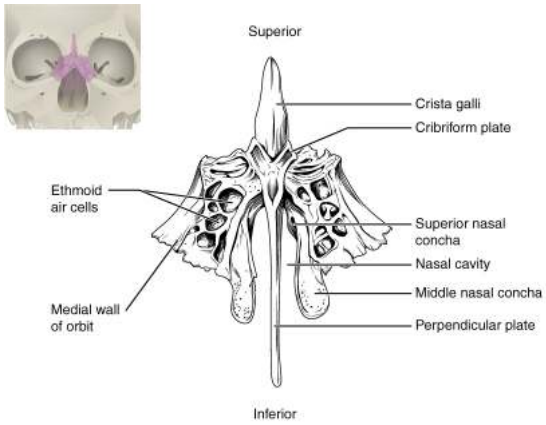


Figure 4.1.10: Ethmoid Bone. The unpaired ethmoid bone is located at the midline within the central skull. It has an upward projection, the crista galli, and a downward projection, the perpendicular plate, which forms the upper nasal septum. The cribriform plates form both the roof of the nasal cavity and a portion of the anterior cranial fossa floor. The lateral sides of the ethmoid bone form the lateral walls of the upper nasal cavity, part of the medial orbit wall, and give rise to the superior and middle nasal conchae. The ethmoid bone also contains the ethmoid air cells.

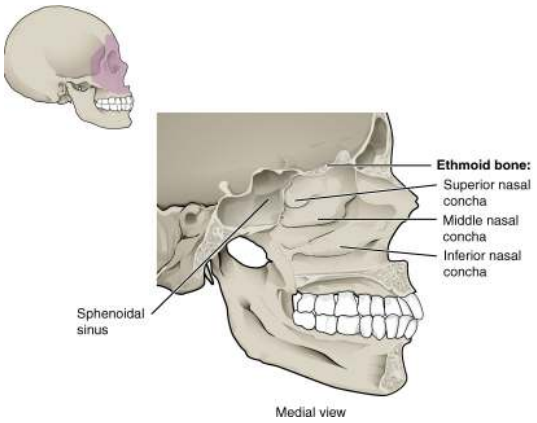


Figure 4.1.11: Lateral Wall of Nasal Cavity. The three nasal conchae are curved bones that project from the lateral walls of the nasal cavity. The superior nasal concha and middle nasal concha are parts of the ethmoid bone. The inferior nasal concha is an independent bone of the skull.

Sutures of the Skull

A **suture** is an immobile joint between adjacent bones of the skull. The narrow gap between the bones is filled with dense, fibrous connective tissue that unites the bones. The long sutures located between the bones of the brain case are not straight, but instead follow irregular, tightly twisting paths. These twisting lines serve to tightly interlock the adjacent bones, thus adding strength to the skull for brain protection.

The two suture lines seen on the top of the skull are the coronal and sagittal sutures. The **coronal suture** runs from side to side across the skull, within the coronal plane of section (see Figure 4.1.3). It joins the frontal bone to the right and left parietal bones. The **sagittal suture** extends posteriorly from the coronal suture, running along the midline at the top of the skull in the sagittal plane of section (see Figure 4.1.7). It unites the right and left parietal bones. On the posterior skull, the sagittal suture terminates by joining the lambdoid suture. The **lambdoid suture** extends downward and laterally to either side away from its junction with the sagittal suture. The lambdoid suture joins the occipital bone to the right and left parietal and temporal bones. This suture is named for its upside-down "V" shape, which resembles the capital letter version of the Greek letter lambda (Λ). The **squamous suture** is located on the lateral skull. It unites the squamous portion of the temporal bone with the parietal bone (see Figure 4.1.3). At the intersection of four bones is the **pterion**, a small, capital-H-shaped suture line region that unites the frontal bone, parietal bone, squamous portion of the temporal bone, and greater wing of the sphenoid bone. It is the weakest part of the skull. The pterion is located approximately two finger widths above the zygomatic arch and a thumb's width posterior to the upward portion of the zygomatic bone.

DISORDERS OF THE...

Skeletal System

Head and traumatic brain injuries are major causes of immediate death and disability, with bleeding and infections as possible additional complications. According to the Centers for Disease Control and Prevention (2010), approximately 30 percent of all injury-related deaths in the United States are caused by head injuries. The majority of head injuries involve falls. They are most common among young children (ages 0–4 years), adolescents (15–19 years), and the elderly (over 65 years). Additional causes vary, but prominent among these are automobile and motorcycle accidents.

Strong blows to the brain-case portion of the skull can produce fractures. These may result in bleeding inside the skull with subsequent injury to the brain. The most common is a linear skull fracture, in which fracture lines radiate from the point of impact. Other fracture types include a

comminuted fracture, in which the bone is broken into several pieces at the point of impact, or a depressed fracture, in which the fractured bone is pushed inward. In a contrecoup (counterblow) fracture, the bone at the point of impact is not broken, but instead a fracture occurs on the opposite side of the skull. Fractures of the occipital bone at the base of the skull can occur in this manner, producing a basilar fracture that can damage the artery that passes through the carotid canal.

A blow to the lateral side of the head may fracture the bones of the pterion. The pterion is an important clinical landmark because located immediately deep to it on the inside of the skull is a major branch of an artery that supplies the skull and covering layers of the brain. A strong blow to this region can fracture the bones around the pterion. If the underlying artery is damaged, bleeding can cause the formation of a hematoma (collection of blood) between the brain and interior of the skull. As blood accumulates, it will put pressure on the brain. Symptoms associated with a hematoma may not be apparent immediately following the injury, but if untreated, blood accumulation will exert increasing pressure on the brain and can result in death within a few hours.

QR Code representing a URL

View this animation to see how a blow to the head may produce a contrecoup (counterblow) fracture of the basilar portion of the occipital bone on the base of the skull. Why may a basilar fracture be life threatening?

Facial Bones of the Skull

The facial bones of the skull form the upper and lower jaws, the nose, nasal cavity and nasal septum, and the orbit. The facial bones include 14 bones, with six paired bones and two unpaired bones. The paired bones are the maxilla, palatine, zygomatic, nasal, lacrimal, and inferior nasal conchae bones. The unpaired bones are the vomer and mandible bones. Although classified with the brain-case bones, the ethmoid bone also contributes to the nasal septum and the walls of the nasal cavity and orbit.

Maxillary Bone

The **maxillary bone**, often referred to simply as the maxilla (plural = maxillae), is one of a pair that together form the upper jaw, much of the hard palate, the medial floor of the orbit, and the lateral base of the nose (see Figure 4.1.2). The curved, inferior margin of the maxillary bone that forms the upper jaw and contains the upper teeth is the **alveolar process of the maxilla** (Figure 4.1.12). Each tooth is anchored into a deep socket called an alveolus. On the anterior maxilla, just below the orbit, is the infraorbital foramen. This is the point of exit for a sensory nerve that supplies the nose, upper lip, and anterior cheek. On the inferior skull, the **palatine process** from each maxillary bone can be seen joining together at the midline to form the anterior three-quarters of the hard palate (see Figure 4.1.6.*a*). The **hard palate** is the bony plate that forms the roof of the mouth and floor of the nasal cavity, separating the oral and nasal cavities.

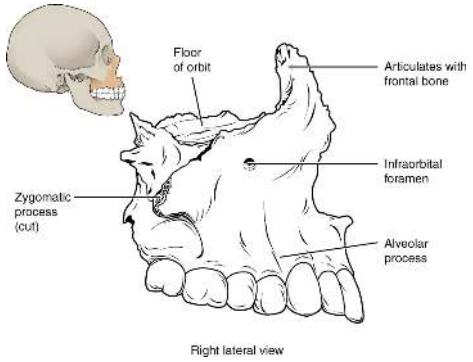


Figure 4.1.12: Maxillary Bone. The maxillary bone forms the upper jaw and supports the upper teeth. Each maxilla also forms the lateral floor of each orbit and the majority of the hard palate.

Palatine Bone

The **palatine bone** is one of a pair of irregularly shaped bones that contribute small areas to the lateral walls of the nasal cavity and the medial wall of each orbit. The largest region of each of the palatine bone is the **horizontal plate**. The plates from the right and left palatine bones join together at the midline to form the posterior quarter of the hard palate (see Figure 4.1.6.*a*). Thus, the palatine bones are best seen in an inferior view of the skull and hard palate.

HOMEOSTATIC IMBALANCES

Cleft Lip and Cleft Palate

During embryonic development, the right and left maxilla bones come together at the midline to form the upper jaw. At the same time, the muscle and skin overlying these bones join together to form the upper lip. Inside the mouth, the palatine processes of the maxilla bones, along with the horizontal plates of the right and left palatine bones, join together to form the hard palate. If an error occurs in these developmental processes, a birth defect of cleft lip or cleft palate may result.

Cleft lip is a common development defect that affects approximately 1:1000 births, most of which are male. This defect involves a partial or complete failure of the right and left portions of the upper lip to fuse together, leaving a cleft (gap).

A more severe developmental defect is cleft palate, which affects the hard palate. The hard palate is the bony structure that separates the nasal cavity from the oral cavity. It is formed during embryonic development by the midline fusion of the horizontal plates from the right and left palatine bones and the palatine processes of the maxilla bones. Cleft palate affects approximately 1:2500 births and is more common in females. It results from a failure of the two halves of the hard palate to completely come together and fuse at the midline, thus leaving a gap between them. This gap allows for communication between the nasal and oral cavities. In severe cases, the bony gap continues into the anterior upper jaw where the alveolar processes of the maxilla bones also do not properly join together above the front teeth. If this occurs, a cleft lip will also be seen. Because of the communication between the oral and nasal cavities, a cleft palate makes it very difficult for an infant to generate the suckling needed for nursing, thus leaving the infant at risk for malnutrition. Surgical repair is required to correct cleft palate defects.

Zygomatic Bone

The **zygomatic bone** is also known as the cheekbone. Each of the paired zygomatic bones forms much of the lateral wall of the orbit and the lateral-inferior margins of the anterior orbital opening (see Figure 4.1.2). The short temporal process of the zygomatic bone projects posteriorly, where it forms the anterior portion of the zygomatic arch (see Figure 4.1.3).

Nasal Bone

The **nasal bone** is one of two small bones that articulate (join) with each other to form the bony base (bridge) of the nose. They also support the cartilages that form the lateral walls of the nose (see Figure 4.1.9). These are the bones that are damaged when the nose is broken.

Lacrimal Bone

Each **lacrimal bone** is a small, rectangular bone that forms the anterior, medial wall of the orbit (see Figure 4.1.2 and Figure 4.1.3). The anterior portion of the lacrimal bone forms a shallow depression called the **lacrimal fossa**, and extending inferiorly from this is the **nasolacrimal canal**. The lacrimal fluid (tears of the eye), which serves to maintain the moist surface of the eye, drains at the medial corner of the eye into the nasolacrimal canal. This duct then extends downward to open into the nasal cavity, behind the inferior nasal concha. In the nasal cavity, the lacrimal fluid normally drains posteriorly, but with an increased flow of tears due to crying or eye irritation, some fluid will also drain anteriorly, thus causing a runny nose.

Inferior Nasal Conchae

The right and left inferior nasal conchae form a curved bony plate that projects into the nasal cavity space from the lower lateral wall (see Figure 4.1.11). The inferior concha is the largest of the nasal conchae and can easily be seen when looking into the anterior opening of the nasal cavity.

Vomer Bone

The unpaired vomer bone, often referred to simply as the vomer, is triangular-shaped and forms the posterior-inferior part of the nasal septum (see Figure 4.1.9). The vomer is best seen when looking from behind into the posterior openings of the nasal cavity (see Figure 4.1.6.*a*). In this view, the vomer is seen to form the entire height of the nasal septum. A much smaller portion of the vomer can also be seen when looking into the anterior opening of the nasal cavity.

Mandible

The **mandible** forms the lower jaw and is the only moveable bone of the skull. At the time of birth, the mandible consists of paired right and left bones, but these fuse together during the first year to form the single U-shaped mandible of the adult skull. Each side of the mandible consists of a horizontal body and posteriorly, a vertically oriented **ramus of the mandible** (ramus = "branch"). The outside margin of the mandible, where the body and ramus come together is called the **angle of the mandible** (Figure 4.1.13).

The ramus on each side of the mandible has two upward-going bony projections. The more anterior projection is the flattened **coronoid process of the mandible**, which provides attachment for one of the biting muscles. The posterior projection is the **condylar process of the mandible**, which is topped by the oval-shaped **condyle**. The condyle of the mandible articulates (joins) with the mandibular fossa and articular tubercle of the temporal bone. Together these articulations form the temporomandibular joint, which allows for opening and closing of the mouth (see Figure 4.1.3). The broad U-shaped curve located between the coronoid and condylar processes is the **mandibular notch**.

Important landmarks for the mandible include the following:

- **Alveolar process of the mandible**—This is the upper border of the mandibular body and serves to anchor the lower teeth.
- **Mental protuberance**—The forward projection from the inferior margin of the anterior mandible that forms the chin (mental = "chin").
- **Mental foramen**—The opening located on each side of the anterior-lateral mandible, which is the exit site for a sensory nerve that supplies the chin.
- **Mylohyoid line**—This bony ridge extends along the inner aspect of the mandibular body (see Figure 4.1.9). The muscle that forms the floor of the oral cavity attaches to the mylohyoid lines on both sides of the mandible.
- **Mandibular foramen**—This opening is located on the medial side of the ramus of the mandible. The opening leads into a tunnel that runs down the length of the mandibular body. The sensory nerve and blood vessels that supply the lower teeth enter the mandibular foramen and then follow this tunnel. Thus, to numb the lower teeth prior to dental work, the dentist must inject anesthesia into the lateral wall of the oral cavity at a point prior to where this sensory nerve enters the mandibular foramen.
- **Lingula**—This small flap of bone is named for its shape (lingula = "little tongue"). It is located immediately next to the mandibular foramen, on the medial side of the ramus. A ligament that anchors the mandible during opening and closing of the mouth extends down from the base of the skull and attaches to the lingula.

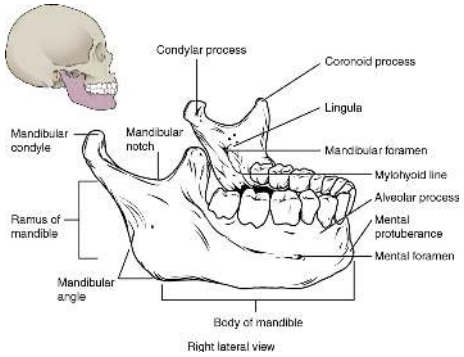


Figure 4.1.13: Isolated Mandible. The mandible is the only moveable bone of the skull.

The Orbit

The orbit is the bony socket that houses the eyeball and contains the muscles that move the eyeball or open the upper eyelid. Each orbit is cone-shaped, with a narrow posterior region that widens toward the large anterior opening. To help protect the eye, the bony margins of the anterior opening are thickened and somewhat constricted. The medial walls of the two orbits are parallel to each other but each lateral wall diverges away from the midline at a 45° angle. This divergence provides greater lateral peripheral vision.

The walls of each orbit include contributions from seven skull bones (Figure 4.1.14). The frontal bone forms the roof and the zygomatic bone forms the lateral wall and lateral floor. The medial floor is primarily formed by the maxilla, with a small contribution from the palatine bone. The ethmoid bone and lacrimal bone make up much of the medial wall and the sphenoid bone forms the posterior orbit.

At the posterior apex of the orbit is the opening of the **optic canal**, which allows for passage of the optic nerve from the retina to the brain. Lateral to this is the elongated and irregularly shaped superior orbital fissure, which provides passage for the artery that supplies the eyeball, sensory nerves, and the nerves that supply the muscles involved in eye movements.

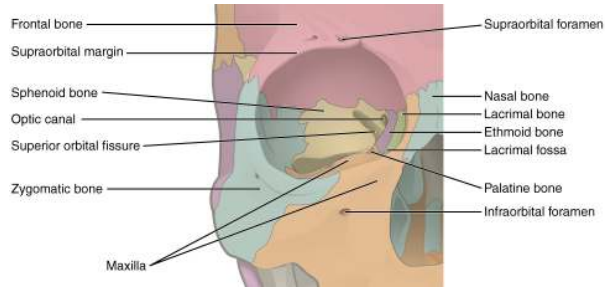


Figure 4.1.14: Bones of the Orbit. Seven skull bones contribute to the walls of the orbit. Opening into the posterior orbit from the cranial cavity are the optic canal and superior orbital fissure.

The Nasal Septum and Nasal Conchae

The **nasal septum** consists of both bone and cartilage components (Figure 4.1.15; see also Figure 4.1.9). The upper portion of the septum is formed by the perpendicular plate of the ethmoid bone. The lower and posterior parts of the septum are formed by the triangular-shaped vomer bone. In an anterior view of the skull, the perpendicular plate of the ethmoid bone is easily seen inside the nasal opening as the upper nasal septum, but only a small portion of the vomer is seen as the inferior septum. A better view of the vomer bone is seen when looking into the posterior nasal cavity with an inferior view of the skull, where the vomer forms the full height of the nasal septum. The anterior nasal septum is formed by the **septal cartilage**, a flexible plate that fills in the gap between the perpendicular plate of the ethmoid and vomer bones. This cartilage also extends outward into the nose where it separates the right and left nostrils. The septal cartilage is not found in the dry skull.

Attached to the lateral wall on each side of the nasal cavity are the superior, middle, and inferior **nasal conchae** (singular = concha), which are named for their positions (see Figure 4.1.11). These are bony plates that curve downward as they project into the space of the nasal cavity. They serve to swirl the incoming air, which helps to warm and moisturize it before the air moves into the delicate air sacs of the lungs. This also allows mucus, secreted by the tissue lining the nasal cavity, to trap incoming dust, pollen, bacteria, and viruses. The largest of the conchae is the inferior nasal concha, which is an independent bone of the skull. The middle concha and the superior conchae, which is the smallest, are both formed by the ethmoid bone. When looking into the anterior nasal opening of the skull, only the inferior and middle conchae can be seen. The small superior nasal concha is well hidden above and behind the middle concha.

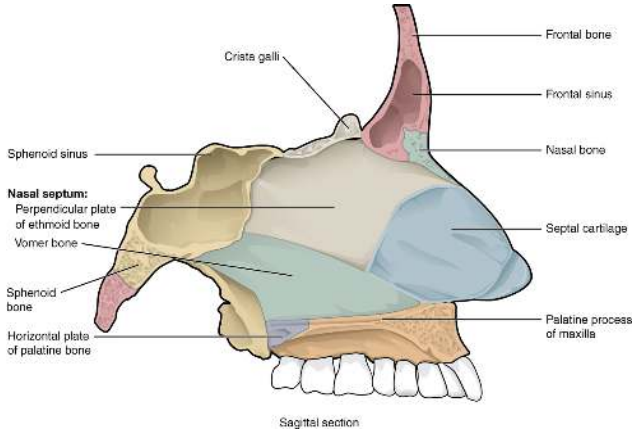


Figure 4.1.15: Nasal Septum. The nasal septum is formed by the perpendicular plate of the ethmoid bone and the vomer bone. The septal cartilage fills the gap between these bones and extends into the nose.

Cranial Fossae

Inside the skull, the floor of the cranial cavity is subdivided into three cranial fossae (spaces), which increase in depth from anterior to posterior (see Figure 4.1.4, Figure 4.1.6.*b*, and Figure 4.1.9). Since the brain occupies these areas, the shape of each conforms to the shape of the brain regions that it contains. Each cranial fossa has anterior and posterior boundaries and is divided at the midline into right and left areas by a significant bony structure or opening.

Anterior Cranial Fossa

The anterior cranial fossa is the most anterior and the shallowest of the three cranial fossae. It overlies the orbits and contains the frontal lobes of the brain. Anteriorly, the anterior fossa is bounded by the frontal bone, which also forms the majority of the floor for this space. The lesser wings of the sphenoid bone form the prominent ledge that marks the boundary between the anterior and middle cranial fossae. Located in the floor of the anterior cranial fossa at the midline is a portion of the ethmoid bone, consisting of the upward projecting crista galli and to either side of this, the cribriform plates.

Middle Cranial Fossa

The middle cranial fossa is deeper and situated posterior to the anterior fossa. It extends from the lesser wings of the sphenoid bone anteriorly, to the petrous ridges (petrous portion of the temporal bones) posteriorly. The large, diagonally positioned petrous ridges give the middle cranial fossa a butterfly shape, making it narrow at the midline and broad laterally. The temporal lobes of the brain occupy this fossa. The middle cranial fossa is divided at the midline by the upward bony prominence of the sella turcica, a part of the sphenoid bone. The middle cranial fossa has several openings for the passage of blood vessels and cranial nerves (see Figure 4.1.6).

Openings in the middle cranial fossa are as follows:

- **Optic canal**—This opening is located at the anterior lateral corner of the sella turcica. It provides for passage of the optic nerve into the orbit.
- **Superior orbital fissure**—This large, irregular opening into the posterior orbit is located on the anterior wall of the middle cranial fossa, lateral to the optic canal and under the projecting margin of the lesser wing of the sphenoid bone. Nerves to the eyeball and associated muscles, and sensory nerves to the forehead pass through this opening.
- **Foramen rotundum**—This rounded opening (rotundum = "round") is located in the floor of the middle cranial fossa, just inferior to the superior orbital fissure. It is the exit point for a major sensory nerve that supplies the cheek, nose, and upper teeth.
- **Foramen ovale of the middle cranial fossa**—This large, oval-shaped opening in the floor of the middle cranial fossa provides passage for a major sensory nerve to the lateral head, cheek, chin, and lower teeth.
- **Foramen spinosum**—This small opening, located posterior-lateral to the foramen ovale, is the entry point for an important artery that supplies the covering layers surrounding the brain. The branching pattern of this artery forms readily visible grooves on the internal surface of the skull and these grooves can be traced back to their origin at the foramen spinosum.
- **Carotid canal**—This is the zig-zag passageway through which a major artery to the brain enters the skull. The entrance to the carotid canal is located on the inferior aspect of the skull, anteromedial to the styloid process (see Figure 4.1.6.*a*). From here, the canal runs anteromedially within the bony base of the skull. Just above the foramen lacerum, the carotid canal opens into the middle cranial cavity, near the posterior-lateral base of the sella turcica.
- **Foramen lacerum**—This irregular opening is located in the base of the skull, immediately inferior to the exit of the carotid canal. This opening is an artifact of the dry skull, because in life it is completely filled with cartilage. All the openings of the skull that provide for passage of nerves or blood vessels have smooth margins; the word lacerum ("ragged" or "torn") tells us that this opening has ragged edges and thus nothing passes through it.

Posterior Cranial Fossa

The posterior cranial fossa is the most posterior and deepest portion of the cranial cavity. It contains the cerebellum of the brain. The posterior fossa is bounded anteriorly by the petrous ridges, while the occipital bone forms the floor and posterior wall. It is divided at the midline by the large foramen magnum ("great aperture"), the opening that provides for passage of the spinal cord.

Located on the medial wall of the petrous ridge in the posterior cranial fossa is the internal acoustic meatus (see Figure 4.1.9). This opening provides for passage of the nerve from the hearing and equilibrium organs of the inner ear, and the nerve that supplies the muscles of the face. Located at the anterior-lateral margin of the foramen magnum is the **hypoglossal canal**. These emerge on the inferior aspect of the skull at the base of the occipital condyle and provide passage for an important nerve to the tongue.

Immediately inferior to the internal acoustic meatus is the large, irregularly shaped **jugular foramen** (see Figure 4.1.6.*a*). Several cranial nerves from the brain exit the skull via this opening. It is also the exit point through the base of the skull for all the venous return blood leaving the brain. The venous structures that carry blood inside the skull form large, curved grooves on the inner walls of the posterior cranial fossa, which terminate at each jugular foramen.

Paranasal Sinuses

The **paranasal sinuses** are hollow, air-filled spaces located within certain bones of the skull (Figure 4.1.16). All of the sinuses communicate with the nasal cavity (paranasal = "next to nasal cavity") and are lined with nasal mucosa. They serve to reduce bone mass and thus lighten the skull, and they also add resonance to the voice. This second feature is most obvious when you have a cold or sinus congestion. These produce swelling of the mucosa and excess mucus production, which can obstruct the narrow passageways between the sinuses and the nasal cavity, causing your voice to sound different to yourself and others. This blockage can also allow the sinuses to fill with fluid, with the resulting pressure producing pain and discomfort.

The paranasal sinuses are named for the skull bone that each occupies. The **frontal sinus** is located just above the eyebrows, within the frontal bone (see Figure 4.1.15). This irregular space may be divided at the midline into bilateral spaces, or these may be fused into a single sinus space. The frontal sinus is the most anterior of the paranasal sinuses. The largest sinus is the **maxillary sinus**. These are paired and located within the right and left maxillary bones, where they occupy the area just below the orbits. The maxillary sinuses are most commonly involved during sinus infections. Because their connection to the nasal cavity is located high on their medial wall, they are difficult to drain. The **sphenoid sinus** is a single, midline sinus. It is located within the body of the sphenoid bone, just anterior and inferior to the sella turcica, thus making it the most posterior of the paranasal sinuses. The lateral aspects of the ethmoid bone contain multiple small spaces separated by very thin bony walls. Each of these spaces is called an **ethmoid air cell**. These are located on both sides of the ethmoid bone, between the upper nasal cavity and medial orbit, just behind the superior nasal conchae.

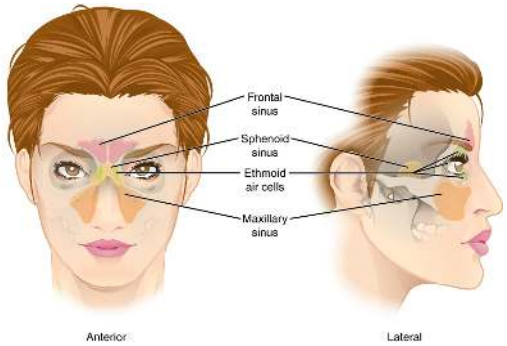


Figure 4.1.16: Paranasal Sinuses. The paranasal sinuses are hollow, air-filled spaces named for the skull bone that each occupies. The most anterior is the frontal sinus, located in the frontal bone above the eyebrows. The largest are the maxillary sinuses, located in the right and left maxillary bones below the orbits. The most posterior is the sphenoid sinus, located in the body of the sphenoid bone, under the sella turcica. The ethmoid air cells are multiple small spaces located in the right and left sides of the ethmoid bone, between the medial wall of the orbit and lateral wall of the upper nasal cavity.

Hyoid Bone

The hyoid bone is an independent bone that does not contact any other bone and thus is not part of the skull (Figure 4.1.17). It is a small U-shaped bone located in the upper neck near the level of the inferior mandible, with the tips of the "U" pointing posteriorly. The hyoid serves as the base for the tongue above, and is attached to the larynx below and the pharynx posteriorly. The hyoid is held in position by a series of small muscles that attach to it either from above or below. These muscles act to move the hyoid up/down or forward/back. Movements of the hyoid are coordinated with movements of the tongue, larynx, and pharynx during swallowing and speaking.

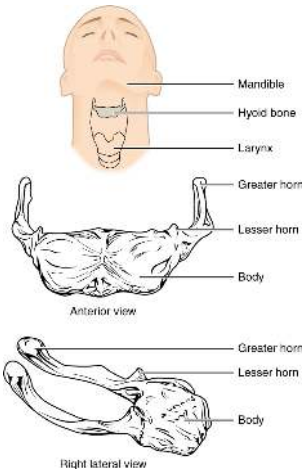


Figure 4.1.17: Hyoid Bone. The hyoid bone is located in the upper neck and does not join with any other bone. It provides attachments for muscles that act on the tongue, larynx, and pharynx.

Chapter Review

The skull consists of the brain case and the facial bones. The brain case surrounds and protects the brain, which occupies the cranial cavity inside the skull. It consists of the rounded calvaria and a complex base. The brain case is formed by eight bones, the paired parietal and temporal bones plus the unpaired frontal, occipital, sphenoid, and ethmoid bones. The narrow gap between the bones is filled with dense, fibrous connective tissue that unites the bones. The sagittal suture joins the right and left parietal bones. The coronal suture joins the parietal bones to the frontal bone, the lamboid suture joins them to the occipital bone, and the squamous suture joins them to the temporal bone.

The facial bones support the facial structures and form the upper and lower jaws. These consist of 14 bones, with the paired maxillary, palatine, zygomatic, nasal, lacrimal, and inferior conchae bones and the unpaired vomer and mandible bones. The ethmoid bone also contributes to the formation of facial structures. The maxilla forms the upper jaw and the mandible forms the lower jaw. The maxilla also forms the larger anterior portion of the hard palate, which is completed by the smaller palatine bones that form the posterior portion of the hard palate.

The floor of the cranial cavity increases in depth from front to back and is divided into three cranial fossae. The anterior cranial fossa is located between the frontal bone and lesser wing of the sphenoid bone. A small area of the ethmoid bone, consisting of the crista galli and cribriform plates, is located at the midline of this fossa. The middle cranial fossa extends from the lesser wing of the sphenoid bone to the petrous ridge (petrous portion of temporal bone). The right and left sides are separated at the midline by the sella turcica, which surrounds the shallow hypophyseal fossa. Openings through the skull in the floor of the middle fossa include the optic canal and superior orbital fissure, which open into the posterior orbit, the foramen rotundum, foramen ovale, and foramen spinosum, and the exit of the carotid canal with its underlying foramen lacerum. The deep posterior cranial fossa extends from the petrous ridge to the occipital bone. Openings here include the large foramen magnum, plus the internal

acoustic meatus, jugular foramina, and hypoglossal canals. Additional openings located on the external base of the skull include the stylomastoid foramen and the entrance to the carotid canal.

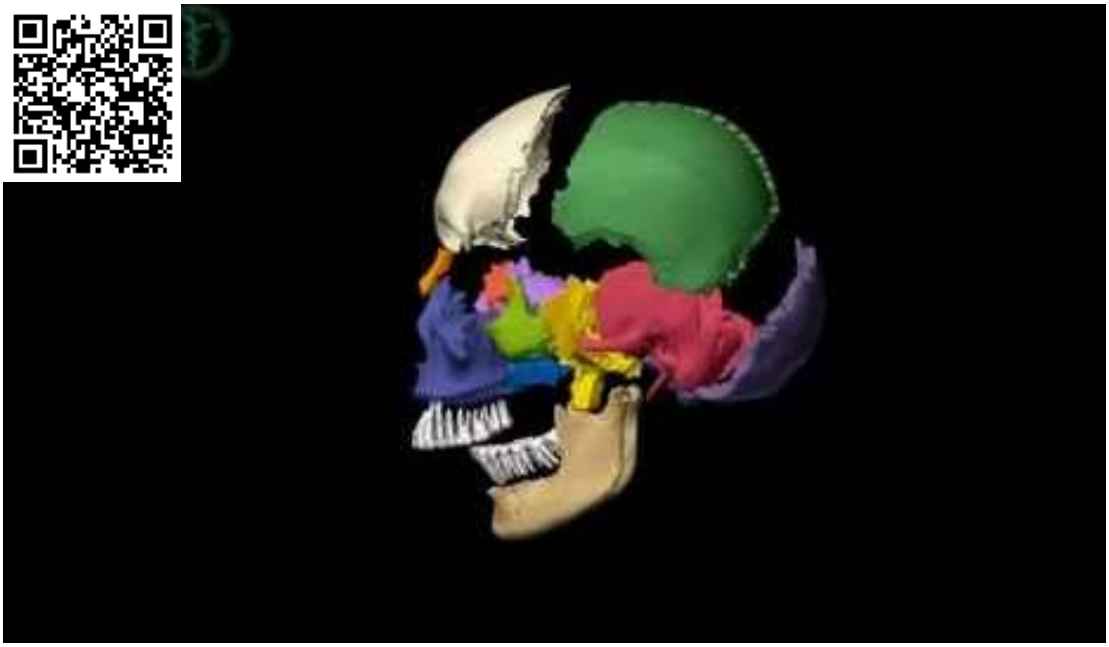
The anterior skull has the orbits that house the eyeballs and associated muscles. The walls of the orbit are formed by contributions from seven bones: the frontal, zygomatic, maxillary, palatine, ethmoid, lacrimal, and sphenoid. Located at the superior margin of the orbit is the supraorbital foramen, and below the orbit is the infraorbital foramen. The mandible has two openings, the mandibular foramen on its inner surface and the mental foramen on its external surface near the chin. The nasal conchae are bony projections from the lateral walls of the nasal cavity. The large inferior nasal concha is an independent bone, while the middle and superior conchae are parts of the ethmoid bone. The nasal septum is formed by the perpendicular plate of the ethmoid bone, the vomer bone, and the septal cartilage. The paranasal sinuses are air-filled spaces located within the frontal, maxillary, sphenoid, and ethmoid bones.

On the lateral skull, the zygomatic arch consists of two parts, the temporal process of the zygomatic bone anteriorly and the zygomatic process of the temporal bone posteriorly. The temporal fossa is the shallow space located on the lateral skull above the level of the zygomatic arch. The infratemporal fossa is located below the zygomatic arch and deep to the ramus of the mandible.

The hyoid bone is located in the upper neck and does not join with any other bone. It is held in position by muscles and serves to support the tongue above, the larynx below, and the pharynx posteriorly.

Interactive Link Questions

Watch this video to view a rotating and exploded skull with color-coded bones. Which bone (yellow) is centrally located and joins with most of the other bones of the skull?



> Answer: The sphenoid bone joins with most other bones of the skull. It is centrally located, where it forms portions of the rounded brain case and cranial base.

View this animation to see how a blow to the head may produce a contrecoup (counterblow) fracture of the basilar portion of the occipital bone on the base of the skull. Why may a basilar fracture be life threatening?

Answer: A basilar fracture may damage an artery entering the skull, causing bleeding in the brain.

Review Questions

Q. Which of the following is a bone of the brain case?

A. parietal bone

B. zygomatic bone

C. maxillary bone

D. lacrimal bone

Answer: A

Q. The lambdoid suture joins the parietal bone to the _____.

A. frontal bone

B. occipital bone

C. other parietal bone

D. temporal bone

Answer: B

Q. The middle cranial fossa _____.

A. is bounded anteriorly by the petrous ridge

B. is bounded posteriorly by the lesser wing of the sphenoid bone

C. is divided at the midline by a small area of the ethmoid bone

D. has the foramen rotundum, foramen ovale, and foramen spinosum

Answer: D

Q. The paranasal sinuses are _____.

A. air-filled spaces found within the frontal, maxilla, sphenoid, and ethmoid bones only

B. air-filled spaces found within all bones of the skull

C. not connected to the nasal cavity

D. divided at the midline by the nasal septum

Answer: A

Q. Parts of the sphenoid bone include the _____.

A. sella turcica

B. squamous portion

C. glabella

D. zygomatic process

Answer: A

Q. The bony openings of the skull include the _____.

A. carotid canal, which is located in the anterior cranial fossa

B. superior orbital fissure, which is located at the superior margin of the anterior orbit

C. mental foramen, which is located just below the orbit

D. hypoglossal canal, which is located in the posterior cranial fossa

Answer: D

Critical Thinking Questions

Q. Define and list the bones that form the brain case or support the facial structures.

A. The brain case is that portion of the skull that surrounds and protects the brain. It is subdivided into the rounded top of the skull, called the calvaria, and the base of the skull. There are eight bones that form the brain case. These are the paired parietal and temporal bones, plus the unpaired frontal, occipital, sphenoid, and ethmoid bones. The facial bones support the facial structures, and form the upper and lower jaws, nasal cavity, nasal septum, and orbit. There are 14 facial bones. These are the paired maxillary, palatine, zygomatic, nasal, lacrimal, and inferior nasal conchae bones, and the unpaired vomer and mandible bones.

Q. Identify the major sutures of the skull, their locations, and the bones united by each.

A. The coronal suture passes across the top of the anterior skull. It unites the frontal bone anteriorly with the right and left parietal bones. The sagittal suture runs at the midline on the top of the skull. It unites the right and left parietal bones with each other. The squamous suture is a curved suture located on the lateral side of the skull. It unites the squamous portion of the temporal bone to the parietal bone. The lambdoid suture is located on the posterior skull and has an inverted V-shape. It unites the occipital bone with the right and left parietal bones.

Q. Describe the anterior, middle, and posterior cranial fossae and their boundaries, and give the midline structure that divides each into right and left areas.

A. The anterior cranial fossa is the shallowest of the three cranial fossae. It extends from the frontal bone anteriorly to the lesser wing of the sphenoid bone posteriorly. It is divided at the midline by the crista galli and cribriform plates of the ethmoid bone. The middle cranial fossa is located in the central skull, and is deeper than the anterior fossa. The middle fossa extends from the lesser wing of the sphenoid bone anteriorly to the petrous ridge posteriorly. It is divided at the midline by the sella turcica. The posterior cranial fossa is the deepest fossa. It extends from the petrous ridge anteriorly to the occipital bone posteriorly. The large foramen magnum is located at the midline of the posterior fossa.

Q. Describe the parts of the nasal septum in both the dry and living skull.

A. There are two bony parts of the nasal septum in the dry skull. The perpendicular plate of the ethmoid bone forms the superior part of the septum. The vomer bone forms the inferior and posterior parts of the septum. In the living skull, the septal cartilage completes the septum by filling in the anterior area between the bony components and extending outward into the nose.

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Glossary

alveolar process of the mandible
upper border of mandibular body that contains the lower teeth

alveolar process of the maxilla
curved, inferior margin of the maxilla that supports and anchors the upper teeth

angle of the mandible
rounded corner located at outside margin of the body and ramus junction

anterior cranial fossa
shallowest and most anterior cranial fossa of the cranial base that extends from the frontal bone to the lesser wing of the sphenoid bone

articular tubercle
smooth ridge located on the inferior skull, immediately anterior to the mandibular fossa

brain case
portion of the skull that contains and protects the brain, consisting of the eight bones that form the cranial base and rounded upper skull

calvaria
(also, skullcap) rounded top of the skull

carotid canal
zig-zag tunnel providing passage through the base of the skull for the internal carotid artery to the brain; begins anteromedial to the styloid process and terminates in the middle cranial cavity, near the posterior-lateral base of the sella turcica

condylar process of the mandible
thickened upward projection from posterior margin of mandibular ramus

condyle
oval-shaped process located at the top of the condylar process of the mandible

coronal suture
joint that unites the frontal bone to the right and left parietal bones across the top of the skull

coronoid process of the mandible
flattened upward projection from the anterior margin of the mandibular ramus

cranial cavity
interior space of the skull that houses the brain

cranium
skull

cribriform plate
small, flattened areas with numerous small openings, located to either side of the midline in the floor of the anterior cranial fossa; formed by the ethmoid bone

crista galli
small upward projection located at the midline in the floor of the anterior cranial fossa; formed by the ethmoid bone

ethmoid air cell
one of several small, air-filled spaces located within the lateral sides of the ethmoid bone, between the orbit and upper nasal cavity

ethmoid bone
unpaired bone that forms the roof and upper, lateral walls of the nasal cavity, portions of the floor of the anterior cranial fossa and medial wall of orbit, and the upper portion of the nasal septum

external acoustic meatus
ear canal opening located on the lateral side of the skull

external occipital protuberance

small bump located at the midline on the posterior skull

facial bones
fourteen bones that support the facial structures and form the upper and lower jaws and the hard palate

foramen lacerum
irregular opening in the base of the skull, located inferior to the exit of carotid canal

foramen magnum
large opening in the occipital bone of the skull through which the spinal cord emerges and the vertebral arteries enter the cranium

foramen ovale of the middle cranial fossa
oval-shaped opening in the floor of the middle cranial fossa

foramen rotundum
round opening in the floor of the middle cranial fossa, located between the superior orbital fissure and foramen ovale

foramen spinosum
small opening in the floor of the middle cranial fossa, located lateral to the foramen ovale

frontal bone
unpaired bone that forms forehead, roof of orbit, and floor of anterior cranial fossa

frontal sinus
air-filled space within the frontal bone; most anterior of the paranasal sinuses

glabella
slight depression of frontal bone, located at the midline between the eyebrows

greater wings of sphenoid bone
lateral projections of the sphenoid bone that form the anterior wall of the middle cranial fossa and an area of the lateral skull

hard palate
bony structure that forms the roof of the mouth and floor of the nasal cavity, formed by the palatine process of the maxillary bones and the horizontal plate of the palatine bones

horizontal plate
medial extension from the palatine bone that forms the posterior quarter of the hard palate

hypoglossal canal
paired openings that pass anteriorly from the anterior-lateral margins of the foramen magnum deep to the occipital condyles

hypophyseal (pituitary) fossa
shallow depression on top of the sella turcica that houses the pituitary (hypophyseal) gland

inferior nasal concha
one of the paired bones that project from the lateral walls of the nasal cavity to form the largest and most inferior of the nasal conchae

infraorbital foramen
opening located on anterior skull, below the orbit

infratemporal fossa
space on lateral side of skull, below the level of the zygomatic arch and deep (medial) to the ramus of the mandible

internal acoustic meatus
opening into petrous ridge, located on the lateral wall of the posterior cranial fossa

jugular foramen
irregularly shaped opening located in the lateral floor of the posterior cranial cavity

lacrimal bone
paired bones that contribute to the anterior-medial wall of each orbit

lacrimal fossa
shallow depression in the anterior-medial wall of the orbit, formed by the lacrimal bone that gives rise to the nasolacrimal canal

lambdoid suture
inverted V-shaped joint that unites the occipital bone to the right and left parietal bones on the posterior skull

lateral pterygoid plate
paired, flattened bony projections of the sphenoid bone located on the inferior skull, lateral to the medial pterygoid plate

lesser wings of the sphenoid bone
lateral extensions of the sphenoid bone that form the bony lip separating the anterior and middle cranial fossae

lingula
small flap of bone located on the inner (medial) surface of mandibular ramus, next to the mandibular foramen

mandible
unpaired bone that forms the lower jaw bone; the only moveable bone of the skull

mandibular foramen
opening located on the inner (medial) surface of the mandibular ramus

mandibular fossa
oval depression located on the inferior surface of the skull

mandibular notch
large U-shaped notch located between the condylar process and coronoid process of the mandible

mastoid process
large bony prominence on the inferior, lateral skull, just behind the earlobe

maxillary bone
(also, maxilla) paired bones that form the upper jaw and anterior portion of the hard palate

maxillary sinus
air-filled space located with each maxillary bone; largest of the paranasal sinuses

medial pterygoid plate
paired, flattened bony projections of the sphenoid bone located on the inferior skull medial to the lateral pterygoid plate; form the posterior portion of the nasal cavity lateral wall

mental foramen
opening located on the anterior-lateral side of the mandibular body

mental protuberance
inferior margin of anterior mandible that forms the chin

middle cranial fossa
centrally located cranial fossa that extends from the lesser wings of the sphenoid bone to the petrous ridge

middle nasal concha
nasal concha formed by the ethmoid bone that is located between the superior and inferior conchae

mylohyoid line
bony ridge located along the inner (medial) surface of the mandibular body

nasal bone
paired bones that form the base of the nose

nasal cavity
opening through skull for passage of air

nasal conchae

curved bony plates that project from the lateral walls of the nasal cavity; include the superior and middle nasal conchae, which are parts of the ethmoid bone, and the independent inferior nasal conchae bone

nasal septum
flat, midline structure that divides the nasal cavity into halves, formed by the perpendicular plate of the ethmoid bone, vomer bone, and septal cartilage

nasolacrimal canal
passage for drainage of tears that extends downward from the medial-anterior orbit to the nasal cavity, terminating behind the inferior nasal conchae

occipital bone
unpaired bone that forms the posterior portions of the brain case and base of the skull

occipital condyle
paired, oval-shaped bony knobs located on the inferior skull, to either side of the foramen magnum

optic canal
opening spanning between middle cranial fossa and posterior orbit

orbit
bony socket that contains the eyeball and associated muscles

palatine bone
paired bones that form the posterior quarter of the hard palate and a small area in floor of the orbit

palatine process
medial projection from the maxilla bone that forms the anterior three quarters of the hard palate

paranasal sinuses
cavities within the skull that are connected to the conchae that serve to warm and humidify incoming air, produce mucus, and lighten the weight of the skull; consist of frontal, maxillary, sphenoidal, and ethmoidal sinuses

parietal bone
paired bones that form the upper, lateral sides of the skull

perpendicular plate of the ethmoid bone
downward, midline extension of the ethmoid bone that forms the superior portion of the nasal septum

petrous ridge
petrous portion of the temporal bone that forms a large, triangular ridge in the floor of the cranial cavity, separating the middle and posterior cranial fossae; houses the middle and inner ear structures

posterior cranial fossa
deepest and most posterior cranial fossa; extends from the petrous ridge to the occipital bone

pterion
H-shaped suture junction region that unites the frontal, parietal, temporal, and sphenoid bones on the lateral side of the skull

ramus of the mandible
vertical portion of the mandible

sagittal suture
joint that unites the right and left parietal bones at the midline along the top of the skull

sella turcica
elevated area of sphenoid bone located at midline of the middle cranial fossa

septal cartilage
flat cartilage structure that forms the anterior portion of the nasal septum

sphenoid bone

unpaired bone that forms the central base of skull

sphenoid sinus
air-filled space located within the sphenoid bone; most posterior of the paranasal sinuses

squamous suture
joint that unites the parietal bone to the squamous portion of the temporal bone on the lateral side of the skull

styloid process
downward projecting, elongated bony process located on the inferior aspect of the skull

stylomastoid foramen
opening located on inferior skull, between the styloid process and mastoid process

superior nasal concha
smallest and most superiorly located of the nasal conchae; formed by the ethmoid bone

superior nuchal line
paired bony lines on the posterior skull that extend laterally from the external occipital protuberance

superior orbital fissure
irregularly shaped opening between the middle cranial fossa and the posterior orbit

supraorbital foramen
opening located on anterior skull, at the superior margin of the orbit

supraorbital margin
superior margin of the orbit

suture
junction line at which adjacent bones of the skull are united by fibrous connective tissue

temporal bone
paired bones that form the lateral, inferior portions of the skull, with squamous, mastoid, and petrous portions

temporal fossa
shallow space on the lateral side of the skull, above the level of the zygomatic arch

temporal process of the zygomatic bone
short extension from the zygomatic bone that forms the anterior portion of the zygomatic arch

vomer bone
unpaired bone that forms the inferior and posterior portions of the nasal septum

zygomatic arch
elongated, free-standing arch on the lateral skull, formed anteriorly by the temporal process of the zygomatic bone and posteriorly by the zygomatic process of the temporal bone

zygomatic bone
cheekbone; paired bones that contribute to the lateral orbit and anterior zygomatic arch

zygomatic process of the temporal bone
extension from the temporal bone that forms the posterior portion of the zygomatic arch

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4.2: The Vertebral Column

Learning Objectives

- Describe each region of the vertebral column and the number of bones in each region
- Discuss the curves of the vertebral column and how these change after birth
- Describe a typical vertebra and determine the distinguishing characteristics for vertebrae in each vertebral region and features of the sacrum and the coccyx
- Define the structure of an intervertebral disc
- Determine the location of the ligaments that provide support for the vertebral column

The vertebral column is also known as the spinal column or spine (Figure 4.2.1). It consists of a sequence of vertebrae (singular = vertebra), each of which is separated and united by an **intervertebral disc**. Together, the vertebrae and intervertebral discs form the vertebral column. It is a flexible column that supports the head, neck, and body and allows for their movements. It also protects the spinal cord, which passes down the back through openings in the vertebrae.

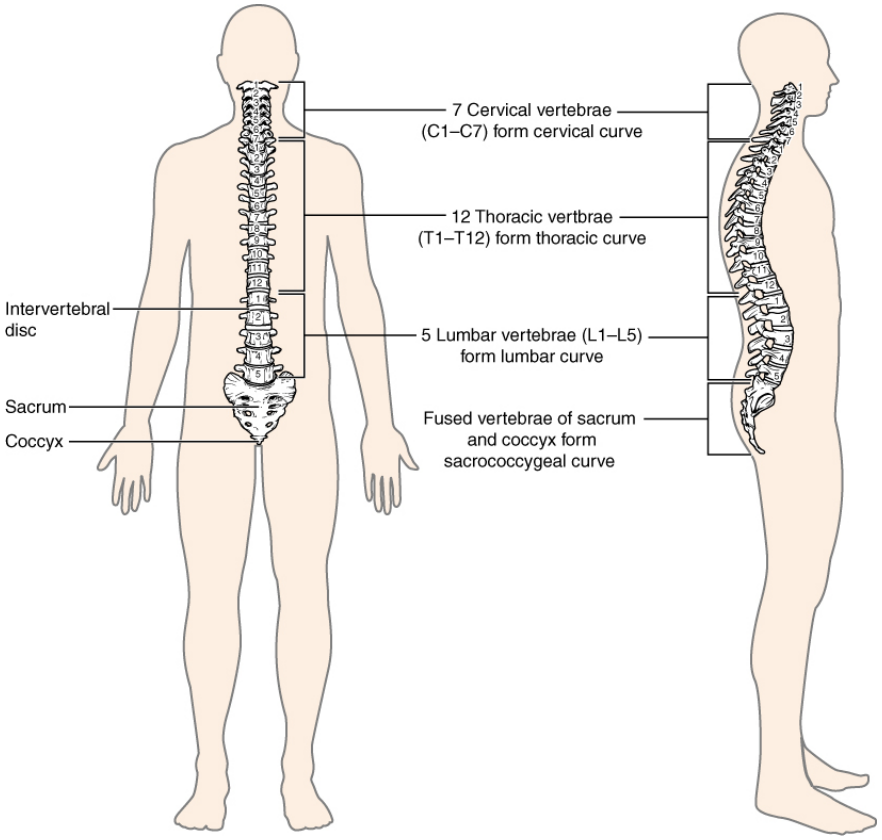


***Figure** 4.2.1**: Vertebral Column.** The adult vertebral column consists of 24 vertebrae, plus the sacrum and coccyx. The vertebrae are divided into three regions: cervical C1–C7 vertebrae, thoracic T1–T12 vertebrae, and lumbar L1–L5 vertebrae. The vertebral column is curved, with two primary curvatures (thoracic and sacrococcygeal curves) and two secondary curvatures (cervical and lumbar curves).*

Regions of the Vertebral Column

The vertebral column originally develops as a series of 33 vertebrae, but this number is eventually reduced to 24 vertebrae, plus the sacrum and coccyx. The vertebral column is subdivided into five regions, with the vertebrae in each area named for that region and numbered in descending order. In the neck, there are seven cervical vertebrae, each designated with the letter “C” followed by its number. Superiorly, the C1 vertebra articulates (forms a joint) with the occipital condyles of the skull. Inferiorly, C1 articulates with the C2 vertebra, and so on. Below these are the 12 thoracic vertebrae, designated T1–T12. The lower back contains the L1–L5 lumbar vertebrae. The single sacrum, which is also part of the pelvis, is formed by the fusion of five sacral vertebrae. Similarly, the coccyx, or tailbone, results from the fusion of four small coccygeal vertebrae. However, the sacral and coccygeal fusions do not start until age 20 and are not completed until middle age.

An interesting anatomical fact is that almost all mammals have seven cervical vertebrae, regardless of body size. This means that there are large variations in the size of cervical vertebrae, ranging from the very small cervical vertebrae of a shrew to the greatly elongated vertebrae in the neck of a giraffe. In a full-grown giraffe, each cervical vertebra is 11 inches tall.

Curvatures of the Vertebral Column

The adult vertebral column does not form a straight line, but instead has four curvatures along its length (see Figure 4.2.1). These curves increase the vertebral column's strength, flexibility, and ability to absorb shock. When the load on the spine is increased, by carrying a heavy backpack for example, the curvatures increase in depth (become more curved) to accommodate the extra weight. They then spring back when the weight is removed. The four adult curvatures are classified as either primary or secondary curvatures. Primary curves are retained from the original fetal curvature, while secondary curvatures develop after birth.

During fetal development, the body is flexed anteriorly into the fetal position, giving the entire vertebral column a single curvature that is concave anteriorly. In the adult, this fetal curvature is retained in two regions of the vertebral column as the **thoracic curve**, which involves the thoracic vertebrae, and the **sacrococcygeal curve**, formed by the sacrum and coccyx. Each of these is thus called a **primary curve** because they are retained from the original fetal curvature of the vertebral column.

A **secondary curve** develops gradually after birth as the child learns to sit upright, stand, and walk. Secondary curves are concave posteriorly, opposite in direction to the original fetal curvature. The **cervical curve** of the neck region develops as the infant begins to hold their head upright when sitting. Later, as the child begins to stand and then to walk, the **lumbar curve** of the lower back develops. In adults, the lumbar curve is generally deeper in females.

Disorders associated with the curvature of the spine include **kyphosis** (an excessive posterior curvature of the thoracic region), **lordosis** (an excessive anterior curvature of the lumbar region), and **scoliosis** (an abnormal, lateral curvature, accompanied by twisting of the vertebral column).

DISORDERS OF THE...Vertebral Column

Developmental anomalies, pathological changes, or obesity can enhance the normal vertebral column curves, resulting in the development of abnormal or excessive curvatures (Figure 4.2.2). Kyphosis, also referred to as humpback or hunchback, is an excessive posterior curvature of the thoracic region. This can develop when osteoporosis causes weakening and erosion of the anterior portions of the upper thoracic vertebrae, resulting in their gradual collapse (Figure 4.2.3). Lordosis, or swayback, is an excessive anterior curvature of the lumbar region and is most commonly associated with obesity or late pregnancy. The accumulation of body weight in the abdominal region results an anterior shift in the line of gravity that carries the weight of the body. This causes in an anterior tilt of the pelvis and a pronounced enhancement of the lumbar curve.

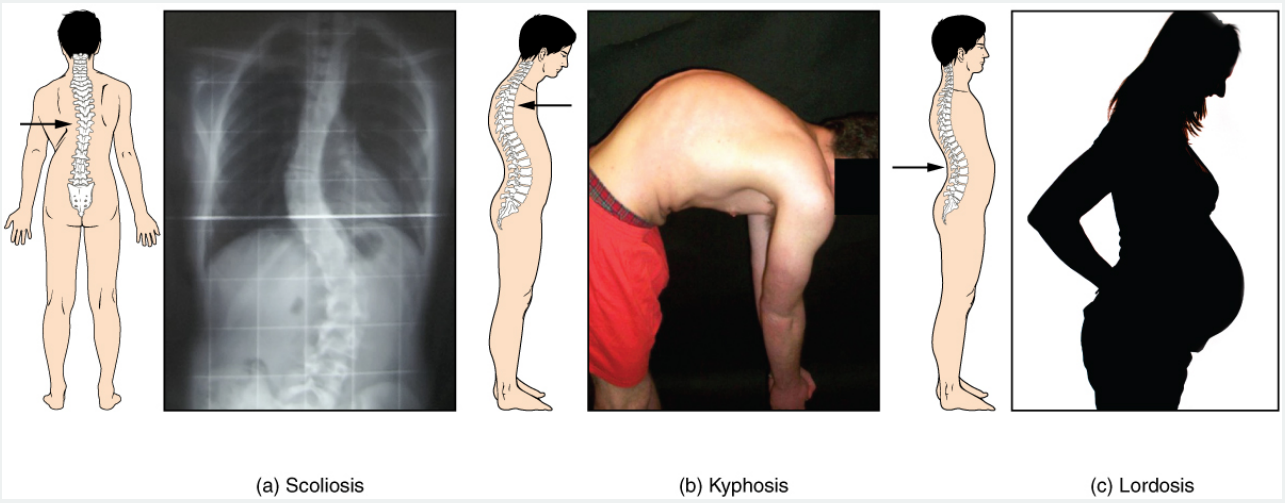


***Figure** 4.2.2**: Abnormal Curvatures of the Vertebral Column.** (a) Scoliosis is an abnormal lateral bending of the vertebral column. (b) An excessive curvature of the upper thoracic vertebral column is called kyphosis. (c) Lordosis is an excessive curvature in the lumbar region of the vertebral column.*

Scoliosis is an abnormal, lateral curvature, accompanied by twisting of the vertebral column. Compensatory curves may also develop in other areas of the vertebral column to help maintain the head positioned over the feet. Scoliosis is the most common vertebral abnormality among girls. The cause is usually unknown, but it may result from weakness of the back muscles, defects such as differential growth rates in the right and left sides of the vertebral column, or differences in the length of the lower limbs. When present, scoliosis tends to get worse during adolescent growth spurts. Although most individuals do not require treatment, a back brace may be recommended for growing children. In extreme cases, surgery may be required.

Excessive vertebral curves can be identified while an individual stands in the anatomical position. Observe the vertebral profile from the side and then from behind to check for kyphosis or lordosis. Then have the person bend forward. If scoliosis is present, an individual will have difficulty in bending directly forward, and the right and left sides of the back will not be level with each other in the bent position.

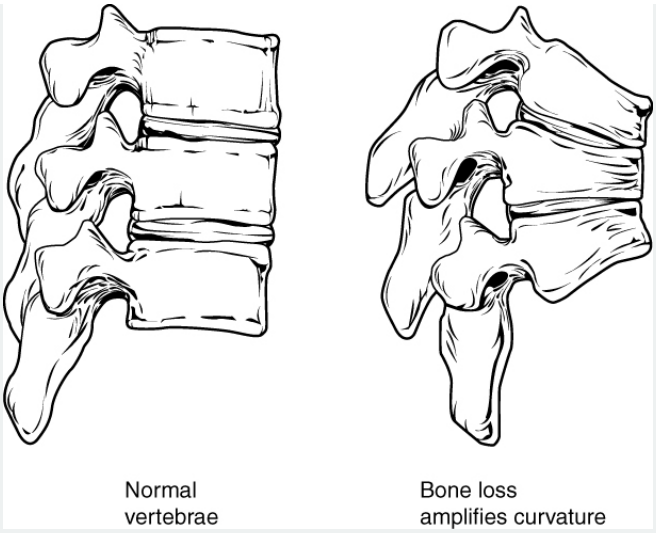


Figure 4.2.3***: Osteoporosis.*** *Osteoporosis is an age-related disorder that causes the gradual loss of bone density and strength. When the thoracic vertebrae are affected, there can be a gradual collapse of the vertebrae. This results in kyphosis, an excessive curvature of the thoracic region.*

Osteoporosis is a common age-related bone disease in which bone density and strength is decreased. Watch this video to get a better understanding of how thoracic vertebrae may become weakened and may fracture due to this disease. How may vertebral osteoporosis contribute to kyphosis?

General Structure of a Vertebra

Within the different regions of the vertebral column, vertebrae vary in size and shape, but they all follow a similar structural pattern. A typical vertebra will consist of a body, a vertebral arch, and seven processes (Figure 4.2.4). The body is the anterior portion of each vertebra and is the part that supports the body weight. Because of this, the vertebral bodies progressively increase in size and thickness going down the vertebral column. The bodies of adjacent vertebrae are separated and strongly united by an intervertebral disc.

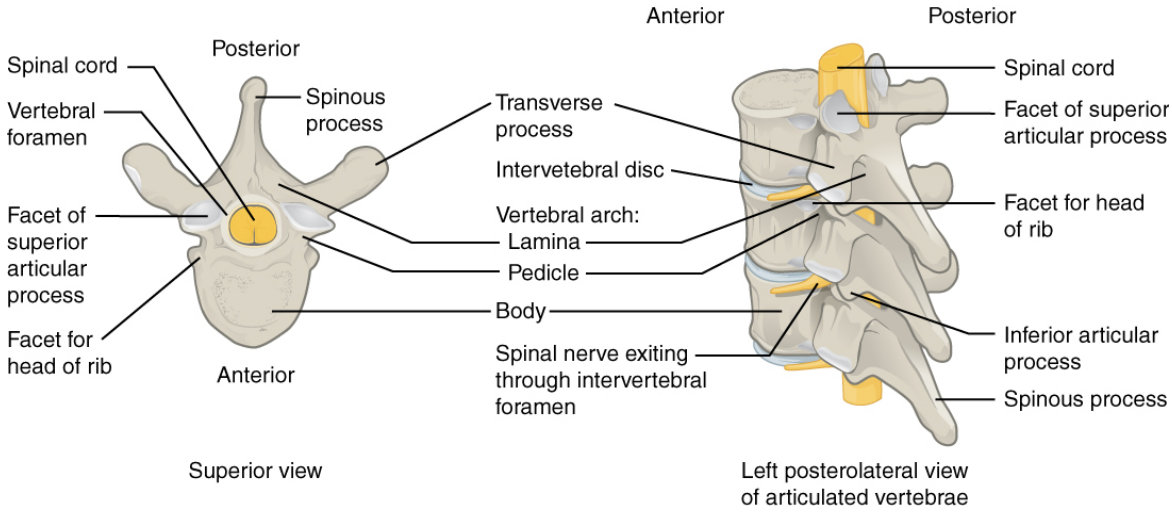


Figure 4.2.4***: Parts of a Typical Vertebra.*** *A typical vertebra consists of a body and a vertebral arch. The arch is formed by the paired pedicles and paired laminae. Arising from the vertebral arch are the transverse, spinous, superior articular, and inferior articular processes. The vertebral foramen provides for passage of the spinal cord. Each spinal nerve exits through an intervertebral foramen, located between adjacent vertebrae. Intervertebral discs unite the bodies of adjacent vertebrae.*

The **vertebral arch** forms the posterior portion of each vertebra. It consists of four parts, the right and left pedicles and the right and left laminae. Each **pedicle** forms one of the lateral sides of the vertebral arch. The pedicles are anchored to the posterior side of the vertebral body. Each **lamina** forms part of the posterior roof of the vertebral arch. The large opening between the vertebral arch and body is the **vertebral foramen**, which contains the spinal cord. In the intact vertebral column, the vertebral foramina of all of the vertebrae align to form the **vertebral (spinal) canal**, which serves as the bony protection and passageway for the spinal cord down the back. When the vertebrae are aligned together in the vertebral column, notches in the margins of the pedicles of adjacent vertebrae together form an **intervertebral foramen**, the opening through which a spinal nerve exits from the vertebral column (Figure 4.2.5).

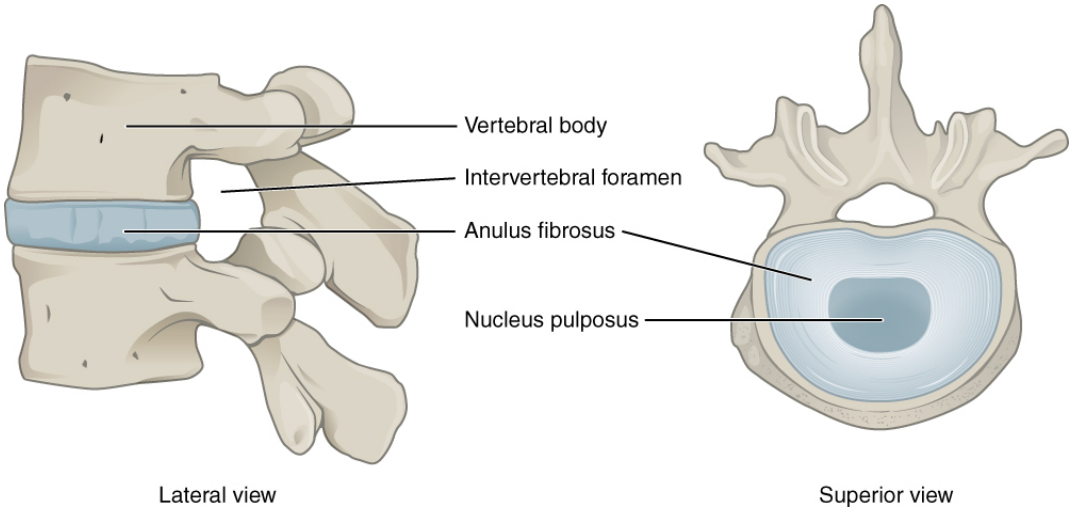


Figure 4.2.5: Intervertebral Disc. The bodies of adjacent vertebrae are separated and united by an intervertebral disc, which provides padding and allows for movements between adjacent vertebrae. The disc consists of a fibrous outer layer called the anulus fibrosus and a gel-like center called the nucleus pulposus. The intervertebral foramen is the opening formed between adjacent vertebrae for the exit of a spinal nerve.

Seven processes arise from the vertebral arch. Each paired **transverse process** projects laterally and arises from the junction point between the pedicle and lamina. The single **spinous process** (vertebral spine) projects posteriorly at the midline of the back. The vertebral spines can easily be felt as a series of bumps just under the skin down the middle of the back. The transverse and spinous processes serve as important muscle attachment sites. A **superior articular process** extends or faces upward, and an **inferior articular process** faces or projects downward on each side of a vertebrae. The paired superior articular processes of one vertebra join with the corresponding paired inferior articular processes from the next higher vertebra. These junctions form slightly moveable joints between the adjacent vertebrae. The shape and orientation of the articular processes vary in different regions of the vertebral column and play a major role in determining the type and range of motion available in each region.

Regional Modifications of Vertebrae

In addition to the general characteristics of a typical vertebra described above, vertebrae also display characteristic size and structural features that vary between the different vertebral column regions. Thus, cervical vertebrae are smaller than lumbar vertebrae due to differences in the proportion of body weight that each supports. Thoracic vertebrae have sites for rib attachment, and the vertebrae that give rise to the sacrum and coccyx have fused together into single bones.

Cervical Vertebrae

Typical **cervical vertebrae**, such as C4 or C5, have several characteristic features that differentiate them from thoracic or lumbar vertebrae (Figure 4.2.6). Cervical vertebrae have a small body, reflecting the fact that they carry the least amount of body weight. Cervical vertebrae usually have a bifid (Y-shaped) spinous process. The spinous processes of the C3–C6 vertebrae are short, but the spine of C7 is much longer. You can find these vertebrae by running your finger down the midline of the posterior neck until you encounter the prominent C7 spine located at the base of the neck. The transverse processes of the cervical vertebrae are sharply curved (U-shaped) to allow for passage of the cervical spinal nerves. Each transverse process also has an opening called the **transverse foramen**. An important artery that supplies the brain ascends up the neck by passing through these openings. The superior and inferior articular processes of the cervical vertebrae are flattened and largely face upward or downward, respectively.

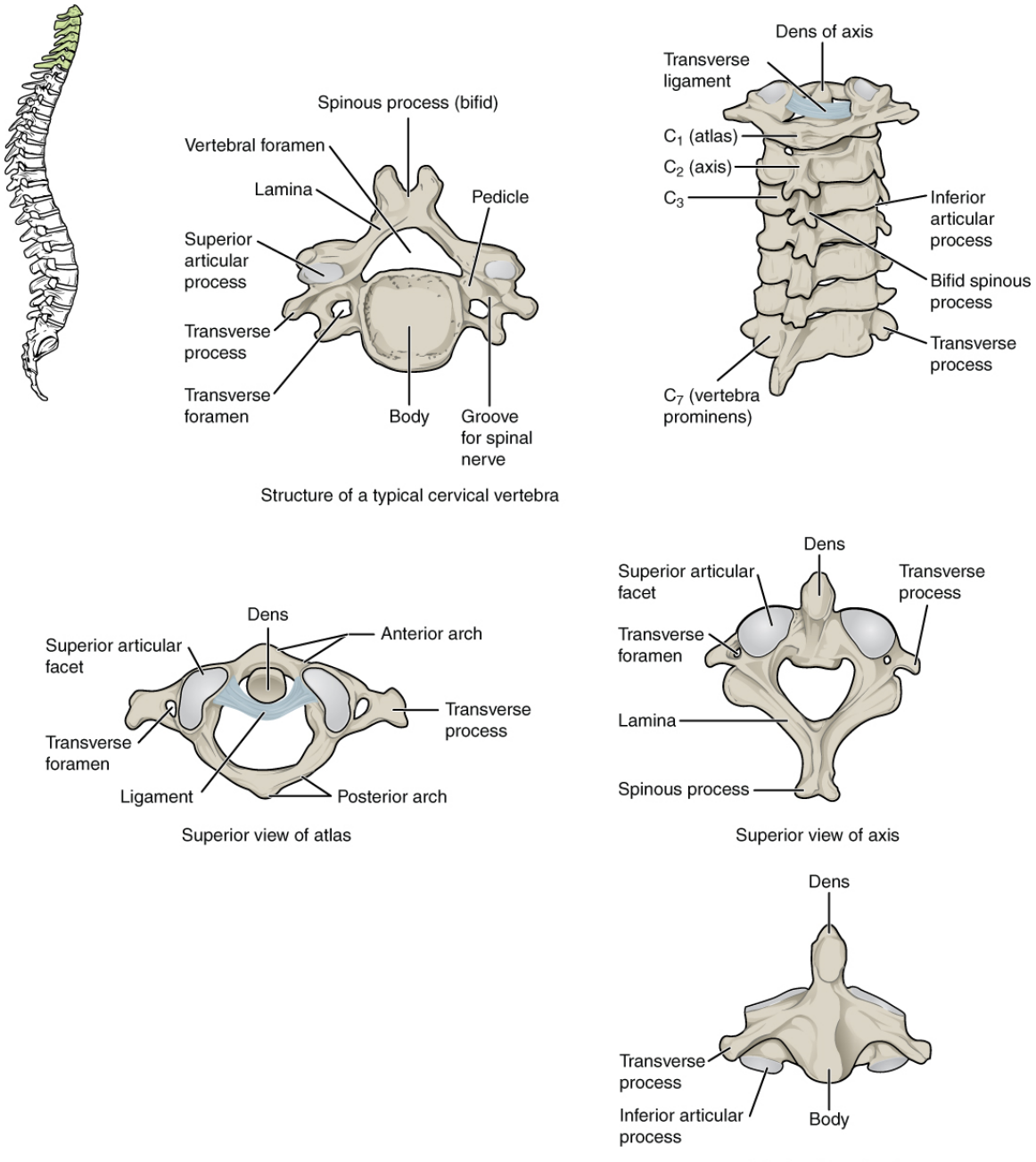


Figure 4.2.6: Cervical Vertebrae. A typical cervical vertebra has a small body, a bifid spinous process, transverse processes that have a transverse foramen and are curved for spinal nerve passage. The atlas (C1 vertebra) does not have a body or spinous process. It consists of an anterior and a posterior arch and elongated transverse processes. The axis (C2 vertebra) has the upward projecting dens, which articulates with the anterior arch of the atlas.

The first and second cervical vertebrae are further modified, giving each a distinctive appearance. The first cervical (C1) vertebra is also called the **atlas**, because this is the vertebra that supports the skull on top of the vertebral column (in Greek mythology, Atlas was the god who supported the heavens on his shoulders). The C1 vertebra does not have a body or spinous process. Instead, it is ring-shaped, consisting of an **anterior arch** and a **posterior arch**. The transverse processes of the atlas are longer and extend more laterally than do the transverse processes of any other cervical vertebrae. The superior articular processes face upward and are deeply curved for articulation with the occipital condyles on the base of the skull. The inferior articular processes are flat and face downward to join with the superior articular processes of the C2 vertebra.

The second cervical (C2) vertebra is called the **axis**, because it serves as the axis for rotation when turning the head toward the right or left. The axis resembles typical cervical vertebrae in most respects, but is easily distinguished by the **dens** (odontoid process), a bony projection that extends upward from the vertebral body. The dens joins with the inner aspect of the anterior arch of the atlas, where it is held in place by transverse ligament.

Thoracic Vertebrae

The bodies of the **thoracic vertebrae** are larger than those of cervical vertebrae (Figure 4.2.7). The characteristic feature for a typical midthoracic vertebra is the spinous process, which is long and has a pronounced downward angle that causes it to overlap the next inferior vertebra. The superior articular processes of thoracic vertebrae face anteriorly and the inferior processes face posteriorly. These orientations are important determinants for the type and range of movements available to the thoracic region of the vertebral column.

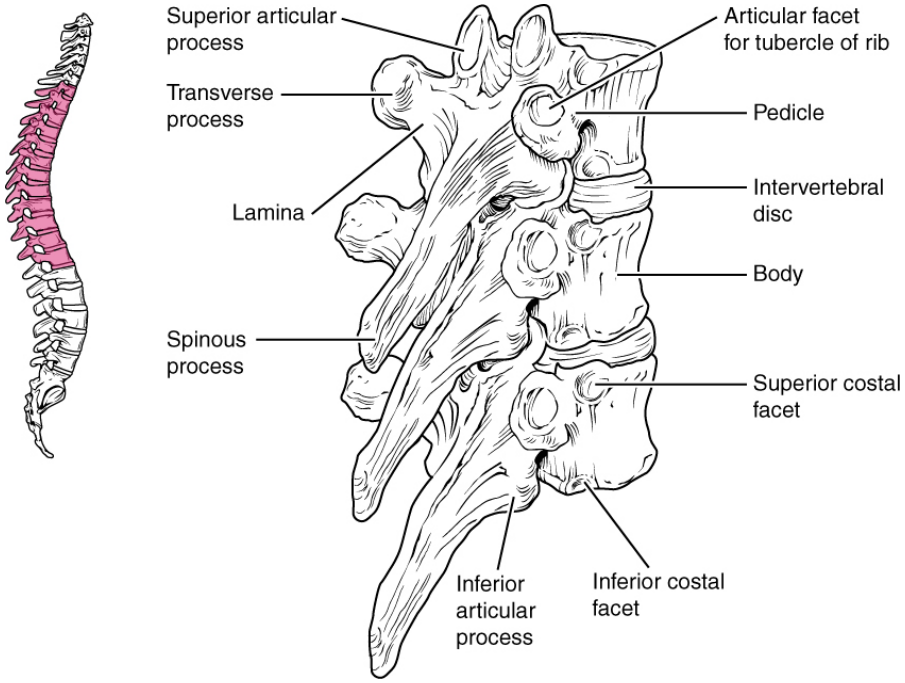


Figure 4.2.7: Thoracic Vertebrae. A typical thoracic vertebra is distinguished by the spinous process, which is long and projects downward to overlap the next inferior vertebra. It also has articulation sites (facets) on the vertebral body and a transverse process for rib attachment.

Thoracic vertebrae have several additional articulation sites, each of which is called a **facet**, where a rib is attached. Most thoracic vertebrae have two facets located on the lateral sides of the body, each of which is called a **costal facet**(costal = "rib"). These are for articulation with the head (end) of a rib. An additional facet is located on the transverse process for articulation with the tubercle of a rib.

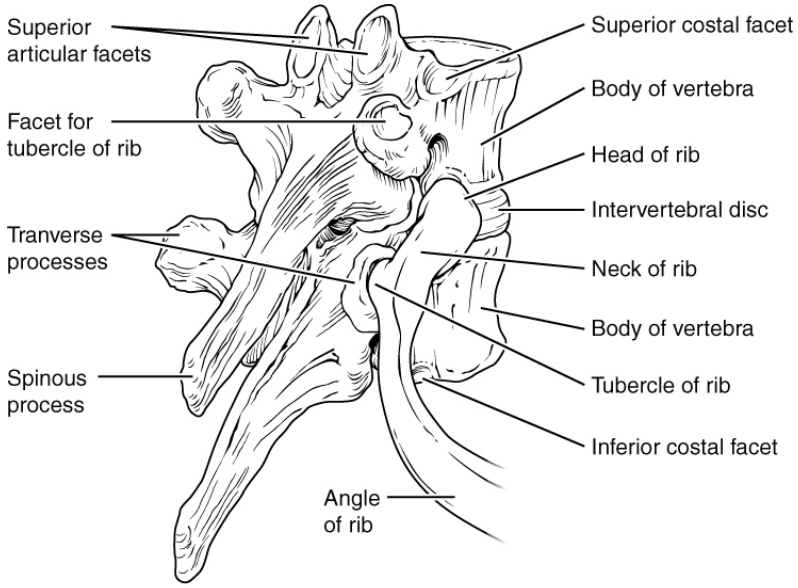


Figure 4.2.8: Rib Articulation in Thoracic Vertebrae. Thoracic vertebrae have superior and inferior articular facets on the vertebral body for articulation with the head of a rib, and a transverse process facet for articulation with the rib tubercle.

Lumbar Vertebrae

Lumbar vertebrae carry the greatest amount of body weight and are thus characterized by the large size and thickness of the vertebral body (Figure 4.2.9). They have short transverse processes and a short, blunt spinous process that projects posteriorly. The articular processes are large, with the

superior process facing backward and the inferior facing forward.

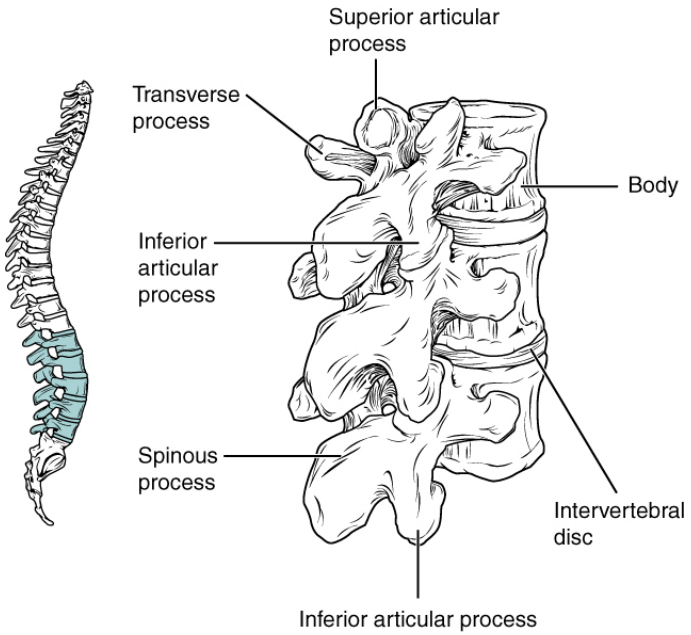


Figure 4.2.9: Lumbar Vertebrae. Lumbar vertebrae are characterized by having a large, thick body and a short, rounded spinous process.

Sacrum and Coccyx

The sacrum is a triangular-shaped bone that is thick and wide across its superior base where it is weight bearing and then tapers down to an inferior, non-weight bearing apex (Figure 4.2.10). It is formed by the fusion of five sacral vertebrae, a process that does not begin until after the age of 20. On the anterior surface of the older adult sacrum, the lines of vertebral fusion can be seen as four transverse ridges. On the posterior surface, running down the midline, is the **median sacral crest**, a bumpy ridge that is the remnant of the fused spinous processes (median = "midline"; while medial = "toward, but not necessarily at, the midline"). Similarly, the fused transverse processes of the sacral vertebrae form the **lateral sacral crest**.

The **sacral promontory** is the anterior lip of the superior base of the sacrum. Lateral to this is the roughened auricular surface, which joins with the ilium portion of the hipbone to form the immobile sacroiliac joints of the pelvis. Passing inferiorly through the sacrum is a bony tunnel called the **sacral canal**, which terminates at the **sacral hiatus** near the inferior tip of the sacrum. The anterior and posterior surfaces of the sacrum have a series of paired openings called **sacral foramina** (singular = foramen) that connect to the sacral canal. Each of these openings is called a **posterior (dorsal) sacral foramen** or **anterior (ventral) sacral foramen**. These openings allow for the anterior and posterior branches of the sacral spinal nerves to exit the sacrum. The **superior articular process of the sacrum**, one of which is found on either side of the superior opening of the sacral canal, articulates with the inferior articular processes from the L5 vertebra.

The coccyx, or tailbone, is derived from the fusion of four very small coccygeal vertebrae (see Figure 4.2.10). It articulates with the inferior tip of the sacrum. It is not weight bearing in the standing position, but may receive some body weight when sitting.

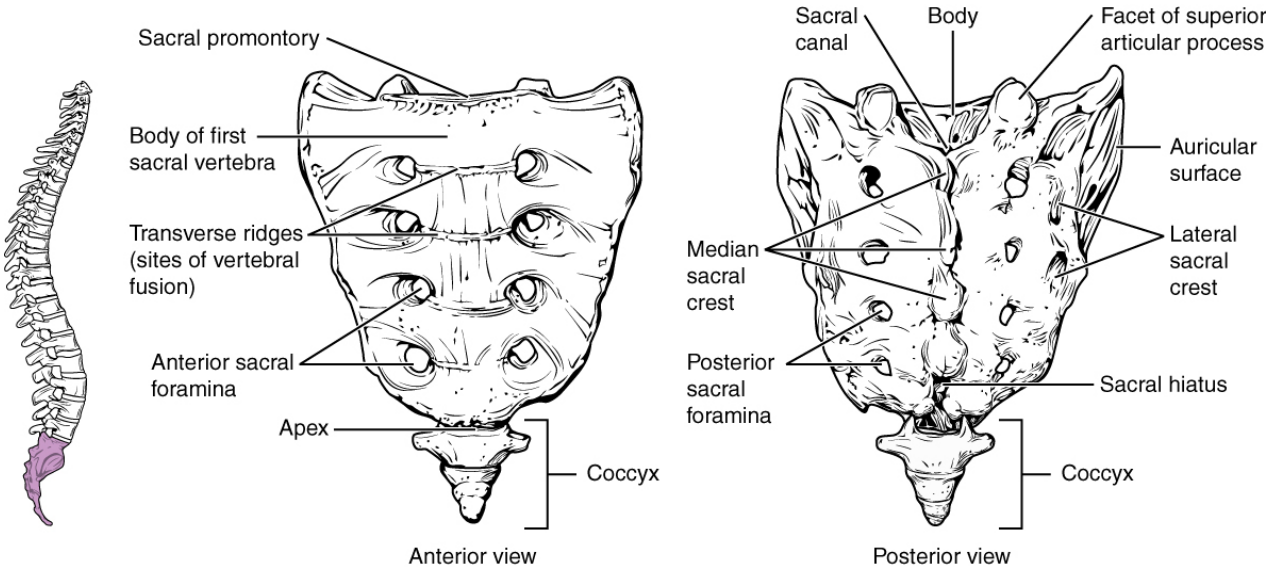


***Figure** 4.2.10**: Sacrum and Coccyx.** The sacrum is formed from the fusion of five sacral vertebrae, whose lines of fusion are indicated by the transverse ridges. The fused spinous processes form the median sacral crest, while the lateral sacral crest arises from the fused transverse processes. The coccyx is formed by the fusion of four small coccygeal vertebrae.*

Intervertebral Discs and Ligaments of the Vertebral Column

The bodies of adjacent vertebrae are strongly anchored to each other by an intervertebral disc. This structure provides padding between the bones during weight bearing, and because it can change shape, also allows for movement between the vertebrae. Although the total amount of movement available between any two adjacent vertebrae is small, when these movements are summed together along the entire length of the vertebral column, large body movements can be produced. Ligaments that extend along the length of the vertebral column also contribute to its overall support and stability.

Intervertebral Disc

An **intervertebral disc** is a fibrocartilaginous pad that fills the gap between adjacent vertebral bodies (see Figure 4.2.5). Each disc is anchored to the bodies of its adjacent vertebrae, thus strongly uniting these. The discs also provide padding between vertebrae during weight bearing. Because of this, intervertebral discs are thin in the cervical region and thickest in the lumbar region, which carries the most body weight. In total, the intervertebral discs account for approximately 25 percent of your body height between the top of the pelvis and the base of the skull. Intervertebral discs are also flexible and can change shape to allow for movements of the vertebral column.

Each intervertebral disc consists of two parts. The **anulus fibrosus** is the tough, fibrous outer layer of the disc. It forms a circle (anulus = “ring” or “circle”) and is firmly anchored to the outer margins of the adjacent vertebral bodies. Inside is the **nucleus pulposus**, consisting of a softer, more gel-like material. It has a high water content that serves to resist compression and thus is important for weight bearing. With increasing age, the water content of the nucleus pulposus gradually declines. This causes the disc to become thinner, decreasing total body height somewhat, and reduces the flexibility and range of motion of the disc, making bending more difficult.

The gel-like nature of the nucleus pulposus also allows the intervertebral disc to change shape as one vertebra rocks side to side or forward and back in relation to its neighbors during movements of the vertebral column. Thus, bending forward causes compression of the anterior portion of the disc but expansion of the posterior disc. If the posterior anulus fibrosus is weakened due to injury or increasing age, the pressure exerted on the disc when bending forward and lifting a heavy object can cause the nucleus pulposus to protrude posteriorly through the anulus fibrosus, resulting in a herniated disc (“ruptured” or “slipped” disc) (Figure 4.2.11). The posterior bulging of the nucleus pulposus can cause compression of a spinal nerve at the point where it exits through the intervertebral foramen, with resulting pain and/or muscle weakness in those body regions supplied by that nerve. The most common sites for disc herniation are the L4/L5 or L5/S1 intervertebral discs, which can cause sciatica, a widespread pain that radiates from the lower back down the thigh and into the leg. Similar injuries of the C5/C6 or C6/C7 intervertebral discs, following forcible hyperflexion of the neck from a collision accident or football injury, can produce pain in the neck, shoulder, and upper limb.

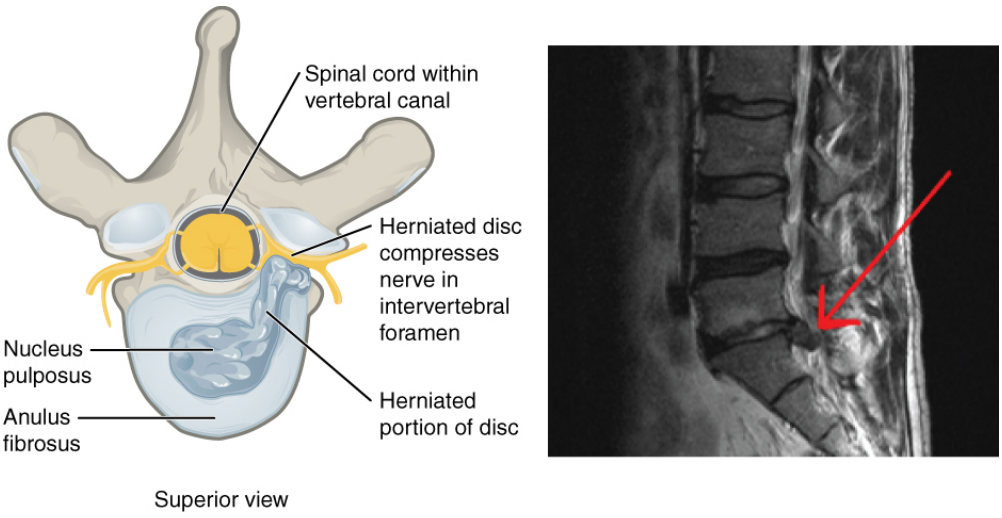


***Figure** 4.2.11**: Herniated Intervertebral Disc.** Weakening of the anulus fibrosus can result in herniation (protrusion) of the nucleus pulposus and compression of a spinal nerve, resulting in pain and/or muscle weakness in the body regions supplied by that nerve.*

Note

Watch this animation to see what it means to “slip” a disk. Watch this second animation to see one possible treatment for a herniated disc, removing and replacing the damaged disc with an artificial one that allows for movement between the adjacent certebrae. How could lifting a heavy object produce pain in a lower limb?

Ligaments of the Vertebral Column

Adjacent vertebrae are united by ligaments that run the length of the vertebral column along both its posterior and anterior aspects (Figure 4.2.12). These serve to resist excess forward or backward bending movements of the vertebral column, respectively.

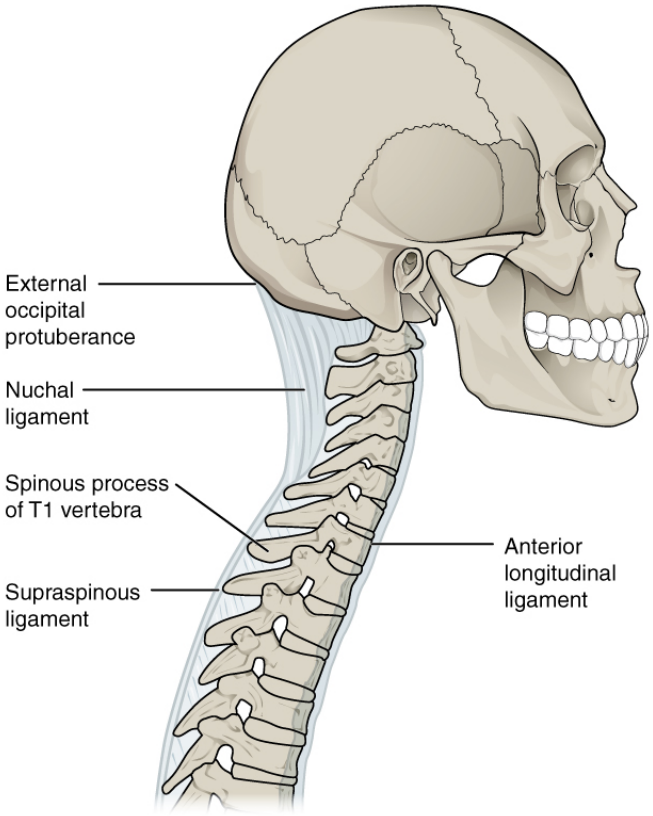


Figure 4.2.12: Ligaments of Vertebral Column. The anterior longitudinal ligament runs the length of the vertebral column, uniting the anterior sides of the vertebral bodies. The supraspinous ligament connects the spinous processes of the thoracic and lumbar vertebrae. In the posterior neck, the supraspinous ligament enlarges to form the nuchal ligament, which attaches to the cervical spinous processes and to the base of the skull.

The **anterior longitudinal ligament** runs down the anterior side of the entire vertebral column, uniting the vertebral bodies. It serves to resist excess backward bending of the vertebral column. Protection against this movement is particularly important in the neck, where extreme posterior bending of the head and neck can stretch or tear this ligament, resulting in a painful whiplash injury. Prior to the mandatory installation of seat headrests, whiplash injuries were common for passengers involved in a rear-end automobile collision.

The **supraspinous ligament** is located on the posterior side of the vertebral column, where it interconnects the spinous processes of the thoracic and lumbar vertebrae. This strong ligament supports the vertebral column during forward bending motions. In the posterior neck, where the cervical spinous processes are short, the supraspinous ligament expands to become the **nuchal ligament** (nuchae = “nape” or “back of the neck”). The nuchal ligament is attached to the cervical spinous processes and extends upward and posteriorly to attach to the midline base of the skull, out to the external occipital protuberance. It supports the skull and prevents it from falling forward. This ligament is much larger and stronger in four-legged animals such as cows, where the large skull hangs off the front end of the vertebral column. You can easily feel this ligament by first extending your head backward and pressing down on the posterior midline of your neck. Then tilt your head forward and you will fill the nuchal ligament popping out as it tightens to limit anterior bending of the head and neck.

Additional ligaments are located inside the vertebral canal, next to the spinal cord, along the length of the vertebral column. The **posterior longitudinal ligament** is found anterior to the spinal cord, where it is attached to the posterior sides of the vertebral bodies. Posterior to the spinal cord is the **ligamentum flavum** (“yellow ligament”). This consists of a series of short, paired ligaments, each of which interconnects the lamina regions of adjacent vertebrae. The ligamentum flavum has large numbers of elastic fibers, which have a yellowish color, allowing it to stretch and then pull back. Both of these ligaments provide important support for the vertebral column when bending forward.

Use this tool to identify the bones, intervertebral discs, and ligaments of the vertebral column. The thickest portions of the anterior longitudinal ligament and the supraspinous ligament are found in which regions of the vertebral column?

CAREER CONNECTIONS: Chiropractor

Chiropractors are health professionals who use nonsurgical techniques to help patients with musculoskeletal system problems that involve the bones, muscles, ligaments, tendons, or nervous system. They treat problems such as neck pain, back pain, joint pain, or headaches.

Chiropractors focus on the patient's overall health and can also provide counseling related to lifestyle issues, such as diet, exercise, or sleep problems. If needed, they will refer the patient to other medical specialists.

Chiropractors use a drug-free, hands-on approach for patient diagnosis and treatment. They will perform a physical exam, assess the patient's posture and spine, and may perform additional diagnostic tests, including taking X-ray images. They primarily use manual techniques, such as spinal manipulation, to adjust the patient's spine or other joints. They can recommend therapeutic or rehabilitative exercises, and some also include acupuncture, massage therapy, or ultrasound as part of the treatment program. In addition to those in general practice, some chiropractors specialize in sport injuries, neurology, orthopaedics, pediatrics, nutrition, internal disorders, or diagnostic imaging.

To become a chiropractor, students must have 3–4 years of undergraduate education, attend an accredited, four-year Doctor of Chiropractic (D.C.) degree program, and pass a licensure examination to be licensed for practice in their state. With the aging of the baby-boom generation, employment for chiropractors is expected to increase.

Chapter Review

The vertebral column forms the neck and back. The vertebral column originally develops as 33 vertebrae, but is eventually reduced to 24 vertebrae, plus the sacrum and coccyx. The vertebrae are divided into the cervical region (C1–C7 vertebrae), the thoracic region (T1–T12 vertebrae), and the lumbar region (L1–L5 vertebrae). The sacrum arises from the fusion of five sacral vertebrae and the coccyx from the fusion of four small coccygeal vertebrae. The vertebral column has four curvatures, the cervical, thoracic, lumbar, and sacrococcygeal curves. The thoracic and sacrococcygeal curves are primary curves retained from the original fetal curvature. The cervical and lumbar curves develop after birth and thus are secondary curves. The cervical curve develops as the infant begins to hold up the head, and the lumbar curve appears with standing and walking.

A typical vertebra consists of an enlarged anterior portion called the body, which provides weight-bearing support. Attached posteriorly to the body is a vertebral arch, which surrounds and defines the vertebral foramen for passage of the spinal cord. The vertebral arch consists of the pedicles, which attach to the vertebral body, and the laminae, which come together to form the roof of the arch. Arising from the vertebral arch are the laterally projecting transverse processes and the posteriorly oriented spinous process. The superior articular processes project upward, where they articulate with the downward projecting inferior articular processes of the next higher vertebrae.

A typical cervical vertebra has a small body, a bifid (Y-shaped) spinous process, and U-shaped transverse processes with a transverse foramen. In addition to these characteristics, the axis (C2 vertebra) also has the dens projecting upward from the vertebral body. The atlas (C1 vertebra) differs from the other cervical vertebrae in that it does not have a body, but instead consists of bony ring formed by the anterior and posterior arches. The atlas articulates with the dens from the axis. A typical thoracic vertebra is distinguished by its long, downward projecting spinous process. Thoracic vertebrae also have articulation facets on the body and transverse processes for attachment of the ribs. Lumbar vertebrae support the greatest amount of body weight and thus have a large, thick body. They also have a short, blunt spinous process. The sacrum is triangular in shape. The median sacral crest is formed by the fused vertebral spinous processes and the lateral sacral crest is derived from the fused transverse processes. Anterior (ventral) and posterior (dorsal) sacral foramina allow branches of the sacral spinal nerves to exit the sacrum. The auricular surfaces are articulation sites on the lateral sacrum that anchor the sacrum to the hipbones to form the pelvis. The coccyx is small and derived from the fusion of four small vertebrae.

The intervertebral discs fill in the gaps between the bodies of adjacent vertebrae. They provide strong attachments and padding between the vertebrae. The outer, fibrous layer of a disc is called the anulus fibrosus. The gel-like interior is called the nucleus pulposus. The disc can change shape to allow for movement between vertebrae. If the anulus fibrosus is weakened or damaged, the nucleus pulposus can protrude outward, resulting in a herniated disc.

The anterior longitudinal ligament runs along the full length of the anterior vertebral column, uniting the vertebral bodies. The supraspinous ligament is located posteriorly and interconnects the spinous processes of the thoracic and lumbar vertebrae. In the neck, this ligament expands to become the nuchal ligament. The nuchal ligament is attached to the cervical spinous processes and superiorly to the base of the skull, out to the external occipital protuberance. The posterior longitudinal ligament runs within the vertebral canal and unites the posterior sides of the vertebral bodies. The ligamentum flavum unites the lamina of adjacent vertebrae.

Interactive Link Questions

Osteoporosis is a common age-related bone disease in which bone density and strength is decreased. Watch this video to get a better understanding of how thoracic vertebrae may become weakened and may fractured due to this disease. How may vertebral osteoporosis contribute to kyphosis?

Answer: Osteoporosis causes thinning and weakening of the vertebral bodies. When this occurs in thoracic vertebrae, the bodies may collapse producing kyphosis, an enhanced anterior curvature of the thoracic vertebral column.

Watch this animation to see what it means to “slip” a disk. Watch this second animation to see one possible treatment for a herniated disc, removing and replacing the damaged disc with an artificial one that allows for movement between the adjacent certebrae. How could lifting a heavy object produce pain in a lower limb?

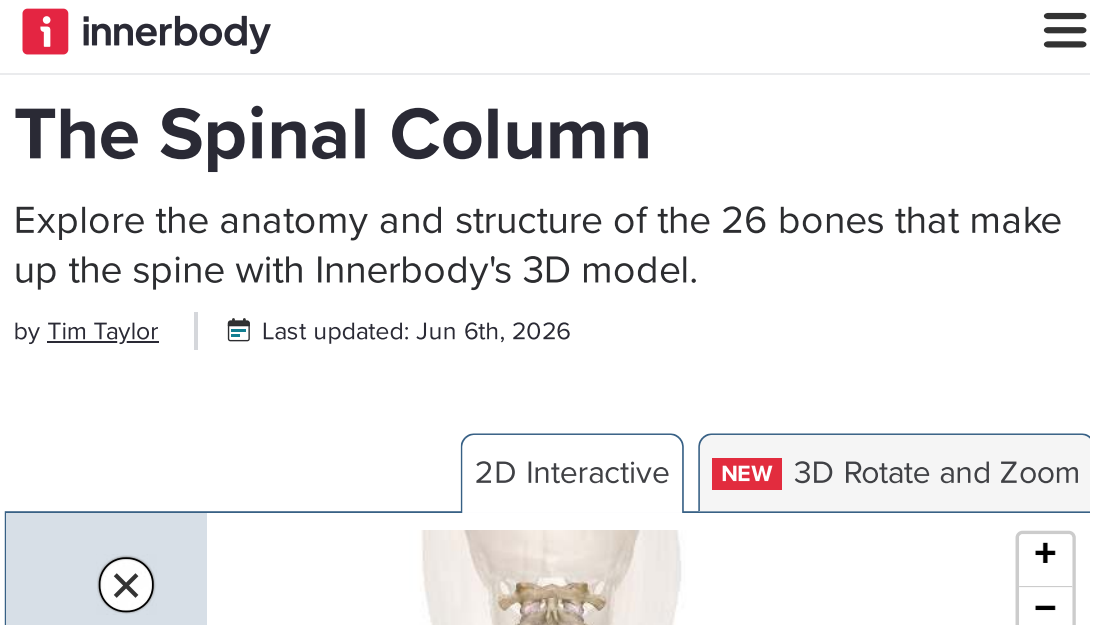


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Answer: Lifting a heavy object can cause an intervertebral disc in the lower back to bulge and compress a spinal nerve as it exits through the intervertebral foramen, thus producing pain in those regions of the lower limb supplied by that nerve.

Use this tool to identify the bones, intervertebral discs, and ligaments of the vertebral column. The thickest portions of the anterior longitudinal ligament and the supraspinous ligament are found in which regions of the vertebral column?



Answer: The anterior longitudinal ligament is thickest in the thoracic region of the vertebral column, while the supraspinous ligament is thickest in the lumbar region.

Review Questions

Q. The cervical region of the vertebral column consists of _____.

A. seven vertebrae

B. 12 vertebrae

C. five vertebrae

D. a single bone derived from the fusion of five vertebrae

Answer: A

Q. The primary curvatures of the vertebral column _____.

A. include the lumbar curve

B. are remnants of the original fetal curvature

C. include the cervical curve

D. develop after the time of birth

Answer: B

Q. A typical vertebra has _____.

A. a vertebral foramen that passes through the body

B. a superior articular process that projects downward to articulate with the superior portion of the next lower vertebra

C. lamina that spans between the transverse process and spinous process

D. a pair of laterally projecting spinous processes

Answer: C

Q. A typical lumbar vertebra has _____.

A. a short, rounded spinous process

B. a bifid spinous process

C. articulation sites for ribs

D. a transverse foramen

Answer: A

Q. Which is found only in the cervical region of the vertebral column?

A. nuchal ligament

B. ligamentum flavum

C. supraspinous ligament

D. anterior longitudinal ligament

Answer: A

Critical Thinking Questions

Q. Describe the vertebral column and define each region.

Answer: The adult vertebral column consists of 24 vertebrae, plus the sacrum and coccyx. The vertebrae are subdivided into cervical, thoracic, and lumbar regions. There are seven cervical vertebrae (C1–C7), 12 thoracic vertebrae (T1–T12), and five lumbar vertebrae (L1–L5). The sacrum is derived from the fusion of five sacral vertebrae and the coccyx is formed by the fusion of four small coccygeal vertebrae.

Q. Describe a typical vertebra.

Answer: A typical vertebra consists of an anterior body and a posterior vertebral arch. The body serves for weight bearing. The vertebral arch surrounds and protects the spinal cord. The vertebral arch is formed by the pedicles, which are attached to the posterior side of the vertebral body, and the lamina, which come together to form the top of the arch. A pair of transverse processes extends laterally from the vertebral arch, at the junction between each pedicle and lamina. The spinous process extends posteriorly from the top of the arch. A pair of superior articular processes project upward and a pair of inferior articular processes project downward. Together, the notches found in the margins of the pedicles of adjacent vertebrae form an intervertebral foramen.

Q. Describe the sacrum.

Answer: The sacrum is a single, triangular-shaped bone formed by the fusion of five sacral vertebrae. On the posterior sacrum, the median sacral crest is derived from the fused spinous processes, and the lateral sacral crest results from the fused transverse processes. The sacral canal contains the sacral spinal nerves, which exit via the anterior (ventral) and posterior (dorsal) sacral foramina. The sacral promontory is the anterior lip. The sacrum also forms the posterior portion of the pelvis.

Q. Describe the structure and function of an intervertebral disc.

Answer: An intervertebral disc fills in the space between adjacent vertebrae, where it provides padding and weight-bearing ability, and allows for movements between the vertebrae. It consists of an outer anulus fibrosus and an inner nucleus pulposus. The anulus fibrosus strongly anchors the adjacent vertebrae to each other, and the high water content of the nucleus pulposus resists compression for weight bearing and can change shape to allow for vertebral column movements.

Q. Define the ligaments of the vertebral column.

Answer: The anterior longitudinal ligament is attached to the vertebral bodies on the anterior side of the vertebral column. The supraspinous ligament is located on the posterior side, where it interconnects the thoracic and lumbar spinous processes. In the posterior neck, this ligament expands to become the nuchal ligament, which attaches to the cervical spinous processes and the base of the skull. The posterior longitudinal ligament and ligamentum flavum are located inside the vertebral canal. The posterior longitudinal ligament unites the posterior sides of the vertebral bodies. The ligamentum flavum unites the lamina of adjacent vertebrae.

Glossary

anterior arch
anterior portion of the ring-like C1 (atlas) vertebra

anterior longitudinal ligament
ligament that runs the length of the vertebral column, uniting the anterior aspects of the vertebral bodies

anterior (ventral) sacral foramen
one of the series of paired openings located on the anterior (ventral) side of the sacrum

anulus fibrosus
tough, fibrous outer portion of an intervertebral disc, which is strongly anchored to the bodies of the adjacent vertebrae

atlas
first cervical (C1) vertebra

axis
second cervical (C2) vertebra

cervical curve
posteriorly concave curvature of the cervical vertebral column region; a secondary curve of the vertebral column

cervical vertebrae
seven vertebrae numbered as C1–C7 that are located in the neck region of the vertebral column

costal facet
site on the lateral sides of a thoracic vertebra for articulation with the head of a rib

dens
bony projection (odontoid process) that extends upward from the body of the C2 (axis) vertebra

facet
small, flattened area on a bone for an articulation (joint) with another bone, or for muscle attachment

inferior articular process
bony process that extends downward from the vertebral arch of a vertebra that articulates with the superior articular process of the next lower vertebra

intervertebral disc
structure located between the bodies of adjacent vertebrae that strongly joins the vertebrae; provides padding, weight bearing ability, and enables vertebral column movements

intervertebral foramen
opening located between adjacent vertebrae for exit of a spinal nerve

kyphosis
(also, humpback or hunchback) excessive posterior curvature of the thoracic vertebral column region

lamina
portion of the vertebral arch on each vertebra that extends between the transverse and spinous process

lateral sacral crest
paired irregular ridges running down the lateral sides of the posterior sacrum that was formed by the fusion of the transverse processes from the five sacral vertebrae

ligamentum flavum
series of short ligaments that unite the lamina of adjacent vertebrae

lordosis
(also, swayback) excessive anterior curvature of the lumbar vertebral column region

lumbar curve
posteriorly concave curvature of the lumbar vertebral column region; a secondary curve of the vertebral column

lumbar vertebrae
five vertebrae numbered as L1–L5 that are located in lumbar region (lower back) of the vertebral column

median sacral crest
irregular ridge running down the midline of the posterior sacrum that was formed from the fusion of the spinous processes of the five sacral vertebrae

nuchal ligament
expanded portion of the supraspinous ligament within the posterior neck; interconnects the spinous processes of the cervical vertebrae and attaches to the base of the skull

nucleus pulposus
gel-like central region of an intervertebral disc; provides for padding, weight-bearing, and movement between adjacent vertebrae

pedicle
portion of the vertebral arch that extends from the vertebral body to the transverse process

posterior arch
posterior portion of the ring-like C1 (atlas) vertebra

posterior longitudinal ligament
ligament that runs the length of the vertebral column, uniting the posterior sides of the vertebral bodies

posterior (dorsal) sacral foramen
one of the series of paired openings located on the posterior (dorsal) side of the sacrum

primary curve
anteriorly concave curvatures of the thoracic and sacrococcygeal regions that are retained from the original fetal curvature of the vertebral column

sacral canal
bony tunnel that runs through the sacrum

sacral foramina
series of paired openings for nerve exit located on both the anterior (ventral) and posterior (dorsal) aspects of the sacrum

sacral hiatus
inferior opening and termination of the sacral canal

sacral promontory

anterior lip of the base (superior end) of the sacrum

sacrococcygeal curve
anteriorly concave curvature formed by the sacrum and coccyx; a primary curve of the vertebral column

scoliosis
abnormal lateral curvature of the vertebral column

secondary curve
posteriorly concave curvatures of the cervical and lumbar regions of the vertebral column that develop after the time of birth

spinous process
unpaired bony process that extends posteriorly from the vertebral arch of a vertebra

superior articular process
bony process that extends upward from the vertebral arch of a vertebra that articulates with the inferior articular process of the next higher vertebra

superior articular process of the sacrum
paired processes that extend upward from the sacrum to articulate (join) with the inferior articular processes from the L5 vertebra

supraspinous ligament
ligament that interconnects the spinous processes of the thoracic and lumbar vertebrae

thoracic curve
anteriorly concave curvature of the thoracic vertebral column region; a primary curve of the vertebral column

thoracic vertebrae
twelve vertebrae numbered as T1–T12 that are located in the thoracic region (upper back) of the vertebral column

transverse foramen
opening found only in the transverse processes of cervical vertebrae

transverse process
paired bony processes that extends laterally from the vertebral arch of a vertebra

vertebral arch
bony arch formed by the posterior portion of each vertebra that surrounds and protects the spinal cord

vertebral (spinal) canal
bony passageway within the vertebral column for the spinal cord that is formed by the series of individual vertebral foramina

vertebral foramen
opening associated with each vertebra defined by the vertebral arch that provides passage for the spinal cord

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4.3: Axial Muscles of the Head, Neck, and Back

Learning Objectives

- Identify the axial muscles of the face, head, and neck
- Identify the movement and function of the face, head, and neck muscles

The skeletal muscles are divided into **axial** (muscles of the trunk and head) and **appendicular** (muscles of the arms and legs) categories. This system reflects the bones of the skeleton system, which are also arranged in this manner. The axial muscles are grouped based on location, function, or both. Some of the axial muscles may seem to blur the boundaries because they cross over to the appendicular skeleton. The first grouping of the axial muscles you will review includes the muscles of the head and neck, then you will review the muscles of the vertebral column, and finally you will review the oblique and rectus muscles.

Muscles That Create Facial Expression

The origins of the muscles of facial expression are on the surface of the skull (remember, the origin of a muscle does not move). The insertions of these muscles have fibers intertwined with connective tissue and the dermis of the skin. Because the muscles insert in the skin rather than on bone, when they contract, the skin moves to create facial expression (Figure 4.3.1).

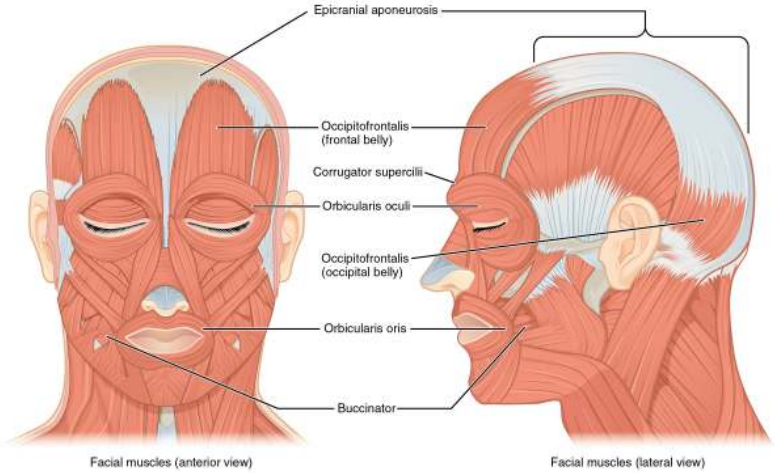


Figure 4.3.1: Muscles of Facial Expression. Many of the muscles of facial expression insert into the skin surrounding the eyelids, nose and mouth, producing facial expressions by moving the skin rather than bones.

The **orbicularis oris** is a circular muscle that moves the lips, and the **orbicularis oculi** is a circular muscle that closes the eye. The **occipitofrontalis** muscle moves up the scalp and eyebrows. The muscle has a frontal belly and an occipital (near the occipital bone on the posterior part of the skull) belly. In other words, there is a muscle on the forehead (**frontalis**) and one on the back of the head (**occipitalis**), but there is no muscle across the top of the head. Instead, the two bellies are connected by a broad tendon called the **epicranial aponeurosis**, or galea aponeurosis (galea = “apple”). The physicians originally studying human anatomy thought the skull looked like an apple.

The majority of the face is composed of the **buccinator** muscle, which compresses the cheek. This muscle allows you to whistle, blow, and suck; and it contributes to the action of chewing. There are several small facial muscles, one of which is the **corrugator supercilii**, which is the prime mover of the eyebrows. Place your finger on your eyebrows at the point of the bridge of the nose. Raise your eyebrows as if you were surprised and lower your eyebrows as if you were frowning. With these movements, you can feel the action of the corrugator supercilli. Additional muscles of facial expression are presented in Figure 4.3.2.

Movement	Target	Target motion direction	Prime mover	Origin	Insertion
Brow					
Furrowing brow	Skin of scalp	Anterior	Occipito-frontalis, frontal belly	Epicraneal aponeurosis	Underneath skin of forehead
Unfurrowing brow	Skin of scalp	Posterior	Occipito-frontalis, occipital belly	Occipital bone; mastoid process (temporal bone)	Epicraneal aponeurosis
Lowering eyebrows (e.g., scowling, frowning)	Skin underneath eyebrows	Inferior	Corrugator supercilii	Frontal bone	Skin underneath eyebrow
Nose					
Flaring nostrils	Nasal cartilage (pushes nostrils open when cartilage is compressed)	Inferior compression; posterior compression	Nasalis	Maxilla	Nasal bone
Mouth					
Raising upper lip	Upper lip	Elevation	Levator labii superioris	Maxilla	Underneath skin at corners of the mouth; orbicularis oris
Lowering lower lip	Lower lip	Depression	Depressor labii inferioris	Mandible	Underneath skin of lower lip
Opening mouth and sliding lower jaw left and right	Lower jaw	Depression, lateral	Depressor angulus oris	Mandible	Underneath skin at corners of mouth
Smiling	Corners of mouth	Lateral elevation	Zygomaticus major	Zygomatic bone	Underneath skin at corners of mouth (dimple area); orbicularis oris
Shaping of lips (as during speech)	Lips	Multiple	Orbicularis oris	Tissue surrounding lips	Underneath skin at corners of the mouth
Lateral movement of cheeks (e.g., sucking on a straw; also used to compress air in mouth while blowing)	Cheeks	Lateral	Buccinator	Maxilla, mandible; sphenoid bone (via pterygomandibular raphae)	Orbicularis oris
Pursing of lips by straightening them laterally	Corners of mouth	Lateral	Risorius	Fascia of parotid salivary gland	Underneath skin at corners of the mouth
Protrusion of lower lip (e.g., pouting expression)	Lower lip and skin of chin	Protraction	Mentalis	Mandible	Underneath skin of chin

Figure 4.3.2: Muscles in Facial Expression.

Muscles That Move the Eyes

The movement of the eyeball is under the control of the **extrinsic eye muscles**, which originate outside the eye and insert onto the outer surface of the white of the eye. These muscles are located inside the eye socket and cannot be seen on any part of the visible eyeball (Figure 4.3.3 and Table 4.3.1). If you have ever been to a doctor who held up a finger and asked you to follow it up, down, and to both sides, he or she is checking to make sure your eye muscles are acting in a coordinated pattern.

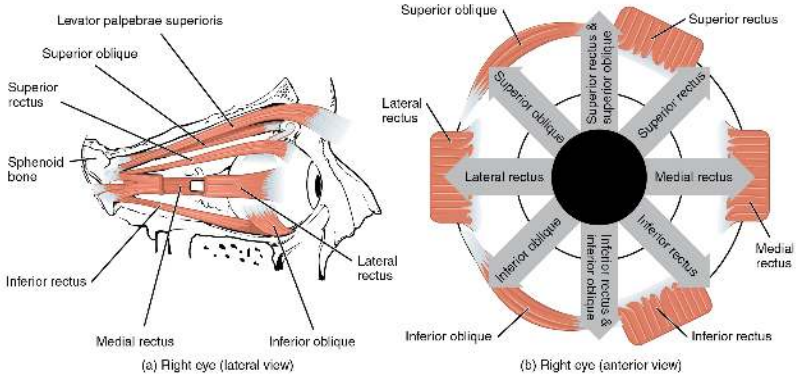


Figure 4.3.3: Muscles of the Eyes. (a) The extrinsic eye muscles originate outside of the eye on the skull. (b) Each muscle inserts onto the eyeball.

Table 4.3.1: Muscles of the Eyes

Movement	Target	Target motion direction	Prime mover	Origin	Insertion
Moves eyes up and toward nose; rotates eyes from 1 o'clock to 3 o'clock	Eyeballs	Superior (elevates); medial (adducts)	Superior rectus	Common tendinous ring (ring attaches to optic foramen)	Superior surface of eyeball
Moves eyes down and toward nose; rotates eyes from 6 o'clock to 3 o'clock	Eyeballs	Inferior (depresses); medial (adducts)	Inferior rectus	Common tendinous ring (ring attaches to optic foramen)	Inferior surface of eyeball
Moves eyes away from nose	Eyeballs	Lateral (abducts)	Lateral rectus	Common tendinous ring (ring attaches to optic foramen)	Lateral surface of eyeball
Moves eyes toward nose	Eyeballs	Medial (adducts)	Medial rectus	Common tendinous ring (ring attaches to optic foramen)	Medial surface of eyeball
Moves eyes up and away from nose; rotates eyeball from 12 o'clock to 9 o'clock	Eyeballs	Superior (elevates); lateral (abducts)	Inferior oblique	Floor of orbit (maxilla)	Surface of eyeball between inferior rectus and lateral rectus
Moves eyes down and away from nose; rotates eyeball from 6 o'clock to 9 o'clock	Eyeballs	Superior (elevates); lateral (abducts)	Superior oblique	Sphenoid bone	Suface of eyeball between superior rectus and lateral rectus
Opens eyes	Upper eyelid	Superior (elevates)	Levator palpabrae superioris	Roof of orbit (sphenoid bone)	Skin of upper eyelids
Closes eyelids	Eyelid skin	Compression along superior–inferior axis	Orbicularis oculi	Medial bones composing the orbit	Circumference of orbit

Muscles That Move the Lower Jaw

In anatomical terminology, chewing is called **mastication**. Muscles involved in chewing must be able to exert enough pressure to bite through and then chew food before it is swallowed (Figure 4.3.4 and Table 4.3.2). The **masseter** muscle is the main muscle used for chewing because it elevates the mandible (lower jaw) to close the mouth, and it is assisted by the **temporalis** muscle, which retracts the mandible. You can feel the temporalis move by putting your fingers to your temple as you chew.

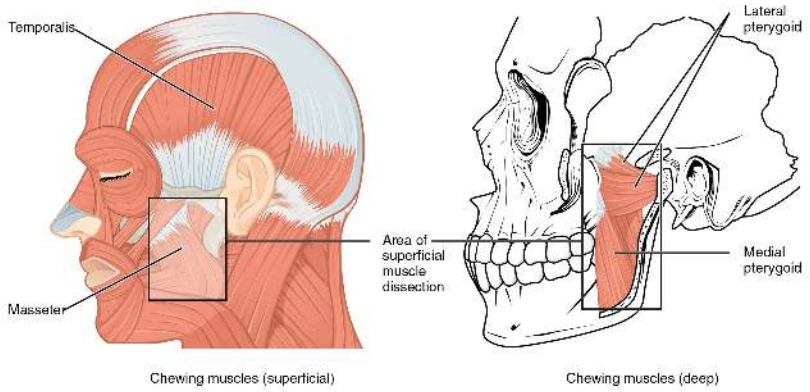


Figure 4.3.4: Muscles That Move the Lower Jaw. The muscles that move the lower jaw are typically located within the cheek and originate from processes in the skull. This provides the jaw muscles with the large amount of leverage needed for chewing.

Table 4.3.2: Muscles of the Lower Jaw

Movement	Target	Target motion direction	Prime mover	Origin	Insertion
Closes mouth; aids chewing	Mandible	Superior (elevates)	Masseter	Maxilla arch; zygomatic arch (for masseter)	Mandible
Closes mouth; pulls lower jaw in under upper jaw	Mandible	Superior (elevates); posterior (retracts)	Temporalis	Temporal bone	Mandible
Opens mouth; pushes lower jaw out under upper jaw; moves lower jaw side-to-side	Mandible	Inferior (depresses); posterior (protracts); lateral (abducts); medial (adducts)	Lateral pterygoid	Pterygoid process of sphenoid bone	Mandible
Closes mouth; pushes lower jaw out under upper jaw; moves lower jaw side-to-side	Mandible	Superior (elevates); posterior (protracts); lateral (abducts); medial (adducts)	Medial pterygoid	Sphenoid bone; maxilla	Mandible; temporo-mandibular joint

Although the masseter and temporalis are responsible for elevating and closing the jaw to break food into digestible pieces, the **medial pterygoid** and **lateral pterygoid** muscles provide assistance in chewing and moving food within the mouth.

Muscles That Move the Tongue

Although the tongue is obviously important for tasting food, it is also necessary for mastication, **deglutition** (swallowing), and speech (Figure 4.3.5 and Figure 4.3.6). Because it is so moveable, the tongue facilitates complex speech patterns and sounds.

Movement	Target	Target motion direction	Prime mover	Origin	Insertion
Tongue					
Moves tongue down; sticks tongue out of mouth	Tongue	Inferior (depresses); anterior (protracts)	Genioglossus	Mandible	Tongue undersurface; hyoid bone
Moves tongue up; retracts tongue back into mouth	Tongue	Superior (elevates); posterior (retracts)	Styloglossus	Temporal bone (styloid process)	Tongue undersurface and sides
Flattens tongue	Tongue	Inferior (depresses)	Hyoglossus	Hyoid bone	Sides of tongue
Bulges tongue	Tongue	Superior (elevation)	Palatoglossus	Soft palate	Side of tongue
Swallowing and speaking					
Raises the hyoid bone in a way that also raises the larynx, allowing the epiglottis to cover the glottis during deglutition; also assists in opening the mouth by depressing the mandible	Hyoid bone; larynx	Superior (elevates)	Digastric	Mandible; temporal bone	Hyoid bone
Raises and retracts the hyoid bone in a way that elongates the oral cavity during deglutition	Hyoid bone	Superior (elevates); posterior (retracts)	Stylohyoid	Temporal bone (styloid process)	Hyoid bone
Raises hyoid bone in a way that presses tongue against the roof of the mouth, pushing food back into the pharynx during deglutition	Hyoid bone	Superior (elevates)	Mylohyoid	Mandible	Hyoid bone; median raphe
Raises and moves hyoid bone forward, widening pharynx during deglutition	Hyoid bone	Superior (elevates); anterior (protracts)	Geniohyoid	Mandible	Hyoid bone
Retracts hyoid bone and moves it down during later phases of deglutition	Hyoid bone	Inferior (depresses); posterior (retracts)	Omohyoid	Scapula	Hyoid bone
Depresses the hyoid bone during swallowing and speaking	Hyoid bone	Inferior (depresses)	Sternohyoid	Clavicle	Hyoid bone
Shrinks distance between thyroid cartilage and hyoid bone, allowing production of high-pitch vocalizations	Hyoid bone; thyroid cartilage	Hyoid bone: inferior (depresses); thyroid cartilage: superior (elevates)	Thyrohyoid	Thyroid cartilage	Hyoid bone
Depresses larynx, thyroid cartilage, and hyoid bone to create different vocal tones	Larynx; thyroid cartilage; hyoid bone	Inferior (depresses)	Sternothyroid	Sternum	Thyroid cartilage
Rotates and tilts head to he side; tilts head forward	Skull; cervical vertebrae	Individually: medial rotation; lateral flexion; bilaterally: anterior (flexes)	Sternocleid-omastoid; semispinalis capitis	Sternum; clavicle	Temporal bone (mastoid process); occipital bone
Rotates and tilts head to the side; tilts head backwards	Skull; cervical vertebrae	Individually: lateral rotation; lateral flexion; bilaterally: anterior (flexes)	Splenius capitis; longissimus capitis		

Figure 4.3.6: Muscles for Tongue Movement, Swallowing, and Speech.

Tongue muscles can be extrinsic or intrinsic. Extrinsic tongue muscles insert into the tongue from outside origins, and the intrinsic tongue muscles insert into the tongue from origins within it. The extrinsic muscles move the whole tongue in different directions, whereas the intrinsic muscles allow the tongue to change its shape (such as, curling the tongue in a loop or flattening it).

The extrinsic muscles all include the word root glossus (glossus = “tongue”), and the muscle names are derived from where the muscle originates. The **genioglossus** (genio = “chin”) originates on the mandible and allows the tongue to move downward and forward. The **styloglossus** originates on the styloid bone, and allows upward and backward motion. The **palatoglossus** originates on the soft palate to elevate the back of the tongue, and the **hyoglossus** originates on the hyoid bone to move the tongue downward and flatten it.

EVERYDAY CONNECTIONS: Anesthesia and the Tongue Muscles

Before surgery, a patient must be made ready for general anesthesia. The normal homeostatic controls of the body are put “on hold” so that the patient can be prepped for surgery. Control of respiration must be switched from the patient’s homeostatic control to the control of the anesthesiologist. The drugs used for anesthesia relax a majority of the body’s muscles.

Among the muscles affected during general anesthesia are those that are necessary for breathing and moving the tongue. Under anesthesia, the tongue can relax and partially or fully block the airway, and the muscles of respiration may not move the diaphragm or chest wall. To avoid possible complications, the safest procedure to use on a patient is called endotracheal intubation. Placing a tube into the trachea allows the doctors to maintain a patient’s (open) airway to the lungs and seal the airway off from the oropharynx. Post-surgery, the anesthesiologist gradually changes the mixture of the gases that keep the patient unconscious, and when the muscles of respiration begin to function, the tube is removed. It still takes about 30 minutes

for a patient to wake up, and for breathing muscles to regain control of respiration. After surgery, most people have a sore or scratchy throat for a few days.

Muscles of the Anterior Neck

The muscles of the anterior neck assist in deglutition (swallowing) and speech by controlling the positions of the larynx (voice box), and the hyoid bone, a horseshoe-shaped bone that functions as a solid foundation on which the tongue can move. The muscles of the neck are categorized according to their position relative to the hyoid bone (Figure 4.3.7). **Suprahyoid muscles** are superior to it, and the **infrahyoid muscles** are located inferiorly.

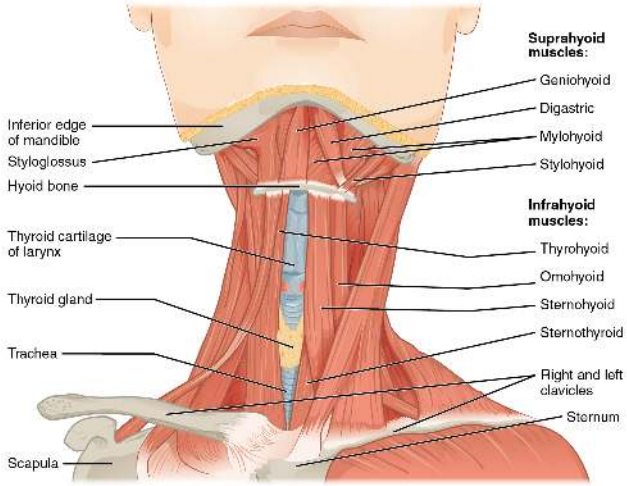


Figure 4.3.7: Muscles of the Anterior Neck. The anterior muscles of the neck facilitate swallowing and speech. The suprahyoid muscles originate from above the hyoid bone in the chin region. The infrahyoid muscles originate below the hyoid bone in the lower neck.

The suprahyoid muscles raise the hyoid bone, the floor of the mouth, and the larynx during deglutition. These include the **digastric** muscle, which has anterior and posterior bellies that work to elevate the hyoid bone and larynx when one swallows; it also depresses the mandible. The **stylohyoid** muscle moves the hyoid bone posteriorly, elevating the larynx, and the **mylohyoid** muscle lifts it and helps press the tongue to the top of the mouth. The **geniohyoid** depresses the mandible in addition to raising and pulling the hyoid bone anteriorly.

The strap-like infrahyoid muscles generally depress the hyoid bone and control the position of the larynx. The **omohyoid** muscle, which has superior and inferior bellies, depresses the hyoid bone in conjunction with the **sternohyoid** and **thyrohyoid** muscles. The thyrohyoid muscle also elevates the larynx's thyroid cartilage, whereas the **sternothyroid** depresses it to create different tones of voice.

Muscles That Move the Head

The head, attached to the top of the vertebral column, is balanced, moved, and rotated by the neck muscles (Table 4.3.3). When these muscles act unilaterally, the head rotates. When they contract bilaterally, the head flexes or extends. The major muscle that laterally flexes and rotates the head is the **sternocleidomastoid**. In addition, both muscles working together are the flexors of the head. Place your fingers on both sides of the neck and turn your head to the left and to the right. You will feel the movement originate there. This muscle divides the neck into anterior and posterior triangles when viewed from the side (Figure 4.3.8).

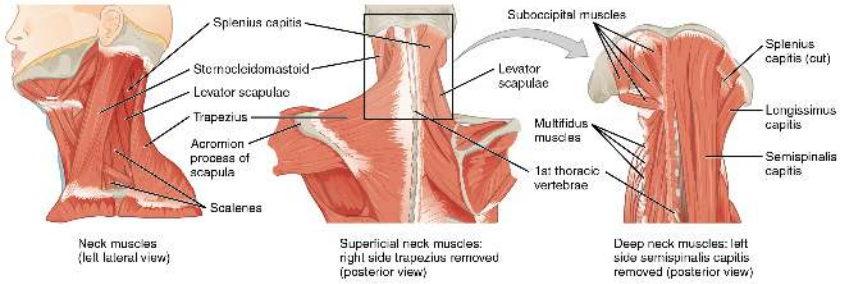


Figure 4.3.8: Posterior and Lateral Views of the Neck. The superficial and deep muscles of the neck are responsible for moving the head, cervical vertebrae, and scapulas.

Table 4.3.3: Muscles That Move the Head

Movement	Target	Target motion direction	Prime mover	Origin	Insertion
Rotates and tilts head to the side; tilts head forward	Skull; vertebrae	Individually: rotates head to opposite side; bilaterally: flexion	Sternocleidomastoid	Sternum; clavicle	Temporal bone (mastoid process); occipital bone
Rotates and tilts head backward	Skull; vertebrae	Individually: laterally flexes and rotates head to same side; bilaterally: extension	Semispinalis capitis	Transverse and articular processes of cervical and thoracic vertebra	Occipital bone
Rotates and tilts head to the side; tilts head backward	Skull; vertebrae	Individually: laterally flexes and rotates head to same side; bilaterally: extension	Splenius capitis	Spinous processes of cervical and thoracic vertebra	Temporal bone (mastoid process); occipital bone
Rotates and tilts head to the side; tilts head backward	Skull; vertebrae	Individually: laterally flexes and rotates head to same side; bilaterally: extension	Longissimus capitis	Transverse and articular processes of cervical and thoracic vertebra	Temporal bone (mastoid process)

Muscles of the Posterior Neck and the Back

The posterior muscles of the neck are primarily concerned with head movements, like extension. The back muscles stabilize and move the vertebral column, and are grouped according to the lengths and direction of the fascicles.

The **splenius** muscles originate at the midline and run laterally and superiorly to their insertions. From the sides and the back of the neck, the **splenius capitis** inserts onto the head region, and the **splenius cervicis** extends onto the cervical region. These muscles can extend the head, laterally flex it, and rotate it (Figure 4.3.9).

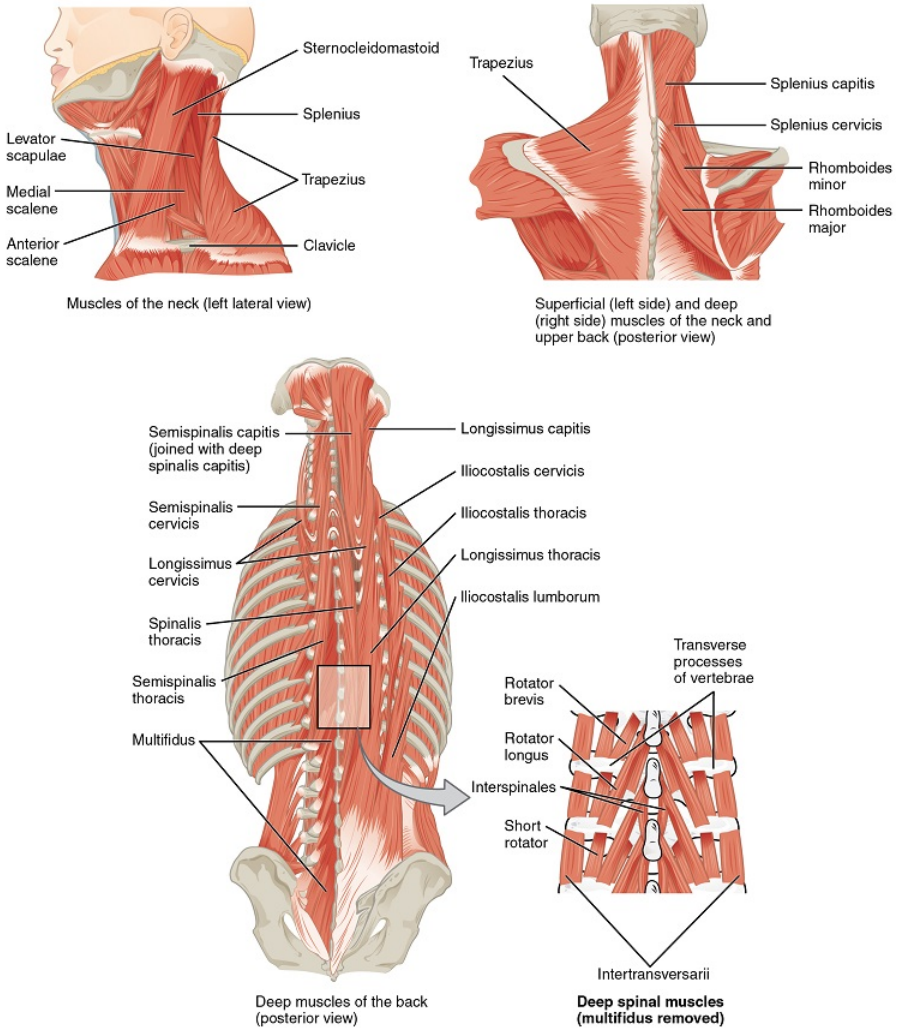


Figure 4.3.9: Muscles of the Neck and Back. The large, complex muscles of the neck and back move the head, shoulders, and vertebral column.

The **erector spinae group** forms the majority of the muscle mass of the back and it is the primary extensor of the vertebral column. It controls flexion, lateral flexion, and rotation of the vertebral column, and maintains the lumbar curve. The erector spinae comprises the iliocostalis (laterally placed) group, the longissimus (intermediately placed) group, and the spinalis (medially placed) group.

The **iliocostalis group** includes the **iliocostalis cervicis**, associated with the cervical region; the **iliocostalis thoracis**, associated with the thoracic region; and the **iliocostalis lumborum**, associated with the lumbar region. The three muscles of the **longissimus group** are the **longissimus capitis**, associated with the head region; the **longissimus cervicis**, associated with the cervical region; and the **longissimus thoracis**, associated with the thoracic region. The third group, the **spinalis group**, comprises the **spinalis capitis** (head region), the **spinalis cervicis** (cervical region), and the **spinalis thoracis** (thoracic region).

The **transversospinales** muscles run from the transverse processes to the spinous processes of the vertebrae. Similar to the erector spinae muscles, the semispinalis muscles in this group are named for the areas of the body with which they are associated. The semispinalis muscles include the **semispinalis capitis**, the **semispinalis cervicis**, and the **semispinalis thoracis**. The **multifidus** muscle of the lumbar region helps extend and laterally flex the vertebral column.

Important in the stabilization of the vertebral column is the **segmental muscle group**, which includes the interspinales and intertransversarii muscles. These muscles bring together the spinous and transverse processes of each consecutive vertebra. Finally, the **scalene muscles** work together to flex, laterally flex, and rotate the head. They also contribute to deep inhalation. The scalene muscles include the **anterior scalene** muscle (anterior to the middle scalene), the **middle scalene** muscle (the longest, intermediate between the anterior and posterior scalenes), and the **posterior scalene** muscle (the smallest, posterior to the middle scalene).

Chapter Review

Muscles are either axial muscles or appendicular. The axial muscles are grouped based on location, function, or both. Some axial muscles cross over to the appendicular skeleton. The muscles of the head and neck are all axial. The muscles in the face create facial expression by inserting into the skin rather than onto bone. Muscles that move the eyeballs are extrinsic, meaning they originate outside of the eye and insert onto it. Tongue muscles are both extrinsic and intrinsic. The genioglossus depresses the tongue and moves it anteriorly; the styloglossus lifts the tongue and retracts it; the palatoglossus elevates the back of the tongue; and the hyoglossus depresses and flattens it. The muscles of the anterior neck facilitate swallowing and speech, stabilize the hyoid bone and position the larynx. The muscles of the neck stabilize and move the head. The sternocleidomastoid divides the neck into anterior and posterior triangles.

The muscles of the back and neck that move the vertebral column are complex, overlapping, and can be divided into five groups. The splenius group includes the splenius capitis and the splenius cervicis. The erector spinae has three subgroups. The iliocostalis group includes the iliocostalis cervicis, the iliocostalis thoracis, and the iliocostalis lumborum. The longissimus group includes the longissimus capitis, the longissimus cervicis, and the longissimus thoracis. The spinalis group includes the spinalis capitis, the spinalis cervicis, and the spinalis thoracis. The transversospinales include the semispinalis capitis, semispinalis cervicis, semispinalis thoracis, multifidus, and rotatores. The segmental muscles include the interspinales and intertransversarii. Finally, the scalenes include the anterior scalene, middle scalene, and posterior scalene.

Review Questions

Q. Which of the following is a prime mover in head flexion?

A. occipitofrontalis

B. corrugator supercilii

C. sternocleidomastoid

D. masseter

Answer: C

Q. Where is the inferior oblique muscle located?

A. in the abdomen

B. in the eye socket

C. in the anterior neck

D. in the face

Answer: B

Q. What is the action of the masseter?

A. swallowing

B. chewing

C. moving the lips

D. closing the eye

A. B

Q. The names of the extrinsic tongue muscles commonly end in _____.

A. -glottis

B. -glossus

C. -gluteus

D. -hyoid

Answer: B

Q. What is the function of the erector spinae?

A. movement of the arms

B. stabilization of the pelvic girdle

C. postural support

D. rotating of the vertebral column

Answer: C

Critical Thinking Questions

Q. Explain the difference between axial and appendicular muscles.

A. Axial muscles originate on the axial skeleton (the bones in the head, neck, and core of the body), whereas appendicular muscles originate on the bones that make up the body's limbs.

Q. Describe the muscles of the anterior neck.

A. The muscles of the anterior neck are arranged to facilitate swallowing and speech. They work on the hyoid bone, with the suprahyoid muscles pulling up and the infrahyoid muscles pulling down.

Q. Why are the muscles of the face different from typical skeletal muscle?

A. Most skeletal muscles create movement by actions on the skeleton. Facial muscles are different in that they create facial movements and expressions by pulling on the skin—no bone movements are involved.

Glossary

anterior scalene
a muscle anterior to the middle scalene

appendicular
of the arms and legs

axial
of the trunk and head

buccinator
muscle that compresses the cheek

corrugator supercilii
prime mover of the eyebrows

deglutition
swallowing

digastric
muscle that has anterior and posterior bellies and elevates the hyoid bone and larynx when one swallows; it also depresses the mandible

epicranial aponeurosis

(also, galea aponeurosis) flat broad tendon that connects the frontalis and occipitalis

erector spinae group
large muscle mass of the back; primary extensor of the vertebral column

extrinsic eye muscles
originate outside the eye and insert onto the outer surface of the white of the eye, and create eyeball movement

frontalis
front part of the occipitofrontalis muscle

genioglossus
muscle that originates on the mandible and allows the tongue to move downward and forward

geniohyoid
muscle that depresses the mandible, and raises and pulls the hyoid bone anteriorly

hyoglossus
muscle that originates on the hyoid bone to move the tongue downward and flatten it

iliocostalis cervicis
muscle of the iliocostalis group associated with the cervical region

iliocostalis group
laterally placed muscles of the erector spinae

iliocostalis lumborum
muscle of the iliocostalis group associated with the lumbar region

iliocostalis thoracis
muscle of the iliocostalis group associated with the thoracic region

infrahyoid muscles
anterior neck muscles that are attached to, and inferior to the hyoid bone

lateral pterygoid
muscle that moves the mandible from side to side

longissimus capitis
muscle of the longissimus group associated with the head region

longissimus cervicis
muscle of the longissimus group associated with the cervical region

longissimus group
intermediately placed muscles of the erector spinae

longissimus thoracis
muscle of the longissimus group associated with the thoracic region

masseter
main muscle for chewing that elevates the mandible to close the mouth

mastication
chewing

medial pterygoid
muscle that moves the mandible from side to side

middle scalene
longest scalene muscle, located between the anterior and posterior scalenes

multifidus
muscle of the lumbar region that helps extend and laterally flex the vertebral column

mylohyoid
muscle that lifts the hyoid bone and helps press the tongue to the top of the mouth

occipitalis
posterior part of the occipitofrontalis muscle

occipitofrontalis
muscle that makes up the scalp with a frontal belly and an occipital belly

omohyoid
muscle that has superior and inferior bellies and depresses the hyoid bone

orbicularis oculi
circular muscle that closes the eye

orbicularis oris
circular muscle that moves the lips

palatoglossus
muscle that originates on the soft palate to elevate the back of the tongue

posterior scalene
smallest scalene muscle, located posterior to the middle scalene

scalene muscles
flex, laterally flex, and rotate the head; contribute to deep inhalation

segmental muscle group
interspinales and intertransversarii muscles that bring together the spinous and transverse processes of each consecutive vertebra

semispinalis capitis
transversospinales muscle associated with the head region

semispinalis cervicis
transversospinales muscle associated with the cervical region

semispinalis thoracis
transversospinales muscle associated with the thoracic region

spinalis capitis
muscle of the spinalis group associated with the head region

spinalis cervicis
muscle of the spinalis group associated with the cervical region

spinalis group

medially placed muscles of the erector spinae

spinalis thoracis
muscle of the spinalis group associated with the thoracic region

splenius
posterior neck muscles; includes the splenius capitis and splenius cervicis

splenius capitis
neck muscle that inserts into the head region

splenius cervicis
neck muscle that inserts into the cervical region

sternocleidomastoid
major muscle that laterally flexes and rotates the head

sternohyoid
muscle that depresses the hyoid bone

sternothyroid
muscle that depresses the larynx's thyroid cartilage

styloglossus
muscle that originates on the styloid bone, and allows upward and backward motion of the tongue

stylohyoid
muscle that elevates the hyoid bone posteriorly

suprahyoid muscles
neck muscles that are superior to the hyoid bone

temporalis
muscle that retracts the mandible

thyrohyoid
muscle that depresses the hyoid bone and elevates the larynx's thyroid cartilage

Contributors and Attributions

transversospinales
muscles that originate at the transverse processes and insert at the spinous processes of the vertebrae

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CHAPTER OVERVIEW

5: Thorax, Hip and Pelvis

5.1: The Thoracic Cage
5.2: The Pelvic Girdle and Pelvis

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5.1: The Thoracic Cage

Learning Objectives

- Discuss the components that make up the thoracic cage
- Identify the parts of the sternum and define the sternal angle
- Discuss the parts of a rib and rib classifications

The thoracic cage (rib cage) forms the thorax (chest) portion of the body. It consists of the 12 pairs of ribs with their costal cartilages and the sternum (Figure 5.1.1). The ribs are anchored posteriorly to the 12 thoracic vertebrae (T1–T12). The thoracic cage protects the heart and lungs.

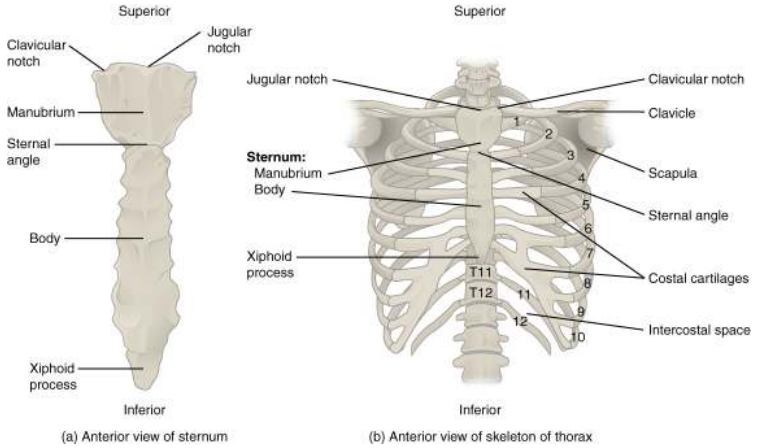


Figure 5.1.1: Thoracic Cage. The thoracic cage is formed by the (a) sternum and (b) 12 pairs of ribs with their costal cartilages. The ribs are anchored posteriorly to the 12 thoracic vertebrae. The sternum consists of the manubrium, body, and xiphoid process. The ribs are classified as true ribs (1–7) and false ribs (8–12). The last two pairs of false ribs are also known as floating ribs (11–12).

Sternum

The sternum is the elongated bony structure that anchors the anterior thoracic cage. It consists of three parts: the manubrium, body, and xiphoid process. The **manubrium** is the wider, superior portion of the sternum. The top of the manubrium has a shallow, U-shaped border called the **jugular (suprasternal) notch**. This can be easily felt at the anterior base of the neck, between the medial ends of the clavicles. The **clavicular notch** is the shallow depression located on either side at the superior-lateral margins of the manubrium. This is the site of the sternoclavicular joint, between the sternum and clavicle. The first ribs also attach to the manubrium.

The elongated, central portion of the sternum is the body. The manubrium and body join together at the **sternal angle**, so called because the junction between these two components is not flat, but forms a slight bend. The second rib attaches to the sternum at the sternal angle. Since the first rib is hidden behind the clavicle, the second rib is the highest rib that can be identified by palpation. Thus, the sternal angle and second rib are important landmarks for the identification and counting of the lower ribs. Ribs 3–7 attach to the sternal body.

The inferior tip of the sternum is the **xiphoid process**. This small structure is cartilaginous early in life, but gradually becomes ossified starting during middle age.

Ribs

Each rib is a curved, flattened bone that contributes to the wall of the thorax. The ribs articulate posteriorly with the T1–T12 thoracic vertebrae, and most attach anteriorly via their costal cartilages to the sternum. There are 12 pairs of ribs. The ribs are numbered 1–12 in accordance with the thoracic vertebrae.

Parts of a Typical Rib

The posterior end of a typical rib is called the **head of the rib** (see [link]). This region articulates primarily with the costal facet located on the body of the same numbered thoracic vertebra and to a lesser degree, with the costal facet located on the body of the

next higher vertebra. Lateral to the head is the narrowed **neck of the rib**. A small bump on the posterior rib surface is the **tubercle of the rib**, which articulates with the facet located on the transverse process of the same numbered vertebra. The remainder of the rib is the **body of the rib** (shaft). Just lateral to the tubercle is the **angle of the rib**, the point at which the rib has its greatest degree of curvature. The angles of the ribs form the most posterior extent of the thoracic cage. In the anatomical position, the angles align with the medial border of the scapula. A shallow **costal groove** for the passage of blood vessels and a nerve is found along the inferior margin of each rib.

Rib Classifications

The bony ribs do not extend anteriorly completely around to the sternum. Instead, each rib ends in a **costal cartilage**. These cartilages are made of hyaline cartilage and can extend for several inches. Most ribs are then attached, either directly or indirectly, to the sternum via their costal cartilage (see Figure 5.1.1). The ribs are classified into three groups based on their relationship to the sternum.

Ribs 1–7 are classified as **true ribs** (vertebrosternal ribs). The costal cartilage from each of these ribs attaches directly to the sternum. Ribs 8–12 are called **false ribs** (vertebrochondral ribs). The costal cartilages from these ribs do not attach directly to the sternum. For ribs 8–10, the costal cartilages are attached to the cartilage of the next higher rib. Thus, the cartilage of rib 10 attaches to the cartilage of rib 9, rib 9 then attaches to rib 8, and rib 8 is attached to rib 7. The last two false ribs (11–12) are also called **floating ribs** (vertebral ribs). These are short ribs that do not attach to the sternum at all. Instead, their small costal cartilages terminate within the musculature of the lateral abdominal wall.

Chapter Review

The thoracic cage protects the heart and lungs. It is composed of 12 pairs of ribs with their costal cartilages and the sternum. The ribs are anchored posteriorly to the 12 thoracic vertebrae. The sternum consists of the manubrium, body, and xiphoid process. The manubrium and body are joined at the sternal angle, which is also the site for attachment of the second ribs.

Ribs are flattened, curved bones and are numbered 1–12. Posteriorly, the head of the rib articulates with the costal facets located on the bodies of thoracic vertebrae and the rib tubercle articulates with the facet located on the vertebral transverse process. The angle of the ribs forms the most posterior portion of the thoracic cage. The costal groove in the inferior margin of each rib carries blood vessels and a nerve. Anteriorly, each rib ends in a costal cartilage. True ribs (1–7) attach directly to the sternum via their costal cartilage. The false ribs (8–12) either attach to the sternum indirectly or not at all. Ribs 8–10 have their costal cartilages attached to the cartilage of the next higher rib. The floating ribs (11–12) are short and do not attach to the sternum or to another rib.

Review Questions

Q. The sternum _____.

A. consists of only two parts, the manubrium and xiphoid process

B. has the sternal angle located between the manubrium and body

C. receives direct attachments from the costal cartilages of all 12 pairs of ribs

D. articulates directly with the thoracic vertebrae

Answer: B

Q. The sternal angle is the _____.

A. junction between the body and xiphoid process

B. site for attachment of the clavicle

C. site for attachment of the floating ribs

D. junction between the manubrium and body

Answer: D

Q. The tubercle of a rib _____.

A. is for articulation with the transverse process of a thoracic vertebra

B. is for articulation with the body of a thoracic vertebra

C. provides for passage of blood vessels and a nerve

D. is the area of greatest rib curvature

> Answer: A

Q. True ribs are _____.

A. ribs 8–12

B. attached via their costal cartilage to the next higher rib

C. made entirely of bone, and thus do not have a costal cartilage

D. attached via their costal cartilage directly to the sternum

> Answer: D

Critical Thinking Questions

Q. Define the parts and functions of the thoracic cage.

> A. The thoracic cage is formed by the 12 pairs of ribs with their costal cartilages and the sternum. The ribs are attached posteriorly to the 12 thoracic vertebrae and most are anchored anteriorly either directly or indirectly to the sternum. The thoracic cage functions to protect the heart and lungs.

Q. Describe the parts of the sternum.

> A. The sternum consists of the manubrium, body, and xiphoid process. The manubrium forms the expanded, superior end of the sternum. It has a jugular (suprasternal) notch, a pair of clavicular notches for articulation with the clavicles, and receives the costal cartilage of the first rib. The manubrium is joined to the body of the sternum at the sternal angle, which is also the site for attachment of the second rib costal cartilages. The body receives the costal cartilage attachments for ribs 3–7. The small xiphoid process forms the inferior tip of the sternum.

Q. Discuss the parts of a typical rib.

> A. A typical rib is a flattened, curved bone. The head of a rib is attached posteriorly to the costal facets of the thoracic vertebrae. The rib tubercle articulates with the transverse process of a thoracic vertebra. The angle is the area of greatest rib curvature and forms the largest portion of the thoracic cage. The body (shaft) of a rib extends anteriorly and terminates at the attachment to its costal cartilage. The shallow costal groove runs along the inferior margin of a rib and carries blood vessels and a nerve.

Q. Define the classes of ribs.

> A. Ribs are classified based on if and how their costal cartilages attach to the sternum. True (vertebrosternal) ribs are ribs 1–7. The costal cartilage for each of these attaches directly to the sternum. False (vertebrochondral) ribs, 8–12, are attached either indirectly or not at all to the sternum. Ribs 8–10 are attached indirectly to the sternum. For these ribs, the costal cartilage of each attaches to the cartilage of the next higher rib. The last false ribs (11–12) are also called floating (vertebral) ribs, because these ribs do not attach to the sternum at all. Instead, the ribs and their small costal cartilages terminate within the muscles of the lateral abdominal wall.

Glossary

angle of the rib

portion of rib with greatest curvature; together, the rib angles form the most posterior extent of the thoracic cage

body of the rib

shaft portion of a rib

clavicular notch
paired notches located on the superior-lateral sides of the sternal manubrium, for articulation with the clavicle

costal cartilage
hyaline cartilage structure attached to the anterior end of each rib that provides for either direct or indirect attachment of most ribs to the sternum

costal groove
shallow groove along the inferior margin of a rib that provides passage for blood vessels and a nerve

false ribs
vertebrochondral ribs 8–12 whose costal cartilage either attaches indirectly to the sternum via the costal cartilage of the next higher rib or does not attach to the sternum at all

floating ribs
vertebral ribs 11–12 that do not attach to the sternum or to the costal cartilage of another rib

head of the rib
posterior end of a rib that articulates with the bodies of thoracic vertebrae

jugular (suprasternal) notch
shallow notch located on superior surface of sternal manubrium

manubrium
expanded, superior portion of the sternum

neck of the rib
narrowed region of a rib, next to the rib head

sternal angle
junction line between manubrium and body of the sternum and the site for attachment of the second rib to the sternum

true ribs
vertebrosternal ribs 1–7 that attach via their costal cartilage directly to the sternum

tubercle of the rib
small bump on the posterior side of a rib for articulation with the transverse process of a thoracic vertebra

Contributors and Attributions

xiphoid process
small process that forms the inferior tip of the sternum

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5.2: The Pelvic Girdle and Pelvis

Learning Objectives

- Define the pelvic girdle and describe the bones and ligaments of the pelvis
- Explain the three regions of the hip bone and identify their bony landmarks
- Describe the openings of the pelvis and the boundaries of the greater and lesser pelvis

The **pelvic girdle** (hip girdle) is formed by a single bone, the **hip bone** or **coxal bone** (coxal = "hip"), which serves as the attachment point for each lower limb. Each hip bone, in turn, is firmly joined to the axial skeleton via its attachment to the sacrum of the vertebral column. The right and left hip bones also converge anteriorly to attach to each other. The bony **pelvis** is the entire structure formed by the two hip bones, the sacrum, and, attached inferiorly to the sacrum, the coccyx (Figure 5.2.1).

Unlike the bones of the pectoral girdle, which are highly mobile to enhance the range of upper limb movements, the bones of the pelvis are strongly united to each other to form a largely immobile, weight-bearing structure. This is important for stability because it enables the weight of the body to be easily transferred laterally from the vertebral column, through the pelvic girdle and hip joints, and into either lower limb whenever the other limb is not bearing weight. Thus, the immobility of the pelvis provides a strong foundation for the upper body as it rests on top of the mobile lower limbs.

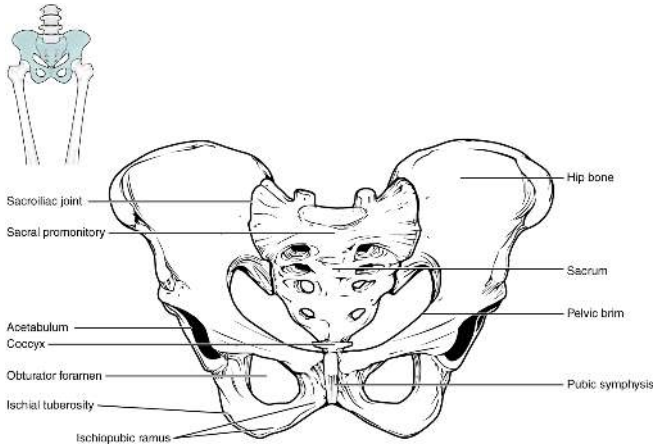


Figure 5.2.1: Pelvis.The pelvic girdle is formed by a single hip bone. The hip bone attaches the lower limb to the axial skeleton through its articulation with the sacrum. The right and left hip bones, plus the sacrum and the coccyx, together form the pelvis.

Hip Bone

The hip bone, or coxal bone, forms the pelvic girdle portion of the pelvis. The paired hip bones are the large, curved bones that form the lateral and anterior aspects of the pelvis. Each adult hip bone is formed by three separate bones that fuse together during the late teenage years. These bony components are the ilium, ischium, and pubis (Figure 5.2.2). These names are retained and used to define the three regions of the adult hip bone.

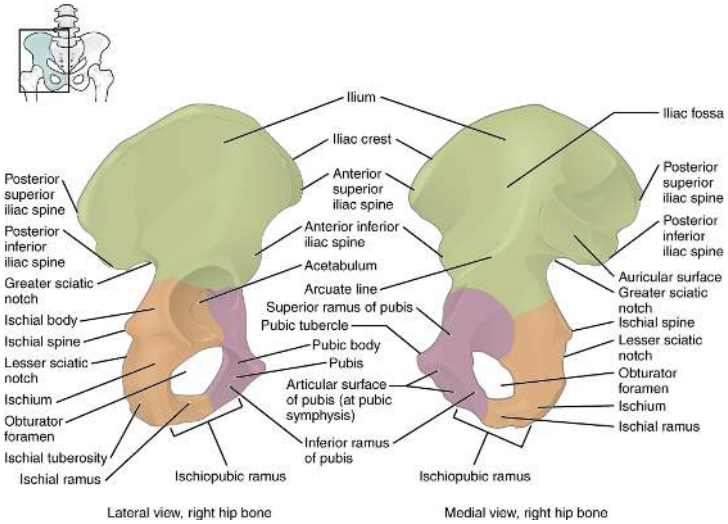


Figure 5.2.2: The Hip Bone. The adult hip bone consists of three regions. The ilium forms the large, fan-shaped superior portion, the ischium forms the posteroinferior portion, and the pubis forms the anteromedial portion.

The **ilium** is the fan-like, superior region that forms the largest part of the hip bone. It is firmly united to the sacrum at the largely immobile **sacroiliac joint** (see Figure 5.2.1). The **ischium** forms the posteroinferior region of each hip bone. It supports the body when sitting. The **pubis** forms the anterior portion of the hip bone. The pubis curves medially, where it joins to the pubis of the opposite hip bone at a specialized joint called the **pubic symphysis**.

Ilium

When you place your hands on your waist, you can feel the arching, superior margin of the ilium along your waistline (see Figure 5.2.2). This curved, superior margin of the ilium is the **iliac crest**. The rounded, anterior termination of the iliac crest is the **anterior superior iliac spine**. This important bony landmark can be felt at your anterolateral hip. Inferior to the anterior superior iliac spine is a rounded protuberance called the **anterior inferior iliac spine**. Both of these iliac spines serve as attachment points for muscles of the thigh. Posteriorly, the iliac crest curves downward to terminate as the **posterior superior iliac spine**. Muscles and ligaments surround but do not cover this bony landmark, thus sometimes producing a depression seen as a “dimple” located on the lower back. More inferiorly is the **posterior inferior iliac spine**. This is located at the inferior end of a large, roughened area called the **auricular surface of the ilium**. The auricular surface articulates with the auricular surface of the sacrum to form the sacroiliac joint. Both the posterior superior and posterior inferior iliac spines serve as attachment points for the muscles and very strong ligaments that support the sacroiliac joint.

The shallow depression located on the anteromedial (internal) surface of the upper ilium is called the **iliac fossa**. The inferior margin of this space is formed by the **arcuate line of the ilium**, the ridge formed by the pronounced change in curvature between the upper and lower portions of the ilium. The large, inverted U-shaped indentation located on the posterior margin of the lower ilium is called the **greater sciatic notch**.

Ischium

The ischium forms the posterolateral portion of the hip bone (see Figure 5.2.2). The large, roughened area of the inferior ischium is the **ischial tuberosity**. This serves as the attachment for the posterior thigh muscles and also carries the weight of the body when sitting. You can feel the ischial tuberosity if you wiggle your pelvis against the seat of a chair. Projecting superiorly and anteriorly from the ischial tuberosity is a narrow segment of bone called the **ischial ramus**. The slightly curved posterior margin of the ischium above the ischial tuberosity is the **lesser sciatic notch**. The bony projection separating the lesser sciatic notch and greater sciatic notch is the **ischial spine**.

Pubis

The pubis forms the anterior portion of the hip bone (see Figure 5.2.2). The enlarged medial portion of the pubis is the **pubic body**. Located superiorly on the pubic body is a small bump called the **pubic tubercle**. The **superior pubic ramus** is the segment of bone that passes laterally from the pubic body to join the ilium. The narrow ridge running along the superior margin of the superior pubic ramus is the **pectineal line of the pubis**.

The pubic body is joined to the pubic body of the opposite hip bone by the pubic symphysis. Extending downward and laterally from the body is the **inferior pubic ramus**. The **pubic arch** is the bony structure formed by the pubic symphysis, and the bodies and inferior pubic rami of the adjacent pubic bones. The inferior pubic ramus extends downward to join the ischial ramus. Together, these form the single **ischiopubic ramus**, which extends from the pubic body to the ischial tuberosity. The inverted V-shape formed as the ischiopubic rami from both sides come together at the pubic symphysis is called the **subpubic angle**.

Pelvis

The pelvis consists of four bones: the right and left hip bones, the sacrum, and the coccyx (see Figure 5.2.1). The pelvis has several important functions. Its primary role is to support the weight of the upper body when sitting and to transfer this weight to the lower limbs when standing. It serves as an attachment point for trunk and lower limb muscles, and also protects the internal pelvic organs. When standing in the anatomical position, the pelvis is tilted anteriorly. In this position, the anterior superior iliac spines and the pubic tubercles lie in the same vertical plane, and the anterior (internal) surface of the sacrum faces forward and downward.

The three areas of each hip bone, the ilium, pubis, and ischium, converge centrally to form a deep, cup-shaped cavity called the **acetabulum**. This is located on the lateral side of the hip bone and is part of the hip joint. The large opening in the anteroinferior hip bone between the ischium and pubis is the **obturator foramen**. This space is largely filled in by a layer of connective tissue and serves for the attachment of muscles on both its internal and external surfaces.

Several ligaments unite the bones of the pelvis (Figure 5.2.3). The largely immobile sacroiliac joint is supported by a pair of strong ligaments that are attached between the sacrum and ilium portions of the hip bone. These are the **anterior sacroiliac ligament** on the anterior side of the joint and the **posterior sacroiliac ligament** on the posterior side. Also spanning the sacrum and hip bone are two additional ligaments. The **sacrospinous ligament** runs from the sacrum to the ischial spine, and the **sacrotuberous ligament** runs from the sacrum to the ischial tuberosity. These ligaments help to support and immobilize the sacrum as it carries the weight of the body.

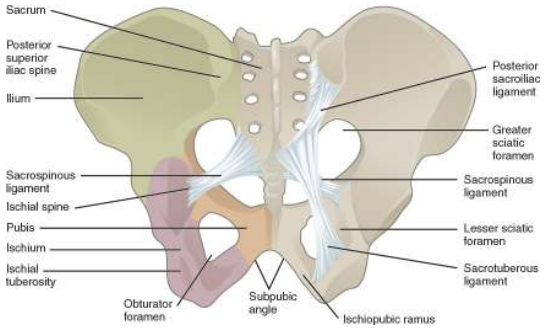
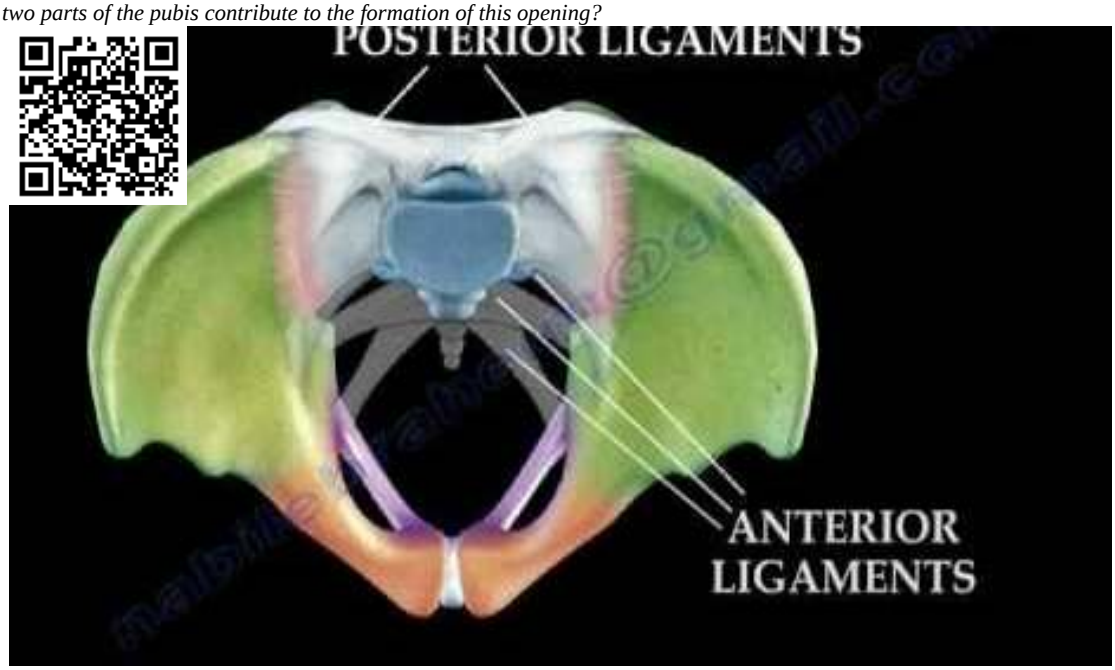


Figure 5.2.3: Ligaments of the Pelvis. The posterior sacroiliac ligament supports the sacroiliac joint. The sacrospinous ligament spans the sacrum to the ischial spine, and the sacrotuberous ligament spans the sacrum to the ischial tuberosity. The sacrospinous and sacrotuberous ligaments contribute to the formation of the greater and lesser sciatic foramens.

Watch this video for a 3-D view of the pelvis and its associated ligaments. What is the large opening in the bony pelvis, located between the ischium and pubic regions, and what two parts of the pubis contribute to the formation of this opening?



The sacrospinous and sacrotuberous ligaments also help to define two openings on the posterolateral sides of the pelvis through which muscles, nerves, and blood vessels for the lower limb exit. The superior opening is the **greater sciatic foramen**. This large opening is formed by the greater sciatic notch of the hip bone, the sacrum, and the sacrospinous ligament. The smaller, more inferior **lesser sciatic foramen** is formed by the lesser sciatic notch of the hip bone, together with the sacrospinous and sacrotuberous ligaments.

The space enclosed by the bony pelvis is divided into two regions (Figure 5.2.4). The broad, superior region, defined laterally by the large, fan-like portion of the upper hip bone, is called the **greater pelvis** (greater pelvic cavity; false pelvis). This broad area is occupied by portions of the small and large intestines, and because it is more closely associated with the abdominal cavity, it is sometimes referred to as the false pelvis. More inferiorly, the narrow, rounded space of the **lesser pelvis** (lesser pelvic cavity; true pelvis) contains the bladder and other pelvic organs, and thus is also known as the true pelvis. The **pelvic brim** (also known as the **pelvic inlet**) forms the superior margin of the lesser pelvis, separating it from the greater pelvis. The pelvic brim is defined by a line formed by the upper margin of the pubic symphysis anteriorly, and the pectineal line of the pubis, the arcuate line of the ilium, and the sacral promontory (the anterior margin of the superior sacrum) posteriorly. The inferior limit of the lesser pelvic cavity is called the **pelvic outlet**. This large opening is defined by the inferior margin of the pubic symphysis anteriorly, and the ischiopubic ramus, the ischial tuberosity, the sacrotuberous ligament, and the inferior tip of the coccyx posteriorly. Because of the anterior tilt of the pelvis, the lesser pelvis is also angled, giving it an anterosuperior (pelvic inlet) to posteroinferior (pelvic outlet) orientation.

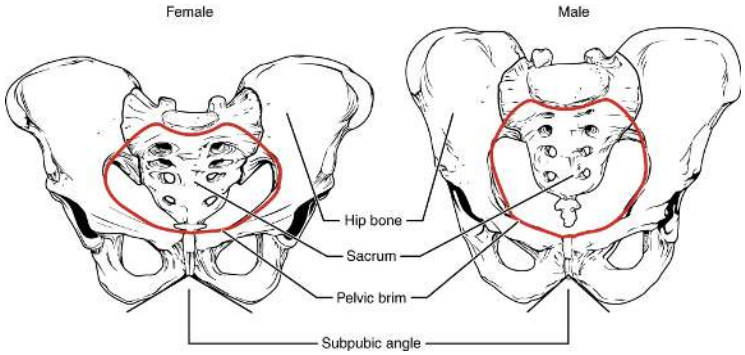


Figure 5.2.4: Male and Female Pelvis. The female pelvis is adapted for childbirth and is broader, with a larger subpubic angle, a rounder pelvic brim, and a wider and more shallow lesser pelvic cavity than the male pelvis.

Comparison of the Female and Male Pelvis

The differences between the adult female and male pelvis relate to function and body size. In general, the bones of the male pelvis are thicker and heavier, adapted for support of the male's heavier physical build and stronger muscles. The greater sciatic notch of the male hip bone is narrower and deeper than the broader notch of females. Because the female pelvis is adapted for childbirth, it is wider than the male pelvis, as evidenced by the distance between the anterior superior iliac spines (see Figure 5.2.4). The ischial tuberosities of females are also farther apart, which increases the size of the pelvic outlet. Because of this increased pelvic width, the subpubic angle is larger in females (greater than 80 degrees) than it is in males (less than 70 degrees). The female sacrum is wider, shorter, and less curved, and the sacral promontory projects less into the pelvic cavity, thus giving the female pelvic inlet (pelvic brim) a more rounded or oval shape compared to males. The lesser pelvic cavity of females is also wider and more shallow than the narrower, deeper, and tapering lesser pelvis of males. Because of the obvious differences between female and male hip bones, this is the one bone of the body that allows for the most accurate sex determination. Table 5.2.1 provides an overview of the general differences between the female and male pelvis.

Table 5.2.1: Overview of Differences between the Female and Male Pelvis

	Female pelvis	Male pelvis
Pelvic weight	Bones of the pelvis are lighter and thinner	Bones of the pelvis are thicker and heavier
Pelvic inlet shape	Pelvic inlet has a round or oval shape	Pelvic inlet is heart-shaped
Lesser pelvic cavity shape	Lesser pelvic cavity is shorter and wider	Lesser pelvic cavity is longer and narrower
Subpubic angle	Subpubic angle is greater than 80 degrees	Subpubic angle is less than 70 degrees
Pelvic outlet shape	Pelvic outlet is rounded and larger	Pelvic outlet is smaller

CAREER CONNECTION: Forensic Pathology and Forensic Anthropology

A forensic pathologist (also known as a medical examiner) is a medically trained physician who has been specifically trained in pathology to examine the bodies of the deceased to determine the cause of death. A forensic pathologist applies his or her understanding of disease as well as toxins, blood and DNA analysis, firearms and ballistics, and other factors to assess the cause and manner of death. At times, a forensic pathologist will be called to testify under oath in situations that involve a possible crime. Forensic pathology is a field that has received much media attention on television shows or following a high-profile death.

While forensic pathologists are responsible for determining whether the cause of someone's death was natural, a suicide, accidental, or a homicide, there are times when uncovering the cause of death is more complex, and other skills are needed. Forensic anthropology brings the tools and knowledge of physical anthropology and human osteology (the study of the skeleton) to the task of investigating a death. A forensic anthropologist assists medical and legal professionals in identifying human remains. The science behind forensic anthropology involves the study of archaeological excavation; the examination of hair; an understanding of plants, insects, and footprints; the ability to determine how much time has elapsed since the person died; the analysis of past medical history and toxicology; the ability to determine whether there are any postmortem injuries or alterations of the skeleton; and the identification of the decedent (deceased person) using skeletal and dental evidence.

Due to the extensive knowledge and understanding of excavation techniques, a forensic anthropologist is an integral and invaluable team member to have on-site when investigating a crime scene, especially when the recovery of human skeletal remains is involved. When remains are bought to a forensic anthropologist for examination, he or she must first determine whether the remains are in fact human. Once the remains have been identified as belonging to a person and not to an animal, the next step is to approximate the individual's age, sex, race, and height. The forensic anthropologist does not determine the cause of death, but rather provides information to the forensic pathologist, who will use all of the data collected to make a final determination regarding the cause of death.

Chapter Review

The pelvic girdle, consisting of a hip bone, serves to attach a lower limb to the axial skeleton. The hip bone articulates posteriorly at the sacroiliac joint with the sacrum, which is part of the axial skeleton. The right and left hip bones converge anteriorly and articulate with each other at the pubic symphysis. The combination of the hip bone, the sacrum, and the coccyx forms the pelvis. The pelvis has a pronounced anterior tilt. The primary function of the pelvis is to support the upper body and transfer body weight to the lower limbs. It also serves as the site of attachment for multiple muscles.

The hip bone consists of three regions: the ilium, ischium, and pubis. The ilium forms the large, fan-like region of the hip bone. The superior margin of this area is the iliac crest. Located at either end of the iliac crest are the anterior superior and posterior superior iliac spines. Inferior to these are the anterior inferior and posterior inferior iliac spines. The auricular surface of the ilium articulates with the sacrum to form the sacroiliac joint. The medial surface of the upper ilium forms the iliac fossa, with the arcuate line marking the inferior limit of this area. The posterior margin of the ilium has the large greater sciatic notch.

The posterolateral portion of the hip bone is the ischium. It has the expanded ischial tuberosity, which supports body weight when sitting. The ischial ramus projects anteriorly and superiorly. The posterior margin of the ischium has the shallow lesser sciatic notch and the ischial spine, which separates the greater and lesser sciatic notches.

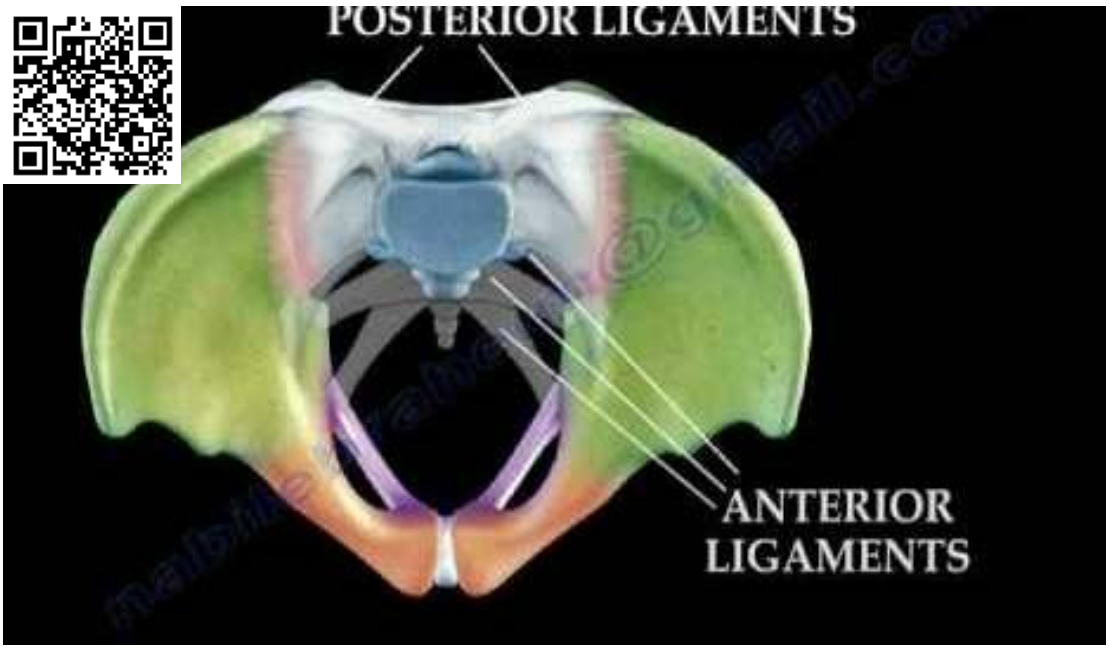
The pubis forms the anterior portion of the hip bone. The body of the pubis articulates with the pubis of the opposite hip bone at the pubic symphysis. The superior margin of the pubic body has the pubic tubercle. The pubis is joined to the ilium by the superior pubic ramus, the superior surface of which forms the pectineal line. The inferior pubic ramus projects inferiorly and laterally. The pubic arch is formed by the pubic symphysis, the bodies of the adjacent pubic bones, and the two inferior pubic rami. The inferior pubic ramus joins the ischial ramus to form the ischiopubic ramus. The subpubic angle is formed by the medial convergence of the right and left ischiopubic rami.

The lateral side of the hip bone has the cup-like acetabulum, which is part of the hip joint. The large anterior opening is the obturator foramen. The sacroiliac joint is supported by the anterior and posterior sacroiliac ligaments. The sacrum is also joined to the hip bone by the sacrospinous ligament, which attaches to the ischial spine, and the sacrotuberous ligament, which attaches to the ischial tuberosity. The sacrospinous and sacrotuberous ligaments contribute to the formation of the greater and lesser sciatic foramina.

The broad space of the upper pelvis is the greater pelvis, and the narrow, inferior space is the lesser pelvis. These areas are separated by the pelvic brim (pelvic inlet). The inferior opening of the pelvis is the pelvic outlet. Compared to the male, the female pelvis is wider to accommodate childbirth, has a larger subpubic angle, and a broader greater sciatic notch.

Interactive Link Questions

Watch this video for a 3-D view of the pelvis and its associated ligaments. What is the large opening in the bony pelvis, located between the ischium and pubic regions, and what two parts of the pubis contribute to the formation of this opening?



Answer: The obturator foramen is located between the ischium and the pubis. The superior and inferior pubic rami contribute to the boundaries of the obturator foramen.

Review Questions

Q. How many bones fuse in adulthood to form the hip bone?

A. 2

B. 3

C. 4

D. 5

Answer: B

Q. Which component forms the superior part of the hip bone?

A. ilium

B. pubis

C. ischium

D. sacrum

Answer: A

Q. Which of the following supports body weight when sitting?

A. iliac crest

B. ischial tuberosity

C. ischiopubic ramus

D. pubic body

Answer: B

Q. The ischial spine is found between which of the following structures?

A. inferior pubic ramus and ischial ramus

B. pectineal line and arcuate line

C. lesser sciatic notch and greater sciatic notch

D. anterior superior iliac spine and posterior superior iliac spine

Answer: C

Q. The pelvis _____.

A. has a subpubic angle that is larger in females

B. consists of the two hip bones, but does not include the sacrum or coccyx

C. has an obturator foramen, an opening that is defined in part by the sacrospinous and sacrotuberous ligaments

D. has a space located inferior to the pelvic brim called the greater pelvis

Answer: A

Critical Thinking Questions

Q. Describe the articulations and ligaments that unite the four bones of the pelvis to each other.

A. The pelvis is formed by the combination of the right and left hip bones, the sacrum, and the coccyx. The auricular surfaces of each hip bone articulate with the auricular surface of the sacrum to form the sacroiliac joint. This joint is supported on either side by the strong anterior and posterior sacroiliac ligaments. The right and left hip bones converge anteriorly, where the pubic bodies articulate with each other to form the pubic symphysis joint. The sacrum is also attached to the hip bone by the sacrospinous ligament, which spans the sacrum to the ischial spine, and the sacrotuberous ligament, which runs from the sacrum to the ischial tuberosity. The coccyx is attached to the inferior end of the sacrum.

Q. Discuss the ways in which the female pelvis is adapted for childbirth.

A. Compared to the male, the female pelvis is wider to accommodate childbirth. Thus, the female pelvis has greater distances between the anterior superior iliac spines and between the ischial tuberosities. The greater width of the female pelvis results in a larger subpubic angle. This angle, formed by the anterior convergence of the right and left ischiopubic rami, is larger in females (greater than 80 degrees) than in males (less than 70 degrees). The female sacral promontory does not project anteriorly as far as it does in males, which gives the pelvic brim (pelvic inlet) of the female a rounded or oval shape. The lesser pelvic cavity is wider and more shallow in females, and the pelvic outlet is larger than in males. Thus, the greater width of the female pelvis, with its larger pelvic inlet, lesser pelvis, and pelvic outlet, are important for childbirth because the baby must pass through the pelvis during delivery.

Glossary

acetabulum
large, cup-shaped cavity located on the lateral side of the hip bone; formed by the junction of the ilium, pubis, and ischium portions of the hip bone

anterior inferior iliac spine
small, bony projection located on the anterior margin of the ilium, below the anterior superior iliac spine

anterior sacroiliac ligament
strong ligament between the sacrum and the ilium portions of the hip bone that supports the anterior side of the sacroiliac joint

anterior superior iliac spine
rounded, anterior end of the iliac crest

arcuate line of the ilium
smooth ridge located at the inferior margin of the iliac fossa; forms the lateral portion of the pelvic brim

auricular surface of the ilium
roughened area located on the posterior, medial side of the ilium of the hip bone; articulates with the auricular surface of the sacrum to form the sacroiliac joint

coxal bone
hip bone

greater pelvis
(also, greater pelvic cavity or false pelvis) broad space above the pelvic brim defined laterally by the fan-like portion of the upper ilium

greater sciatic foramen
pelvic opening formed by the greater sciatic notch of the hip bone, the sacrum, and the sacrospinous ligament

greater sciatic notch
large, U-shaped indentation located on the posterior margin of the ilium, superior to the ischial spine

hip bone
coxal bone; single bone that forms the pelvic girdle; consists of three areas, the ilium, ischium, and pubis

iliac crest
curved, superior margin of the ilium

iliac fossa
shallow depression found on the anterior and medial surfaces of the upper ilium

ilium
superior portion of the hip bone

inferior pubic ramus
narrow segment of bone that passes inferiorly and laterally from the pubic body; joins with the ischial ramus to form the ischiopubic ramus

ischial ramus
bony extension projecting anteriorly and superiorly from the ischial tuberosity; joins with the inferior pubic ramus to form the ischiopubic ramus

ischial spine
pointed, bony projection from the posterior margin of the ischium that separates the greater sciatic notch and lesser sciatic notch

ischial tuberosity
large, roughened protuberance that forms the posteroinferior portion of the hip bone; weight-bearing region of the pelvis when sitting

ischiopubic ramus
narrow extension of bone that connects the ischial tuberosity to the pubic body; formed by the junction of the ischial ramus and inferior pubic ramus

ischium
posteroinferior portion of the hip bone

lesser pelvis
(also, lesser pelvic cavity or true pelvis) narrow space located within the pelvis, defined superiorly by the pelvic brim (pelvic inlet) and inferiorly by the pelvic outlet

lesser sciatic foramen
pelvic opening formed by the lesser sciatic notch of the hip bone, the sacrospinous ligament, and the sacrotuberous ligament

lesser sciatic notch
shallow indentation along the posterior margin of the ischium, inferior to the ischial spine

obturator foramen
large opening located in the anterior hip bone, between the pubis and ischium regions

pectineal line
narrow ridge located on the superior surface of the superior pubic ramus

pelvic brim
pelvic inlet; the dividing line between the greater and lesser pelvic regions; formed by the superior margin of the pubic symphysis, the pectineal lines of each pubis, the arcuate lines of each ilium, and the sacral promontory

pelvic girdle
hip girdle; consists of a single hip bone, which attaches a lower limb to the sacrum of the axial skeleton

pelvic inlet
pelvic brim

pelvic outlet
inferior opening of the lesser pelvis; formed by the inferior margin of the pubic symphysis, right and left ischiopubic rami and sacrotuberous ligaments, and the tip of the coccyx

pelvis
ring of bone consisting of the right and left hip bones, the sacrum, and the coccyx

posterior inferior iliac spine
small, bony projection located at the inferior margin of the auricular surface on the posterior ilium

posterior sacroiliac ligament
strong ligament spanning the sacrum and ilium of the hip bone that supports the posterior side of the sacroiliac joint

posterior superior iliac spine
rounded, posterior end of the iliac crest

pubic arch
bony structure formed by the pubic symphysis, and the bodies and inferior pubic rami of the right and left pubic bones

pubic body
enlarged, medial portion of the pubis region of the hip bone

pubic symphysis
joint formed by the articulation between the pubic bodies of the right and left hip bones

pubic tubercle

small bump located on the superior aspect of the pubic body

pubis
anterior portion of the hip bone

sacroiliac joint
joint formed by the articulation between the auricular surfaces of the sacrum and ilium

sacrospinous ligament
ligament that spans the sacrum to the ischial spine of the hip bone

sacrotuberous ligament
ligament that spans the sacrum to the ischial tuberosity of the hip bone

subpubic angle
inverted V-shape formed by the convergence of the right and left ischiopubic rami; this angle is greater than 80 degrees in females and less than 70 degrees in males

superior pubic ramus
narrow segment of bone that passes laterally from the pubic body to join the ilium

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CHAPTER OVERVIEW

6: Bones, Joints and Muscles of the Pelvic Girdle and Lower Limb

6.1: Bones of the Lower Limb

6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs

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6.1: Bones of the Lower Limb

Learning Objectives

- Identify the divisions of the lower limb and describe the bones of each region
- Describe the bones and bony landmarks that articulate at each joint of the lower limb

Like the upper limb, the lower limb is divided into three regions. The **thigh** is that portion of the lower limb located between the hip joint and knee joint. The **leg** is specifically the region between the knee joint and the ankle joint. Distal to the ankle is the **foot**. The lower limb contains 30 bones. These are the femur, patella, tibia, fibula, tarsal bones, metatarsal bones, and phalanges (see [link]). The **femur** is the single bone of the thigh. The **patella** is the kneecap and articulates with the distal femur. The **tibia** is the larger, weight-bearing bone located on the medial side of the leg, and the **fibula** is the thin bone of the lateral leg. The bones of the foot are divided into three groups. The posterior portion of the foot is formed by a group of seven bones, each of which is known as a **tarsal bone**, whereas the mid-foot contains five elongated bones, each of which is a **metatarsal bone**. The toes contain 14 small bones, each of which is a **phalanx bone of the foot**.

Femur

The femur, or thigh bone, is the single bone of the thigh region (Figure 6.1.1). It is the longest and strongest bone of the body, and accounts for approximately one-quarter of a person's total height. The rounded, proximal end is the **head of the femur**, which articulates with the acetabulum of the hip bone to form the **hip joint**. The **fovea capitis** is a minor indentation on the medial side of the femoral head that serves as the site of attachment for the **ligament of the head of the femur**. This ligament spans the femur and acetabulum, but is weak and provides little support for the hip joint. It does, however, carry an important artery that supplies the head of the femur.

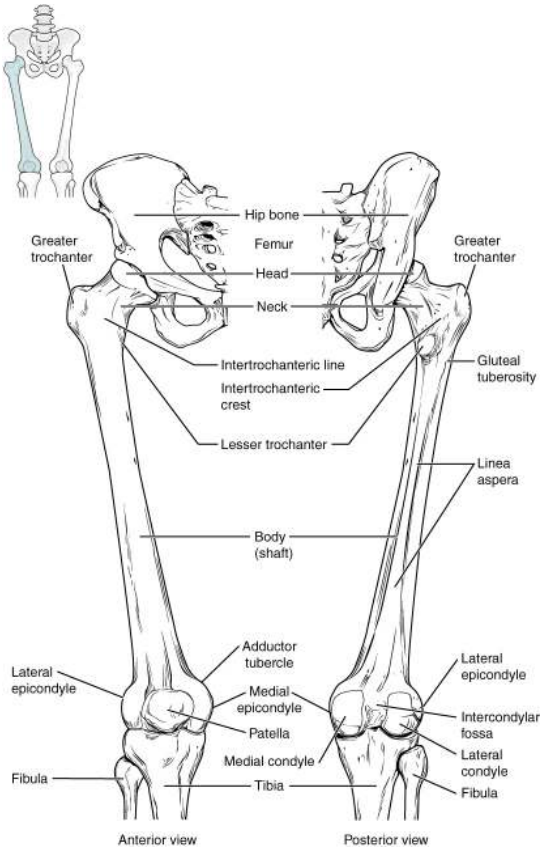


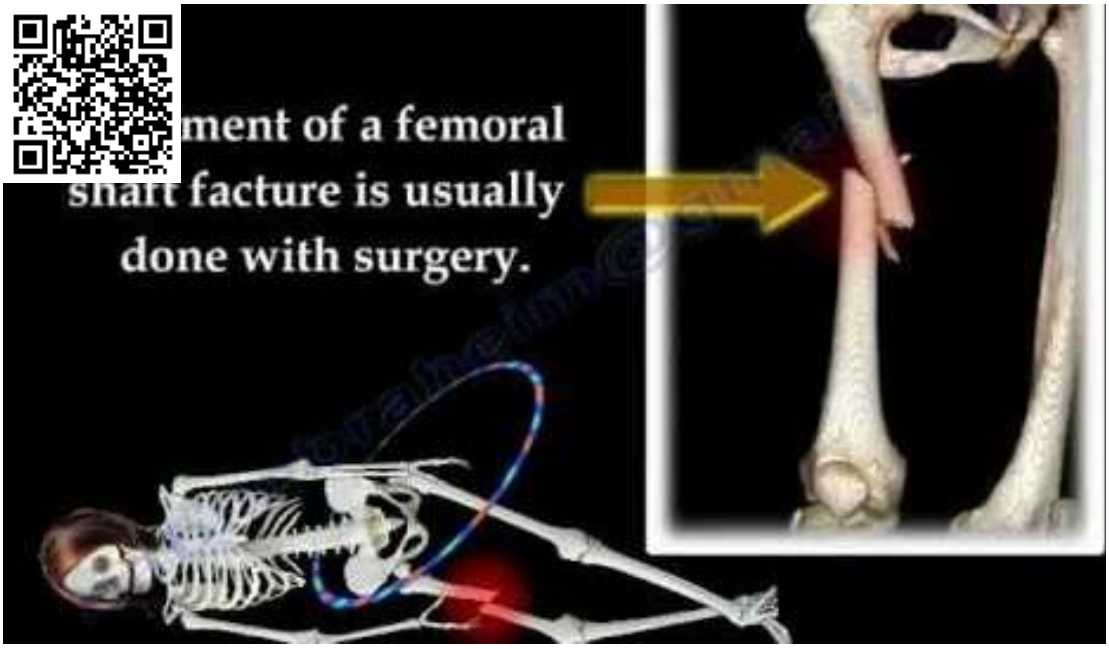
Figure 6.1.1: Femur and Patella. The femur is the single bone of the thigh region. It articulates superiorly with the hip bone at the hip joint, and inferiorly with the tibia at the knee joint. The patella only articulates with the distal end of the femur.

The narrowed region below the head is the **neck of the femur**. This is a common area for fractures of the femur. The **greater trochanter** is the large, upward, bony projection located above the base of the neck. Multiple muscles that act across the hip joint attach to the greater trochanter, which, because of its projection from the femur, gives additional leverage to these muscles. The greater trochanter can be felt just under the skin on the lateral side of your upper thigh. The **lesser trochanter** is a small, bony prominence that lies on the medial aspect of the femur, just below the neck. A single, powerful muscle attaches to the lesser trochanter. Running between the greater and lesser trochanters on the anterior side of the femur is the roughened **intertrochanteric line**. The trochanters are also connected on the posterior side of the femur by the larger **intertrochanteric crest**.

The elongated **shaft of the femur** has a slight anterior bowing or curvature. At its proximal end, the posterior shaft has the **gluteal tuberosity**, a roughened area extending inferiorly from the greater trochanter. More inferiorly, the gluteal tuberosity becomes continuous with the **linea aspera** ("rough line"). This is the roughened ridge that passes distally along the posterior side of the mid-femur. Multiple muscles of the hip and thigh regions make long, thin attachments to the femur along the linea aspera.

The distal end of the femur has medial and lateral bony expansions. On the lateral side, the smooth portion that covers the distal and posterior aspects of the lateral expansion is the **lateral condyle of the femur**. The roughened area on the outer, lateral side of the condyle is the **lateral epicondyle of the femur**. Similarly, the smooth region of the distal and posterior medial femur is the **medial condyle of the femur**, and the irregular outer, medial side of this is the **medial epicondyle of the femur**. The lateral and medial condyles articulate with the tibia to form the knee joint. The epicondyles provide attachment for muscles and supporting ligaments of the knee. The **adductor tubercle** is a small bump located at the superior margin of the medial epicondyle. Posteriorly, the medial and lateral condyles are separated by a deep depression called the **intercondylar fossa**. Anteriorly, the smooth surfaces of the condyles join together to form a wide groove called the **patellar surface**, which provides for articulation with the patella bone. The combination of the medial and lateral condyles with the patellar surface gives the distal end of the femur a horseshoe (U) shape.

Watch this video to view how a fracture of the mid-femur is surgically repaired. How are the two portions of the broken femur stabilized during surgical repair of a fractured femur?



Patella

The patella (kneecap) is largest sesamoid bone of the body (see Figure 6.1.1). A sesamoid bone is a bone that is incorporated into the tendon of a muscle where that tendon crosses a joint. The sesamoid bone articulates with the underlying bones to prevent damage to the muscle tendon due to rubbing against the bones during movements of the joint. The patella is found in the tendon of the quadriceps femoris muscle, the large muscle of the anterior thigh that passes across the anterior knee to attach to the tibia. The patella articulates with the patellar surface of the femur and thus prevents rubbing of the muscle tendon against the distal femur. The patella also lifts the tendon away from the knee joint, which increases the leverage power of the quadriceps femoris muscle as it acts across the knee. The patella does not articulate with the tibia.

> *Visit this site to perform a virtual knee replacement surgery. The prosthetic knee components must be properly aligned to function properly. How is this alignment ensured?*

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HOMEOSTATIC IMBALANCES: Runner's Knee

Runner's knee, also known as patellofemoral syndrome, is the most common overuse injury among runners. It is most frequent in adolescents and young adults, and is more common in females. It often results from excessive running, particularly downhill, but may also occur in athletes who do a lot of knee bending, such as jumpers, skiers, cyclists, weight lifters, and soccer players. It is felt as a dull, aching pain around the front of the knee and deep to the patella. The pain may be felt when walking or running, going up or down stairs, kneeling or squatting, or after sitting with the knee bent for an extended period.

Patellofemoral syndrome may be initiated by a variety of causes, including individual variations in the shape and movement of the patella, a direct blow to the patella, or flat feet or improper shoes that cause excessive turning in or out of the feet or leg. These factors may cause in an imbalance in the muscle pull that acts on the patella, resulting in an abnormal tracking of the patella that allows it to deviate too far toward the lateral side of the patellar surface on the distal femur.

Because the hips are wider than the knee region, the femur has a diagonal orientation within the thigh, in contrast to the vertically oriented tibia of the leg (Figure 6.1.2). The Q-angle is a measure of how far the femur is angled laterally away from vertical. The Q-angle is normally 10–15 degrees, with females typically having a larger Q-angle due to their wider pelvis. During extension of the knee, the quadriceps femoris muscle pulls the patella both superiorly and laterally, with the lateral pull greater in women due to their large Q-angle. This makes women more vulnerable to developing patellofemoral syndrome than men. Normally, the large lip on the lateral side of the patellar surface of the femur compensates for the lateral pull on the patella, and thus helps to maintain its proper tracking.

However, if the pull produced by the medial and lateral sides of the quadriceps femoris muscle is not properly balanced, abnormal tracking of the patella toward the lateral side may occur. With continued use, this produces pain and could result in damage to the articulating surfaces of the patella and femur, and the possible future development of arthritis. Treatment generally involves stopping the activity that produces knee pain for a period of time, followed by a gradual resumption of activity. Proper strengthening of the quadriceps femoris muscle to correct for imbalances is also important to help prevent reoccurrence.

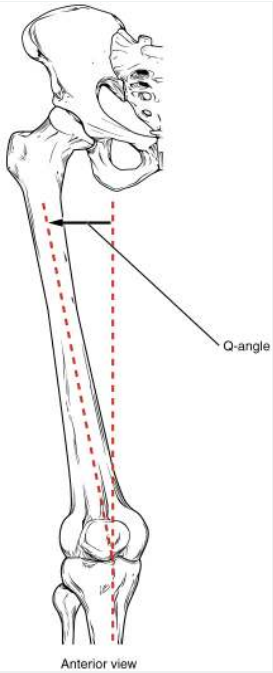


Figure 6.1.2: The Q-Angle. The Q-angle is a measure of the amount of lateral deviation of the femur from the vertical line of the tibia. Adult females have a larger Q-angle due to their wider pelvis than adult males.

Tibia

The tibia (shin bone) is the medial bone of the leg and is larger than the fibula, with which it is paired (Figure 6.1.3). The tibia is the main weight-bearing bone of the lower leg and the second longest bone of the body, after the femur. The medial side of the tibia is located immediately under the skin, allowing it to be easily palpated down the entire length of the medial leg.

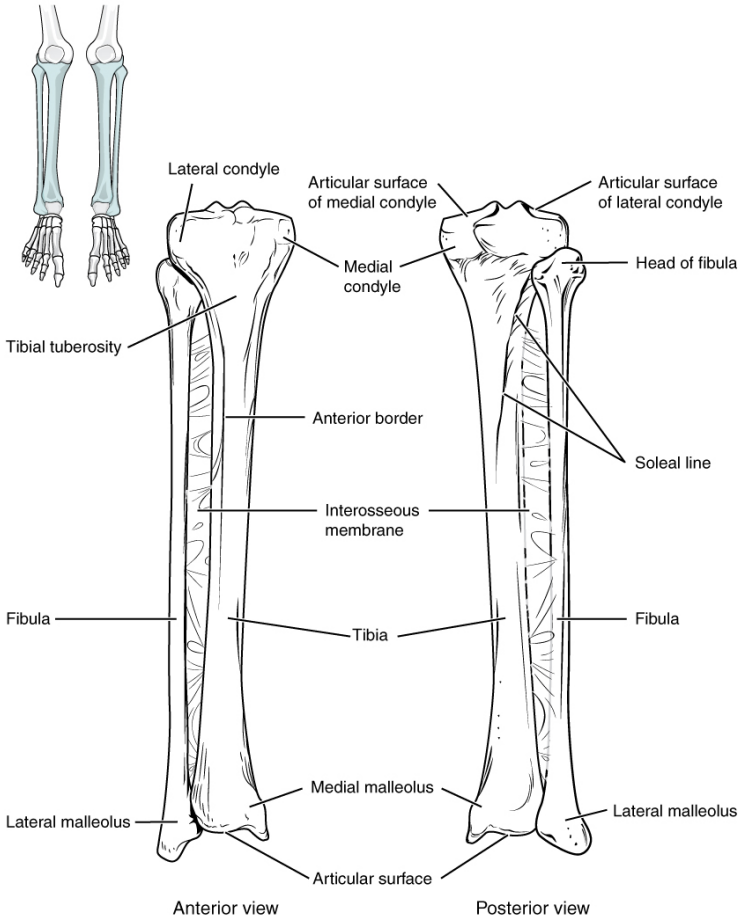


Figure 6.1.3: Tibia and Fibula. The tibia is the larger, weight-bearing bone located on the medial side of the leg. The fibula is the slender bone of the lateral side of the leg and does not bear weight.

The proximal end of the tibia is greatly expanded. The two sides of this expansion form the **medial condyle of the tibia** and the **lateral condyle of the tibia**. The tibia does not have epicondyles. The top surface of each condyle is smooth and flattened. These areas articulate with the medial and lateral condyles of the femur to form the **knee joint**. Between the articulating surfaces of the tibial condyles is the **intercondylar eminence**, an irregular, elevated area that serves as the inferior attachment point for two supporting ligaments of the knee.

The **tibial tuberosity** is an elevated area on the anterior side of the tibia, near its proximal end. It is the final site of attachment for the muscle tendon associated with the patella. More inferiorly, the **shaft of the tibia** becomes triangular in shape. The anterior apex of

MH this triangle forms the **anterior border of the tibia**, which begins at the tibial tuberosity and runs inferiorly along the length of the tibia. Both the anterior border and the medial side of the triangular shaft are located immediately under the skin and can be easily palpated along the entire length of the tibia. A small ridge running down the lateral side of the tibial shaft is the **interosseous border of the tibia**. This is for the attachment of the **interosseous membrane of the leg**, the sheet of dense connective tissue that unites the tibia and fibula bones. Located on the posterior side of the tibia is the **soleal line**, a diagonally running, roughened ridge that begins below the base of the lateral condyle, and runs down and medially across the proximal third of the posterior tibia. Muscles of the posterior leg attach to this line.

The large expansion found on the medial side of the distal tibia is the **medial malleolus** (“little hammer”). This forms the large bony bump found on the medial side of the ankle region. Both the smooth surface on the inside of the medial malleolus and the smooth area at the distal end of the tibia articulate with the talus bone of the foot as part of the ankle joint. On the lateral side of the distal tibia is a wide groove called the **fibular notch**. This area articulates with the distal end of the fibula, forming the **distal tibiofibular joint**.

Fibula

The fibula is the slender bone located on the lateral side of the leg (see Figure 6.1.3). The fibula does not bear weight. It serves primarily for muscle attachments and thus is largely surrounded by muscles. Only the proximal and distal ends of the fibula can be palpated.

The **head of the fibula** is the small, knob-like, proximal end of the fibula. It articulates with the inferior aspect of the lateral tibial condyle, forming the **proximal tibiofibular joint**. The thin **shaft of the fibula** has the **interosseous border of the fibula**, a narrow ridge running down its medial side for the attachment of the interosseous membrane that spans the fibula and tibia. The distal end of the fibula forms the **lateral malleolus**, which forms the easily palpated bony bump on the lateral side of the ankle. The deep (medial) side of the lateral malleolus articulates with the talus bone of the foot as part of the ankle joint. The distal fibula also articulates with the fibular notch of the tibia.

Tarsal Bones

The posterior half of the foot is formed by seven tarsal bones (Figure 6.1.4). The most superior bone is the **talus**. This has a relatively square-shaped, upper surface that articulates with the tibia and fibula to form the **ankle joint**. Three areas of articulation form the ankle joint: The superomedial surface of the talus bone articulates with the medial malleolus of the tibia, the top of the talus articulates with the distal end of the tibia, and the lateral side of the talus articulates with the lateral malleolus of the fibula. Inferiorly, the talus articulates with the **calcaneus** (heel bone), the largest bone of the foot, which forms the heel. Body weight is transferred from the tibia to the talus to the calcaneus, which rests on the ground. The medial calcaneus has a prominent bony extension called the **sustentaculum tali** ("support for the talus") that supports the medial side of the talus bone.

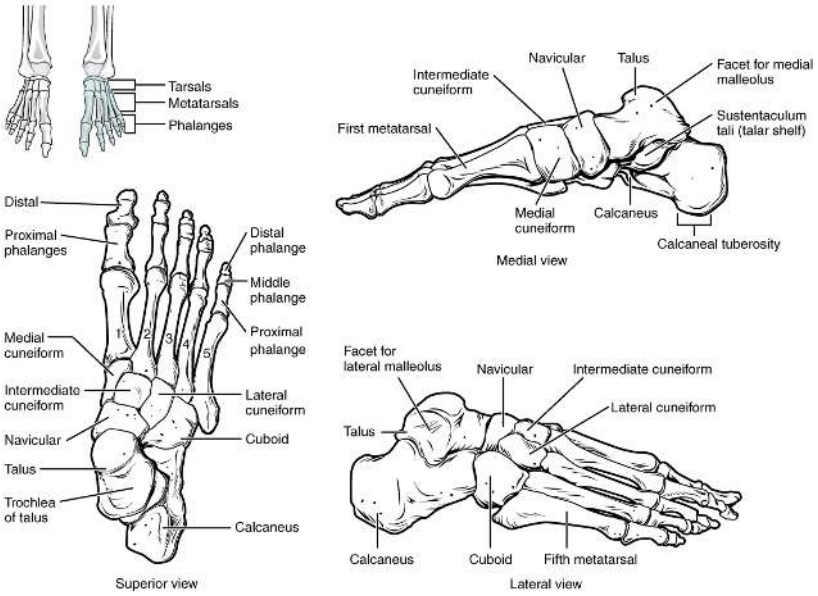


Figure 6.1.4: Bones of the Foot. The bones of the foot are divided into three groups. The posterior foot is formed by the seven tarsal bones. The mid-foot has the five metatarsal bones. The toes contain the phalanges.

The **cuboid** bone articulates with the anterior end of the calcaneus bone. The cuboid has a deep groove running across its inferior surface, which provides passage for a muscle tendon. The talus bone articulates anteriorly with the **navicular** bone, which in turn articulates anteriorly with the three cuneiform ("wedge-shaped") bones. These bones are the **medial cuneiform**, the **intermediate cuneiform**, and the **lateral cuneiform**. Each of these bones has a broad superior surface and a narrow inferior surface, which together produce the transverse (medial-lateral) curvature of the foot. The navicular and lateral cuneiform bones also articulate with the medial side of the cuboid bone.

Use this tutorial to review the bones of the foot. Which tarsal bones are in the proximal, intermediate, and distal groups?



Metatarsal Bones

The anterior half of the foot is formed by the five metatarsal bones, which are located between the tarsal bones of the posterior foot and the phalanges of the toes (see Figure 6.1.4). These elongated bones are numbered 1–5, starting with the medial side of the foot. The first metatarsal bone is shorter and thicker than the others. The second metatarsal is the longest. The **base of the metatarsal bone** is the proximal end of each metatarsal bone. These articulate with the cuboid or cuneiform bones. The base of the fifth metatarsal has a large, lateral expansion that provides for muscle attachments. This expanded base of the fifth metatarsal can be felt as a bony bump at the midpoint along the lateral border of the foot. The expanded distal end of each metatarsal is the **head of the metatarsal bone**. Each metatarsal bone articulates with the proximal phalanx of a toe to form a **metatarsophalangeal joint**. The heads of the metatarsal bones also rest on the ground and form the ball (anterior end) of the foot.

Phalanges

The toes contain a total of 14 phalanx bones (phalanges), arranged in a similar manner as the phalanges of the fingers (see Figure 6.1.4). The toes are numbered 1–5, starting with the big toe (**hallux**). The big toe has two phalanx bones, the proximal and distal phalanges. The remaining toes all have proximal, middle, and distal phalanges. A joint between adjacent phalanx bones is called an interphalangeal joint.

View this link to learn about a bunion, a localized swelling on the medial side of the foot, next to the first metatarsophalangeal joint, at the base of the big toe. What is a bunion and what type of shoe is most likely to cause this to develop? http://bones.emedtv.com/bunionectomy-with-fusion-video/what-are-bunions-video.html

Arches of the Foot

When the foot comes into contact with the ground during walking, running, or jumping activities, the impact of the body weight puts a tremendous amount of pressure and force on the foot. During running, the force applied to each foot as it contacts the ground can be up to 2.5 times your body weight. The bones, joints, ligaments, and muscles of the foot absorb this force, thus greatly reducing the amount of shock that is passed superiorly into the lower limb and body. The arches of the foot play an important role in this shock-absorbing ability. When weight is applied to the foot, these arches will flatten somewhat, thus absorbing energy. When the weight is removed, the arch rebounds, giving "spring" to the step. The arches also serve to distribute body weight side to side and to either end of the foot.

The foot has a transverse arch, a medial longitudinal arch, and a lateral longitudinal arch (see Figure 6.1.4). The transverse arch forms the medial-lateral curvature of the mid-foot. It is formed by the wedge shapes of the cuneiform bones and bases (proximal ends) of the first to fourth metatarsal bones. This arch helps to distribute body weight from side to side within the foot, thus allowing the foot to accommodate uneven terrain.

The longitudinal arches run down the length of the foot. The lateral longitudinal arch is relatively flat, whereas the medial longitudinal arch is larger (taller). The longitudinal arches are formed by the tarsal bones posteriorly and the metatarsal bones anteriorly. These arches are supported at either end, where they contact the ground. Posteriorly, this support is provided by the calcaneus bone and anteriorly by the heads (distal ends) of the metatarsal bones. The talus bone, which receives the weight of the body, is located at the top of the longitudinal arches. Body weight is then conveyed from the talus to the ground by the anterior and posterior ends of these arches. Strong ligaments unite the adjacent foot bones to prevent disruption of the arches during weight bearing. On the bottom of the foot, additional ligaments tie together the anterior and posterior ends of the arches. These ligaments have elasticity, which allows them to stretch somewhat during weight bearing, thus allowing the longitudinal arches to spread. The stretching of these ligaments stores energy within the foot, rather than passing these forces into the leg. Contraction of the foot muscles also plays an important role in this energy absorption. When the weight is removed, the elastic ligaments recoil and pull the ends of the arches closer together. This recovery of the arches releases the stored energy and improves the energy efficiency of walking.

Stretching of the ligaments that support the longitudinal arches can lead to pain. This can occur in overweight individuals, with people who have jobs that involve standing for long periods of time (such as a waitress), or walking or running long distances. If stretching of the ligaments is prolonged, excessive, or repeated, it can result in a gradual lengthening of the supporting ligaments, with subsequent depression or collapse of the longitudinal arches, particularly on the medial side of the foot. This condition is called pes planus ("flat foot" or "fallen arches").

Chapter Review

The lower limb is divided into three regions. These are the thigh, located between the hip and knee joints; the leg, located between the knee and ankle joints; and distal to the ankle, the foot. There are 30 bones in each lower limb. These are the femur, patella, tibia, fibula, seven tarsal bones, five metatarsal bones, and 14 phalanges.

The femur is the single bone of the thigh. Its rounded head articulates with the acetabulum of the hip bone to form the hip joint. The head has the fovea capitis for attachment of the ligament of the head of the femur. The narrow neck joins inferiorly with the greater and lesser trochanters. Passing between these bony expansions are the intertrochanteric line on the anterior femur and the larger intertrochanteric crest on the posterior femur. On the posterior shaft of the femur is the gluteal tuberosity proximally and the linea aspera in the mid-shaft region. The expanded distal end consists of three articulating surfaces: the medial and lateral condyles, and the patellar surface. The outside margins of the condyles are the medial and lateral epicondyles. The adductor tubercle is on the superior aspect of the medial epicondyle.

The patella is a sesamoid bone located within a muscle tendon. It articulates with the patellar surface on the anterior side of the distal femur, thereby protecting the muscle tendon from rubbing against the femur.

The leg contains the large tibia on the medial side and the slender fibula on the lateral side. The tibia bears the weight of the body, whereas the fibula does not bear weight. The interosseous border of each bone is the attachment site for the interosseous membrane of the leg, the connective tissue sheet that unites the tibia and fibula.

The proximal tibia consists of the expanded medial and lateral condyles, which articulate with the medial and lateral condyles of the femur to form the knee joint. Between the tibial condyles is the intercondylar eminence. On the anterior side of the proximal tibia is the tibial tuberosity, which is continuous inferiorly with the anterior border of the tibia. On the posterior side, the proximal tibia has the curved soleal line. The bony expansion on the medial side of the distal tibia is the medial malleolus. The groove on the lateral side of the distal tibia is the fibular notch.

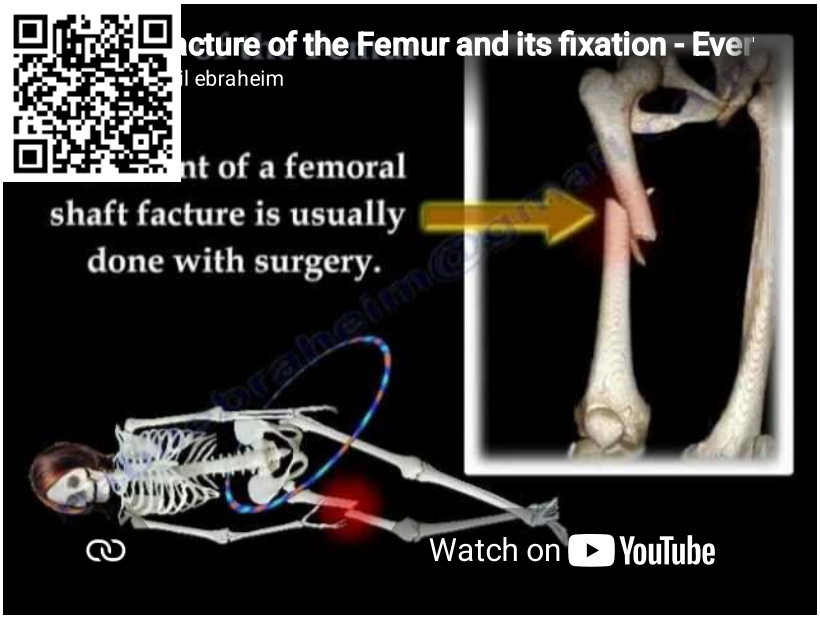
The head of the fibula forms the proximal end and articulates with the underside of the lateral condyle of the tibia. The distal fibula articulates with the fibular notch of the tibia. The expanded distal end of the fibula is the lateral malleolus.

The posterior foot is formed by the seven tarsal bones. The talus articulates superiorly with the distal tibia, the medial malleolus of the tibia, and the lateral malleolus of the fibula to form the ankle joint. The talus articulates inferiorly with the calcaneus bone. The sustentaculum tali of the calcaneus helps to support the talus. Anterior to the talus is the navicular bone, and anterior to this are the medial, intermediate, and lateral cuneiform bones. The cuboid bone is anterior to the calcaneus.

The five metatarsal bones form the anterior foot. The base of these bones articulate with the cuboid or cuneiform bones. The metatarsal heads, at their distal ends, articulate with the proximal phalanges of the toes. The big toe (toe number 1) has proximal and distal phalanx bones. The remaining toes have proximal, middle, and distal phalanges.

Interactive Link Questions

Watch this video to view how a fracture of the mid-femur is surgically repaired. How are the two portions of the broken femur stabilized during surgical repair of a fractured femur?



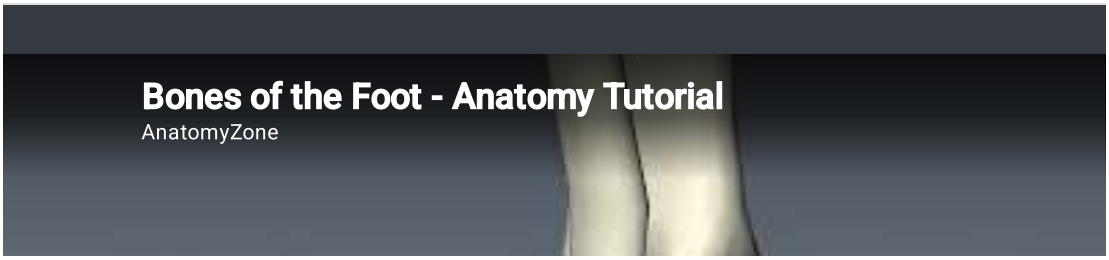
Answer: A hole is drilled into the greater trochanter, the bone marrow (medullary) space inside the femur is enlarged, and finally an intramedullary rod is inserted into the femur. This rod is then anchored to the bone with screws.

Visit this site to perform a virtual knee replacement surgery. The prosthetic knee components must be properly aligned to function properly. How is this alignment ensured?

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Answer: Metal cutting jigs are attached to the bones to ensure that the bones are cut properly prior to the attachment of prosthetic components.

Use this tutorial to review the bones of the foot. Which tarsal bones are in the proximal, intermediate, and distal groups?



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Answer: The proximal group of tarsal bones includes the calcaneus and talus bones, the navicular bone is intermediate, and the distal group consists of the cuboid bone plus the medial, intermediate, and lateral cuneiform bones.

View this link to learn about a bunion, a localized swelling on the medial side of the foot, next to the first metatarsophalangeal joint, at the base of the big toe. What is a bunion and what type of shoe is most likely to cause this to develop?

Answer: A bunion results from the deviation of the big toe toward the second toe, which causes the distal end of the first metatarsal bone to stick out. A bunion may also be caused by prolonged pressure on the foot from pointed shoes with a narrow toe box that compresses the big toe and pushes it toward the second toe.

Review Questions

Q. Which bony landmark of the femur serves as a site for muscle attachments?

A. fovea capitis

B. lesser trochanter

C. head

D. medial condyle

Answer: B

Q. What structure contributes to the knee joint?

A. lateral malleolus of the fibula

B. tibial tuberosity

C. medial condyle of the tibia

D. lateral epicondyle of the femur

Answer: C

Q. Which tarsal bone articulates with the tibia and fibula?

A. calcaneus

B. cuboid

C. navicular

D. talus

Answer: D

Q. What is the total number of bones found in the foot and toes?

A. 7

B. 14

C. 26

D. 30

Answer: C

Q. The tibia _____.

A. has an expanded distal end called the lateral malleolus

B. is not a weight-bearing bone

C. is firmly anchored to the fibula by an interosseous membrane

D. can be palpated (felt) under the skin only at its proximal and distal ends

Answer: C

Critical Thinking Questions

Q. Define the regions of the lower limb, name the bones found in each region, and describe the bony landmarks that articulate together to form the hip, knee, and ankle joints.

A. The lower limb is divided into three regions. The thigh is the region located between the hip and knee joints. It contains the femur and the patella. The hip joint is formed by the articulation between the acetabulum of the hip bone and the head of the femur. The leg is the region between the knee and ankle joints, and contains the tibia (medially) and the fibula (laterally). The knee joint is formed by the articulations between the medial and lateral condyles of the femur, and the medial and lateral condyles of the tibia. Also associated with the knee is the patella, which articulates with the patellar surface of the distal femur. The foot is found distal to the ankle and contains 26 bones. The ankle joint is formed by the articulations between the talus bone of the foot and the distal end of the tibia, the medial malleolus of the tibia, and the lateral malleolus of the fibula. The posterior foot contains the seven tarsal bones, which are the talus, calcaneus, navicular, cuboid, and the medial, intermediate, and lateral cuneiform bones. The anterior foot consists of the five metatarsal bones, which are numbered 1–5 starting on the medial

side of the foot. The toes contain 14 phalanx bones, with the big toe (toe number 1) having a proximal and a distal phalanx, and the other toes having proximal, middle, and distal phalanges.

Q. The talus bone of the foot receives the weight of the body from the tibia. The talus bone then distributes this weight toward the ground in two directions: one-half of the body weight is passed in a posterior direction and one-half of the weight is passed in an anterior direction. Describe the arrangement of the tarsal and metatarsal bones that are involved in both the posterior and anterior distribution of body weight.

A. The talus bone articulates superiorly with the tibia and fibula at the ankle joint, with body weight passed from the tibia to the talus. Body weight from the talus is transmitted to the ground by both ends of the medial and lateral longitudinal foot arches. Weight is passed posteriorly through both arches to the calcaneus bone, which forms the heel of the foot and is in contact with the ground. On the medial side of the foot, body weight is passed anteriorly from the talus bone to the navicular bone, and then to the medial, intermediate, and lateral cuneiform bones. The cuneiform bones pass the weight anteriorly to the first, second, and third metatarsal bones, whose heads (distal ends) are in contact with the ground. On the lateral side, body weight is passed anteriorly from the talus through the calcaneus, cuboid, and fourth and fifth metatarsal bones. The talus bone thus transmits body weight posteriorly to the calcaneus and anteriorly through the navicular, cuneiform, and cuboid bones, and metatarsals one through five.

Glossary

adductor tubercle

: small, bony bump located on the superior aspect of the medial epicondyle of the femur

ankle joint

: joint that separates the leg and foot portions of the lower limb; formed by the articulations between the talus bone of the foot inferiorly, and the distal end of the tibia, medial malleolus of the tibia, and lateral malleolus of the fibula superiorly

anterior border of the tibia

: narrow, anterior margin of the tibia that extends inferiorly from the tibial tuberosity

base of the metatarsal bone

: expanded, proximal end of each metatarsal bone

calcaneus

: heel bone; posterior, inferior tarsal bone that forms the heel of the foot

cuboid

: tarsal bone that articulates posteriorly with the calcaneus bone, medially with the lateral cuneiform bone, and anteriorly with the fourth and fifth metatarsal bones

distal tibiofibular joint

: articulation between the distal fibula and the fibular notch of the tibia

femur

: thigh bone; the single bone of the thigh

fibula

: thin, non-weight-bearing bone found on the lateral side of the leg

fibular notch

: wide groove on the lateral side of the distal tibia for articulation with the fibula at the distal tibiofibular joint

foot

: portion of the lower limb located distal to the ankle joint

fovea capitis

: minor indentation on the head of the femur that serves as the site of attachment for the ligament to the head of the femur

gluteal tuberosity

: roughened area on the posterior side of the proximal femur, extending inferiorly from the base of the greater trochanter

greater trochanter

large, bony expansion of the femur that projects superiorly from the base of the femoral neck

hallux

big toe; digit 1 of the foot

head of the femur

rounded, proximal end of the femur that articulates with the acetabulum of the hip bone to form the hip joint

head of the fibula

small, knob-like, proximal end of the fibula; articulates with the inferior aspect of the lateral condyle of the tibia

head of the metatarsal bone

expanded, distal end of each metatarsal bone

hip joint

joint located at the proximal end of the lower limb; formed by the articulation between the acetabulum of the hip bone and the head of the femur

intercondylar eminence

irregular elevation on the superior end of the tibia, between the articulating surfaces of the medial and lateral condyles

intercondylar fossa

deep depression on the posterior side of the distal femur that separates the medial and lateral condyles

intermediate cuneiform

middle of the three cuneiform tarsal bones; articulates posteriorly with the navicular bone, medially with the medial cuneiform bone, laterally with the lateral cuneiform bone, and anteriorly with the second metatarsal bone

interosseous border of the fibula

small ridge running down the medial side of the fibular shaft; for attachment of the interosseous membrane between the fibula and tibia

interosseous border of the tibia

small ridge running down the lateral side of the tibial shaft; for attachment of the interosseous membrane between the tibia and fibula

interosseous membrane of the leg

sheet of dense connective tissue that unites the shafts of the tibia and fibula bones

intertrochanteric crest

short, prominent ridge running between the greater and lesser trochanters on the posterior side of the proximal femur

intertrochanteric line

small ridge running between the greater and lesser trochanters on the anterior side of the proximal femur

knee joint

joint that separates the thigh and leg portions of the lower limb; formed by the articulations between the medial and lateral condyles of the femur, and the medial and lateral condyles of the tibia

lateral condyle of the femur

smooth, articulating surface that forms the distal and posterior sides of the lateral expansion of the distal femur

lateral condyle of the tibia

lateral, expanded region of the proximal tibia that includes the smooth surface that articulates with the lateral condyle of the femur as part of the knee joint

lateral cuneiform

most lateral of the three cuneiform tarsal bones; articulates posteriorly with the navicular bone, medially with the intermediate cuneiform bone, laterally with the cuboid bone, and anteriorly with the third metatarsal bone

lateral epicondyle of the femur

roughened area of the femur located on the lateral side of the lateral condyle

lateral malleolus

expanded distal end of the fibula

leg

portion of the lower limb located between the knee and ankle joints

lesser trochanter

small, bony projection on the medial side of the proximal femur, at the base of the femoral neck

ligament of the head of the femur

ligament that spans the acetabulum of the hip bone and the fovea capitis of the femoral head

linea aspera

longitudinally running bony ridge located in the middle third of the posterior femur

medial condyle of the femur

smooth, articulating surface that forms the distal and posterior sides of the medial expansion of the distal femur

medial condyle of the tibia

medial, expanded region of the proximal tibia that includes the smooth surface that articulates with the medial condyle of the femur as part of the knee joint

medial cuneiform

most medial of the three cuneiform tarsal bones; articulates posteriorly with the navicular bone, laterally with the intermediate cuneiform bone, and anteriorly with the first and second metatarsal bones

medial epicondyle of the femur

roughened area of the distal femur located on the medial side of the medial condyle

medial malleolus

bony expansion located on the medial side of the distal tibia

metatarsal bone

one of the five elongated bones that forms the anterior half of the foot; numbered 1–5, starting on the medial side of the foot

metatarsophalangeal joint

articulation between a metatarsal bone of the foot and the proximal phalanx bone of a toe

navicular

tarsal bone that articulates posteriorly with the talus bone, laterally with the cuboid bone, and anteriorly with the medial, intermediate, and lateral cuneiform bones

neck of the femur

narrowed region located inferior to the head of the femur

patella

kneecap; the largest sesamoid bone of the body; articulates with the distal femur

patellar surface

smooth groove located on the anterior side of the distal femur, between the medial and lateral condyles; site of articulation for the patella

phalanx bone of the foot

(plural = phalanges) one of the 14 bones that form the toes; these include the proximal and distal phalanges of the big toe, and the proximal, middle, and distal phalanx bones of toes two through five

proximal tibiofibular joint

articulation between the head of the fibula and the inferior aspect of the lateral condyle of the tibia

shaft of the femur

cylindrically shaped region that forms the central portion of the femur

shaft of the fibula

elongated, slender portion located between the expanded ends of the fibula

shaft of the tibia

triangular-shaped, central portion of the tibia

soleal line

small, diagonally running ridge located on the posterior side of the proximal tibia

sustentaculum tali

bony ledge extending from the medial side of the calcaneus bone

talus

tarsal bone that articulates superiorly with the tibia and fibula at the ankle joint; also articulates inferiorly with the calcaneus bone and anteriorly with the navicular bone

tarsal bone

one of the seven bones that make up the posterior foot; includes the calcaneus, talus, navicular, cuboid, medial cuneiform, intermediate cuneiform, and lateral cuneiform bones

thigh

portion of the lower limb located between the hip and knee joints

tibia

shin bone; the large, weight-bearing bone located on the medial side of the leg

Contributors and Attributions

tibial tuberosity

elevated area on the anterior surface of the proximal tibia

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6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs

Learning Objectives

- Identify the appendicular muscles of the pelvic girdle and lower limb
- Identify the movement and function of the pelvic girdle and lower limb

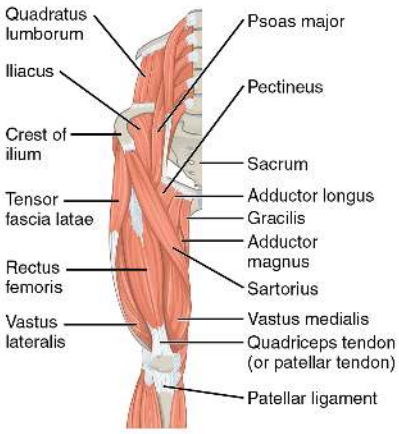
The appendicular muscles of the lower body position and stabilize the **pelvic girdle**, which serves as a foundation for the lower limbs. Comparatively, there is much more movement at the pectoral girdle than at the pelvic girdle. There is very little movement of the pelvic girdle because of its connection with the sacrum at the base of the axial skeleton. The pelvic girdle is less range of motion because it was designed to stabilize and support the body.

Muscles of the Thigh

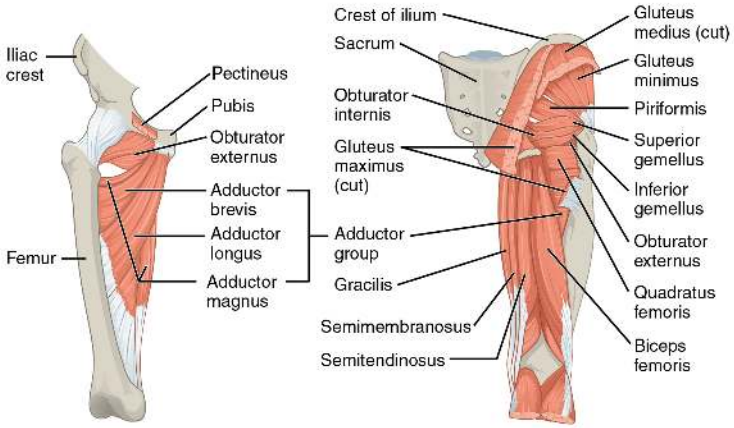
What would happen if the pelvic girdle, which attaches the lower limbs to the torso, were capable of the same range of motion as the pectoral girdle? For one thing, walking would expend more energy if the heads of the femurs were not secured in the acetabula of the pelvis. The body's center of gravity is in the area of the pelvis. If the center of gravity were not to remain fixed, standing up would be difficult as well. Therefore, what the leg muscles lack in range of motion and versatility, they make up for in size and power, facilitating the body's stabilization, posture, and movement.

Gluteal Region Muscles That Move the Femur

Most muscles that insert on the femur (the thigh bone) and move it, originate on the pelvic girdle. The **psoas major** and **iliacus** make up the **iliopsoas group**. Some of the largest and most powerful muscles in the body are the gluteal muscles or **gluteal group**. The **gluteus maximus** is the largest; deep to the gluteus maximus is the **gluteus medius**, and deep to the gluteus medius is the **gluteus minimus**, the smallest of the trio (Figure 6.2.1 and Figure 6.2.2).



Superficial pelvic and thigh muscles of right leg (anterior view)



Deep pelvic and thigh muscles of right leg (anterior view)

Pelvic and thigh muscles of right leg (posterior view)

Figure 6.2.1: Hip and Thigh Muscles. The large and powerful muscles of the hip that move the femur generally originate on the pelvic girdle and insert into the femur. The muscles that move the lower leg typically originate on the femur and insert into the bones of the knee joint. The anterior muscles of the femur extend the lower leg but also aid in flexing the thigh. The posterior muscles of the femur flex the lower leg but also aid in extending the thigh. A combination of gluteal and thigh muscles also adduct, abduct, and rotate the thigh and lower leg.

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Movement	Target	Target motion direction	Prime mover	Origin	Insertion
Iliopsoas group					
Raises knee at hip, as if performing a knee attack; assists lateral rotators in twisting thigh (and lower leg) outward; assists with bending over, maintaining posture	Femur	Thigh: flexion and lateral rotation; torso: flexion	Psoas major	Lumbar vertebrae (L1–L5); thoracic vertebra (T12)	Lesser trochanter of femur
Raises knee at hip, as if performing a knee attack; assists lateral rotators in twisting thigh (and lower leg) outward; assists with bending over, maintaining posture	Femur	Thigh: flexion and lateral rotation; torso: flexion	Iliacus	Iliac fossa; iliac crest; lateral sacrum	Lesser trochanter of femur
Gluteal group					
Lowers knee and moves thigh back, as when getting ready to kick a ball	Femur	Extension	Gluteus maximus	Dorsal ilium; sacrum; coccyx	Gluteal tuberosity of femur; iliotibial tract
Opens thighs, as when doing a split	Femur	Abduction	Gluteus medius	Lateral surface of ilium	Greater trochanter of femur
Brings the thighs back together	Femur	Abduction	Gluteus minimus	External surface of ilium	Greater trochanter of femur
Assists with raising knee at hip and opening thighs; maintains posture by stabilizing the iliotibial track, which connects to the knee	Femur	Flexion; abduction	Tensor fascia lata	Anterior aspect of iliac crest; anterior superior iliac spine	Iliotibial tract
Lateral rotators					
Twists thigh (and lower leg) outward; maintains posture by stabilizing hip joint	Femur	Lateral rotation	Piriformis	Anterolateral surface of sacrum	Greater trochanter of femur
Twists thigh (and lower leg) outward; maintains posture by stabilizing hip joint	Femur	Lateral rotation	Obutrator internus	Inner surface of obturator membrane; greater sciatic notch; margins of obturator foramen	Greater trochanter in front of piriformis
Twists thigh (and lower leg) outward; maintains posture by stabilizing hip joint	Femur	Lateral rotation	Obturator externus	Outer surfaces of obturator membrane, pubic, and ischium; margins of obturator foramen	Trochanteric fossa of posterior femur
Twists thigh (and lower leg) outward; maintains posture by stabilizing hip joint	Femur	Lateral rotation	Superior gemellus	Ischial spine	Greater trochanter of femur
Twists thigh (and lower leg) outward; maintains posture by stabilizing hip joint	Femur	Lateral rotation	Inferior gemellus	Ischial tuberosity	Greater trochanter of femur
Twists thigh (and lower leg) outward; maintains posture by stabilizing hip joint	Femur	Lateral rotation	Quadratus femoris	Ischial tuberosity	Trochanteric crest of femur
Adductors					
Brings the thighs back together; assists with raising the knee	Femur	Adduction; flexion	Adductor longus	Pubis near pubic symphysis	Linea aspera
Brings the thighs back together; assists with raising the knee	Femur	Adduction; flexion	Adductor brevis	Body of pubis; inferior ramus of pubis	Linea aspera above adductor longus
Brings the thighs back together; assists with raising the knee and moving the thigh back	Femur	Adduction; flexion; extension	Adductor magnus	Ischial rami; pubic rami; ischial tuberosity	Linea aspera; adductor tubercle of femur
Opens thighs; assists with raising the knee and turning the thigh (and lower leg) inward	Femur	Adduction; flexion; medial rotation	Pectineus	Pectineal line of pubis	Lesser trochanter to linea aspera of posterior aspect of femur

Figure 6.2.2: Gluteal Region Muscles That Move the Femur.

The **tensor fascia latae** is a thick, squarish muscle in the superior aspect of the lateral thigh. It acts as a synergist of the gluteus medius and iliopsoas in flexing and abducting the thigh. It also helps stabilize the lateral aspect of the knee by pulling on the iliotibial tract (band), making it taut. Deep to the gluteus maximus, the **piriformis**, **obturator internus**, **obturator externus**, **superior gemellus**, **inferior gemellus**, and **quadratus femoris** laterally rotate the femur at the hip.

The **adductor longus**, **adductor brevis**, and **adductor magnus** can both medially and laterally rotate the thigh depending on the placement of the foot. The adductor longus flexes the thigh, whereas the adductor magnus extends it. The **pectineus** adducts and flexes the femur at the hip as well. The pectineus is located in the **femoral triangle**, which is formed at the junction between the hip and the leg and also includes the femoral nerve, the femoral artery, the femoral vein, and the deep inguinal lymph nodes.

Thigh Muscles That Move the Femur, Tibia, and Fibula

Deep fascia in the thigh separates it into medial, anterior, and posterior compartments (see Figure 6.2.1 and Figure 6.2.3). The muscles in the **medial compartment of the thigh** are responsible for adducting the femur at the hip. Along with the adductor

longus, adductor brevis, adductor magnus, and pectineus, the strap-like **gracilis** adducts the thigh in addition to flexing the leg at the knee.

Movement	Target	Target motion direction	Prime mover	Origin	Insertion
Medial compartment of thigh					
Moves back of lower legs up toward buttocks, as when kneeling; assists in opening thighs	Femur; tibia/fibula	Tibia/fibula: flexion; thigh: adduction	Gracilis	Inferior ramus; body of pubis; ischial ramus	Medial surface of tibia
Anterior compartment of thigh: Quadriceps femoris group					
Moves lower leg out in front of body, as when kicking; assists in raising the knee	Femur; tibia/fibula	Tibia/fibula: extension; thigh: flexion	Rectus femoris	Anterior inferior iliac spine; superior margin of acetabulum	Patella; tibial tuberosity
Moves lower leg out in front of body, as when kicking	Tibia/fibula	Extension	Vastus lateralis	Greater trochanter; intertrochanteric line; linea aspera	Patella; tibial tuberosity
Moves lower leg out in front of body, as when kicking	Tibia/fibula	Extension	Vastus medialis	Linea aspera; intertrochanteric line	Patella; tibial tuberosity
Moves lower leg out in front of body, as when kicking	Tibia/fibula	Extension	Vastus intermedius	Proximal femur shaft	Patella; tibial tuberosity
Moves back of lower legs up and back toward the buttocks, as when kneeling; assists in moving thigh diagonally upward and outward as when mounting a bike	Femur; tibia/fibula	Tibia: flexion; thigh: flexion, abduction, lateral rotation	Sartorius	Anterior superior iliac spine	Medial aspect of proximal tibia
Posterior compartment of thigh: Hamstring group					
Moves back of lower legs up and back toward the buttocks, as when kneeling; moves thigh down and back; twists the thigh (and lower leg) outward	Femur; tibia/fibula	Tibia/fibula: flexion; thigh: extension, lateral rotation	Biceps femoris	Ischial tuberosity; linea aspera; distal femur	Head of fibula; lateral condyle of tibia
Moves back of lower legs up toward buttocks, as when kneeling; moves thigh down and back; twists the thigh (and lower leg) inward	Femur; tibia/fibula	Tibia/fibula: flexion; thigh: extension, medial rotation	Semitendinosus	Ischial tuberosity	Upper tibial shaft
Moves back of lower legs up and back toward the buttocks as when kneeling; moves thigh down and back; twists the thigh (and lower leg) inward	Femur; tibia/fibula	Tibia/fibula: flexion; thigh: extension, medial rotation	Semi-membranosus	Ischial tuberosity	Medial condyle of tibia; lateral condyle of femur

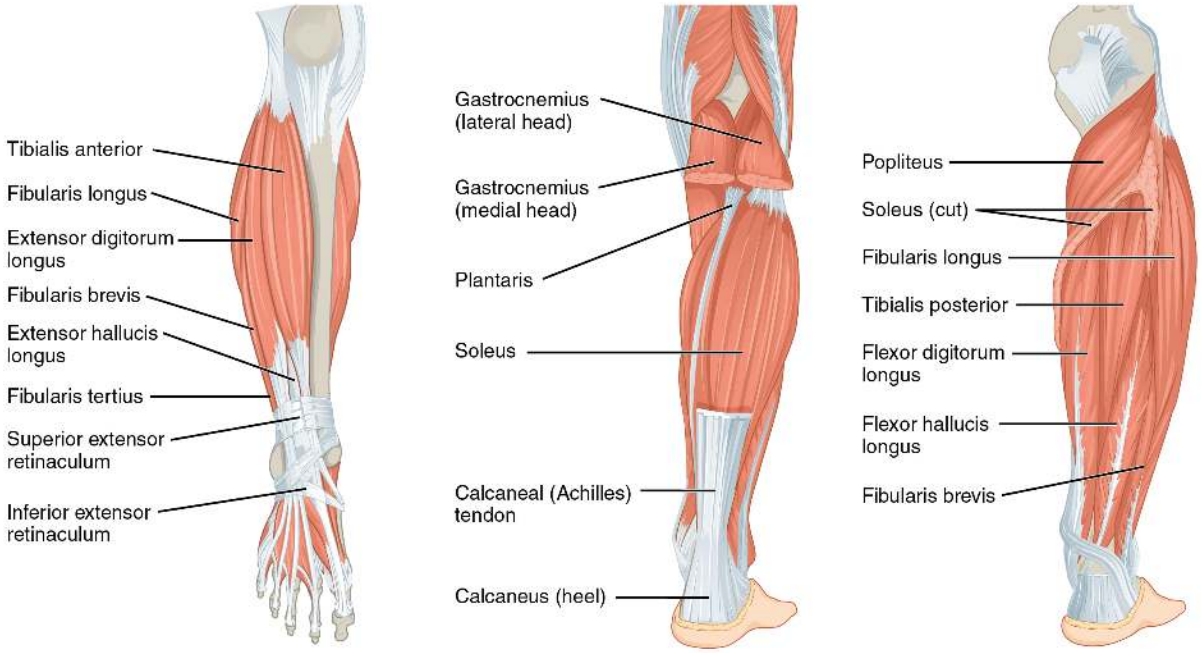
Figure 6.2.3: Thigh Muscles That Move the Femur, Tibia, and Fibula.

The muscles of the **anterior compartment of the thigh** flex the thigh and extend the leg. This compartment contains the **quadriceps femoris group**, which actually comprises four muscles that extend and stabilize the knee. The **rectus femoris** is on the anterior aspect of the thigh, the **vastus lateralis** is on the lateral aspect of the thigh, the **vastus medialis** is on the medial aspect of the thigh, and the **vastus intermedius** is between the vastus lateralis and vastus medialis and deep to the rectus femoris. The tendon common to all four is the **quadriceps tendon** (patellar tendon), which inserts into the patella and continues below it as the **patellar ligament**. The patellar ligament attaches to the tibial tuberosity. In addition to the quadriceps femoris, the **sartorius** is a band-like muscle that extends from the anterior superior iliac spine to the medial side of the proximal tibia. This versatile muscle flexes the leg at the knee and flexes, abducts, and laterally rotates the leg at the hip. This muscle allows us to sit cross-legged.

The **posterior compartment of the thigh** includes muscles that flex the leg and extend the thigh. The three long muscles on the back of the knee are the **hamstring group**, which flexes the knee. These are the **biceps femoris**, **semitendinosus**, and **semimembranosus**. The tendons of these muscles form the **popliteal fossa**, the diamond-shaped space at the back of the knee.

Muscles That Move the Feet and Toes

Similar to the thigh muscles, the muscles of the leg are divided by deep fascia into compartments, although the leg has three: anterior, lateral, and posterior (Figure 6.2.4 and Figure 6.2.5).



Superficial muscles of the right lower leg (anterior view)

Superficial muscles of the right lower leg (posterior view)

Deep muscles of the right lower leg (posterior view)

Figure 6.2.4: Muscles of the Lower Leg. The muscles of the anterior compartment of the lower leg are generally responsible for dorsiflexion, and the muscles of the posterior compartment of the lower leg are generally responsible for plantar flexion. The lateral and medial muscles in both compartments invert, evert, and rotate the foot.

Movement	Target	Target motion direction	Prime mover	Origin	Insertion
Anterior compartment of leg					
Raises the sole of the foot off the ground, as when preparing to foot-tap; bends the inside of the foot upwards, as when catching your balance while falling laterally toward the opposite side as the balancing foot	Foot	Dorsiflexion; inversion	Tibialis anterior	Lateral condyle and upper tibial shaft; interosseous membrane	Interior surface of medial cuneiform; First metatarsal bone
Raises the sole of the foot off the ground, as when preparing to foot-tap; extends the big toe	Foot; big toe	Foot: dorsiflexion; big toe: extension	Extensor hallucis longus	Anteromedial fibula shaft; interosseous membrane	Distal phalanx of big toe
Raises the sole of the foot off the ground, as when preparing to foot-tap; extends toes	Foot; toes 2–5	Foot: dorsiflexion; toes: extension	Extensor digitorum longus	Lateral condyle of tibia; proximal portion of fibula; interosseous membrane	Middle and distal phalanges of toes 2–5
Lateral compartment of leg					
Lowers the sole of the foot to the ground, as when foot-tapping or jumping; bends the inside of the foot downwards, as when catching your balance while falling laterally toward the same side as the balancing foot	Foot	Plantar flexion and eversion	Fibularis longus	Upper portion of lateral fibula	First metatarsal; medial cuneiform
Lowers the sole of the foot to the ground, as when foot-tapping or jumping; bends the inside of the foot downward, as when catching your balance while falling laterally toward the same side as the balancing foot	Foot	Plantar flexion and eversion	Fibularis (peroneus) brevis	Distal fibula shaft	Proximal end of fifth metatarsal
Posterior compartment of leg: Superficial muscles					
Lowers the sole of the foot to the ground, as when foot-tapping or jumping; assists in moving the back of the lower legs up and back toward the buttocks	Foot; tibia/ fibula	Foot: plantar flexion; tibia/fibula: flexion	Gastrocnemius	Medial and lateral condyles of femur	Posterior calcaneus
Lowers the sole of the foot to the ground, as when foot-tapping or jumping; maintains posture while walking	Foot	Plantar flexion	Soleus	Superior tibia; fibula; interosseous membrane	Posterior calcaneus
Lowers the sole of the foot to the ground, as when foot-tapping or jumping; assists in moving the back of the lower legs up and back toward the buttocks	Foot; tibia/ fibula	Foot: plantar flexion; tibia/fibula: flexion	Plantaris	Posterior femur above lateral condyle	Calcaneus or calcaneus tendon
Lowers the sole of the foot to the ground, as when foot-tapping or jumping	Foot	Plantar flexion	Tibialis posterior	Superior tibia and fibula; interosseous membrane	Several tarsals and metatarsals 2–4
Posterior compartment of leg: Deep muscles					
Moves the back of the lower legs up and back toward the buttocks; assists in rotation of the leg at the knee and thigh	Tibia/ fibula	Tibia/fibula: flexion thigh and lower leg: medial and lateral rotation	Popliteus	Lateral condyle of femur; lateral meniscus	Proximal tibia
Lowers the sole of the foot to the ground, as when foot-tapping or jumping; bends the inside of the foot upward and flexes toes	Foot; toes 2–5	Foot: plantar flexion and inversion toes: flexion	Flexor digitorum longus	Posterior tibia	Distal phalanges of toes 2–5
Flexes the big toe	Big toe; foot	Big toe: flexion foot: plantar flexion	Flexor hallucis longus	Midshaft of fibula; interosseous membrane	Distal phalanx of big toe

Figure 6.2.5: Muscles That Move the Feet and Toes.

The muscles in the **anterior compartment of the leg**: the **tibialis anterior**, a long and thick muscle on the lateral surface of the tibia, the **extensor hallucis longus**, deep under it, and the **extensor digitorum longus**, lateral to it, all contribute to raising the front of the foot when they contract. The **fibularis tertius**, a small muscle that originates on the anterior surface of the fibula, is associated with the extensor digitorum longus and sometimes fused to it, but is not present in all people. Thick bands of connective tissue called the **superior extensor retinaculum** (transverse ligament of the ankle) and the **inferior extensor retinaculum**, hold the tendons of these muscles in place during dorsiflexion.

The **lateral compartment of the leg** includes two muscles: the **fibularis longus** (peroneus longus) and the **fibularis brevis** (peroneus brevis). The superficial muscles in the **posterior compartment of the leg** all insert onto the **calcaneal tendon** (Achilles tendon), a strong tendon that inserts into the calcaneal bone of the ankle. The muscles in this compartment are large and strong and keep humans upright. The most superficial and visible muscle of the calf is the **gastrocnemius**. Deep to the gastrocnemius is the wide, flat **soleus**. The **plantaris** runs obliquely between the two; some people may have two of these muscles, whereas no plantaris is observed in about seven percent of other cadaver dissections. The plantaris tendon is a desirable substitute for the fascia lata in hernia repair, tendon transplants, and repair of ligaments. There are four deep muscles in the posterior compartment of the leg as well: the **popliteus**, **flexor digitorum longus**, **flexor hallucis longus**, and **tibialis posterior**.

The foot also has intrinsic muscles, which originate and insert within it (similar to the intrinsic muscles of the hand). These muscles primarily provide support for the foot and its arch, and contribute to movements of the toes (Figure 6.2.6 and Figure 6.2.7). The principal support for the longitudinal arch of the foot is a deep fascia called **plantar aponeurosis**, which runs from the calcaneus bone to the toes (inflammation of this tissue is the cause of "plantar fasciitis," which can affect runners. The intrinsic muscles of the foot consist of two groups. The **dorsal group** includes only one muscle, the **extensor digitorum brevis**. The second group is the **plantar group**, which consists of four layers, starting with the most superficial.

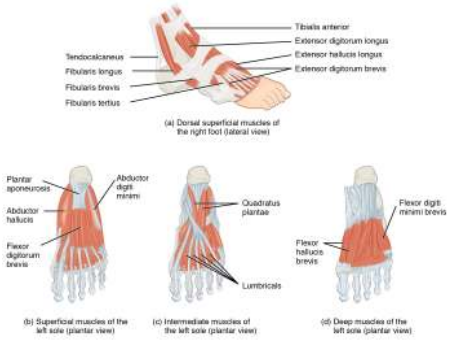


Figure 6.2.6: Intrinsic Muscles of the Foot. The muscles along the dorsal side of the foot (a) generally extend the toes while the muscles of the plantar side of the foot (b, c, d) generally flex the toes. The plantar muscles exist in three layers, providing the foot the strength to counterbalance the weight of the body. In this diagram, these three layers are shown from a plantar view beginning with the bottom-most layer just under the plantar skin of the foot (b) and ending with the top-most layer (d) located just inferior to the foot and toe bones.

Movement	Target	Target motion direction	Prime mover	Origin	Insertion
Dorsal group					
Extends toes 2–5	Toes 2–5	Extension	Extensor digitorum brevis	Calcaneus; extensor retinaculum	Base of proximal phalanx of big toe; extensor expansions on toes 2–5
Plantar group (layer 1)					
Abducts and flexes big toe	Big toe	Adduction; flexion	Abductor hallucis	Calcaneal tuberosity; flexor retinaculum	Proximal phalanx of big toe
Flexes toes 2–4	Middle toes	Flexion	Flexor digitorum brevis	Calcaneal tuberosity	Middle phalanx of toes 2–4
Abducts and flexes small toe	Toe 5	Abduction; flexion	Abductor digiti minimi	Calcaneal tuberosity	Proximal phalanx of little toe
Plantar group (layer 2)					
Assists in flexing toes 2–5	Toes 2–5	Flexion	Quadratus plantae	Medial and lateral sides of calcaneus	Tendon of flexor digitorum longus
Extends toes 2–5 at the interphalangeal joints; flexes the small toes at the metatarsophalangeal joints	Toes 2–5	Extension; flexion	Lumbricals	Tendons of flexor digitorum longus	Medial side of proximal phalanx of toes 2–5
Plantar group (layer 3)					
Flexes big toe	Big toe	Flexion	Flexor hallucis brevis	Lateral cuneiform; cuboid bones	Base of proximal phalanx of big toe
Adducts and flexes big toe	Big toe	Adduction; flexion	Adductor hallucis	Bases of metatarsals 2–4; fibularis longus tendon sheath; ligament across metatarsophalangeal joints	Base of proximal phalanx of big toe
Flexes small toe	Little toe	Flexion	Flexor digiti minimi brevis	Base of metatarsal 5; tendon sheath of fibularis longus	Base of proximal phalanx of little toe
Plantar group (layer 4)					
Abducts and flexes middle toes at metatarsophalangeal joints; extends middle toes at interphalangeal joints	Middle toes	Abduction; flexion; extension	Dorsal interossei	Sides of metatarsals	Both sides of toe 2; for each other toe, extensor expansion over first phalanx on side opposite toe 2
Abducts toes 3–5; flexes proximal phalanges and extends distal phalanges	Small toes	Abduction; flexion; extension	Plantar interossei	Side of each metatarsal that faces metatarsal 2 (absent from metatarsal 2)	Extensor expansion on first phalanx of each toe (except to 2) on side facing toe 2

Figure 6.2.7: Intrinsic Muscles in the Foot.

Chapter Review

The pelvic girdle attaches the legs to the axial skeleton. The hip joint is where the pelvic girdle and the leg come together. The hip is joined to the pelvic girdle by many muscles. In the gluteal region, the psoas major and iliacus form the iliopsoas. The large and strong gluteus maximus, gluteus medius, and gluteus minimus extend and abduct the femur. Along with the gluteus maximus, the tensor fascia lata muscle forms the iliotibial tract. The lateral rotators of the femur at the hip are the piriformis, obturator internus, obturator externus, superior gemellus, inferior gemellus, and quadratus femoris. On the medial part of the thigh, the adductor longus, adductor brevis, and adductor magnus adduct the thigh and medially rotate it. The pectineus muscle adducts and flexes the femur at the hip.

The thigh muscles that move the femur, tibia, and fibula are divided into medial, anterior, and posterior compartments. The medial compartment includes the adductors, pectineus, and the gracilis. The anterior compartment comprises the quadriceps femoris, quadriceps tendon, patellar ligament, and the sartorius. The quadriceps femoris is made of four muscles: the rectus femoris, the vastus lateralis, the vastus medius, and the vastus intermedius, which together extend the knee. The posterior compartment of the thigh includes the hamstrings: the biceps femoris, semitendinosus, and the semimembranosus, which all flex the knee.

The muscles of the leg that move the foot and toes are divided into anterior, lateral, superficial- and deep-posterior compartments. The anterior compartment includes the tibialis anterior, the extensor hallucis longus, the extensor digitorum longus, and the fibularis (peroneus) tertius. The lateral compartment houses the fibularis (peroneus) longus and the fibularis (peroneus) brevis. The

superficial posterior compartment has the gastrocnemius, soleus, and plantaris; and the deep posterior compartment has the popliteus, tibialis posterior, flexor digitorum longus, and flexor hallucis longus.

Review Questions

Q. The large muscle group that attaches the leg to the pelvic girdle and produces extension of the hip joint is the _____ group.

A. gluteal

B. obturator

C. adductor

D. abductor

Answer: A

Q. Which muscle produces movement that allows you to cross your legs?

A. the gluteus maximus

B. the piriformis

C. the gracilis

D. the sartorius

Answer: D

Q. What is the largest muscle in the lower leg?

A. soleus

B. gastrocnemius

C. tibialis anterior

D. tibialis posterior

Answer: B

Q. The vastus intermedius muscle is deep to which of the following muscles?

A. biceps femoris

B. rectus femoris

C. vastus medialis

D. vastus lateralis

Answer: B

Critical Thinking Questions

Q. Which muscles form the hamstrings? How do they function together?

A. The biceps femoris, semimembranosus, and semitendinosus form the hamstrings. The hamstrings flex the leg at the knee joint.

Q. Which muscles form the quadriceps? How do they function together?

A. The rectus femoris, vastus medialis, vastus lateralis, and vastus intermedius form the quadriceps. The quadriceps muscles extend the leg at the knee joint.

Glossary

adductor brevis
muscle that adducts and medially rotates the thigh

adductor longus
muscle that adducts, medially rotates, and flexes the thigh

adductor magnus
muscle with an anterior fascicle that adducts, medially rotates and flexes the thigh, and a posterior fascicle that assists in thigh extension

anterior compartment of the leg
region that includes muscles that dorsiflex the foot

anterior compartment of the thigh
region that includes muscles that flex the thigh and extend the leg

biceps femoris
hamstring muscle

calcaneal tendon
(also, Achilles tendon) strong tendon that inserts into the calcaneal bone of the ankle

dorsal group
region that includes the extensor digitorum brevis

extensor digitorum brevis
muscle that extends the toes

extensor digitorum longus
muscle that is lateral to the tibialis anterior

extensor hallucis longus
muscle that is partly deep to the tibialis anterior and extensor digitorum longus

femoral triangle
region formed at the junction between the hip and the leg and includes the pectineus, femoral nerve, femoral artery, femoral vein, and deep inguinal lymph nodes

fibularis brevis
(also, peroneus brevis) muscle that plantar flexes the foot at the ankle and everts it at the intertarsal joints

fibularis longus
(also, peroneus longus) muscle that plantar flexes the foot at the ankle and everts it at the intertarsal joints

fibularis tertius
small muscle that is associated with the extensor digitorum longus

flexor digitorum longus
muscle that flexes the four small toes

flexor hallucis longus
muscle that flexes the big toe

gastrocnemius

most superficial muscle of the calf

gluteal group
muscle group that extends, flexes, rotates, adducts, and abducts the femur

gluteus maximus
largest of the gluteus muscles that extends the femur

gluteus medius
muscle deep to the gluteus maximus that abducts the femur at the hip

gluteus minimus
smallest of the gluteal muscles and deep to the gluteus medius

gracilis
muscle that adducts the thigh and flexes the leg at the knee

hamstring group
three long muscles on the back of the leg

iliacus
muscle that, along with the psoas major, makes up the iliopsoas

iliopsoas group
muscle group consisting of iliacus and psoas major muscles, that flexes the thigh at the hip, rotates it laterally, and flexes the trunk of the body onto the hip

iliotibial tract
muscle that inserts onto the tibia; made up of the gluteus maximus and connective tissues of the tensor fasciae latae

inferior extensor retinaculum
cruciate ligament of the ankle

inferior gemellus
muscle deep to the gluteus maximus on the lateral surface of the thigh that laterally rotates the femur at the hip

lateral compartment of the leg
region that includes the fibularis (peroneus) longus and the fibularis (peroneus) brevis and their associated blood vessels and nerves

medial compartment of the thigh
a region that includes the adductor longus, adductor brevis, adductor magnus, pectineus, gracilis, and their associated blood vessels and nerves

obturator externus
muscle deep to the gluteus maximus on the lateral surface of the thigh that laterally rotates the femur at the hip

obturator internus
muscle deep to the gluteus maximus on the lateral surface of the thigh that laterally rotates the femur at the hip

patellar ligament
extension of the quadriceps tendon below the patella

pectineus
muscle that abducts and flexes the femur at the hip

pelvic girdle
hips, a foundation for the lower limb

piriformis
muscle deep to the gluteus maximus on the lateral surface of the thigh that laterally rotates the femur at the hip

plantar aponeurosis
muscle that supports the longitudinal arch of the foot

plantar group
four-layered group of intrinsic foot muscles

plantaris
muscle that runs obliquely between the gastrocnemius and the soleus

popliteal fossa
diamond-shaped space at the back of the knee

popliteus
muscle that flexes the leg at the knee and creates the floor of the popliteal fossa

posterior compartment of the leg
region that includes the superficial gastrocnemius, soleus, and plantaris, and the deep popliteus, flexor digitorum longus, flexor hallucis longus, and tibialis posterior

posterior compartment of the thigh
region that includes muscles that flex the leg and extend the thigh

psoas major
muscle that, along with the iliacus, makes up the iliopsoas

quadratus femoris
muscle deep to the gluteus maximus on the lateral surface of the thigh that laterally rotates the femur at the hip

quadriceps femoris group
four muscles, that extend and stabilize the knee

quadriceps tendon
(also, patellar tendon) tendon common to all four quadriceps muscles, inserts into the patella

rectus femoris
quadricep muscle on the anterior aspect of the thigh

sartorius
band-like muscle that flexes, abducts, and laterally rotates the leg at the hip

semimembranosus
hamstring muscle

semitendinosus
hamstring muscle

soleus
wide, flat muscle deep to the gastrocnemius

superior extensor retinaculum

transverse ligament of the ankle

superior gemellus
muscle deep to the gluteus maximus on the lateral surface of the thigh that laterally rotates the femur at the hip

tensor fascia lata
muscle that flexes and abducts the thigh

tibialis anterior
muscle located on the lateral surface of the tibia

tibialis posterior
muscle that plantar flexes and inverts the foot

vastus intermedius
quadricep muscle that is between the vastus lateralis and vastus medialis and is deep to the rectus femoris

vastus lateralis
quadricep muscle on the lateral aspect of the thigh

vastus medialis
quadricep muscle on the medial aspect of the thigh

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CHAPTER OVERVIEW

7: Bones, Joint and Muscles of the Pectoral Girdle and Upper Limb

7.1: The Pectoral Girdle

7.2: Bones of the Upper Limb

7.3: Axial Muscles of the Abdominal Wall and Thorax

7.4: Muscles of the Pectoral Girdle and Upper Limbs

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7.1: The Pectoral Girdle

Learning Objectives

- Describe the bones that form the pectoral girdle
- List the functions of the pectoral girdle

The appendicular skeleton includes all of the limb bones, plus the bones that unite each limb with the axial skeleton (Figure 7.1.1). The bones that attach each upper limb to the axial skeleton form the pectoral girdle (shoulder girdle). This consists of two bones, the scapula and clavicle (Figure 7.1.2). The clavicle (collarbone) is an S-shaped bone located on the anterior side of the shoulder. It is attached on its medial end to the sternum of the thoracic cage, which is part of the axial skeleton. The lateral end of the clavicle articulates (joins) with the scapula just above the shoulder joint. You can easily palpate, or feel with your fingers, the entire length of your clavicle.

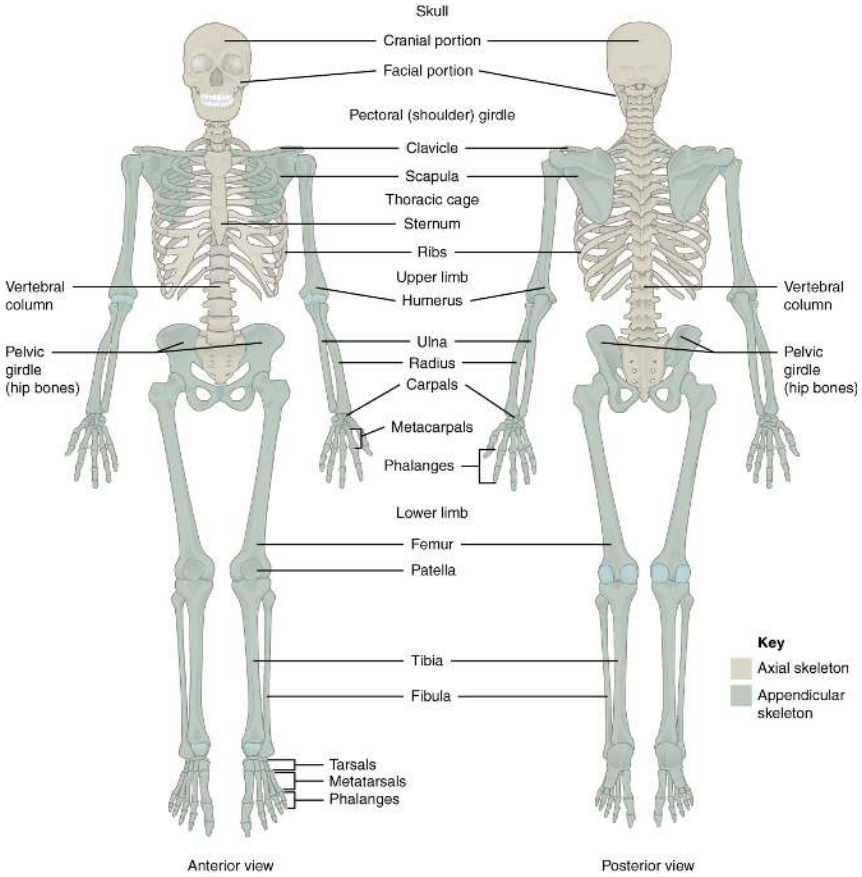


Figure 7.1.1: Axial and Appendicular Skeletons. The axial skeleton forms the central axis of the body and consists of the skull, vertebral column, and thoracic cage. The appendicular skeleton consists of the pectoral and pelvic girdles, the limb bones, and the bones of the hands and feet.

The **scapula** (shoulder blade) lies on the posterior aspect of the shoulder. It is supported by the **clavicle**, which also articulates with the humerus (arm bone) to form the shoulder joint. The scapula is a flat, triangular-shaped bone with a prominent ridge running across its posterior surface. This ridge extends out laterally, where it forms the bony tip of the shoulder and joins with the lateral end of the clavicle. By following along the clavicle, you can palpate out to the bony tip of the shoulder, and from there, you can move back across your posterior shoulder to follow the ridge of the scapula. Move your shoulder around and feel how the clavicle and scapula move together as a unit. Both of these bones serve as important attachment sites for muscles that aid with movements of the shoulder and arm.

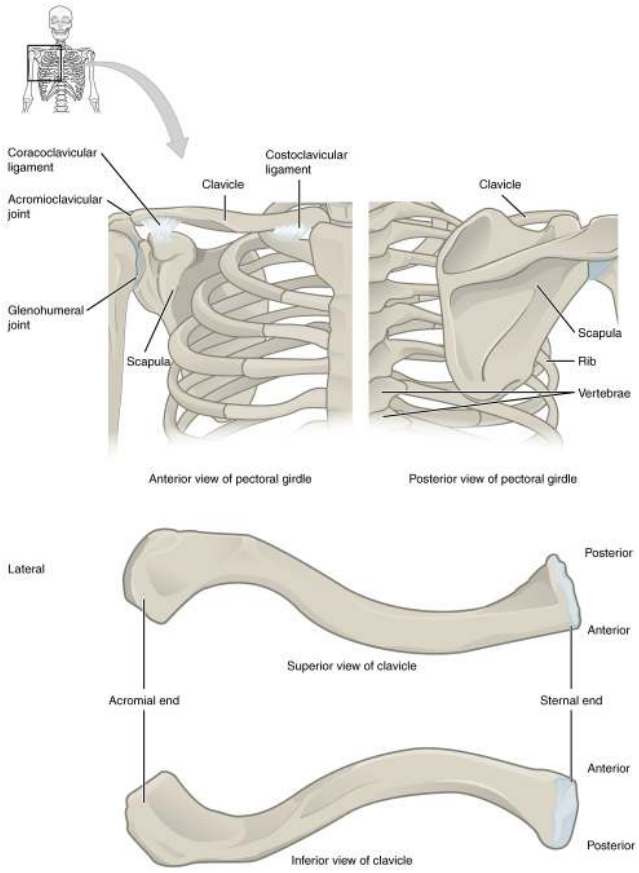


Figure 7.1.2: Pectoral Girdle. The pectoral girdle consists of the clavicle and the scapula, which serve to attach the upper limb to the sternum of the axial skeleton.

The right and left pectoral girdles are not joined to each other, allowing each to operate independently. In addition, the clavicle of each **pectoral girdle** is anchored to the axial skeleton by a single, highly mobile joint. This allows for the extensive mobility of the entire pectoral girdle, which in turn enhances movements of the shoulder and upper limb.

Clavicle

The clavicle is the only long bone that lies in a horizontal position in the body (Figure 7.1.2). The clavicle has several important functions. First, anchored by muscles from above, it serves as a strut that extends laterally to support the scapula. This in turn holds the shoulder joint superiorly and laterally from the body trunk, allowing for maximal freedom of motion for the upper limb. The clavicle also transmits forces acting on the upper limb to the sternum and axial skeleton. Finally, it serves to protect the underlying nerves and blood vessels as they pass between the trunk of the body and the upper limb.

The clavicle has three regions: the medial end, the lateral end, and the shaft. The medial end, known as the **sternal end of the clavicle**, has a triangular shape and articulates with the manubrium portion of the sternum. This forms the **sternoclavicular joint**, which is the only bony articulation between the pectoral girdle of the upper limb and the axial skeleton. This joint allows considerable mobility, enabling the clavicle and scapula to move in upward/downward and anterior/posterior directions during shoulder movements. The sternoclavicular joint is indirectly supported by the **costoclavicular ligament** (costo- = “rib”), which spans the sternal end of the clavicle and the underlying first rib. The lateral or **acromial end of the clavicle** articulates with the acromion of the scapula, the portion of the scapula that forms the bony tip of the shoulder. There are some sex differences in the morphology of the clavicle. In women, the clavicle tends to be shorter, thinner, and less curved. In men, the clavicle is heavier and longer, and has a greater curvature and rougher surfaces where muscles attach, features that are more pronounced in manual workers.

The clavicle is the most commonly fractured bone in the body. Such breaks often occur because of the force exerted on the clavicle when a person falls onto his or her outstretched arms, or when the lateral shoulder receives a strong blow. Because the sternoclavicular joint is strong and rarely dislocated, excessive force results in the breaking of the clavicle, usually between the

middle and lateral portions of the bone. If the fracture is complete, the shoulder and lateral clavicle fragment will drop due to the weight of the upper limb, causing the person to support the sagging limb with their other hand. Muscles acting across the shoulder will also pull the shoulder and lateral clavicle anteriorly and medially, causing the clavicle fragments to override. The clavicle overlies many important blood vessels and nerves for the upper limb, but fortunately, due to the anterior displacement of a broken clavicle, these structures are rarely affected when the clavicle is fractured.

Scapula

The scapula is also part of the pectoral girdle and thus plays an important role in anchoring the upper limb to the body. The scapula is located on the posterior side of the shoulder. It is surrounded by muscles on both its anterior (deep) and posterior (superficial) sides, and thus does not articulate with the ribs of the thoracic cage.

The scapula has several important landmarks (Figure 7.1.3). The three margins or borders of the scapula, named for their positions within the body, are the **superior border of the scapula**, the **medial border of the scapula**, and the **lateral border of the scapula**. The **suprascapular notch** is located lateral to the midpoint of the superior border. The corners of the triangular scapula, at either end of the medial border, are the **superior angle of the scapula**, located between the medial and superior borders, and the **inferior angle of the scapula**, located between the medial and lateral borders. The inferior angle is the most inferior portion of the scapula, and is particularly important because it serves as the attachment point for several powerful muscles involved in shoulder and upper limb movements. The remaining corner of the scapula, between the superior and lateral borders, is the location of the **glenoid cavity** (glenoid fossa). This shallow depression articulates with the humerus bone of the arm to form the **glenohumeral joint** (shoulder joint). The small bony bumps located immediately above and below the glenoid cavity are the **supraglenoid tubercle** and the **infraglenoid tubercle**, respectively. These provide attachments for muscles of the arm.

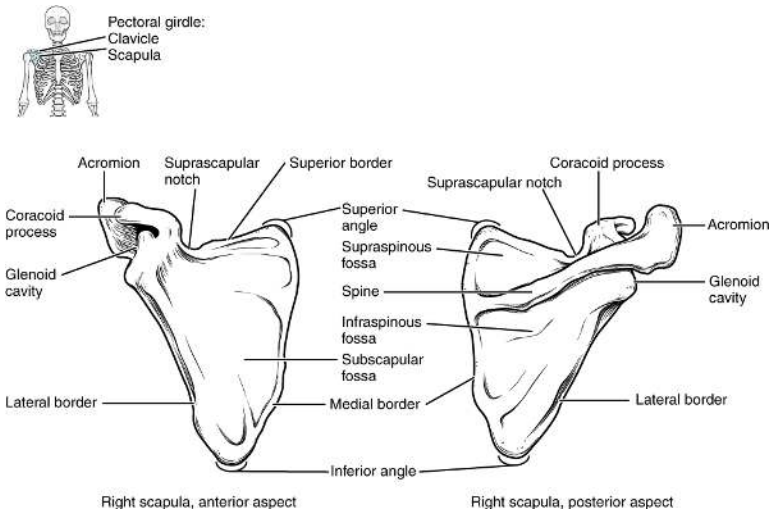


Figure 7.1.3: Scapula. The isolated scapula is shown here from its anterior (deep) side and its posterior (superficial) side.

The scapula also has two prominent projections. Toward the lateral end of the superior border, between the suprascapular notch and glenoid cavity, is the hook-like **coracoid process** (coracoid = “shaped like a crow’s beak”). This process projects anteriorly and curves laterally. At the shoulder, the coracoid process is located inferior to the lateral end of the clavicle. It is anchored to the clavicle by a strong ligament, and serves as the attachment site for muscles of the anterior chest and arm. On the posterior aspect, the **spine of the scapula** is a long and prominent ridge that runs across its upper portion. Extending laterally from the spine is a flattened and expanded region called the **acromion** or **acromial process**. The acromion forms the bony tip of the superior shoulder region and articulates with the lateral end of the clavicle, forming the **acromioclavicular joint** (see Figure 7.1.2). Together, the clavicle, acromion, and spine of the scapula form a V-shaped bony line that provides for the attachment of neck and back muscles that act on the shoulder, as well as muscles that pass across the shoulder joint to act on the arm.

The scapula has three depressions, each of which is called a **fossa** (plural = fossae). Two of these are found on the posterior scapula, above and below the scapular spine. Superior to the spine is the narrow **supraspinous fossa**, and inferior to the spine is the broad **infraspinous fossa**. The anterior (deep) surface of the scapula forms the broad **subscapular fossa**. All of these fossae provide large surface areas for the attachment of muscles that cross the shoulder joint to act on the humerus.

The acromioclavicular joint transmits forces from the upper limb to the clavicle. The ligaments around this joint are relatively weak. A hard fall onto the elbow or outstretched hand can stretch or tear the acromioclavicular ligaments, resulting in a moderate

injury to the joint. However, the primary support for the acromioclavicular joint comes from a very strong ligament called the **coracoclavicular ligament** (see Figure 7.1.2). This connective tissue band anchors the coracoid process of the scapula to the inferior surface of the acromial end of the clavicle and thus provides important indirect support for the acromioclavicular joint. Following a strong blow to the lateral shoulder, such as when a hockey player is driven into the boards, a complete dislocation of the acromioclavicular joint can result. In this case, the acromion is thrust under the acromial end of the clavicle, resulting in ruptures of both the acromioclavicular and coracoclavicular ligaments. The scapula then separates from the clavicle, with the weight of the upper limb pulling the shoulder downward. This dislocation injury of the acromioclavicular joint is known as a "shoulder separation" and is common in contact sports such as hockey, football, or martial arts.

Chapter Review

The pectoral girdle, consisting of the clavicle and the scapula, attaches each upper limb to the axial skeleton. The clavicle is an anterior bone whose sternal end articulates with the manubrium of the sternum at the sternoclavicular joint. The sternal end is also anchored to the first rib by the costoclavicular ligament. The acromial end of the clavicle articulates with the acromion of the scapula at the acromioclavicular joint. This end is also anchored to the coracoid process of the scapula by the coracoclavicular ligament, which provides indirect support for the acromioclavicular joint. The clavicle supports the scapula, transmits the weight and forces from the upper limb to the body trunk, and protects the underlying nerves and blood vessels.

The scapula lies on the posterior aspect of the pectoral girdle. It mediates the attachment of the upper limb to the clavicle, and contributes to the formation of the glenohumeral (shoulder) joint. This triangular bone has three sides called the medial, lateral, and superior borders. The suprascapular notch is located on the superior border. The scapula also has three corners, two of which are the superior and inferior angles. The third corner is occupied by the glenoid cavity. Posteriorly, the spine separates the supraspinous and infraspinous fossae, and then extends laterally as the acromion. The subscapular fossa is located on the anterior surface of the scapula. The coracoid process projects anteriorly, passing inferior to the lateral end of the clavicle.

Review Questions

Q. Which part of the clavicle articulates with the manubrium?

A. shaft

B. sternal end

C. acromial end

D. coracoid process

Answer: B

Q. A shoulder separation results from injury to the _____.

A. glenohumeral joint

B. costoclavicular joint

C. acromioclavicular joint

D. sternoclavicular joint

Answer: C

Q. Which feature lies between the spine and superior border of the scapula?

A. suprascapular notch

B. glenoid cavity

C. superior angle

D. supraspinous fossa

Answer: D

Q. What structure is an extension of the spine of the scapula?

A. acromion

B. coracoid process

C. supraglenoid tubercle

D. glenoid cavity

Answer: A

Q. Name the short, hook-like bony process of the scapula that projects anteriorly.

A. acromial process

B. clavicle

C. coracoid process

D. glenoid fossa

Answer: C

Critical Thinking Questions

Q. Describe the shape and palpable line formed by the clavicle and scapula.

A. The clavicle extends laterally across the anterior shoulder and can be palpated along its entire length. At its lateral end, the clavicle articulates with the acromion of the scapula, which forms the bony tip of the shoulder. The acromion is continuous with the spine of the scapula, which can be palpated medially and posteriorly along its length. Together, the clavicle, acromion, and spine of the scapula form a V-shaped line that serves as an important area for muscle attachment.

Q. Discuss two possible injuries of the pectoral girdle that may occur following a strong blow to the shoulder or a hard fall onto an outstretched hand.

A. A blow to the shoulder or falling onto an outstretched hand passes strong forces through the scapula to the clavicle and sternum. A hard fall may thus cause a fracture of the clavicle (broken collarbone) or may injure the ligaments of the acromioclavicular joint. In a severe case, the coracoclavicular ligament may also rupture, resulting in complete dislocation of the acromioclavicular joint (a “shoulder separation”).

Glossary

acromial end of the clavicle
lateral end of the clavicle that articulates with the acromion of the scapula

acromial process
acromion of the scapula

acromioclavicular joint
articulation between the acromion of the scapula and the acromial end of the clavicle

acromion
flattened bony process that extends laterally from the scapular spine to form the bony tip of the shoulder

clavicle
collarbone; elongated bone that articulates with the manubrium of the sternum medially and the acromion of the scapula laterally

coracoclavicular ligament

strong band of connective tissue that anchors the coracoid process of the scapula to the lateral clavicle; provides important indirect support for the acromioclavicular joint

coracoid process
short, hook-like process that projects anteriorly and laterally from the superior margin of the scapula

costoclavicular ligament
band of connective tissue that unites the medial clavicle with the first rib

fossa
(plural = fossae) shallow depression on the surface of a bone

glenohumeral joint
shoulder joint; formed by the articulation between the glenoid cavity of the scapula and the head of the humerus

glenoid cavity
(also, glenoid fossa) shallow depression located on the lateral scapula, between the superior and lateral borders

inferior angle of the scapula
inferior corner of the scapula located where the medial and lateral borders meet

infraglenoid tubercle
small bump or roughened area located on the lateral border of the scapula, near the inferior margin of the glenoid cavity

infraspinous fossa
broad depression located on the posterior scapula, inferior to the spine

lateral border of the scapula
diagonally oriented lateral margin of the scapula

medial border of the scapula
elongated, medial margin of the scapula

pectoral girdle
shoulder girdle; the set of bones, consisting of the scapula and clavicle, which attaches each upper limb to the axial skeleton

scapula
shoulder blade bone located on the posterior side of the shoulder

spine of the scapula
prominent ridge passing mediolaterally across the upper portion of the posterior scapular surface

sternal end of the clavicle
medial end of the clavicle that articulates with the manubrium of the sternum

sternoclavicular joint
articulation between the manubrium of the sternum and the sternal end of the clavicle; forms the only bony attachment between the pectoral girdle of the upper limb and the axial skeleton

subscapular fossa
broad depression located on the anterior (deep) surface of the scapula

superior angle of the scapula
corner of the scapula between the superior and medial borders of the scapula

superior border of the scapula

superior margin of the scapula

supraglenoid tubercle
small bump located at the superior margin of the glenoid cavity

suprascapular notch
small notch located along the superior border of the scapula, medial to the coracoid process

supraspinous fossa
narrow depression located on the posterior scapula, superior to the spine

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7.2: Bones of the Upper Limb

Learning Objectives

- Identify the divisions of the upper limb and describe the bones in each region
- List the bones and bony landmarks that articulate at each joint of the upper limb

The upper limb is divided into three regions. These consist of the **arm**, located between the shoulder and elbow joints; the **forearm**, which is between the elbow and wrist joints; and the **hand**, which is located distal to the wrist. There are 30 bones in each upper limb (see [link]). The humerus is the single bone of the upper arm, and the **ulna** (medially) and the **radius** (laterally) are the paired bones of the forearm. The base of the hand contains eight bones, each called a **carpal bone**, and the palm of the hand is formed by five bones, each called a **metacarpal bone**. The fingers and thumb contain a total of 14 bones, each of which is a **phalanx bone of the hand**.

Humerus

The humerus is the single bone of the upper arm region (Figure 7.2.1). At its proximal end is the **head of the humerus**. This is the large, round, smooth region that faces medially. The head articulates with the glenoid cavity of the scapula to form the glenohumeral (shoulder) joint. The margin of the smooth area of the head is the **anatomical neck** of the humerus. Located on the lateral side of the proximal humerus is an expanded bony area called the **greater tubercle**. The smaller **lesser tubercle** of the humerus is found on the anterior aspect of the humerus. Both the greater and lesser tubercles serve as attachment sites for muscles that act across the shoulder joint. Passing between the greater and lesser tubercles is the narrow **intertubercular groove (sulcus)**, which is also known as the **bicipital groove** because it provides passage for a tendon of the biceps brachii muscle. The **surgical neck** is located at the base of the expanded, proximal end of the humerus, where it joins the narrow **shaft of the humerus**. The surgical neck is a common site of arm fractures. The **deltoid tuberosity** is a roughened, V-shaped region located on the lateral side in the middle of the humerus shaft. As its name indicates, it is the site of attachment for the deltoid muscle.

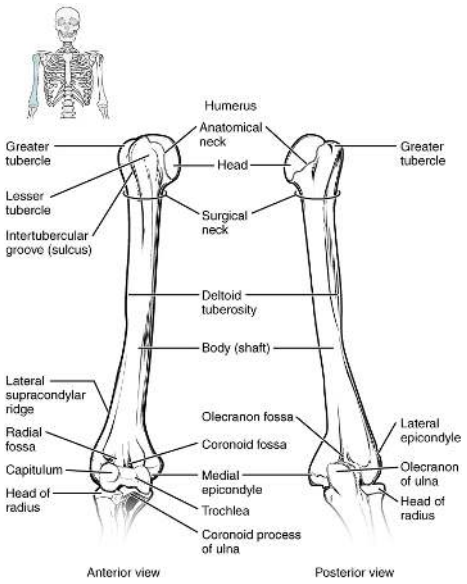


Figure 7.2.1: Humerus and Elbow Joint. The humerus is the single bone of the upper arm region. It articulates with the radius and ulna bones of the forearm to form the elbow joint.

Distally, the humerus becomes flattened. The prominent bony projection on the medial side is the **medial epicondyle of the humerus**. The much smaller **lateral epicondyle of the humerus** is found on the lateral side of the distal humerus. The roughened ridge of bone above the lateral epicondyle is the **lateral supracondylar ridge**. All of these areas are attachment points for muscles that act on the forearm, wrist, and hand. The powerful grasping muscles of the anterior forearm arise from the medial epicondyle, which is thus larger and more robust than the lateral epicondyle that gives rise to the weaker posterior forearm muscles.

The distal end of the humerus has two articulation areas, which join the ulna and radius bones of the forearm to form the **elbow joint**. The more medial of these areas is the **trochlea**, a spindle- or pulley-shaped region (trochlea = “pulley”), which articulates with the ulna bone. Immediately lateral to the trochlea is the **capitulum** (“small head”), a knob-like structure located on the anterior surface of the distal humerus. The capitulum articulates with the radius bone of the forearm. Just above these bony areas are two small depressions. These spaces accommodate the forearm bones when the elbow is fully bent (flexed). Superior to the trochlea is the **coronoid fossa**, which receives the coronoid process of the ulna, and above the capitulum is the **radial fossa**, which receives the head of the radius when the elbow is flexed. Similarly, the posterior humerus has the **olecranon fossa**, a larger depression that receives the olecranon process of the ulna when the forearm is fully extended.

Ulna

The ulna is the medial bone of the forearm. It runs parallel to the radius, which is the lateral bone of the forearm (Figure 7.2.2). The proximal end of the ulna resembles a crescent wrench with its large, C-shaped **trochlear notch**. This region articulates with the trochlea of the humerus as part of the elbow joint. The inferior margin of the trochlear notch is formed by a prominent lip of bone called the **coronoid process of the ulna**. Just below this on the anterior ulna is a roughened area called the **ulnar tuberosity**. To the lateral side and slightly inferior to the trochlear notch is a small, smooth area called the **radial notch of the ulna**. This area is the site of articulation between the proximal radius and the ulna, forming the **proximal radioulnar joint**. The posterior and superior portions of the proximal ulna make up the **olecranon process**, which forms the bony tip of the elbow.

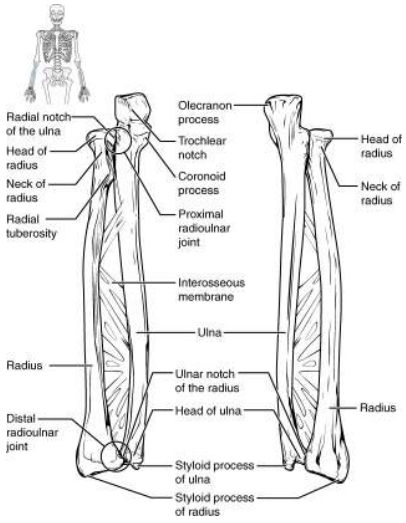


Figure 7.2.2: Ulna and Radius.The ulna is located on the medial side of the forearm, and the radius is on the lateral side. These bones are attached to each other by an interosseous membrane.

More distal is the **shaft of the ulna**. The lateral side of the shaft forms a ridge called the **interosseous border of the ulna**. This is the line of attachment for the **interosseous membrane of the forearm**, a sheet of dense connective tissue that unites the ulna and radius bones. The small, rounded area that forms the distal end is the **head of the ulna**. Projecting from the posterior side of the ulnar head is the **styloid process of the ulna**, a short bony projection. This serves as an attachment point for a connective tissue structure that unites the distal ends of the ulna and radius.

In the anatomical position, with the elbow fully extended and the palms facing forward, the arm and forearm do not form a straight line. Instead, the forearm deviates laterally by 5–15 degrees from the line of the arm. This deviation is called the carrying angle. It allows the forearm and hand to swing freely or to carry an object without hitting the hip. The carrying angle is larger in females to accommodate their wider pelvis.

Radius

The radius runs parallel to the ulna, on the lateral (thumb) side of the forearm (see Figure 7.2.2). The **head of the radius** is a disc-shaped structure that forms the proximal end. The small depression on the surface of the head articulates with the capitulum of the humerus as part of the elbow joint, whereas the smooth, outer margin of the head articulates with the radial notch of the ulna at the proximal radioulnar joint. The **neck of the radius** is the narrowed region immediately below the expanded head. Inferior to this point on the medial side is the **radial tuberosity**, an oval-shaped, bony protuberance that serves as a muscle attachment point. The **shaft of the radius** is slightly curved and has a small ridge along its medial side. This ridge forms the **interosseous border of the radius**, which, like the similar border of the ulna, is the line of attachment for the interosseous membrane that unites the two forearm bones. The distal end of the radius has a smooth surface for articulation with two carpal bones to form the **radiocarpal joint** or wrist joint (Figure 7.2.3 and Figure 7.2.4). On the medial side of the distal radius is the **ulnar notch of the radius**. This shallow depression articulates with the head of the ulna, which together form the **distal radioulnar joint**. The lateral end of the radius has a pointed projection called the **styloid process of the radius**. This provides attachment for ligaments that support the lateral side of the wrist joint. Compared to the styloid process of the ulna, the styloid process of the radius projects more distally, thereby limiting the range of movement for lateral deviations of the hand at the wrist joint.

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Watch this video to see how fractures of the distal radius bone can affect the wrist joint. Explain the problems that may occur if a fracture of the distal radius involves the joint surface of the radiocarpal joint of the wrist.

Carpal Bones

The wrist and base of the hand are formed by a series of eight small carpal bones (see Figure 7.2.3). The carpal bones are arranged in two rows, forming a proximal row of four carpal bones and a distal row of four carpal bones. The bones in the proximal row, running from the lateral (thumb) side to the medial side, are the **scaphoid** (“boat-shaped”), **lunate** (“moon-shaped”), **triquetrum** (“three-cornered”), and **pisiform** (“pea-shaped”) bones. The small, rounded pisiform bone articulates with the anterior surface of the triquetrum bone. The pisiform thus projects anteriorly, where it forms the bony bump that can be felt at the medial base of your hand. The distal bones (lateral to medial) are the **trapezium** (“table”), **trapezoid**

("resembles a table"), **capitate** ("head-shaped"), and **hamate** ("hooked bone") bones. The hamate bone is characterized by a prominent bony extension on its anterior side called the **hook of the hamate bone**.

A helpful mnemonic for remembering the arrangement of the carpal bones is "So Long To Pinky, Here Comes The Thumb." This mnemonic starts on the lateral side and names the proximal bones from lateral to medial (scaphoid, lunate, triquetrum, pisiform), then makes a U-turn to name the distal bones from medial to lateral (hamate, capitate, trapezoid, trapezium). Thus, it starts and finishes on the lateral side.

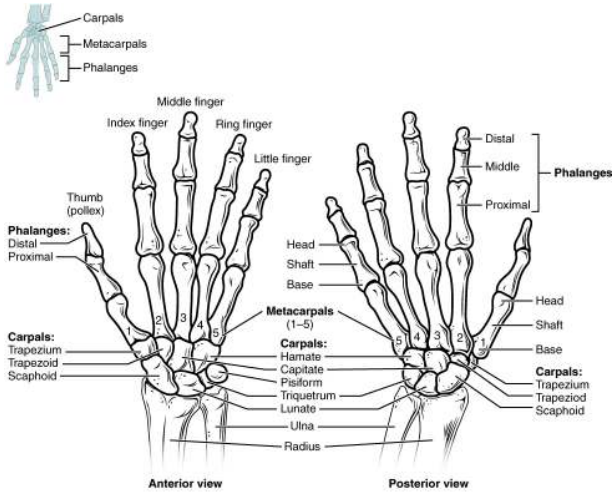


Figure 7.2.3: Bones of the Wrist and Hand. The eight carpal bones form the base of the hand. These are arranged into proximal and distal rows of four bones each. The metacarpal bones form the palm of the hand. The thumb and fingers consist of the phalanx bones.

The carpal bones form the base of the hand. This can be seen in the radiograph (X-ray image) of the hand that shows the relationships of the hand bones to the skin creases of the hand (see Figure 7.2.4). Within the carpal bones, the four proximal bones are united to each other by ligaments to form a unit. Only three of these bones, the scaphoid, lunate, and triquetrum, contribute to the radiocarpal joint. The scaphoid and lunate bones articulate directly with the distal end of the radius, whereas the triquetrum bone articulates with a fibrocartilaginous pad that spans the radius and styloid process of the ulna. The distal end of the ulna thus does not directly articulate with any of the carpal bones.

The four distal carpal bones are also held together as a group by ligaments. The proximal and distal rows of carpal bones articulate with each other to form the **midcarpal joint** (see Figure 7.2.4). Together, the radiocarpal and midcarpal joints are responsible for all movements of the hand at the wrist. The distal carpal bones also articulate with the metacarpal bones of the hand.

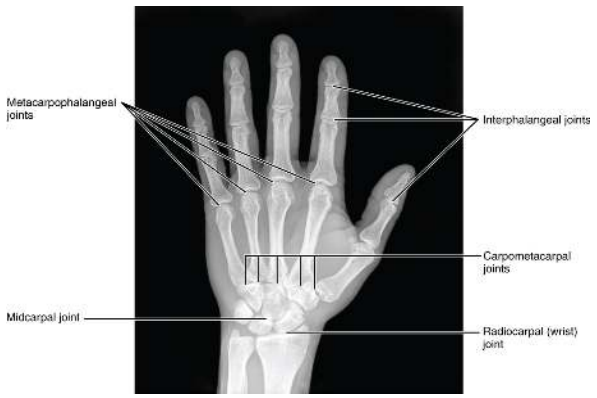


Figure 7.2.4: Bones of the Hand. This radiograph shows the position of the bones within the hand. Note the carpal bones that form the base of the hand. (credit: modification of work by Trace Meek)

In the articulated hand, the carpal bones form a U-shaped grouping. A strong ligament called the **flexor retinaculum** spans the top of this U-shaped area to maintain this grouping of the carpal bones. The flexor retinaculum is attached laterally to the trapezium and scaphoid bones, and medially to the hamate and pisiform bones. Together, the carpal bones and the flexor retinaculum form a passageway called the **carpal tunnel**, with the carpal bones forming the walls and floor, and the flexor retinaculum forming the roof of this space (Figure 7.2.5). The tendons of nine muscles of the anterior forearm and an important nerve pass through this narrow tunnel to enter the hand. Overuse of the muscle tendons or wrist injury can produce inflammation and swelling within this space. This produces compression of the nerve, resulting in carpal tunnel syndrome, which is characterized by pain or numbness, and muscle weakness in those areas of the hand supplied by this nerve.

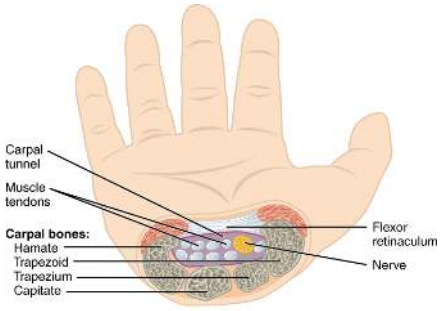


Figure 7.2.5: Carpal Tunnel. The carpal tunnel is the passageway by which nine muscle tendons and a major nerve enter the hand from the anterior forearm. The walls and floor of the carpal tunnel are formed by the U-shaped grouping of the carpal bones, and the roof is formed by the flexor retinaculum, a strong ligament that anteriorly unites the bones.

Metacarpal Bones

The palm of the hand contains five elongated metacarpal bones. These bones lie between the carpal bones of the wrist and the bones of the fingers and thumb (see Figure 7.2.3). The proximal end of each metacarpal bone articulates with one of the distal carpal bones. Each of these articulations is a **carpometacarpal joint** (see Figure 7.2.4). The expanded distal end of each metacarpal bone articulates at the **metacarpophalangeal joint** with the proximal phalanx bone of the thumb or one of the fingers. The distal end also forms the knuckles of the hand, at the base of the fingers. The metacarpal bones are numbered 1–5, beginning at the thumb.

The first metacarpal bone, at the base of the thumb, is separated from the other metacarpal bones. This allows it a freedom of motion that is independent of the other metacarpal bones, which is very important for thumb mobility. The remaining metacarpal bones are united together to form the palm of the hand. The second and third metacarpal bones are firmly anchored in place and are immobile. However, the fourth and fifth metacarpal bones have limited anterior-posterior mobility, a motion that is greater for the fifth bone. This mobility is important during power gripping with the hand (Figure 7.2.6). The anterior movement of these bones, particularly the fifth metacarpal bone, increases the strength of contact for the medial hand during gripping actions.

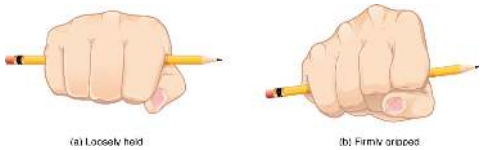


Figure 7.2.6: Hand During Gripping. During tight gripping—compare (b) to (a)—the fourth and, particularly, the fifth metatarsal bones are pulled anteriorly. This increases the contact between the object and the medial side of the hand, thus improving the firmness of the grip.

Phalanx Bones

The fingers and thumb contain 14 bones, each of which is called a phalanx bone (plural = phalanges), named after the ancient Greek phalanx (a rectangular block of soldiers). The thumb (**pollex**) is digit number 1 and has two phalanges, a proximal phalanx, and a distal phalanx bone (see Figure 7.2.3). Digits 2 (index finger) through 5 (little finger) have three phalanges each, called the proximal, middle, and distal phalanx bones. An **interphalangeal joint** is one of the articulations between adjacent phalanges of the digits (see Figure 7.2.4).

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Visit this site to explore the bones and joints of the hand. What are the three arches of the hand, and what is the importance of these during the gripping of an object?

DISORDERS OF THE...

Appendicular System: Fractures of Upper Limb Bones

Due to our constant use of the hands and the rest of our upper limbs, an injury to any of these areas will cause a significant loss of functional ability. Many fractures result from a hard fall onto an outstretched hand. The resulting transmission of force up the limb may result in a fracture of the humerus, radius, or scaphoid bones. These injuries are especially common in elderly people whose bones are weakened due to osteoporosis.

Falls onto the hand or elbow, or direct blows to the arm, can result in fractures of the humerus (Figure). Following a fall, fractures at the surgical neck, the region at which the expanded proximal end of the humerus joins with the shaft, can result in an impacted fracture, in which the distal portion of the humerus is driven into the proximal portion. Falls or blows to the arm can also produce transverse or spiral fractures of the humeral shaft.

In children, a fall onto the tip of the elbow frequently results in a distal humerus fracture. In these, the olecranon of the ulna is driven upward, resulting in a fracture across the distal humerus, above both epicondyles (supracondylar fracture), or a fracture between the epicondyles, thus separating one or both of the epicondyles from the body of the humerus (intercondylar fracture). With these injuries, the immediate concern is possible compression of the artery to the forearm due to swelling of the surrounding tissues. If compression occurs, the resulting ischemia (lack of oxygen) due to reduced blood flow can quickly produce irreparable damage to the forearm muscles. In addition, four major nerves for shoulder and upper limb muscles are closely associated with different regions of the humerus, and thus, humeral fractures may also damage these nerves.

Another frequent injury following a fall onto an outstretched hand is a Colles fracture ("col-lees") of the distal radius (see Figure 7.2.7). This involves a complete transverse fracture across the distal radius that drives the separated distal fragment of the radius posteriorly and superiorly. This injury results in a characteristic "dinner fork" bend of the forearm just above the wrist due to the posterior displacement of the hand. This is the most frequent forearm fracture and is a common injury in persons over the age of 50, particularly in older women with osteoporosis. It also commonly occurs following a high-speed fall onto the hand during activities such as snowboarding or skating.

The most commonly fractured carpal bone is the scaphoid, often resulting from a fall onto the hand. Deep pain at the lateral wrist may yield an initial diagnosis of a wrist sprain, but a radiograph taken several weeks after the injury, after tissue swelling has subsided, will reveal the fracture. Due to the poor blood supply to the scaphoid bone, healing will be slow and there is the danger of bone necrosis and subsequent degenerative joint disease of the wrist.

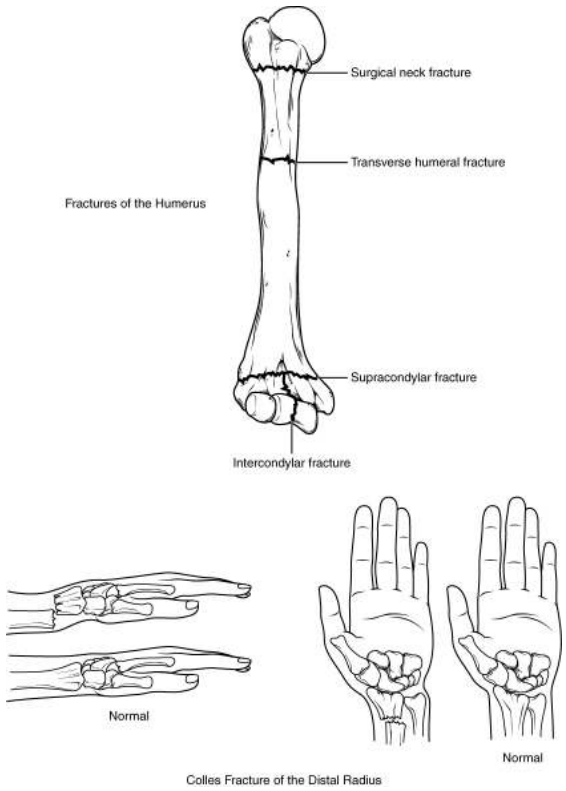


Figure 7.2.7: Fractures of the Humerus and Radius. Falls or direct blows can result in fractures of the surgical neck or shaft of the humerus. Falls onto the elbow can fracture the distal humerus. A Colles fracture of the distal radius is the most common forearm fracture.

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Watch this video to learn about a Colles fracture, a break of the distal radius, usually caused by falling onto an outstretched hand. When would surgery be required and how would the fracture be repaired in this case?

Chapter Review

Each upper limb is divided into three regions and contains a total of 30 bones. The upper arm is the region located between the shoulder and elbow joints. This area contains the humerus. The proximal humerus consists of the head, which articulates with the scapula at the glenohumeral joint, the greater and lesser tubercles separated by the intertubercular (bicipital) groove, and the anatomical and surgical necks. The humeral shaft has the roughened area of the deltoid tuberosity on its lateral side. The distal humerus is flattened, forming a lateral supracondylar ridge that terminates at the small lateral epicondyle. The medial side of the distal humerus has the large, medial epicondyle. The articulating surfaces of the distal humerus consist of the trochlea medially and the capitulum laterally. Depressions on the humerus that accommodate the forearm bones during bending (flexing) and straightening (extending) of the elbow include the coronoid fossa, the radial fossa, and the olecranon fossa.

The forearm is the region of the upper limb located between the elbow and wrist joints. This region contains two bones, the ulna medially and the radius on the lateral (thumb) side. The elbow joint is formed by the articulation between the trochlea of the humerus and the trochlear notch of the ulna, plus the articulation between the capitulum of the humerus and the head of the radius. The proximal radioulnar joint is the articulation between the head of the radius and the radial notch of the ulna. The proximal ulna also has the olecranon process, forming an expanded posterior region, and the coronoid process and ulnar tuberosity on its anterior aspect. On the proximal radius, the narrowed region below the head is the neck; distal to this is the radial tuberosity. The shaft portions of both the ulna and radius have an interosseous border, whereas the distal ends of each bone have a pointed styloid process. The distal radioulnar joint is found between the head of the ulna and the ulnar notch of the radius. The distal end of the radius articulates with the proximal carpal bones, but the ulna does not.

The base of the hand is formed by eight carpal bones. The carpal bones are united into two rows of bones. The proximal row contains (from lateral to medial) the scaphoid, lunate, triquetrum, and pisiform bones. The scaphoid, lunate, and triquetrum bones contribute to the formation of the radiocarpal joint. The distal row of carpal bones contains (from medial to lateral) the hamate, capitate, trapezoid, and trapezium bones (“So Long To Pinky, Here Comes The Thumb”). The anterior hamate has a prominent bony hook. The proximal and distal carpal rows articulate with each other at the midcarpal joint. The carpal bones, together with the flexor retinaculum, also form the carpal tunnel of the wrist.

The five metacarpal bones form the palm of the hand. The metacarpal bones are numbered 1–5, starting with the thumb side. The first metacarpal bone is freely mobile, but the other bones are united as a group. The digits are also numbered 1–5, with the thumb being number 1. The fingers and thumb contain a total of 14 phalanges (phalanx bones). The thumb contains a proximal and a distal phalanx, whereas the remaining digits each contain proximal, middle, and distal phalanges.

Interactive Link Questions

Watch this video to see how fractures of the distal radius bone can affect the wrist joint. Explain the problems that may occur if a fracture of the distal radius involves the joint surface of the radiocarpal joint of the wrist.

> Answer: A fracture through the joint surface of the distal radius may make the articulating surface of the radius rough or jagged. This can then cause painful movements involving this joint and the early development of arthritis. Surgery can return the joint surface to its original smoothness, thus allowing for the return of normal function.

Visit this site to explore the bones and joints of the hand. What are the three arches of the hand, and what is the importance of these during the gripping of an object?

Answer: The hand has a proximal transverse arch, a distal transverse arch, and a longitudinal arch. These allow the hand to conform to objects being held. These arches maximize the amount of surface contact between the hand and object, which enhances stability and increases sensory input.

Watch this video to learn about a Colles fracture, a break of the distal radius, usually caused by falling onto an outstretched hand. When would surgery be required and how would the fracture be repaired in this case?



Answer: Surgery may be required if the fracture is unstable, meaning that the broken ends of the radius won't stay in place to allow for proper healing. In this case, metal plates and screws can be used to stabilize the fractured bone.

Review Questions

Q. How many bones are there in the upper limbs combined?

A. 20

B. 30

C. 40

D. 60

Answer: D

Q. Which bony landmark is located on the lateral side of the proximal humerus?

A. greater tubercle

B. trochlea

C. lateral epicondyle

D. lesser tubercle

Answer: A

Q. Which region of the humerus articulates with the radius as part of the elbow joint?

A. trochlea

B. styloid process

C. capitulum

D. olecranon process

Answer: C

Q. Which is the lateral-most carpal bone of the proximal row?

A. trapezium

B. hamate

C. pisiform

D. scaphoid

Answer: D

Q. The radius bone _____.

A. is found on the medial side of the forearm

B. has a head that articulates with the radial notch of the ulna

C. does not articulate with any of the carpal bones

D. has the radial tuberosity located near its distal end

Answer: B

Critical Thinking Questions

Q. Your friend runs out of gas and you have to help push his car. Discuss the sequence of bones and joints that convey the forces passing from your hand, through your upper limb and your pectoral girdle, and to your axial skeleton.

A. As you push against the car, forces will pass from the metacarpal bones of your hand into the carpal bones at the base of your hand. Forces will then pass through the midcarpal and radiocarpal joints into the radius and ulna bones of the forearm. These will pass the force through the elbow joint into the humerus of the arm, and then through the glenohumeral joint into the scapula. The force will travel through the acromioclavicular joint into the clavicle, and then through the sternoclavicular joint into the sternum, which is part of the axial skeleton.

Q. Name the bones in the wrist and hand, and describe or sketch out their locations and articulations.

A. The base of the hand is formed by the eight carpal bones arranged in two rows (distal and proximal) of four bones each. The proximal row contains (from lateral to medial) the scaphoid, lunate, triquetrum, and pisiform bones. The distal row contains (from medial to lateral) the hamate, capitate, trapezoid, and trapezium bones. (Use the mnemonic “So Long To Pinky, Here Comes The Thumb” to remember this sequence). The rows of the proximal and distal carpal bones articulate with each other at the midcarpal joint. The palm of the hand contains the five metacarpal bones, which are numbered 1–5 starting on the thumb side. The proximal ends of the metacarpal bones articulate with the distal row of the carpal bones. The distal ends of the metacarpal bones articulate with the proximal phalanx bones of the

thumb and fingers. The thumb (digit 1) has both a proximal and distal phalanx bone. The fingers (digits 2–5) all contain proximal, middle, and distal phalanges.

Glossary

anatomical neck
line on the humerus located around the outside margin of the humeral head

arm
region of the upper limb located between the shoulder and elbow joints; contains the humerus bone

bicipital groove
intertubercular groove; narrow groove located between the greater and lesser tubercles of the humerus

capitate
from the lateral side, the third of the four distal carpal bones; articulates with the scaphoid and lunate proximally, the trapezoid laterally, the hamate medially, and primarily with the third metacarpal distally

capitulum
knob-like bony structure located anteriorly on the lateral, distal end of the humerus

carpal bone
one of the eight small bones that form the wrist and base of the hand; these are grouped as a proximal row consisting of (from lateral to medial) the scaphoid, lunate, triquetrum, and pisiform bones, and a distal row containing (from lateral to medial) the trapezium, trapezoid, capitate, and hamate bones

carpal tunnel
passageway between the anterior forearm and hand formed by the carpal bones and flexor retinaculum

carpometacarpal joint
articulation between one of the carpal bones in the distal row and a metacarpal bone of the hand

coronoid fossa
depression on the anterior surface of the humerus above the trochlea; this space receives the coronoid process of the ulna when the elbow is maximally flexed

coronoid process of the ulna
projecting bony lip located on the anterior, proximal ulna; forms the inferior margin of the trochlear notch

deltoid tuberosity
roughened, V-shaped region located laterally on the mid-shaft of the humerus

distal radioulnar joint
articulation between the head of the ulna and the ulnar notch of the radius

elbow joint
joint located between the upper arm and forearm regions of the upper limb; formed by the articulations between the trochlea of the humerus and the trochlear notch of the ulna, and the capitulum of the humerus and the head of the radius

flexor retinaculum
strong band of connective tissue at the anterior wrist that spans the top of the U-shaped grouping of the carpal bones to form the roof of the carpal tunnel

forearm
region of the upper limb located between the elbow and wrist joints; contains the radius and ulna bones

greater tubercle
enlarged prominence located on the lateral side of the proximal humerus

hamate
from the lateral side, the fourth of the four distal carpal bones; articulates with the lunate and triquetrum proximally, the fourth and fifth metacarpals distally, and the capitate laterally

hand
region of the upper limb distal to the wrist joint

head of the humerus
smooth, rounded region on the medial side of the proximal humerus; articulates with the glenoid fossa of the scapula to form the glenohumeral (shoulder) joint

head of the radius
disc-shaped structure that forms the proximal end of the radius; articulates with the capitulum of the humerus as part of the elbow joint, and with the radial notch of the ulna as part of the proximal radioulnar joint

head of the ulna
small, rounded distal end of the ulna; articulates with the ulnar notch of the distal radius, forming the distal radioulnar joint

hook of the hamate bone
bony extension located on the anterior side of the hamate carpal bone

humerus
single bone of the upper arm

interosseous border of the radius
narrow ridge located on the medial side of the radial shaft; for attachment of the interosseous membrane between the ulna and radius bones

interosseous border of the ulna
narrow ridge located on the lateral side of the ulnar shaft; for attachment of the interosseous membrane between the ulna and radius

interosseous membrane of the forearm
sheet of dense connective tissue that unites the radius and ulna bones

interphalangeal joint
articulation between adjacent phalanx bones of the hand or foot digits

intertubercular groove (sulcus)
bicipital groove; narrow groove located between the greater and lesser tubercles of the humerus

lateral epicondyle of the humerus
small projection located on the lateral side of the distal humerus

lateral supracondylar ridge
narrow, bony ridge located along the lateral side of the distal humerus, superior to the lateral epicondyle

lesser tubercle
small, bony prominence located on anterior side of the proximal humerus

lunate
from the lateral side, the second of the four proximal carpal bones; articulates with the radius proximally, the capitate and hamate distally, the scaphoid laterally, and the triquetrum medially

medial epicondyle of the humerus
enlarged projection located on the medial side of the distal humerus

metacarpal bone
one of the five long bones that form the palm of the hand; numbered 1–5, starting on the lateral (thumb) side of the hand

metacarpophalangeal joint
articulation between the distal end of a metacarpal bone of the hand and a proximal phalanx bone of the thumb or a finger

midcarpal joint
articulation between the proximal and distal rows of the carpal bones; contributes to movements of the hand at the wrist

neck of the radius
narrowed region immediately distal to the head of the radius

olecranon fossa
large depression located on the posterior side of the distal humerus; this space receives the olecranon process of the ulna when the elbow is fully extended

olecranon process
expanded posterior and superior portions of the proximal ulna; forms the bony tip of the elbow

phalanx bone of the hand
(plural = phalanges) one of the 14 bones that form the thumb and fingers; these include the proximal and distal phalanges of the thumb, and the proximal, middle, and distal phalanx bones of the fingers two through five

pisiform
from the lateral side, the fourth of the four proximal carpal bones; articulates with the anterior surface of the triquetrum

pollex
(also, thumb) digit 1 of the hand

proximal radioulnar joint
articulation formed by the radial notch of the ulna and the head of the radius

radial fossa
small depression located on the anterior humerus above the capitulum; this space receives the head of the radius when the elbow is maximally flexed

radial notch of the ulna
small, smooth area on the lateral side of the proximal ulna; articulates with the head of the radius as part of the proximal radioulnar joint

radial tuberosity
oval-shaped, roughened protuberance located on the medial side of the proximal radius

radiocarpal joint
wrist joint, located between the forearm and hand regions of the upper limb; articulation formed proximally by the distal end of the radius and the fibrocartilaginous pad that unites the distal radius and ulna bone, and distally by the scaphoid, lunate, and triquetrum carpal bones

radius
bone located on the lateral side of the forearm

scaphoid
from the lateral side, the first of the four proximal carpal bones; articulates with the radius proximally, the trapezoid, trapezium, and capitate distally, and the lunate medially

shaft of the humerus
narrow, elongated, central region of the humerus

shaft of the radius
narrow, elongated, central region of the radius

shaft of the ulna
narrow, elongated, central region of the ulna

styloid process of the radius
pointed projection located on the lateral end of the distal radius

styloid process of the ulna
short, bony projection located on the medial end of the distal ulna

surgical neck
region of the humerus where the expanded, proximal end joins with the narrower shaft

trapezium
from the lateral side, the first of the four distal carpal bones; articulates with the scaphoid proximally, the first and second metacarpals distally, and the trapezoid medially

trapezoid
from the lateral side, the second of the four distal carpal bones; articulates with the scaphoid proximally, the second metacarpal distally, the trapezium laterally, and the capitate medially

triquetrum
from the lateral side, the third of the four proximal carpal bones; articulates with the lunate laterally, the hamate distally, and has a facet for the pisiform

trochlea
pulley-shaped region located medially at the distal end of the humerus; articulates at the elbow with the trochlear notch of the ulna

trochlear notch
large, C-shaped depression located on the anterior side of the proximal ulna; articulates at the elbow with the trochlea of the humerus

ulna
bone located on the medial side of the forearm

ulnar notch of the radius
shallow, smooth area located on the medial side of the distal radius; articulates with the head of the ulna at the distal radioulnar joint

ulnar tuberosity
roughened area located on the anterior, proximal ulna inferior to the coronoid process

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7.3: Axial Muscles of the Abdominal Wall and Thorax

Learning Objectives

- Identify the intrinsic skeletal muscles of the back and neck, and the skeletal muscles of the abdominal wall and thorax
- Identify the movement and function of the intrinsic skeletal muscles of the back and neck, and the skeletal muscles of the abdominal wall and thorax

It is a complex job to balance the body on two feet and walk upright. The muscles of the vertebral column, thorax, and abdominal wall extend, flex, and stabilize different parts of the body's trunk. The deep muscles of the core of the body help maintain posture as well as carry out other functions. The brain sends out electrical impulses to these various muscle groups to control posture by alternate contraction and relaxation. This is necessary so that no single muscle group becomes fatigued too quickly. If any one group fails to function, body posture will be compromised.

Muscles of the Abdomen

There are four pairs of abdominal muscles that cover the anterior and lateral abdominal region and meet at the anterior midline. These muscles of the anterolateral abdominal wall can be divided into four groups: the external obliques, the internal obliques, the transversus abdominis, and the rectus abdominis (Figure 7.3.1 and Table 7.3.1).

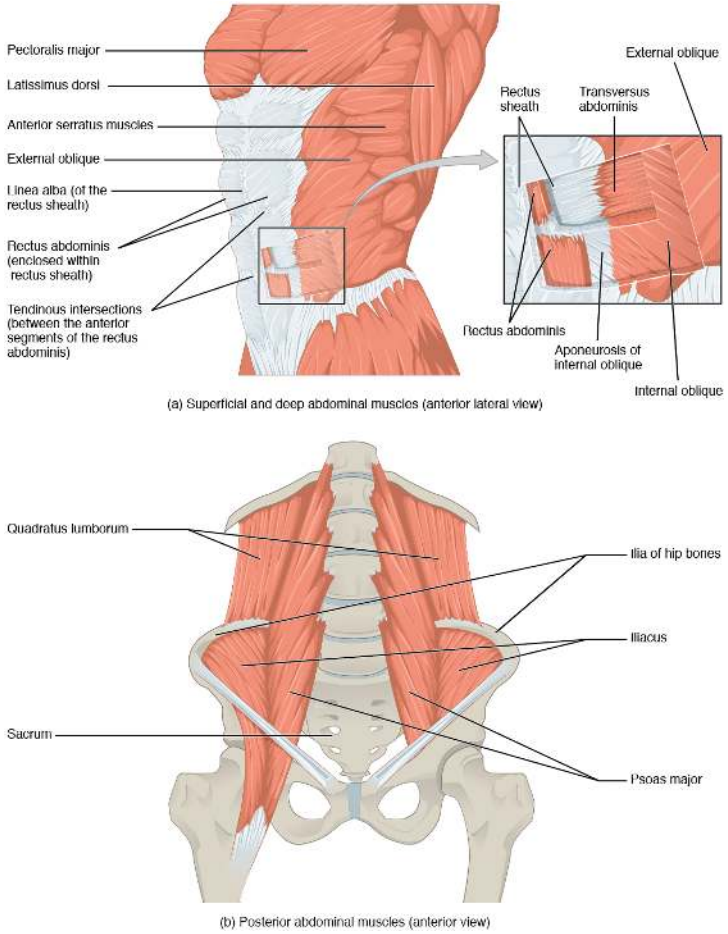


Figure 7.3.1: Muscles of the Abdomen. (a) The anterior abdominal muscles include the medially located rectus abdominis, which is covered by a sheet of connective tissue called the rectus sheath. On the flanks of the body, medial to the rectus abdominis, the abdominal wall is composed of three layers. The external oblique muscles form the superficial layer, while the internal oblique muscles form the middle layer, and the transverses abdominus forms the deepest layer. (b) The muscles of the lower back move the lumbar spine but also assist in femur movements.

Table 7.3.1

Muscles of the Abdomen					
Movement	Target	Target motion direction	Prime mover	Origin	Insertion
Twisting at waist; also bending to the side	Vertebral column	Supination; lateral flexion	External obliques; internal obliques	Ribs 5–12; ilium	Ribs 7–10; linea alba; ilium
Squeezing abdomen during forceful exhalations, defecation, urination, and childbirth	Abdominal cavity	Compression	Transversus abdominus	Ilium; ribs 5–10	Sternum; linea alba; pubis
Sitting up	Vertebral column	Flexion	Rectus abdominis	Pubis	Sternum; ribs 5 and 7
Bending to the side	Vertebral column	Lateral flexion	Quadratus lumborum	Ilium; ribs 5–10	Rib 12; vertebrae L1–L4

There are three flat skeletal muscles in the antero-lateral wall of the abdomen. The **external oblique**, closest to the surface, extend inferiorly and medially, in the direction of sliding one's four fingers into pants pockets. Perpendicular to it is the intermediate **internal oblique**, extending superiorly and medially, the direction the thumbs usually go when the other fingers are in the pants pocket. The deep muscle, the **transversus abdominis**, is arranged transversely around the abdomen, similar to the front of a belt on a pair of pants. This arrangement of three bands of muscles in different orientations allows various movements and rotations of the trunk. The three layers of muscle also help to protect the internal abdominal organs in an area where there is no bone.

The **linea alba** is a white, fibrous band that is made of the bilateral **rectus sheaths** that join at the anterior midline of the body. These enclose the **rectus abdominis** muscles (a pair of long, linear muscles, commonly called the "sit-up" muscles) that originate at the pubic crest and symphysis, and extend the length of the body's trunk. Each muscle is segmented by three transverse bands of collagen fibers called the **tendinous intersections**. This results in the look of "six-pack abs," as each segment hypertrophies on individuals at the gym who do many sit-ups.

The posterior abdominal wall is formed by the lumbar vertebrae, parts of the ilia of the hip bones, psoas major and iliacus muscles, and **quadratus lumborum** muscle. This part of the core plays a key role in stabilizing the rest of the body and maintaining posture.

CAREER CONNECTIONS

Physical Therapists

Those who have a muscle or joint injury will most likely be sent to a physical therapist (PT) after seeing their regular doctor. PTs have a master's degree or doctorate, and are highly trained experts in the mechanics of body movements. Many PTs also specialize in sports injuries.

If you injured your shoulder while you were kayaking, the first thing a physical therapist would do during your first visit is to assess the functionality of the joint. The range of motion of a particular joint refers to the normal movements the joint performs. The PT will ask you to abduct and adduct, circumduct, and flex and extend the arm. The PT will note the shoulder's degree of function, and based on the assessment of the injury, will create an appropriate physical therapy plan.

The first step in physical therapy will probably be applying a heat pack to the injured site, which acts much like a warm-up to draw blood to the area, to enhance healing. You will be instructed to do a series of exercises to continue the therapy at home, followed by icing, to decrease inflammation and swelling, which will continue for several weeks. When physical therapy is complete, the PT will do an exit exam and send a detailed report on the improved range of motion and return of normal limb function to your doctor. Gradually, as the injury heals, the shoulder will begin to function correctly. A PT works closely with patients to help them get back to their normal level of physical activity.

Muscles of the Thorax

The muscles of the chest serve to facilitate breathing by changing the size of the thoracic cavity (Table 7.3.2). When you inhale, your chest rises because the cavity expands. Alternately, when you exhale, your chest falls because the thoracic cavity decreases in size.

Table 7.3.2

Muscles of the Thorax					
Movement	Target	Target motion direction	Prime mover	Origin	Insertion
Inhalation; exhalation	Thoracic cavity	Compression; expansion	Diaphragm	Sternum; ribs 6–12; lumbar vertebrae	Central tendon
Inhalation;exhalation	Ribs	Elevation (expands thoracic cavity)	External intercostals	Rib superior to each intercostal muscle	Rib inferior to each intercostal muscle
Forced exhalation	Ribs	Movement along superior/inferior axis to bring ribs closer together	Internal intercostals	Rib inferior to each intercostal muscle	Rib superior to each intercostal muscle

The Diaphragm

The change in volume of the thoracic cavity during breathing is due to the alternate contraction and relaxation of the **diaphragm** (Figure 7.3.2). It separates the thoracic and abdominal cavities, and is dome-shaped at rest. The superior surface of the diaphragm is convex, creating the elevated floor of the thoracic cavity. The inferior surface is concave, creating the curved roof of the abdominal cavity.

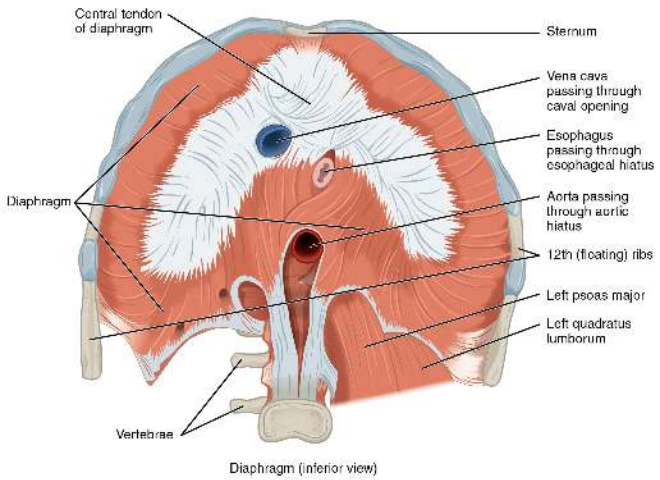


Figure 7.3.2: Muscles of the Diaphragm. The diaphragm separates the thoracic and abdominal cavities.

Defecating, urination, and even childbirth involve cooperation between the diaphragm and abdominal muscles (this cooperation is referred to as the “Valsalva maneuver”). You hold your breath by a steady contraction of the diaphragm; this stabilizes the volume and pressure of the peritoneal cavity. When the abdominal muscles contract, the pressure cannot push the diaphragm up, so it increases pressure on the intestinal tract (defecation), urinary tract (urination), or reproductive tract (childbirth).

The inferior surface of the pericardial sac and the inferior surfaces of the pleural membranes (parietal pleura) fuse onto the central tendon of the diaphragm. To the sides of the tendon are the skeletal muscle portions of the diaphragm, which insert into the tendon while having a number of origins including the xiphoid process of the sternum anteriorly, the inferior six ribs and their cartilages laterally, and the lumbar vertebrae and 12th ribs posteriorly.

The diaphragm also includes three openings for the passage of structures between the thorax and the abdomen. The inferior vena cava passes through the **caval opening**, and the esophagus and attached nerves pass through the esophageal hiatus. The aorta,

thoracic duct, and azygous vein pass through the aortic hiatus of the posterior diaphragm.

The Intercostal Muscles

There are three sets of muscles, called **intercostal muscles**, which span each of the intercostal spaces. The principal role of the intercostal muscles is to assist in breathing by changing the dimensions of the rib cage (Figure 7.3.3).

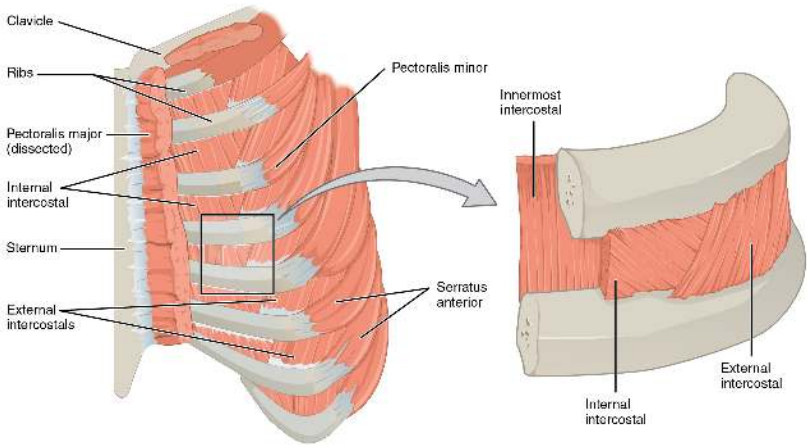


Figure 7.3.3: Intercostal Muscles. The external intercostals are located laterally on the sides of the body. The internal intercostals are located medially near the sternum. The innermost intercostals are located deep to both the internal and external intercostals.

The 11 pairs of superficial **external intercostal** muscles aid in inspiration of air during breathing because when they contract, they raise the rib cage, which expands it. The 11 pairs of **internal intercostal** muscles, just under the externals, are used for expiration because they draw the ribs together to constrict the rib cage. The **innermost intercostal** muscles are the deepest, and they act as synergists for the action of the internal intercostals.

Muscles of the Pelvic Floor and Perineum

The pelvic floor is a muscular sheet that defines the inferior portion of the pelvic cavity. The **pelvic diaphragm**, spanning anteriorly to posteriorly from the pubis to the coccyx, comprises the levator ani and the ischiococcygeus. Its openings include the anal canal and urethra, and the vagina in women.

The large **levator ani** consists of two skeletal muscles, the **pubococcygeus** and the **iliococcygeus** (Figure 7.3.4). The levator ani is considered the most important muscle of the pelvic floor because it supports the pelvic viscera. It resists the pressure produced by contraction of the abdominal muscles so that the pressure is applied to the colon to aid in defecation and to the uterus to aid in childbirth (assisted by the **ischiococcygeus**, which pulls the coccyx anteriorly). This muscle also creates skeletal muscle sphincters at the urethra and anus.

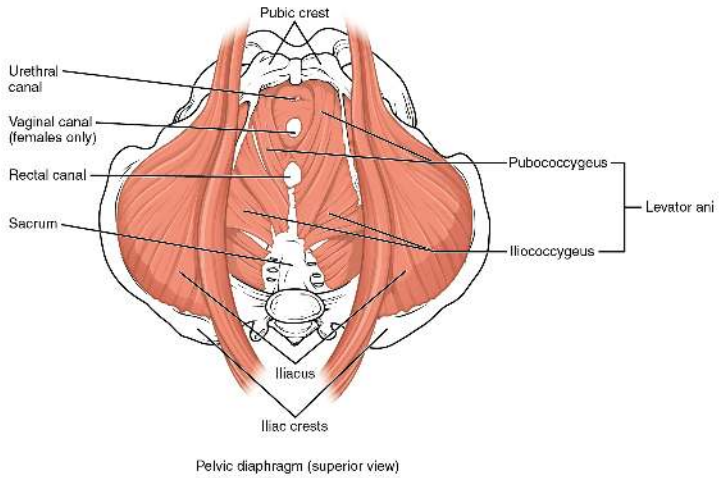


Figure 7.3.4: Muscles of the Pelvic Floor. The pelvic floor muscles support the pelvic organs, resist intra-abdominal pressure, and work as sphincters for the urethra, rectum, and vagina.

The **perineum** is the diamond-shaped space between the pubic symphysis (anteriorly), the coccyx (posteriorly), and the ischial tuberosities (laterally), lying just inferior to the pelvic diaphragm (levator ani and coccygeus). Divided transversely into triangles, the anterior is the **urogenital triangle**, which includes the external genitals. The posterior is the **anal triangle**, which contains the anus (Figure 7.3.5). The perineum is also divided into superficial and deep layers with some of the muscles common to men and women (Figure 7.3.6). Women also have the **compressor urethrae** and the **sphincter urethrovaginalis**, which function to close the vagina. In men, there is the **deep transverse perineal** muscle that plays a role in ejaculation.

Movement	Target	Target motion direction	Prime mover	Origin	Insertion
Defecation; urination; birth; coughing	Abdominal cavity	Superior (resists pressure during abdominal compression)	Levator ani pubococcygeus; levator ani iliococcygeus	Pubis; ischium	Urethra; anal canal; perineal body; coccyx
Superficial muscles					
None—supports perineal body maintaining anus at center of perineum	Perineal body	None	Superficial transverse perineal	Ischium	Perineal body
Involuntary response that compresses urethra when excreting urine in both sexes or while ejaculating in males; also aids in erection of penis in males	Urethra	Compression	Bulbospongiosus	Perineal body	Perineal membrane; corpus spongiosum of penis; deep fascia of penis; clitoris in female
Compresses veins to maintain erection of penis in males; erection of clitoris in females	Veins of penis and clitoris	Compression	Ischiocavernosus	Ischium; ischial rami; pubic rami	Pubic symphysis; corpus cavernosum of penis in male; clitoris of female
Deep muscles					
Voluntarily compresses urethra during urination	Urethra	Compression	External urethral sphincter	Ischial rami; pubic rami	Male: median raphe; female: vaginal wall
Closes anus	Anus	Sphincter	External anal sphincter	Anococcygeal ligament	Perineal body

Figure 7.3.6: Muscles of the Perineum Common to Men and Women.

Chapter Review

Made of skin, fascia, and four pairs of muscle, the anterior abdominal wall protects the organs located in the abdomen and moves the vertebral column. These muscles include the rectus abdominis, which extends through the entire length of the trunk, the external oblique, the internal oblique, and the transversus abdominus. The quadratus lumborum forms the posterior abdominal wall.

The muscles of the thorax play a large role in breathing, especially the dome-shaped diaphragm. When it contracts and flattens, the volume inside the pleural cavities increases, which decreases the pressure within them. As a result, air will flow into the lungs. The external and internal intercostal muscles span the space between the ribs and help change the shape of the rib cage and the volume-pressure ratio inside the pleural cavities during inspiration and expiration.

The perineum muscles play roles in urination in both sexes, ejaculation in men, and vaginal contraction in women. The pelvic floor muscles support the pelvic organs, resist intra-abdominal pressure, and work as sphincters for the urethra, rectum, and vagina.

Review Questions

Q. Which of the following abdominal muscles is not a part of the anterior abdominal wall?

A. quadratus lumborum

B. rectus abdominis

C. interior oblique

D. exterior oblique

Answer: A

Q. Which muscle pair plays a role in respiration?

A. intertransversarii, interspinales

B. semispinalis cervicis, semispinalis thoracis

C. trapezius, rhomboids

D. diaphragm, scalene

Answer: D

Q. What is the linea alba?

A. a small muscle that helps with compression of the abdominal organs

B. a long tendon that runs down the middle of the rectus abdominis

C. a long band of collagen fibers that connects the hip to the knee

D. another name for the tendinous inscription

Answer: B

Critical Thinking Questions

Q. Describe the fascicle arrangement in the muscles of the abdominal wall. How do they relate to each other?

A. Arranged into layers, the muscles of the abdominal wall are the internal and external obliques, which run on diagonals, the rectus abdominis, which runs straight down the midline of the body, and the transversus abdominis, which wraps across the trunk of the body.

Q. What are some similarities and differences between the diaphragm and the pelvic diaphragm?

A. Both diaphragms are thin sheets of skeletal muscle that horizontally span areas of the trunk. The diaphragm separating the thoracic and abdominal cavities is the primary muscle of breathing. The pelvic diaphragm, consisting of two paired muscles, the coccygeus and the levator ani, forms the pelvic floor at the inferior end of the trunk.

Glossary

anal triangle
posterior triangle of the perineum that includes the anus

caval opening
opening in the diaphragm that allows the inferior vena cava to pass through; foramen for the vena cava

compressor urethrae
deep perineal muscle in women

deep transverse perineal
deep perineal muscle in men

diaphragm
skeletal muscle that separates the thoracic and abdominal cavities and is dome-shaped at rest

external intercostal
superficial intercostal muscles that raise the rib cage

external oblique
superficial abdominal muscle with fascicles that extend inferiorly and medially

iliococcygeus
muscle that makes up the levator ani along with the pubococcygeus

innermost intercostal
the deepest intercostal muscles that draw the ribs together

intercostal muscles
muscles that span the spaces between the ribs

internal intercostal
muscles the intermediate intercostal muscles that draw the ribs together

internal oblique
flat, intermediate abdominal muscle with fascicles that run perpendicular to those of the external oblique

ischiococcygeus
muscle that assists the levator ani and pulls the coccyx anteriorly

levator ani
pelvic muscle that resists intra-abdominal pressure and supports the pelvic viscera

linea alba
white, fibrous band that runs along the midline of the trunk

pelvic diaphragm
muscular sheet that comprises the levator ani and the ischiococcygeus

perineum
diamond-shaped region between the pubic symphysis, coccyx, and ischial tuberosities

pubococcygeus
muscle that makes up the levator ani along with the iliococcygeus

quadratus lumborum
posterior part of the abdominal wall that helps with posture and stabilization of the body

rectus abdominis
long, linear muscle that extends along the middle of the trunk

rectus sheaths
tissue that makes up the linea alba

sphincter urethrovaginalis
deep perineal muscle in women

tendinous intersections
three transverse bands of collagen fibers that divide the rectus abdominis into segments

transversus abdominis
deep layer of the abdomen that has fascicles arranged transversely around the abdomen

urogenital triangle
anterior triangle of the perineum that includes the external genitals

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7.4: Muscles of the Pectoral Girdle and Upper Limbs

Learning Objectives

- Identify the muscles of the pectoral girdle and upper limbs
- Identify the movement and function of the pectoral girdle and upper limbs

Muscles of the shoulder and upper limb can be divided into four groups: muscles that stabilize and position the pectoral girdle, muscles that move the arm, muscles that move the forearm, and muscles that move the wrists, hands, and fingers. The **pectoral girdle**, or shoulder girdle, consists of the lateral ends of the clavicle and scapula, along with the proximal end of the humerus, and the muscles covering these three bones to stabilize the shoulder joint. The girdle creates a base from which the head of the humerus, in its ball-and-socket joint with the glenoid fossa of the scapula, can move the arm in multiple directions.

Muscles That Position the Pectoral Girdle

Muscles that position the pectoral girdle are located either on the anterior thorax or on the posterior thorax (Figure 7.4.1 and Table 7.4.1). The anterior muscles include the **subclavius**, **pectoralis minor**, and **serratus anterior**. The posterior muscles include the **trapezius**, **rhomboid major**, and **rhomboid minor**. When the rhomboids are contracted, your scapula moves medially, which can pull the shoulder and upper limb posteriorly.

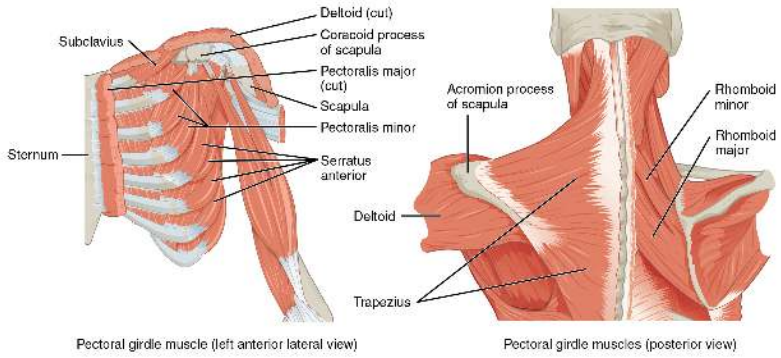


Figure 7.4.1: Muscles That Position the Pectoral Girdle. The muscles that stabilize the pectoral girdle make it a steady base on which other muscles can move the arm. Note that the pectoralis major and deltoid, which move the humerus, are cut here to show the deeper positioning muscles.

Table 7.4.1

Muscles that Position the Pectoral Girdle						
Position in the thorax	Movement	Target	Target motion direction	Prime mover	Origin	Insertion
Anterior thorax	Stabilizes clavicle during movement by depressing it	Clavicle	Depression	Subclavius	First rib	Inferior surface of clavicle
Anterior thorax	Rotates shoulder anteriorly (throwing motion); assists with inhalation	Scapula; ribs	Scapula: depresses; ribs: elevates	Pectoralis minor	Anterior surfaces of certain ribs (2–4 or 3–5)	Coracoid process of scapula
Anterior thorax	Moves arm from side of body to front of body; assists with inhalation	Scapula; ribs	Scapula: protracts; ribs: elevates	Serratus anterior	Muscle slips from certain ribs (1–8 or 1–9)	Anterior surface of vertebral border of scapula

Muscles that Position the Pectoral Girdle						
Position in the thorax	Movement	Target	Target motion direction	Prime mover	Origin	Insertion
Posterior thorax	Elevates shoulders (shrugging); pulls shoulder blades together; tilts head backwards	Scapula; cervical spine	Scapula: rotests inferiorly, retracts, elevates, and depresses; spine: extends	Trapezius	Skull; vertebral column	Acromion and spine of scapula; clavicle
Posterior thorax	Stabilizes scapula during pectoral girdle movement	Scapula	Retracts; rotates inferiorly	Rhomboid major	Thoracic vertebrae (T2–T5)	Medial border of scapula
Posterior thorax	Stabilizes scapula during pectoral girdle movement	Scapula	Retracts; rotates inferiorly	Rhomboid minor	Cervical and thoracic vertebrae (C7 and T1)	Medial border of scapula

Muscles That Move the Humerus

Similar to the muscles that position the pectoral girdle, muscles that cross the shoulder joint and move the humerus bone of the arm include both axial and scapular muscles (Figure 7.4.2 and Figure 7.4.3). The two axial muscles are the **pectoralis major** and the latissimus dorsi. The pectoralis major is thick and fan-shaped, covering much of the superior portion of the anterior thorax. The broad, triangular **latissimus dorsi** is located on the inferior part of the back, where it inserts into a thick connective tissue shealth called an aponeurosis.

Movement	Target	Target motion direction	Prime mover	Origin	Insertion
Axial muscles					
Brings elbows together; moves elbow up (as during an uppercut punch)	Humerus	Flexion; adduction; medial rotation	Pectoralis major	Clavicle; sternum; cartilage of certain ribs (1–6 or 1–7); aponeurosis of external oblique muscle	Greater tubercle of humerus
Moves elbow back (as in elbowing someone standing behind you); spreads elbows apart	Humerus; scapula	Humerus: extension, adduction, and medial rotation; scapula: depression	Latissimus dorsi	Thoracic vertebrae (T7–T12); lumbar vertebrae; lower ribs (9–12); iliac crest	Intertubercular sulcus of humerus
Scapular muscles					
Lifts arms at shoulder	Humerus	Abduction; flexion; extension; medial and lateral rotation	Deltoid	Trapezius; clavicle; acromion; spine of scapula	Deltoid tuberosity of humerus
Assists pectoralis major in bringing elbows together and stabilizes shoulder joint during movement of the pectoral girdle	Humerus	Medial rotation	Subscapularis	Subscapular fossa of scapula	Lesser tubercle of humerus
Rotates elbow outwards, as during a tennis swing	Humerus	Abduction	Supraspinatus	Supraspinous fossa of scapula	Greater tubercle of humerus
Rotates elbow outwards, as during a tennis swing	Humerus	Extension; adduction	Infraspinatus	Infraspinous fossa of scapula	Greater tubercle of humerus
Assists infraspinatus in rotating elbow outwards	Humerus	Extension; adduction	Teres major	Posterior surface of scapula	Intertubercular sulcus of humerus
Assists infraspinatus in rotating elbow outwards	Humerus	Extension; adduction	Teres minor	Lateral border of dorsal scapular surface	Greater tubercle of humerus
Moves elbow up and across body, as when putting hand on chest	Humerus	Flexion; adduction	Coracobra chialis	Coracoid process of scapula	Medial surface of humerus shaft

Figure 7.4.3: Muscles That Move the Humerus.

The rest of the shoulder muscles originate on the scapula. The anatomical and ligamental structure of the shoulder joint and the arrangements of the muscles covering it, allows the arm to carry out different types of movements. The **deltoid**, the thick muscle that creates the rounded lines of the shoulder is the major abductor of the arm, but it also facilitates flexing and medial rotation, as well as extension and lateral rotation. The **subscapularis** originates on the anterior scapula and medially rotates the arm. Named for their locations, the **supraspinatus** (superior to the spine of the scapula) and the **infraspinatus** (inferior to the spine of the scapula) abduct the arm, and laterally rotate the arm, respectively. The thick and flat **teres major** is inferior to the teres minor and extends the arm, and assists in adduction and medial rotation of it. The long **teres minor** laterally rotates and extends the arm. Finally, the **coracobrachialis** flexes and adducts the arm.

The tendons of the deep subscapularis, supraspinatus, infraspinatus, and teres minor connect the scapula to the humerus, forming the **rotator cuff** (musculotendinous cuff), the circle of tendons around the shoulder joint. When baseball pitchers undergo shoulder surgery it is usually on the rotator cuff, which becomes pinched and inflamed, and may tear away from the bone due to the repetitive motion of bring the arm overhead to throw a fast pitch.

Muscles That Move the Forearm

The forearm, made of the radius and ulna bones, has four main types of action at the hinge of the elbow joint: flexion, extension, pronation, and supination. The forearm flexors include the biceps brachii, brachialis, and brachioradialis. The extensors are the **triceps brachii** and **anconeus**. The pronators are the **pronator teres** and the **pronator quadratus**, and the **supinator** is the only one that turns the forearm anteriorly. When the forearm faces anteriorly, it is supinated. When the forearm faces posteriorly, it is pronated.

The biceps brachii, brachialis, and brachioradialis flex the forearm. The two-headed **biceps brachii** crosses the shoulder and elbow joints to flex the forearm, also taking part in supinating the forearm at the radioulnar joints and flexing the arm at the shoulder joint. Deep to the biceps brachii, the **brachialis** provides additional power in flexing the forearm. Finally, the **brachioradialis** can flex the forearm quickly or help lift a load slowly. These muscles and their associated blood vessels and nerves form the **anterior compartment of the arm** (anterior flexor compartment of the arm) (Figure 7.4.4 and Figure 7.4.5).

Movement	Target	Target motion direction	Prime mover	Origin	Insertion
Anterior muscles (flexion)					
Performs a bicep curl; also allows palm of hand to point toward body while flexing	Forearm	Flexion; supination	Biceps brachii	Coracoid process; tubercle above glenoid cavity	Radial tuberosity
	Forearm	Flexion	Brachialis	Front of distal humerus	Coronoid process of ulna
Assists and stabilizes elbow during bicep-curl motion	Forearm	Flexion	Brachioradialis	Lateral supracondylar ridge at distal end of humerus	Base of styloid process of radius
Posterior muscles (extension)					
Extends forearm, as during a punch	Forearm	Extension	Triceps brachii	Infraglenoid tubercle of scapula; posterior shaft of humerus; posterior humeral shaft distal to radial groove	Olecranon process of ulna
Assists in extending forearm; also allows forearm to extend away from body	Forearm	Extension; abduction	Anconeus	Lateral epicondyle of humerus	Lateral aspect of olecranon process of ulna
Anterior muscles (pronation)					
Turns hand palm-down	Forearm	Pronation	Pronator teres	Medial epicondyle of humerus; coronoid process of ulna	Lateral radius
Assists in turning hand palm-down	Forearm	Pronation	Pronator quadratus	Distal portion of anterior ulnar shaft	Distal surface of anterior radius
Posterior muscles (supination)					
Turns hand palm-up	Forearm	Supination	Supinator	Lateral epicondyle of humerus; proximal ulna	Proximal end of radius

Figure 7.4.5: Muscles That Move the Forearm.

Muscles That Move the Wrist, Hand, and Fingers

Wrist, hand, and finger movements are facilitated by two groups of muscles. The forearm is the origin of the **extrinsic muscles of the hand**. The palm is the origin of the intrinsic muscles of the hand.

Muscles of the Arm That Move the Wrists, Hands, and Fingers

The muscles in the **anterior compartment of the forearm** (anterior flexor compartment of the forearm) originate on the humerus and insert onto different parts of the hand. These make up the bulk of the forearm. From lateral to medial, the **superficial anterior compartment of the forearm** includes the **flexor carpi radialis**, **palmaris longus**, **flexor carpi ulnaris**, and **flexor digitorum superficialis**. The flexor digitorum superficialis flexes the hand as well as the digits at the knuckles, which allows for rapid finger movements, as in typing or playing a musical instrument (see Figure 7.4.6 and Table 7.4.2). However, poor ergonomics can irritate the tendons of these muscles as they slide back and forth with the carpal tunnel of the anterior wrist and pinch the median nerve, which also travels through the tunnel, causing Carpal Tunnel Syndrome. The **deep anterior compartment** produces flexion and bends fingers to make a fist. These are the **flexor pollicis longus** and the **flexor digitorum profundus**.

The muscles in the **superficial posterior compartment of the forearm** (superficial posterior extensor compartment of the forearm) originate on the humerus. These are the **extensor radialis longus**, **extensor carpi radialis brevis**, **extensor digitorum**, **extensor digiti minimi**, and the **extensor carpi ulnaris**.

The muscles of the **deep posterior compartment of the forearm** (deep posterior extensor compartment of the forearm) originate on the radius and ulna. These include the **abductor pollicis longus**, **extensor pollicis brevis**, **extensor pollicis longus**, and **extensor indicis** (see Figure 7.4.6).

Movement	Target	Target motion direction	Prime mover	Origin	Insertion
Superficial anterior compartment of forearm					
Bends wrist toward body; tilts hand to side away from body	Wrist; hand	Flexion; abduction	Flexor carpi radialis	Medial epicondyle of humerus	Base of second and third metacarpals
Assists in bending hand up toward shoulder	Wrist	Flexion	Palmaris longus	Medial epicondyle of humerus	Palmar aponeurosis; skin and fascia of palm
Assists in bending hand up toward shoulder; tilts hand to side away from body; stabilizes wrist	Wrist; hand	Flexion, abduction	Flexor carpi ulnaris	Medial epicondyle of humerus; olecranon process; posterior surface of ulna	Pisiform, hamate bones, and base of fifth metacarpal
Bends fingers to make a fist	Wrist; fingers 2–5	Flexion	Flexor digitorum superficialis	Medial epicondyle of humerus; coronoid process of ulna; shaft of radius	Middle phalanges of fingers 2–5
Deep anterior compartment of forearm					
Bends tip of thumb	Thumb	Flexion	Flexor pollicis longus	Anterior surface of radius; interosseous membrane	Distal phalanx of thumb
Bends fingers to make a fist; also bends wrist toward body	Wrist; fingers	Flexion	Flexor digitorum profundus	Coronoid process; anteromedial surface of ulna; interosseous membrane	Distal phalanges of fingers 2–5
Superficial posterior compartment of forearm					
Straightens wrist away from body; tilts hand to side away from body	Wrist	Extension; abduction	Extensor radialis longus	Lateral supracondylar ridge of humerus	Base of second metacarpal
Assists extensor radialis longus in extending and abducting wrist; also stabilizes hand during finger flexion.	Wrist	Extension, abduction	Extensor carpi radialis brevis	Lateral epicondyle of humerus	Base of third metacarpal
Opens fingers and moves them sideways away from the body	Wrist; fingers	Extension; abduction	Extensor digitorum	Lateral epicondyle of humerus	Extensor expansions; distal phalanges of fingers
Extends little finger	Little finger	Extension	Extensor digiti minimi	Lateral epicondyle of humerus	Extensor expansion; distal phalanx of finger 5
Straightens wrist away from body; tilts hand to side toward body	Wrist	Extension; adduction	Extensor carpi ulnaris	Lateral epicondyle of humerus; posterior border of ulna	Base of fifth metacarpal
Deep posterior compartment of forearm					
Moves thumb sideways toward body; extends thumb; moves hand sideways toward body	Wrist; thumb	Thumb: abduction, extension; wrist: abduction	Abductor pollicis longus	Posterior surface of radius and ulna; interosseous membrane	Base of first metacarpal; trapezium
Extends thumb	Thumb	Extension	Extensor pollicis brevis	Dorsal shaft of radius and ulna; interosseous membrane	Base of proximal phalanx of thumb
Extends thumb	Thumb	Extension	Extensor pollicis longus	Dorsal shaft of radius and ulna; interosseous membrane	Base of distal phalanx of thumb
Extends index finger; straightens wrist away from body	Wrist; index finger	Extension	Extensor indicis	Posterior surface of distal ulna; interosseous membrane	Tendon of extensor digitorum of index finger

Figure 7.4.6: Muscles That Move the Wrist, Hands, andForearm.

The tendons of the forearm muscles attach to the wrist and extend into the hand. Fibrous bands called **retinacula** sheath the tendons at the wrist. The **flexor retinaculum** extends over the palmar surface of the hand while the **extensor retinaculum** extends over the dorsal surface of the hand.

Intrinsic Muscles of the Hand

The **intrinsic muscles of the hand** both originate and insert within it (Figure 7.4.7). These muscles allow your fingers to also make precise movements for actions, such as typing or writing. These muscles are divided into three groups. The **thenar** muscles are on the radial aspect of the palm. The **hypothenar** muscles are on the medial aspect of the palm, and the **intermediate** muscles are midpalmar.

The thenar muscles include the **abductor pollicis brevis**, **opponens pollicis**, **flexor pollicis brevis**, and the **adductor pollicis**. These muscles form the **thenar eminence**, the rounded contour of the base of the thumb, and all act on the thumb. The movements of the thumb play an integral role in most precise movements of the hand.

The hypothenar muscles include the **abductor digiti minimi**, **flexor digiti minimi brevis**, and the **opponens digiti minimi**. These muscles form the **hypothenar eminence**, the rounded contour of the little finger, and as such, they all act on the little finger. Finally, the intermediate muscles act on all the fingers and include the **lumbrical**, the **palmar interossei**, and the **dorsal interossei**.

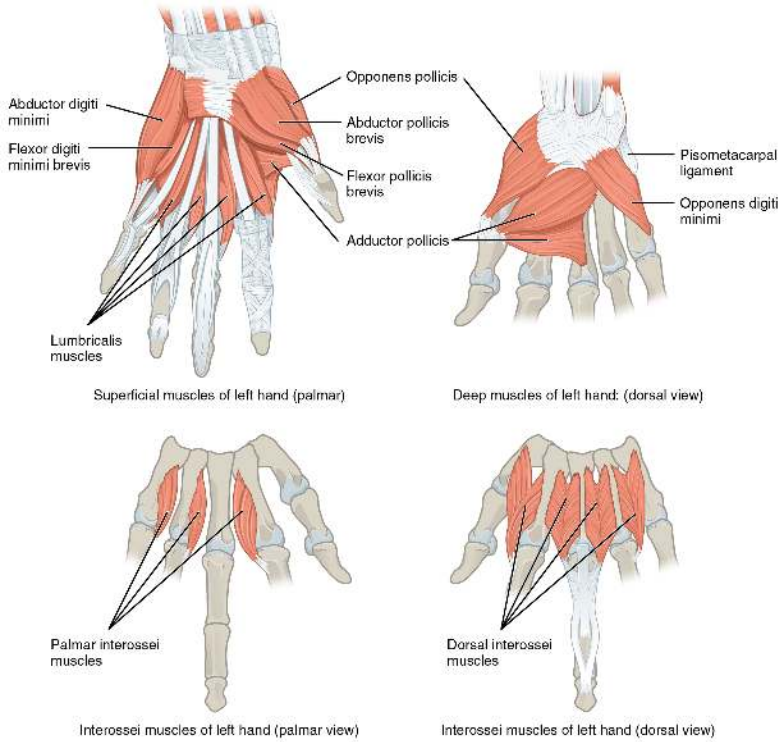


Figure 7.4.7: Intrinsic Muscles of the Hand. The intrinsic muscles of the hand both originate and insert within the hand. These muscles provide the fine motor control of the fingers by flexing, extending, abducting, and adducting the more distal finger and thumb segments.

Table 7.4.2

Intrinsic Muscles of the Hand						
Muscle	Movement	Target	Target motion direction	Prime mover	Origin	Insertion
Thenar muscles	Moves thumb toward body	Thumb	Abduction	Abductor pollicis brevis	Flexor retinaculum; and nearby carpals	Lateral base of proximal phalanx of thumb
Thenar muscles	Moves thumb across palm to touch other fingers	Thumb	Opposition	Opponens pollicis	Flexor retinaculum; trapezium	Anterior of first metacarpal
Thenar muscles	Flexes thumb	Thumb	Flexion	Flexor pollicis brevis	Flexor retinaculum; trapezium	Lateral base of proximal phalanx of thumb
Thenar muscles	Moves thumb away from body	Thumb	Adduction	Adductor pollicis	Capitate bone; bases of metacarpals 2–4; front of metacarpal 3	Medial base of proximal phalanx of thumb
Hypothenar muscles	Moves little finger toward body	Little finger	Abduction	Abductor digiti minimi	Pisiform bone	Medial side of proximal phalanx of little finger

Intrinsic Muscles of the Hand						
Muscle	Movement	Target	Target motion direction	Prime mover	Origin	Insertion
Hypothenar muscles	Flexes little finger	Little finger	Flexion	Flexor digiti minimi brevis	Hamate bone; flexor retinaculum	Medial side of proximal phalanx of little finger
Hypothenar muscles	Moves little finger across palm to touch thumb	Little finger	Opposition	Opponens digiti minimi	Hamate bone; flexor retinaculum	Medial side of fifth metacarpal
Intermediate muscles	Flexes each finger at metacarpo-phalangeal joints; extends each finger at interphalangeal joints	Fingers	Flexion	Lumbricals	Palm (lateral sides of tendons in flexor digitorum profundus)	Fingers 2–5 (lateral edges of extensional expansions on first phalanges)
Intermediate muscles	Adducts and flexes each finger at metacarpo-phalangeal joints; extends each finger at interphalangeal joints	Fingers	Adduction; flexion; extension	Palmar interossei	Side of each metacarpal that faces metacarpal 3 (absent from metacarpal 3)	Extensor expansion on first phalanx of each finger (except finger 3) on side facing finger 3
Intermediate muscles	Abducts and flexes the three middle fingers at metacarpo-phalangeal joints; extends the three middle fingers at interphalangeal joints	Fingers	Abduction; flexion; extension	Dorsal interossei	Sides of metacarpals	Both sides of finger 3; for each other finger, extensor expansion over first phalanx on side opposite finger 3

Chapter Review

The clavicle and scapula make up the pectoral girdle, which provides a stable origin for the muscles that move the humerus. The muscles that position and stabilize the pectoral girdle are located on the thorax. The anterior thoracic muscles are the subclavius, pectoralis minor, and the serratus anterior. The posterior thoracic muscles are the trapezius, levator scapulae, rhomboid major, and rhomboid minor. Nine muscles cross the shoulder joint to move the humerus. The ones that originate on the axial skeleton are the pectoralis major and the latissimus dorsi. The deltoid, subscapularis, supraspinatus, infraspinatus, teres major, teres minor, and coracobrachialis originate on the scapula.

The forearm flexors include the biceps brachii, brachialis, and brachioradialis. The extensors are the triceps brachii and anconeus. The pronators are the pronator teres and the pronator quadratus. The supinator is the only one that turns the forearm anteriorly.

The extrinsic muscles of the hands originate along the forearm and insert into the hand in order to facilitate crude movements of the wrists, hands, and fingers. The superficial anterior compartment of the forearm produces flexion. These muscles are the flexor carpi radialis, palmaris longus, flexor carpi ulnaris, and the flexor digitorum superficialis. The deep anterior compartment produces flexion as well. These are the flexor pollicis longus and the flexor digitorum profundus. The rest of the compartments produce extension. The extensor carpi radialis longus, extensor carpi radialis brevis, extensor digitorum, extensor digiti minimi, and extensor carpi ulnaris are the muscles found in the superficial posterior compartment. The deep posterior compartment includes the abductor longus, extensor pollicis brevis, extensor pollicis longus, and the extensor indicis.

Finally, the intrinsic muscles of the hands allow our fingers to make precise movements, such as typing and writing. They both originate and insert within the hand. The thenar muscles, which are located on the lateral part of the palm, are the abductor pollicis brevis, opponens pollicis, flexor pollicis brevis, and adductor pollicis. The hypothenar muscles, which are located on the medial part of the palm, are the abductor digiti minimi, flexor digiti minimi brevis, and opponens digiti minimi. The intermediate muscles, located in the middle of the palm, are the lumbricals, palmar interossei, and dorsal interossei.

Review Questions

Q. The rhomboid major and minor muscles are deep to the _____.

A. rectus abdominis

B. scalene muscles

C. trapezius

D. ligamentum nuchae

Answer: C

Q. Which muscle extends the forearm?

A. biceps brachii

B. triceps brachii

C. brachialis

D. deltoid

Answer: B

Q. What is the origin of the wrist flexors?

A. the lateral epicondyle of the humerus

B. the medial epicondyle of the humerus

C. the carpal bones of the wrist

D. the deltoid tuberosity of the humerus

Answer: B

Q. Which muscles stabilize the pectoral girdle?

A. axial and scapular

B. axial

C. appendicular

D. axial and appendicular

Answer: A

Critical Thinking Questions

Q. The tendons of which muscles form the rotator cuff? Why is the rotator cuff important?

> A. Tendons of the infraspinatus, supraspinatus, teres minor, and the subscapularis form the rotator cuff, which forms a foundation on which the arms and shoulders can be stabilized and move.

Q. List the general muscle groups of the shoulders and upper limbs as well as their subgroups.

> A. The muscles that make up the shoulders and upper limbs include the muscles that position the pelvic girdle, the muscles that move the humerus, the muscles that move the forearm, and the muscles that move the wrists, hands, and fingers.

Glossary

abductor digiti minimi
muscle that abducts the little finger

adductor pollicis
muscle that adducts the thumb

abductor pollicis brevis
muscle that abducts the thumb

abductor pollicis longus
muscle that inserts into the first metacarpal

anconeus
small muscle on the lateral posterior elbow that extends the forearm

anterior compartment of the arm
(anterior flexor compartment of the arm) the biceps brachii, brachialis, brachioradialis, and their associated blood vessels and nerves

anterior compartment of the forearm
(anterior flexor compartment of the forearm) deep and superficial muscles that originate on the humerus and insert into the hand

biceps brachii
two-headed muscle that crosses the shoulder and elbow joints to flex the forearm while assisting in supinating it and flexing the arm at the shoulder

brachialis
muscle deep to the biceps brachii that provides power in flexing the forearm.

brachioradialis
muscle that can flex the forearm quickly or help lift a load slowly

coracobrachialis
muscle that flexes and adducts the arm

deep anterior compartment
flexor pollicis longus, flexor digitorum profundus, and their associated blood vessels and nerves

deep posterior compartment of the forearm
(deep posterior extensor compartment of the forearm) the abductor pollicis longus, extensor pollicis brevis, extensor pollicis longus, extensor indicis, and their associated blood vessels and nerves

deltoid
shoulder muscle that abducts the arm as well as flexes and medially rotates it, and extends and laterally rotates it

dorsal interossei
muscles that abduct and flex the three middle fingers at the metacarpophalangeal joints and extend them at the interphalangeal joints

extensor carpi radialis brevis
muscle that extends and abducts the hand at the wrist

extensor carpi ulnaris
muscle that extends and adducts the hand

extensor digiti minimi
muscle that extends the little finger

extensor digitorum
muscle that extends the hand at the wrist and the phalanges

extensor indicis
muscle that inserts onto the tendon of the extensor digitorum of the index finger

extensor pollicis brevis
muscle that inserts onto the base of the proximal phalanx of the thumb

extensor pollicis longus
muscle that inserts onto the base of the distal phalanx of the thumb

extensor radialis longus
muscle that extends and abducts the hand at the wrist

extensor retinaculum
band of connective tissue that extends over the dorsal surface of the hand

extrinsic muscles of the hand
muscles that move the wrists, hands, and fingers and originate on the arm

flexor carpi radialis
muscle that flexes and abducts the hand at the wrist

flexor carpi ulnaris
muscle that flexes and adducts the hand at the wrist

flexor digiti minimi brevis
muscle that flexes the little finger

flexor digitorum profundus
muscle that flexes the phalanges of the fingers and the hand at the wrist

flexor digitorum superficialis
muscle that flexes the hand and the digits

flexor pollicis brevis
muscle that flexes the thumb

flexor pollicis longus

muscle that flexes the distal phalanx of the thumb

flexor retinaculum
band of connective tissue that extends over the palmar surface of the hand

hypothenar
group of muscles on the medial aspect of the palm

hypothenar eminence
rounded contour of muscle at the base of the little finger

infraspinatus
muscle that laterally rotates the arm

intermediate
group of midpalmar muscles

intrinsic muscles of the hand
muscles that move the wrists, hands, and fingers and originate in the palm

latissimus dorsi
broad, triangular axial muscle located on the inferior part of the back

lumbrical
muscle that flexes each finger at the metacarpophalangeal joints and extend each finger at the interphalangeal joints

opponens digiti minimi
muscle that brings the little finger across the palm to meet the thumb

opponens pollicis
muscle that moves the thumb across the palm to meet another finger

palmar interossei
muscles that abduct and flex each finger at the metacarpophalangeal joints and extend each finger at the interphalangeal joints

palmaris longus
muscle that provides weak flexion of the hand at the wrist

pectoral girdle
shoulder girdle, made up of the clavicle and scapula

pectoralis major
thick, fan-shaped axial muscle that covers much of the superior thorax

pectoralis minor
muscle that moves the scapula and assists in inhalation

pronator quadratus
pronator that originates on the ulna and inserts on the radius

pronator teres
pronator that originates on the humerus and inserts on the radius

retinacula
fibrous bands that sheath the tendons at the wrist

rhomboid major
muscle that attaches the vertebral border of the scapula to the spinous process of the thoracic vertebrae

rhomboid minor
muscle that attaches the vertebral border of the scapula to the spinous process of the thoracic vertebrae

rotator cuff
(also, musculotendinous cuff) the circle of tendons around the shoulder joint

serratus anterior
large and flat muscle that originates on the ribs and inserts onto the scapula

subclavius
muscle that stabilizes the clavicle during movement

subscapularis
muscle that originates on the anterior scapula and medially rotates the arm

superficial anterior compartment of the forearm
flexor carpi radialis, palmaris longus, flexor carpi ulnaris, flexor digitorum superficialis, and their associated blood vessels and nerves

superficial posterior compartment of the forearm
extensor radialis longus, extensor carpi radialis brevis, extensor digitorum, extensor digiti minimi, extensor carpi ulnaris, and their associated blood vessels and nerves

supinator
muscle that moves the palm and forearm anteriorly

supraspinatus
muscle that abducts the arm

teres major
muscle that extends the arm and assists in adduction and medial rotation of it

teres minor
muscle that laterally rotates and extends the arm

thenar
group of muscles on the lateral aspect of the palm

thenar eminence
rounded contour of muscle at the base of the thumb

trapezius
muscle that stabilizes the upper part of the back

triceps brachii
three-headed muscle that extends the forearm

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Index

A

abduct
1.2G: Interactions of Skeletal Muscles, Their Fascicle Arrangement, and Their Lever Systems
abduction
2.8E: Types of Body Movements
abductor
1.2H: Naming Skeletal Muscle
abductor digiti minimi
7.4: Muscles of the Pectoral Girdle and Upper Limbs
abductor pollicis brevis
7.4: Muscles of the Pectoral Girdle and Upper Limbs
abductor pollicis longus
7.4: Muscles of the Pectoral Girdle and Upper Limbs
accommodation
3.4A: The Cranial Nerve Exam
accommodation–convergence reflex
3.4A: The Cranial Nerve Exam
acetabular labrum
2.8F: Anatomy of Selected Synovial Joints
acromial end of the clavicle
7.1: The Pectoral Girdle
acromial process
7.1: The Pectoral Girdle
acromioclavicular joint
7.1: The Pectoral Girdle
acromion
7.1: The Pectoral Girdle
adduction
2.8E: Types of Body Movements
adductor
1.2H: Naming Skeletal Muscle
adductor brevis
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
adductor longus
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
adductor magnus
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
adductor pollicis
7.4: Muscles of the Pectoral Girdle and Upper Limbs
adductor tubercle
6.1: Bones of the Lower Limb
agonist
1.2G: Interactions of Skeletal Muscles, Their Fascicle Arrangement, and Their Lever Systems
alar plate
3.4: The Central Nervous System
alveolar process of the mandible
4.1: The Skull
alveolar process of the maxilla
4.1: The Skull
amphiarthrosis
2.8A: Classification of Joints
amygdala
3.4: The Central Nervous System
anal triangle
7.3: Axial Muscles of the Abdominal Wall and Thorax
anatomical neck
7.2: Bones of the Upper Limb
anconeus
7.4: Muscles of the Pectoral Girdle and Upper Limbs
angle of the mandible
4.1: The Skull
angle of the rib
5.1: The Thoracic Cage
ankle joint
6.1: Bones of the Lower Limb
annular ligament
2.8F: Anatomy of Selected Synovial Joints
antagonist
1.2G: Interactions of Skeletal Muscles, Their Fascicle Arrangement, and Their Lever Systems
anterior (ventral) sacral foramen
4.2: The Vertebral Column
anterior arch
4.2: The Vertebral Column
anterior border of the tibia
6.1: Bones of the Lower Limb
anterior column
3.4: The Central Nervous System
anterior compartment of the arm
7.4: Muscles of the Pectoral Girdle and Upper Limbs
anterior compartment of the forearm
7.4: Muscles of the Pectoral Girdle and Upper Limbs
anterior compartment of the leg
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
anterior compartment of the thigh
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
anterior cranial fossa
4.1: The Skull
anterior cruciate ligament
2.8F: Anatomy of Selected Synovial Joints
anterior horn
3.4: The Central Nervous System
anterior longitudinal ligament
4.2: The Vertebral Column
anterior median fissure
3.4: The Central Nervous System
anterior scalene
4.3: Axial Muscles of the Head, Neck, and Back
anterior spinal artery
3.5: Circulation and the Central Nervous System
anterior talofibular ligament
2.8F: Anatomy of Selected Synovial Joints
anulus fibrosus
4.2: The Vertebral Column
appendicular
4.3: Axial Muscles of the Head, Neck, and Back
arachnoid granulation
3.5: Circulation and the Central Nervous System
arachnoid mater
3.5: Circulation and the Central Nervous System
arachnoid trabeculae
3.5: Circulation and the Central Nervous System
arm
7.2: Bones of the Upper Limb
articular capsule
2.8D: Synovial Joints
articular cartilage
2.6: Bone Structure
2.8D: Synovial Joints
articular disc
2.8D: Synovial Joints
articular tubercle
4.1: The Skull
articulation
2.6: Bone Structure
2.8A: Classification of Joints
ascending tract
3.4: The Central Nervous System
astrocyte
3.2: Nervous Tissue
atlantoaxial joint
2.8F: Anatomy of Selected Synovial Joints
atlas
4.2: The Vertebral Column
autonomic nervous system (ANS)
3.1: Basic Structures and Function of the Nervous System
axial
4.3: Axial Muscles of the Head, Neck, and Back
axis
4.2: The Vertebral Column
axon
3.1: Basic Structures and Function of the Nervous System
axon hillock
3.2: Nervous Tissue
axon segment
3.2: Nervous Tissue
axon terminal
3.2: Nervous Tissue
axoplasm
3.2: Nervous Tissue

B

basal forebrain
3.4: The Central Nervous System
basal nuclei
3.4: The Central Nervous System
basal plate
3.4: The Central Nervous System
base of the metatarsal bone
6.1: Bones of the Lower Limb
basilar artery
3.5: Circulation and the Central Nervous System
belly
1.2G: Interactions of Skeletal Muscles, Their Fascicle Arrangement, and Their Lever Systems
bi
1.2H: Naming Skeletal Muscle
biaxial joint
2.8A: Classification of Joints
biceps brachii
7.4: Muscles of the Pectoral Girdle and Upper Limbs
biceps femoris
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs

bicipital groove
7.2: Bones of the Upper Limb
bipennate
1.2G: Interactions of Skeletal Muscles, Their Fascicle Arrangement, and Their Lever Systems
bipolar
3.2: Nervous Tissue
body of the rib
5.1: The Thoracic Cage
bone
2.2: The Functions of the Skeletal System
brachialis
7.4: Muscles of the Pectoral Girdle and Upper Limbs
brachioradialis
7.4: Muscles of the Pectoral Girdle and Upper Limbs
brain
3.1: Basic Structures and Function of the Nervous System
brain case
4.1: The Skull
brevis
1.2H: Naming Skeletal Muscle
Broca's area
3.4: The Central Nervous System
Brodmann’s areas
3.4: The Central Nervous System
buccinator
4.3: Axial Muscles of the Head, Neck, and Back
bursa
2.8D: Synovial Joints

C

calcaneal tendon
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
calcaneofibular ligament
2.8F: Anatomy of Selected Synovial Joints
calcaneus
6.1: Bones of the Lower Limb
calvaria
4.1: The Skull
canaliculi
2.6: Bone Structure
capitate
7.2: Bones of the Upper Limb
capitulum
7.2: Bones of the Upper Limb
carotid canal
3.5: Circulation and the Central Nervous System
4.1: The Skull
carpal bone
7.2: Bones of the Upper Limb
carpal tunnel
7.2: Bones of the Upper Limb
carpometacarpal joint
7.2: Bones of the Upper Limb
cartilage
2.2: The Functions of the Skeletal System
cartilaginous joint
2.8A: Classification of Joints
cauda equina
3.4: The Central Nervous System
caval opening
7.3: Axial Muscles of the Abdominal Wall and Thorax
central canal
2.6: Bone Structure
3.5: Circulation and the Central Nervous System
central nervous system (CNS)
3.1: Basic Structures and Function of the Nervous System
central sulcus
3.4: The Central Nervous System
cerebellum
3.4: The Central Nervous System
cerebral aqueduct
3.5: Circulation and the Central Nervous System
cerebral cortex
3.4: The Central Nervous System
cerebral hemisphere
3.4: The Central Nervous System
cerebrospinal fluid (CSF)
3.2: Nervous Tissue
cerebrum
3.4: The Central Nervous System
cervical curve
4.2: The Vertebral Column
cervical vertebrae
4.2: The Vertebral Column
choroid plexus
3.2: Nervous Tissue
3.5: Circulation and the Central Nervous System
circle of Willis
3.5: Circulation and the Central Nervous System
circular
1.2G: Interactions of Skeletal Muscles, Their Fascicle Arrangement, and Their Lever Systems
circumduction
2.8E: Types of Body Movements
claudate
3.4: The Central Nervous System
clavicle
7.1: The Pectoral Girdle
clavicular notch
5.1: The Thoracic Cage
closed reduction
2.10: Fractures - Bone Repair
common carotid artery
3.5: Circulation and the Central Nervous System
compact bone
2.6: Bone Structure
compressor urethrae
7.3: Axial Muscles of the Abdominal Wall and Thorax
conductive hearing
3.4A: The Cranial Nerve Exam
condylar process of the mandible
4.1: The Skull
condyloid joint
2.8D: Synovial Joints
conjugate gaze
3.4A: The Cranial Nerve Exam
convergence
3.4A: The Cranial Nerve Exam
convergent
1.2G: Interactions of Skeletal Muscles, Their Fascicle Arrangement, and Their Lever Systems
coracobrachialis
7.4: Muscles of the Pectoral Girdle and Upper Limbs
coracoclavicular ligament
7.1: The Pectoral Girdle
coracohumeral ligament
2.8F: Anatomy of Selected Synovial Joints
coracoid process
7.1: The Pectoral Girdle
coronoid fossa
7.2: Bones of the Upper Limb
coronoid process of the ulna
7.2: Bones of the Upper Limb
corpus callosum
3.4: The Central Nervous System
corrugator supercilii
4.3: Axial Muscles of the Head, Neck, and Back
costal cartilage
5.1: The Thoracic Cage
costal facet
4.2: The Vertebral Column
costal groove
5.1: The Thoracic Cage
costoclavicular ligament
7.1: The Pectoral Girdle
cranial cavity
4.1: The Skull
cranium
4.1: The Skull
cribriform plate
4.1: The Skull
crista galli
4.1: The Skull
cuboid
6.1: Bones of the Lower Limb

D

deep anterior compartment
7.4: Muscles of the Pectoral Girdle and Upper Limbs
deep posterior compartment of the forearm
7.4: Muscles of the Pectoral Girdle and Upper Limbs
deep transverse perineal
7.3: Axial Muscles of the Abdominal Wall and Thorax
deglutition
4.3: Axial Muscles of the Head, Neck, and Back
deltoid
7.4: Muscles of the Pectoral Girdle and Upper Limbs
deltoid ligament
2.8F: Anatomy of Selected Synovial Joints
deltoid tuberosity
7.2: Bones of the Upper Limb
dendrite
3.1: Basic Structures and Function of the Nervous System
dens
4.2: The Vertebral Column
depression
2.8E: Types of Body Movements
descending tract
3.4: The Central Nervous System
diaphragm
7.3: Axial Muscles of the Abdominal Wall and Thorax
diaphysis
2.6: Bone Structure

diarthrosis
2.8A: Classification of Joints
digastric
4.3: Axial Muscles of the Head, Neck, and Back
diploë
2.6: Bone Structure
diplopia
3.4A: The Cranial Nerve Exam
direct pathway
3.4: The Central Nervous System
disinhibition
3.4: The Central Nervous System
distal radioulnar joint
7.2: Bones of the Upper Limb
distal tibiofibular joint
6.1: Bones of the Lower Limb
dorsal (posterior) nerve root
3.4: The Central Nervous System
dorsal group
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
dorsal interossei
7.4: Muscles of the Pectoral Girdle and Upper Limbs
dorsiflexion
2.8E: Types of Body Movements
dura mater
3.5: Circulation and the Central Nervous System
dural sinus
3.5: Circulation and the Central Nervous System

E

elbow joint
2.8F: Anatomy of Selected Synovial Joints
7.2: Bones of the Upper Limb
elevation
2.8E: Types of Body Movements
endochondral ossification
2.9: Bone Formation and Development
endosteum
2.6: Bone Structure
enteric nervous system (ENS)
3.1: Basic Structures and Function of the Nervous System
ependymal cell
3.2: Nervous Tissue
epicranial aponeurosis
4.3: Axial Muscles of the Head, Neck, and Back
epiphyseal line
2.9: Bone Formation and Development
epiphyseal plate
2.6: Bone Structure
epiphysis
2.6: Bone Structure
epithalamus
3.4: The Central Nervous System
erector spinae group
4.3: Axial Muscles of the Head, Neck, and Back
ethmoid air cell
4.1: The Skull
eversion
2.8E: Types of Body Movements
extension
2.8E: Types of Body Movements
extensor
1.2H: Naming Skeletal Muscle
extensor carpi radialis brevis
7.4: Muscles of the Pectoral Girdle and Upper Limbs
extensor carpi ulnaris
7.4: Muscles of the Pectoral Girdle and Upper Limbs
extensor digiti minimi
7.4: Muscles of the Pectoral Girdle and Upper Limbs
extensor digitorum
7.4: Muscles of the Pectoral Girdle and Upper Limbs
extensor digitorum brevis
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
extensor digitorum longus
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
extensor hallucis longus
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
extensor indicis
7.4: Muscles of the Pectoral Girdle and Upper Limbs
extensor pollicis brevis
7.4: Muscles of the Pectoral Girdle and Upper Limbs
extensor pollicis longus
7.4: Muscles of the Pectoral Girdle and Upper Limbs
extensor radialis longus
7.4: Muscles of the Pectoral Girdle and Upper Limbs
extensor retinaculum
7.4: Muscles of the Pectoral Girdle and Upper Limbs
external acoustic meatus
4.1: The Skull
external callus
2.10: Fractures - Bone Repair
external intercostal
7.3: Axial Muscles of the Abdominal Wall and Thorax
external oblique
7.3: Axial Muscles of the Abdominal Wall and Thorax
external occipital protuberance
4.1: The Skull
extrinsic eye muscles
4.3: Axial Muscles of the Head, Neck, and Back
extrinsic ligament
2.8D: Synovial Joints
extrinsic muscles of the hand
7.4: Muscles of the Pectoral Girdle and Upper Limbs
extrinsic muscles of the tongue
3.4A: The Cranial Nerve Exam

F

facet
4.2: The Vertebral Column
facial bones
4.1: The Skull
false ribs
5.1: The Thoracic Cage
fascicle
1.2G: Interactions of Skeletal Muscles, Their Fascicle Arrangement, and Their Lever Systems
fauces
3.4A: The Cranial Nerve Exam
femoral triangle
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
femoropatellar joint
2.8F: Anatomy of Selected Synovial Joints
femur
6.1: Bones of the Lower Limb
fibrous joint
2.8A: Classification of Joints
fibula
6.1: Bones of the Lower Limb
fibular collateral ligament
2.8F: Anatomy of Selected Synovial Joints
fibular notch
6.1: Bones of the Lower Limb
fibularis brevis
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
fibularis longus
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
fibularis tertius
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
flat bone
2.5: Bone Classification
flexion
1.2G: Interactions of Skeletal Muscles, Their Fascicle Arrangement, and Their Lever Systems
2.8E: Types of Body Movements
flexor
1.2H: Naming Skeletal Muscle
flexor carpi radialis
7.4: Muscles of the Pectoral Girdle and Upper Limbs
flexor carpi ulnaris
7.4: Muscles of the Pectoral Girdle and Upper Limbs
flexor digiti minimi brevis
7.4: Muscles of the Pectoral Girdle and Upper Limbs
flexor digitorum longus
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
flexor digitorum profundus
7.4: Muscles of the Pectoral Girdle and Upper Limbs
flexor digitorum superficialis
7.4: Muscles of the Pectoral Girdle and Upper Limbs
flexor hallucis longus
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
flexor pollicis brevis
7.4: Muscles of the Pectoral Girdle and Upper Limbs
flexor pollicis longus
7.4: Muscles of the Pectoral Girdle and Upper Limbs
flexor retinaculum
7.2: Bones of the Upper Limb
7.4: Muscles of the Pectoral Girdle and Upper Limbs
floating ribs
5.1: The Thoracic Cage
fontanelles
2.8B: Fibrous Joints
foot
6.1: Bones of the Lower Limb
foramen magnum
3.5: Circulation and the Central Nervous System
4.1: The Skull
foramen ovale of the middle cranial fossa
4.1: The Skull
foramen rotundum
4.1: The Skull

foramen spinosum
4.1: The Skull
forearm
7.2: Bones of the Upper Limb
fossa
7.1: The Pectoral Girdle
fourth ventricle
3.5: Circulation and the Central Nervous System
fovea capitis
6.1: Bones of the Lower Limb
fracture
2.10: Fractures - Bone Repair
fracture hematoma
2.10: Fractures - Bone Repair
frontal bone
4.1: The Skull
frontal eye field
3.4: The Central Nervous System
frontal lobe
3.4: The Central Nervous System
frontal sinus
4.1: The Skull
frontalis
4.3: Axial Muscles of the Head, Neck, and Back
fusiform
1.2G: Interactions of Skeletal Muscles, Their Fascicle Arrangement, and Their Lever Systems

G

ganglion
3.1: Basic Structures and Function of the Nervous System
gastrocnemius
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
genioglossus
4.3: Axial Muscles of the Head, Neck, and Back
geniohyoid
4.3: Axial Muscles of the Head, Neck, and Back
glabella
4.1: The Skull
glenohumeral joint
2.8F: Anatomy of Selected Synovial Joints
7.1: The Pectoral Girdle
glenohumeral ligament
2.8F: Anatomy of Selected Synovial Joints
glenoid cavity
7.1: The Pectoral Girdle
glenoid labrum
2.8F: Anatomy of Selected Synovial Joints
glial cell
3.1: Basic Structures and Function of the Nervous System
globus pallidus
3.4: The Central Nervous System
gluteal group
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
gluteal tuberosity
6.1: Bones of the Lower Limb
gluteus maximus
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
gluteus medius
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
gluteus minimus
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
gomphosis
2.8B: Fibrous Joints
gracilis
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
gray matter
3.1: Basic Structures and Function of the Nervous System
greater trochanter
6.1: Bones of the Lower Limb
greater tubercle
7.2: Bones of the Upper Limb
greater wings of sphenoid bone
4.1: The Skull
gyrus
3.4: The Central Nervous System

H

hallux
6.1: Bones of the Lower Limb
hamate
7.2: Bones of the Upper Limb
hamstring group
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
hand
7.2: Bones of the Upper Limb
hard palate
4.1: The Skull
head of the femur
6.1: Bones of the Lower Limb
head of the fibula
6.1: Bones of the Lower Limb
head of the humerus
7.2: Bones of the Upper Limb
head of the metatarsal bone
6.1: Bones of the Lower Limb
head of the radius
7.2: Bones of the Upper Limb
head of the rib
5.1: The Thoracic Cage
Head of the ulna
7.2: Bones of the Upper Limb
hematopoiesis
2.2: The Functions of the Skeletal System
hinge joint
2.8D: Synovial Joints
hip joint
6.1: Bones of the Lower Limb
hippocampus
3.4: The Central Nervous System
hole
2.6: Bone Structure
hook of the hamate bone
7.2: Bones of the Upper Limb
horizontal plate
4.1: The Skull
humeroradial joint
2.8F: Anatomy of Selected Synovial Joints
humeroulnar joint
2.8F: Anatomy of Selected Synovial Joints
humerus
7.2: Bones of the Upper Limb
hyoglossus
4.3: Axial Muscles of the Head, Neck, and Back
hyperextension
2.8E: Types of Body Movements
hyperflexion
2.8E: Types of Body Movements
hypoglossal canal
4.1: The Skull
hypophyseal (pituitary) fossa
4.1: The Skull
hypothalamus
3.4: The Central Nervous System
hypothenar
7.4: Muscles of the Pectoral Girdle and Upper Limbs
hypothenar eminence
7.4: Muscles of the Pectoral Girdle and Upper Limbs

I

iliacus
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
iliococcygeus
7.3: Axial Muscles of the Abdominal Wall and Thorax
iliocostalis cervicis
4.3: Axial Muscles of the Head, Neck, and Back
iliocostalis group
4.3: Axial Muscles of the Head, Neck, and Back
iliocostalis lumborum
4.3: Axial Muscles of the Head, Neck, and Back
iliocostalis thoracis
4.3: Axial Muscles of the Head, Neck, and Back
iliofemoral ligament
2.8F: Anatomy of Selected Synovial Joints
iliopsoas group
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
iliotibial tract
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
indirect pathway
3.4: The Central Nervous System
inferior angle of the scapula
7.1: The Pectoral Girdle
inferior articular process
4.2: The Vertebral Column
inferior colliculus
3.4: The Central Nervous System
inferior extensor retinaculum
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
inferior gemellus
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
inferior nasal concha
4.1: The Skull
inferior olive
3.4: The Central Nervous System
inferior rotation
2.8E: Types of Body Movements

infraglenoid fossa
7.1: The Pectoral Girdle
infraglenoid tubercle
7.1: The Pectoral Girdle
infrahyoid muscles
4.3: Axial Muscles of the Head, Neck, and Back
infraorbital foramen
4.1: The Skull
infraspinatus
7.4: Muscles of the Pectoral Girdle and Upper Limbs
infraspinous fossa
7.1: The Pectoral Girdle
infratemporal fossa
4.1: The Skull
initial segment
3.2: Nervous Tissue
innermost intercostal
7.3: Axial Muscles of the Abdominal Wall and Thorax
insertion
1.2G: Interactions of Skeletal Muscles, Their Fascicle Arrangement, and Their Lever Systems
integration
3.1: Basic Structures and Function of the Nervous System
intercondylar eminence
6.1: Bones of the Lower Limb
intercondylar fossa
6.1: Bones of the Lower Limb
intercostal muscles
7.3: Axial Muscles of the Abdominal Wall and Thorax
intermediate
7.4: Muscles of the Pectoral Girdle and Upper Limbs
intermediate cuneiform
6.1: Bones of the Lower Limb
internal callus
2.10: Fractures - Bone Repair
internal carotid artery
3.5: Circulation and the Central Nervous System
internal intercostal
7.3: Axial Muscles of the Abdominal Wall and Thorax
internal oblique
7.3: Axial Muscles of the Abdominal Wall and Thorax
internuclear ophthalmoplegia
3.4A: The Cranial Nerve Exam
interosseous border of the fibula
6.1: Bones of the Lower Limb
interosseous border of the radius
7.2: Bones of the Upper Limb
interosseous border of the tibia
6.1: Bones of the Lower Limb
interosseous border of the ulna
7.2: Bones of the Upper Limb
interosseous membrane
2.8B: Fibrous Joints
interosseous membrane of the forearm
7.2: Bones of the Upper Limb
interosseous membrane of the leg
6.1: Bones of the Lower Limb
interphalangeal joint
7.2: Bones of the Upper Limb
intertrochanteric crest
6.1: Bones of the Lower Limb
intertrochanteric line
6.1: Bones of the Lower Limb
intertubercular groove (sulcus)
7.2: Bones of the Upper Limb
interventricular foramina
3.5: Circulation and the Central Nervous System
intervertebral disc
4.2: The Vertebral Column
intervertebral foramen
4.2: The Vertebral Column
intorsion
3.4A: The Cranial Nerve Exam
intracapsular ligament
2.8D: Synovial Joints
intramembranous ossification
2.9: Bone Formation and Development
intrinsic ligament
2.8D: Synovial Joints
intrinsic muscles of the hand
7.4: Muscles of the Pectoral Girdle and Upper Limbs
intrinsic muscles of the tongue
3.4A: The Cranial Nerve Exam
inversion
2.8E: Types of Body Movements
irregular bone
2.5: Bone Classification
ischiococcygeus
7.3: Axial Muscles of the Abdominal Wall and Thorax
ischiofemoral ligament
2.8F: Anatomy of Selected Synovial Joints

J

joint
2.8A: Classification of Joints
joint cavity
2.8A: Classification of Joints
jugular (suprasternal) notch
5.1: The Thoracic Cage
jugular foramen
4.1: The Skull
jugular veins
3.5: Circulation and the Central Nervous System

K

kinesthesia
3.4: The Central Nervous System
knee joint
6.1: Bones of the Lower Limb
kyphosis
4.2: The Vertebral Column

L

lacrimal bone
4.1: The Skull
lacrimal fossa
4.1: The Skull
lambdoid suture
4.1: The Skull
lamina
4.2: The Vertebral Column
lateral (external) rotation
2.8E: Types of Body Movements
lateral apertures
3.5: Circulation and the Central Nervous System
lateral border of the scapula
7.1: The Pectoral Girdle
lateral column
3.4: The Central Nervous System
lateral compartment of the leg
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
lateral condyle of the femur
6.1: Bones of the Lower Limb
lateral condyle of the tibia
6.1: Bones of the Lower Limb
lateral cuneiform
6.1: Bones of the Lower Limb
lateral epicondyle of the femur
6.1: Bones of the Lower Limb
lateral epicondyle of the humerus
7.2: Bones of the Upper Limb
lateral excursion
2.8E: Types of Body Movements
lateral flexion
2.8E: Types of Body Movements
lateral horn
3.4: The Central Nervous System
lateral malleolus
6.1: Bones of the Lower Limb
lateral meniscus
2.8F: Anatomy of Selected Synovial Joints
lateral pterygoid
4.3: Axial Muscles of the Head, Neck, and Back
lateral pterygoid plate
4.1: The Skull
lateral sacral crest
4.2: The Vertebral Column
lateral sulcus
3.4: The Central Nervous System
lateral supracondylar ridge
7.2: Bones of the Upper Limb
lateral tibiofemoral joint
2.8F: Anatomy of Selected Synovial Joints
lateral ventricles
3.5: Circulation and the Central Nervous System
lateralis
1.2H: Naming Skeletal Muscle
latissimus dorsi
7.4: Muscles of the Pectoral Girdle and Upper Limbs
leg
6.1: Bones of the Lower Limb
lesser trochanter
6.1: Bones of the Lower Limb
lesser tubercle
7.2: Bones of the Upper Limb
lesser wings of the sphenoid bone
4.1: The Skull
levator ani
7.3: Axial Muscles of the Abdominal Wall and Thorax
ligament
2.8B: Fibrous Joints

ligament of the head of the femur
2.8F: Anatomy of Selected Synovial Joints
6.1: Bones of the Lower Limb
ligamentum flavum
4.2: The Vertebral Column
limbic cortex
3.4: The Central Nervous System
limbic system
3.4: The Central Nervous System
linea alba
7.3: Axial Muscles of the Abdominal Wall and Thorax
linea aspera
6.1: Bones of the Lower Limb
lingula
4.1: The Skull
long bone
2.5: Bone Classification
longissimus capitis
4.3: Axial Muscles of the Head, Neck, and Back
longissimus group
4.3: Axial Muscles of the Head, Neck, and Back
longissimus thoracis
4.3: Axial Muscles of the Head, Neck, and Back
longitudinal fissure
3.4: The Central Nervous System
longus
1.2H: Naming Skeletal Muscle
lordosis
4.2: The Vertebral Column
lucunae
2.6: Bone Structure
lumbar curve
4.2: The Vertebral Column
lumbar puncture
3.5: Circulation and the Central Nervous System
lumbar vertebrae
4.2: The Vertebral Column
lumbrical
7.4: Muscles of the Pectoral Girdle and Upper Limbs
lunate
7.2: Bones of the Upper Limb

M

mandible
4.1: The Skull
mandibular foramen
4.1: The Skull
mandibular fossa
4.1: The Skull
mandibular notch
4.1: The Skull
manubrium
5.1: The Thoracic Cage
masseter
4.3: Axial Muscles of the Head, Neck, and Back
mastication
4.3: Axial Muscles of the Head, Neck, and Back
mastoid process
4.1: The Skull
maxillary bone
4.1: The Skull
maxillary sinus
4.1: The Skull
maximus
1.2H: Naming Skeletal Muscle
medial (internal) rotation
2.8E: Types of Body Movements
medial border of the scapula
7.1: The Pectoral Girdle
medial compartment of the thigh
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
medial condyle of the femur
6.1: Bones of the Lower Limb
medial condyle of the tibia
6.1: Bones of the Lower Limb
medial cuneiform
6.1: Bones of the Lower Limb
medial epicondyle of the femur
6.1: Bones of the Lower Limb
medial epicondyle of the humerus
7.2: Bones of the Upper Limb
medial excursion
2.8E: Types of Body Movements
medial longitudinal fasciculus (MLF)
3.4A: The Cranial Nerve Exam
medial malleolus
6.1: Bones of the Lower Limb
medial meniscus
2.8F: Anatomy of Selected Synovial Joints
medial pterygoid
4.3: Axial Muscles of the Head, Neck, and Back
medial pterygoid plate
4.1: The Skull
medial tibiofemoral joint
2.8F: Anatomy of Selected Synovial Joints
medialis
1.2H: Naming Skeletal Muscle
medius
1.2H: Naming Skeletal Muscle
medullary cavity
2.6: Bone Structure
meninges
3.5: Circulation and the Central Nervous System
meniscus
2.8D: Synovial Joints
mental foramen
4.1: The Skull
mental protuberance
4.1: The Skull
metacarpal bone
7.2: Bones of the Upper Limb
metacarpophalangeal joint
7.2: Bones of the Upper Limb
metatarsal bone
6.1: Bones of the Lower Limb
metatarsophalangeal joint
6.1: Bones of the Lower Limb
microglia
3.2: Nervous Tissue
midcarpal joint
7.2: Bones of the Upper Limb
middle cranial fossa
4.1: The Skull
middle nasal concha
4.1: The Skull
middle scalene
4.3: Axial Muscles of the Head, Neck, and Back
minimus
1.2H: Naming Skeletal Muscle
modeling
2.9: Bone Formation and Development
multiaxial joint
2.8A: Classification of Joints
multifidus
4.3: Axial Muscles of the Head, Neck, and Back
multipennate
1.2G: Interactions of Skeletal Muscles, Their Fascicle Arrangement, and Their Lever Systems
multipolar
3.2: Nervous Tissue
myelin
3.1: Basic Structures and Function of the Nervous System
myelin sheath
3.2: Nervous Tissue
mylohyoid
4.3: Axial Muscles of the Head, Neck, and Back
mylohyoid line
4.1: The Skull

N

nasal cavity
4.1: The Skull
nasal conchae
4.1: The Skull
nasal septum
4.1: The Skull
nasolacrimal canal
4.1: The Skull
navicular
6.1: Bones of the Lower Limb
neck of the femur
6.1: Bones of the Lower Limb
neck of the radius
7.2: Bones of the Upper Limb
neck of the rib
5.1: The Thoracic Cage
nerve
3.1: Basic Structures and Function of the Nervous System
neuron
3.1: Basic Structures and Function of the Nervous System
node of Ranvier
3.2: Nervous Tissue
nuchal ligament
4.2: The Vertebral Column
nucleus
3.1: Basic Structures and Function of the Nervous System
nucleus pulposus
4.2: The Vertebral Column
nutrient foramen
2.6: Bone Structure

O

oblique
1.2H: Naming Skeletal Muscle

obturator externus
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
obturator internus
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
occipital bone
4.1: The Skull
occipital condyle
4.1: The Skull
occipital lobe
3.4: The Central Nervous System
occipital sinuses
3.5: Circulation and the Central Nervous System
occipitalis
4.3: Axial Muscles of the Head, Neck, and Back
occipitofrontalis
4.3: Axial Muscles of the Head, Neck, and Back
olecranon fossa
7.2: Bones of the Upper Limb
olecranon process
7.2: Bones of the Upper Limb
olfaction
3.4: The Central Nervous System
oligodendrocyte
3.2: Nervous Tissue
omohyoid
4.3: Axial Muscles of the Head, Neck, and Back
ongissimus cervicis
4.3: Axial Muscles of the Head, Neck, and Back
open reduction
2.10: Fractures - Bone Repair
opponens digiti minimi
7.4: Muscles of the Pectoral Girdle and Upper Limbs
opponens pollicis
7.4: Muscles of the Pectoral Girdle and Upper Limbs
opposition
2.8E: Types of Body Movements
orbicularis oculi
4.3: Axial Muscles of the Head, Neck, and Back
orbicularis oris
4.3: Axial Muscles of the Head, Neck, and Back
origin
1.2G: Interactions of Skeletal Muscles, Their Fascicle Arrangement, and Their Lever Systems
orthopedist
2.2: The Functions of the Skeletal System
orthostatic reflex
3.5: Circulation and the Central Nervous System
osseous tissue
2.2: The Functions of the Skeletal System
ossification
2.9: Bone Formation and Development
ossification center
2.9: Bone Formation and Development
osteoblast
2.6: Bone Structure
osteoclast
2.6: Bone Structure
osteocyte
2.6: Bone Structure
osteogenic cell
2.6: Bone Structure
osteoid
2.9: Bone Formation and Development
osteon
2.6: Bone Structure

P

palatine bone
4.1: The Skull
palatine process
4.1: The Skull
palatoglossus
4.3: Axial Muscles of the Head, Neck, and Back
palmar interossei
7.4: Muscles of the Pectoral Girdle and Upper Limbs
palmaris longus
7.4: Muscles of the Pectoral Girdle and Upper Limbs
parallel
1.2G: Interactions of Skeletal Muscles, Their Fascicle Arrangement, and Their Lever Systems
paramedian pontine reticular formation (PPRF)
3.4A: The Cranial Nerve Exam
paranasal sinuses
4.1: The Skull
parietal bone
4.1: The Skull
parietal lobe
3.4: The Central Nervous System
patella
6.1: Bones of the Lower Limb
patellar ligament
2.8F: Anatomy of Selected Synovial Joints
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
patellar surface
6.1: Bones of the Lower Limb
pectineus
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
pectoral girdle
7.1: The Pectoral Girdle
7.4: Muscles of the Pectoral Girdle and Upper Limbs
pectoralis major
7.4: Muscles of the Pectoral Girdle and Upper Limbs
pectoralis minor
7.4: Muscles of the Pectoral Girdle and Upper Limbs
pedicle
4.2: The Vertebral Column
pelvic diaphragm
7.3: Axial Muscles of the Abdominal Wall and Thorax
pelvic girdle
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
pennate
1.2G: Interactions of Skeletal Muscles, Their Fascicle Arrangement, and Their Lever Systems
perforating canal
2.6: Bone Structure
perichondrium
2.9: Bone Formation and Development
perineum
7.3: Axial Muscles of the Abdominal Wall and Thorax
periodontal ligament
2.8B: Fibrous Joints
periosteum
2.6: Bone Structure
peripheral nervous system (PNS)
3.1: Basic Structures and Function of the Nervous System
perpendicular plate of the ethmoid bone
4.1: The Skull
petrous ridge
4.1: The Skull
phalanx bone of the foot
6.1: Bones of the Lower Limb
phalanx bone of the hand
7.2: Bones of the Upper Limb
pia mater
3.5: Circulation and the Central Nervous System
piriformis
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
pisiform
7.2: Bones of the Upper Limb
pivot joint
2.8D: Synovial Joints
plane joint
2.8D: Synovial Joints
plantar aponeurosis
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
plantar flexion
2.8E: Types of Body Movements
plantar group
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
plantaris
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
pollex
7.2: Bones of the Upper Limb
popliteal fossa
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
popliteus
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
postcentral gyrus
3.4: The Central Nervous System
posterior (dorsal) sacral foramen
4.2: The Vertebral Column
posterior arch
4.2: The Vertebral Column
posterior columns
3.4: The Central Nervous System
posterior compartment of the leg
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
posterior compartment of the thigh
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
posterior cruciate ligament
2.8F: Anatomy of Selected Synovial Joints
posterior horn
3.4: The Central Nervous System
posterior longitudinal ligament
4.2: The Vertebral Column

posterior median sulcus
3.4: The Central Nervous System
posterior scalene
4.3: Axial Muscles of the Head, Neck, and Back
posterior talofibular ligament
2.8F: Anatomy of Selected Synovial Joints
posterolateral sulcus
3.4: The Central Nervous System
precentral gyrus
3.4: The Central Nervous System
prefrontal lobe
3.4: The Central Nervous System
premotor area
3.4: The Central Nervous System
primary curve
4.2: The Vertebral Column
primary ossification center
2.9: Bone Formation and Development
prime mover
1.2G: Interactions of Skeletal Muscles, Their Fascicle Arrangement, and Their Lever Systems
process
3.1: Basic Structures and Function of the Nervous System
projection
2.6: Bone Structure
proliferative zone
2.9: Bone Formation and Development
pronated position
2.8E: Types of Body Movements
pronation
2.8E: Types of Body Movements
pronator quadratus
7.4: Muscles of the Pectoral Girdle and Upper Limbs
pronator teres
7.4: Muscles of the Pectoral Girdle and Upper Limbs
Proprioception
3.4: The Central Nervous System
protraction
2.8E: Types of Body Movements
proximal radioulnar joint
2.8D: Synovial Joints
7.2: Bones of the Upper Limb
proximal tibiofibular joint
6.1: Bones of the Lower Limb
psoas major
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
pterion
4.1: The Skull
pubococcygeus
7.3: Axial Muscles of the Abdominal Wall and Thorax
pubofemoral ligament
2.8F: Anatomy of Selected Synovial Joints
putamen
3.4: The Central Nervous System

Q

quadratus femoris
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
quadratus lumborum
7.3: Axial Muscles of the Abdominal Wall and Thorax
quadriceps femoris group
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
quadriceps tendon
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs

R

radial collateral ligament
2.8F: Anatomy of Selected Synovial Joints
radial fossa
7.2: Bones of the Upper Limb
radial notch of the ulna
7.2: Bones of the Upper Limb
radial tuberosity
7.2: Bones of the Upper Limb
radiocarpal joint
7.2: Bones of the Upper Limb
radius
7.2: Bones of the Upper Limb
ramus of the mandible
4.1: The Skull
rectus
1.2H: Naming Skeletal Muscle
rectus abdominis
7.3: Axial Muscles of the Abdominal Wall and Thorax
rectus femoris
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
rectus sheaths
7.3: Axial Muscles of the Abdominal Wall and Thorax
red marrow
2.2: The Functions of the Skeletal System
remodeling
2.9: Bone Formation and Development
reposition
2.8E: Types of Body Movements
reserve zone
2.9: Bone Formation and Development
response
3.1: Basic Structures and Function of the Nervous System
reticular formation
3.4: The Central Nervous System
retinacula
7.4: Muscles of the Pectoral Girdle and Upper Limbs
retraction
2.8E: Types of Body Movements
rhomboid major
7.4: Muscles of the Pectoral Girdle and Upper Limbs
rhomboid minor
7.4: Muscles of the Pectoral Girdle and Upper Limbs
Rinne test
3.4A: The Cranial Nerve Exam
rotation
2.8E: Types of Body Movements
rotator cuff
2.8F: Anatomy of Selected Synovial Joints
7.4: Muscles of the Pectoral Girdle and Upper Limbs

S

saccade
3.4A: The Cranial Nerve Exam
sacral canal
4.2: The Vertebral Column
sacral foramina
4.2: The Vertebral Column
sacral hiatus
4.2: The Vertebral Column
sacral promontory
4.2: The Vertebral Column
sacrococcygeal curve
4.2: The Vertebral Column
saddle joint
2.8D: Synovial Joints
sagittal suture
4.1: The Skull
sartorius
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
satellite cell
3.2: Nervous Tissue
scalene muscles
4.3: Axial Muscles of the Head, Neck, and Back
scaphoid
7.2: Bones of the Upper Limb
scapula
7.1: The Pectoral Girdle
Schwann cell
3.2: Nervous Tissue
scoliosis
4.2: The Vertebral Column
secondary curve
4.2: The Vertebral Column
secondary ossification center
2.9: Bone Formation and Development
segmental muscle group
4.3: Axial Muscles of the Head, Neck, and Back
sella turcica
4.1: The Skull
semimembranosus
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
semispinalis capitis
4.3: Axial Muscles of the Head, Neck, and Back
semispinalis cervicis
4.3: Axial Muscles of the Head, Neck, and Back
semispinalis thoracis
4.3: Axial Muscles of the Head, Neck, and Back
semitendinosus
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
sensation
3.1: Basic Structures and Function of the Nervous System
sensorineural hearing
3.4A: The Cranial Nerve Exam
septal cartilage
4.1: The Skull
serratus anterior
7.4: Muscles of the Pectoral Girdle and Upper Limbs
sesamoid bone
2.5: Bone Classification

shaft of the femur
6.1: Bones of the Lower Limb
shaft of the fibula
6.1: Bones of the Lower Limb
shaft of the humerus
7.2: Bones of the Upper Limb
shaft of the radius
7.2: Bones of the Upper Limb
shaft of the tibia
6.1: Bones of the Lower Limb
shaft of the ulna
7.2: Bones of the Upper Limb
short bone
2.5: Bone Classification
sigmoid sinuses
3.5: Circulation and the Central Nervous System
skeletal system
2.2: The Functions of the Skeletal System
Snellen chart
3.4A: The Cranial Nerve Exam
soleal line
6.1: Bones of the Lower Limb
soleus
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
soma
3.1: Basic Structures and Function of the Nervous System
somatic nervous system (SNS)
3.1: Basic Structures and Function of the Nervous System
somatosensation
3.4: The Central Nervous System
special senses
7.1: The Pectoral Girdle
sphenoid bone
4.1: The Skull
sphenoid sinus
4.1: The Skull
sphincter urethrovaginalis
7.3: Axial Muscles of the Abdominal Wall and Thorax
spinal cord
3.1: Basic Structures and Function of the Nervous System
spinalis capitis
4.3: Axial Muscles of the Head, Neck, and Back
spinalis cervicis
4.3: Axial Muscles of the Head, Neck, and Back
spinalis group
4.3: Axial Muscles of the Head, Neck, and Back
spinalis thoracis
4.3: Axial Muscles of the Head, Neck, and Back
spine of the scapula
7.1: The Pectoral Girdle
spinous process
4.2: The Vertebral Column
splenius
4.3: Axial Muscles of the Head, Neck, and Back
splenius capitis
4.3: Axial Muscles of the Head, Neck, and Back
splenius cervicis
4.3: Axial Muscles of the Head, Neck, and Back
spongy bone
2.6: Bone Structure
squamous suture
4.1: The Skull
sternal angle
5.1: The Thoracic Cage
sternal end of the clavicle
7.1: The Pectoral Girdle
sternoclavicular joint
7.1: The Pectoral Girdle
sternocleidomastoid
4.3: Axial Muscles of the Head, Neck, and Back
sternohyoid
4.3: Axial Muscles of the Head, Neck, and Back
sternothyroid
4.3: Axial Muscles of the Head, Neck, and Back
stimulus
3.1: Basic Structures and Function of the Nervous System
straight sinus
3.5: Circulation and the Central Nervous System
striatum
3.4: The Central Nervous System
styloglossus
4.3: Axial Muscles of the Head, Neck, and Back
stylohyoid
4.3: Axial Muscles of the Head, Neck, and Back
styloid process
4.1: The Skull
styloid process of the radius
7.2: Bones of the Upper Limb
styloid process of the ulna
7.2: Bones of the Upper Limb
stylomastoid foramen
4.1: The Skull
subacromial bursa
2.8F: Anatomy of Selected Synovial Joints
subarachnoid space
3.5: Circulation and the Central Nervous System
subclavius
7.4: Muscles of the Pectoral Girdle and Upper Limbs
subcortical nucleus
3.4: The Central Nervous System
subcutaneous bursa
2.8D: Synovial Joints
submuscular bursa
2.8D: Synovial Joints
subscapular bursa
2.8F: Anatomy of Selected Synovial Joints
subscapular fossa
7.1: The Pectoral Girdle
subscapularis
7.4: Muscles of the Pectoral Girdle and Upper Limbs
substantia nigra pars compacta
3.4: The Central Nervous System
substantia nigra pars reticulata
3.4: The Central Nervous System
subtalar joint
2.8F: Anatomy of Selected Synovial Joints
subtendinous bursa
2.8D: Synovial Joints
subthalamus
3.4: The Central Nervous System
sulcus
3.4: The Central Nervous System
superficial anterior compartment of the forearm
7.4: Muscles of the Pectoral Girdle and Upper Limbs
superficial posterior compartment of the forearm
7.4: Muscles of the Pectoral Girdle and Upper Limbs
superior angle of the scapula
7.1: The Pectoral Girdle
superior articular process
4.2: The Vertebral Column
superior articular process of the sacrum
4.2: The Vertebral Column
superior border of the scapula
7.1: The Pectoral Girdle
superior colliculus
3.4: The Central Nervous System
superior extensor retinaculum
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
superior gemellus
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
superior nuchal line
4.1: The Skull
superior orbital fissure
4.1: The Skull
superior rotation
2.8E: Types of Body Movements
superior sagittal sinus
3.5: Circulation and the Central Nervous System
supinated position
2.8E: Types of Body Movements
supination
2.8E: Types of Body Movements
supinator
7.4: Muscles of the Pectoral Girdle and Upper Limbs
supraglenoid tubercle
7.1: The Pectoral Girdle
suprahyoid muscles
4.3: Axial Muscles of the Head, Neck, and Back
supraorbital foramen
4.1: The Skull
supraorbital margin
4.1: The Skull
suprascapular notch
7.1: The Pectoral Girdle
supraspinatus
7.4: Muscles of the Pectoral Girdle and Upper Limbs
supraspinous fossa
7.1: The Pectoral Girdle
supraspinous ligament
4.2: The Vertebral Column
surgical neck
7.2: Bones of the Upper Limb
sustentaculum tali
6.1: Bones of the Lower Limb
suture
2.8B: Fibrous Joints
4.1: The Skull
symphysis
2.8C: Cartilaginous Joints
synapse
3.2: Nervous Tissue

synaptic end bulb
3.2: Nervous Tissue
synarthrosis
2.8A: Classification of Joints
synchondrosis
2.8C: Cartilaginous Joints
syndesmosis
2.8B: Fibrous Joints
synergist
1.2G: Interactions of Skeletal Muscles, Their Fascicle Arrangement, and Their Lever Systems
synostosis
2.8B: Fibrous Joints
synovial fluid
2.8D: Synovial Joints
synovial joint
2.8A: Classification of Joints
synovial membrane
2.8D: Synovial Joints

T

talocrural joint
2.8F: Anatomy of Selected Synovial Joints
talus
6.1: Bones of the Lower Limb
tarsal bone
6.1: Bones of the Lower Limb
tectum
3.4: The Central Nervous System
tegmentum
3.4: The Central Nervous System
temporal bone
4.1: The Skull
temporal fossa
4.1: The Skull
temporal lobe
3.4: The Central Nervous System
temporal process of the zygomatic bone
4.1: The Skull
temporalis
4.3: Axial Muscles of the Head, Neck, and Back
temporomandibular joint (TMJ)
2.8F: Anatomy of Selected Synovial Joints
tendinous intersections
7.3: Axial Muscles of the Abdominal Wall and Thorax
tendon
2.8D: Synovial Joints
tendon sheath
2.8D: Synovial Joints
tensor fascia lata
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
teres major
7.4: Muscles of the Pectoral Girdle and Upper Limbs
teres minor
7.4: Muscles of the Pectoral Girdle and Upper Limbs
thalamus
3.4: The Central Nervous System
thenar
7.4: Muscles of the Pectoral Girdle and Upper Limbs
thenar eminence
7.4: Muscles of the Pectoral Girdle and Upper Limbs
thigh
6.1: Bones of the Lower Limb
third ventricle
3.5: Circulation and the Central Nervous System
thoracic curve
4.2: The Vertebral Column
thoracic vertebrae
4.2: The Vertebral Column
thyrohyoid
4.3: Axial Muscles of the Head, Neck, and Back
tibia
6.1: Bones of the Lower Limb
tibial collateral ligament
2.8F: Anatomy of Selected Synovial Joints
tibialis anterior
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
tibialis posterior
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
trabeculae
2.6: Bone Structure
tract
3.1: Basic Structures and Function of the Nervous System
transverse foramen
4.2: The Vertebral Column
transverse process
4.2: The Vertebral Column
transverse sinuses
3.5: Circulation and the Central Nervous System
transversus abdominis
7.3: Axial Muscles of the Abdominal Wall and Thorax
trapezium
7.2: Bones of the Upper Limb
trapezius
7.4: Muscles of the Pectoral Girdle and Upper Limbs
trapezoid
7.2: Bones of the Upper Limb
tri
1.2H: Naming Skeletal Muscle
triceps brachii
7.4: Muscles of the Pectoral Girdle and Upper Limbs
triquetrum
7.2: Bones of the Upper Limb
trochlea
7.2: Bones of the Upper Limb
trochlear notch
7.2: Bones of the Upper Limb
true ribs
5.1: The Thoracic Cage
tubercle of the rib
5.1: The Thoracic Cage

U

ulna
7.2: Bones of the Upper Limb
ulnar collateral ligament
2.8F: Anatomy of Selected Synovial Joints
ulnar notch of the radius
7.2: Bones of the Upper Limb
ulnar tuberosity
7.2: Bones of the Upper Limb
uniaxial joint
2.8A: Classification of Joints
unipennate
1.2G: Interactions of Skeletal Muscles, Their Fascicle Arrangement, and Their Lever Systems
unipolar
3.2: Nervous Tissue
urogenital triangle
7.3: Axial Muscles of the Abdominal Wall and Thorax

V

vastus lateralis
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
vastus medialis
6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs
ventricles
3.5: Circulation and the Central Nervous System
vertebral (spinal) canal
4.2: The Vertebral Column
vertebral arch
4.2: The Vertebral Column
vertebral foramen
4.2: The Vertebral Column
vomer bone
4.1: The Skull

W

Weber test
3.4A: The Cranial Nerve Exam
white matter
3.1: Basic Structures and Function of the Nervous System

Y

yellow marrow
2.2: The Functions of the Skeletal System

Z

zone of calcified matrix
2.9: Bone Formation and Development
zone of maturation and hypertrophy
2.9: Bone Formation and Development
zygapophysial joints
2.8F: Anatomy of Selected Synovial Joints
zygomatic arch
4.1: The Skull
zygomatic bone
4.1: The Skull
zygomatic process of the temporal bone
4.1: The Skull

Glossary

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    - 1.1: Defining Anatomy - *CC BY-SA 4.0*
    - 1.2: Mapping the Body - *CC BY-SA 4.0*
      - 1.2A: Anatomical Position - *CC BY-SA 4.0*
      - 1.2B: Directional Terms - *CC BY-SA 4.0*
      - 1.2C: Regional Terms and Axes - *CC BY-SA 4.0*
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      - 1.2E: Body Cavities - *CC BY-SA 4.0*
      - 1.2F: Abdominopelvic Regions - *CC BY-SA 4.0*
      - 1.2G: Interactions of Skeletal Muscles, Their Fascicle Arrangement, and Their Lever Systems - *CC BY 4.0*
      - 1.2H: Naming Skeletal Muscle - *CC BY 4.0*
  - 2: The Skeletal System - *CC BY-NC-SA 4.0*
    - 2.1: Introduction - *CC BY 4.0*
    - 2.2: The Functions of the Skeletal System - *CC BY 4.0*
    - 2.3: The Axial Skeleton - *CC BY-SA 4.0*
    - 2.4: The Appendicular Skeleton - *CC BY-SA 4.0*
    - 2.5: Bone Classification - *CC BY 4.0*
    - 2.6: Bone Structure - *CC BY 4.0*
    - 2.7: Cartilage - *CC BY-SA 4.0*
      - 2.7A: Structure, Type, and Location of Cartilage - *CC BY-SA 4.0*
      - 2.7B: Cartilage Growth - *CC BY-SA 4.0*
    - 2.8: Joints - *CC BY 4.0*
      - 2.8A: Classification of Joints - *CC BY 4.0*
      - 2.8B: Fibrous Joints - *CC BY 4.0*
      - 2.8C: Cartilaginous Joints - *CC BY 4.0*
      - 2.8D: Synovial Joints - *CC BY 4.0*
      - 2.8E: Types of Body Movements - *CC BY 4.0*
      - 2.8F: Anatomy of Selected Synovial Joints - *CC BY 4.0*
    - 2.9: Bone Formation and Development - *CC BY 4.0*
    - 2.10: Fractures - Bone Repair - *CC BY 4.0*
  - 3: The Nervous System - *Undeclared*
    - 3.1: Basic Structures and Function of the Nervous System - *CC BY 4.0*
    - 3.2: Nervous Tissue - *CC BY 4.0*
    - 3.3: Spinal Nerves - *CC BY-SA 4.0*
      - 3.3A: Overview of the Spinal Nerves - *CC BY-SA 4.0*
      - 3.3B: Branches of Spinal Nerves - *CC BY-SA 4.0*
      - 3.3C: Plexuses - *CC BY-SA 4.0*
      - 3.3D: Intercostal Nerves - *CC BY-SA 4.0*
      - 3.3E: Dermatomes - *CC BY-SA 4.0*
      - 3.3F: Function and Physiology of the Spinal Nerves - *CC BY-SA 4.0*
    - 3.4: The Central Nervous System - *CC BY 4.0*
      - 3.4A: The Cranial Nerve Exam - *CC BY 4.0*
    - 3.5: Circulation and the Central Nervous System - *CC BY 4.0*
  - 4: Head, Neck, Spine and Abdominal Core - *Undeclared*
    - 4.1: The Skull - *CC BY 4.0*
    - 4.2: The Vertebral Column - *CC BY 4.0*
    - 4.3: Axial Muscles of the Head, Neck, and Back - *CC BY 4.0*
  - 5: Thorax, Hip and Pelvis - *Undeclared*
    - 5.1: The Thoracic Cage - *CC BY 4.0*
    - 5.2: The Pelvic Girdle and Pelvis - *CC BY 4.0*

- 6: Bones, Joints and Muscles of the Pelvic Girdle and Lower Limb - *Undeclared*
  - 6.1: Bones of the Lower Limb - *CC BY 4.0*
  - 6.2: Appendicular Muscles of the Pelvic Girdle and Lower Limbs - *CC BY 4.0*
- 7: Bones, Joint and Muscles of the Pectoral Girdle and Upper Limb - *CC BY-NC-SA 4.0*
  - 7.1: The Pectoral Girdle - *CC BY 4.0*
  - 7.2: Bones of the Upper Limb - *CC BY 4.0*
  - 7.3: Axial Muscles of the Abdominal Wall and Thorax - *CC BY 4.0*
  - 7.4: Muscles of the Pectoral Girdle and Upper Limbs - *CC BY 4.0*
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  - Glossary - *CC BY-NC-SA 4.0*
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