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UGA Anatomy and Physiology 2 Lab Manual, 3rd Edition

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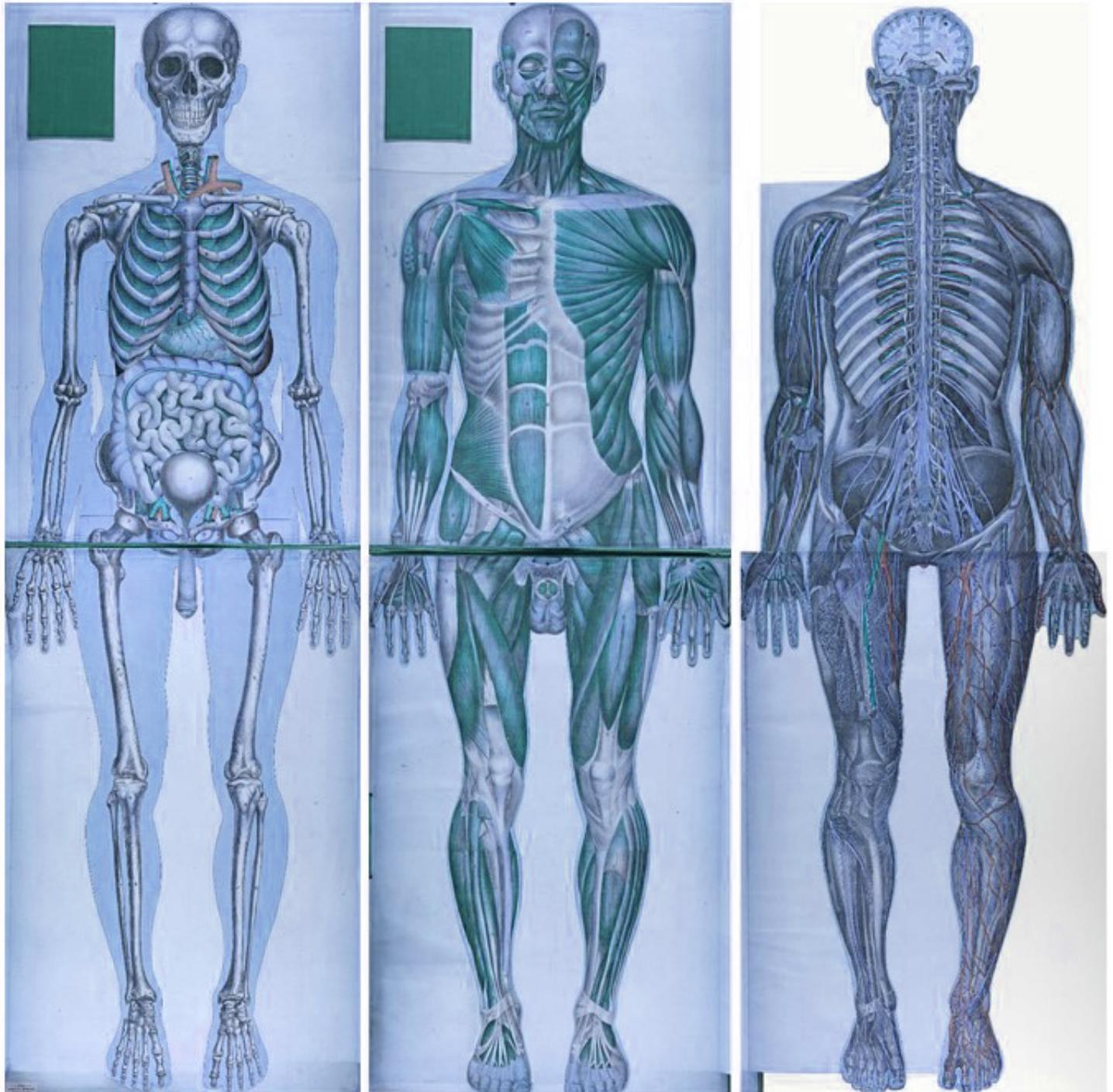
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Anatomy and Physiology Lab II

Daniel McNabney and DeLoris Hesse



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Bouglé, Julien. Le corps humain en grandeur naturelle : planches coloriées et superposées, avec texte explicatif. Paris : J. B. Baillière et fils, 1899. 1 plate : col. ill.

Source: U.S. National Library of Medicine.

http://www.nlm.nih.gov/exhibition/historicalanatomies/bougle_home.html

Introduction

This laboratory manual was written in 2019 via an OER Revisions and Ancillary Materials Creation Mini-Grant from Affordable Learning Georgia (affordablelearninggeorgia.org). The goal of the project is to create an open educational resource lab manual that provides students in our second-semester large introductory Anatomy and Physiology laboratory course (CBIO2210L) at the University of Georgia (GA, USA) with a tailored, low-cost set of course materials.

Source and Companion Materials

Each lesson contains specific citations used during the creation of course materials. The following sources played a major role in the development of this lab manual:

- The majority of background information is a derivative of "Anatomy and Physiology" by OpenStax CNX used under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/). Aug 2, 2019. Access for free at <https://openstax.org/books/anatomy-and-physiology/pages/1-introduction>
- Histological resources and a virtual microscope via the University of Michigan Medical School: <https://histology.medicine.umich.edu/>
- The lessons found within this document were uploaded into the digital learning platform, Lt by ADInstruments (<https://www.adinstruments.com/lit>). Lt is a browser-based learning platform that allows our students to interact with the course materials via lab activities that are not possible with a traditional paper lab manual (ex: photo and video activities, interactive question sets, etc.). Lt also allows our students to collect, analyze, and present human physiological data via PowerLab data acquisition systems (<https://www.adinstruments.com/products/powerlab>).

Acknowledgements

We would like to thank the following people for their help and support during this project: Gabriella Sandberg, Aimee Williams, Manashree Malpe, Nurgul Kaya, Lindsey Beebe, Angie Holliday, Ann Massey, Rob Nichols, Kojo Mensa-Wilmot, Robin Fowler, Beverly Martin, Fall 2019 CBIO2210L TAs, Fall 2019 CBIO2210L students.

The Endocrine System

Introduction

The endocrine system is responsible for regulating many of the variables controlling the body's internal environment. The laboratory exercises in this module will identify several of the "classical" endocrine glands, describe the location and structure of these glands (both gross and histological), and outline the functions of the hormones that are secreted from these glands. Regulation of the glands by factors in the internal environment will also be explored in a simulated experiment.

Learning Objectives

By the end of this lesson you will be able to:

- Identify the classical endocrine glands on a model or diagram
 - Anterior and posterior pituitary glands
 - Thyroid and parathyroid glands
 - Adrenal gland
 - Pancreas
 - Testes
 - Ovaries
- List the hormones produced by each endocrine gland identified, and discuss the actions of each hormone identified
- Differentiate among the histology of the above glands when viewed on a microscope slide (ie, be able to identify the gland if you saw the tissue on a slide)
 - Distinguish between the anterior and posterior lobes
 - Distinguish among the thyroid follicles, parafollicular cells
 - Identify the zona glomerulosa, zona fasciculata, zona reticularis, and adrenal medulla, and list the hormones that are released from each region
 - Identify pancreatic islets
- Describe the relationship between the hypothalamus and the pituitary gland; the pituitary gland and the target gland; the target gland and the hypothalamus / pituitary (ie, describe the nature of the feedback loops that regulate the activity of the hypothalamus, pituitary and endocrine glands)

- Identify the following structures of importance:

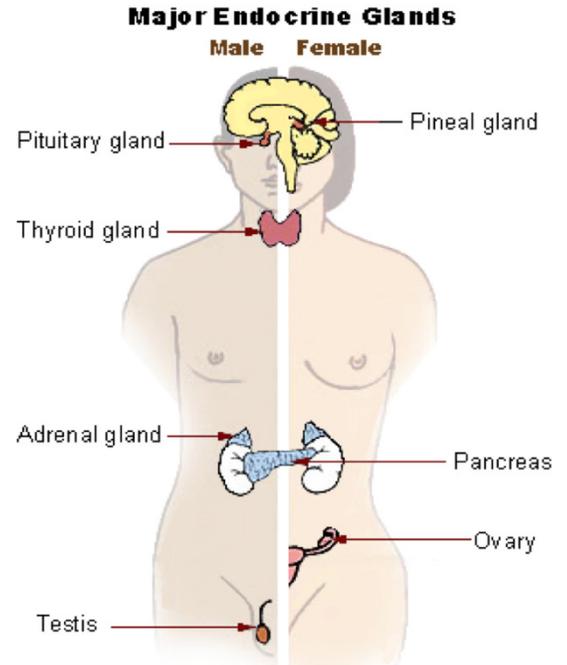
Pituitary Gland – Figures 17.7 – 17.10 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/17-3-the-pituitary-gland-and-hypothalamus	Adrenal Gland – Figure 17.17 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/17-6-the-adrenal-glands
Anterior and posterior lobes (adenohypophysis and neurohypophysis)	Adrenal cortex: Zona glomerulosa; zona fasciculata; zona reticularis
Basophils and acidophils (if visible)	Adrenal medulla
Infundibulum	
Thyroid Gland – Figures 17.12 – 17.13 in the OpenStax text : https://openstax.org/books/anatomy-and-physiology/pages/17-4-the-thyroid-gland	
Follicular and parafollicular cells	
Thyroid follicle	Pancreas – Figures 17.18 – 17.19 in the OpenStax text https://openstax.org/books/anatomy-and-physiology/pages/17-9-the-endocrine-pancreas
Colloid / thyroglobulin	Islet cells
	Exocrine acini (acinar cells)
Parathyroid Gland – Figures 17.15 – 17.16 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/17-3-the-pituitary-gland-and-hypothalamus	
Oxyphil and chief cells (if visible)	
Ovary – Figures 27.12 – 27.13 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/27-2-anatomy-and-physiology-of-the-female-reproductive-system	Testis - Figure 27.5 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/27-1-anatomy-and-physiology-of-the-male-reproductive-system
Vesicular or Graafian follicle	Seminiferous tubule
Antrum	Interstitial cell (Leydig cell)
Ovum	
Primary and primordial follicles	
Medulla and cortex	
*distinguish between oocytes and follicles	

Background Information

OVERVIEW

Hormones are chemical messengers produced by cells and released into the bloodstream, where they travel throughout the body. This allows these messengers to act on cells and organs that may be distant from the cells that synthesized them. Although many cells release chemicals that communicate with other cells, we typically describe some organs or glands as being part of the “endocrine system.” Glands that are typically included in discussions of the anatomy and physiology of the endocrine system are shown at right.

Each endocrine gland secretes particular hormones, which in turn has particular effects on the target cells and organs. We’ll be looking at these glands and hormones individually as part of this exercise.



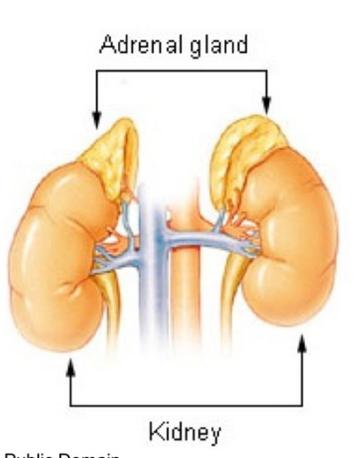
https://commons.wikimedia.org/wiki/File:Illu_endocrine_system_New.png

SPECIFIC ENDOCRINE GLANDS

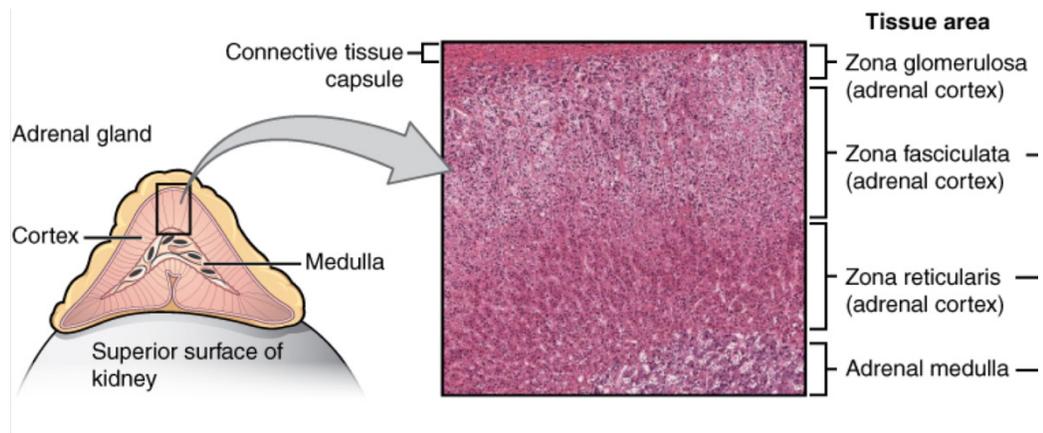
Adrenal glands

The adrenal glands (as their name implies) are located near the kidneys (ad-RENAL). They are paired, pyramidal glands, that sit on the superior aspect of each kidney.

The adrenal glands are composed of two distinct regions: the outer adrenal cortex, and the inner adrenal medulla. These regions can be seen when the glands are sectioned, but the real differences are clear when the tissue is viewed under a microscope.



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https://en.wikipedia.org/wiki/Adrenal_gland#/media/File:Illu_adrenal_gland.jpg



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Adrenal Cortex

The adrenal cortex can be further divided into 3 sub-regions or layers:

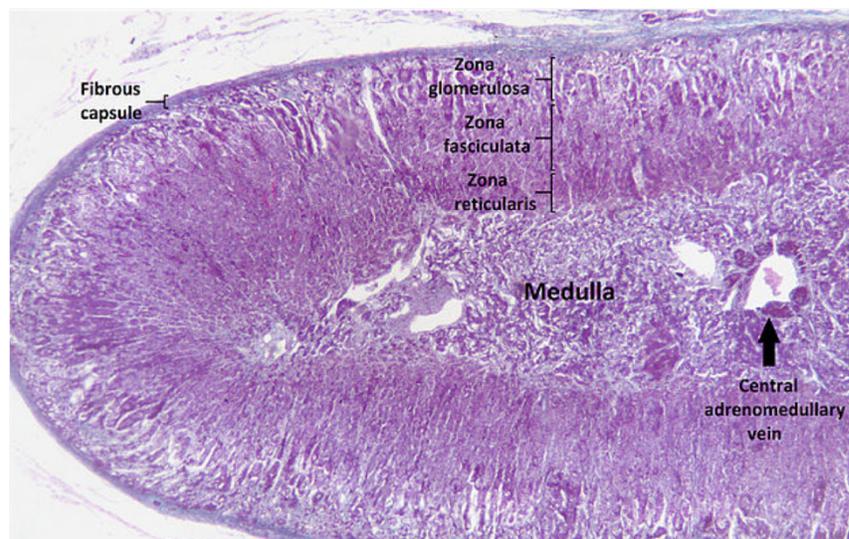
1. The **zona glomerulosa**, the outermost or most superficial layer, which synthesizes and secretes aldosterone in response to stimuli like decreased blood pressure. Aldosterone (a steroid) regulates Na^+ and K^+ balance, and plays an important role in fluid homeostasis.
2. The **zone fasciculata**, the middle layer, synthesizes and secretes cortisol and other glucocorticoids in response to ACTH from the anterior pituitary.
3. The **zona reticularis**, the deepest layer of the cortex, secretes androgens, or sex hormones (that are also steroids). These hormones act throughout the body and have similar effects as sex steroids produced by the ovaries and testes.

Adrenal Medulla

The adrenal medulla is the innermost (deepest) region of the adrenal gland, and consists mostly of modified sympathetic nerves. As a result, the adrenal medulla synthesizes and secretes catecholamines epinephrine and norepinephrine into the bloodstream.

A nice histological image (from Wikipedia) that clearly shows the cortex and medulla, and the layers of the cortex, is below.

See the link: https://en.wikipedia.org/wiki/Adrenal_gland

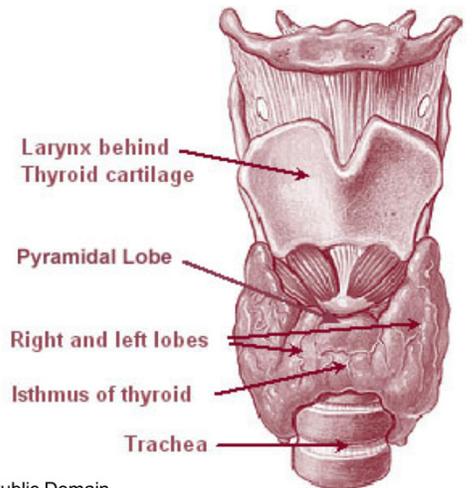


By Jpogi -
https://commons.wikimedia.org/wiki/File:Adrenal_gland_%28cortex%29.JPG,
CC0, <https://commons.wikimedia.org/w/index.php?curid=37838551>

Thyroid gland

The thyroid gland is a butterfly-shaped gland located on the anterior aspect of the larynx (voicebox). The right and left lobes on either side (analogous to the butterfly's wings) are connected by a thin band of glandular tissue called the isthmus.

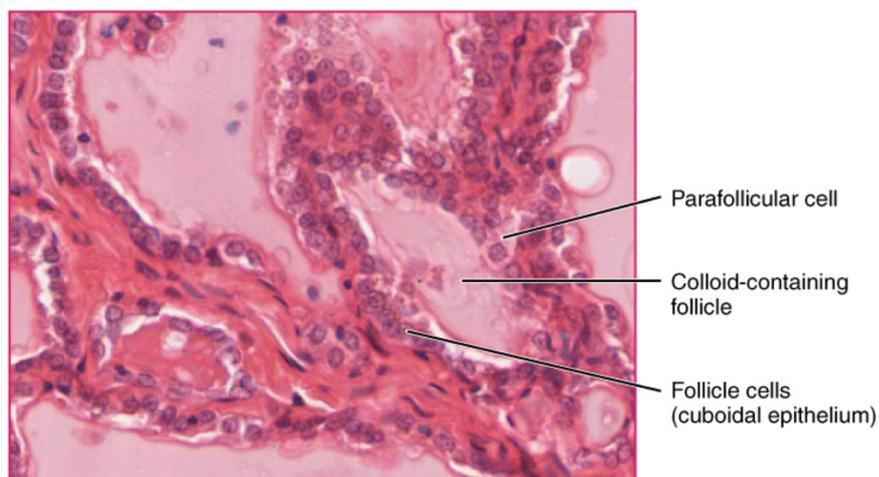
Histologically, the thyroid gland is composed of follicles, round structures where thyroid hormones are synthesized and released. Several follicles can be seen in the photomicrograph below. The substance in the follicles is called colloid, which is an iodine-rich precursor to thyroid hormones. The follicular cells use these precursor molecules to synthesize and release the finished thyroid hormones (triiodothyronine, or T3, and thyroxine, or T4). Thyroid hormones act on many other cells in the body and have many effects, including increasing heart rate, increasing protein synthesis, and increasing overall metabolic rate. Parafollicular cells are found in-between the follicles. These cells synthesize another hormone called calcitonin, which plays a role in calcium balance in the body.



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https://commons.wikimedia.org/wiki/File:Illu08_thyroid.jpg

The photomicrograph below (from the OpenStax text) shows the histological features of the thyroid gland.

See the link: <https://openstax.org/books/anatomy-and-physiology/pages/17-4-the-thyroid-gland>

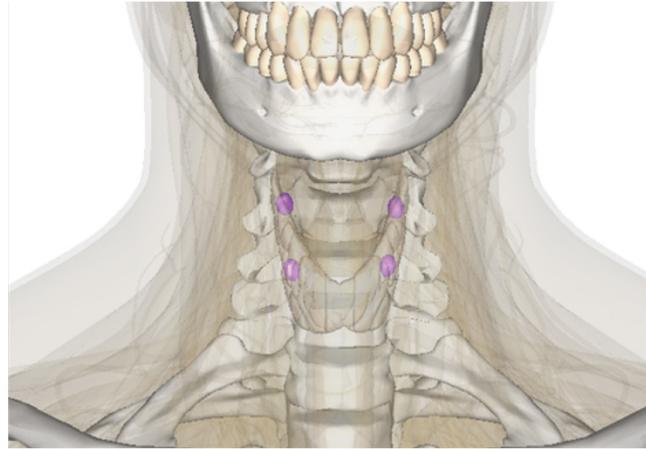


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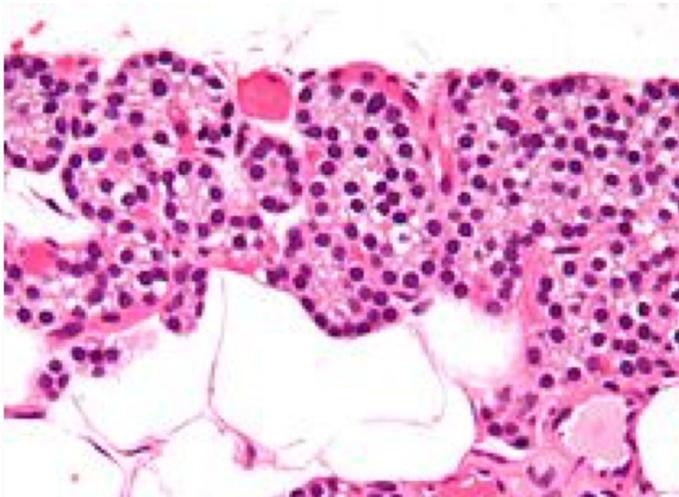
Parathyroid glands

The parathyroid glands are 4 – 6 small, round glands found on the posterior aspect of the thyroid gland (seen in the Wikimedia image at the right):

https://commons.wikimedia.org/wiki/Category:Parathyroid_gland). These glands secrete parathyroid hormone (PTH) in response to low levels of calcium in the plasma. PTH acts to activate osteoclasts to dissolve existing bone tissue, liberating the calcium that is stored there. PTH also acts to increase calcium absorption from the intestines and increases the reabsorption of calcium in the kidney tubules. The net result of PTH on the body is to increase calcium ion levels in the plasma.



By BodyParts3D is made by DBCLS - Polygondata is from BodyParts3D, CC BY-SA 2.1 jp, <https://commons.wikimedia.org/w/index.php?curid=39109054>



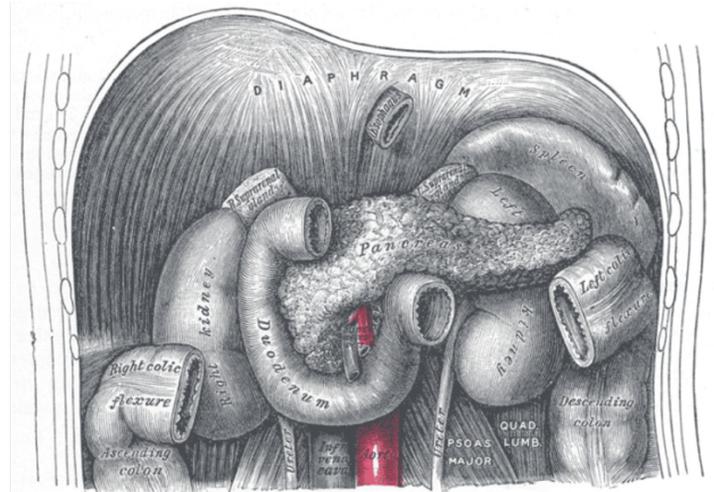
By Nephron - Own work, CC BY-SA 3.0, <https://commons.wikimedia.org/w/index.php?curid=7844854>

A photomicrograph (from Wikipedia: https://en.wikipedia.org/wiki/Parathyroid_gland) of the parathyroid gland is seen at the left. The cells that are responsible for the synthesis and release of PTH are called chief cells, or parathyroid cells. Other cells that are present in the parathyroid glands are called oxyphil cells, but their function is not clear.

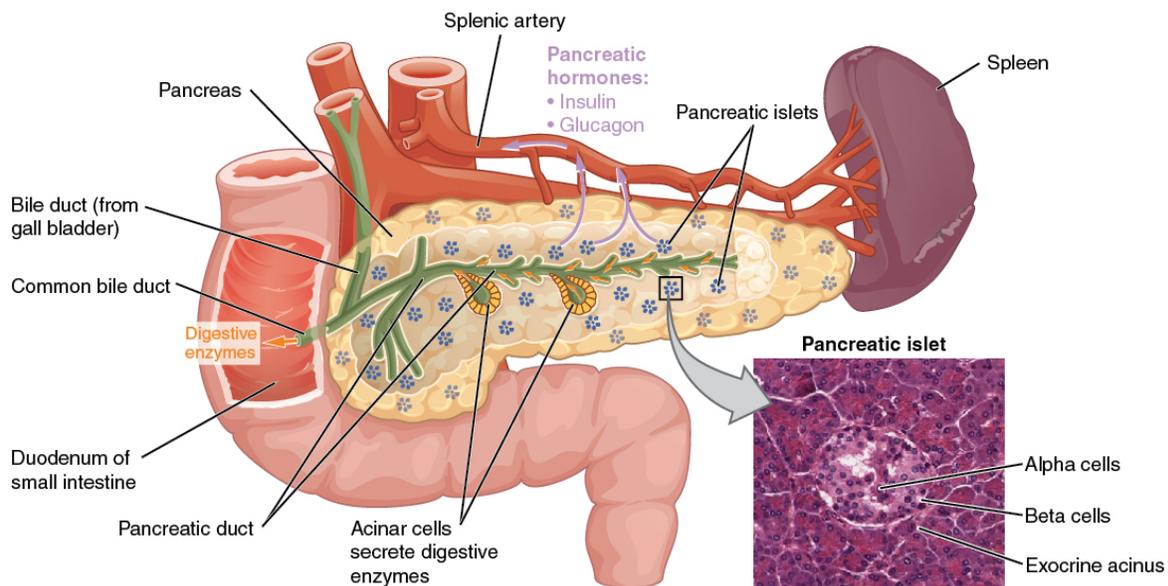
Pancreas

The pancreas is a large, comma-shaped organ that has both exocrine functions (synthesizing digestive juices that are secreted into the small intestine) and endocrine functions. It is located in the abdominal cavity, posterior to the stomach and tucked into the curve of the duodenum.

Several hormones are synthesized and secreted from the pancreas, including insulin, glucagon, and somatostatin. (Somatostatin is known by another name – **growth hormone inhibiting hormone**, the same hormone that is released from the hypothalamus to regulate the activity of the anterior pituitary.)



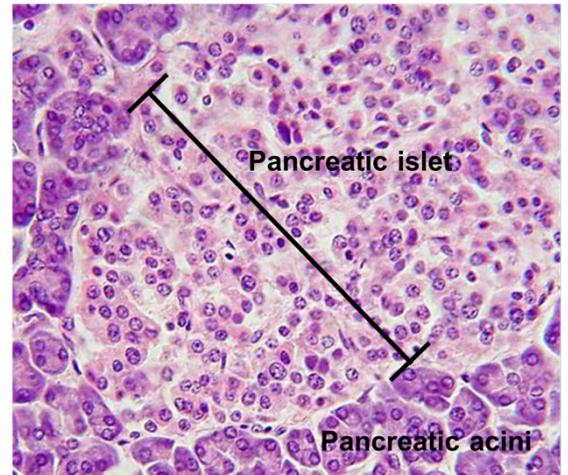
By Henry Vandyke Carter - Henry Gray (1918) Anatomy of the Human Body (See "Book" section below) Bartleby.com: Gray's Anatomy, Plate 1098, Public Domain, <https://commons.wikimedia.org/w/index.php?curid=567057>



The diagram below (from OpenStax) shows the location of the pancreas relative to the duodenum. This diagram also shows the relationship between the exocrine cells (those that produce the digestive juices) and the clusters of endocrine cells – the pancreatic islets - that are scattered throughout the tissue. See the link:

<https://cnx.org/contents/FPtK1zmh@15.2:kwSMou0C@8/17-9-The-Endocrine-Pancreas>

A magnified photomicrograph of the pancreatic islets is seen at the right (See the link: <https://commons.wikimedia.org/wiki/Category:Pancreas>). The pancreatic islets can be clearly distinguished from the exocrine tissue that surrounds them.



By User:Polarlys - Own work, CC BY 2.5, <https://commons.wikimedia.org/w/index.php?curid=1032935>

The two main hormones released from the pancreatic islet cells are insulin and glucagon. Insulin is released from beta cells in the pancreatic islets, and has the actions to increase the uptake of glucose from the blood into tissues. This results in decreased glucose in the blood plasma. Glucagon is released from alpha cells, and has the effect to release glucose from body cells into the plasma, resulting in increased blood glucose levels. Somatostatin is released from delta cells in the islets. The action of somatostatin is generally inhibitory. In the digestive system, somatostatin acts to inhibit the release of both insulin and glucagon. In the anterior pituitary (discussed above), somatostatin inhibits the release of growth hormone (GH) from the anterior pituitary.

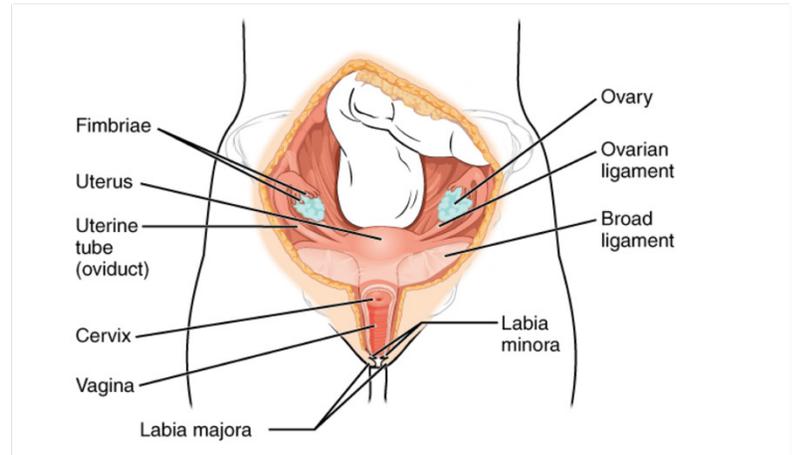
Activity 1: Hormones of the Pancreas

Fill in the below table with the hormone that is released from each cell type found in the pancreatic islets. In the last column, briefly describe the actions of each hormone.

Cell type	Hormone released	Actions
Alpha cells		
Beta cells		
Delta cells		

Reproductive Glands: Ovary and Testes

The ovaries are the female gonads that produce both gametes (cells that play a role in reproduction) and hormones. They are small, paired glands located deep in the pelvic cavity, and the gametes they produce are called **oocytes**. The production of oocytes is dependent on the hormonal activity of the anterior pituitary. The oocytes are released from the ovary and travel through the uterine tube to the uterus.



The photomicrograph at the right (figure 27.12 from the OpenStax text) at high magnification, shows a developing oocyte in the cortex of the ovary. The process where oocytes are released from the ovary is called **ovulation**. See the link:

<https://openstax.org/books/anatomy-and-physiology/pages/27-2-anatomy-and-physiology-of-the-female-reproductive-system>

The ovary also produces female sex hormones called **estrogens**. There are three estrogens produced by the ovary: **estrone, estradiol and estriol**. All the estrogens are classified as steroids due to their chemical structure. Estrogens regulate the ovarian and menstrual cycles, influencing the maturation of the oocyte in the ovary, the release of the oocyte during ovulation, and the changes seen in the uterus as it prepares to receive a potential zygote.

Estrogens are also important in the development of secondary sex characteristics like breast development and fat redistribution. Another hormone produced by the ovary is **progesterone**, a hormone that plays important roles in preparing the body for pregnancy in the event that an oocyte is fertilized by a sperm cell.

(b) A Secondary Follicle

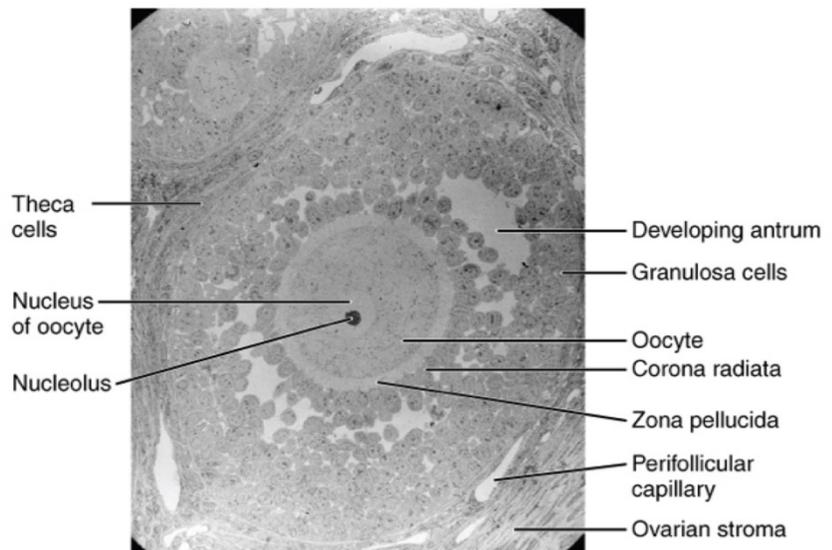
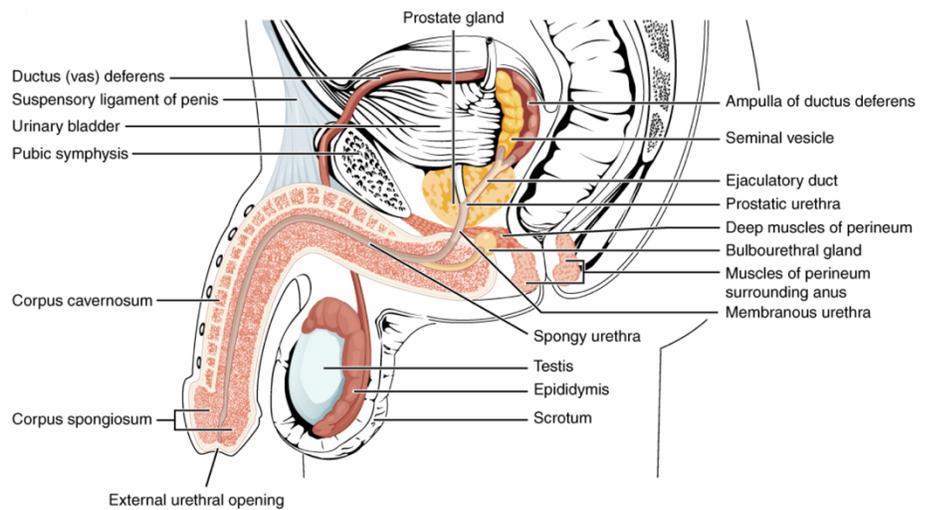


Figure 27.12 Folliculogenesis In this electron micrograph of a secondary follicle, the oocyte, theca cells (thecae folliculi), and developing antrum are clearly visible. EM \times 1100. (Micrograph provided by the Regents of University of Michigan Medical School \copyright 2012)

The testes are male gonads, and like the ovaries in females they produce both gametes (sperm) and hormones. The testes are also small paired structures, however they are located outside the pelvic cavity in males. Sperm that are produced in the testes must travel back into the pelvic cavity through a long duct system before being released from the body via



the penis as part of the semen. The production of sperm in the male is regulated similarly to the oocyte production in females, via hormones that are released from the anterior pituitary.

The photomicrograph at the right (figure 27.5 from the OpenStax text) shows a section of the seminiferous tubule, where the sperm are produced. Maturing sperm move through an extensive duct system both in the testis and to / through the pelvic cavity. See the link:

<https://openstax.org/books/anatomy-and-physiology/pages/27-1-anatomy-and-physiology-of-the-male-reproductive-system>

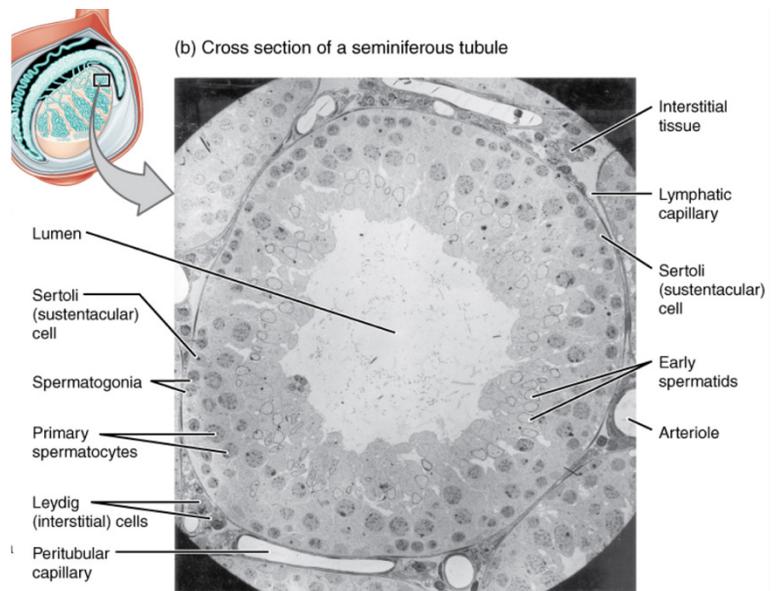


Figure 27.5 Spermatogenesis (b) In this electron micrograph of a cross-section of a seminiferous tubule from a rat, the lumen is the light-shaded area in the center of the image. The location of the primary spermatocytes is near the basement membrane, and the early spermatids are approaching the lumen (tissue source: rat). EM × 900. (Micrograph provided by the Regents of University of Michigan Medical School © 2012)

The main male sex hormone produced by the testes is **testosterone**. Like the estrogens from the ovary, testosterone is a steroid hormone that plays important roles in the development of secondary sex characteristics in males (increased bone and muscle mass, deepening voice, facial hair). Testosterone also influences the development of the sperm. A second hormone produced by the testes is inhibin, which plays a role in regulating the development and maturation of sperm.

Activity 2: Sex Hormones

Fill in the below table with the hormone that is released from each gonad. Note that there is more than one hormone released from each gonad. In the last column, briefly describe the actions of each hormone.

Gonad	Hormone released	Actions – on gametes and on other cells in the body
Testes		
Ovary		

Activity 3: Summary of Hormone Action. For each hormone in the left-hand column, fill in the below table with the target cells or tissues on which each hormone acts; the effects of the hormones on those target cells or organs; and the stimulus for the release of each hormone.

Thyroid and Parathyroid Hormones			
Hormone	Stimulus for Release	Target Cells / Tissues	Effects
Thyroid Hormones (T3 and T4)			
Calcitonin			
Parathyroid Hormone			
Adrenal Gland Hormones			
Hormone	Stimulus for Release	Target Cells / Tissues	Effects
Aldosterone (from zona glomerulosa)			
Cortisol (from zona fasciculata)			
Androgens (from zona reticularis)			
Epinephrine and norepinephrine (from adrenal medulla)			

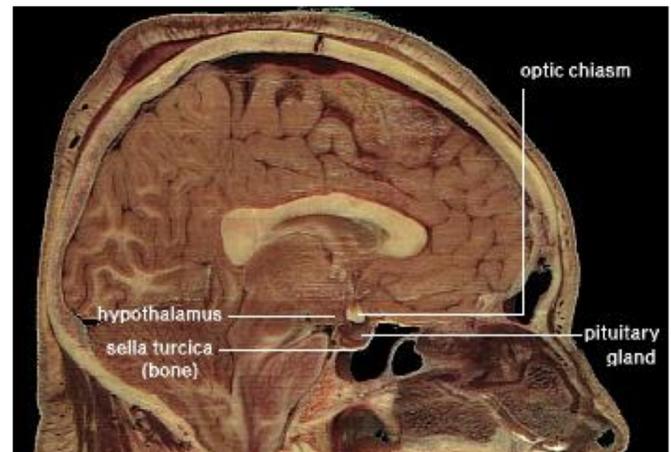
Pancreatic Hormones			
Hormone	Stimulus for Release	Target Cells / Tissues	Effects
Insulin (from beta cells in pancreatic islets)			
Glucagon (from alpha cells in pancreatic islets)			
Gonadal (Sex) Hormones			
Hormone	Stimulus for Release	Target Cells / Tissues	Effects
Estrogens (from ovaries)			
Testosterone (from testes)			

Pituitary Gland and Hypothalamus

Anatomy and Histology

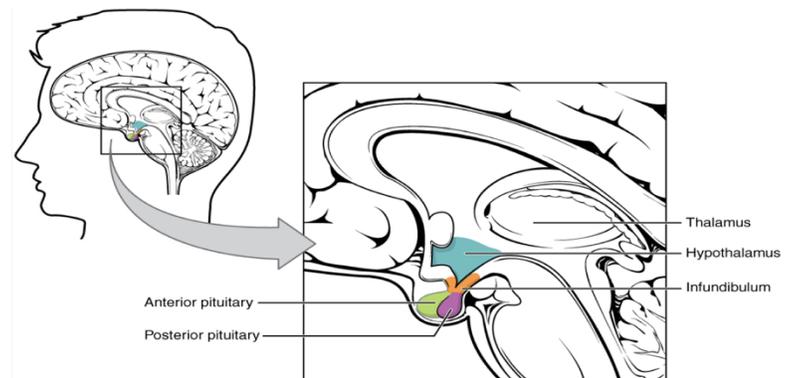
The pituitary gland extends below the inferior aspect of the brain, inferior to the hypothalamus. The photo of the brain at the right (from Wikipedia, see the link:

https://en.wikipedia.org/wiki/Pituitary_gland) shows the location of the pituitary gland relative to the brain. We describe the pituitary gland as the “master gland” because it secretes hormones that regulate the activity of other endocrine glands, in addition to hormones that act on other cells and tissues in the body.



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Figure 17.7 Hypothalamus–Pituitary Complex The hypothalamus region lies inferior and anterior to the thalamus. It connects to the pituitary gland by the stalk-like infundibulum. The pituitary gland consists of an anterior and posterior lobe, with each lobe secreting different hormones in response to signals from the hypothalamus.



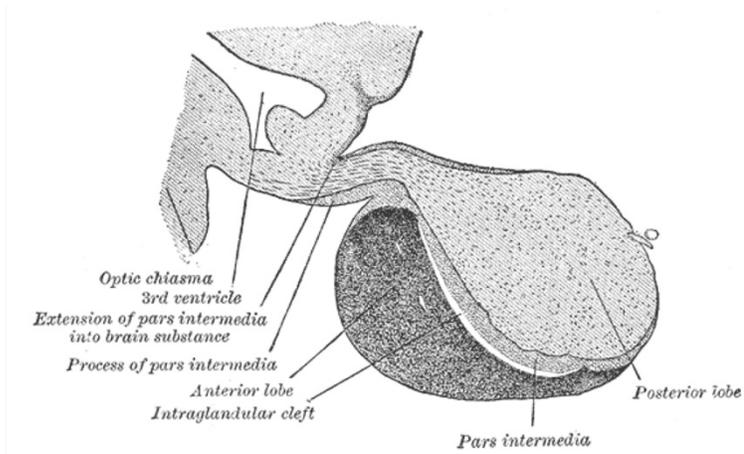
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The pituitary gland is composed of 2 distinct regions, or lobes:

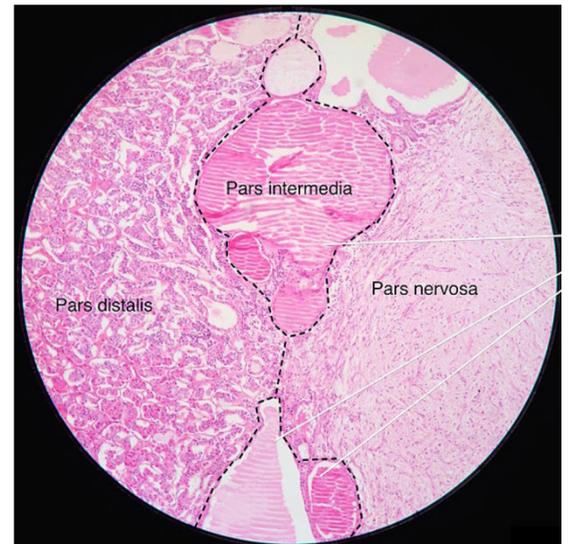
- the **ANTERIOR lobe** (also called the **adenohypophysis**; sometimes called the *pars distalis*)
- and the **POSTERIOR lobe** (also called the **neurohypophysis**; sometimes called the *pars nervosa*).

The diagram at the right (figure 17.7 from the OpenStax text) clearly shows the relationship between the pituitary lobes and the hypothalamus by color-coding the individual components. See the link: <https://openstax.org/books/anatomy-and-physiology/pages/17-3-the-pituitary-gland-and-hypothalamus>.

The differences between the two lobes can be seen easily when the tissue is examined under the microscope. The drawing on the left and the photomicrograph on the right can be found in Wikipedia. See the link: https://en.wikipedia.org/wiki/Pituitary_gland



By Henry Vandyke Carter - Henry Gray (1918) Anatomy of the Human Body (See "Book" section below) Bartleby.com: Gray's Anatomy, Plate 1181, Public Domain, <https://commons.wikimedia.org/w/index.php?curid=567163>



Athikhun.suw [CC BY-SA 4.0 (<https://creativecommons.org/licenses/by-sa/4.0/>)], from Wikimedia Commons

The posterior lobe is an extension of the brain tissue in the hypothalamus. This means that the posterior lobe is actually nervous tissue and not true glandular tissue. Hormones are synthesized in cell bodies in the hypothalamus, then transported to the axon terminals in the posterior lobe. These hormones are released from the axon terminals into the bloodstream. The anterior lobe is true glandular tissue: hormones are synthesized, stored and released from the cells here.

Some online sites where you can see more histology of the pituitary gland are below:

Histology Guide Virtual Histology Laboratory
<http://www.histologyguide.com/slidebox/13-endocrine-glands.html>

Hormones Secreted from the Pituitary Gland

Two hormones are secreted from the posterior pituitary:

- Antidiuretic hormone (ADH) and
- Oxytocin.

The figure at the right (figure 17.8 from the OpenStax text) shows ADH and oxytocin being synthesized in the hypothalamus and then transported to the posterior pituitary for release to the blood.

See the link:

<https://openstax.org/books/anatomy-and-physiology/pages/17-3-the-pituitary-gland-and-hypothalamus>

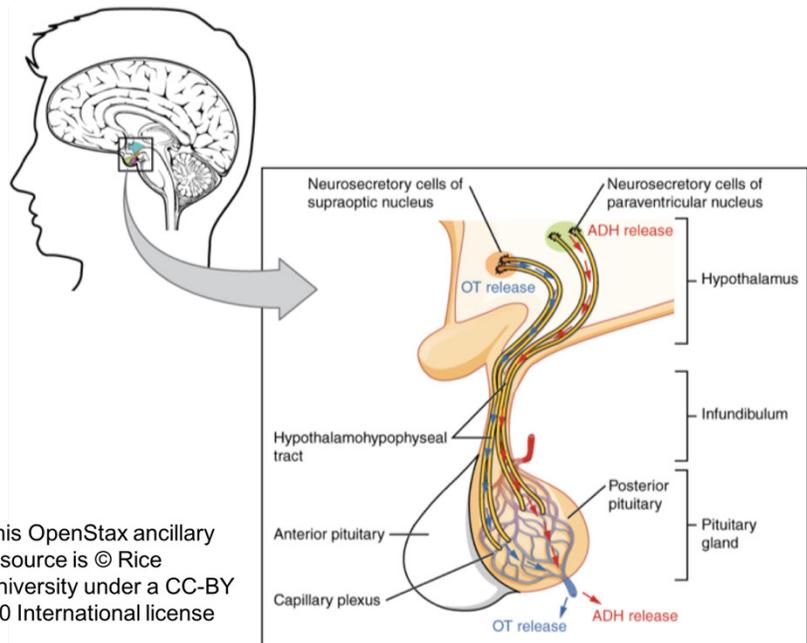


Figure 17.8 Posterior Pituitary Neurosecretory cells in the hypothalamus release oxytocin (OT) or ADH into the posterior lobe of the pituitary gland. These hormones are stored or released into the blood via the capillary plexus.

Six hormones are released from the anterior pituitary:

- Growth hormone (GH)
- Prolactin
- Follicle-stimulating hormone (FSH)
- Luteinizing hormone (LH)
- Adrenocorticotrophic hormone (ACTH)
- Thyroid-stimulating hormone (TSH)

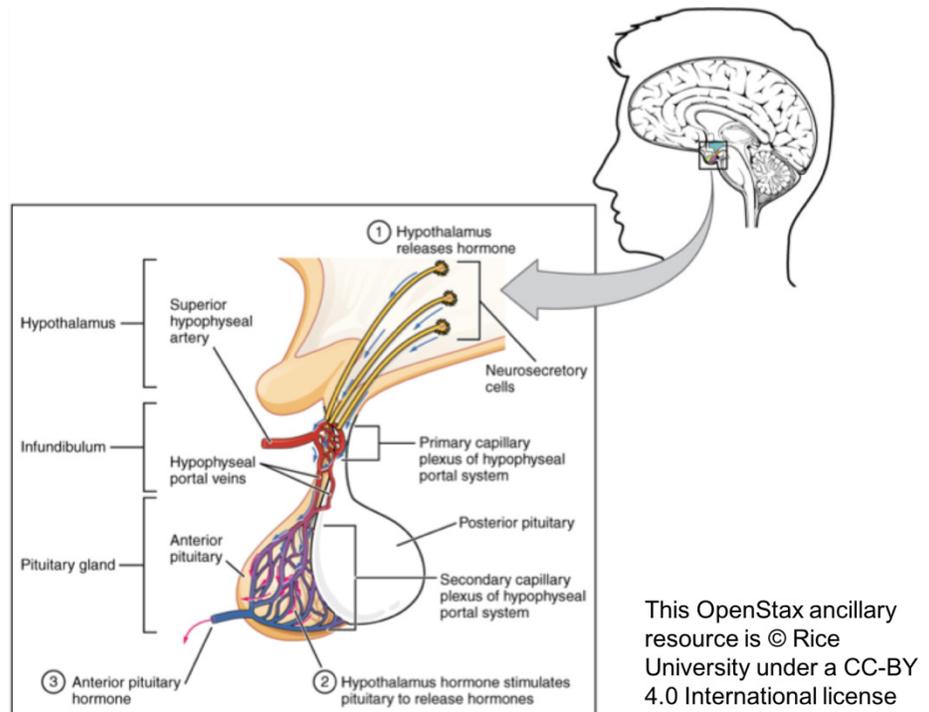


Figure 17.9 Anterior Pituitary The anterior pituitary manufactures seven hormones. The hypothalamus produces separate hormones that stimulate or inhibit hormone production in the anterior pituitary. Hormones from the hypothalamus reach the anterior pituitary via the hypophyseal portal system.

The image at the right (figure 17.9 from the OpenStax text) shows hormones from the hypothalamus being sent directly to the anterior pituitary via the hypophyseal portal system, where they act on the cells of that gland to stimulate or inhibit their release. See the link: <https://openstax.org/books/anatomy-and-physiology/pages/17-3-the-pituitary-gland-and-hypothalamus>

The anterior pituitary is composed of three distinct cell types that can be seen more easily when they are stained with acidic or basic dyes. ACIDOPHILS are cells that appear red when stained with acidic dyes. BASOPHILS are cells that appear blue when stained with basic dyes. CHROMOPHOBES are cells that remain uncolored in the presence of either type of dye. The hormones that are released from the anterior pituitary are associated with either acidophils or basophils. The table below shows you which hormones are released from each type of cell.

See the link to Histology Guide for good histology images of acidophils, basophils and chromophobes.

<http://www.histologyguide.com/slideview/MH-150a-pituitary/13-slide-1.html?x=0&y=0&z=-1&page=1>

Activity 3. Source, Actions, and Hypothalamic Regulation of the Anterior Pituitary

Fill in the table with the actions of each hormone, and the name of the hypothalamic hormone(s) that regulate their release.

Pituitary Gland	Cells	Hormones Produced	Action of Hormones	Hypothalamic Releasing or Inhibiting Hormone
Anterior (adenohypophysis)	Acidophils	GH Prolactin		
	Basophils	FSH LH ACTH TSH		
	Chromophobes	NA	NA	NA
Posterior (neurohypophysis)	Axon terminals	ADH		NA
	Axon terminals	Oxytocin		NA

REGULATION OF THE PITUITARY AND TARGET ORGANS / GLANDS

Feedback Loops

The release of hormones in the endocrine system are regulated through feedback mechanisms. Negative feedback is used to inhibit further hormone secretion: when a sufficient amount of hormone is released, it “feeds back” to decrease or prevent further release. In other words, the gland has released sufficient hormone to produce the desired effect, so further hormone release is inhibited. Because the hypothalamus and pituitary glands are regulating the activity of endocrine glands, they are also subject to feedback mechanisms and their activity will be altered in response to levels of other hormones.

The regulation of the anterior pituitary involves the release of hormones from the hypothalamus; regulation of the endocrine glands involves the release of hormones from the anterior pituitary. Further, hormones released from the endocrine glands interact with both the hypothalamus and the pituitary to regulate their activity, in a classic arrangement known as a feedback loop.

The pathways of three hormones are examined in this activity: thyroid hormone, cortisol and testosterone. The hormonal pathways are similar in all three cases. In each case:

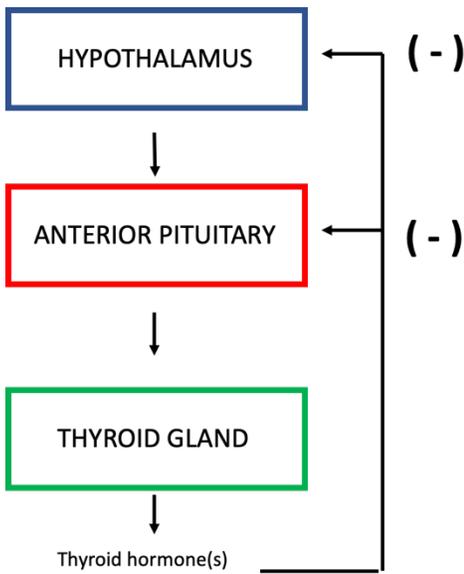
- the hypothalamus secretes a releasing hormone to regulate the activity of the anterior pituitary gland,
- the anterior pituitary then secretes hormones that regulate the activity of a target gland (the thyroid gland, the adrenal gland or the testis)
- the hormones released from the target glands “feed back” to the anterior pituitary and the hypothalamus to inhibit the further release of those hormones

The hypothalamus is like a command center: if it is not stimulated, it will not secrete releasing hormones to stimulate the anterior pituitary, which in turn will not stimulate the target glands.

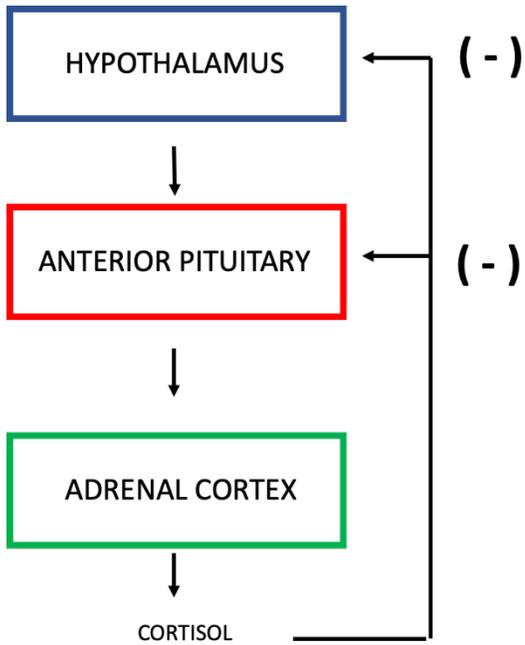
Activity 4 – Predict the actions of three hormones on selected glands or organs

Three examples of feedback loops (for regulation of the thyroid gland, the adrenal cortex, and the testes) are shown below.

For each step in the loop, indicate the hormone that is released and regulates the next organ or gland in the loop. Then, fill in the following tables with your predictions of the effect of each hormone (in the top row) on the size of the glands in the first column. For example, if exposure to TRH is expected to stimulate the anterior pituitary, you might expect this stimulation would increase the size of that gland over time. You may want to use the feedback loops you completed to aid your predictions.

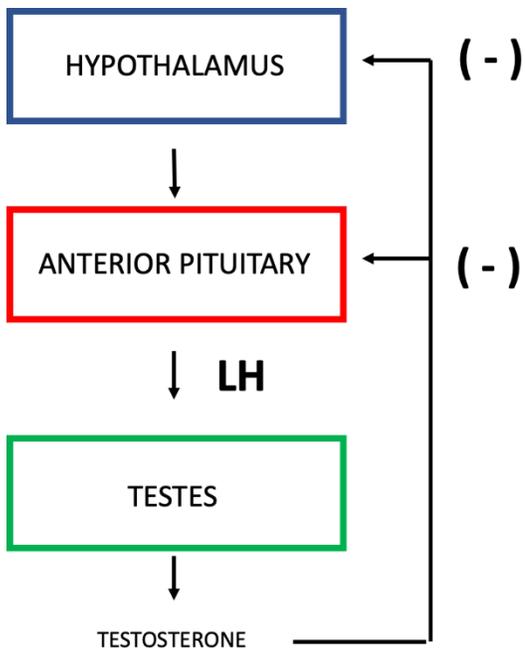


Gland	TRH	TSH
Anterior pituitary		
Thyroid		



Gland	ACTH	cortisol
Anterior pituitary		
Adrenal cortex		

(NOTE – “castrated” male rats have had testes removed shortly after birth. “Intact” male rats have intact testes. The correct anterior pituitary hormone is already given.)



Gland	Testosterone		LH	
	intact	castrated	intact	castrated
Anterior pituitary				
Testes				

Activity 5 - Experimental data and unknown hormones

You've conducted an experiment where you've treated pairs of male rats (matched for weight) with unknown hormones. In each pair of animals, one rat is "intact" (retaining testes) and "castrated" (having had testes removed to eliminate testosterone production) shortly after birth. Each pair of rats was treated with an unknown hormone daily for 2 weeks. At the end of the treatment, the pairs were euthanized humanely and the following organs / glands were obtained and weighed. Weights for each are recorded in the table below. One pair of animals received injections of saline instead of an unknown – data from this pair of animals represents the control situation.

How can you use this data to determine the identity of each unknown hormone? Describe, in one - two sentences.

Fill in the table below with your conclusions. For each unknown, give 1 or 2 pieces of evidence that lead you to this conclusion.

Unknown	Identity of the unknown hormone	Evidence that leads you to this conclusion
1		
2		
3		
4		
5		
6		

Data Table 1 (in 2 parts) – Effect of hormone treatment on organ / gland weight in male rats (intact and castrated).

Gland	CONTROL		UNKNOWN #1		UNKNOWN #2		UNKNOWN #3	
	intact	castrated	intact	castrated	intact	castrated	intact	castrated
Anterior pituitary	12.9 mg	12.0mg	12.8mg	12.9mg	9.8mg	13.0mg	10.2mg	10.1mg
Thyroid	250mg	250mg	245mg	250mg	250mg	250mg	252mg	250mg
Adrenal cortex	40mg	40mg	100mg	95mg	40mg	42mg	38mg	41mg
Testes	3200mg	NA	3000mg	NA	5700mg	NA	2400mg	NA
Prostate / seminal vesicles	425mg / 500mg	387mg / 450mg	430mg/ 490mg	380mg / 410mg	800mg / 900mg	375mg / 412mg	900mg / 1400mg	800mg / 1200mg
Overall body weight	300g	270g	200g	195g	385g	275mg	490g	485g

Gland	CONTROL		UNKNOWN #4		UNKNOWN #5		UNKNOWN #6	
	intact	castrated	intact	castrated	intact	castrated	intact	castrated
Anterior pituitary	12.9 mg	12.0mg	25mg	25.7mg	9.8mg	9.7mg	8mg	7.8mg
Thyroid	250mg	250mg	490mg	495mg	245mg	247mg	500mg	505mg
Adrenal cortex	40mg	40mg	39mg	38mg	30mg	29mg	37mg	37mg
Testes	3200mg	NA	3150mg	NA	3200mg	NA	1600mg	NA
Prostate / seminal vesicles	425mg / 500mg	387mg / 450mg	400mg/ 480mg	375mg / 450mg	410mg / 475mg	380mg / 440mg	405mg / 480mg	375mg / 445mg
Overall body weight	300g	270g	160g	144g	150g	135mg	152g	135g

(Modified from Odenweller, C.M., et al. Laboratory exercise using “virtual rats” to teach endocrine physiology. *Adv. Physiol. Educ.* 18: S24-S40, 1997)

Exit Ticket: Before you leave lab today, read the following scenarios and answer the associated questions.

When the carnival came to a small town, the local health professionals and consumer groups joined forces to enforce truth-in-advertising laws to protect selected employees of the carnival. They demanded that the **fat man, the dwarf, the giant and the bearded lady** be billed as “people with endocrine system disorders,” (which of course removed all the sensationalism usually associated with these attractions).

Identify the endocrine disorder in each case and explain how (or why) the disorder produced the characteristic features of these four show people.

A young girl is brought to your clinic by her father. The girl fatigues easily and seems mentally sluggish. You notice a slight swelling in the anterior neck.

What condition do you suspect, and why? Are her symptoms related to HYPERsecretion or HYPOsecretion of a hormone? Outline the sequence of events involved in the secretion of this hormone, starting with the hypothalamus.

Structure of the Cardiovascular System: The Heart

Introduction

The cardiovascular system includes the heart, which pumps blood, and blood vessels, which deliver blood to the organs of the body. The heart is often thought to be the most important organ in the body, and in fact when the heart fails the subject may die. Approximately 50% of the population of the United States is believed to have heart disease, so healthcare professionals in every discipline can expect to work with patients experiencing some form of cardiovascular dysfunction.

In this laboratory, you will use models, diagrams and preserved specimens (sheep or pig hearts) to study the anatomy of the heart. You should be able to identify chambers, and the valves (in the vessels and between the chambers) that ensure one-way flow of blood through the heart and circulatory system.

Learning Objectives

By the end of this lesson you will be able to:

- Describe the location of the human heart
- Name and located the major external and internal anatomical features and structures of the heart on a chart, model, diagram or preserved specimen (see the Structures of Importance)
- Trace the pathway of blood through the heart
- Compare the pulmonary and systemic circuits
- Describe the features and operation of the atrioventricular and semilunar valves
- Describe the blood supply to the heart (see the table)
- Compare and contrast cardiac tissue histology with skeletal and smooth muscle

- Identify the following structures of importance:

External structures (Fig 19.6 in the OpenStax text – https://openstax.org/books/anatomy-and-physiology/pages/19-1-heart-anatomy)	Internal structures (Figs 19.4, 19.9 in the OpenStax text - https://openstax.org/books/anatomy-and-physiology/pages/19-1-heart-anatomy)
Great vessels (if visible): aorta, superior vena cava, inferior vena cava, pulmonary trunk	Right and left atria
Right and left atria / auricles	Right and left ventricles
Right and left ventricles	Right and left atrioventricular valves (mitral and tricuspid valves)
Pulmonary veins	Aortic and pulmonary semilunar valves
Pericardium (visceral and fibrous, if visible)	Interventricular septum
	Papillary muscles and trabeculae carneae
	Chordae tendineae
Coronary arteries (Fig. 19.15 in the OpenStax text - https://openstax.org/books/anatomy-and-physiology/pages/19-1-heart-anatomy)	Coronary veins (Fig. 19.15 in the OpenStax text – https://openstax.org/books/anatomy-and-physiology/pages/19-1-heart-anatomy)
Right coronary artery	Coronary sinus
Marginal artery / right marginal artery	Great cardiac vein
Left coronary artery	Middle cardiac vein
Anterior interventricular artery	
Circumflex artery	
Posterior interventricular artery	
Heart microanatomy (Fig 19.17 in the OpenStax text – (See Fig. 19.15 in the OpenStax text - https://openstax.org/books/anatomy-and-physiology/pages/19-1-heart-anatomy)	Conducting system structures (seen only on models)
Cardiac muscle cells / nuclei / striations	SA and AV nodes
Intercalated disks	Bundle of His, bundle branches, Purkinje fibers

Background Information

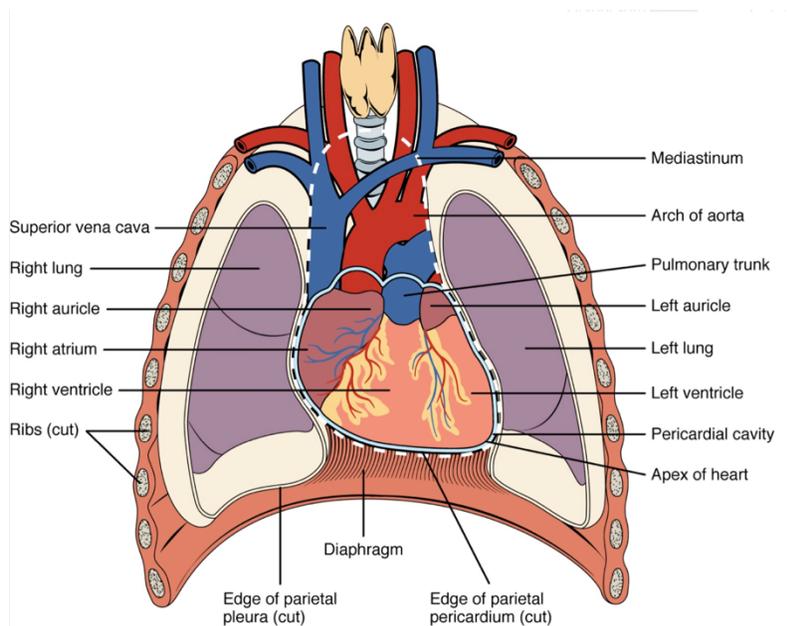
OVERVIEW

The heart pumps blood without stopping to deliver oxygen and nutrients, throughout the entire body. Assuming a heart rate of 75 beats per minute, with 70mL of blood ejected during each heartbeat, normal healthy people will have nearly 11,000 heartbeats in a single day, pumping more than 7500L of blood. The purpose of these exercises is to describe the location and major anatomical features of the heart, to describe bloodflow to the heart and through the heart, and to observe the electrical activity of the heart by obtaining an ECG.

EXTERIOR OF THE HEART

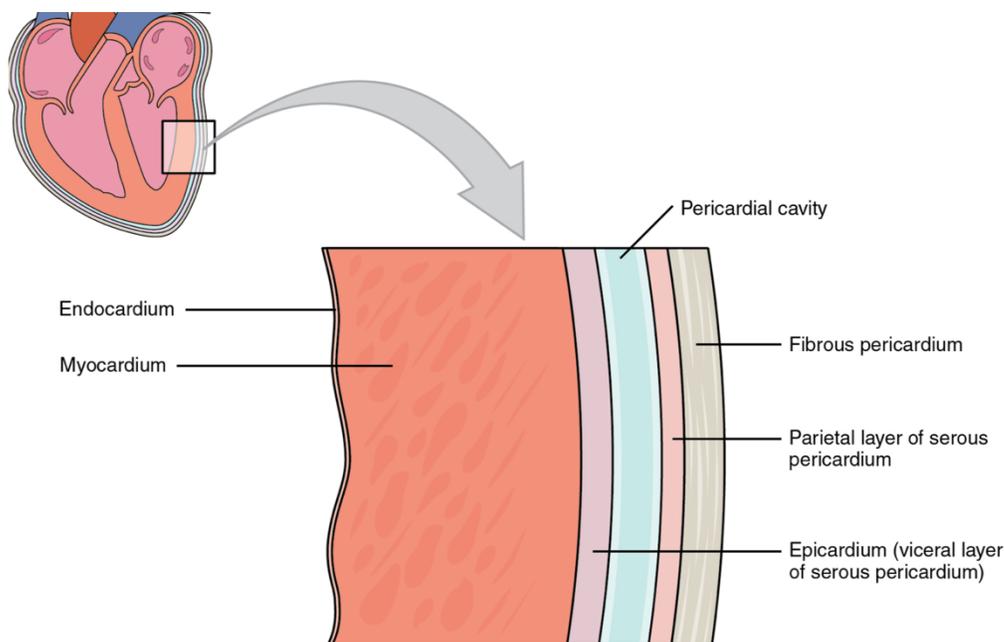
Location of the heart in the thorax

The heart is located in the thoracic cavity, between the lungs, in a space called the **mediastinum**, the middle region of the thoracic cavity that contains the heart and its vessels. The mediastinum is separated from the pleura (which surround the lungs) by a serous membrane surrounding the heart called the **pericardium**.



Pericardium

The heart is surrounded by a tough, double-layered structure called the **pericardium**. The outer portion called the fibrous pericardium is composed of dense irregular connective tissue. The inner portion is composed of two layers: the parietal pericardium (the parietal layer of the serous pericardium), which adheres to the fibrous layer, and the visceral pericardium (also called the epicardium) which is tightly adhered to the heart muscle. Between the visceral and parietal layers is the thin pericardial cavity, which contains serous fluid. Thus, the pericardium is a type of serous membrane, a double-layered membrane with a thin layer of lubricating serous fluid between the layers. You probably remember that serous membranes are found surrounding organs that move, like the lungs and the digestive organs.



External features of the heart

The heart is not actually heart-shaped! The broad superior aspect of the heart is called the **base**, and is the site of large blood vessels that deliver blood to the heart and carry blood away from it. The **apex** is the pointy inferior tip that points to the left side of the body. The walls of the heart chambers are muscular. The heart is composed internally of four chambers, or spaces, that contain blood at some point during a heartbeat: the right and left atria, located superiorly; and the right and left ventricles, which are inferior to the atria. The chambers of the heart can be seen on the external surface. Grooves separate the atria from the ventricles (the **atrioventricular sulcus**), and the right from the left ventricles (the **interventricular sulcus**). These grooves have coronary blood vessels coursing in them.

Anterior view of the external heart

The heart, being a three-dimensional structure, is expected to look different depending on the view. We will focus here on the anterior, exterior structures.

a. Great Vessels

In the anterior view, the great vessels are found superiorly. We can organize these vessels into four groups:

- The pulmonary trunk, which exits from the right ventricle, is the most anterior vessel on the anterior surface of the heart. It splits shortly after leaving the ventricle into the right and left pulmonary arteries. The pulmonary arteries deliver DEOXYGENATED blood to the right and left lungs – this is different from most arteries, which deliver OXYGENATED blood to organs. (In many models and diagrams, the pulmonary trunk and arteries are depicted in BLUE, which is typically reserved for vessels that are veins. Conventional wisdom tells us that veins carry deoxygenated blood.)
- The aorta is a large artery that emerges from the left ventricle. It may be difficult to see the place where the aorta leaves the ventricle since it's close to (and may be hidden by) the pulmonary trunk. It almost immediately changes course by 180°, such that it proceeds inferiorly through the thorax and the abdominal cavity. Other arteries branch off the aorta to deliver oxygenated blood to the organs of the body.
- The inferior and superior vena cavae are large vessels that deliver deoxygenated blood to the right atrium, back to the heart from the systemic circulatory system. They get their designations as superior or inferior based on their location superior or inferior to the heart. The superior vena cava generally receives blood from organs and vessels above the diaphragm; the inferior vena cava generally receives blood from organs and vessels below the diaphragm.
- The four pulmonary veins (two from the right lung and two from the left lung) are most easily seen on the posterior aspect of the heart. All four drain blood into the left atrium, giving it a distinctive appearance. Because these vessels drain blood from the lungs, the blood is OXYGENATED – on models and diagrams these vessels will be depicted in RED because of this, despite the fact that they are veins.

b. Heart chambers

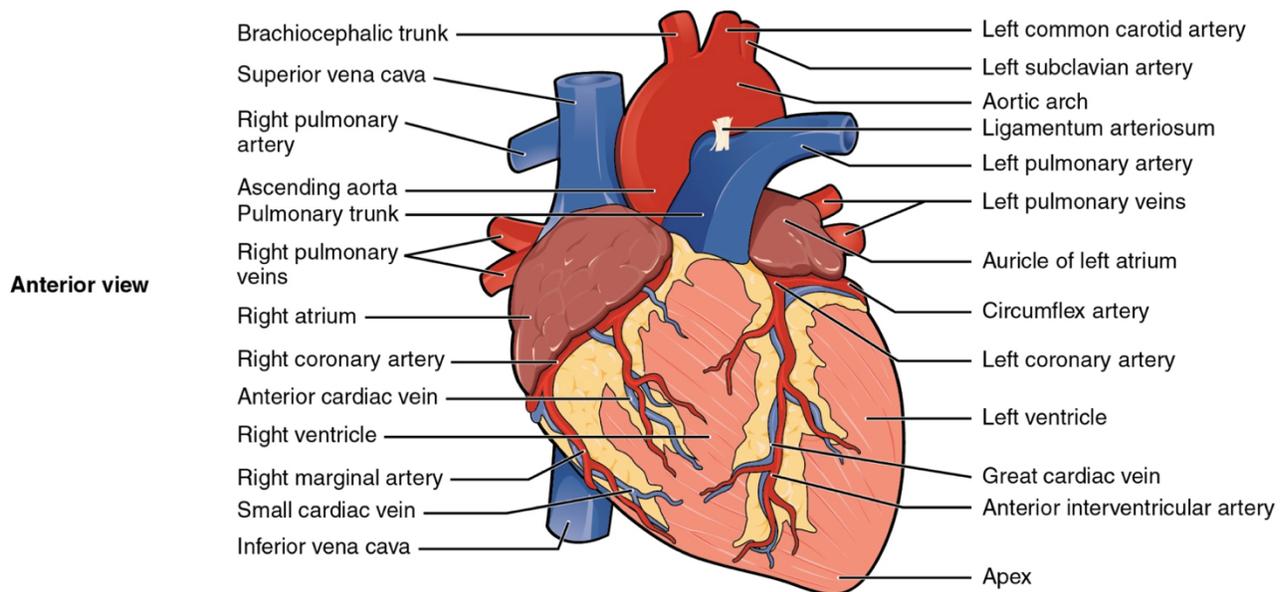
In the anterior view, the right and left atria are easily identified by the thin-walled, “ruffled” appearance of the auricles, the most external portion of these chambers. The right and left ventricles are inferior to their respective atria. The ventricles appear more muscular than the atria. On the anterior aspect of the heart, the right and left ventricles are separated by the interventricular sulcus, a groove where coronary blood vessels are found. The separation of the ventricles from the atria is clearer due to the very different appearance of the chambers, and the groove separating them is called the atrioventricular sulcus.

c. Coronary blood vessels

The coronary circulation provides oxygen- and nutrient-rich blood to the heart muscle. As mentioned earlier, these blood vessels are often located in the interventricular / atrioventricular sulci. In similar fashion to the rest of the systemic circulation, coronary arteries take oxygenated blood from the aorta and deliver it to the heart muscle, while coronary veins drain deoxygenated blood from the heart tissue and return it to the heart.

Coronary arteries originate at the base of the aorta, where it emerges from the left ventricle.

- The right coronary artery travels in a clockwise direction in the atrioventricular sulcus to the posterior side of the heart. It terminates on the posterior side as the posterior interventricular artery, traveling toward the apex in the posterior interventricular sulcus. It delivers blood to the heart muscle tissue on that side.
- The left coronary artery travels in a counter-clockwise direction, in the atrioventricular sulcus.
 - It branches shortly after emerging from the aorta to form the anterior interventricular artery (sometimes called the left anterior descending artery – LAD), which travels inferiorly on the anterior surface of the heart in the anterior interventricular sulcus. Blood from the anterior interventricular artery delivers oxygen and nutrients to the heart tissue of the anterior heart.
 - The other branch of the left coronary artery continues coursing in the atrioventricular sulcus in a counter-clockwise direction around the heart as the circumflex artery. Blood in this vessel supplies oxygenated blood to the left atrium and the posterior left ventricle.



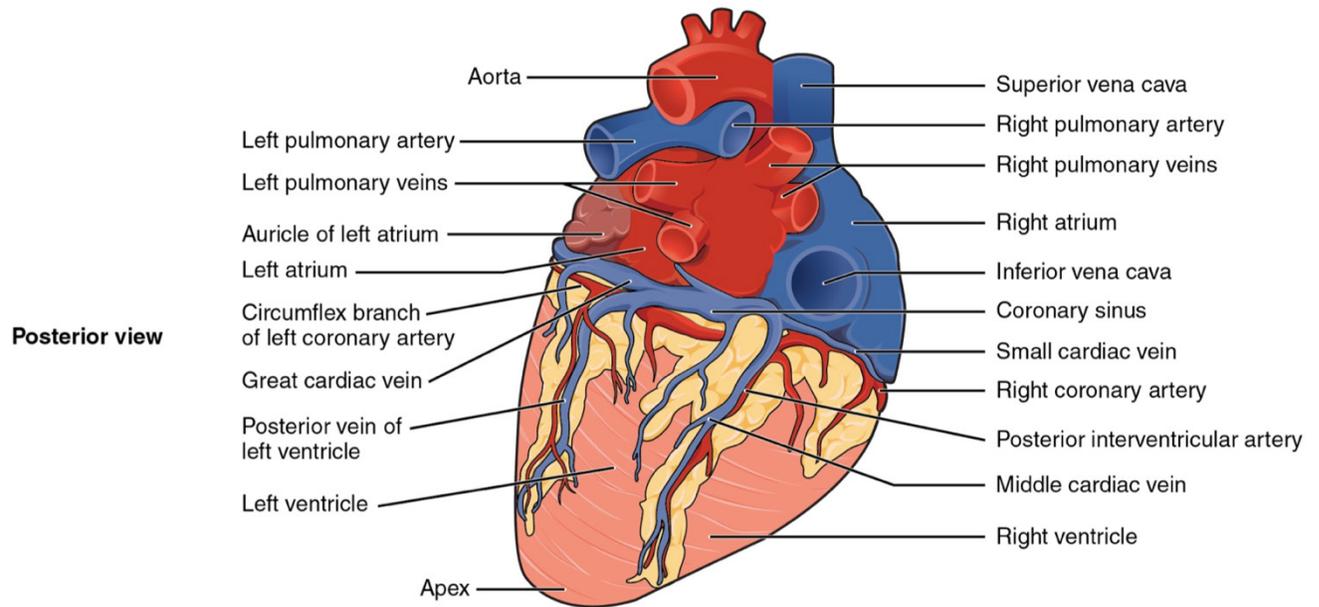
Coronary veins drain blood from the heart muscle tissue and return it to the right atrium, from where it can return to the lungs for oxygenation. There are three main coronary veins.

- **The small cardiac vein** drains blood from the right inferior heart. It travels with the right marginal artery, a branch of the right coronary artery.
- **The middle cardiac vein** is found on the posterior aspect of the heart. It travels with the posterior interventricular artery, in the posterior interventricular sulcus.
- **The great cardiac vein** is found on the anterior surface of the heart, in the anterior interventricular sulcus, traveling with the anterior interventricular artery superiorly to the atrioventricular sulcus, then around the heart with the circumflex artery. This vessel drains blood from the left side of the heart.

All of the coronary veins drain blood into the coronary sinus, a large thin-walled vessel on the posterior side of the heart near the right atrium. Blood in the coronary sinus then travels to the right atrium.

Posterior view of the external heart

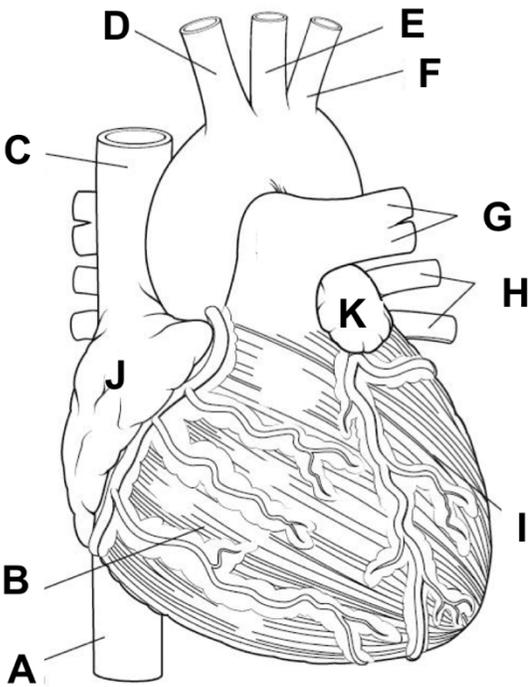
On the posterior aspect of the heart, many of the structures described above are visible as well (albeit, on the opposite side). Of the great vessels, the pulmonary veins are particularly visible as they enter the left atrium, and the entrance of the inferior vena cava may also be more visible. The right and left ventricles are separated by the posterior interventricular sulcus, and like the anterior counterpart this groove is the site of coronary blood vessels.



Activity 1 – External features of the heart

Fill in the tables on the right with the name of the labeled heart structure (which should be a chamber or a blood vessel) from the pictures on the left.

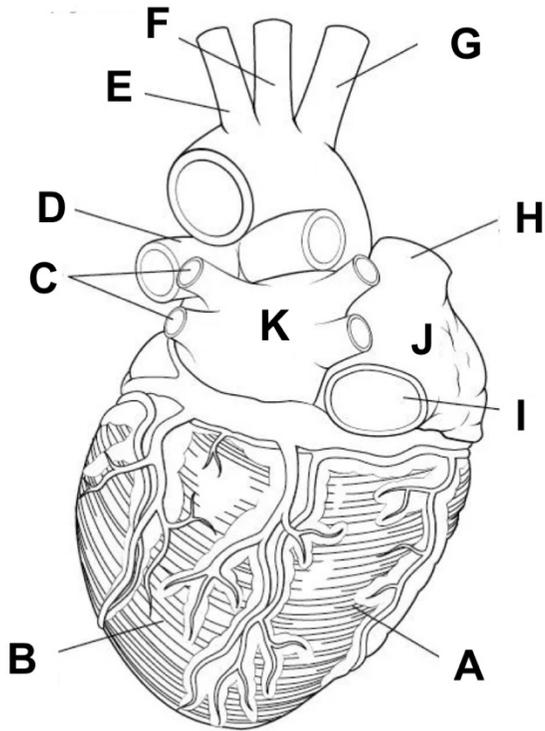
ANTERIOR HEART



<https://emedicine.medscape.com/article/905502-overview>

Letter	Name of this structure (chamber or blood vessel)
A	
B	
C	
D	
E	
F	
G	
H	
I	
J	
K	

POSTERIOR HEART



<https://emedicine.medscape.com/article/905502-overview>

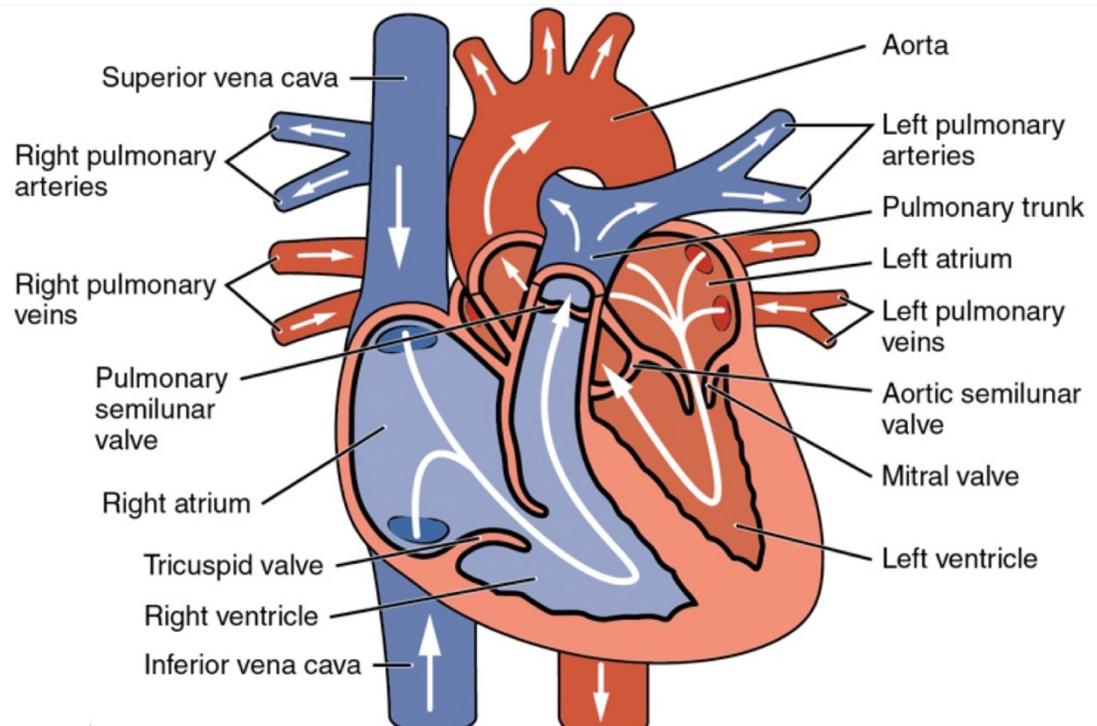
Letter	Name of this structure (chamber or blood vessel)
A	
B	
C	
D	
E	
F	
G	
H	
I	
J	
K	

INTERNAL FEATURES OF THE HEART

To view the internal structures and features of the heart, we will need to look at dissected models and specimens. We'll begin with a diagram of a frontal section of the heart (below).

See the link to Figure 19.4 in the OpenStax text:

<https://openstax.org/books/anatomy-and-physiology/pages/19-1-heart-anatomy>



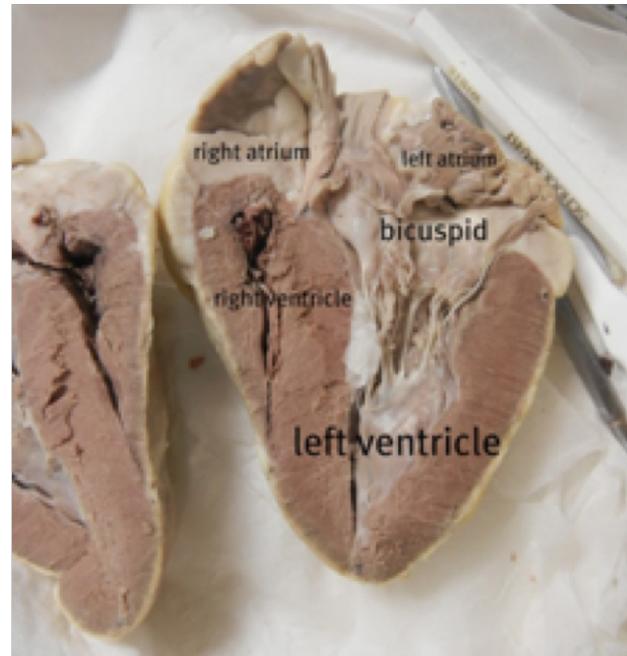
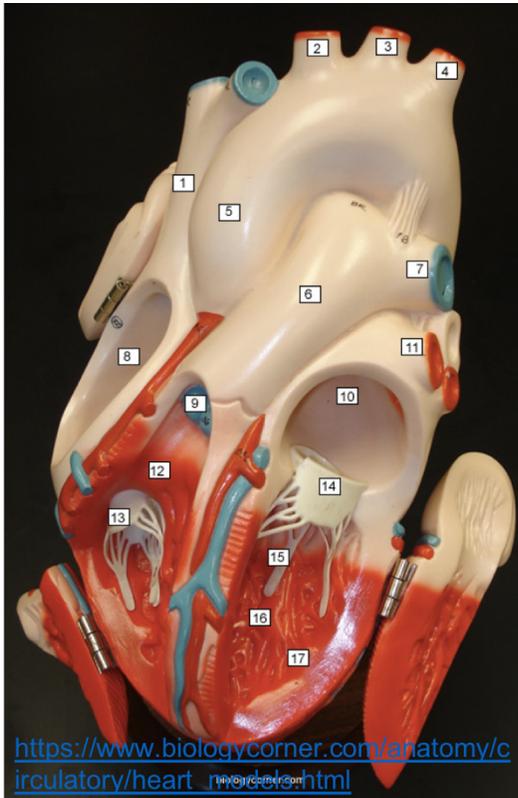
The chambers of the heart can be seen in the above diagram. The right side (in blue) pumps blood to the lungs, while the left side (in red) pumps blood to the rest of the body. Follow the arrows of blood flow through the heart.

Heart Chambers

The same chambers that you identified in the intact heart (above) can be seen in this diagram. The thin-walled atria (right and left) can be seen superior to the more muscular right and left ventricles. On the inner surface of the atria you can see thin ridges of muscle called pectinate muscles.

1. The right atrium, receives deoxygenated blood from the superior and inferior vena cavae, and the coronary sinus. A flap-like extension that is easily seen externally is called the auricle. On the inner surface of the wall of this chamber you can see thin ridges of muscle called pectinate muscles. Blood in this chamber travels to the right ventricle next, through a valve called the tricuspid valve.
2. Although the right ventricle is relatively thin-walled when compared to the left ventricle, the walls of this chamber are significantly more muscular than the atria. Deoxygenated blood is pumped from the right ventricle through another valve, the pulmonary valve, to the pulmonary trunk and out of the heart.
3. The left atrium receives oxygenated blood from the pulmonary veins as it returns from the lungs. As in the right atrium, an external puppy-ear shaped auricle can be seen. Pectinate muscle ridges are evident in the wall of the internal wall.
4. The left ventricle is a thick-walled chamber. Oxygenated blood enters through the bicuspid valve from the left atrium, and is pumped out to the aorta through yet another valve, the aortic valve. The right and left ventricles are adjacent to each other, separated by the interventricular septum, a wall of myocardium.

The below images show a model of the heart with internal structures, and a corresponding sheep heart in roughly the same orientation.



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https://www.biologycorner.com/anatomy/circulatory/heart/heart_dissection.html, Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License

Heart Valves

It should be clear from the previous discussion that bloodflow into and out of the ventricles must pass through two valves: the atrioventricular (AV) valves (the tricuspid and bicuspid valves), which regulate the flow of blood into these chambers; and the semilunar valves (the aortic and pulmonary valves), which regulate the flow of blood out.

1. The tricuspid valve (“three cusps,” or “three teeth,”), with three leaflets guarding the entrance to the right ventricle, and the bicuspid (“two cusps,” or “two teeth,”) are composed of dense connective tissue covered by folds of endocardium. The leaflets of both valves are attached by string-like structures called chordae tendineae, or tendinous strings, to the nipple-shaped papillary muscles in the wall of the corresponding ventricle.
2. The aortic and pulmonary semilunar valves are also composed of dense connective tissue. While both of these valves have three leaflets that open and close there are no chordae tendineae or papillary muscles to anchor them.

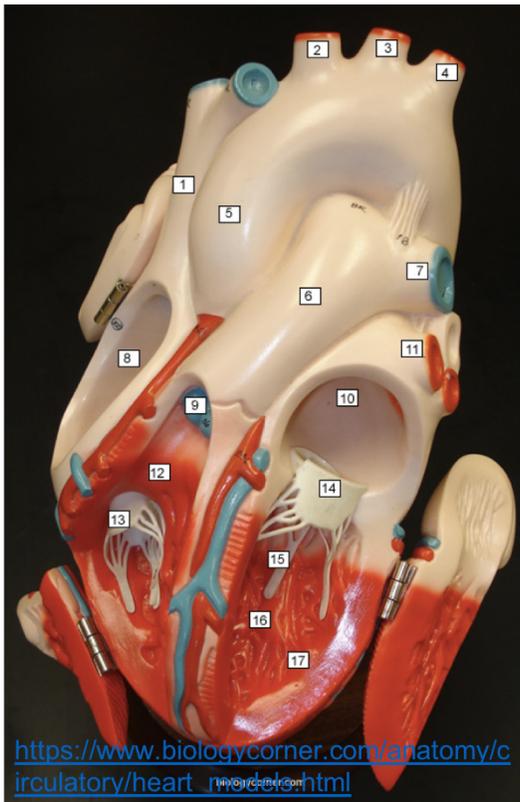
Activity 2 – Summary of heart valve structure.

Fill in the table with the characteristics of the heart valves.

	AV valves		Semilunar valves	
	tricuspid	bicuspid	aortic	pulmonary
Location: between the _____ and _____ (name the vessels or chambers)				
Number of leaflets				
Chordae tendineae? (YES or NO)				
Attached to papillary muscle? (YES or NO)				

Activity 3 – Internal structures of the heart

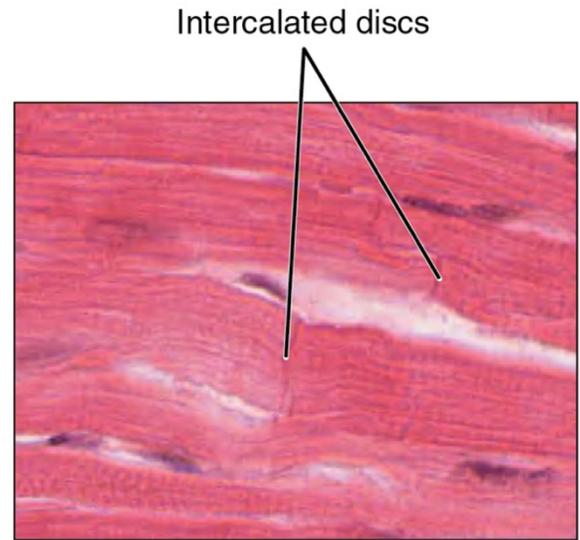
Use the labeled model at the left to identify the structures of the heart. (The structure can be a vessel, a chamber, a valve, or another feature related to heart anatomy.)



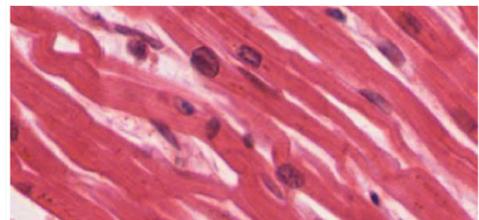
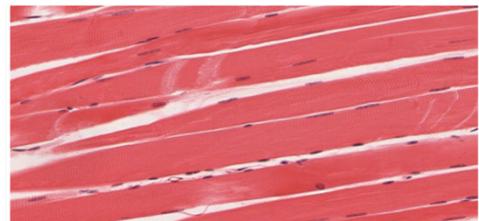
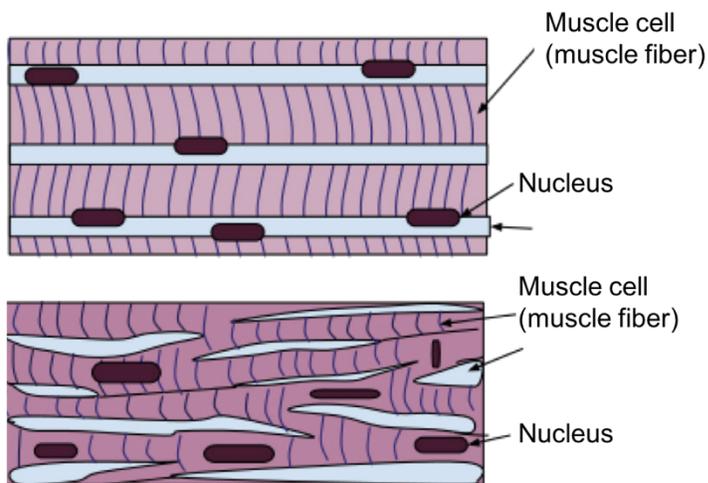
Number	Name of this structure?
1	
2	
3	
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5	
6	
7	
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12	
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16	
17	

HISTOLOGY

Cardiac muscle resembles skeletal muscle in that both muscle tissues are striated (have a striped appearance). The striations are related to the arrangements of the contractile proteins in both types of cells. However, some important differences exist between these muscle types. Skeletal muscle cells are long and cylindrical, with many nuclei (making them multinucleate). The arrangement of the contractile proteins in skeletal muscle cells pushes the nuclei to the cell periphery, making it look almost as if the nuclei were outside the cell. Cardiac muscle cells are branched, unlike skeletal muscle cells. Cardiac muscle cells are joined together, end-to-end, at unique junctions called **intercalated disks**. The connections between cells are very tight here, due to the presence of desmosomes, and gap junctions (ion channels) allow rapid communication between cells. It is very important that all cardiac muscle cells are functioning as a unit so that the heart can efficiently pump blood – the gap junctions ensure that all muscle cells “get the message” at the same time.



You can see a comparison of cardiac and skeletal muscle below. A diagram on the left shows some of the important features of the tissues, while photomicrographs on the right give a more detailed view.



Mdunning13 [CC BY-SA 3.0 (<https://creativecommons.org/licenses/by-sa/3.0/>)], from Wikimedia Commons

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Activity 4 - Comparing skeletal and cardiac muscle.

Fill in the table with the characteristics of SKELETAL and CARDIAC muscle.

	SKELETAL muscle	CARDIAC muscle
Shapes of the individual cells		
Number of nuclei per cell		
Striations present?		
Intercalated disks present?		

Activity 5 – Create and label a cardiac histology image.

The University of Michigan has a virtual histology site with numerous images of tissues in the organs of the cardiovascular system. Here is a link to an image of the heart:

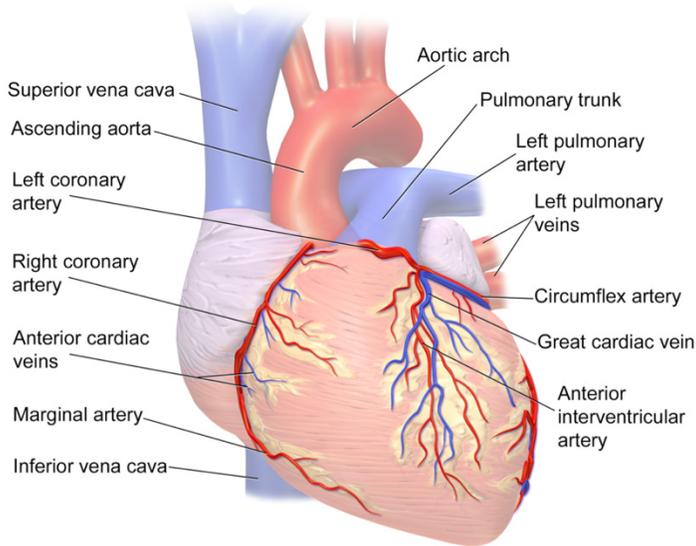
[http://virtuallslides.med.umich.edu/Histology/Cardiovascular%20System/099_HISTO_20X.svs/vi
ew.apml?cwidth=860&cheight=733&chost=virtuallslides.med.umich.edu&listview=1&title=&csi
s=1](http://virtuallslides.med.umich.edu/Histology/Cardiovascular%20System/099_HISTO_20X.svs/vi
ew.apml?cwidth=860&cheight=733&chost=virtuallslides.med.umich.edu&listview=1&title=&csi
s=1)

Create and upload / paste an image at the highest -power magnification (20X on this site). OR - Using a prepared slide of cardiac muscle, draw what you see under the 20X power magnification. On the image you created, label the cardiac myocytes, the nuclei, the striations and the intercalated disks. (You may have to search the tissue to find a grouping of cells that are in the proper orientation to see these features.)

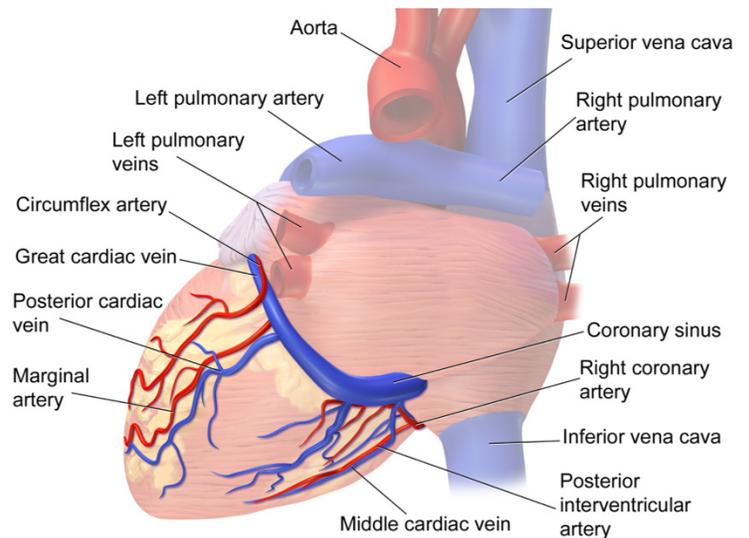
CIRCULATION TO THE HEART

The coronary circulation is the circulation of blood to the heart muscle. Because the heart is working tissue, it also requires oxygen and nutrients to remain viable. Coronary arteries supply oxygenated blood to the muscle, while coronary veins drain deoxygenated blood away from the heart muscle tissue.

Two coronary arteries branch from the root of the aorta, very near the place where the aorta emerges from the heart: the right coronary artery (distributing blood to the right atrium and both ventricles), and the left coronary artery (distributing blood to the left atrium and ventricle, and the interventricular septum).



Coronary Circulation (Anterior)



Coronary Circulation (Posterior)

By Blausen Medical Communications, Inc. - Donated via OTRS, see ticket for details, CC BY 3.0, <https://commons.wikimedia.org/w/index.php?curid=26986337>

Blausen.com staff (2014). "Medical gallery of Blausen Medical 2014". WikiJournal of Medicine 1 (2). DOI:10.15347/wjm/2014.010. ISSN 2002-4436. - Own work, CC BY 3.0, <https://commons.wikimedia.org/w/index.php?curid=29140360>

You can see that the coronary vessels – those blood vessels that are delivering blood to and draining blood away from the heart muscle – are located in the grooves, or sulci, in the surface of the heart. The groove between the atria and ventricles is called the **atrioventricular sulcus**; the grooves between the right and left ventricles are the **interventricular sulci**. One interventricular sulcus (the **anterior interventricular sulcus**) is found on the anterior face of the heart, and the other sulcus is found on the posterior face of the heart (the **posterior interventricular sulcus**).

Coronary Arteries

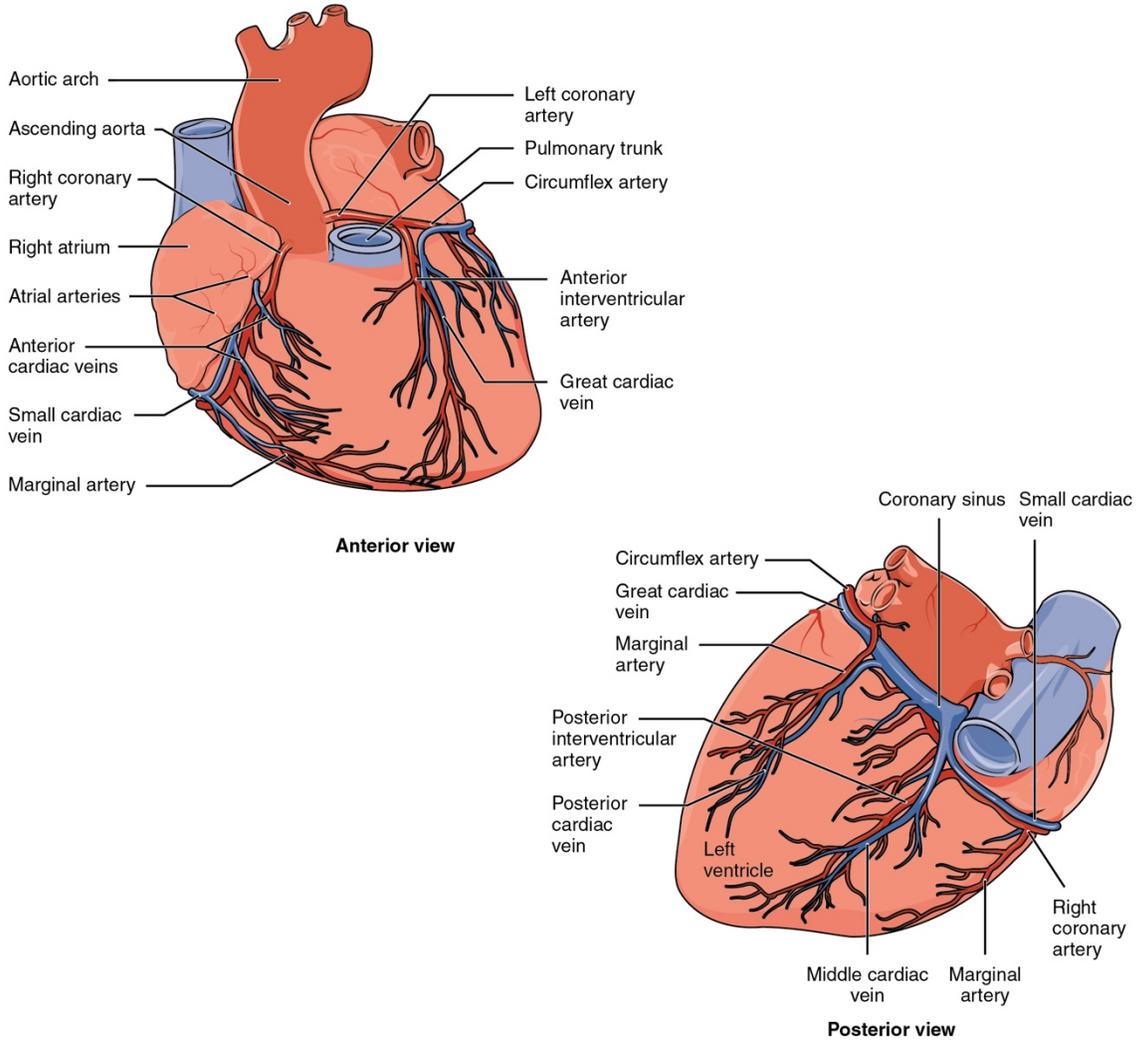
The coronary arteries – one right, and one left - branch off the base of the aorta very close to the heart itself. They deliver oxygenated blood to the heart muscle. The **right coronary artery** travels in the right atrioventricular sulcus along the right side of the heart. It branches into at least one marginal artery, then ends as the posterior interventricular artery, on the posterior side of the heart. The right coronary artery delivers blood to the right atrium, parts of both ventricles, and the conduction system of the heart.

The **left coronary artery** travels in the left atrioventricular sulcus, along the left side of the heart. It divides quickly into the anterior ventricular artery (sometimes called the left anterior descending artery), which travels toward the apex of the heart in the anterior interventricular sulcus. The other branch is the circumflex artery, which continues to circumnavigate the heart in the atrioventricular sulcus. The left coronary artery provides oxygenated blood to the anterior heart, the posterior left ventricle and the left atrium. Eventually the small branches of the right and left coronary arteries will fuse in anastomoses.

Coronary Veins

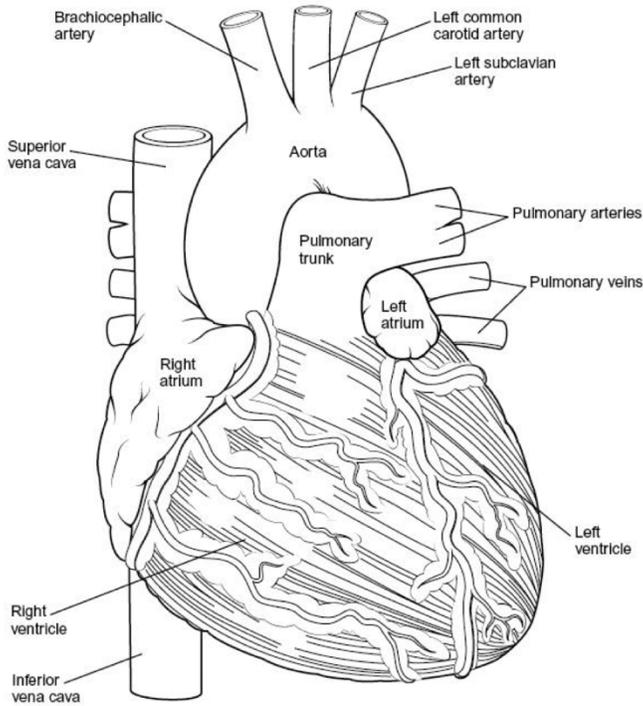
Deoxygenated blood from the heart muscle is drained by three main coronary veins: **the small cardiac vein**, near the right coronary artery; **the middle cardiac vein**, located near the posterior interventricular artery; and **the great cardiac vein**, located near the anterior ventricular artery in the anterior interventricular sulcus. All three major cardiac veins drain blood into the **coronary sinus**, a thin-walled vessel found on the posterior surface of the heart. The coronary sinus drains blood to the right atrium.

Figure 19.15 in the OpenStax text presents views of the coronary circulation from both the anterior and posterior views.

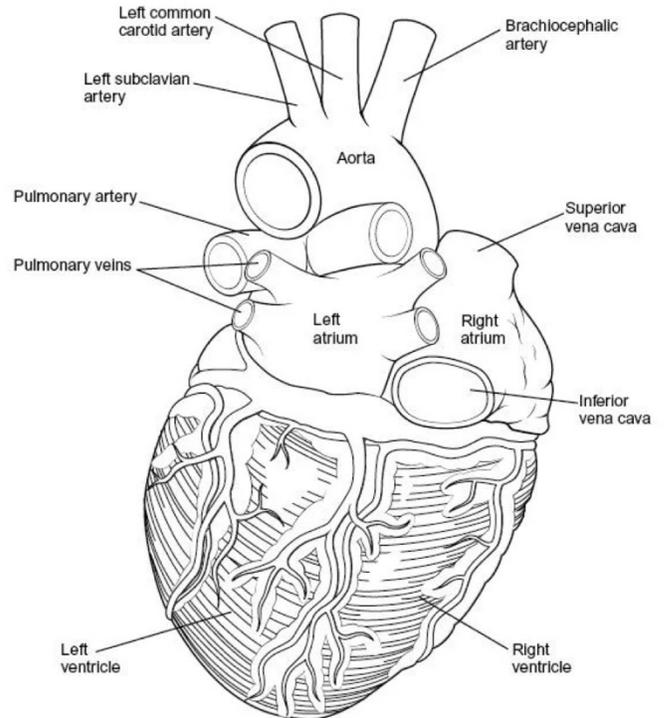


Activity 6 - Labeling the coronary vessels.

On the below pictures, label the right and left coronary arteries, the marginal artery, the posterior interventricular artery, the circumflex artery, the anterior interventricular artery, the small / middle / great cardiac veins and the coronary sinus. Label the arteries RED and the veins BLUE. (If you're completing this activity in Lt, this will be a drag-and-drop activity.)



<https://emedicine.medscape.com/article/905502-overview>



<https://emedicine.medscape.com/article/905502-overview>

Activity 7 – Summary of coronary circulation.

Fill in the below table with the details of the coronary circulation.

Coronary Arteries	Description (location, course, nearby anatomical structures that pinpoint this vessel)	Branches / regions of the heart supplied with blood
Right coronary artery		
Left coronary artery		
Cardiac Veins	Description	Regions of the heart drained
Great cardiac vein		
Middle cardiac vein		
Small cardiac vein		
Coronary sinus		

Activity 8 - Sheep heart dissection.

Note – Gloves, safety glasses and lab coats are required. Be sure you follow your TA's instructions. The dissecting tools are sharp! Be careful when cutting your specimen.

A wonderful dissection guide can be found here:

https://www.biologycorner.com/worksheets/heart_dissection.html

Equipment

- dissecting pan,
- dissecting tools (knife or scalpel; blunt probes; scissors)
- gloves
- preserved sheep or pig heart

Procedure

1. Orient yourself to the superficial aspect of the heart first. Many preserved specimens have fat associated with them, making the features difficult to see (unlike models). If the fibrous pericardium is intact, slit it open with a scalpel or cut it with scissors, then cut it from the attachments. Note how the visceral pericardium differs from the parietal pericardium.
2. Examine the external surface of the heart. Determine which side is superior (broad, with large blood vessels issuing from it) and which side is inferior (the apex is pointed). Next, determine which side is anterior. Locate the **pulmonary trunk**. This large vessel delivers blood to the lungs from the right side of the heart. It can be found in the middle of the anterior side of the heart.
3. Once you've distinguished anterior from posterior aspects of the heart, you should locate the **auricles**, the puppy-ear-shaped external extensions of the atria. The rest of the heart will be the **ventricles**. With your gloved hands you may be able to distinguish between the right and left ventricles – the right ventricle is smaller and thinner-walled, and will feel flabby when you squeeze it. You should also be able to feel with fingers the **interventricular sulcus** (but it may be filled with fat). The **atrioventricular sulci** can also be felt just underneath the auricles on each side.

4. Using a large dissecting knife, make a single cut through the ventricle up to the atria / base of the heart, so that the heart is divided into anterior and posterior halves. Open the two halves (or, if you've cut completely through the heart, separate the two halves) so that you can observe the internal features of the heart. Identify the **AV valves (bicuspid and tricuspid)** and their features, including the **chordae tendineae** and their attachment to the **papillary muscles**. Within the walls of the ventricles, you should be able to see and feel the **trabeculae carneae**, or muscular ridges that are distinct from the papillary muscle. The thick **interventricular septum** between the **right and left ventricles** should be very evident. Note that the walls of the left ventricle are much thicker than those of the right ventricle. In the atria, you may be able to see and feel the ridges of the **pectinate muscles**.

5. When your dissection has been inspected by your TA, discard your specimen in the biohazard waste container. Wash and dry your tray and instruments, and clean your bench area.

Create or upload a picture of your dissected sheep heart. On your image, label the right and left ventricles, the right and left atria, the bicuspid and tricuspid valves, the papillary muscles, the chordae tendineae, the interventricular septum, the pulmonary trunk and the aorta.

Activity 9 - Tracing bloodflow through the heart

Beginning with a drop of blood in the superior / inferior vena cavae, trace the pathway taken by a drop of blood as it travels throughout the body. Include as many heart chambers, great vessels, and valves as you can. You will end at the AORTA.

Exit Ticket: Before you leave lab today, read the following scenario and fill in the blanks.

Beginning with a drop of blood in the superior vena cava, trace the pathway taken by this drop of blood as it travels to the heart muscle of the left ventricle / interventricular septum, then returns to the superior vena cava. Identify as many vessels and structures (like heart valves) as you can.

Why might a blood clot in the left anterior descending artery lead to sudden death?

The Structure of the Cardiovascular System: Blood Vessels, Part 1

Introduction

In this laboratory, you will use models, diagrams and histological samples/ images to study the structure of blood vessels. You'll examine the differences between the pulmonary (delivering blood to and from the lungs) and systemic (delivering blood to and from the rest of the body) circuits, and trace bloodflow through both. You will also compare and contrast the structures of arteries, veins and capillaries and describe how their structure contributes to their function in the cardiovascular system.

Learning Objectives

By the end of this lesson you will be able to:

- Describe the microanatomy of blood vessel walls and the tissues that compose each, and to state the function of each layer
- Correlate differences in artery, vein and capillary structure with the functions of these vessels
- Recognize and differentiate an artery and a vein in cross-section on a slide, in a picture, on a diagram or on a model
- List or identify the major arteries branching from the aorta, and indicate the body region supplied by each (see the below table)
- List or identify the major veins draining to the superior or inferior vena cava, and the body region drained by each (see the below table)
- Compare and contrast pulmonary circulation from systemic circulation
- Describe "special" circulatory systems (the hepatic portal system, the circle of Willis, and fetal circulatory system – being sure to identify fetal circulatory features that are different from adult circulatory systems)

- To identify the following structures of importance:

Microanatomy of arteries, veins, and capillaries – Fig 20.3 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-1-structure-and-function-of-blood-vessels	
Tunica intima (or tunica interna)	
Tunica media	
Tunica externa	
Valves	
Arteries of head and neck - Figs. 20.26 – 20.27 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways	Veins of the head, neck and brain – Fig. 20.37 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways
Brachiocephalic trunk (artery)	Superior sagittal sinus
Subclavian artery	Internal jugular veins
Common carotid artery	Superficial temporal vein
External and internal carotid arteries	Facial vein
Facial artery	External and internal jugular veins
Superficial temporal artery	Brachiocephalic vein
Vertebral artery	Subclavian vein
	Superior vena cava
Arteries of the upper limb and thorax – Figs. 20.28 – 20.29, 20.31 – 20.32 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways	Veins of the thorax, upper limb and shoulder – Figs. 20.36 – 20.39 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways
Brachiocephalic trunk (artery)	Radial vein
Subclavian artery	Ulnar vein
Axillary artery	Median antebrachial vein
Brachial artery	Median cubital vein
Radial artery	Basilic vein
Ulnar artery	Cephalic vein
Aortic arch	Brachial vein
Descending aorta	Axillary vein
	Subclavian veins
Arteries of the abdomen – Figs. 20.29 – 20.30 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways	Brachiocephalic veins
Celiac trunk	Superior vena cava
Splenic artery	Inferior vena cava
Common hepatic artery	Azygos vein
Left gastric artery	Hemiazygos vein
Hepatic artery proper	

Arteries of the abdomen (continued)	
Superior mesenteric artery	Veins of the abdomen – Fig. 20.36 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways
Inferior mesenteric artery	Hepatic veins
Renal arteries	Renal veins
Gonadal arteries (testicular or ovarian)	Left and right gonadal vein
Common iliac arteries	Common iliac vein
	External and internal iliac veins
Arteries of the pelvis and lower limb – Figs. 20.29 – 20.30. 20.33 – 20.34 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways	Veins of the lower limb – Figs. 20.41 – 20.42 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways
External and internal iliac arteries	Dorsalis pedis vein
Femoral artery	Anterior tibial vein
Popliteal artery	Posterior tibial vein
Anterior tibial artery	Fibular or peroneal vein
Posterior tibial artery	Popliteal vein
Fibular artery	Femoral vein
Dorsalis pedis artery	Great saphenous vein
	External and internal iliac vein
	Common iliac vein

Special Circulatory Systems	
Pulmonary circulation – Fig. 20.23 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways	Hepatic portal circulation – Fig. 20.43 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways
Right and left atria	Hepatic portal vein
Right and left ventricles	Splenic vein
Pulmonary trunk	Inferior mesenteric vein
Right and left pulmonary arteries	Superior mesenteric vein
Pulmonary veins	Hepatic veins
Fetal circulation – Fig. 20.44 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways	Circulation to the brain (Circle of Willis) – Figs. 20.26 – 20.27 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways
Superior and inferior vena cavae	Circle of Willis
Aorta, aortic arch and descending aorta	Internal carotid arteries
Pulmonary trunk, pulmonary arteries and veins	Anterior cerebral arteries
Hepatic portal vein	Anterior communicating artery
Umbilical arteries and veins	Posterior communicating artery
Ductus arteriosus	Posterior cerebral arteries
Ligamentum arteriosum	Basilar artery
Foramen ovale	Vertebral artery
Fossa ovalis	
Ductus venosus	
Ligamentum venosum	
Ligamentum teres	

Background Information

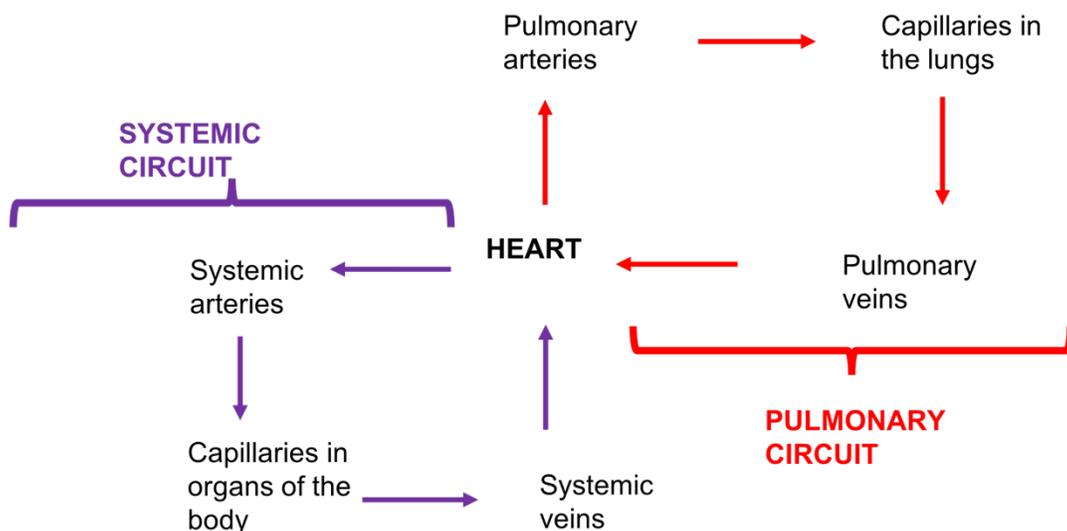
OVERVIEW

Blood vessels are mostly tubular passageways that carry blood throughout the body, forming a closed circuit (meaning that blood does not exit the body). Blood is pumped from the heart through the **arteries** to organs. As arteries travel throughout the body, they branch into progressively smaller vessels. In the organs, the smallest vessels are called capillaries and are the sites of gas, nutrient and waste exchange: oxygen and nutrients pass out of the capillary into the tissue, while waste products pass into the capillary. Capillaries drain blood to the larger venules, which converge to become larger veins. Blood returns to the heart by way of **veins**.

Blood that is pumped from the heart and travels to the lungs by way of the pulmonary trunk / pulmonary arteries, where it is oxygenated. It then returns to the heart via pulmonary veins to be pumped to the rest of the body.

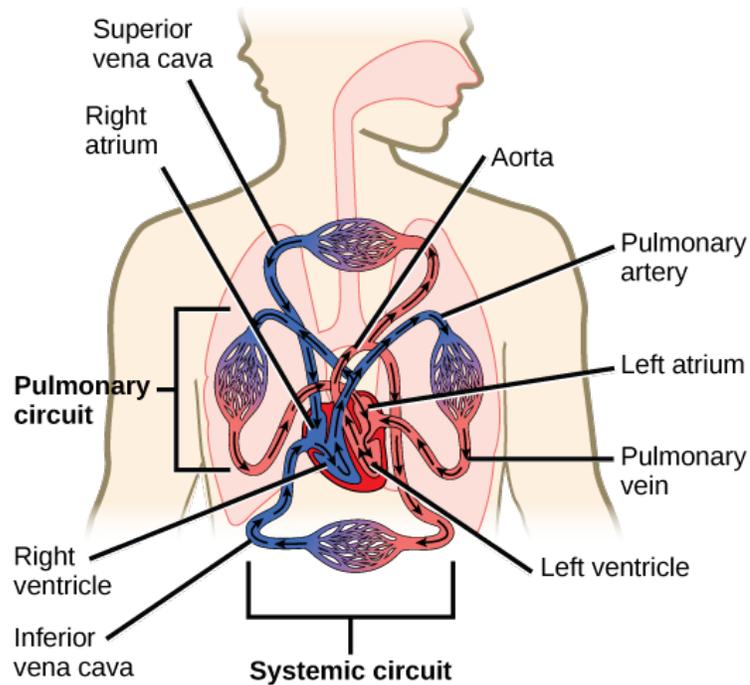
The **pulmonary circuit** is the system of blood vessels (arteries, veins, capillaries) that allow bloodflow between the heart and the lungs. The **systemic circuit** is the system of blood vessels (arteries, veins, capillaries) that allow bloodflow between the heart and the rest of the body.

Starting at the heart, a generalized scheme of bloodflow throughout the body might look something like this...



The below image from LumenLearning puts the systemic and pulmonary circuits into the context of the human body. See the link:

https://courses.lumenlearning.com/suny-osbiology2e/chapter/mammalian-heart-and-blood-vessels/#fig-ch40_03_01



The systemic circuit can be further subdivided into the coronary circulation, the hepatic portal circulation, the fetal circulation (a circulatory route seen only in the fetus), and the Circle of Willis (a circulatory route in the brain). We'll be discussing the unique features associated with these special circulatory routes separately.

Histology and Structure of Different Types of Vessels
Common Design of the Blood Vessel Wall

Arteries and veins have a common design in the structure of the vessel walls. Modifications of this common design are responsible for vessels with different structures and functions. Both types of vessels have three tissue layers or tunics. From innermost to outermost, these layers are called tunica intima, tunica media, and tunica externa.

The **tunica intima** (sometimes called tunica interna) is composed of endothelium (a specialized thin layer of flattened cells that is continuous with the endothelium in the heart) and a thin acellular basement membrane. The flattened endothelium cells help regulate bloodflow and permeability in the vessel, while providing a slick surface that discourages cells in the blood from sticking to it. The basement membrane anchors the endothelium to the underlying tissue. A third layer, the internal elastic lamina, regulates the movement of substances through the tunica interna.

The tunica media, or middle layer, is composed mostly of smooth muscle and elastic fibers. The smooth muscle fibers are arranged circularly around the vessel wall: constriction of these fibers decreases the diameter of the vessel. The elastic fibers allow the vessel wall to stretch and recoil in response to the pressure of the blood inside. Another thin sheet of elastic fibers called the external elastic lamina separates the tunica media from the tunica externa. Variations in this muscular layer structure account for differences in the functions of various vessels.

The outermost **tunica externa** is composed of connective tissue with collagen and elastic fibers. It anchors the wall of the vessel to the surrounding tissues. In large vessels, the tunica externa is the site of nerves and tiny blood vessels that supply blood to the tissues in the vessel wall (the vasa vasorum, or “vessel of the vessel”). The vasa vasorum are analogous to the coronary vessels of the heart: both provide oxygenated blood to the organs of the cardiovascular system.

The below image from OpenStax (Figure 20.3) demonstrates the general organization of the three layers, or tunics, of the walls of blood vessels. See the link:

<https://cnx.org/contents/FPtK1znh@16.7:WNsszrPZ@8/20-1-Structure-and-Function-of-Blood-Vessels>

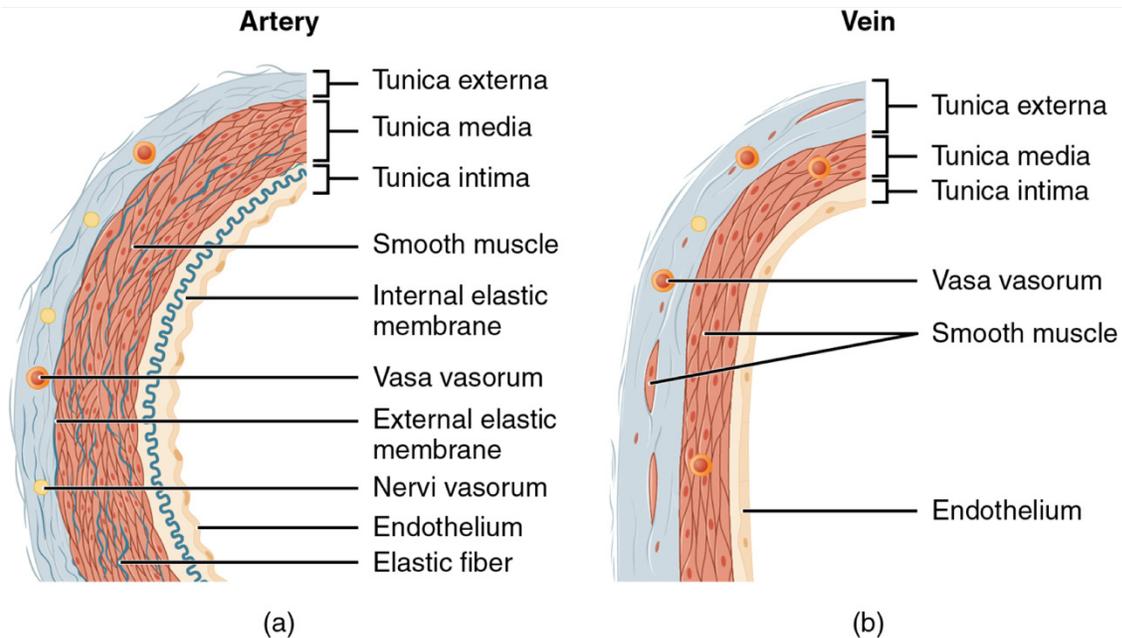


Figure 20.3 Structure of Blood Vessels (a) Arteries and (b) veins share the same general features, but the walls of arteries are much thicker because of the higher pressure of the blood that flows through them. (c) A micrograph shows the relative differences in thickness. LM \times 160. (Micrograph provided by the Regents of the University of Michigan Medical School \copyright 2012)

Types of blood vessels

Elastic arteries

Elastic arteries are found closest to the heart, and are the largest arteries in the body. Examples of elastic arteries include the aorta, the pulmonary trunk, and the major early branches off the aorta (brachiocephalic, left common carotid, left subclavian). Although the diameter of elastic arteries is large, the walls of these vessels are relatively thin. These vessels have a thick tunica media where elastic fibers predominate, and the internal / external elastic laminae are well-defined. When blood is pumped into the elastic arteries from the heart, the walls stretch easily to accommodate it. The stretched vessel walls then recoil, like a rubber band that is stretched and released, to continue to propel the blood in the vessel independent of the heartbeat. This ensures that blood will continue to move in the arteries.

Muscular arteries

Muscular arteries are medium-sized vessels located distally to the elastic arteries. Their diameter is smaller than elastic arteries, but because the vessel wall is thicker it makes up a larger percentage of the overall diameter. The tunica media in muscular arteries is composed of more smooth muscle and fewer elastic fibers than elastic arteries. This means that the walls of muscular arteries are fairly rigid and cannot recoil to push blood through the vessels. It also means that these vessels keep their shape better when they are prepared for microscopic examination. The smooth muscle layers found in these vessels are responsible for constriction (narrowing) of the vessel, which further stiffens the wall and promotes efficient bloodflow. The outermost tunica externa is also thick in these vessels and may contain nerves and vasa vasorum.

Arterioles

Arterioles are tiny vessels (diameter = 15um – 300um) that deliver blood into the capillary networks throughout the body. All three layers of the vessel wall are thin, but because the overall diameter is small, the wall thickness represent approximately half the diameter. Although there are only two layers of smooth muscle fibers in the tunica media of these vessels, they are very sensitive to nervous stimulation and constrict / relax readily. The very large number of arterioles in the body means that constriction and dilation of these vessels contributes substantially to the overall blood pressure.

Venules

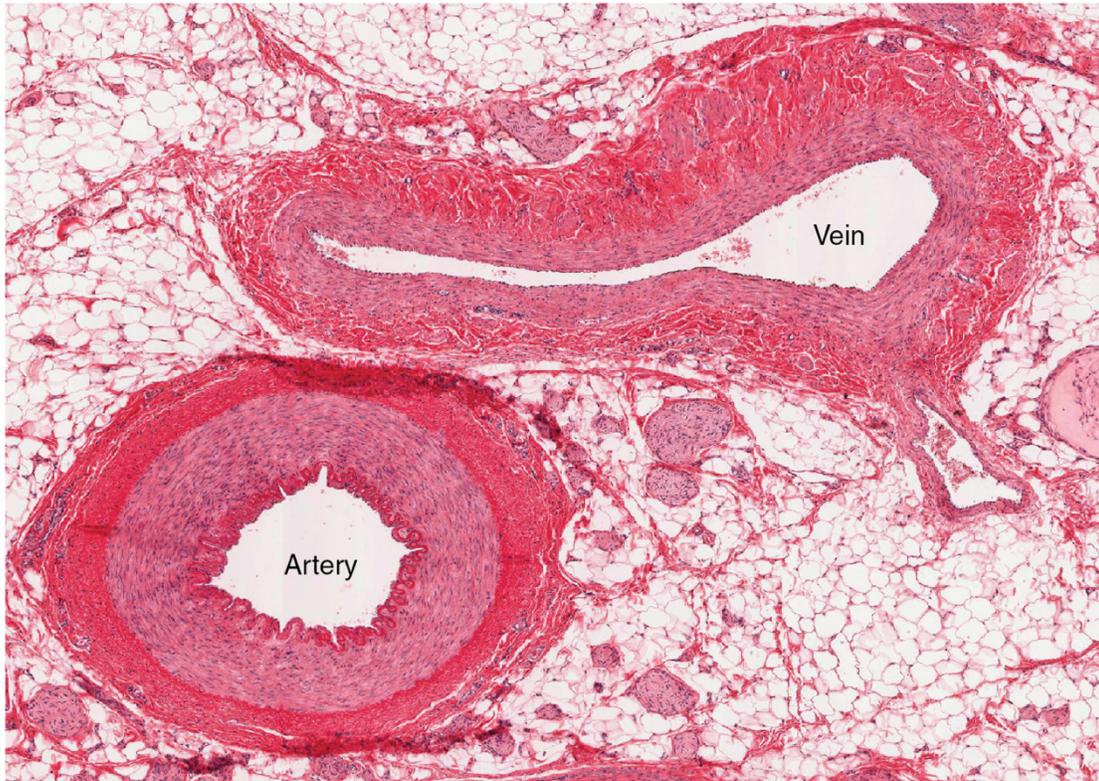
Venules are small venous counterparts to arterioles, ranging in size from 50um – 100um. Venules receive blood from capillary beds in tissues and organs. The layers of the vessel wall are thin and distensible, making them reservoirs for the blood in the body.

Veins

Although veins are larger than venules, the structure differences between them is small. The three layers comprising the wall of the vein are thin, making them distensible. The tunica media has only a few layers of smooth muscle cells, so veins often appear flattened or misshapen when viewed under a microscope. Many veins have **valves** that are composed of endothelium, the same tissue found in the innermost tunica interna. Veins are proximal to venules, receiving blood from them and emptying into the superior or inferior vena cavae in the systemic circuit.

Activity 1 – Common features of blood vessel structure.

Label the tunica interna, tunica media and tunica externa in both vessels below.



(c)

<https://opentextbc.ca/anatomyandphysiology/chapter/20-1-structure-and-function-of-blood-vessels/>

Activity 2 – Describe the blood vessel wall structure.

Fill in the table with a brief description of the tissue layers found in the walls of each vessel.
The last two rows ask for characteristics of the vessels in general.

	Arteries	Veins
Tunica intima		
Tunica media		
Tunica externa		
Direction of bloodflow (ie, toward the heart or away from the heart)		
Valves present?		

Exit Ticket: Before you leave lab today, answer the following questions.

Why are valves present in VEINS but not ARTERIES?

Why do arteries keep their round shape better than veins?

The Structure of the Cardiovascular System: Blood Vessels, Part 2

Axial Vessels of the Systemic Circuit

Introduction

In these laboratory exercises, you will use models, diagrams and preserved specimens to study the distribution of blood vessels throughout the body. Specifically, you'll be studying the largest vessels that take blood away and return it to the heart (the **aorta** and the **vena cavae**), and the smaller vessels that branch from them.

Learning Objectives

By the end of this lesson you will be able to:

- Describe the microanatomy of blood vessel walls and the tissues that compose each, and to state the function of each layer
- Correlate differences in artery, vein and capillary structure with the functions of these vessels
- Recognize and differentiate an artery and a vein in cross-section on a slide, in a picture, on a diagram or on a model
- List or identify the major arteries branching from the aorta, and indicate the body region supplied by each (see the below table)
- List or identify the major veins draining to the superior or inferior vena cava, and the body region drained by each (see the below table)
- Compare and contrast pulmonary circulation from systemic circulation
- Describe "special" circulatory systems (the hepatic portal system, the circle of Willis, and fetal circulatory system – being sure to identify fetal circulatory features that are different from adult circulatory systems)

- To identify the following structures of importance:

Microanatomy of arteries, veins, and capillaries – Fig 20.3 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-1-structure-and-function-of-blood-vessels	
Tunica intima (or tunica interna)	
Tunica media	
Tunica externa	
Valves	
Arteries of head and neck - Figs. 20.26 – 20.27 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways	Veins of the head, neck and brain – Fig. 20.37 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways
Brachiocephalic trunk (artery)	Superior sagittal sinus
Subclavian artery	Internal jugular veins
Common carotid artery	Superficial temporal vein
External and internal carotid arteries	Facial vein
Facial artery	External and internal jugular veins
Superficial temporal artery	Brachiocephalic vein
Vertebral artery	Subclavian vein
	Superior vena cava
Arteries of the upper limb and thorax – Figs. 20.28 – 20.29, 20.31 – 20.32 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways	Veins of the thorax, upper limb and shoulder – Figs. 20.36 – 20.39 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways
Brachiocephalic trunk (artery)	Radial vein
Subclavian artery	Ulnar vein
Axillary artery	Median antebrachial vein
Brachial artery	Median cubital vein
Radial artery	Basilic vein
Ulnar artery	Cephalic vein
Aortic arch	Brachial vein
Descending aorta	Axillary vein
	Subclavian veins
Arteries of the abdomen – Figs. 20.29 – 20.30 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways	Brachiocephalic veins
Celiac trunk	Superior vena cava
Splenic artery	Inferior vena cava
Common hepatic artery	Azygos vein
Left gastric artery	Hemiazygos vein

Hepatic artery proper	
Arteries of the abdomen (continued)	
Superior mesenteric artery	Veins of the abdomen – Fig. 20.36 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways
Inferior mesenteric artery	Hepatic veins
Renal arteries	Renal veins
Gonadal arteries (testicular or ovarian)	Left and right gonadal vein
Common iliac arteries	Common iliac vein
	External and internal iliac veins
Arteries of the pelvis and lower limb – Figs. 20.29 – 20.30. 20.33 – 20.34 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways	Veins of the lower limb – Figs. 20.41 – 20.42 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways
External and internal iliac arteries	Dorsalis pedis vein
Femoral artery	Anterior tibial vein
Popliteal artery	Posterior tibial vein
Anterior tibial artery	Fibular or peroneal vein
Posterior tibial artery	Popliteal vein
Fibular artery	Femoral vein
Dorsalis pedis artery	Great saphenous vein
	External and internal iliac vein
	Common iliac vein

Special Circulatory Systems	
Pulmonary circulation – Fig. 20.23 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways	Hepatic portal circulation – Fig. 20.43 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways
Right and left atria	Hepatic portal vein
Right and left ventricles	Splenic vein
Pulmonary trunk	Inferior mesenteric vein
Right and left pulmonary arteries	Superior mesenteric vein
Pulmonary veins	Hepatic veins
Fetal circulation – Fig. 20.44 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways	Circulation to the brain (Circle of Willis) – Figs. 20.26 – 20.27 the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways
Superior and inferior vena cavae	Circle of Willis
Aorta, aortic arch and descending aorta	Internal carotid arteries
Pulmonary trunk, pulmonary arteries and veins	Anterior cerebral arteries
Hepatic portal vein	Anterior communicating artery
Umbilical arteries and veins	Posterior communicating artery
Ductus arteriosus	Posterior cerebral arteries
Ligamentum arteriosum	Basilar artery
Foramen ovale	Vertebral artery
Fossa ovalis	
Ductus venosus	
Ligamentum venosum	
Ligamentum teres	

Background Information

Overview of the Axial Blood Vessels

The systemic circuit delivers oxygenated blood from the heart to the other organs of the body via a system of arteries. The arteries closest to the heart are large, and the vessels become progressively smaller as they diverge and travel further away from the heart. After delivery of oxygen and nutrients to the organs of the body, the now-deoxygenated blood is returned to the heart via a system of veins. The veins that are furthest from the heart are smaller and converge to form larger vessels as they travel toward the heart. We will divide our discussion into axial vessels (those serving the organs of the thoracic and abdominal cavities), appendicular vessels (those serving the upper and lower limbs), and special circulatory routes (vessels that serve the liver and digestive system, the brain, and the fetus).

Major Axial Arteries

Aorta

The discussion of the major arteries of the body begins with the aorta, which begins at the left ventricle. Blood pumped from the left ventricle must pass through the aortic semilunar valve before entering the vessel.

The aorta ascends superiorly after leaving the left ventricle, then makes a turn to descend inferiorly and toward the left side in the thoracic cavity, behind or posterior to the heart. The part of the aorta found in the thoracic cavity can be described either as the ascending aorta, the aortic arch, or the descending aorta.

The below image (Figure 20.25) from OpenStax shows the regions of the thoracic aorta and its major branches. See the link:

<https://cnx.org/contents/FPtK1zmh@16.5:GqYHW4Z4@7/20-5-Circulatory-Pathways>

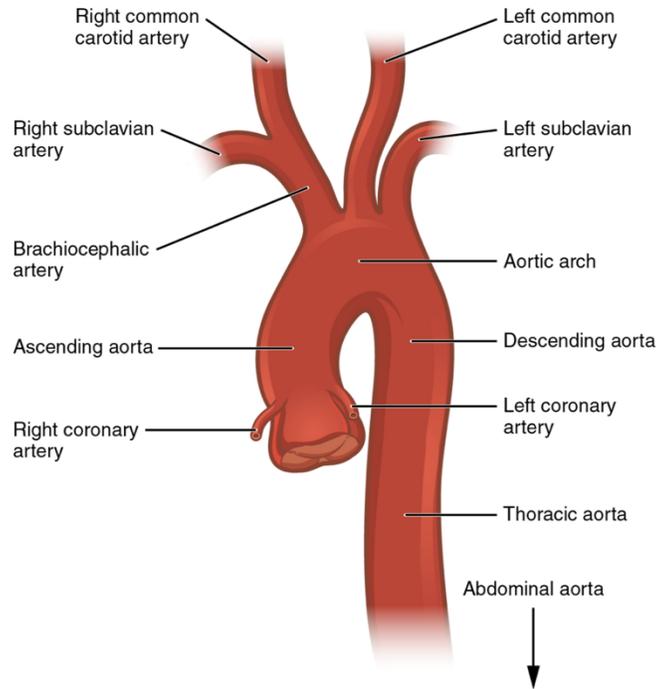


Figure 20.25 Aorta The aorta has distinct regions, including the ascending aorta, aortic arch, and the descending aorta, which includes the thoracic and abdominal regions.

Branches off the thoracic aorta / aortic arch

The first two vessels that branch off the aorta are the **right and left coronary arteries**. They deliver oxygenated blood to the heart muscle and were discussed as part of the exercise on the heart. The coronary arteries branch off the aorta very close to the heart. From the aortic arch, there are three important vessels that branch off: the **brachiocephalic trunk (artery)**, the **left common carotid artery**, and the **left subclavian artery**. The left and right descriptors are important because they describe the course of the vessel (to the right side or to the left side of the body). You can see them in the figure above.

In addition to these major arteries that branch off the thoracic aorta, there are numerous intercostal arteries that course between the ribs and deliver oxygenated blood to the muscles of the thoracic wall, and several small arteries (for example, bronchial, esophageal, mediastinal) that deliver oxygenated blood to the organs there.

Circulation to the Head and Neck

The arteries that deliver oxygenated blood to the head arise primarily from the **left and right common carotid arteries**. The left common carotid artery is one of the major branches off the aorta, as discussed above. The right common carotid artery branches off of the brachiocephalic trunk. The right and left common carotid arteries follow a similar course: both divide into the **internal and external carotid arteries**. The external carotid arteries, both right and left, have several branches including the **facial and occipital arteries**, and bifurcates to terminate as the **superficial temporal artery and the maxillary artery**. The internal carotid arteries, both right and left, course into the skull through the carotid canals in the skull, and are important in supplying oxygenated blood to the brain.

A second important set of arteries that deliver blood to the brain are the **vertebral arteries**. The **right and left vertebral arteries** are branches from the **right and left subclavian arteries** that ascend through the neck in the transverse foramen of the vertebrae, eventually entering the skull through the large foramen magnum.

The below image from OpenStax (Figure 20.26) shows the arteries delivering blood to the head and neck on the right side. See the link:

<https://cnx.org/contents/FPtK1zmh@16.5:GqYHW4Z4@7/20-5-Circulatory-Pathways>

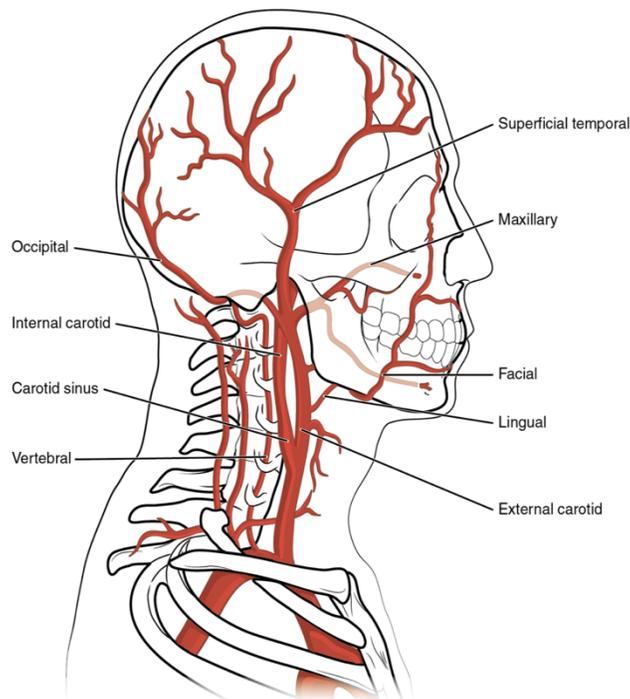


Figure 20.26 Arteries Supplying the Head and Neck The common carotid artery gives rise to the external and internal carotid arteries. The external carotid artery remains superficial and gives rise to many arteries of the head. The internal carotid artery first forms the carotid sinus and then reaches the brain via the carotid canal and carotid foramen, emerging into the cranium via the foramen lacerum. The vertebral artery branches from the subclavian artery and passes through the transverse foramen in the cervical vertebrae, entering the base of the skull at the vertebral foramen. The subclavian artery continues toward the arm as the axillary artery.

Circulation to the Abdomen

After passing through the diaphragm, the thoracic aorta becomes the **abdominal aorta**. Several major vessels branch off of the abdominal aorta, some paired (having left and right branches) and some unpaired. The **celiac trunk** is the most superior of these branches. The celiac trunk quickly divides into three vessels that deliver blood to several organs in the abdominal cavity: the common hepatic artery, the splenic artery and the left gastric artery, delivering blood to the liver / gallbladder, the the spleen, and the stomach / esophagus, respectively. The **superior mesenteric artery** travels through the mesentery of the small intestine and delivers blood to the small intestine and the first part of the large intestine. The **right and left suprarenal arteries** supply the adrenal glands with blood; **the right and left renal arteries** deliver blood to the kidneys, and the nearby **right and left gonadal arteries** deliver blood to the testes (in males) or ovaries (in females). The **inferior mesenteric artery** is the most inferior branch off the abdominal artery, and it delivers blood to the bulk of the large intestine and rectum.

The below image from OpenStax (Figure 20.28) shows the anterior view of the abdominal aorta and its branches. See the link:

<https://cnx.org/contents/FPtK1zmh@16.5:GqYHW4Z4@7/20-5-Circulatory-Pathways>

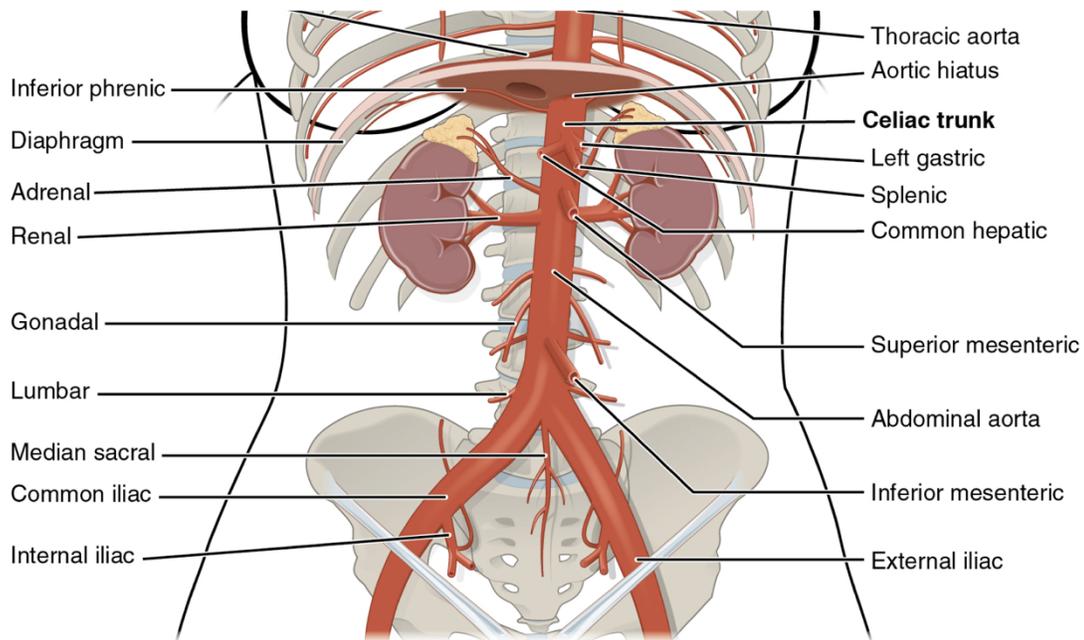
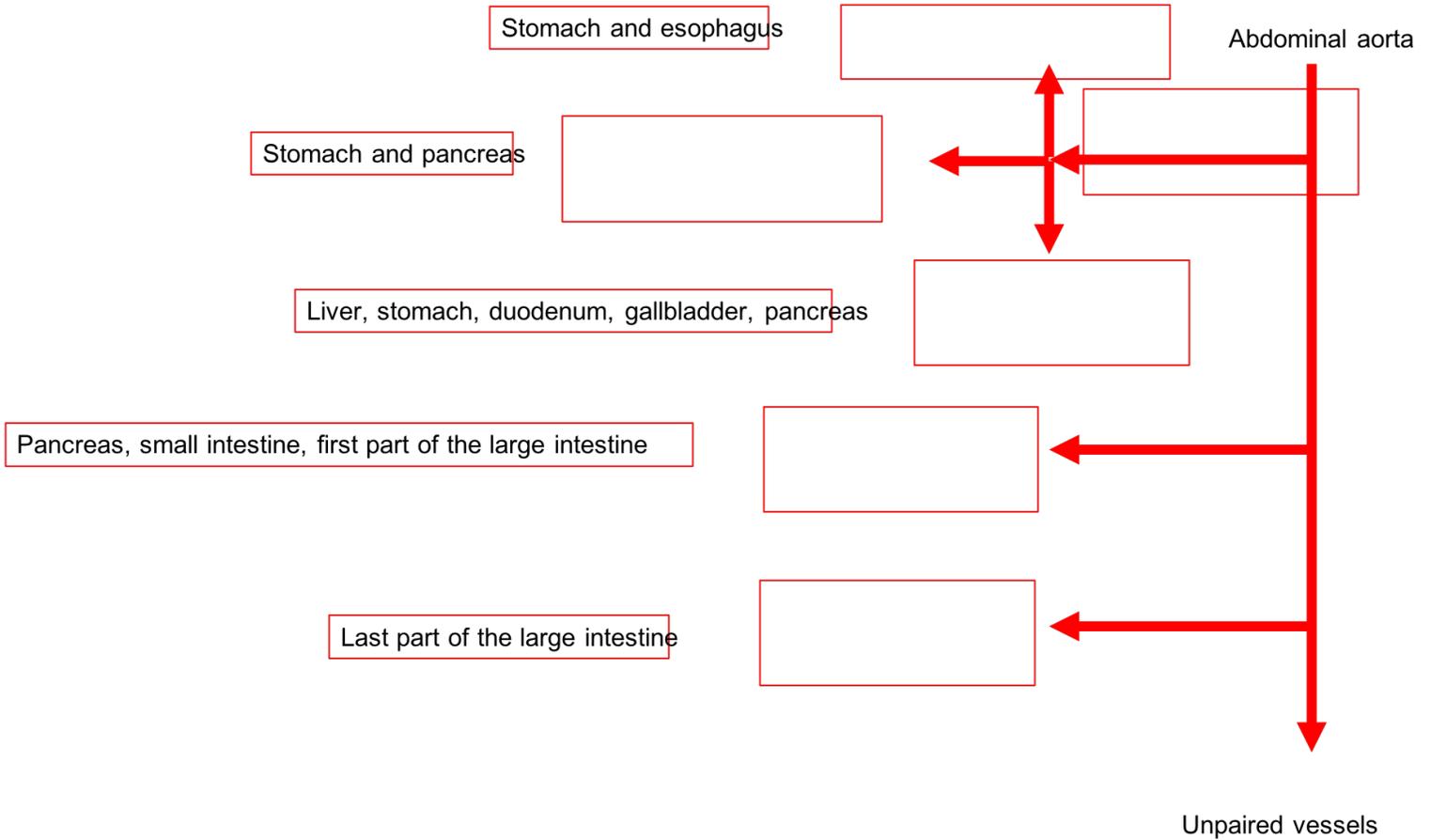


Figure 20.28 Arteries of the Thoracic and Abdominal Regions The thoracic aorta gives rise to the arteries of the visceral and parietal branches.

The abdominal aorta terminates inferiorly when it bifurcates into the **left and right common iliac arteries**, which ultimately deliver blood to the lower limbs.

Activity 2 – Unpaired arteries in the abdomen.

Fill in the boxes with the names of the UNPAIRED vessels that branch from the abdominal aorta.



Major Axial Veins

Inferior Vena Cava

The veins drain deoxygenated blood from organs of the body and returns it to the heart. The superior and inferior vena cavae are the largest veins in the body, and both drain blood into the right atrium. Deoxygenated blood from organs above the diaphragm returns to the heart by way of the superior vena cava, while blood from organs located below the diaphragm travels through the inferior vena cava.

Circulation from the Head and Neck

Most blood returning to the heart from the head travels via the **internal and external jugular veins**. From the capillaries in the brain, blood drains into the **dural sinuses** (the spaces between the layers of the dura mater of the skull), and then to the **left and right internal jugular veins**. Blood then travels to the **left and right brachiocephalic veins**, which join to form the **superior vena cava**. From the capillaries in the face and scalp, blood drains to the **left and right external jugular veins**, and from there to the **left and right subclavian veins**. The subclavian veins drain to the **brachiocephalic veins**, which are formed by the convergence of the subclavian and internal jugular veins. Blood in the superior vena cava returns to the right atrium.

The below diagram from OpenStax (Figure 20.37). shows the venous drainage from the head and neck on the right side. The deep sinuses are show in light blue, while the superficial vessels are darker.

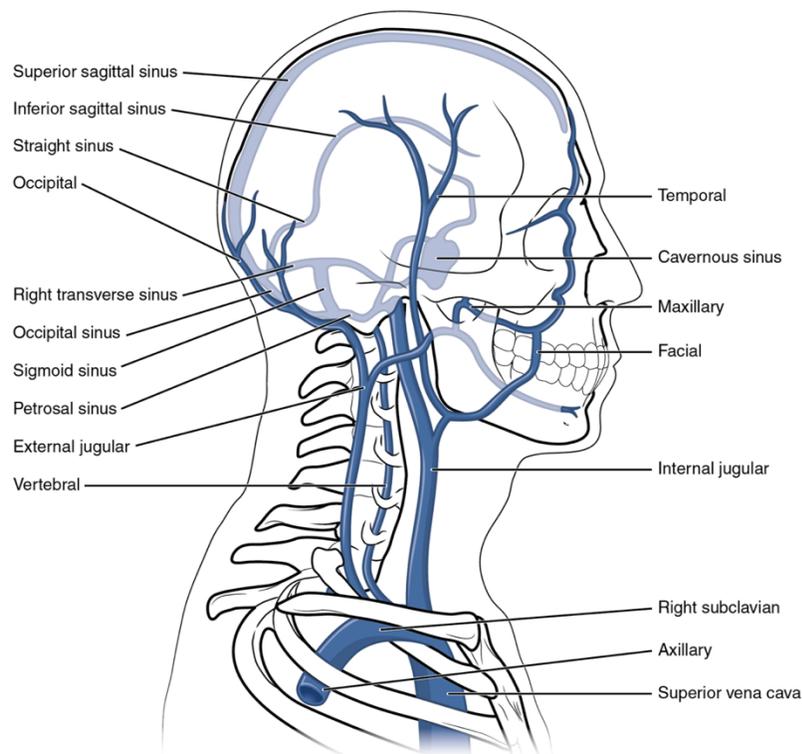
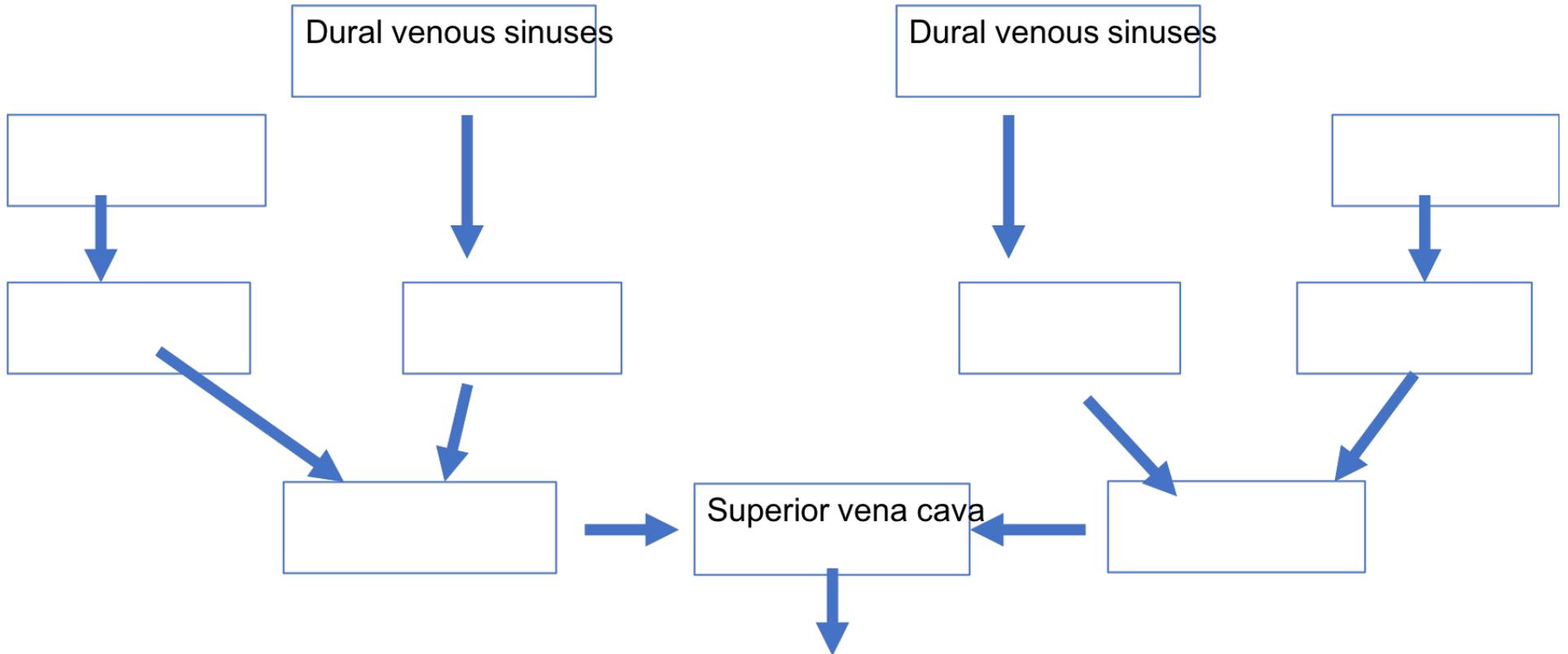


Figure 20.37 Veins of the Head and Neck This left lateral view shows the veins of the head and neck, including the intercranial sinuses.

Activity 3 – Bloodflow from the head and neck.

Fill in the boxes with the names of the vessels that drain blood from the head and neck to the superior vena cava.



Circulation from the Abdomen

Alternative Venous Drainage from the Thorax

Blood from organs other than the lungs and heart drain into the **azygos system**, which consists of three vessels: **the azygos vein**, located to the right of the vertebral column on the posterior thoracic wall; **the hemiazygos vein**, located on the right of the vertebral column on the posterior thoracic wall; and **the accessory hemiazygos vein**, also located to the right of the vertebral column, superior to the hemiazygos vein. These are unpaired veins that provide an alternative route for blood to return to the right atrium bypassing the inferior vena cava. The anatomy of the azygos system is variable in humans.

The azygos vein is formed by the convergence of the lumbar veins in the abdominal cavity, near the lumbar region of the vertebral column. It ascends through the diaphragm and converges with the brachiocephalic veins to form the superior vena cava. Thus, the azygos vein drains blood from the posterior walls of the abdomen and thorax to the right atrium by way of the superior vena cava.

The hemiazygos vein is the “left-sided counterpart” to the azygos vein, also originating in the lumbar veins of the right side of the abdominal cavity. After reaching the thorax, the hemiazygos vein may cross the midline (behind the aorta) to converge with the azygos vein before it becomes the superior vena cava, or it may be continuous with the accessory hemiazygos vein which drains blood from the superior portion of the thoracic cavity.

The accessory hemiazygos vein may drain blood to the brachiocephalic vein, or the azygos vein. The net result is a route allowing deoxygenated blood draining from the walls of the thorax, the abdomen, and some thoracic organs to return to the heart independent of the inferior vena cava.

The below image from OpenStax (modified from Figure 20.36) shows the azygos vein draining to the superior vena cava, and the hemiazygos vein draining both to the azygos vein and the unlabeled accessory hemiazygos vein. Follow the link:

<https://cnx.org/contents/FPtK1zmh@16.7:GqYHW4Z4@7/20-5-Circulatory-Pathways>

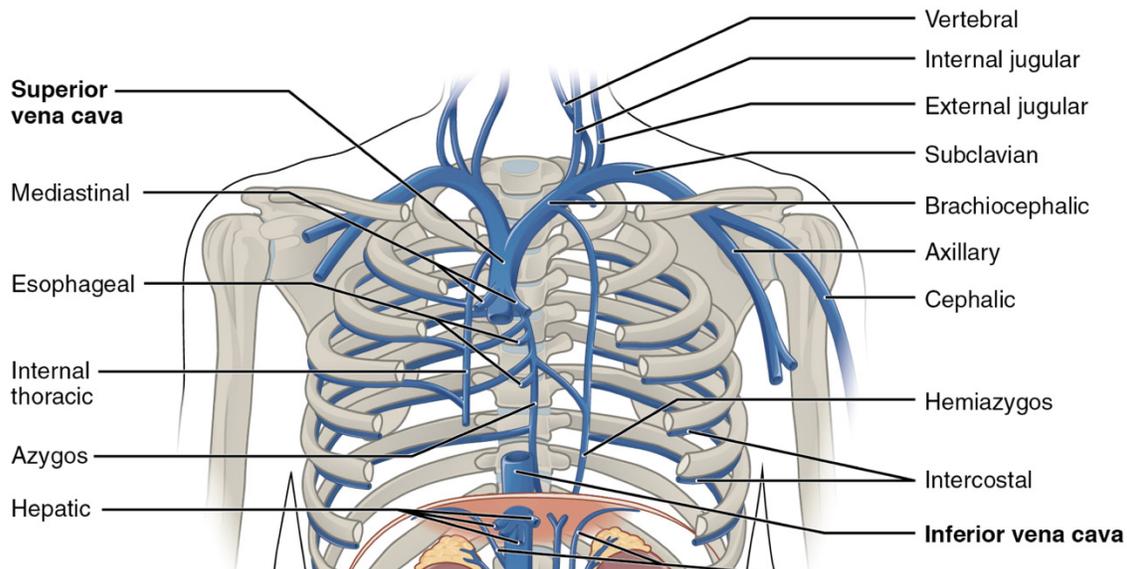


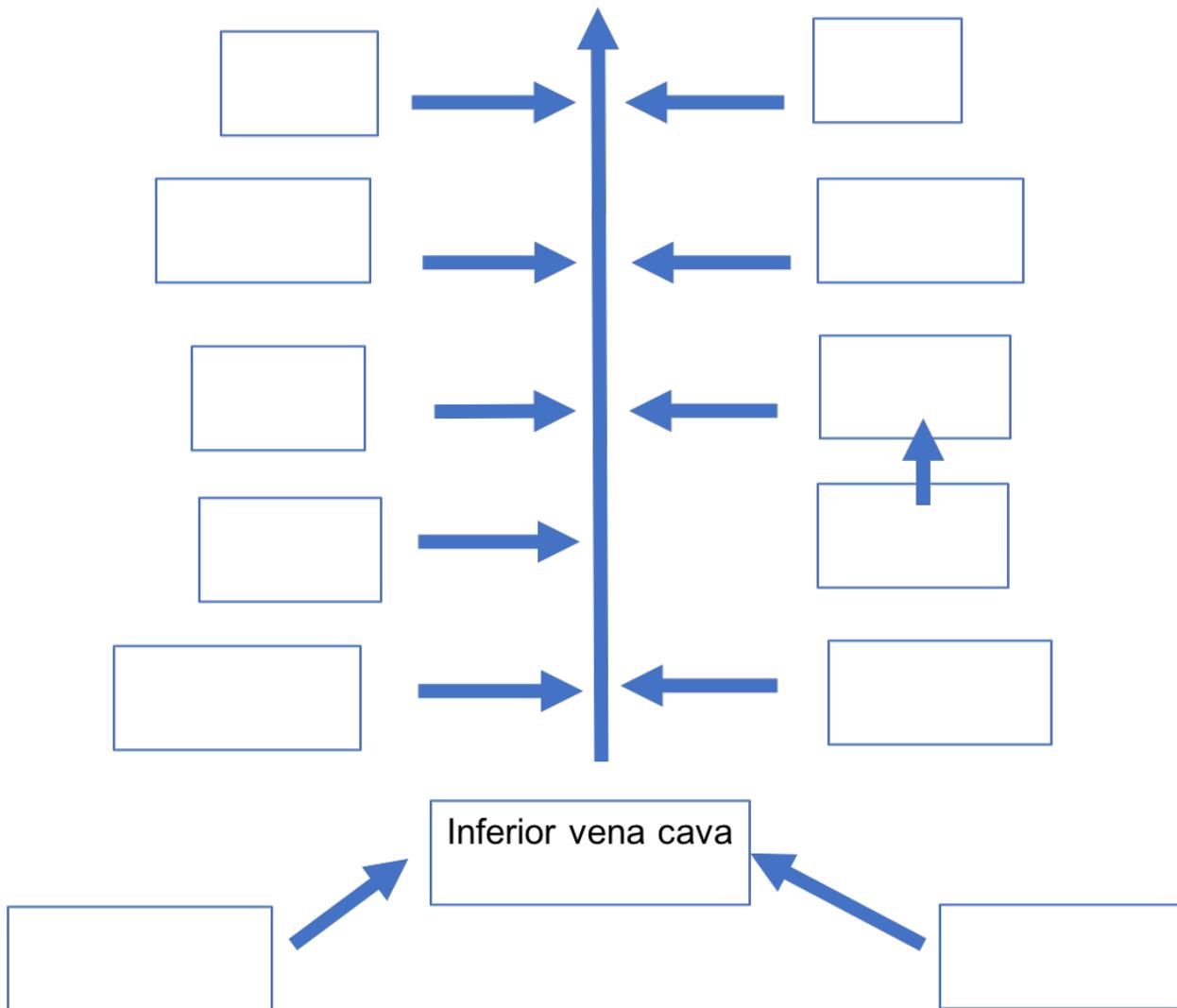
Figure 20.36 Veins of the Thoracic and Abdominal Regions Veins of the thoracic and abdominal regions drain blood from the area above the diaphragm, returning it to the right atrium via the superior vena cava.

Circulation from the Abdomen

Blood in the abdominal and pelvic cavities travels to the heart by way of the inferior vena cava. However, the inferior vena cava does not receive blood from the gastrointestinal organs – blood from the digestive tract passes through the liver first by way of a special circulatory route called the hepatic portal system. The inferior vena cava begins as the convergence of the common iliac veins, which drain blood from the lower limbs, external genitals and pelvis. The inferior vena cava ascends through the abdominal cavity just to the right of the vertebral column. A series of small, mostly paired vessels drain blood into the inferior vena cava, including the lumbar veins (which are also the origin of the azygos vein, discussed above), **gonadal veins**, **renal veins**, **suprarenal veins** and **hepatic veins** (which may number two or three). The **gonadal veins**, called testicular veins in males and ovarian veins in females, drain blood from the testes or ovaries. The right gonadal vein drains blood directly into the inferior vena cava, while the left gonadal vein delivers blood to the left renal vein. The **renal veins** empty into the vena cava, draining blood from the kidneys. The **suprarenal veins** drain blood from the adrenal glands. The **hepatic veins** (which should not be confused with the hepatic portal vein) drain blood from the capillary beds in the liver to the inferior vena cava just inferior to the diaphragm.

Activity 4 – Bloodflow from the abdomen.

Fill in the boxes with the vessels that drain blood from the organs in the abdominal cavity (excepting the digestive system organs).



Exit Ticket: Before you leave lab today, trace the flow of blood through the specified organs.

Trace the flow of blood through the heart, to the kidney, and back to the heart. Start and end at the RIGHT ATRIUM. Name as many vessels, structures, chambers, valves, etc. as you can. (NOTE – you don't need to trace the bloodflow through the kidney other than artery – capillary - vein.)

Trace the flow of blood through the heart, to the heart tissue of the left ventricle, and back to the heart chambers. **Start and end at the RIGHT ATRIUM.** Name as many vessels, structures, chambers, valves, etc. as you can. (HINT - the artery that you'll use to deliver blood to the heart muscle tissue is the left anterior descending. You may want to review the coronary circulation from heart laboratory exercises.)

The Structure of the Cardiovascular System: Blood Vessels, Part 3

Appendicular Vessels of the Systemic Circuit

Introduction

In these laboratory exercises, you will use models, diagrams and preserved specimens to study the distribution of blood vessels throughout the body. Specifically, you'll be studying the vessels that take blood to and return it from the upper and lower limbs of the body (arms and legs). Because the limbs are paired, many of these vessels should be identified as right or left. Names of the appendicular vessels reflect the region of the body where they are found, and whether they are superficial (closer to the surface of the body) or deep (further away from the surface of the body).

Learning Objectives

By the end of this lesson you will be able to:

- Describe the microanatomy of blood vessel walls and the tissues that compose each, and to state the function of each layer
- Correlate differences in artery, vein and capillary structure with the functions of these vessels
- Recognize and differentiate an artery and a vein in cross-section on a slide, in a picture, on a diagram or on a model
- List or identify the major arteries branching from the aorta, and indicate the body region supplied by each (see the below table)
- List or identify the major veins draining to the superior or inferior vena cava, and the body region drained by each (see the below table)
- Compare and contrast pulmonary circulation from systemic circulation
- Describe “special” circulatory systems (the hepatic portal system, the circle of Willis, and fetal circulatory system – being sure to identify fetal circulatory features that are different from adult circulatory systems)

- To identify the following structures of importance:

Microanatomy of arteries, veins, and capillaries – Fig 20.3 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-1-structure-and-function-of-blood-vessels	
Tunica intima (or tunica interna)	
Tunica media	
Tunica externa	
Valves	
Arteries of head and neck - Figs. 20.26 – 20.27 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways	Veins of the head, neck and brain – Fig. 20.37 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways
Brachiocephalic trunk (artery)	Superior sagittal sinus
Subclavian artery	Internal jugular veins
Common carotid artery	Superficial temporal vein
External and internal carotid arteries	Facial vein
Facial artery	External and internal jugular veins
Superficial temporal artery	Brachiocephalic vein
Vertebral artery	Subclavian vein
	Superior vena cava
Arteries of the upper limb and thorax – Figs. 20.28 – 20.29, 20.31 – 20.32 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways	Veins of the thorax, upper limb and shoulder – Figs. 20.36 – 20.39 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways
Brachiocephalic trunk (artery)	Radial vein
Subclavian artery	Ulnar vein
Axillary artery	Median antebrachial vein
Brachial artery	Median cubital vein
Radial artery	Basilic vein
Ulnar artery	Cephalic vein
Aortic arch	Brachial vein
Descending aorta	Axillary vein
	Subclavian veins
Arteries of the abdomen – Figs. 20.29 – 20.30 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways	Brachiocephalic veins
Celiac trunk	Superior vena cava
Splenic artery	Inferior vena cava
Common hepatic artery	Azygos vein
Left gastric artery	Hemiazygos vein
Hepatic artery proper	

Arteries of the abdomen (continued)	
Superior mesenteric artery	Veins of the abdomen – Fig. 20.36 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways
Inferior mesenteric artery	Hepatic veins
Renal arteries	Renal veins
Gonadal arteries (testicular or ovarian)	Left and right gonadal vein
Common iliac arteries	Common iliac vein
	External and internal iliac veins
Arteries of the pelvis and lower limb – Figs. 20.29 – 20.30. 20.33 – 20.34 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways	Veins of the lower limb – Figs. 20.41 – 20.42 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways
External and internal iliac arteries	Dorsalis pedis vein
Femoral artery	Anterior tibial vein
Popliteal artery	Posterior tibial vein
Anterior tibial artery	Fibular or peroneal vein
Posterior tibial artery	Popliteal vein
Fibular artery	Femoral vein
Dorsalis pedis artery	Great saphenous vein
	External and internal iliac vein
	Common iliac vein

Special Circulatory Systems	
Pulmonary circulation – Fig. 20.23 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways	Hepatic portal circulation – Fig. 20.43 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways
Right and left atria	Hepatic portal vein
Right and left ventricles	Splenic vein
Pulmonary trunk	Inferior mesenteric vein
Right and left pulmonary arteries	Superior mesenteric vein
Pulmonary veins	Hepatic veins
Fetal circulation – Fig. 20.44 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways	Circulation to the brain (Circle of Willis) – Figs. 20.26 – 20.27 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways
Superior and inferior vena cavae	Circle of Willis
Aorta, aortic arch and descending aorta	Internal carotid arteries
Pulmonary trunk, pulmonary arteries and veins	Anterior cerebral arteries
Hepatic portal vein	Anterior communicating artery
Umbilical arteries and veins	Posterior communicating artery
Ductus arteriosus	Posterior cerebral arteries
Ligamentum arteriosum	Basilar artery
Foramen ovale	Vertebral artery
Fossa ovalis	
Ductus venosus	
Ligamentum venosum	
Ligamentum teres	

Background Information

Overview

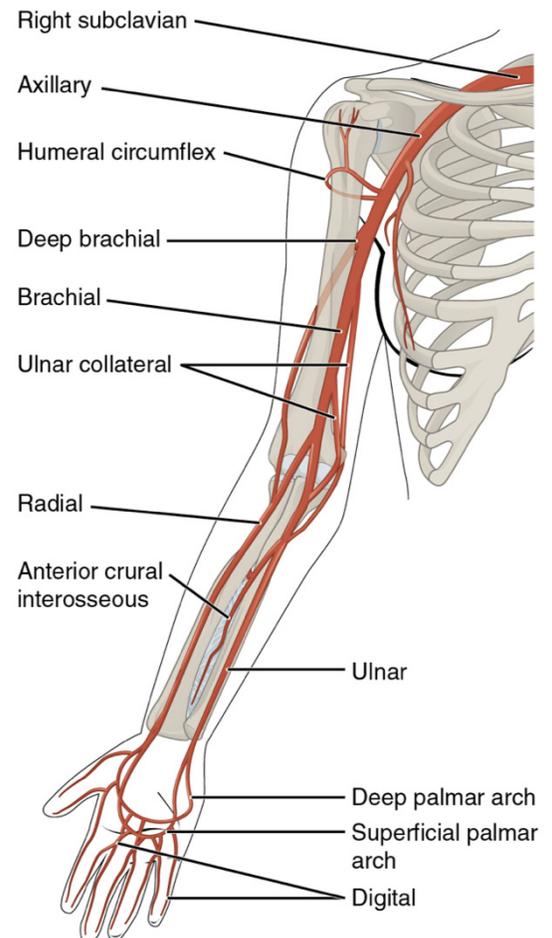
Circulation to the Upper Limb

In the discussion of the axial vessels, we identified the major branches from the aorta. Blood vessels traveling to the upper limbs will branch from the vessels that exit from the thoracic aorta. In both right and left limbs, a good starting point is the **subclavian artery**. The **left subclavian artery** is the third vessel that branches from the aortic arch. The **right subclavian artery** is a branch from the brachiocephalic trunk (brachio- = arm; cephalic = head). In both limbs, the subclavian arteries branch to the **axillary arteries** (named for the axillary region of the body), and the axillary arteries branch to form the **brachial arteries** as they pass through the upper arm. At the elbow (the antecubital fossa), the brachial artery splits into the **radial and ulnar arteries**, so named for the bones of the forearm they travel alongside. The radial and ulnar arteries deliver blood to the vessels of the hand.

The OpenStax image at right (Figure 20.31) shows the distribution of bloodflow via the arteries in the arm. See the link:

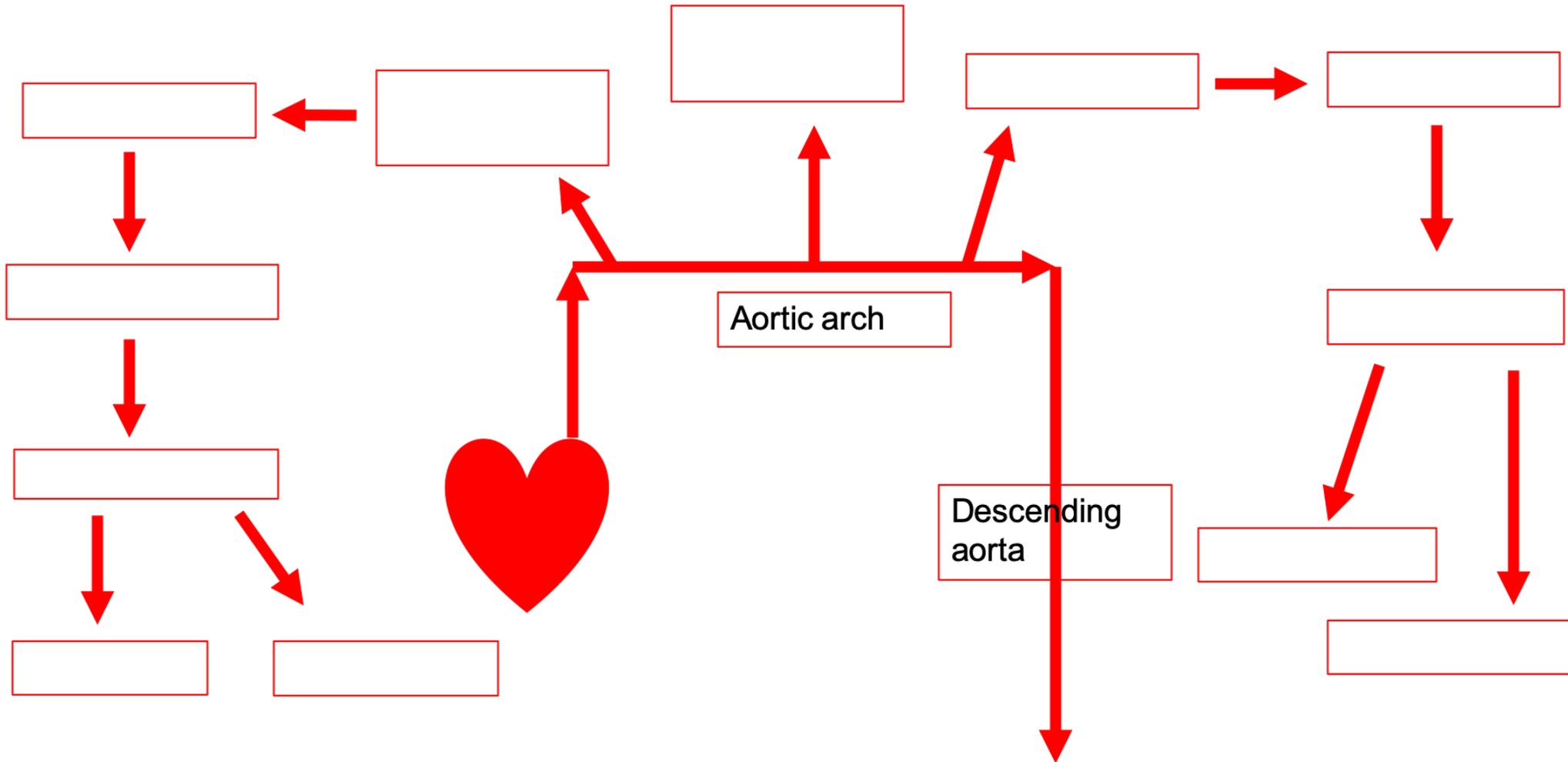
<https://cnx.org/contents/FPtK1zmh@16.7:GqYHW4Z4@7/20-5-Circulatory-Pathways>

Figure 20.31 Major Arteries Serving the Thorax and Upper Limb The arteries that supply blood to the arms and hands are extensions of the subclavian arteries.



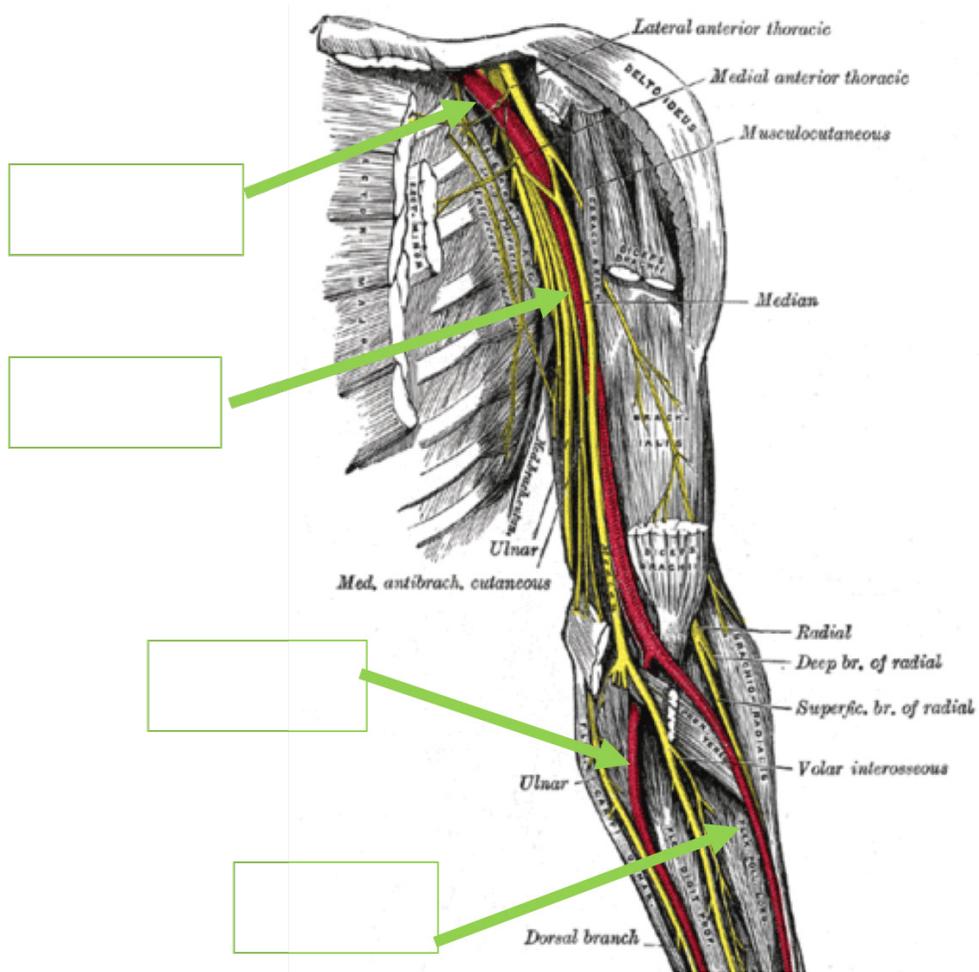
Activity 1 – Bloodflow to the upper limb.

Fill in the names of the arteries to complete the scheme of distribution of blood to the upper limbs.



Activity 2 – Identification of arteries in the upper limb.

Fill in the boxes with the correct names of the labeled vessels. Remember, this is a LEFT arm.



Circulation to the Lower Limb

In the discussion of the axial vessels, the abdominal aorta terminates in the pelvic cavity when it bifurcates into the **right and left common iliac arteries**. This provides a good starting point for identifying the branches of these vessels that distribute blood to the legs and feet. The right and left common iliac arteries divide into two branches: **the internal and external iliac arteries**. The **internal iliac arteries** supply blood to the organs in the pelvic cavity, the pelvic wall and some large muscles of the hip. The **external iliac arteries** descend into the thigh to become the **femoral arteries** (changing name at the point where they emerge from behind the inguinal ligament). The femoral arteries travel just posterior to sartorius, then travel to the posterior aspect of the knee where they become the **popliteal arteries**. The popliteal arteries bifurcate to form the **posterior tibial arteries** (continuing as an extension of the popliteal arteries) and the **anterior tibial arteries** (crossing the interosseous membrane between tibia and fibula and descending along the anterior aspect of the leg). The anterior tibial arteries supply blood to the muscles and bones of the leg and foot. The posterior tibial arteries branch to form the **fibular (peroneal) arteries**, which descend to the foot along the fibula (and is named for this bone). The anterior tibial artery becomes the **dorsalis pedis artery** at the ankle.

The below image from OpenStax (figure 20.33) shows both anterior and posterior views of the distribution scheme to the lower limb. See the link:

<https://cnx.org/contents/FPtK1zmh@16.7:GqYHW4Z4@7/20-5-Circulatory-Pathways>

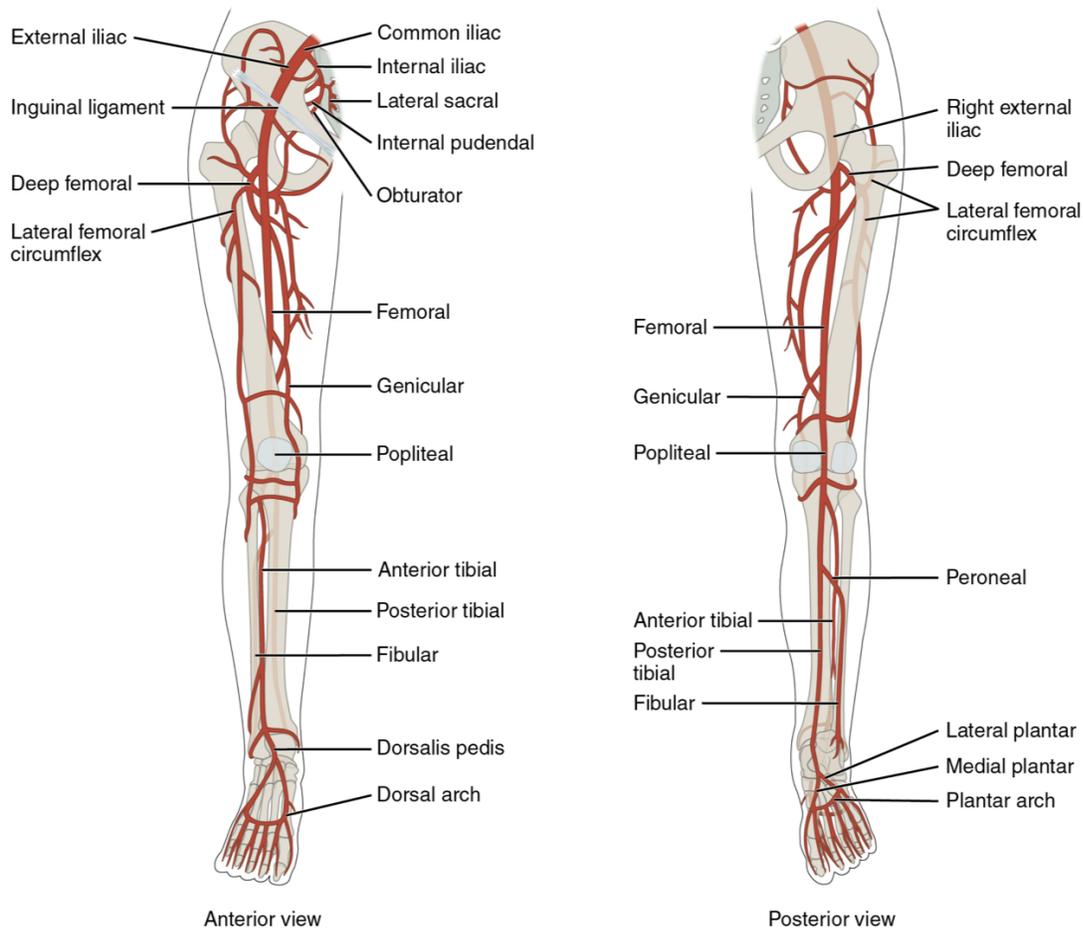


Figure 20.33 Major Arteries Serving the Lower Limb Major arteries serving the lower limb are shown in anterior and posterior views.

Circulation from the upper limb

Veins that return blood to the heart from the upper limb can be located superficial (closer to the skin) or deep. **Superficial veins** are variable from person to person and form extensive anastomoses (connections between blood vessels), which provide numerous alternative pathways for blood. **Deep veins** are usually found traveling with a corresponding artery (of the same name) deep in the limb.

The deep veins follow a course that can be predicted by the course of the companion arteries (discussed earlier). The **right and left radial veins** drain blood from the deep palmar arches in the hand, then travel alongside the radial arteries (and the radius) in the forearm. The **ulnar veins** drain blood from the superficial vein networks in the hand, and course superiorly toward the elbow with the ulnar arteries (and the ulna). The radial veins drain the lateral forearm while the ulnar veins drain the medial forearm. Inferior to the elbow, the radial and ulnar veins combine to form the **brachial veins**, draining blood from the muscles and bones of the arm and elbow. The brachial veins continue to course superiorly to join with the **basilic veins** to form the **axillary veins** in the armpit. Axillary veins continue to travel toward the border of the first rib, where the name changes and the vessels become **subclavian veins**. The subclavian veins unite with the internal veins to form the **brachiocephalic veins**.

The superficial veins follow less predictable courses. The right and left **cephalic veins** drain blood from the venous network on the dorsal side of the hand, ascending along the length of the antero-lateral side of the arm to join with the **axillary vein**. The **basilic veins** also drain blood from the veins on the dorsal aspect of the hands, and ascend the arm along the medial side. The **median cubital veins**, branching off of the cephalic veins at the elbow, join with the basilic vein here. The basilic vein continues to travel proximally toward the trunk. In the middle of the arm, it penetrates the upper arm muscles to travel alongside the deep brachial arteries to join the **brachial veins** and become the **axillary veins**.

The below image from OpenStax (Figure 20.38) gives a clear view of the relationship among the vessels that drain blood from the arm. See the link:

<https://cnx.org/contents/FPtK1zmh@16.7:GqYHW4Z4@7/20-5-Circulatory-Pathways>

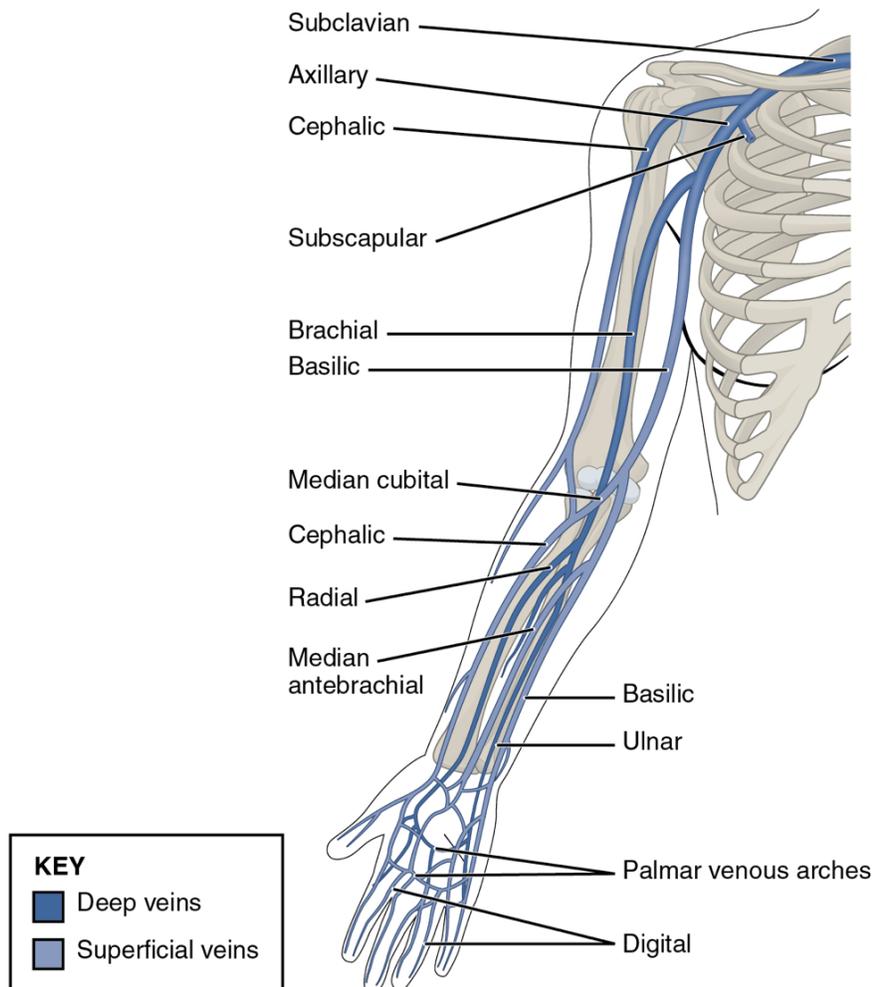
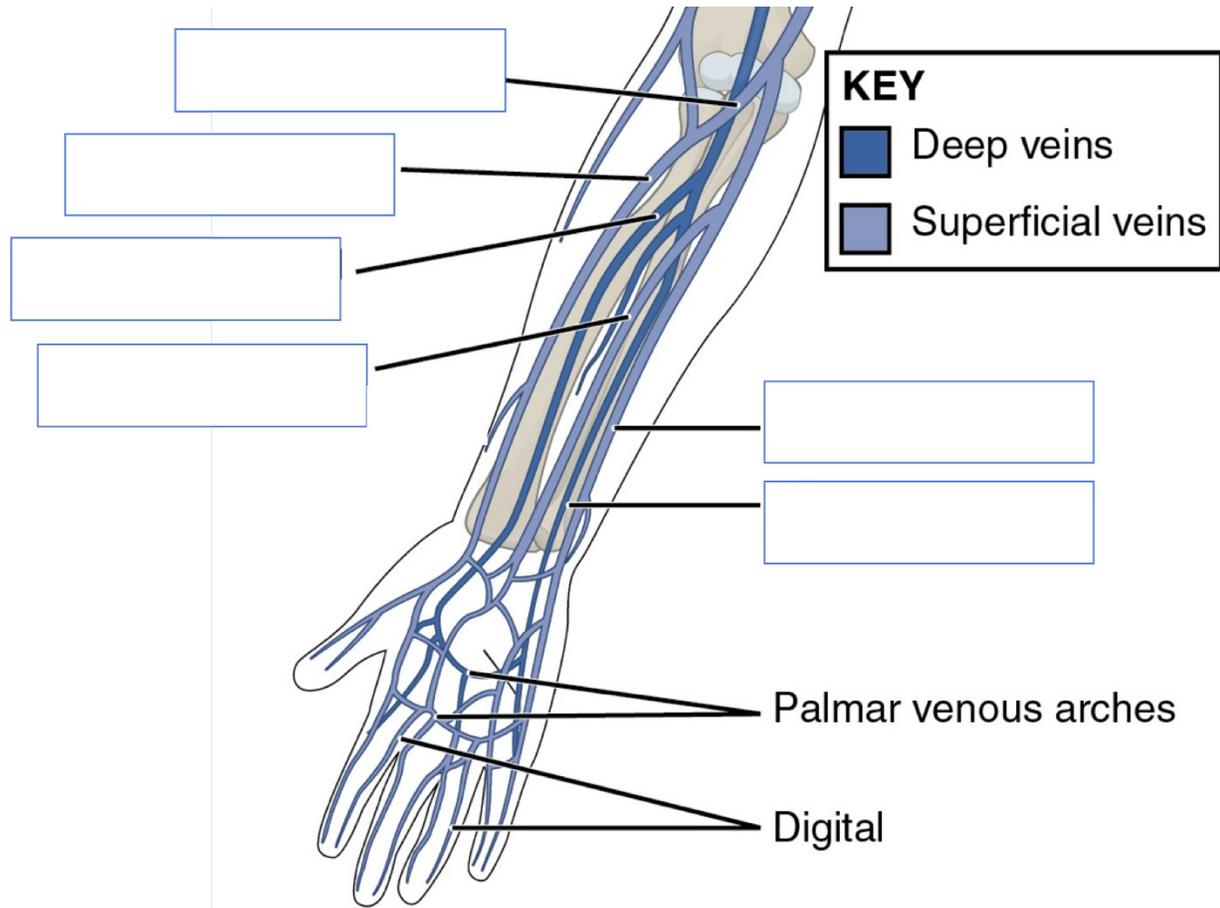


Figure 20.38 Veins of the Upper Limb This anterior view shows the veins that drain the upper limb.

Activity 5 – Identification of the veins of the upper limb.

Fill in the boxes with the correct names of the vessels. The arm is shown in anterior view, and deep vs. superficial vessels are color-coded.



Circulation from the lower limb

Like the upper limbs, veins in the lower limb are superficial and deep. Deep veins tend to travel alongside and have the same names as the corresponding arteries. Superficial veins form anastomoses with both other superficial and deep veins.

The deep veins of the leg, like those in the arm, follow a familiar course. The **anterior tibial veins** arise from the dorsal venous arch of the foot, and travel superiorly behind the tibialis anterior muscle with the anterior tibial arteries. The **posterior tibial veins** drain blood from the plantar surface of the foot, and travel superiorly in the leg deep to soleus with the **posterior tibial artery**. The **peroneal (fibular)** vein joins with the posterior tibial vein. The anterior and posterior tibial veins join to form the **popliteal veins**. The popliteal veins travel with the popliteal arteries to pass to the front of the knee, where they change names to become the **femoral veins**. The femoral veins course alongside the femoral arteries through the thigh, deep to sartorius, and join with the **great saphenous vein** (a superficial vein). Entering the pelvis under the inguinal ligament, the femoral veins then become the **external iliac veins**.

The main superficial vein of the leg is the **great saphenous vein**. The great saphenous veins arise in the dorsal venous arch of the foot, then travel along the medial aspect of the leg until they join with the **femoral veins** in the groin. The great saphenous veins are located just deep to the skin, and are the longest veins in the body.

The below image from OpenStax (Figure 20.41) shows the superficial and deep veins of the leg in this overview image. See the link:

<https://cnx.org/contents/FPtK1zmh@16.7:GqYHW4Z4@7/20-5-Circulatory-Pathways>

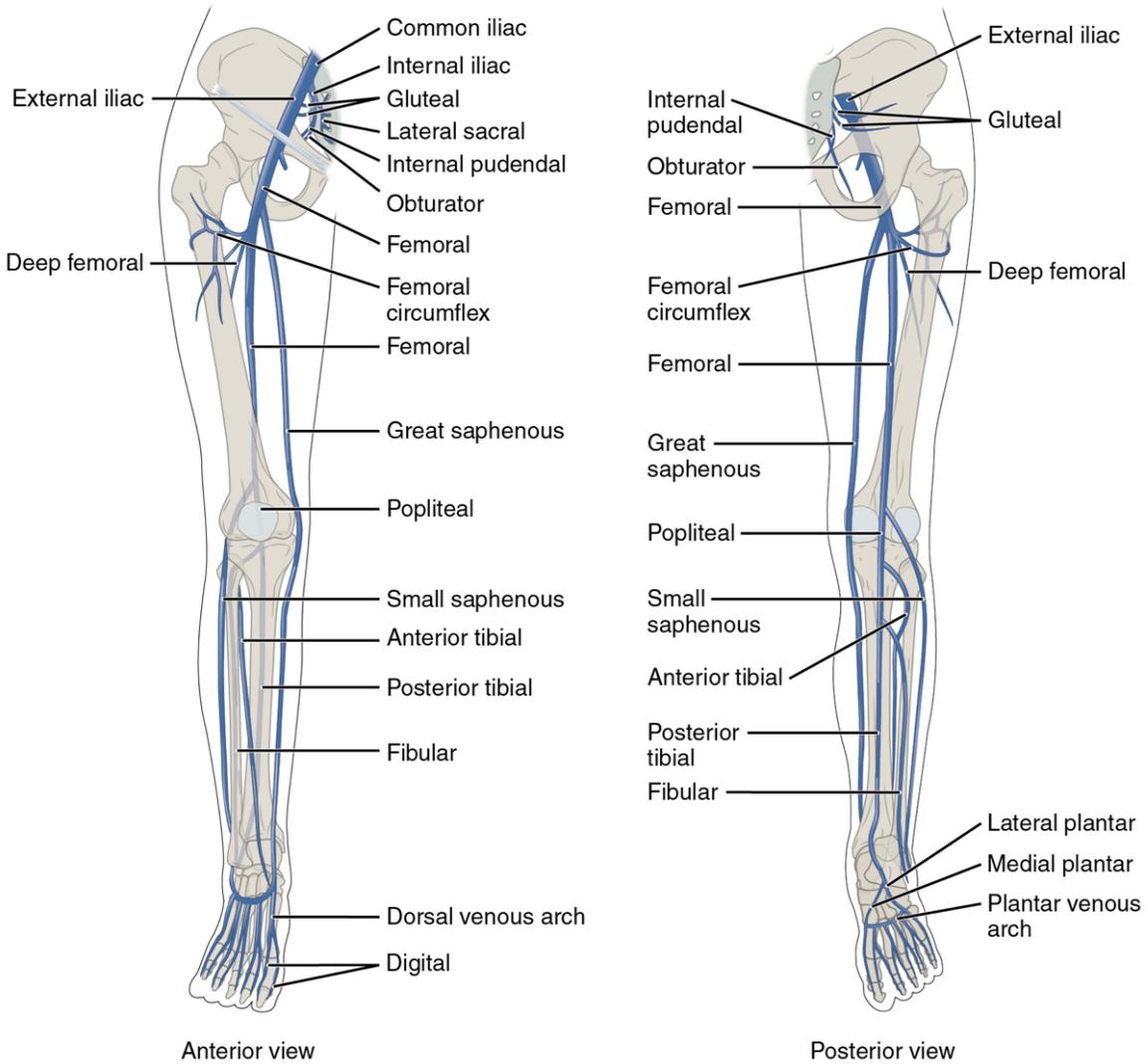
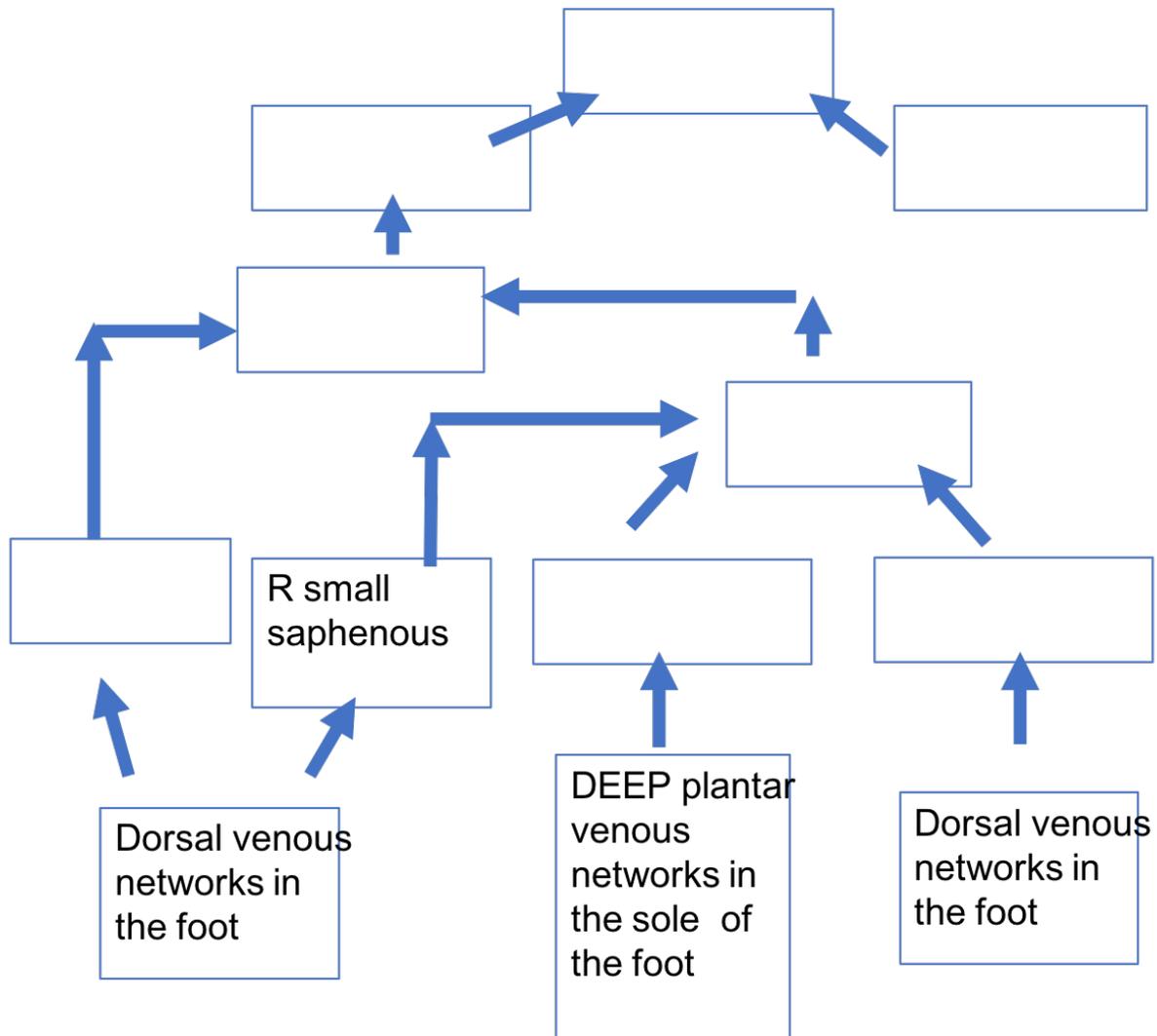


Figure 20.41 Major Veins Serving the Lower Limbs Anterior and posterior views show the major veins that drain the lower limb into the inferior vena cava.

Activity 6 – Bloodflow from the lower limb.

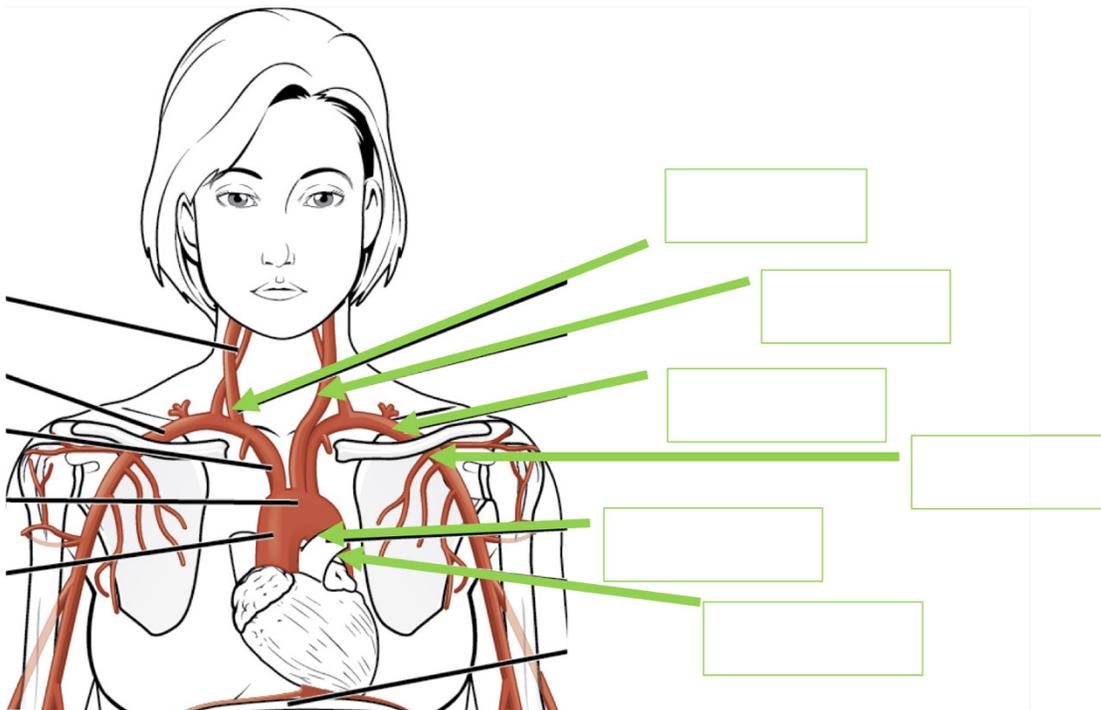
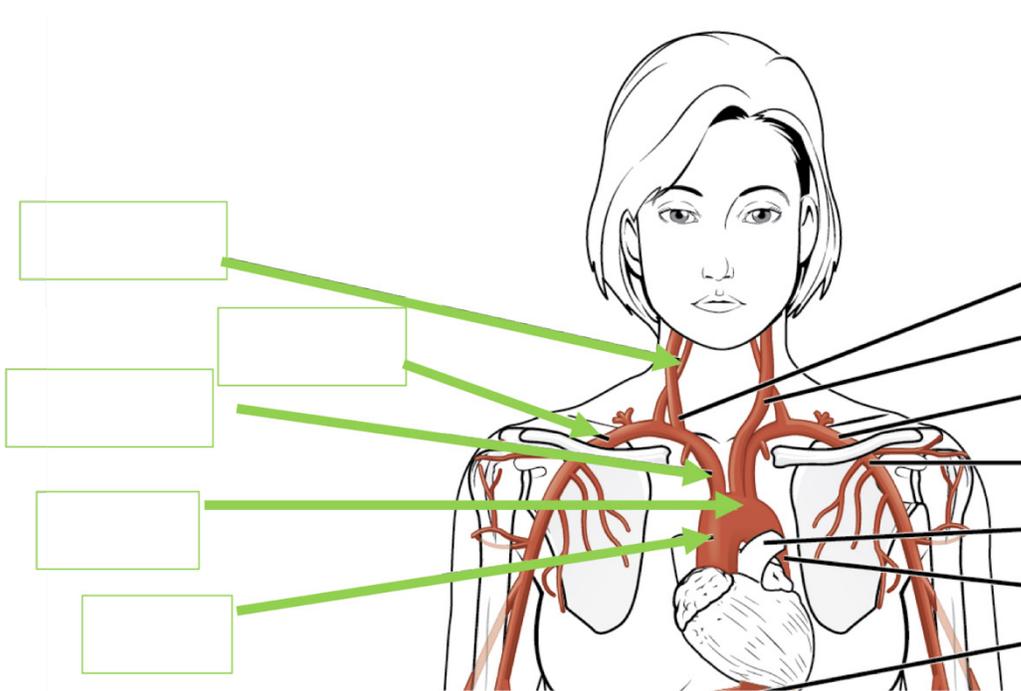
Fill in the boxes with the names of the vessels that will correctly complete the drainage scheme from the leg.



Review Activities: Use the below diagrams to identify the vessels in question.

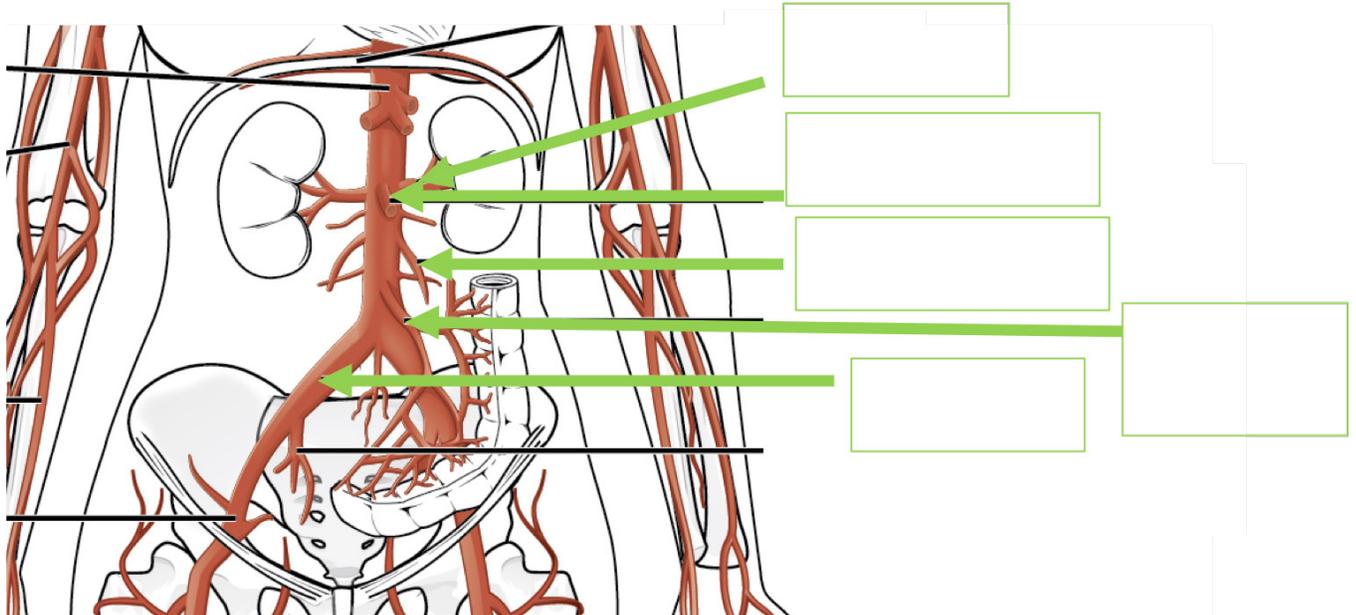
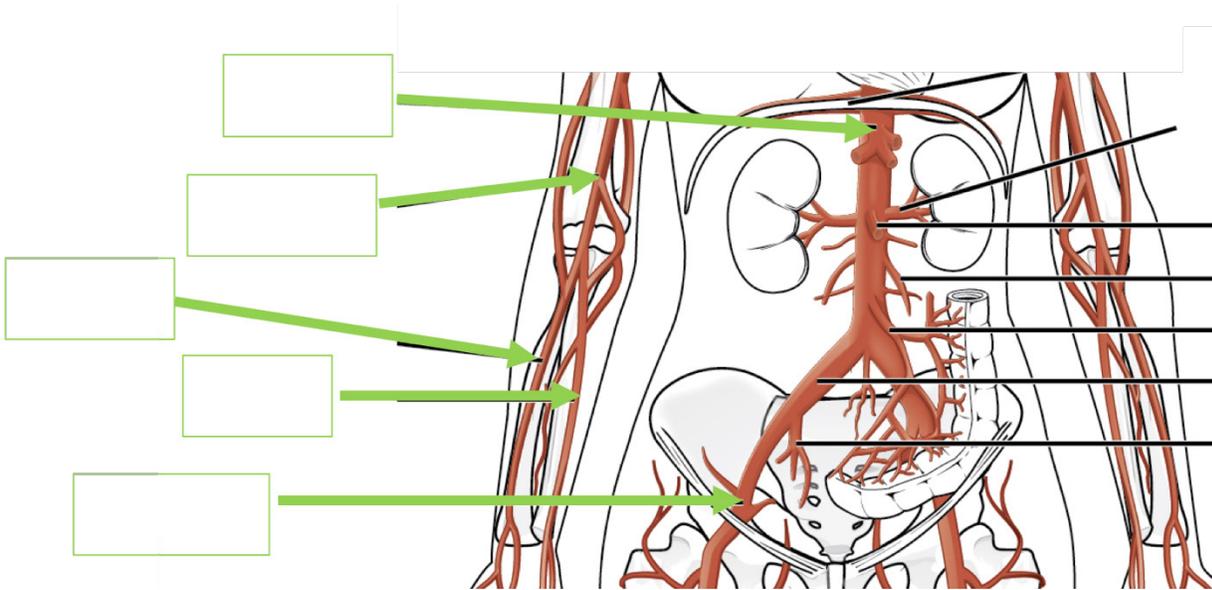
Activity 7 – Review of arteries.

Fill in the boxes with the name that correctly identifies each artery of the upper body.



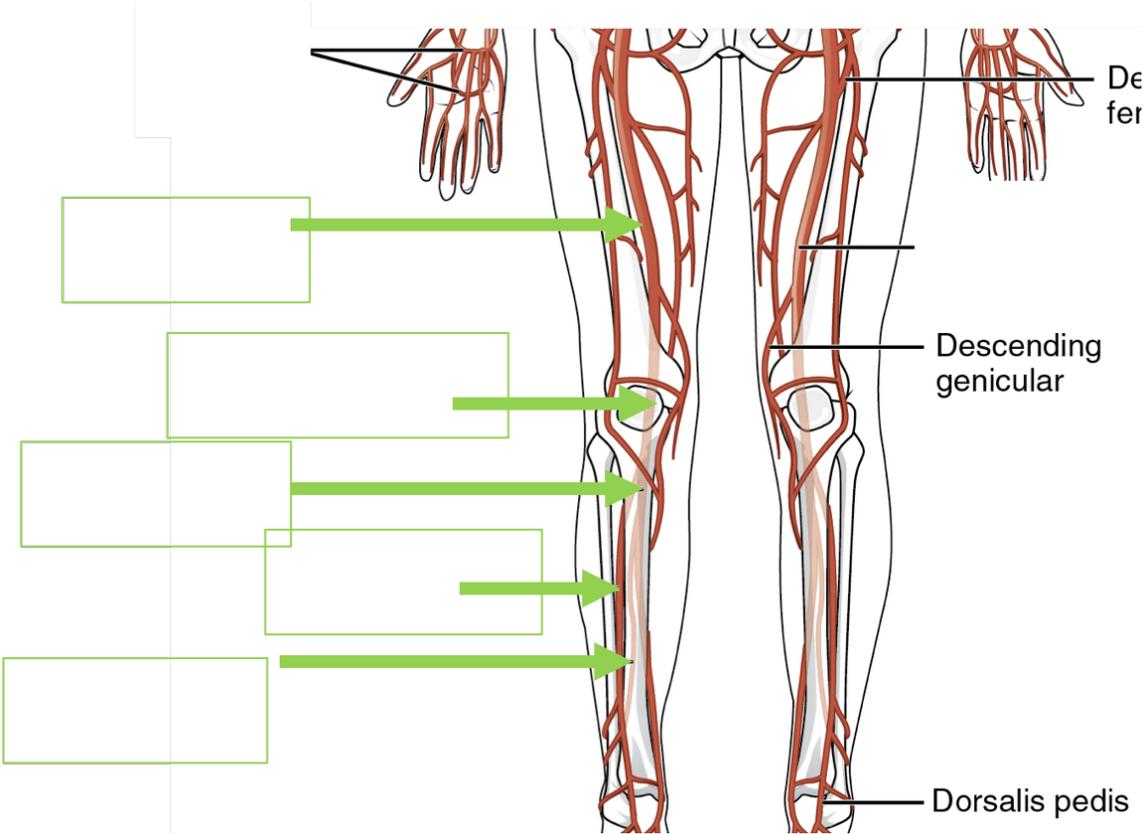
Activity 8 – Review of arteries.

Fill in the boxes with the name that correctly identifies each artery of the abdomen and arm.



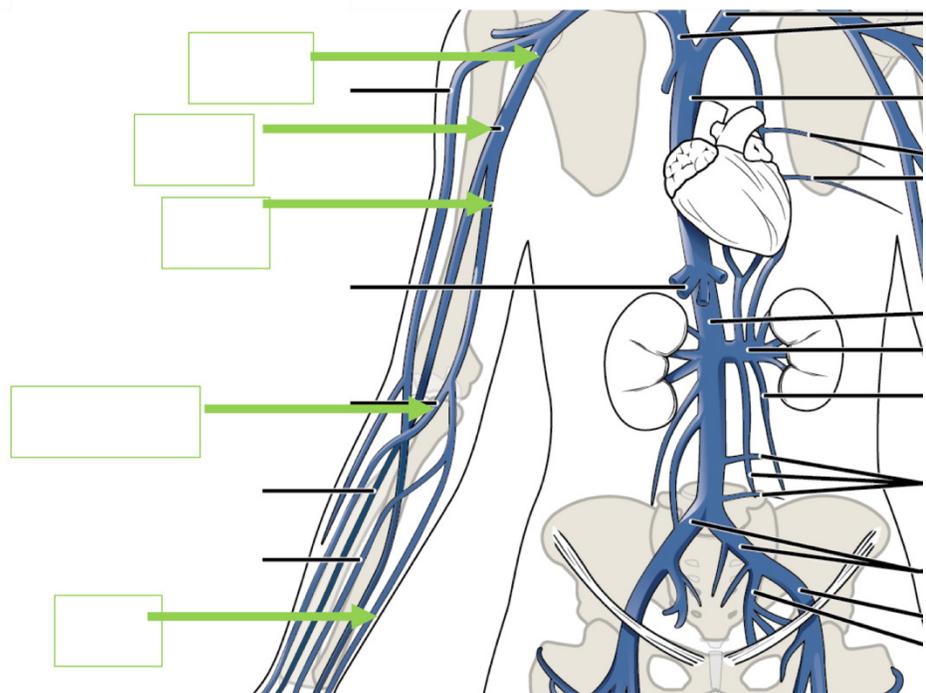
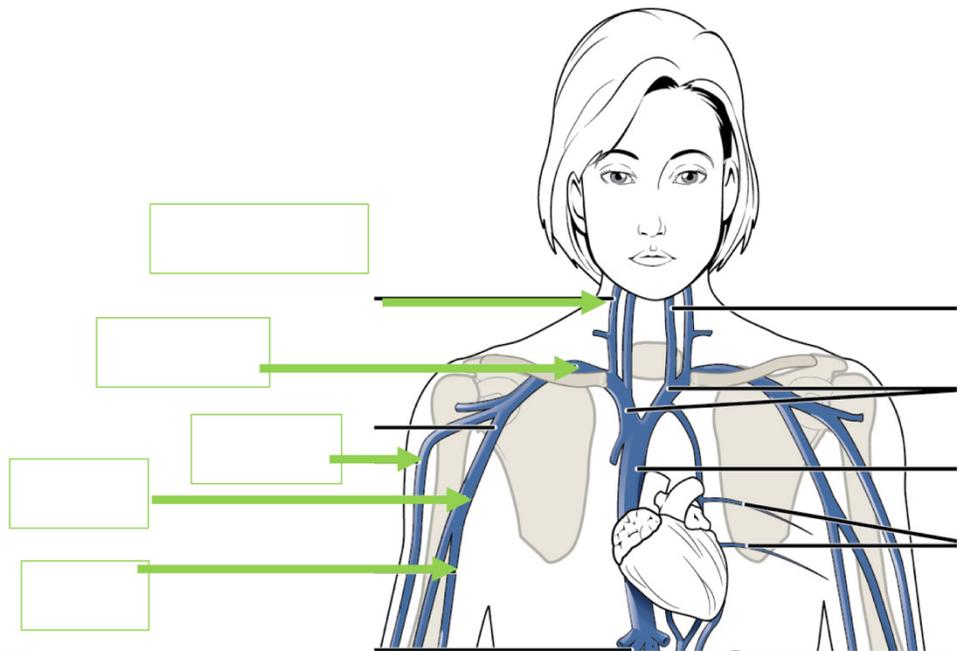
Activity 9 – Review of arteries.

Fill in the boxes with the name that correctly identifies each artery of the lower limb.



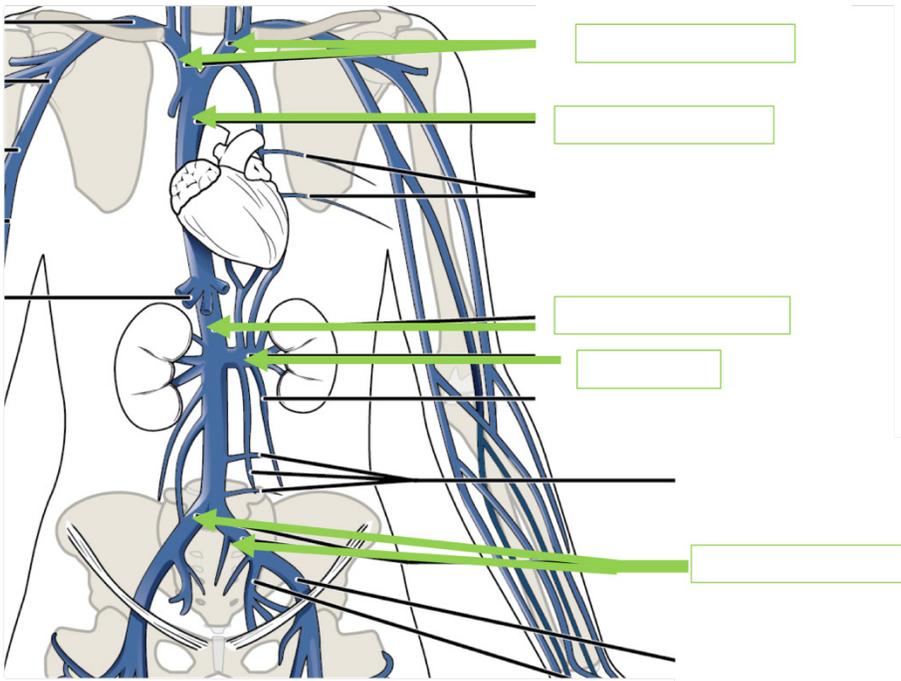
Activity 10 – Review of veins.

Fill in the boxes with the name that correctly identifies each vein of the upper body and arm.



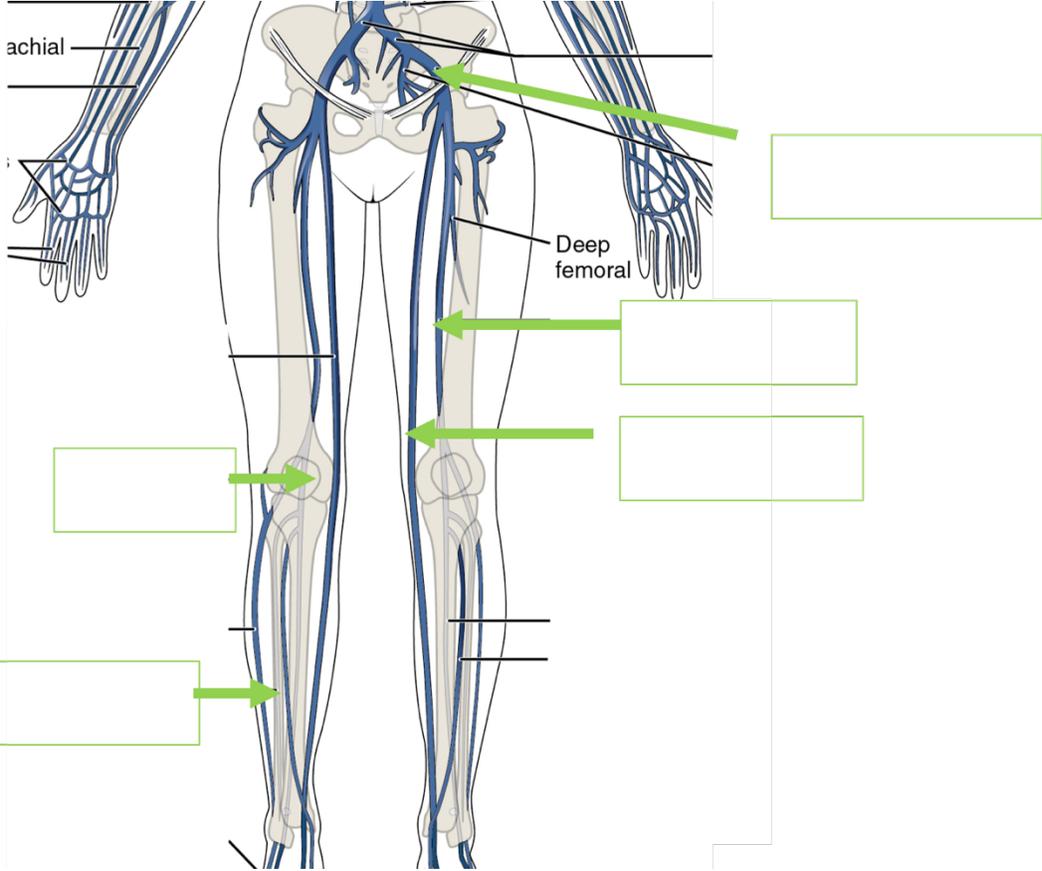
Activity 11 – Review of veins.

Fill in the boxes with the name that correctly identifies each vein of the abdomen.



Activity 12 – Review of veins.

Fill in the boxes with the name that correctly identifies each vein of the abdomen and leg.



Exit Ticket: Before you leave lab today, trace the flow of blood through the specified organs and structures.

Your dad stepped on a Lego® on the floor. The Lego® broke and pierced the sole of his foot. After a visit to the emergency department at your local hospital the Lego® pieces have been removed and there's no danger of infection, but your dad is in some pain. The physician has said that he can take acetaminophen for the pain.

Acetaminophen is a medication that is taken by mouth, but will act at the site if the pain (in this case, in the foot). It is absorbed by the blood vessels in the small intestine.

Trace the pathway taken by the acetaminophen as it travels throughout the body to alleviate your dad's pain.

The Structure of the Cardiovascular System: Blood Vessels, Part 4

Special Circulatory Routes

Introduction

In this laboratory, you will use models and diagrams to study some particular circulatory routes that have unusual features: the hepatic portal system, the Circle of Willis in the brain, and the fetal circulation. (The pulmonary circulatory route has already been discussed in Part 1.). You will be able to identify the unusual features associated with each, and describe how these features benefit the organ served, or the fetus (in the case of fetal circulation).

Learning Objectives

By the end of this lesson you will be able to:

1. Describe the microanatomy of blood vessel walls and the tissues that compose each, and to state the function of each layer
2. Correlate differences in artery, vein and capillary structure with the functions of these vessels
3. Recognize and differentiate an artery and a vein in cross-section on a slide, in a picture, on a diagram or on a model
4. List or identify the major arteries branching from the aorta, and indicate the body region supplied by each (see the below table)
5. List or identify the major veins draining to the superior or inferior vena cava, and the body region drained by each (see the below table)
6. Compare and contrast pulmonary circulation from systemic circulation
7. Describe “special” circulatory systems (the hepatic portal system, the circle of Willis, and fetal circulatory system – being sure to identify fetal circulatory features that are different from adult circulatory systems)

8. To identify the following structures of importance:

Microanatomy of arteries, veins, and capillaries – Fig 20.3 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-1-structure-and-function-of-blood-vessels	
Tunica intima (or tunica interna)	
Tunica media	
Tunica externa	
Valves	
Arteries of head and neck - Figs. 20.26 – 20.27 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways	Veins of the head, neck and brain – Fig. 20.37 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways
Brachiocephalic trunk (artery)	Superior sagittal sinus
Subclavian artery	Internal jugular veins
Common carotid artery	Superficial temporal vein
External and internal carotid arteries	Facial vein
Facial artery	External and internal jugular veins
Superficial temporal artery	Brachiocephalic vein
Vertebral artery	Subclavian vein
	Superior vena cava
Arteries of the upper limb and thorax – Figs. 20.28 – 20.29, 20.31 – 20.32 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways	Veins of the thorax, upper limb and shoulder – Figs. 20.36 – 20.39 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways
Brachiocephalic trunk (artery)	Radial vein
Subclavian artery	Ulnar vein
Axillary artery	Median antebrachial vein
Brachial artery	Median cubital vein
Radial artery	Basilic vein
Ulnar artery	Cephalic vein
Aortic arch	Brachial vein
Descending aorta	Axillary vein
	Subclavian veins
Arteries of the abdomen – Figs. 20.29 – 20.30 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways	Brachiocephalic veins
Celiac trunk	Superior vena cava
Splenic artery	Inferior vena cava
Common hepatic artery	Azygos vein
Left gastric artery	Hemiazygos vein
Hepatic artery proper	

Arteries of the abdomen (continued)	
Superior mesenteric artery	Veins of the abdomen – Fig. 20.36 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways
Inferior mesenteric artery	Hepatic veins
Renal arteries	Renal veins
Gonadal arteries (testicular or ovarian)	Left and right gonadal vein
Common iliac arteries	Common iliac vein
	External and internal iliac veins
Arteries of the pelvis and lower limb – Figs. 20.29 – 20.30. 20.33 – 20.34 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways	Veins of the lower limb – Figs. 20.41 – 20.42 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways
External and internal iliac arteries	Dorsalis pedis vein
Femoral artery	Anterior tibial vein
Popliteal artery	Posterior tibial vein
Anterior tibial artery	Fibular or peroneal vein
Posterior tibial artery	Popliteal vein
Fibular artery	Femoral vein
Dorsalis pedis artery	Great saphenous vein
	External and internal iliac vein
	Common iliac vein

Special Circulatory Systems	
Pulmonary circulation – Fig. 20.23 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways	Hepatic portal circulation – Fig. 20.43 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways
Right and left atria	Hepatic portal vein
Right and left ventricles	Splenic vein
Pulmonary trunk	Inferior mesenteric vein
Right and left pulmonary arteries	Superior mesenteric vein
Pulmonary veins	Hepatic veins
Fetal circulation – Fig. 20.44 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways	Circulation to the brain (Circle of Willis) – Figs. 20.26 – 20.27 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways
Superior and inferior vena cavae	Circle of Willis
Aorta, aortic arch and descending aorta	Internal carotid arteries
Pulmonary trunk, pulmonary arteries and veins	Anterior cerebral arteries
Hepatic portal vein	Anterior communicating artery
Umbilical arteries and veins	Posterior communicating artery
Ductus arteriosus	Posterior cerebral arteries
Ligamentum arteriosum	Basilar artery
Foramen ovale	Vertebral artery
Fossa ovalis	
Ductus venosus	
Ligamentum venosum	
Ligamentum teres	

Background Information

Hepatic Portal System

As part of the discussion of the axial veins of the abdomen, it was seen that blood from organs located in the abdomen and pelvis drained to the inferior vena cava, excepting the organs of the digestive system. Blood draining the stomach, intestines (large and small) and spleen is carried first to the liver by way of the **hepatic portal vein**. A portal vein is a vessel that carries blood from one capillary bed to another, without traveling to the heart or lungs first. The hepatic portal vein receives blood from the capillaries of the gastrointestinal organs and conveys it to the sinusoids (capillaries) in the liver. This blood is deoxygenated, but rich in nutrients after a meal. The liver stores some nutrients, and metabolizes others so they can be used by cells in the body or eliminated as waste.

The hepatic portal vein receives blood from the **splenic** and **superior mesenteric veins**. The inferior mesenteric vein and the gastric veins also contribute to bloodflow entering the hepatic portal vein. The **superior mesenteric vein** drains blood from the small intestine and portions of the pancreas, stomach and large intestine. The **splenic vein** drains blood from the spleen, the stomach, the pancreas, and some of the large intestine. The **gastric vein** drains blood from the stomach, and may drain into the splenic vein before it becomes the hepatic portal vein. The **inferior mesenteric vein** drains blood from the last portion of the large intestine.

The following OpenStax image (Figure 20.43) shows the vessels that drain to the liver in a simple, color-coded image. You can follow the link:

<https://openstax.org/books/anatomy-and-physiology/pages/20-5-circulatory-pathways>

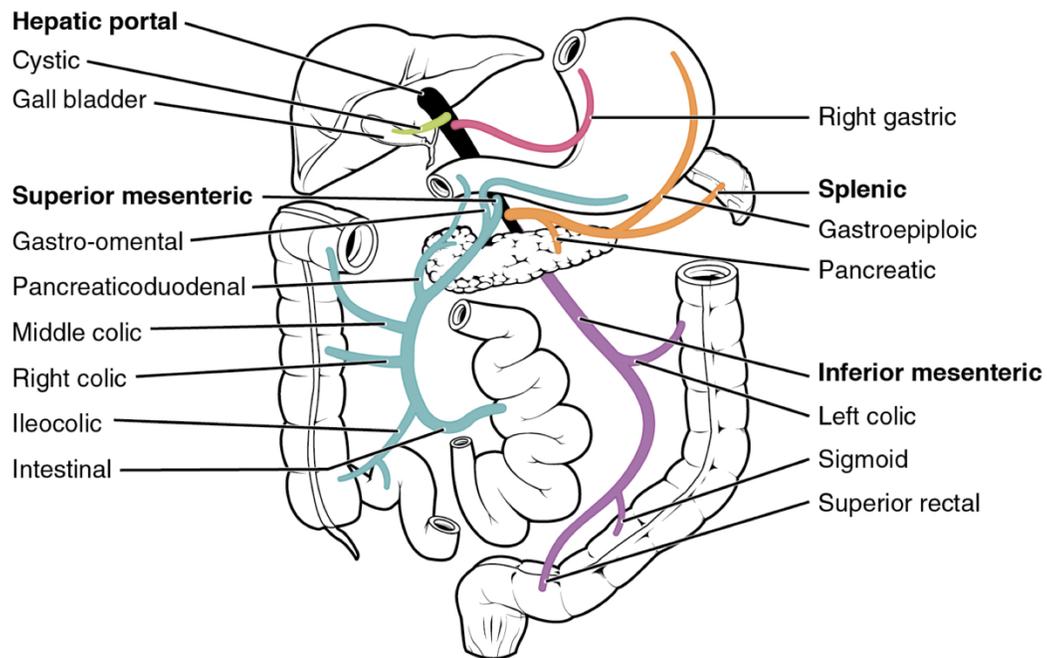
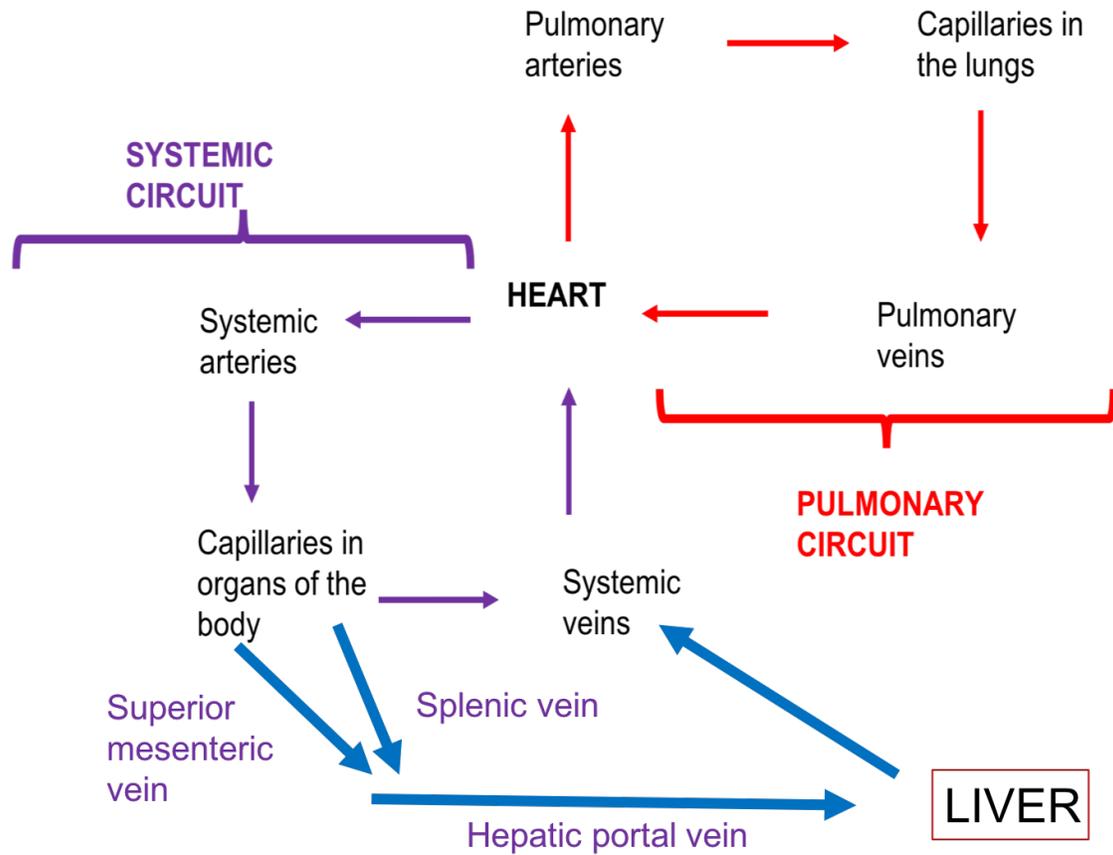


Figure 20.43 Hepatic Portal System The liver receives blood from the normal systemic circulation via the hepatic artery. It also receives and processes blood from other organs, delivered via the veins of the hepatic portal system. All blood exits the liver via the hepatic vein, which delivers the blood to the inferior vena cava. (Different colors are used to help distinguish among the different vessels in the system.)

The scheme of bloodflow through the hepatic portal system thus looks like this:



Blood from the liver is drained to the inferior vena cava by the **hepatic veins**, and then travels to the heart and lungs. The liver receives oxygenated blood by way of the **hepatic artery**, which is a branch of the celiac trunk.

Circle of Willis

The Circle of Willis (cerebral arterial circle) is a unique arrangement of blood vessels found at the base of the brain, formed by anastomoses of arteries. The **right and left internal carotid arteries** enter the skull through the carotid foramen, and then give off several branches. The **anterior cerebral arteries** travel anteriorly, toward the frontal lobes. The **middle cerebral arteries** travel laterally, between the temporal and parietal lobes. The **right and left vertebral arteries** enter the skull through the foramen magnum, and join to form the **basilar artery** on the base of the pons. The basilar artery is a large, distinctive vessel that travels anteriorly and ends by bifurcating into the **posterior cerebral arteries**. The Circle of Willis is formed by the anastomoses of the posterior cerebral arteries with the internal carotid arteries by way of the **posterior communicating arteries**, and the anastomoses of the anterior cerebral arteries by way of a **small anterior communicating artery**. The vertebral and carotid vessels, both of which deliver oxygenated blood to the brain, are thus linked. The resulting circular arrangement of blood vessels surrounds the pituitary gland and the optic chiasm.

An image that shows the circular arrangement of blood vessels can be seen in OpenStax text (Figure 20.27). Follow the link:

<https://opentextbc.ca/anatomyandphysiology/chapter/20-5-circulatory-pathways/>

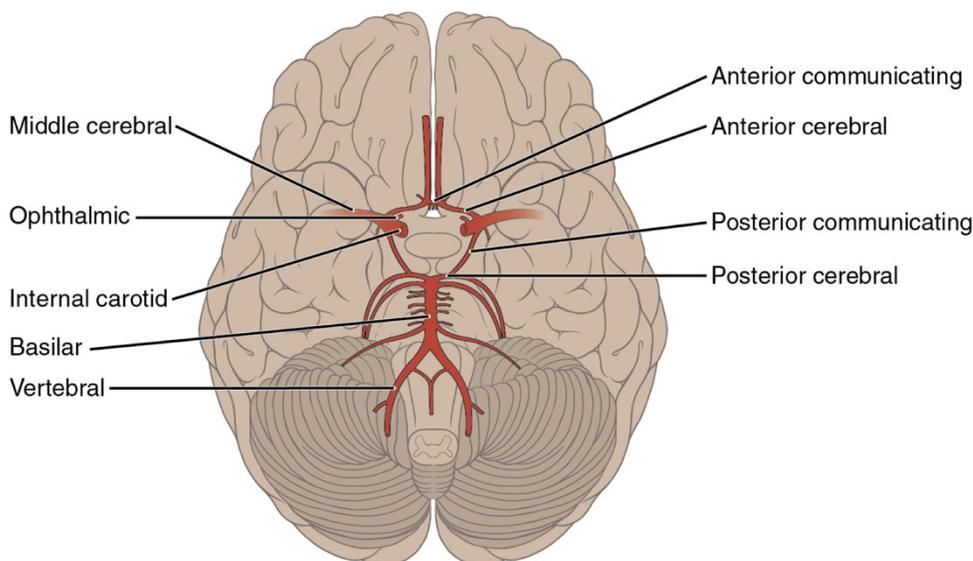
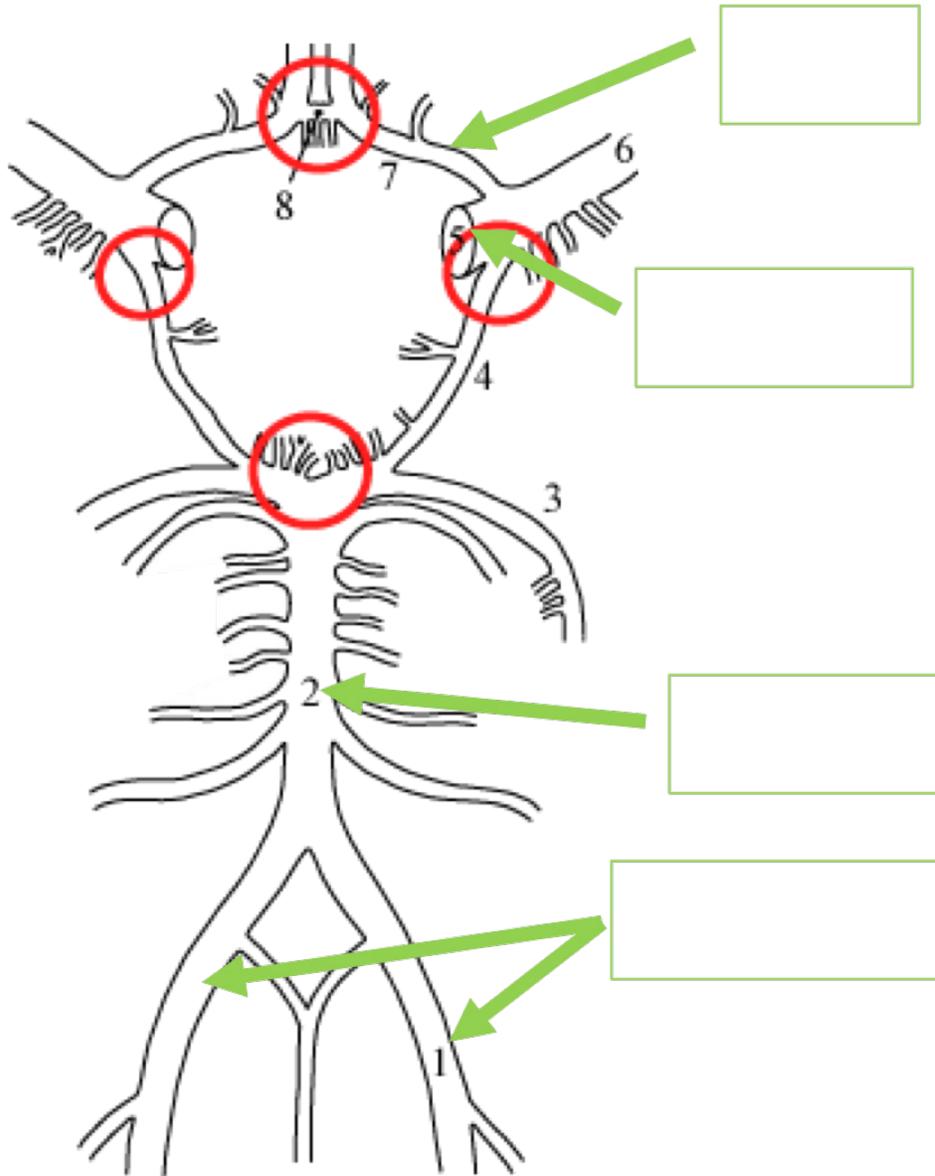


Figure 20.27 Arteries Serving the Brain This inferior view shows the network of arteries serving the brain. The structure is referred to as the arterial circle or circle of Willis.

The function of the Circle of Willis has historically been described as ensuring bloodflow to the brain by providing alternative, redundant pathways. A more recent hypothesis is that the Circle of Willis equalizes blood pressure in the brain and thus prevents wide swings that could damage brain tissue.

Activity 1 – Identifying the vessels of the Circle of Willis.

Fill in the boxes with the names of the vessels of the Circle of Willis. (NOTE – the vessels are shown in posterior view, as though you were looking at the base of the brain.)



Fetal Circulation

Because the fetus obtains oxygen and nutrients from the mother, the fetal pulmonary and systemic circulatory routes have several features that allow it to function in utero, bypass fetal organ systems that are not in use before birth, and extract oxygen and nutrients from the mother's blood while eliminating waste products at the placenta. The **placenta** is a unique organ that develops during pregnancy, rich in blood vessels that allow the exchange of substances between mother and baby without allowing mixing of fetal and maternal blood.

The **umbilical cord** attaches the fetus to the placenta. The umbilical cord contains two **umbilical arteries**, which are extensions of the fetal internal iliac arteries, and one **umbilical vein**. The umbilical arteries carry oxygen-poor fetal blood toward the placenta, and the umbilical vein carries oxygenated fetal blood from the placenta back toward the fetal heart.

Within the fetal circulation there are three "shunts," or alternative pathways for bloodflow, which divert blood away from the fetal lungs and the digestive organs (which won't become functional until after birth). The first is the **foramen ovale**, an opening between the right and left atria. Blood that enters the right atrium passes through this opening to the left atrium, and thus bypasses the pulmonary circuit in the fetus. A small amount of blood does travel to the fetal lungs via the pulmonary trunk. The second shunt is the **ductus arteriosus**, a short temporary vessel that connects the pulmonary trunk to the aorta in the fetus. This also allows blood that enters the pulmonary trunk to bypass the non-functioning fetal lungs and directly enter the fetal systemic circuit. The third is the **ductus venosus**, a vessel that diverts blood from the umbilical vein to the inferior vena cava. This allows blood returning from the placenta to bypass the liver and return directly to the heart. At birth, changes in blood pressure and vasoconstriction cause the shunts to close so that bloodflow follows the same pattern seen in adults. All shunts become permanently closed, occluded with connective tissue, within the first year of life.

The locations of the three shunts in fetal circulation are seen in the OpenStax image below (Figure 20.44). You can follow the link:

<https://openstax.org/books/anatomy-and-physiology/pages/20-6-development-of-blood-vessels-and-fetal-circulation>

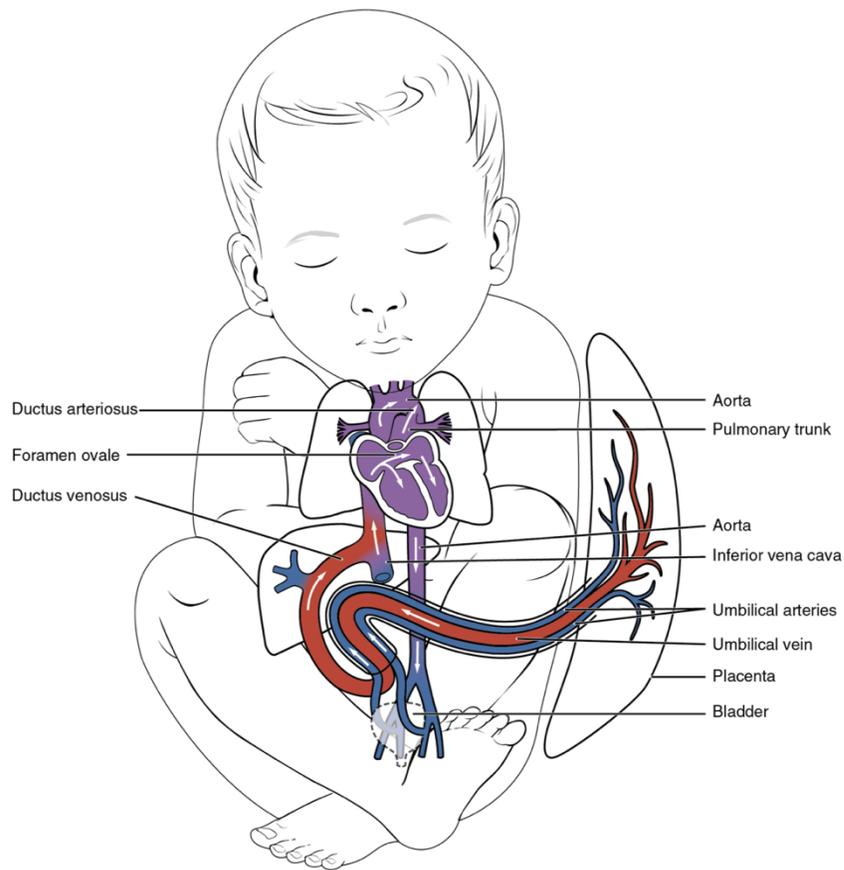
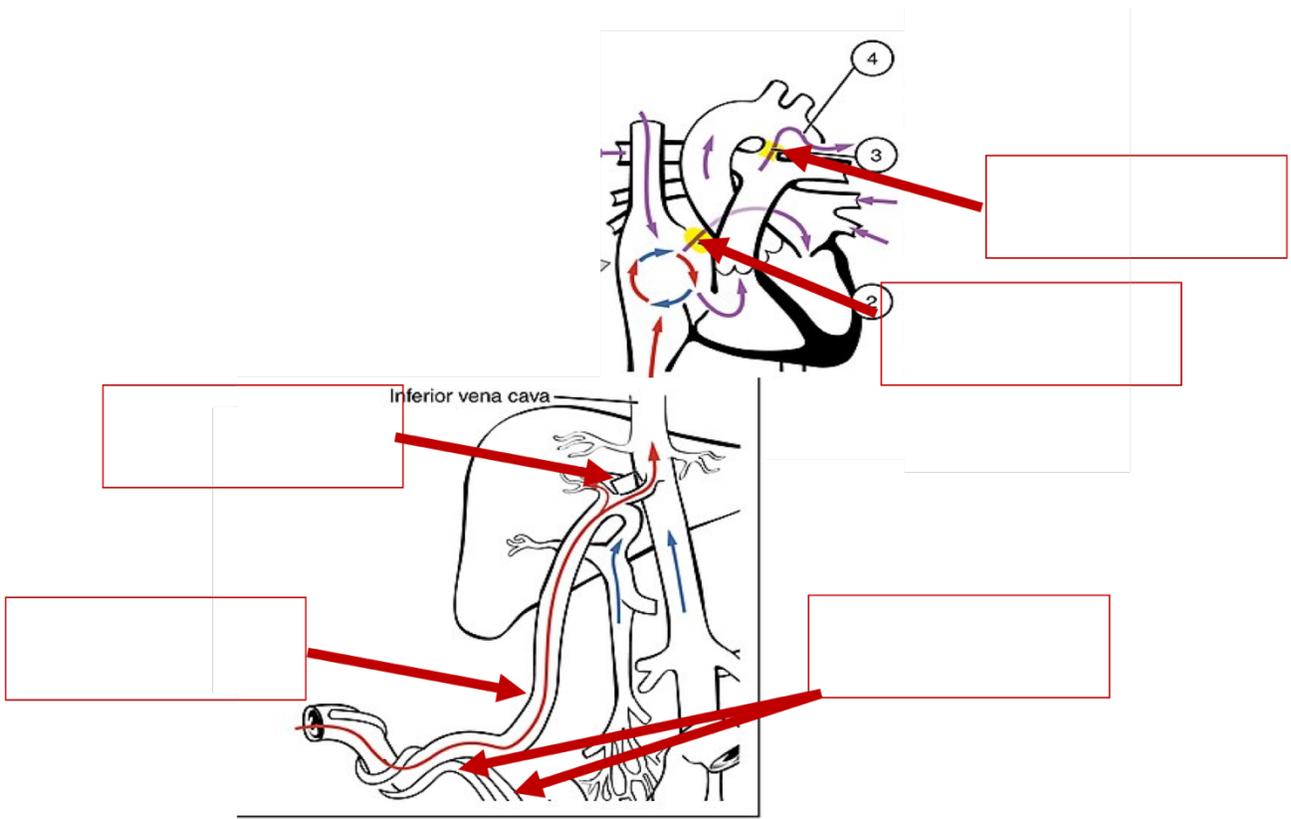


Figure 20.44 Fetal Shunts The foramen ovale in the interatrial septum allows blood to flow from the right atrium to the left atrium. The ductus arteriosus is a temporary vessel, connecting the aorta to the pulmonary trunk. The ductus venosus links the umbilical vein to the inferior vena cava largely through the liver.

Activity 2 – Vessels and “shunts” of the fetal circulation.

Label the features of the fetal circulation. The structures you name should be a vessel or a shunt that is present in the FETUS.



Exit Ticket: Before you leave lab today, fill in the table with the details of the shunts and vessels of the fetal circulation.

Structure	In the fetus, this structure delivers blood from _____ to _____	In the adult, this structure becomes
Umbilical artery		
Umbilical vein		
Ductus venosus		
Ductus arteriosus		
Foramen ovale		

Functions of the Cardiovascular System: Blood Pressure and Pulse

Introduction

In this laboratory, you will learn how to measure blood pressure with a sphygmomanometer (a blood pressure cuff) and a stethoscope. You'll then measure the effects of several stressors (changing position; exercise; a noxious stimulus) on blood pressure, and examine the mechanisms behind these changes.

Learning Objectives

By the end of this lesson you will be able to:

- Define the following
 - Systole
 - Diastole
 - Cardiac cycle
- To use a stethoscope and a recording microphone to auscultate heart and pulse sounds, and to relate heart sounds to events in the cardiac cycle
- To determine a subject's heart rate by auscultation and by obtaining a radial pulse
- To accurately determine a subject's blood pressure with a sphygmomanometer
- To describe changes in blood pressure that occur with a change in position or in response to a stimulus
- To record an ECG (using three leads), and identify the components of the ECG
- To identify or describe the following structures or processes of importance:

Blood Pressure	ECG and cardiac cycle
Systolic and diastolic pressures	Systole and diastole
sphygmomanometer	Atrioventricular and semilunar valves
stethoscope	Heart sounds
Korotkoff sounds	Atrial and ventricular depolarization
pulse	Atrial and ventricular repolarization
pulse point	P wave, T wave, QRS complex

Background Information

OVERVIEW

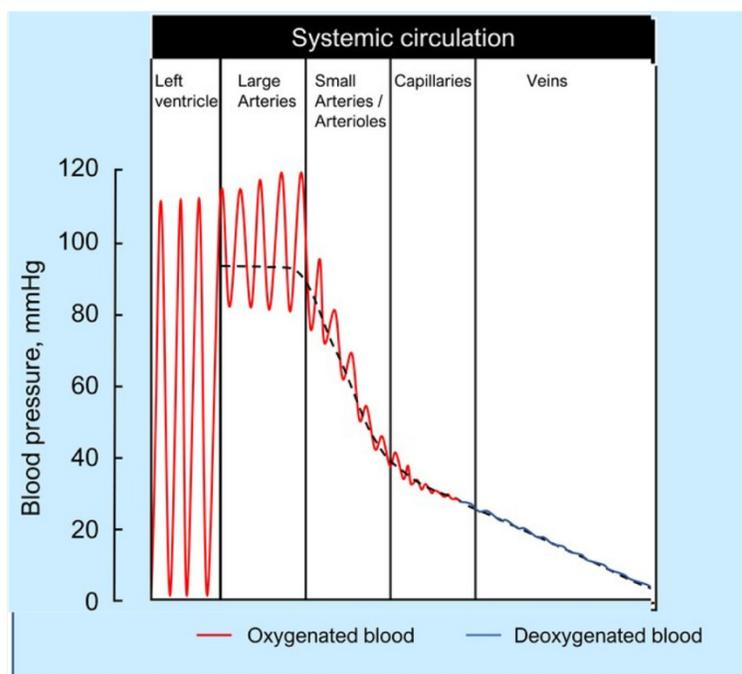
Blood pressure and blood vessels

Blood pressure is the hydrostatic pressure (the pressure exerted by a fluid) of the blood on the walls of the blood vessels. It is determined by cardiac output, resistance of the vessels, and the volume of the blood. Since bloodflow in the body is determined by a pressure gradient, blood pressure is highest in the arteries closest to the heart, and decreases as blood travels throughout the systemic circuit.

Arteries, having muscular and elastic walls, expand when the blood pushes more forcefully against the vessel walls, then recoil when the force of blood on the vessel wall is less. This produces a pulse-like flow of blood through the arteries, such that the pressure increases when the heart is contracting, and decreases when the heart is relaxing during each heartbeat. Blood pressure measurements thus have two components: one that reflects the pressure when the heart is in systole (**the systolic pressure**), and one that reflects the pressure when the heart is in diastole (**the diastolic pressure**).

The Wikipedia image below is a graphical depiction of the pulsatile flow of blood in arteries. The pressure fluctuates dramatically in the left ventricle, at the far left of the graph. Vessels that are closer to the heart also show clear pressure fluctuations of about 40 mmHg. As blood moves into arteries that are further away from the heart, the pressure fluctuations decrease and diminish completely when the blood reaches the capillaries. See the link:

https://en.wikipedia.org/wiki/Blood_pressure



Measuring blood pressure with a sphygmomanometer

Blood pressure is commonly measured using two instruments: a stethoscope, to listen for sounds created by turbulent bloodflow in an artery, and a sphygmomanometer (blood pressure cuff), to temporarily occlude the artery and measure the systolic and diastolic pressures in that vessel.



By BruceBlaus - Own work, CC BY-SA 4.0,
<https://commons.wikimedia.org/w/index.php?curid=47242985>

The cuff is placed around the arm, and the bladder inside is inflated to a pressure higher than the systolic pressure. This occludes the brachial artery and prevents bloodflow to the forearm. A stethoscope is used to listen for the **sounds of Korotkoff** as the pressure is released slowly. When the pressure in the cuff exceeds that in the brachial artery, and this vessel is completely occluded, there are no sounds heard in the stethoscope because there is no bloodflow. At the point where the pressure in the cuff is just below the systolic pressure in the brachial artery, blood begins to flow into the forearm again and soft tapping or whooshing sounds can be heard. As the pressure in the cuff is decreased further and bloodflow in the brachial artery increases, the sounds become louder. When the pressure in the cuff is lowered so that the bloodflow in the brachial artery is no longer occluded and blood flows freely, the sounds of Korotkoff disappear. The pressure reading where the sounds of Korotkoff first appear is the systolic pressure, and the pressure reading where the sounds disappear is the diastolic pressure.

Activity 1 – Measuring Blood Pressure

In this activity you will learn how to measure blood pressure manually, using a sphygmomanometer and a stethoscope. You should work in pairs. One student will measure blood pressure and the other will be the subject, then you should switch.

Materials

- Stethoscope
- Blood pressure cuff (adult-sized; you may need a pediatric cuff or an extra-large cuff, depending on the size of the volunteer)
- Alcohol wipes

Procedure

1. Clean the earpieces of the stethoscope with the alcohol wipes. Be sure the cuff is deflated.
2. Have the subject sit comfortably with their arm on the lab bench, so that the arm is about the level of the heart. Wrap the cuff around the arm (above the elbow). The cuff may be marked with an arrow to indicate the position of the cuff relative to the brachial artery. Secure the cuff with the Velcro®
3. Locate the brachial artery location in the antecubital fossa. Place the diaphragm of the stethoscope over the pulse point. Place the earpieces of the stethoscope in your ears, pointing forward.
4. Adjust the screw valve of the bulb so that air will not flow out of the cuff. Squeeze the bulb to inflate the cuff to a pressure greater than 160 mmHg. The pressure in the cuff can be monitored by watching the pressure gauge.
5. Loosen the screw valve of the bulb so that the pressure in the cuff decreases slowly. Listen for soft tapping, thudding, or whooshing sounds which accompany the turbulent bloodflow through the partially occluded brachial artery. Mentally note the pressure reading on the gauge when these sounds are first heard – this is the **systolic pressure**.
6. Continue to decrease the pressure in the cuff, and note the pressure reading on the gauge when the sounds disappear. This is the **diastolic pressure**.
7. Deflate the cuff after the diastolic pressure has been determined. Re-inflate the cuff and repeat the determination.

After you've made two determinations on the subject, switch places so that both students have a chance to measure blood pressure. **Record the measurements in the data table (below).**

Data Table - Systolic and Diastolic Pressures in a Subject at Rest

Trial	Systolic pressure (mm Hg)	Diastolic pressure (mm Hg)
1		
2		

Effects of Various Stimuli on Blood Pressure and Heart Rate

A simple mathematical equation describes the relationship between blood pressure, cardiac output and peripheral resistance:

$$BP = CO \times R$$

It is easily seen that blood pressure is directly related to both cardiac output (the amount of blood pumped out of the heart in a single heartbeat) and the resistance to blood flow. Many factors can change blood pressure by changing either CO or PR. The following two activities look at some of these factors.

Activity 2 – Effect of position on BP and heart rate (measured as pulse)

In this activity, you'll be measuring blood pressure and heart rate in a subject as they change position (from lying down to standing). You should work in groups of 4 – at least 2 of the same sex in a group. Choose a person to be the subject and one to be the data recorder. The remaining 2 members will measure radial pulse and BP. The blood pressure cuff should remain attached to the subject's arm, although deflated, in-between measurements.

Materials

- Stethoscope
- Blood pressure cuff (adult-sized; you may need a pediatric cuff or an extra-large cuff, depending on the size of the volunteer)
- Alcohol wipes

NOTE – an automated blood pressure cuff may be useful to quickly determine the subjects' blood pressure as they change position.

Procedure

1. Take a "baseline" reading of pulse and blood pressure with the subject sitting quietly. Repeat these measurements and record BOTH readings. Record data in the following data sheet.
2. Let the subject recline (lay down) for 2-3 minutes, then record BP and pulse.
3. Have the subject stand, and IMMEDIATELY record blood pressure and pulse. Measure again after 2 -3 minutes, and record.
4. Allow the subject to remain standing for 2 – 3 minutes, then record BP and pulse rate again. Record the data.
5. REPEAT steps 2-4, having the subject lay down for 2 – 3 minutes, recording pulse and BP. Record both trials in the following data table.

Data Table – Effect of Position on BP and HR

Effect of Position or Posture				
	Trial 1		Trial 2	
	Blood Pressure	Heart Rate	Blood Pressure	Heart Rate
Resting quietly, sitting upright				
Reclining, laying down after 2 – 3 minutes				
Immediately upon standing from a reclined position				
After standing at attention for 3 minutes				

Check your understanding

In which position (sitting, reclining / laying down, standing) is the blood pressure normally the highest? The lowest? **HINT – you might look at this link...**

<https://www.belmarrahealth.com/blood-pressure-differences-when-lying-down-standing-up-and-sitting/>

What immediate changes did you observe when the subject stood up after sitting or reclining?

After the subject had been standing for 3 minutes, what changes in blood pressure were observed?

Activity 3 – Effect of a noxious stimulus (cold) on HR and BP

In this activity, you'll examine the effects of a noxious stimulus on blood pressure and heart rate. Work in groups of 4. Choose a person to be the subject and one to be the data recorder. The remaining 2 members will measure radial pulse and BP. The blood pressure cuff should remain attached to the subject's arm, although deflated, in-between measurements.

Materials

- Stethoscope
- Blood pressure cuff (adult-sized; you may need a pediatric cuff or an extra-large cuff, depending on the size of the volunteer)
- Alcohol wipes

NOTE – an automated blood pressure cuff may be useful to quickly determine the subjects' blood pressure as they change position.

Procedure

1. Take one recording of baseline pulse and BP while the subject is sitting quietly. Record in the following data sheet.
2. Place the subject's non-cuffed hand (the hand on the arm that does NOT have the BP cuff) in a basin of ice water (temperature ~ 5°C). Record the pulse and BP at one-minute intervals for a period of 3 minutes.

	Effect of a Noxious Stimulus (Cold)							
	Baseline		1 minute		2 minutes		3 minutes	
subject	HR	BP	HR	BP	HR	BP	HR	BP
1								
2								
3								
4								

Check your understanding

What was the effect of immersing the subject's hand in ice water on HR and BP?

What might you expect to see if the subject had been exposed to heat?

Exit Ticket: Before you leave lab today, answer the following questions.

Describe the change you saw in BP and HR when your subject stood up after reclining for several minutes. How can you explain this change?

Structure of the Cardiovascular System: Blood

Introduction

Blood is a liquid connective tissue. Red and white blood cells, and cell fragments called platelets are suspended in a liquid matrix (plasma). Blood serves to deliver oxygen and nutrients to tissues, remove wastes. It also serves to deliver immune system cells to tissues, and regulate body temperature. In these laboratory activities, we'll be focusing on the formed elements in blood: identifying them and their functions. We'll also be looking at what determines blood types in the ABO blood typing scheme.

Learning Objectives

By the end of this lesson you will be able to:

- Define the following terms
 - Formed element Granulocytes
 - Plasma Agranulocytes
 - Buffy coat Polycythemia
 - Erythrocytes Anemia
 - Leukocytes Agglutination
 - Platelets Hematocrit
 - Hemoglobin
- Name the major components of blood and identify the percentage of each present in whole blood
- Identify red blood cells, leukocytes, and platelets microscopically; and give their relative percentages / abundance
- Compare and contrast the morphological features of erythrocytes and white blood cell types that are present in blood; to classify the white blood cells (leukocytes) as granulocytes or agranulocytes
 - Neutrophils
 - Lymphocytes
 - Monocytes
 - Eosinophils
 - Basophils
- Identify the white blood cell types on a microscope slide or a diagram, and to state their function

- Conduct ABO and Rh blood typing on simulated blood samples, and state the importance of this test
 - Identify the antigens present in types A,B, O
 - Identify the antibodies present in the plasma in types A,B,O
 - Identify the antibodies that will produced agglutination when mixed with types A,B,O
 - Distinguish between Rh+ and Rh- blood types
- Predict which blood types are compatible and what happens when the incorrect ABO / Rh blood type is transfused
- Identify the ABO blood types that are considered to be “universal donor,” and “universal recipient,” and defend your choices

Background

The components of whole blood are **plasma** (the liquid matrix), accounting for 55% of the volume, and the **formed elements** (red blood cells, white blood cells and platelets), which account for the remaining 45% of volume. Plasma is a straw-colored liquid consisting of 90% water, salts and proteins that are important for maintaining osmotic balance, buffering against pH changes, maintaining blood viscosity, transporting certain materials, and for blood clotting when a blood vessel is injured. There are three major formed elements – **red blood cells (erythrocytes)**, **white blood cells (leukocytes)**, and **platelets (which are cell fragments)**.

Red blood cells, the most numerous cells in the blood, carry oxygen from the lungs to all parts of the body. A red blood cell is a biconcave disk with a thin center, a shape that provides a large surface area for efficient diffusion of oxygen, and the flexibility to pass through even the smallest blood vessels. Red blood cells contain the protein **hemoglobin** which has an iron ion incorporated into its structure. When blood travels through the lungs, the oxygen in the lungs combines with the iron in the hemoglobin. When the blood moves through the body's capillary system, the oxygen carried in the red blood cells is released from the iron to the other cells of the body.

White blood cells make up only about 1% of the blood volume. They are an important part of the immune system. Their primary function is to provide defense against invaders in the body, which may include bacterial, parasites, fungi, and viruses. White blood cells may attack a foreign body directly, produce antibodies that identify, attach to and neutralize a foreign body, or they may trigger other cells to act in destroying the foreign body.

Platelets perform a vital function in the process of coagulation, or blood clotting, which occurs when a blood vessel is injured.

FORMED ELEMENTS

Erythrocytes (Red Blood Cells)

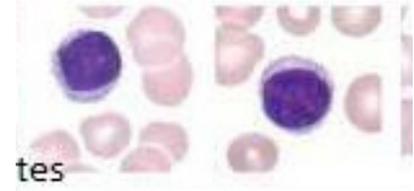
Erythrocytes are the cells that carry oxygen to tissues and waste products (like CO₂) back to the lungs. They have a unique, biconcave-disk shape that is reminiscent of an old-timey dough drop: thin in the center, but thicker at the periphery. Erythrocytes have no nuclei and almost no organelles, but do contain large amounts of the oxygen-binding protein **hemoglobin**. Some estimates indicate there are as many as 300 million hemoglobin molecules per red blood cell. Erythrocytes are the most numerous formed elements.

Leukocytes (White Blood Cells)

Leukocytes are usually divided into two groups, based on the presence of granules that appear in the cytoplasm when stained: **granular leukocytes** (which contain granules), and **agranular leukocytes** (without granules). Leukocytes have immune functions.

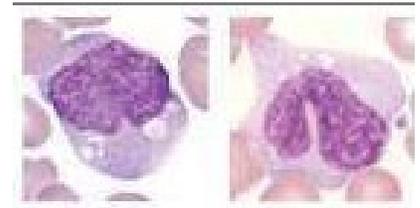
Agranular leukocytes: Lymphocytes

Lymphocytes are small cells that are notable for the large, darkly staining nucleus surrounded by a thin crescent of cytoplasm. These are the second-most numerous leukocytes.



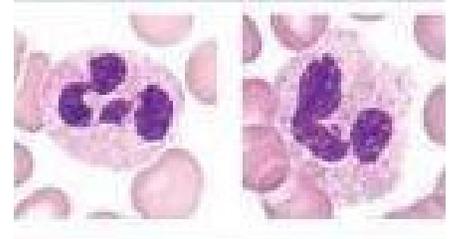
Agranular leukocytes: Monocytes

Monocytes are large cells that have a large, horseshoe shaped or U-shaped nucleus. The surrounding cytoplasm tends to be light blue when stained.



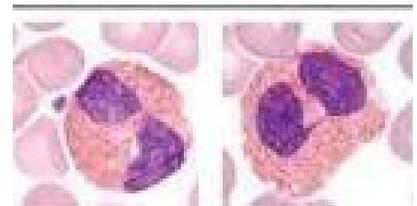
Granular leukocytes: Neutrophils.

Neutrophils are so named because they do not interact strongly with a dye (hence, NEUTR-ophils). The cytoplasm may have a pink-ish or purplish tint and the granules may be pink or purple. They are notable for their multi-lobed nuclei in mature cells (although less-mature cells may have a horseshoe or U-shaped nuclei, making them difficult to distinguish from monocytes). Neutrophils are the most common leukocyte.



Granular leukocytes: Eosinophils

Eosinophils interact strongly with the acidic dye eosin, which stains the granules an orange color (and give them their name, EOSIN-ophils). The nuclei of eosinophils are lobed, like neutrophils, but the bright red-orange granules make these cells distinctive.



Granular leukocytes: Basophils

Basophils are small cells that interact strongly with basic dye (and so are named BAS-ophils), which stains the granules in the cytoplasm a dark blue color. The nuclei are often not visible through the dark granules. Basophils are the least numerous leukocytes.



Platelets

Platelets are not cells, but rather cell fragments and thus are quite small. They have no organelles or nuclei, and their cytoplasm often stains purple or blue. They contain granules which may also stain dark blue or purple. Platelets play important roles in blood clotting.

Below is a table from OpenStax (Figure 18.15) that summarizes the appearance and functions of the formed elements in the blood. See the link:

https://openstax.org/books/anatomy-and-physiology/pages/18-3-erythrocytes#fig-ch19_03_01

Formed element	Major subtypes	Numbers present per microliter (μL) and mean (range)	Appearance in a standard blood smear	Summary of functions	Comments
Erythrocytes (red blood cells) 		5.2 million (4.4–6.0 million)	Flattened biconcave disk; no nucleus; pale red color	Transport oxygen and some carbon dioxide between tissues and lungs	Lifespan of approximately 120 days
Leukocytes (white blood cells)		7000 (5000–10,000)	Obvious dark-staining nucleus	All function in body defenses	Exit capillaries and move into tissues; lifespan of usually a few hours or days
	Granulocytes including neutrophils, eosinophils, and basophils	4360 (1800–9950)	Abundant granules in cytoplasm; nucleus normally lobed	Nonspecific (innate) resistance to disease	Classified according to membrane-bound granules in cytoplasm
	Neutrophils 	4150 (1800–7300)	Nuclear lobes increase with age; pale lilac granules	Phagocytic; particularly effective against bacteria. Release cytotoxic chemicals from granules	Most common leukocyte; lifespan of minutes to days
	Eosinophils 	165 (0–700)	Nucleus generally two-lobed; bright red-orange granules	Phagocytic cells; particularly effective with antigen- antibody complexes. Release antihistamines. Increase in allergies and parasitic infections	Lifespan of minutes to days
	Basophils 	44 (0–150)	Nucleus generally two-lobed but difficult to see due to presence of heavy, dense, dark purple granules	Promotes inflammation	Least common leukocyte; lifespan unknown
	Agranulocytes including lymphocytes and monocytes	2640 (1700–4950)	Lack abundant granules in cytoplasm; have a simple-shaped nucleus that may be indented	Body defenses	Group consists of two major cell types from different lineages
	Lymphocytes 	2185 (1500–4000)	Spherical cells with a single often large nucleus occupying much of the cell's volume; stains purple; seen in large (natural killer cells) and small (B and T cells) variants	Primarily specific (adaptive) immunity; T cells directly attack other cells (cellular immunity); B cells release antibodies (humoral immunity); natural killer cells are similar to T cells but nonspecific	Initial cells originate in bone marrow, but secondary production occurs in lymphatic tissue; several distinct subtypes; memory cells form after exposure to a pathogen and rapidly increase responses to subsequent exposure; lifespan of many years
	Monocytes 	455 (200–950)	Largest leukocyte with an indented or horseshoe-shaped nucleus	Very effective phagocytic cells engulfing pathogens or worn out cells; also serve as antigen-presenting cells (APCs) for other components of the immune system	Produced in red bone marrow; referred to as macrophages after leaving circulation
Platelets 		350,000 (150,000–500,000)	Cellular fragments surrounded by a plasma membrane and containing granules; purple stain	Hemostasis plus release growth factors for repair and healing of tissue	Formed from megakaryocytes that remain in the red bone marrow and shed platelets into circulation

Figure 18.5 Summary of Formed Elements in Blood

Activity 1 – Virtual Microscopy of a Blood Smear

The University of Michigan School of Medicine has a virtual histology site with several blood smear slides:

<http://virtuallslides.med.umich.edu/Hematopathology/Hematology%20Lab/Hematology%20Lab%20Normal2%2063X.svs/view.apml?>

This site has images that “work” like a microscope – that is, you can zoom in, move the image to change the field of view. Using the slides labeled Hematology Lab Normal1 and Hematology Lab Normal2, identify the white blood cells that were described above.

Create and upload an image of each formed element OR draw what you see using colored pencils. Be sure you indicate that magnification of each image. For each formed element, label the nucleus and give a brief explanation as to why this image represents that particular formed element.

Formed Element	Image / Magnification	This image represents this formed element because....
Erythrocyte		
Platelet(s)		
Monocytes		
Neutrophils		
Lymphocytes		
Eosinophils		
Basophils		

Activity 2 - Fill in the table below with the properties of formed elements.

Formed Element	Nucleus Shape or Appearance	Other Features of the Cytoplasm / Granules	Functions
Erythrocyte			
Basophil			
Eosinophil			
Lymphocyte			
Monocyte			
Neutrophil			

Activity 3 - Differential White Blood Cell Counts

Most of you will never do differential white blood cell counts on the job but you should know how counts can be used to diagnose infections. You should suspect bacterial infections if the number of neutrophils are high; viral infection if lymphocytes are high; parasitic worms if eosinophil counts are high (although allergy is a possibility too); and HIV / AIDS if lymphocyte counts are low. You should know that high numbers of band neutrophils suggest acute bacterial infections. "Bands" are replacement neutrophils that are just entering circulation. Their nuclei are band-shaped, unlike the segmented nuclei of mature neutrophils (called "segs"). You should know that atypical lymphocytes are an important indicator of infectious mononucleosis. These cells are transformed T lymphocytes responding to B lymphocytes which are infected with the Epstein-Barr virus. Atypical lymphocytes are irregularly shaped because the cytoplasm is frequently indented by the surrounding red blood cells. You can see pictures of these white blood cells below.

Before you begin the differential count, fill in the blanks from the reading above.

High numbers of neutrophils suggest _____ infections.

High numbers of lymphocytes suggest _____ infections.

High numbers of eosinophils suggest _____ or _____.

Low numbers of lymphocytes suggest _____.

High numbers of band neutrophils suggest acute _____ infections.

The presence of atypical lymphocytes suggest _____.

Equipment Needed

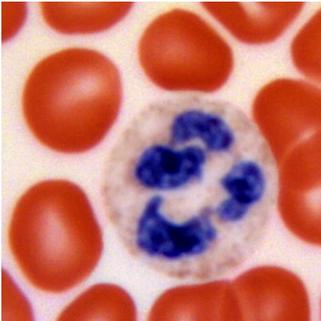
- simulated blood smears of 5 patients, each with 100 white blood cells
- “key” with pictures of each formed element (below)
- table to record observations and counts (below)

Procedure

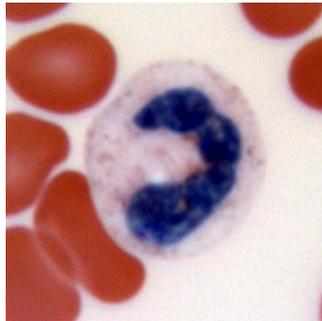
1. Using the key, identify every white blood cell in the simulated smear for each patient
2. Record the numbers of each white blood cell in Table 1. Be sure that you record the counts for the correct patient. The total number of white blood cells for each patient should total 100.

Key

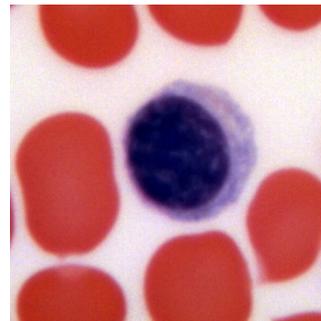
Segmented neutrophil



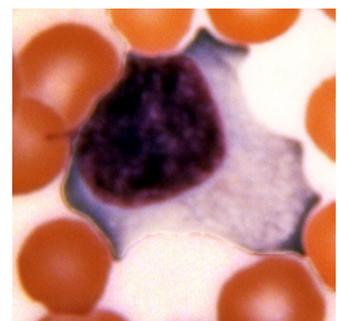
Band neutrophil



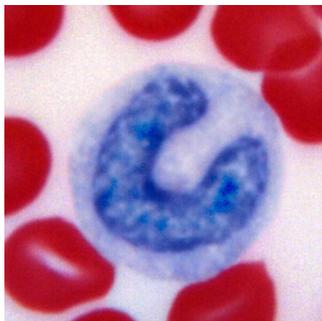
Lymphocyte



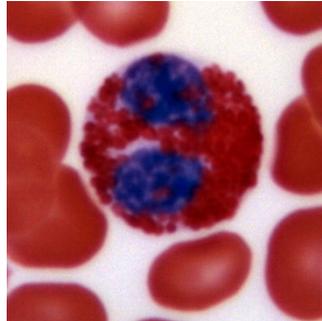
Atypical lymphocyte



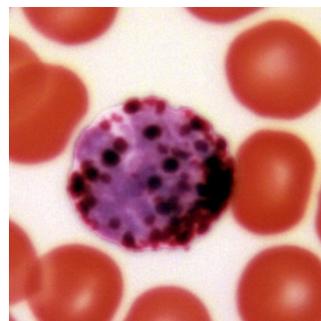
Monocyte



Eosinophil



Basophil



Data Table - Differential WBC counts for five patients.

Patient #	1	2	3	4	5
"Segs" (normal = 50 – 65%)					
"Bands" (normal = 0 – 3%)					
Normal Lymphocytes (normal = 20 – 40%)					
"Atypical Lymphocytes" (normal = 0 – 1%)					
Monocytes (normal = 2 – 8%)					
Eosinophils (normal = 1 – 4%)					
Basophils (normal = 0.5 – 1%)					
Diagnosis?					

See <https://medlineplus.gov/ency/article/003657.htm> for some ranges of normal values.

Next, using the below information, decide which diagnosis is appropriate for each patient. (One patient will be a normal, or control, patient). Write the diagnosis in the last row of the above table.

- High eosinophils often indicate parasites
- High neutrophils with high bands indicate acute bacterial infection
- High lymphocytes plus atypical lymphocytes suggest viral mononucleosis
- Low lymphocytes suggest HIV/AIDS. Keep in mind that the counts of other leukocytes will seem high when lymphocyte counts are low.

Check your understanding

The developed world has a lower incidence of parasites than the developing world. If your patient has high levels of eosinophils, what would be a good follow-up question to ask?

The immune system usually increases lymphocytes when fighting viral infections. Why, then, are lymphocyte levels LOW in patients with HIV/AIDS?

Which one of patients 1 – 4 most likely contracted an infection during surgery? Explain your answer.

What concern should you have if the patient with infectious mononucleosis is a high school football player?

Blood Types and Blood Typing

In this exercise, you will determine the blood type of four different synthetic blood samples using antisera to the A, B, and Rh (D) antigens that exist on human red blood cells. The procedure for the blood test is the same that would be used for a real blood test, but for convenience and safety, the blood and antisera are synthetic and contain no biological materials.

Blood Types

Although the basic composition and function of blood in each of us is the same, there are different human blood types. The cell membrane of red blood cells, like that of other cells, has molecules that project from its surface. Some of the molecules function as identification badges, allowing the immune system to recognize the cell as normal component of an individual's body. If blood from a person whose red cells have different surface molecules is injected into someone, those molecules are recognized as foreign to the body, or antigenic. The immune system attacks the antigens and attempts to destroy them and the cells that carry them. This is why transfusion with an incompatible blood type is harmful. The recipient's body recognizes the antigens on the transfused red blood cells as foreign and attacks and destroys the cells. For that reason, donated blood is thoroughly tested for A, B, O and Rh antigens, and is transfused only into compatible recipients.

The ABO Blood Groups

The ABO blood groups (types) result from the presence or absence of two antigens, A and B, on the surface of the red blood cells. If antigens are present very early in life, the immune system recognizes those antigens as "self" and will not generate an immune response to them. As a result, the body does not generate antibodies to any A and B antigens present on its own blood cells. However, the immune system does produce antibodies to any A and B blood antigens not present on the organism's own cells. Type A blood has the A antigen on its red blood cells and anti-B antibodies in the plasma. Type B blood has the B antigen on its red blood cells and A antibodies in the plasma. Type AB blood has both A and B antigens on the red blood cells and no antibodies in the plasma. Finally, type O blood has neither A nor B antigens on the red blood cells and both A and B antibodies in the plasma. These antibodies are present even if the person has not had any foreign blood introduced into their body. It is hypothesized that the antibodies are present because of similarity between the A and B blood antigens and other antigens present in the environment. If two antigens are similar enough, the antibodies generated to one antigen will also recognize the other.

The relationships of the ABO blood types to the presence of antigens and antibodies in the blood are summarized in the table that follows.

Blood Group	Antigen Present on RBCs	Antibody Present in Plasma
A	A	Anti-B
B	B	Anti-A
AB	A and B	Neither anti-A nor anti-B
O	Neither A nor B	Both anti-A and anti-B

The Rh Blood Groups

Another important antigen found on the surface of blood cells is the Rh factor. The Rh antigen is actually a whole group of closely related antigens. Blood containing an Rh antigen is said to be Rh positive (Rh+); blood lacking the antigen is said to be Rh negative (Rh-). Unlike the case for the ABO antigens, the production of Rh antibody requires prior exposure to the antigen, such as would occur in an Rh- pregnant woman carrying a fetus that was Rh+.

Activity 3 - Predicting the reactions of individual blood types with various anti-sera.

Fill in the table with predictions. Indicate whether you expect to see **agglutination** (“clumping”) or **no agglutination** when each of the following blood types is mixed with each anti-serum. (Anti-serum contains antibodies, so anti-A antiserum contains anti-A antibodies, anti-B antiserum contains anti-B antibodies, and anti-Rh serum contains anti-Rh antibodies)

Data Table – Predicted reactions when different bloodtypes are mixed with various anti-serums.

Blood type	When mixed with anti-A serum....	When mixed with anti-B serum...	When mixed with anti-Rh serum...
A+			
A –			
B+			
B-			
AB+			
AB-			
O+			
O-			

Activity 4 – ABO-Rh Blood Typing with Synthetic Blood
 (Carolina Biological Supply Company; Burlington, NC; www.carolina.com)

Equipment Needed

- simulated blood samples (4), in dropper vials
- simulated anti-A, anti-B, and anti-Rh serum, in dropper vials
- plastic well plates for blood typing
- plastic toothpicks for stirring

Procedure

1. Using the dropper vial, place a drop of Sample 1 in each well of the blood typing slide. To prevent contamination, always close the cap on one vial before opening the next vial.
2. Add a drop of anti-A serum to well A. Close the cap.
3. Add a drop of anti-B serum to well B. Close the cap.
4. Add a drop of anti-RH serum (clear) to well Rh. Close the cap.
5. Using a different mixing stick for each well, gently stir the synthetic blood and antiserum drops for 30 seconds. Remember to use a new mixing stick for each sample to avoid contamination of our samples.
6. Carefully examine the resulting thin films of liquid in each well. If a film is uniform in appearance there is no agglutination. If the sample appears granular, agglutination has occurred.
7. Enter your results in the following data table. Enter YES if agglutination has occurred, NO if there is no agglutination.
8. Get a clean slide and repeat the above steps for samples 2 – 4.

Data Table - Results of mixing synthetic blood samples with various anti-serums.

	Sample 1	Sample 2	Sample 3	Sample 4
Anti-A serum				
Anti-B serum				
Anti-Rh serum				
Blood type?				

Exit Ticket: Before you leave lab today, read the following scenario and answer the following questions.

A crime has been committed: At 1:00am, someone breaks a window in the back of the store and robs the safe. On the way out, the thief is cut on a piece of broken glass. A forensic team collects and tests a sample of blood left behind by the thief. It is type O-. The police bring in a suspect with a cut forearm who was arrested just three blocks from the store. This person resembles someone seen leaving the store at the time of the robbery. A sample of the suspect's blood is taken and tested for blood type.

Once the suspects' blood is mixed with anti-A serum, it is immediately clear that the suspect is NOT the person who was cut on the broken glass in the store. How did the test indicate this?

A crime has been committed: At 1:00am, someone breaks a window in the back of the store and robs the safe. On the way out, the thief is cut on a piece of broken glass. A forensic team collects and tests a sample of blood left behind by the thief. It is type O-. The police bring in another suspect with a cut forearm who was arrested just three blocks from the store. This person resembles someone seen leaving the store at the time of the robbery. A sample of the suspect's blood is taken and tested for blood type.

The suspect's blood does not agglutinate when tested with either anti-A or anti-B serum. However, agglutination is seen when his blood is tested with anti-Rh serum. Does this result connect the suspect to the crime scene? Why or why not?

Functions of the Cardiovascular System: ECG and Heart Sounds

Introduction

In this series of laboratory exercises, you will examine the activity of the cardiovascular system by measuring pulse and blood pressure. Changes in cardiovascular activity that result from several stressors (exercise, change in position, change in temperature) will also be measured. The electrical activity of the heart will be examined using an electrocardiogram, obtained in real time.

Learning Objectives

By the end of this lesson you will be able to:

- Define the following
 - Systole
 - Diastole
 - Cardiac cycle
- To use a stethoscope and a recording microphone to auscultate heart and pulse sounds, and to relate heart sounds to events in the cardiac cycle
- To determine a subject's heart rate by auscultation and by obtaining a radial pulse
- To accurately determine a subject's blood pressure with a sphygmomanometer
- To describe changes in blood pressure that occur with a change in position or in response to a stimulus
- To record an ECG (using three leads), and identify the components of the ECG
- To identify or describe the following structures or processes of importance:

Blood Pressure	ECG and cardiac cycle
Systolic and diastolic pressures	Systole and diastole
sphygmomanometer	Atrioventricular and semilunar valves
stethoscope	Heart sounds
Korotkoff sounds	Atrial and ventricular depolarization
pulse	Atrial and ventricular repolarization
pulse point	P wave, T wave, QRS complex

Background Information

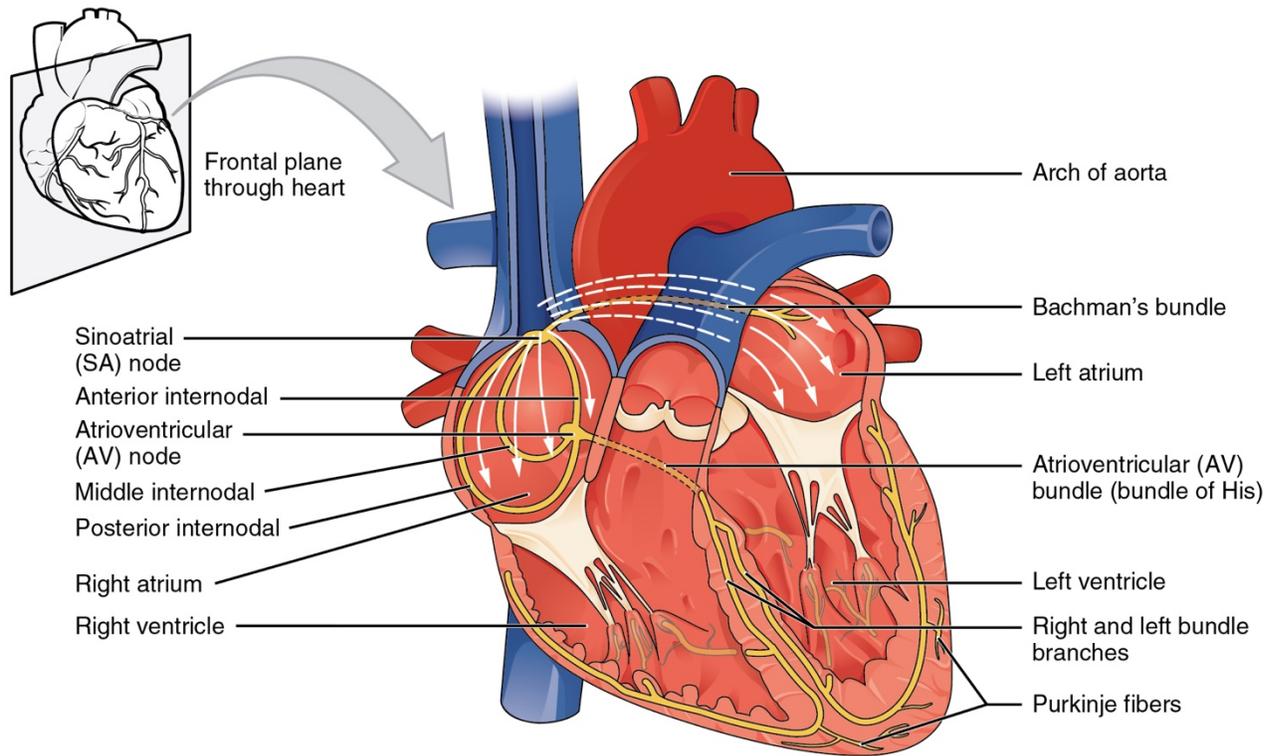
Electrical Conduction in the Heart

The heart is an electrical organ: like skeletal muscles, cardiac cells contract in response to electrical signals (depolarization and repolarization). Unlike skeletal muscle, the electrical signals that produce contraction are generated by specialized heart cells themselves. This means that the electrical signals (and the resulting contractions) will continue even after nerves that stimulate the heart have been cut. The system of specialized conduction cells in the heart is called the intrinsic conduction system because it is intrinsic, or part of, the heart itself.

The components of the conduction system of the heart are shown in the OpenStax figure below, and include the sinoatrial node, the atrioventricular node, the bundle of His, the bundle branches, and Purkinje fibers.

See the link:

<https://openstax.org/books/anatomy-and-physiology/pages/19-2-cardiac-muscle-and-electrical-activity>



Anterior view of frontal section

The depolarizations spread in waves throughout the heart muscle, producing coordinated contractions of the atria and ventricles which are responsible for each heartbeat.

The SA and AV node spontaneously depolarize, generating the electrical impulse (and action potential) that travels throughout the heart muscle via the conduction system. The action potential that is generated in the SA node travels throughout the atrial tissue, depolarizing the muscle cells in both the right and left atria. The action potential reaches the AV node in the “floor” of the right atrium, where it is delayed for about 100msec. From the AV node, the signal travels through the Bundle of His, which divides into the left and right bundle branches. From the bundle branches, the action potentials travel throughout the rest of the ventricular muscle, including the papillary muscles, via the Purkinje fibers.

Although the SA and AV nodes are capable of generating action potentials, the SA node depolarizes more rapidly. This ensures that the impulses initiated at the SA node will be transmitted throughout the heart muscle and thus drive the heart rate. The conduction system forms a pathway through the ventricular tissue, which ensures that the action potential is transmitted in a predictable, repeatable manner – this is important since all of the cells in the heart are electrically active. When this transmission of electrical signals is disrupted, the heart rhythm and function can also be disrupted.

Activity 1 – Location of the conduction system in the heart.

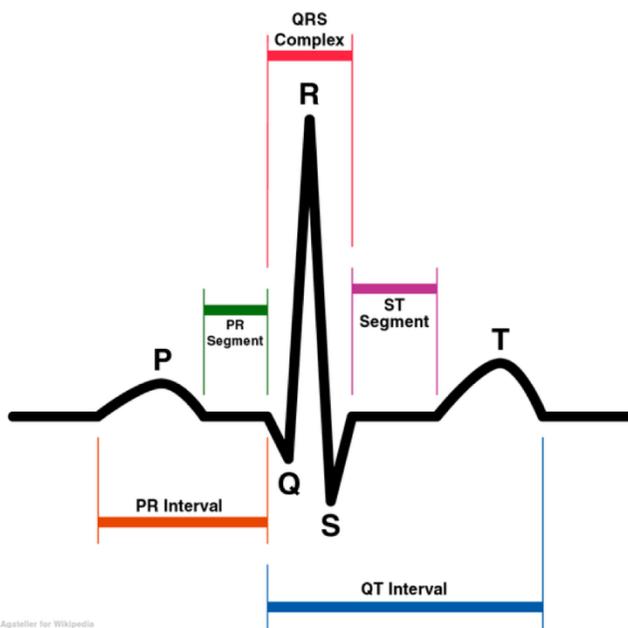
Use the image of the heart to fill in the table with the locations of the components of the conduction system of the heart.

Component	Location
AV node	
Bundle branches	
Bundle of His	
Purkinje fibers	
SA node	

Electrocardiography

The depolarization and repolarization of the heart muscle tissue can be detected on the surface of the body and recorded with an electrocardiograph. The resulting **electrocardiogram** (ECG or EKG) is a graphic representation over time of the electrical changes occurring in the heart. A simplified ECG tracing of a single heartbeat is shown below.

See the link: <https://en.wikipedia.org/wiki/Electrocardiography>



ECG feature	Electrical Event
P wave	Depolarization of the atria
QRS complex	Depolarization of the ventricles
T wave	Repolarization of the ventricles

Created by Agateller (Anthony Atkielski), converted to svg by atom. - SinusRhythmLabels.png, Public Domain, <https://commons.wikimedia.org/w/index.php?curid=15608>
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Electrodes are placed on the surface of the body where the electrical signals can be detected. Electrical activity is described as depolarization and repolarization, which you may remember describe the movement of ions and the change in polarization of the plasma membrane of electrically active tissues. The ECG trace reflects these same overall changes in the electrically active heart muscle tissue, but because the signal is detected and integrated from multiple sites on the body's surface, the distinctive shape of the trace is different from an action potential that can be measured at a single cell.

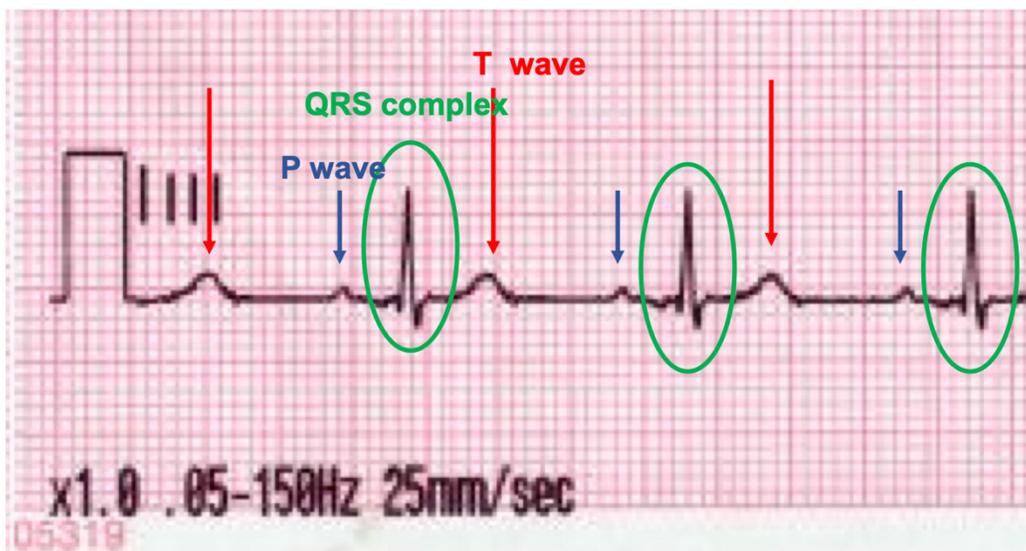
Features of the ECG

Waveforms

Three distinct deflections, or waves, are very evident in the sample ECG. Each deflection corresponds to a particular change in electrical activity in the heart – a discrete event in the cardiac cycle. The **P wave** is seen when the atrial tissue depolarizes, and it is a deflection in the positive (upward) direction. The **QRS complex**, the largest wave. Each “point” of the deflection are labeled with a letter (Q, R, S in order) and the deflection has both positive and negative (or upward and downward) components. The QRS complex is the largest deflection, which reflects the greatest amount of electrical activity in the greatest amount of tissue (the ventricular tissue). The **T wave** is seen when the ventricular tissue repolarizes, and it also is a deflection in the positive direction. This pattern of PQRST deflections repeat with each heartbeat.

A sample ECG recording (from Wikimedia:

https://commons.wikimedia.org/wiki/File:12_lead_generated_sinus_rhythm.JPG) is seen below:



Glenlarsen [Public domain]

https://upload.wikimedia.org/wikipedia/commons/f/f0/12_lead_generated_sinus_rhythm.JPG

Segments

Segments are portions of the ECG found connecting two waves. **The PR segment** is the straight line extending from the end of the P wave to the beginning of the QRS complex. This means that the PR segment represents what is happening between the end of atrial depolarization and the beginning of ventricular depolarization. The **ST segment** is a line that extends from the end of the QRS complex to the T wave. The ST segment represents what is happening between ventricular depolarization and ventricular repolarization. Alterations in the position and shape of the segments provides useful information about the activity of the heart.

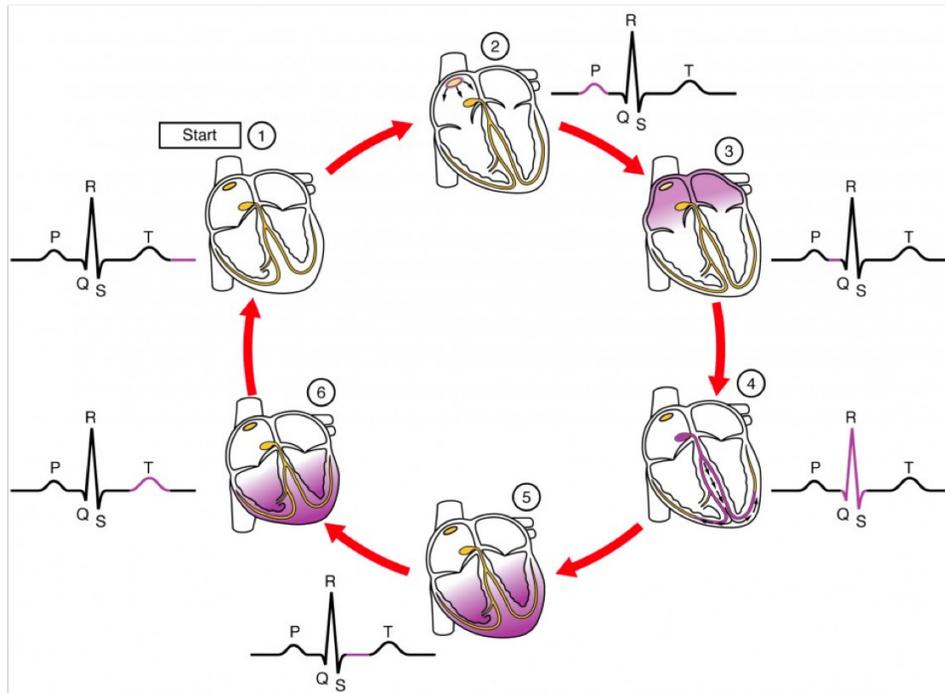
Intervals

Intervals are regions on the ECG that contain BOTH a deflection / wave AND a segment. **The PR interval** extends from the beginning of the P wave to the beginning of the QRS complex (thus, it is composed of the P wave and the PR segment). **The QT interval** extends from the beginning of the QRS complex to the end of the T wave (meaning that it is composed of the QRS complex and the ST segment). Because an interval is composed of both a discrete electrical event and the timeframe until the next discrete electrical event, they are measured in time (milliseconds). Disruptions or changes in the normal duration of intervals provide useful information about the activity of the heart.

This image from LumenLearning (below) correlates the electrical events seen on the ECG trace with the mechanical events of contraction and relaxation in the heart muscle.

Here is the link:

<https://courses.lumenlearning.com/suny-ap2/chapter/cardiac-muscle-and-electrical-activity/>



<https://courses.lumenlearning.com/suny-ap2/chapter/cardiac-muscle-and-electrical-activity/>

1. The atria and ventricles are electrically and mechanically “quiet,” (The atria and ventricles are in diastole.)
2. Depolarization, initiated in the SA node, is spreading throughout the atria. This correlates to the P wave in the ECG.
3. Atrial depolarization is complete. Atrial contraction (systole) is underway. Atrial repolarization has not yet begun, nor has ventricular depolarization. During this part of the ECG, the electrical signal - delayed by the slower depolarization of the AV node - is travelling through the Bundle of His / bundle branches toward the apex of the heart.
4. Ventricular depolarization is underway, as reflected by the large QRS complex seen in the ECG
5. Ventricular contraction (systole) is underway. The ventricles have not yet begun to repolarize.
6. Ventricular contraction is ending, and the muscle cells of the ventricle are repolarizing. Ventricular repolarization is seen as the T wave on the ECG.

Activity 2 - Correlating electrical and mechanical events in the cardiac cycle.

Fill in the table with the mechanical events that are occurring at each part of the ECG (wave, interval, segment).

ECG feature	Electrical event(s) – depolarization, repolarization	Mechanical event(s) – contraction / systole, relaxation / diastole
P wave	Depolarization of the atria	
PR segment	Depolarization conducted through AV node, bundle branches	
QRS complex	Depolarization of the ventricles; Repolarization of the atria	
ST segment	Ventricles remain depolarized	
T wave	Repolarization of the ventricles	
PR interval	Atrial depolarization / repolarization and conduction through conduction system	
QT interval	Ventricular depolarization / repolarization	

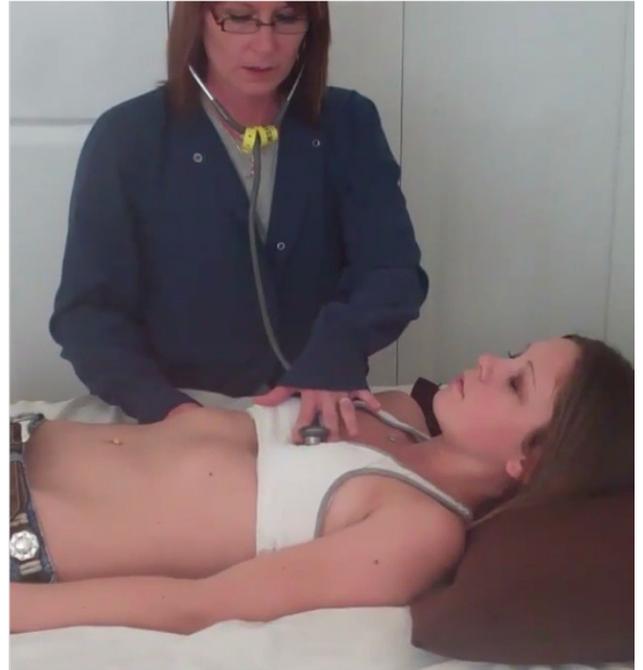
Heart Sounds

Listening to the sounds made by various organs of the body is a very old method of gathering information about the function (or dysfunction) of that organ. **Auscultation** is the process of listening to these sounds, usually with a stethoscope, to aid in making a diagnostic determination. Heart and respiratory sounds are commonly auscultated, as are bowel sounds (or the sounds made by the organs of the alimentary canal as it digests and moves foodstuffs toward the anus).

The photo at the right (from Wikipedia – see the link:

<https://en.wikipedia.org/wiki/Auscultation>)

shows a nurse auscultating the heart sounds of a student using a stethoscope.



In the cardiovascular system, distinct sounds can be attributed to the function of the heart.

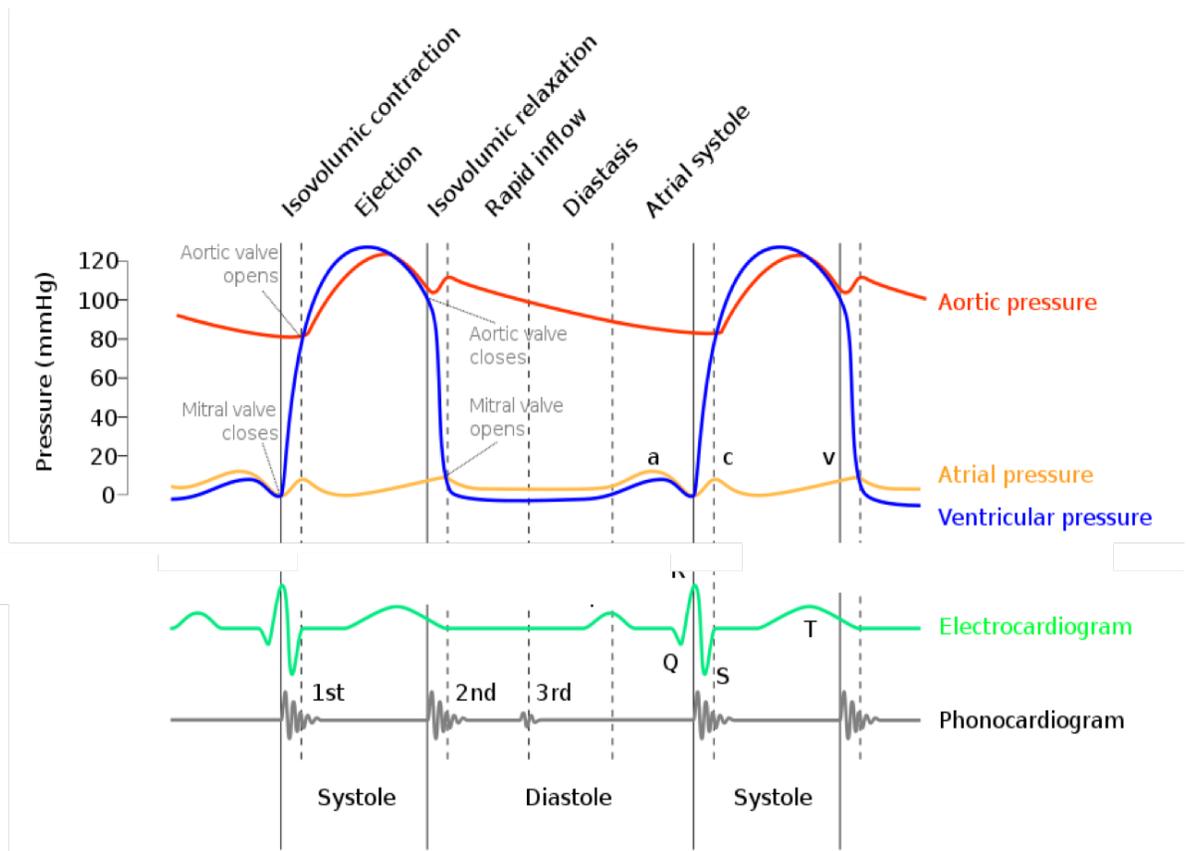
Classically, the sounds associated with a normal heartbeat are described as “lubb-dubb,” technically called the **S1 (“lubb”)** and **S2 (“dubb”)** sounds. The S1 sound is attributed to turbulence in the bloodflow when the AV valves in the heart close after the beginning of ventricular systole. The S2 sound is attributed to turbulent bloodflow that results when the semilunar valves close after the beginning of ventricular diastole. (Two additional sounds, S3 and S4, may also heard, however they are not as loud or easy to identify.)

By Alith3204 - Own work, CC0,
<https://commons.wikimedia.org/w/index.php?curid=84657055>

The relationship between the events of the cardiac cycle, the electrical events of the ECG, and the heart sounds is seen in this graph (modified from Wikipedia) – see the link:

https://en.wikipedia.org/wiki/Cardiac_cycle

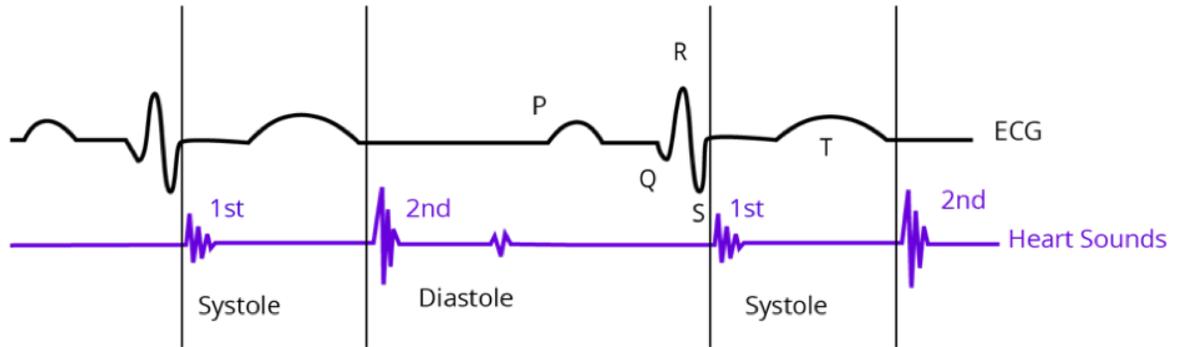
(At this same site, you will find a nice animation of a beating heart that moves in sync with the events of the Wiggers diagram.)



Modified from: adh30 revised work by DanielChangMD who revised original work of DestinyQx;
 Redrawn as SVG by xavax - Wikimedia Commons: Wiggers Diagram.svg, CC BY-SA 4.0,
<https://commons.wikimedia.org/w/index.php?curid=50317988>

Activity 3 – Correlation of heart sounds and electrical events of the ECG.

Draw a circle around the letter of the electrical event (P wave, QRS complex, or T wave) that immediately precedes the 1st heart sound. Using a *different color*, draw a circle around the letter of the electrical event (P wave, QRS complex, or T wave) that immediately precedes the 2nd heart sound.



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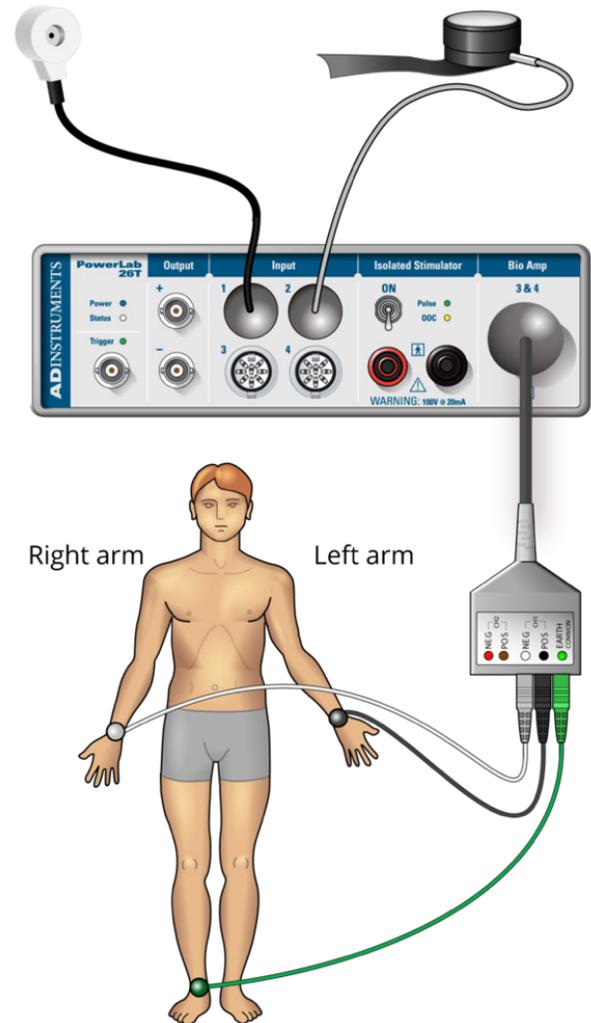
Activity 4 – Recording an ECG

In this activity, you'll be obtaining your own ECG and interpreting the resulting trace. You'll need to be able to access Lt in order to record the data and analyze the resulting trace(s).

Procedure

It is essential for volunteers to keep still and stay relaxed while their ECG is being recorded.

1. The volunteer should relax and sit as still as possible to minimize signal artifacts due to movement.
2. **Start** recording, then **Add** a comment with "Volunteer 1."
3. **Auto scale** as required to ensure that you can see all the data as it is being recorded.
4. If the ECG cannot be seen, check that all the electrodes are correctly attached. If the signal is noisy and indistinct, make sure that the volunteer is relaxed. Consider using the alternative attachment positions.
5. **Stop** recording.
6. **Start** recording again. While recording, ask the volunteer to open and close his or her hands, and then move both arms across the chest. **Stop** recording. This should illustrate how dramatically movement affects readings.
7. With the volunteer sitting quietly, **Start** recording again.
8. Prepare the comment: "Resting ECG - Volunteer 1". When you have a trace without movement artifacts, **Add** the comment.
9. **Stop** recording.



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Analysis

1. Expand your data so that you can observe four of the regularly occurring ECG cycles.
2. To measure the amplitude of the P wave, place the Marker on the baseline immediately before the P wave. Then move the Single Data Handle to the peak of the wave.
3. Enter the number from the Value panel into the table.
4. To measure the duration of the P wave, leave the Marker at the start of the wave and position the Data Handle at the end of the wave.

Repeat steps 2–4 for the QRS complex and T wave.

Enter the values from the VALUE panels into the table:

ECG feature	Amplitude (mV)	Duration (s)
P wave		
QRS complex		
T wave		

Check your understanding:

Describe the physiological events occurring in the heart muscle represented by each ECG component (the P wave, the QRS complex, and T wave). Why does the QRS complex have the largest amplitude?

Activity 5 – ECG and Phonocardiogram

In this exercise you will record an ECG *and* use a Cardio Microphone to record the heart sounds or phonocardiogram (PCG) of a resting volunteer. You will use your recording to measure the time between the peak of the R wave and the beginning of the first heart sound.

Procedure

1. Have the volunteer lie on the yoga mat on the floor (if available) or remain seated quietly while still connected to the ECG. Another group member should help manage the cords.
2. Using the stethoscope, have the volunteer move the bell of over the left side of their chest until you identify the area with the strongest sounds. Have the volunteer temporarily hold the cardio microphone over this area.
3. Keep the cardio microphone firmly in place taping it to the chest wall. You may need to move the microphone wire out of the way and tape it in place also. (Additionally, you might try holding it in place with a book placed on top of it – surprisingly, this has worked well.)
 - Do not hold it in place on the chest wall by hand, as the inevitable movement of the hand introduces considerable noise into the recording.
4. Make sure all electrodes are still firmly attached.
5. Have the volunteer sit or lie in a relaxed position with their hands by their sides.
6. **Start** recording the ECG and PCG. If you cannot see distinct heart sounds, move the cardio microphone to get the best possible PCG.
7. Once you have a good signal (you may need to adjust the horizontal axis and autoscale to visualize the PCG data well), record for about 15 seconds, then **Stop** recording

For the comfort of your volunteer you may want to collect data for the next activity before analyzing your data from this activity.

Analysis

1. Scale your data so it is convenient to view using the Compression buttons for each channel, or by using the Auto Scale button.
2. Drag the Double Data Handles so that they measure from the peak of the R wave to the beginning of the **first heart sound**.
3. Now measure the time between the peak of the T wave and the beginning of the **second heart sound**.
4. Enter the time values in seconds into the table below.

Time from R to first heart sound (s)	T from R to second heart sound (s)

Check your understanding

Explain why the FIRST heart sound is not heard until after the QRS complex.

Explain why the SECOND heart sound is not heard until after the T wave.

Activity 6 – ECG, Phonocardiogram, and Pulse

In this exercise you will record three things: a peripheral pulse, an ECG, and a PCG.

Procedure

1. Check that the Pulse Transducer is connected to Input 2 on the front of the PowerLab unit.
2. With the volunteer still lying flat on the yoga mat or resting quietly in a seated position, place the pressure pad of the Pulse Transducer against the distal segment (the tip) of the middle finger of either hand. Use the Velcro strap to attach it firmly.
3. Make sure all electrodes are still firmly attached.
4. **Start** recording.
5. Record for 60 seconds.
6. **Stop** recording.

Analysis

1. Make sure you have completed the analysis on Page 11 before completing this analysis.
2. Using the Marker and Data Handle, measure the time-to-peak and the total time taken for the finger pulse.
3. Now measure the time from the peak of the R wave to the start of the finger pulse.
4. Finally, measure the time from the peak of the T wave to the peak of the pulse.

Enter your data in the tables below.

Finger Pulse

Start of the pulse upswing to peak (seconds)	Total time (upswing to baseline) (seconds)

ECG and Finger Pulse

R wave to start of pulse upswing (seconds)	T wave to peak of the pulse (seconds)

ECG and phonocardiogram

R wave to first sounds (seconds)	T wave to second sounds (s)

Exit Ticket: Before you leave lab today, answer the following questions.

With respect to the ECG, where is the finger pulse pressure the GREATEST? Where is the aortic pressure the greatest?

Describe the relationships between the ECG, the first and second heart sounds, and the finger pulse.

If you had recorded the pulse at the carotid artery, where might you expect to see the greatest pressure? Explain your answer.

The Respiratory System: Anatomy

Introduction

In this laboratory, you will use models and histological samples to study the anatomy of the respiratory system. As you study the anatomy, be aware of the role that other systems play in respiration, such as the cardiovascular system, which aids in the transport of oxygen and carbon dioxide, and the muscular system, which increases demand for oxygen during times of activity. You will then use observation and a handheld spirometer to determine respiratory rates, lung volumes, and factors that can influence these characteristics.

Learning Objectives

By the end of this lesson you will be able to:

1. Identify the major respiratory system structures on a cadaver specimen, model, or diagram.
2. Describe the functions of each structure within the respiratory system.
3. Identify tracheal or lung tissue on a microscope slide.
4. Identify the major features of tracheal and lung tissue and describe their functions.
5. Identify the following structures of the Upper Respiratory Tract:

External and internal nares	Glottis
Superior, middle, inferior conchae	Nasopharynx
Superior, middle, inferior meatus	Oropharynx
Hard and soft palate	Laryngopharynx
Uvula	Larynx
Epiglottis	Vestibular folds
Vocal folds	Trachea
Pharyngotympanic (auditory) tube	Thyroid cartilage
Arytenoid cartilage	Cricoid cartilage

6. Identify the following structures of the Lower Respiratory Tract:

Trachea	Terminal bronchiole
Cardiac notch	Superior, inferior, middle lobe
Alveolar duct	Hilum
Respiratory bronchiole	Apex
Alveoli	Base
Bronchi (primary, secondary, tertiary)	Visceral and parietal pleura
Pleural cavity	Fissures (horizontal and oblique)
Lung	Alveolar sac
Respiratory membrane	

Background Information

Overview of the Respiratory System

The major organs of the respiratory system function primarily to provide oxygen to body tissues for cellular respiration, to remove the waste product carbon dioxide, and to help maintain acid-base balance. Portions of the respiratory system are also used for non-vital functions, such as sensing odors, speech production, and for straining, such as during childbirth or coughing.

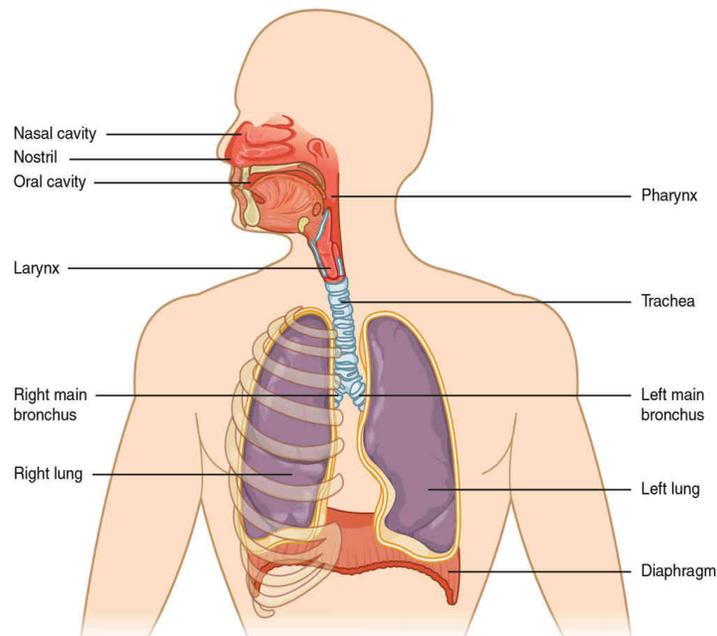


Figure 1. Major Respiratory Structures

The major respiratory structures extend from the nasal cavity to the diaphragm. Functionally, the respiratory system can be divided into a conducting zone and a respiratory zone. The **conducting zone** includes the organs and structures not directly involved in gas exchange, while gas exchange occurs solely in the **respiratory zone**. The major functions of the conducting zone are to provide a route for incoming and outgoing air, remove debris and pathogens from the incoming air, and to warm and humidify the incoming air. Several structures within the conducting zone perform other functions as well.

Source Material

OpenStax, 22.1 Organs and Structures of the Respiratory System. OpenStax CNX. May 2, 2019
<http://cnx.org/contents/b76b2090-243e-429a-8144-2e45bda6ab75@14>.

Nose and Nasal Cartilages

The major entrance and exit for the respiratory system is through the nose. When discussing the nose, it is helpful to divide it into two major sections: the **external nose**, and the **nasal cavity** or **internal nose**.

The **external nose** consists of the surface and skeletal structures that result in the outward appearance of the nose and contribute to its numerous functions (**Figure 2**). The **root** is the region of the nose located between the eyebrows, while the **bridge** is the part of the nose that connects the root to the rest of the nose. The **dorsum nasi** is the length of the nose, while the **apex** is the tip of the nose. On either side of the apex, the nostrils are formed by the **alae** (singular = **ala**), which are cartilaginous structures that form the lateral sides of each **naris** (plural = **nares**), or nostril opening. Each external naris is protected by guard hairs.

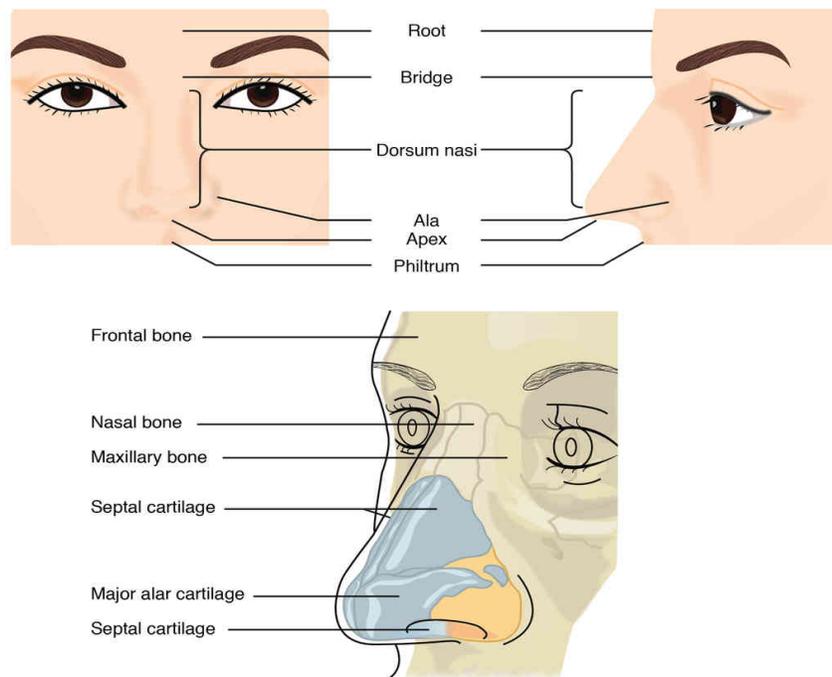


Figure 2. Nose

This illustration shows features of the external (top) and skeletal features of the nose (bottom).

Underneath the thin skin of the nose are its skeletal features (see **Figure 2**, lower illustration). While the root and bridge of the nose consist of bone, the protruding portion of the nose is composed of cartilage. As a result, when looking at a skull, the nose is missing. The **nasal bone** is one of a pair of bones that lies under the root and bridge of the nose. The nasal bone articulates superiorly with the **frontal bone** and laterally with the **maxillary bones**. **Septal cartilage** is flexible hyaline cartilage connected to the nasal bone, forming the dorsum nasi. The **alar cartilage** makes up the apex of the nose and extends to surround each naris.

Internally, the **nares** open into the **nasal vestibule**, which is lined with stratified squamous epithelium. Behind the vestibule is the **nasal cavity**, which is separated into left and right sections by the nasal septum (**Figure 3**). The **nasal septum** is formed anteriorly by a portion of the septal cartilage (the flexible portion you can touch with your fingers) and posteriorly by the perpendicular plate of the ethmoid bone (a cranial bone located just posterior to the nasal bones) and the thin vomer bones (whose name refers to its plough shape). Each lateral wall of the nasal cavity has three bony projections, called the **superior, middle, and inferior nasal conchae** (singular = **concha**). Conchae serve to increase the surface area of the nasal cavity and to disrupt the flow of air as it enters into the nose, causing air to bounce along the epithelium, where it is cleaned and warmed. Each concha overlies a corresponding (superior, middle, inferior) **meatus**, or passageway that leads posteriorly away from the nasal cavity. The conchae and **meatuses** also conserve water and prevent dehydration of the nasal epithelium by trapping water during exhalation. The floor of the nasal cavity is composed of the **palate**. The **hard palate** at the anterior region of the nasal cavity is composed of bone, while the **soft palate**, at the posterior portion of the nasal cavity, consists of muscle tissue. Air exits the nasal cavities via the **internal nares** and moves into the **pharynx** (**Figure 3**).

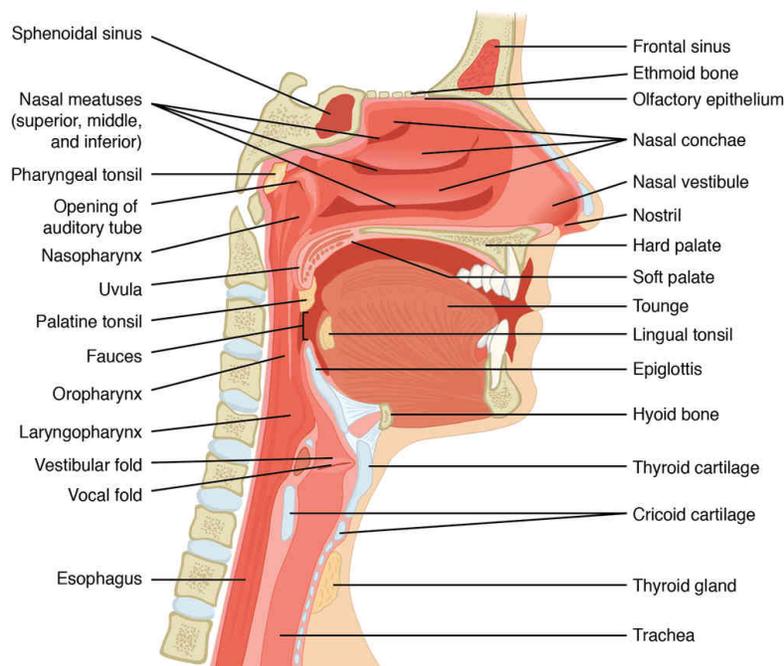


Figure 3. The Upper Airway

Behind the vestibule, the conchae, meatuses, and sinuses are lined by **respiratory epithelium** composed of **pseudostratified ciliated columnar epithelium** (**Figure 4**). The cilia of the respiratory epithelium help remove the mucus and debris from the nasal cavity with a constant beating motion, sweeping materials towards the throat so that it may be swallowed. This moist epithelium also functions to warm and humidify incoming air.

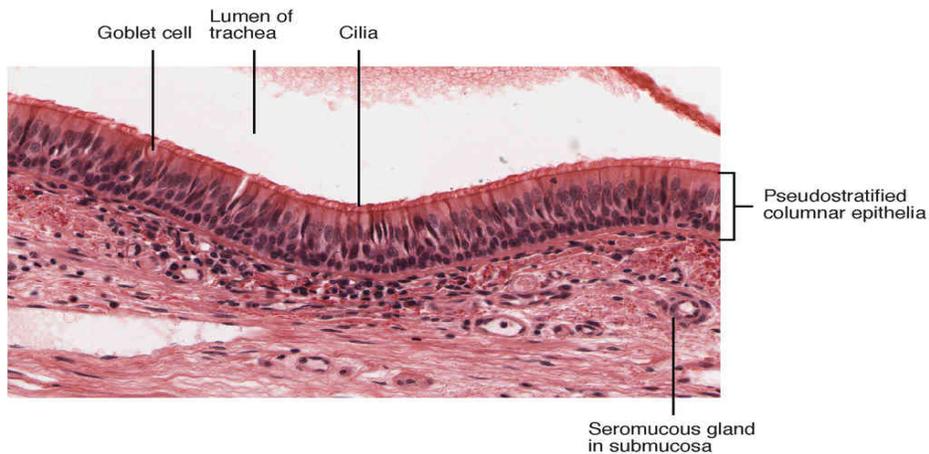


Figure 4. Pseudostratified Ciliated Columnar Epithelium

Respiratory epithelium is pseudostratified ciliated columnar epithelium. Seromucous glands provide lubricating mucus. LM \times 680. (Micrograph provided by the Regents of University of Michigan Medical School \copyright 2012)

Source Material

OpenStax, 22.1 Organs and Structures of the Respiratory System. OpenStax CNX. May 2, 2019
<http://cnx.org/contents/b76b2090-243e-429a-8144-2e45bda6ab75@14>.

Pharynx

The **pharynx** is a tube that is formed by skeletal muscle and lined by a mucous membrane that is continuous with that of the nasal cavities (see **Figure 3**). The pharynx is divided into three major regions: the nasopharynx, the oropharynx, and the laryngopharynx (**Figure 5**).

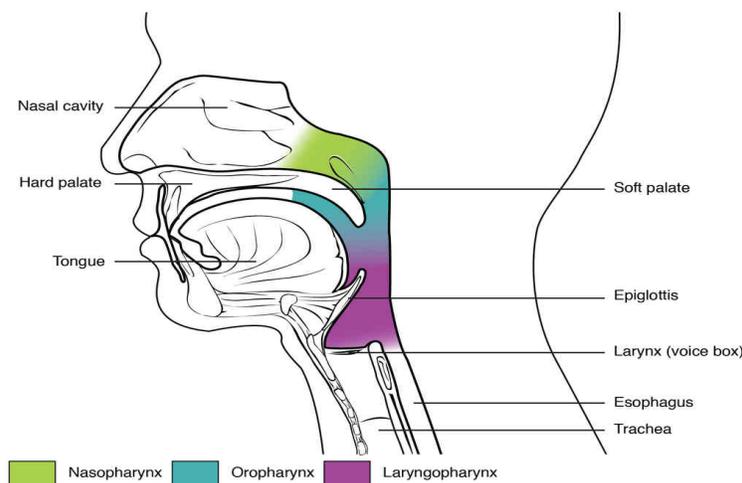


Figure 5. Divisions of the Pharynx

The pharynx is divided into three regions: the nasopharynx, the oropharynx, and the laryngopharynx.

The uppermost **nasopharynx** sits directly posterior to the nasal cavity, and it serves only as an airway. The nasopharynx has two openings on the lateral walls though. These openings are the

auditory (eustachian or pharyngotympanic) tubes, which connect the nasopharynx to each middle ear cavity. These connections are why colds often lead to ear infections. As the pharynx descends behind the oral cavity it becomes the **oropharynx**, which serves as a passageway for both air and food. The **uvula** is a small bulbous, teardrop-shaped structure located at the apex of the soft palate that partially separates the oral cavity from this region. Both the uvula and soft palate move like a pendulum during swallowing, swinging upward to close off the nasopharynx to prevent ingested materials from entering in to the nasal cavity. The most inferior portion of the pharynx is the **laryngopharynx**, which is located posterior to the larynx. It continues the route for ingested material and air until its inferior end, where the digestive and respiratory systems diverge. The stratified squamous epithelium of the oropharynx is continuous with the laryngopharynx. Anteriorly, the laryngopharynx opens into the **larynx**, whereas posteriorly, it enters the **esophagus (Figure 5)**.

Source Material

OpenStax, 22.1 Organs and Structures of the Respiratory System. OpenStax CNX. May 2, 2019
<http://cnx.org/contents/b76b2090-243e-429a-8144-2e45bda6ab75@14>.

Larynx

The **larynx** is commonly known as the “voice box” because it is an important organ for sound production in humans. It is a cartilaginous structure oriented inferior to the laryngopharynx that connects the pharynx to the **trachea** and helps regulate the volume of air that enters and leaves the lungs (**Figure 6**). The larynx occurs about the level of the fourth through sixth cervical vertebrae and consists of a number of cartilages. Three large cartilage pieces—the **thyroid cartilage** (anterior), **epiglottis** (superior), and **cricoid cartilage** (inferior)—form the major structure of the larynx. The thyroid cartilage is the largest piece of cartilage that makes up the larynx. It is a shield-shaped structure made of hyaline cartilage. The thyroid cartilage contains the **laryngeal prominence**, or “Adam’s apple”, which tends to be more prominent in males due to the presence of increased testosterone levels. Inferior to the thyroid cartilage is the **cricoid cartilage**, which forms a ring. The cricoid cartilage also consists of hyaline cartilage and it appears relatively narrow when observed from the anterior, but increases in size at its posterior surface.

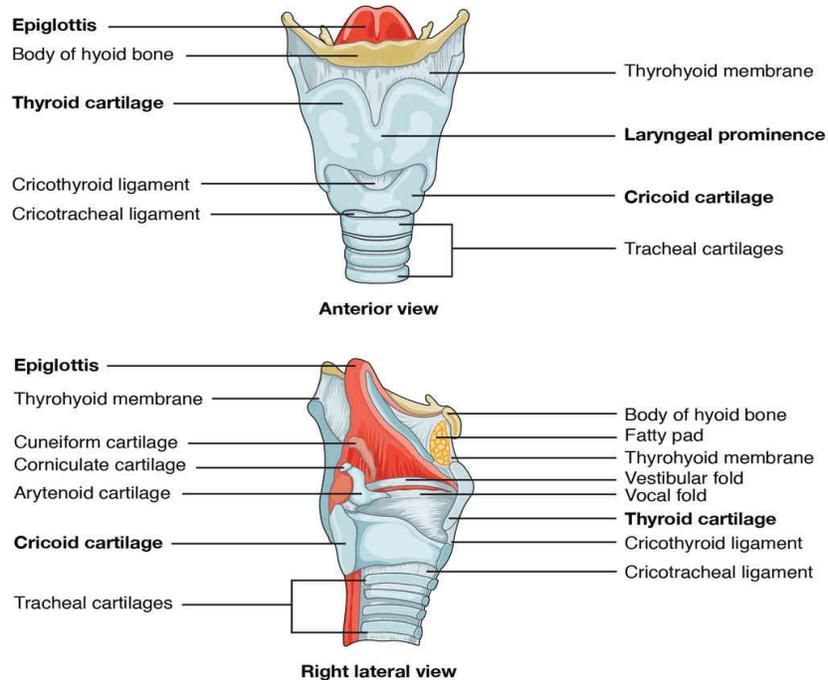


Figure 6. The Larynx

The larynx extends from the laryngopharynx and the hyoid bone to the trachea.

Three smaller, paired cartilages—the **arytenoids**, **corniculates**, and **cuneiforms**—attach to the **epiglottis** and the vocal cords and muscles that help move the vocal cords to produce speech (**Figure 6**). Superior to the cricoid cartilage in the posterior wall of the pharynx are the paired **arytenoid cartilages**. These cartilages attach to the posterior end of the **vocal cords (vocal folds)**. Movement of the arytenoids pulls on the vocal cords, causing them to stretch and increase the pitch of the voice. This requires the contraction of intrinsic muscles attached to the arytenoid cartilages, while the vocal cords are held stationary by the thyroid cartilage anteriorly. Superior to the vocal cords are a folded pair of mucous membranes, known as the **vestibular folds (false vocal cords)** (**Figure 7**). At the posterior, superior edge of the larynx is the **corniculate** and **cuneiform cartilages** (**Figure 6**). Each of this is made from hyaline cartilage.

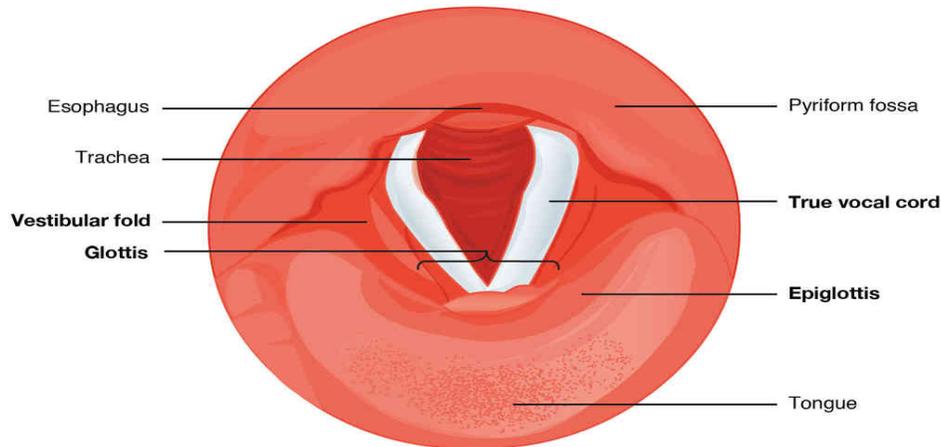


Figure 7. The Vocal Cords

The true vocal cords and vestibular folds of the larynx are viewed inferiorly from the laryngopharynx.

The most posterior cartilage of the larynx is the **epiglottis**, which is composed of elastic cartilage and mucous membrane. This cartilage is a very flexible piece of cartilage that covers the opening of the trachea (**Figure 3**). During swallowing, the epiglottis is pulled down and in to the "closed" position where the unattached end rests on the **glottis**. The glottis is composed of the vestibular folds, the true vocal cords, and the space between these folds (**Figure 7**). The act of swallowing causes the pharynx and larynx to lift upward, allowing the pharynx to expand and the epiglottis of the larynx to swing downward, closing the opening to the trachea. These movements produce a larger area for food to pass through, while preventing food and beverages from entering the trachea.

Source Material

OpenStax, 22.1 Organs and Structures of the Respiratory System. OpenStax CNX. May 2, 2019
<http://cnx.org/contents/b76b2090-243e-429a-8144-2e45bda6ab75@14>.

Trachea and Bronchi

The trachea is commonly known as the "windpipe" because it extends and carries air from the larynx toward the lungs (**Figure 8a**). The trachea is a straight tube whose lumen is kept open by 16 to 20 stacked, C-shaped **tracheal cartilages**. These cartilages are composed of hyaline cartilage and they are connected to one another by dense connective tissue. The trachea is also lined with respiratory epithelium, which is continuous with the larynx (**Figure 8b**). The esophagus borders the trachea posteriorly.

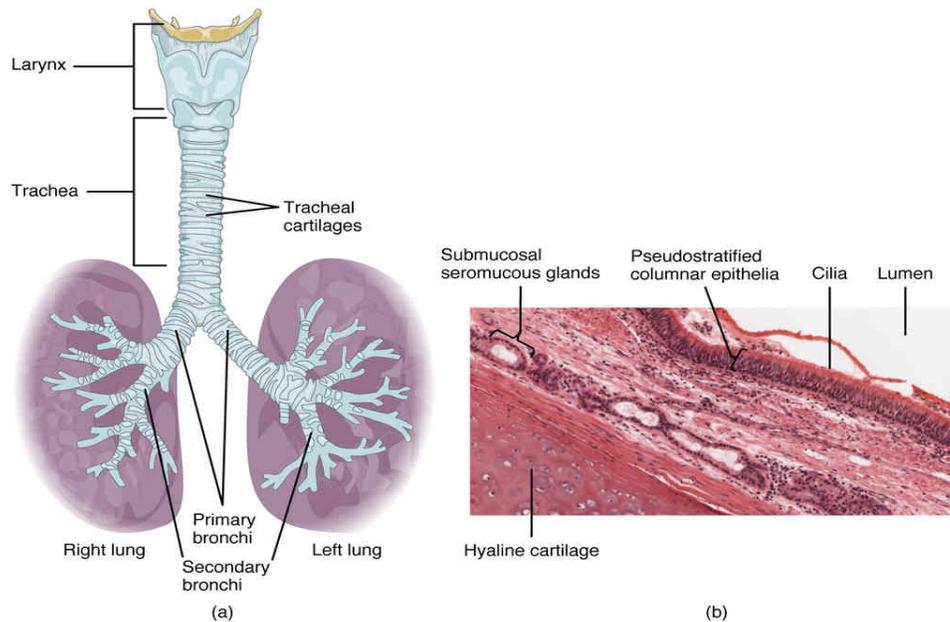


Figure 8. The Trachea

(a) The tracheal tube is formed by stacked, C-shaped pieces of hyaline cartilage. (b) The layer visible in this cross-section of tracheal wall tissue between the hyaline cartilage and the lumen of the trachea is the mucosa, which is composed of pseudostratified ciliated columnar epithelium that contains goblet cells. LM $\times 1220$. (Micrograph provided by the Regents of University of Michigan Medical School \copyright 2012)

Source Material

OpenStax, 22.1 Organs and Structures of the Respiratory System. OpenStax CNX. May 2, 2019
<http://cnx.org/contents/b76b2090-243e-429a-8144-2e45bda6ab75@14>.

Bronchial Tree

At its most inferior end, the trachea branches into two tubes, which enter the lungs. These tubes are the right and left **primary (main) bronchi**. These bronchi are also lined by pseudostratified ciliated columnar epithelium containing mucus-producing goblet cells (**Figure 8b**). Rings of cartilage, similar to those of the trachea, support the structure of these bronchi and prevent their collapse. The primary bronchi enter the lungs at the **hilum (Figure 9)**, a concave region where blood vessels, lymphatic vessels, and nerves also enter the lungs. Once inside the lungs, the main bronchi first divide into **lobar (secondary) bronchi**, which further divide to form the **segmental bronchi (Figure 9)**. This extensive branching of the bronchi produces a structure called a **bronchial tree (respiratory tree)**. The main function of the bronchi, like other conducting zone structures, is to provide a passageway for air to move into and out of each lung. In addition, the mucous membrane of these structures helps to trap debris and pathogens.

The bronchi continue to divide until they become the **bronchioles**, small respiratory tubes with smooth muscle in their walls, no cartilage, and an inner lining of respiratory epithelium (**Figures**

9 and 11). There are more than 1000 **terminal bronchioles** in each lung and the muscular wall can change the size of the tubing to increase or decrease airflow through the tube.

Source Material

OpenStax, 22.1 Organs and Structures of the Respiratory System. OpenStax CNX. May 2, 2019

<http://cnx.org/contents/b76b2090-243e-429a-8144-2e45bda6ab75@14>.

Lungs and Histology

From a gross perspective, the lungs are pyramid-shaped, paired organs that are connected to the trachea by the right and left bronchi. On the inferior surface, the lungs are bordered by the diaphragm (**Figure 10**). The right lung is shorter and wider than the left lung, and the left lung occupies a smaller volume than the right. The **cardiac notch** is an indentation on the surface of the left lung that allows space for the heart (**Figure 9**). The apex of the lung is the superior region, whereas the base is the opposite region near the diaphragm.

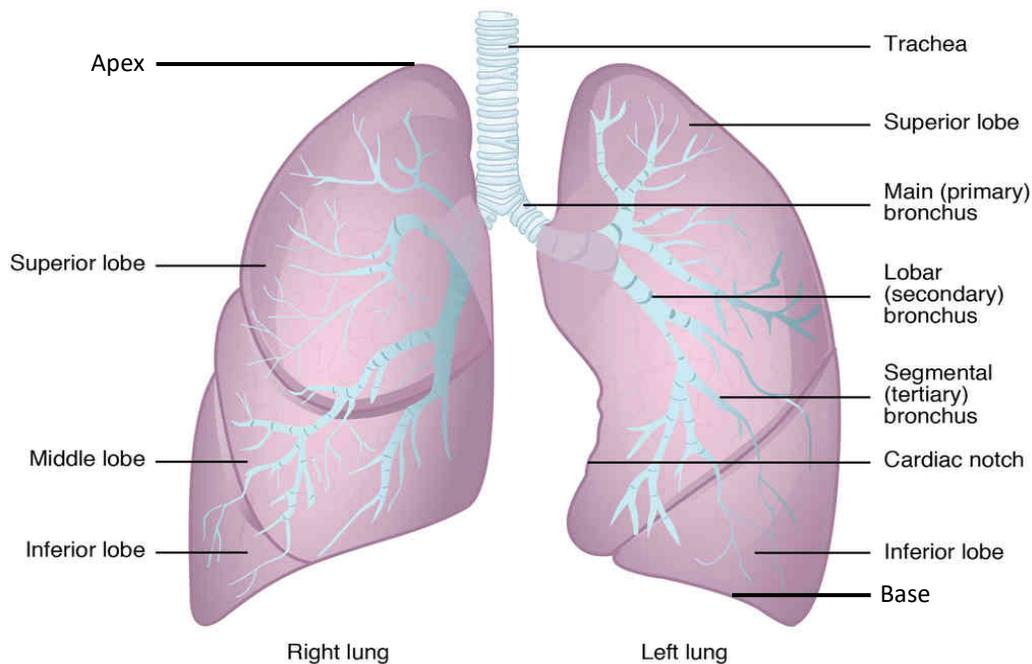


Figure 9. Gross Anatomy of the Lungs

Each lung is composed of smaller units called **lobes**. The right lung consists of three lobes: the **superior**, **middle**, and **inferior lobes**. The left lung consists of two lobes: the **superior** and **inferior lobes** (**Figure 9**). **Fissures** separate these lobes from each other. In the right lung, the upper, **horizontal fissure**, separates the upper from the middle lobes while the lower, **oblique fissure** separates the inferior and middle lobes. Since the left lung only has a superior and inferior lobe, one **oblique fissure** is present, separating these two regions.

The lungs are enclosed by membranous sacs known as the **pleurae**, which are attached to the mediastinum. The pleurae consist of two layers. The **visceral pleura** is the layer that is superficial to the lungs, and extends into and lines the lung fissures (**Figure 10**). In contrast, the **parietal pleura** is the outer layer that connects to the thoracic wall, the mediastinum, and the diaphragm. The visceral and parietal pleurae connect to each other at the **hilum** and the **pleural cavity** is the space that sits between these layers.

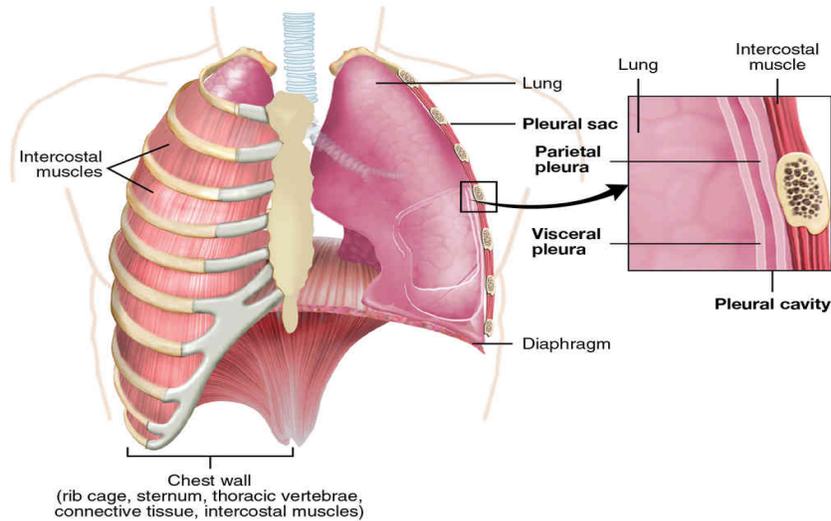


Figure 10. The Parietal and Visceral Pleurae of the Lungs

The pleurae perform two major functions: They produce pleural fluid and create cavities that separate the major organs. **Pleural fluid** is secreted by mesothelial cells from both pleural layers and it helps to reduce friction between the two layers to prevent trauma during breathing. It also creates surface tension that helps maintain the position of the lungs against the thoracic wall.

In contrast to the conducting zone, the respiratory zone includes structures that are directly involved in gas exchange. The respiratory zone begins where the terminal bronchioles join a **respiratory bronchiole**, the smallest type of bronchiole (**Figure 11**), which then leads to an **alveolar duct**. This passageway ultimately opens into a cluster of **alveoli**. An **alveolus** is one of the many small, grape-like sacs that are attached to each of the alveolar ducts. An **alveolar sac** is a cluster of many individual alveoli that are responsible for gas exchange.

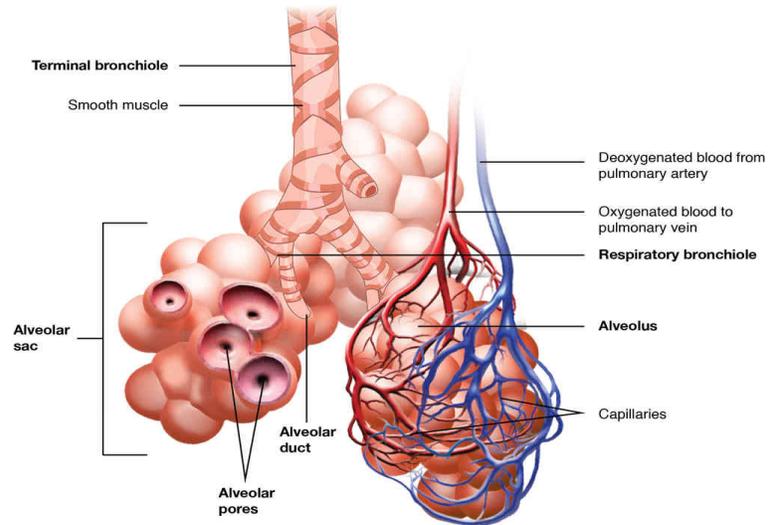


Figure 11. The Respiratory Zone

Bronchioles lead to alveolar sacs in the respiratory zone, where gas exchange occurs.

Each alveolus has elastic walls that allow it to stretch during air intake, which greatly increases the surface area available for gas exchange. Alveoli are connected to their neighbors by **alveolar pores**, which help maintain equal air pressure throughout the alveoli and lung (**Figure 12**).

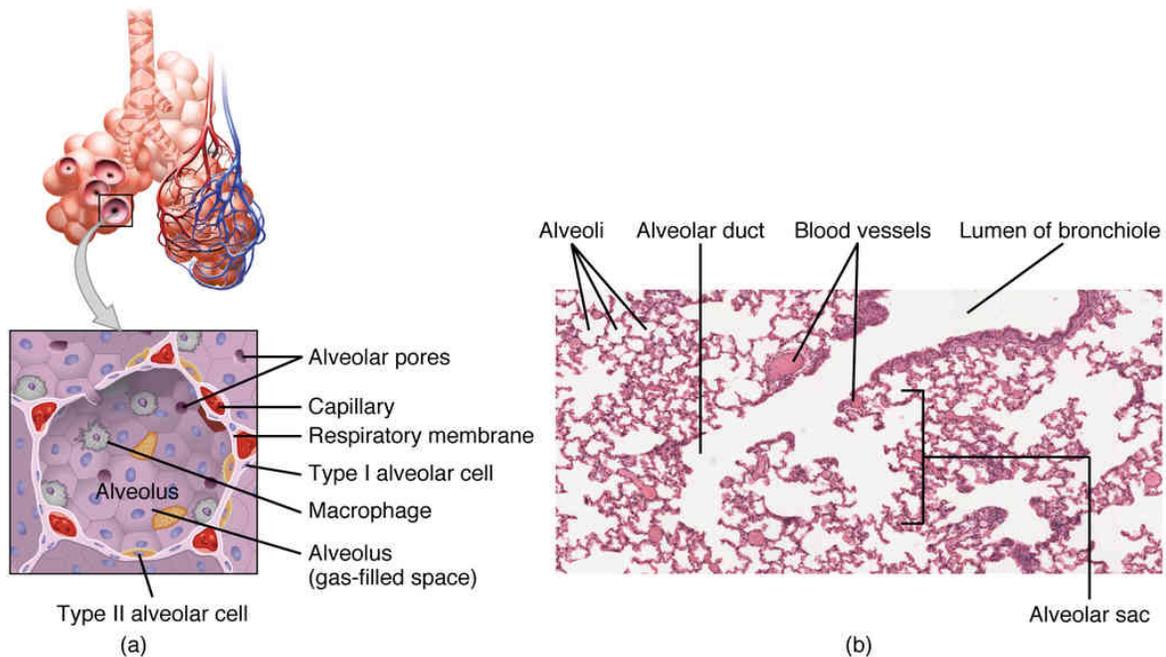


Figure 12. Structures of the Respiratory Zone

(a) The alveolus is responsible for gas exchange. (b) A micrograph shows the alveolar structures within lung tissue. LM $\times 178$. (Micrograph provided by the Regents of University of Michigan Medical School \copyright 2012)

The alveolar wall consists of three major cell types: **type I alveolar cells**, **type II alveolar cells**, and **alveolar macrophages**. A type I alveolar cell is a squamous epithelial cell of the alveoli,

which constitute up to 97 percent of the alveolar surface area. These cells are about 25 nm thick and are highly permeable to gases. Type II alveolar cells are interspersed among the type I cells and secrete pulmonary surfactant. This substance is composed of phospholipids and proteins that help to reduce the surface tension of the alveoli. Roaming around the alveolar wall are the alveolar macrophages, phagocytic cells of the immune system that removes debris and pathogens that have reached the alveoli.

Source Material

OpenStax, 22.1 Organs and Structures of the Respiratory System. OpenStax CNX. May 2, 2019
<http://cnx.org/contents/b76b2090-243e-429a-8144-2e45bda6ab75@14>.

OpenStax, 22.2 The Lungs. OpenStax CNX. May 2, 2019 <http://cnx.org/contents/b9d25fb9-1fc4-4e4d-8100-e3604ce9a657@9>.

Pre-Assessment

1. What is the role of the respiratory system, in terms of the overall function of the body?

Equipment List & Setup – Anatomy

Equipment List

- Lung models or detailed torso model, including median section of head
- Model of larynx
- Charts and illustrations of the respiratory system
- Microscope
- Prepared slides or histological images of:
 - Normal lung tissue
 - Smoker's lung
 - Trachea
- Charts and illustrations of the respiratory system

Equipment Setup

Identify the location of the necessary equipment needed to complete the activities. Models will be spread throughout the lab, so familiarize yourself to their locations.

Activities – Anatomy

In this exercise, you will study the anatomy and organization of the respiratory system. This activity contributes to each of the Learning Objectives identified at the beginning of the section.

Part 1: Overview of the Respiratory System

Procedure

1. Look at the charts and models of the respiratory system for a general orientation and compare them to figure 1. Locate the following structures:
 - a. Bronchus
 - b. Nasal cavity
 - c. Right lung
 - d. Left lung
 - e. Larynx
 - f. Nose
 - g. Trachea
 - h. Pharynx

Part 2: Nose and Nasal Cartilages

Procedure

1. Examine a median section on a model or chart of the head and look for the **nose, nasal cartilages, external nares** (nostrils), and **nasal septum**.
2. Examine the features identified in step 1 and compare them to what you see in Figures 2 and 3.
3. Using the models and charts, locate the **superior, middle, and inferior conchae** in the nasal cavity.
4. Identify where the nasal cavity ends, giving rise to two openings, the **posterior nasal apertures, or choanae**, which lead to the **pharynx**.
5. The **pharynx** can be divided in to three regions based on location. Use the models and charts to find these regions.
6. Examine the features from step 5 in Figures 3 and 5.
7. The **larynx** is commonly known as the “voice box” because it is an important organ for sound production in humans. Using the models and charts, locate the prominent cartilages of the larynx; these include the **thyroid cartilage, cricoid cartilage, and arytenoid cartilage**. Locate the **vocal cords (vocal folds)**, which attach to the anterior end of these cartilages.
8. Examine the features from step 7 in Figures 6 and 7. Also use this figure to locate the **vestibular folds**, which are oriented superior to the vocal cords.
9. Using the models and charts, locate the posterior structures of the larynx. These include the **corniculate and cuneiform cartilages, the epiglottis, and the glottis**.
10. Examine the features from step 9 in Figure 6.

Part 3: Trachea and Bronchi

Procedure

1. The **trachea** is a straight tube whose lumen is kept open by c-shaped **tracheal cartilages**. Examine these cartilages by running your fingers gently down the outside of your throat. Palpate the cartilage rings below the larynx.
2. Locate the tracheal cartilages and the inferior **carina** in Figures 8 and 9.
3. Obtain a prepared slide or a histological section of the trachea and find the tracheal cartilage, **respiratory epithelium**, and **posterior tracheal membrane** (absent in some slide preparations).
4. Examine the features from step 3 in Figure 8.
5. Using the provided models and charts, observe the extensive branching of the bronchi, which produce a structure called the **bronchial tree**.
6. Examine the bronchial tree in Figures 8, 9 and 11. You should be able to identify the **main bronchi**, **lobar bronchi**, and **segmental bronchi**.

Part 4: Lungs

Procedure

1. Look at the models or charts in the lab and identify the major features of the lungs. These include the **superior lobe**, **middle lobe**, and **inferior lobe** of the right lung and the **superior lobe** and **inferior lobe** of the left lung. Also identify the indentation of the left lung, the **cardiac impression** where the apex of the heart rests.
2. Examine these lung features in Figure 9.
3. Use Figure 10 to locate and identify the **visceral** and **parietal pleura** that surround the lungs. You should be able to identify the **pleural cavity**, which is the space that separates these two membranes.
4. Obtain a prepared slide or look at the provided histological image and scan it first under low magnification. Identify the **main bronchi**. You should be able to see that the main **bronchi** continue to divide until they become **bronchioles**.
5. The **bronchioles** continue to divide, leading to passageways known as the **alveolar ducts**, which branch into **alveoli**. Using the provided slide or image, locate the **terminal bronchioles**, **respiratory bronchioles**, **alveolar ducts**, and **alveoli**. Also examine these alveolar features in Figure 12.
6. Using your slide and provided image(s), observe the **alveolar sac**, the cluster of alveoli located around the terminal end of the alveolar duct. Draw an example of what you see in the provided space.
7. Obtain and examine a prepared slide or provided image of a smoker's lung. Note the similarities and differences that you observe between this image and that of the normal lung tissue.

Analysis
None

Check your understanding

1. Some of the nasal cartilages are made of hyaline cartilage. What functional adaptation does cartilage have over bone in making up the framework of the nose?
2. The trachea branches into two tubes that go to the lungs. What are these tubes called?
3. What small structure in the lung is the site of exchange of oxygen with the blood capillaries?
4. Considering the differences that you observed between the normal lung and the smoker's lung, how would these differences lead to functional differences in a non-smoker versus a smoker?

The Respiratory System: Physiology

Introduction

In this laboratory, you will use models and histological samples to study the anatomy of the respiratory system. As you study the anatomy, be aware of the role that other systems play in respiration, such as the cardiovascular system, which aids in the transport of oxygen and carbon dioxide, and the muscular system, which increases demand for oxygen during times of activity. You will use observation and a spirometer to determine respiratory rates, lung volumes, and factors that can influence these characteristics.

Learning Objectives

By the end of this lesson you will be able to:

1. Describe the role of muscle contraction and volume changes in the thorax in the mechanics of breathing.
2. Perform pulmonary function tests on a volunteer.
3. Describe the sounds heard with a stethoscope when breathing.
4. Identify and explain the importance of various chemical and mechanical factors in producing respiratory variations and how these variations are produced.
5. Identify the locations and functions of chemoreceptors.
6. Define hyperventilation, hypoventilation, and identify the changes in blood pH that occur with each.
7. Define the following terms:

Respiratory system	Forced expiration
Pulmonary ventilation	Tidal volume
External respiration	Expiratory reserve volume
Internal respiration	Inspiratory reserve volume
Inspiration	Residual volume
Expiration	

Background Information

Physiology of the Respiratory System

Mechanics of Breathing

Pulmonary ventilation is the act of breathing, which can be described as the movement of air into and out of the lungs. The major mechanisms that drive pulmonary ventilation are **atmospheric pressure**, the air pressure within the lungs, called **intrapulmonary pressure**, and the pressure within the pleural cavity, called **intrapleural pressure**. **Atmospheric pressure** is the amount of force that is exerted by gases in the air surrounding any given surface, such as the body. Atmospheric pressure can be expressed in terms of the unit atmosphere, abbreviated atm, or in millimeters of mercury (mm Hg). One atm is equal to 760 mm Hg, which is the atmospheric pressure at sea level. **Intrapulmonary pressure** is the pressure of the air within the lungs, which changes during the different phases of breathing. **Intrapleural pressure** is the pressure of the air within the pleural cavity, between the visceral and parietal pleurae. The difference in these pressures drives pulmonary ventilation because air flows down a pressure gradient, that is, air flows from an area of higher pressure to an area of lower pressure. Air flows into the lungs largely due to a difference in pressure; atmospheric pressure is greater than intrapulmonary pressure, and intrapulmonary pressure is greater than intrapleural pressure. Air flows out of the lungs based on the same principle; pressure within the lungs becomes greater than the atmospheric pressure.

Pulmonary ventilation comprises two major steps: **inspiration** and **expiration**, both of which are dependent upon the differences in pressure between the atmosphere and the lungs.

Inspiration is the process that causes air to enter the lungs while **expiration** is the process that causes air to leave the lungs (**Figure 1**). A **respiratory cycle** is one sequence of inspiration and expiration. In general, two muscle groups are used during normal inspiration: the diaphragm and the external intercostal muscles. Additional muscles can be used if a bigger breath is required though. When the diaphragm contracts, it moves inferiorly toward the abdominal cavity, creating a larger thoracic cavity and more space for the lungs. At the same time, contraction of the external intercostal muscles moves the ribs upward and outward, causing the rib cage to expand, which increases the volume of the thoracic cavity. Due to the adhesive force of the pleural fluid, the expansion of the thoracic cavity forces the lungs to stretch and expand as well. This increase in volume leads to a decrease in alveolar pressure, creating a pressure lower than atmospheric pressure. As a result, a pressure gradient is created that drives air into the lungs. Inspiration and expiration occur due to the expansion and contraction of the thoracic cavity, respectively.

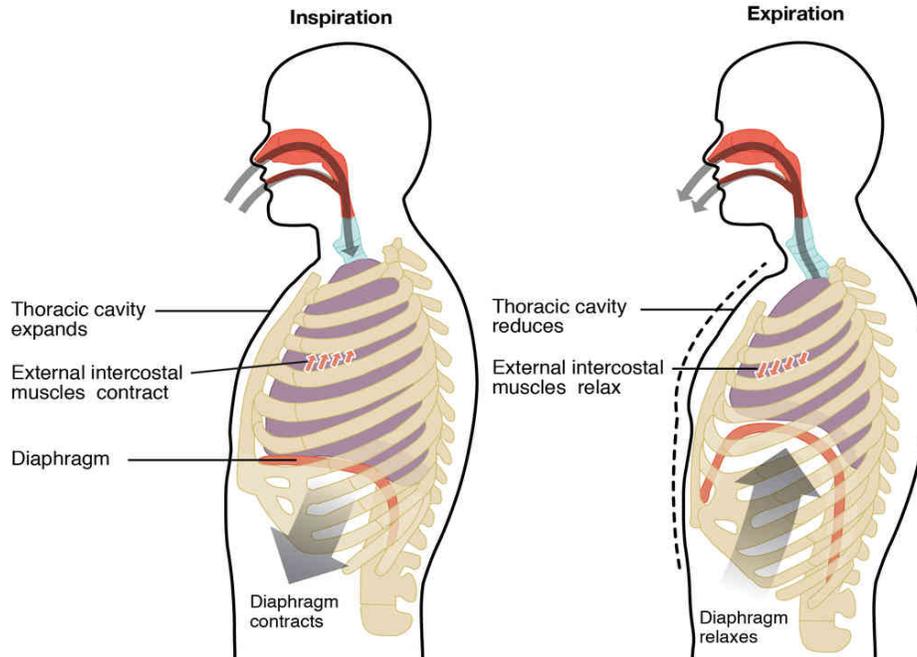


Figure 1. Inspiration and Expiration

The process of normal expiration is **passive**, meaning that energy is not required to push air out of the lungs. Instead, the elasticity of the lung tissue causes the lungs to recoil, as the diaphragm and intercostal muscles relax following inspiration (**Figure 1**). In turn, the thoracic cavity and lungs decrease in volume, causing an increase in interpulmonary pressure. The interpulmonary pressure rises above atmospheric pressure, creating a pressure gradient that causes air to leave the lungs.

There are different types, or modes, of breathing that require a slightly different process to allow inspiration and expiration. **Quiet breathing**, also known as **eupnea**, is a mode of breathing that occurs at rest and does not require the cognitive thought of the individual. During quiet breathing, the diaphragm and external intercostals must contract. In contrast, **forced breathing**, also known as **hyperpnea**, is a mode of breathing that can occur during exercise or actions that require the active manipulation of breathing, such as singing. During forced breathing, inspiration and expiration both occur due to muscle contractions. In addition to the contraction of the diaphragm and intercostal muscles, other accessory muscles must also contract. During forced inspiration, muscles of the neck, including the scalenes, contract and lift the thoracic wall, increasing lung volume. During forced expiration, accessory muscles of the abdomen, including the obliques, contract, forcing abdominal organs upward against the diaphragm. This helps to push the diaphragm further into the thorax, pushing more air out. In addition, accessory muscles (primarily the internal intercostals) help to compress the rib cage, which also reduces the volume of the thoracic cavity.

Source Material

OpenStax, 22.3 The Process of Breathing. OpenStax CNX. May 2, 2019 <http://cnx.org/contents/bbaedbf4-4d78-4b7c-bc94-2a742f0f2f8c@14>.

Measurement of Respiratory Parameters

Gas exchange between air and blood occurs within the alveolar air sacs (**Figure 2**). The efficiency of gas exchange is dependent on ventilation. Cyclical breathing movements alternately inflate and deflate the alveolar air sacs. Inspiration provides the alveoli with some fresh atmospheric air, and expiration removes some of the stale air, which has reduced oxygen and increased carbon dioxide concentrations.

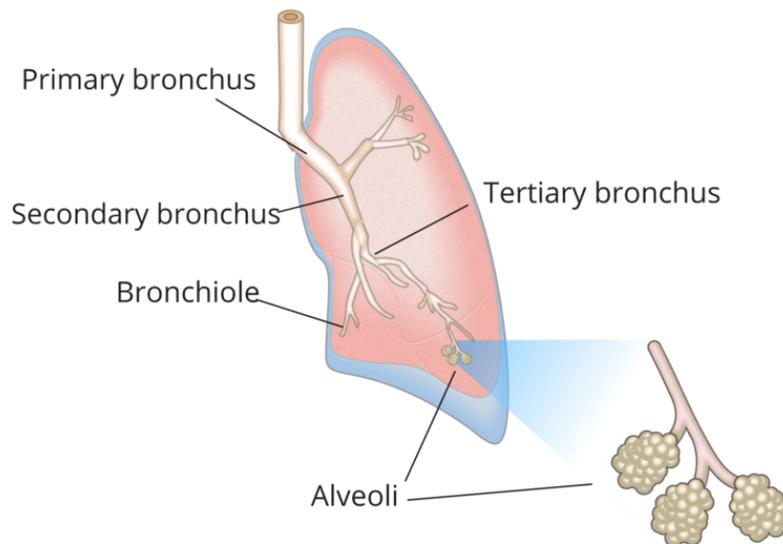


Figure 2. Schematic diagram of the bronchial tree.

The use of spirometry is becoming increasingly important due to a worldwide increase in respiratory diseases. Spirometry is the method of choice for a fast and reliable screening of patients suspected of having Chronic Obstructive Pulmonary Disease (COPD). COPD is the 12th leading cause of death worldwide and 5th in Western countries. COPD could climb to be the 3rd leading killer by 2020. Most COPD cases are completely avoidable with 85–90% of cases caused by tobacco smoking.

Many important aspects of lung function can be determined by measuring airflow and the corresponding changes in lung volume. In the past, the common method employed involved breathing into a bell spirometer, in which the level of a floating bell tank gave a measure of changes in lung volume. Flow (F) was then calculated from the slope (rate of change) of the volume (V):

$$F = \frac{dV}{dt}$$

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The Pneumotachometer

Airflow can now be measured directly with a pneumotachometer, (from Greek roots meaning “breath speed measuring device”). The PowerLab pneumotachometer arrangement is shown in **Figure 3**, below.

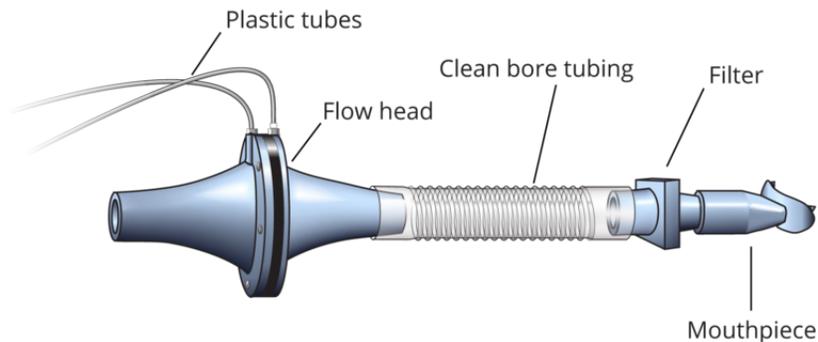


Figure 3. The PowerLab pneumotachometer.

The flow head contains a fine mesh. Air breathed through the mesh gives rise to a small pressure difference that is proportional to flow rate. Two small plastic tubes transmit this pressure difference to the Spirometer Pod, where a transducer converts the pressure signal into a changing voltage that is recorded by a data acquisition device, such as the PowerLab system. The volume, V , is then calculated as the integral of flow:

$$V = \int F dt$$

This integration represents a summation over time. The volume traces that you will see during a spirometry recording are obtained by adding successive sampled values of the flow signal and scaling the sum appropriately. The integral is reset to zero every time a recording is started.

A complication in volume measurement is caused by the difference in air temperature between the Spirometer Pod (at room temperature) and the air exhaled from the lungs (at body temperature, 37°C). Because gas expands with warming, its volume increases. For this reason, the air volume expired from the lungs will be slightly greater than that inspired. Thus, a volume trace, as calculated by integration of flow, drifts in the expiratory direction. To reduce the drift,

the flow has to be integrated separately during inspiration and expiration, with the inspiratory volume being corrected by a factor related to the BTPS factor (body temperature, atmospheric pressure, saturated with water vapor). This correction can be applied automatically by the data acquisition software.

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Pulmonary Volumes and Capacities

Spirometry allows many components of pulmonary function to be visualized, measured, and calculated. Respiration consists of repeated cycles of inspiration followed by expiration. During the respiratory cycle, a specific volume of air is drawn into and then expired from the lungs – the **Tidal Volume** (V_T). In normal ventilation, the rate of breathing (breaths/minute) is approximately 15 respiratory cycles per minute. This value varies with the level of activity. The product of breaths/minute and V_T is the **Expired Minute Volume** – the amount of air exhaled in one minute of breathing, which also changes according to the level of activity.

Note that the volume of air remaining in the lungs after a full expiration, **residual volume** (RV), cannot be measured by spirometry as it is impossible to exhale all the gas in the lungs. [There are specialized techniques to measure RV, but normally this volume is estimated from tables that predict RV based on age, sex, height and weight.]

The common lung volumes and capacities are shown in Figure 4 and Table 1, below. Note that the lung capacities are always the *sum* of at least two lung volumes, e.g., **vital capacity** (VC) is the sum of **tidal volume** (V_T), **expiratory reserve volume** (ERV) and **inspiratory reserve volume** (IRV).

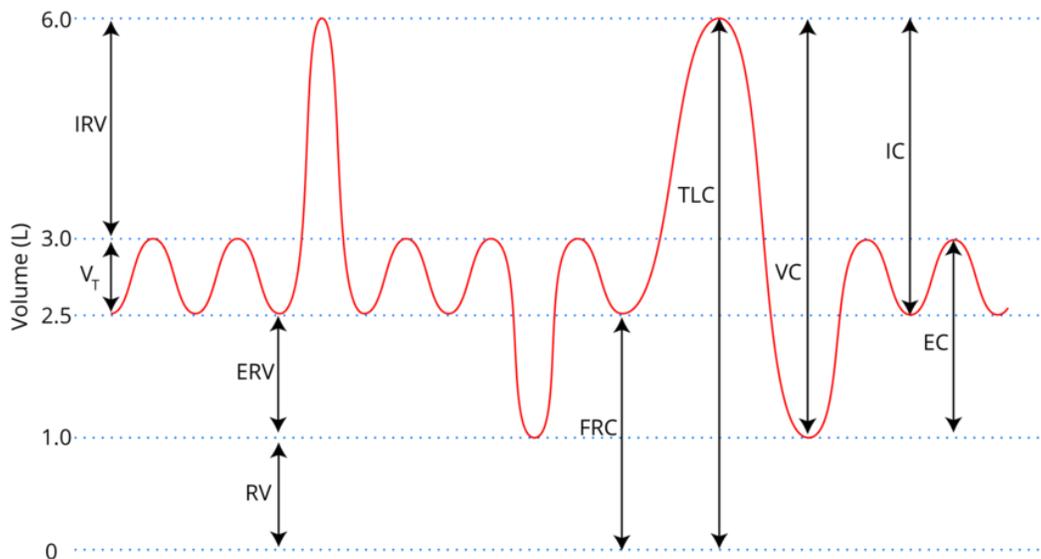


Figure 4. Lung volumes and capacities. Volumes are representative of a healthy young male adult.

Looking at the spirometry graph above from left to right, we start with the various lung volumes:

- **V_T** : the volume breathed in and out in each breath.
- **IRV**: the maximum volume above the tidal volume that we can inhale into our lungs.
- **ERV**: the maximum volume we can exhale from our lungs at the end of a normal breath.
- **RV**: the volume of air remaining in the lungs which is impossible for use to expire.

Then we have the lung capacities:

- **Expiratory capacity (EC)**: the volume of air that we can expire after a normal inspiration and $= V_T + ERV$.
- **Functional residual capacity (FRC)**: the volume of air remaining in the lungs at the end of a normal expiration and $= ERV + RV$.
- **Total lung capacity (TLC)**: all the air that it is possible for the lungs to contain and $= RV + ERV + V_T + IRV$.
- **Vital capacity (VC)**: all the air that can be expired following a maximal inhalation and $= ERV + V_T + IRV$.
- **Inspiratory capacity (IC)**: all the air breathed in during a maximal inhalation and $= V_T + IRV$.

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Pulmonary Function Tests

Common pulmonary function tests are also listed in Table 1, below. Clinically, peak flows are measured with a Peak Flow Meter which patients can be taught to use.

In spirometry, the peak flows are the rates of flow at the beginning of inspiration or expiration. Forced Vital Capacity and FEV_1 are measured in a Respiratory Laboratory. You can measure all of these parameters with the materials available in lab.

Table1. Respiratory-Related Terms, Abbreviations, and Units

Term	Symbols	Units
Respiration Rate	RR	breaths/min (BPM)
Expired Minute Volume	$V_E = RR \times V_T$	L/min
<i>Lung Volumes</i>		
Tidal Volume	V_T	L
Inspiratory Reserve Volume	IRV	L
Expiratory Reserve Volume	ERV	L
Residual Volume	RV (predicted)	L
<i>Lung Capacities</i>		
Inspiratory Capacity	$IC = V_T + IRV$	L
Expiratory Capacity	$EC = V_T + ERV$	L
Vital Capacity	$VC = IRV + V_T + ERV$	L
Functional Residual Capacity	$FRC = ERV + RV$	L
Total Lung Capacity	$TLC = VC + RV$	L

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Dyspnea

Dyspnea refers to difficulty in breathing. What is difficult for one person is not necessarily so for another, so dyspnea has a psychological dimension. Perhaps the simplest view is to regard dyspnea as being a consequence of a mismatch between the afferent inputs that stimulate breathing (such as decreased PO_2 , increased PCO_2 , decreased pH, and activation of lung and chest wall receptors) and the efferent output to the muscles of respiration. That is, for whatever reason, breathing can not increase sufficiently to match the perceived central nervous system requirements, leading to feelings of distress and breathlessness.

Dyspnea may be acute or chronic. When people tell you that they are "breathless", it is necessary to try to understand what they mean by this. Everyone gets breathless if they exercise vigorously. This is physiological and reversed rapidly when exercise finishes and should not be regarded as dyspnea. Illnesses that can be associated with the acute onset of dyspnea include pneumothorax, acute asthmatic attacks, pneumonia, myocardial infarction and rapidly developing heart failure. The major respiratory diseases associated with chronic dyspnea are COPD and restrictive lung disease.

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Acid-Base Effects of the Respiratory Gases

The respiratory rate and the depth of inspiration are regulated by the medulla oblongata and pons; however, these regions of the brain do so in response to systemic stimuli. It is a dose-response, positive-feedback relationship in which the greater the stimulus, the greater the response. Thus, increasing stimuli results in forced breathing. Multiple systemic factors are involved in stimulating the brain to produce pulmonary ventilation.

The major factor that stimulates the medulla and pons to produce changes in respiration is surprisingly not oxygen concentration, but rather the concentration of carbon dioxide in the blood. As you may recall, carbon dioxide is a waste product of cellular respiration and can be toxic. Concentrations of chemicals are sensed by **chemoreceptors**. A **central chemoreceptor** is one of the specialized receptors that are located in the brain and brainstem, whereas a **peripheral chemoreceptor** is one of these receptors located in the carotid arteries and aortic arch. Concentration changes in certain substances, such as carbon dioxide or hydrogen ions, stimulate these receptors, which in turn signal the respiration centers of the brain. In the case of carbon dioxide, as the concentration of CO₂ in the blood increases, it readily diffuses across the blood-brain barrier, where it collects in the extracellular fluid. Increased carbon dioxide levels lead to increased levels of hydrogen ions, ultimately decreasing the pH of the blood. This increase in hydrogen ions in the brain triggers the central chemoreceptors to stimulate the respiratory centers to initiate contraction of the diaphragm and intercostal muscles. As a result, the rate and depth of respiration increase, allowing more carbon dioxide to be expelled, which brings more air into and out of the lungs. These actions promote a reduction in the blood levels of carbon dioxide, and therefore hydrogen ions. In contrast, low levels of carbon dioxide in the blood cause low levels of hydrogen ions in the brain and an increase in blood pH. These changes lead to a decrease in the rate and depth of pulmonary ventilation, producing shallow, slow breathing.

Another factor involved in influencing the respiratory activity of the brain is systemic arterial concentrations of hydrogen ions. Increasing carbon dioxide levels can lead to increased H⁺ levels, as mentioned above, as well as other metabolic activities, such as lactic acid accumulation after strenuous exercise. Peripheral chemoreceptors of the aortic arch and carotid arteries sense arterial levels of hydrogen ions. Removal of carbon dioxide from the blood helps to reduce hydrogen ions, thus increasing systemic pH. The peripheral chemoreceptors are also responsible for sensing large changes in blood oxygen levels. If blood oxygen levels become quite low—about 60 mm Hg or less—then peripheral chemoreceptors stimulate an increase in respiratory activity.

Source Material

OpenStax, 22.3 The Process of Breathing. OpenStax CNX. May 2, 2019 <http://cnx.org/contents/bbaedbf4-4d78-4b7c-bc94-2a742f0f2f8c@14>.

Pre-Assessment

1. Which of the following statements regarding tidal volume (V_T) is true?
 - a. It is the volume breathed during forced breathing.
 - b. It is the volume breathed in each breath.
 - c. It is the volume breathed in each minute.
 - d. It is unaffected by the frequency of breathing.
2. Which of the following statements regarding the Expiratory Reserve Volume (ERV) is true?
 - a. ERV is kept at a low volume so that the vast bulk of the alveolar gas can be replaced with fresh air during the next inspiration.
 - b. ERV is the maximal amount of air that can be exhaled from the lungs after a normal expiration.
 - c. ERV is very small and unimportant in normal respiration.
3. Which of the following does Vital Capacity (VC) measure?
 - a. The amount of gas that it is vital to retain in the respiratory system at the end of expiration.
 - b. The maximum volume of gas in the respiratory system that can be exchanged with each breath.
 - c. The volume of gas exchanged during normal breathing.
4. Which of the following statements regarding Total Lung Capacity (TLC) is true?
 - a. It increases as the frequency of breathing increases.
 - b. It is a measure of the volume of gas in the respiratory system at the end of a maximal inspiration.
 - c. It is constant in amount from person to person.
5. In the respiratory system, what is the major difference between a volume and a capacity?
 - a. A capacity is the sum of at least two volumes.
 - b. A volume is the sum of at least two capacities.
 - c. Their units are different.
6. Pulmonary function measurement check: Pre-Assessment Challenge built in Lt, with details below.

Pulmonary function measurements

Pulmonary function measurements, or tests, can be classified as either static or dynamic. Before proceeding with this Laboratory, check that you know the difference between these.

Place each of the measures below into either the static or dynamic category:

Equipment List & Setup – Respiratory Sounds

Equipment List

- Stethoscope
- Alcohol wipes
- Partner

Equipment Setup

1. Find a partner to complete this activity with.
2. Obtain a stethoscope.
3. Clean the earpieces of the stethoscope with an alcohol wipe and let them dry.
4. Make sure that the earpieces of the stethoscope point toward the anterior as you would insert them into your ear.

Before beginning

You should work with a partner to complete this activity. Make sure that you thoroughly clean the earpieces of the stethoscope before you begin and that they are oriented correctly.

Activities – Respiratory Sounds

In this exercise, you will listen to the normal breathing sounds of an individual.

Procedure

1. Locate the larynx of your partner and place the diaphragm of the stethoscope just inferior to it.
2. Listen for the sounds as your lab partner inhales and exhales. These are tracheal and bronchial sounds.
3. Locate the triangle of auscultation, an area just medial to the inferior angle of the scapula. This is an ideal area for listening to sounds because fewer muscles cover this region of the thoracic cavity.
4. Have your lab partner inhale and exhale deeply several times.
5. Listen for a smooth flow of air into and out of the lungs. Wheezing or other rattling-like noises are indicators of congestion in the lungs.
6. Record the observations of what you hear in the space below. Indicate the breathing condition of your lab partner.

Analysis

Sounds heard:

Check your understanding

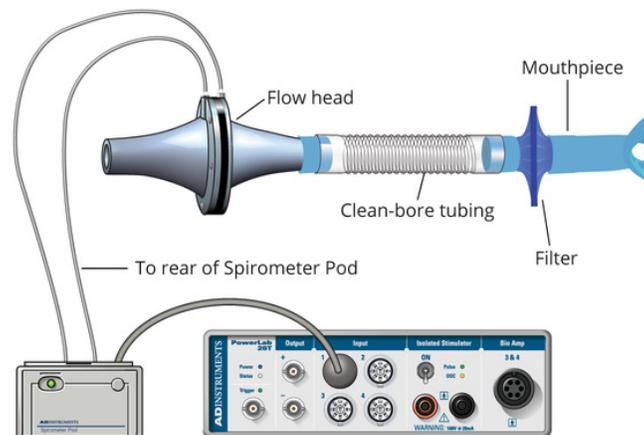
None

Equipment List & Setup – Spirometry

Equipment List

- PowerLab System
- Spirometer Pod
- Two small diameter plastic tubes
- Clean-bore tubing
- Disposable filter (one for each volunteer)
- Mouthpiece (one for each volunteer)

Equipment Setup



Spirometer Setup

1. Connect the Spirometer Pod to Input 1 on the PowerLab.
2. The Spirometer Pod is sensitive to temperature and tends to drift during warm-up, so turn on the PowerLab for **at least 5 minutes** before use. To prevent temperature drift due to heating of the pod, place it on a shelf or beside the PowerLab, away from the PowerLab power supply.
3. Connect the two plastic tubes from the flow head to the short pipes on the back of the Spirometer Pod.
4. Attach clean-bore tubing, a filter, and mouthpiece to the flow head.
5. Make sure you have access to extra mouthpieces and disposable air filters for **each** volunteer.

Before beginning

If you are suffering from a respiratory infection, do not volunteer to complete this experiment. In order to calculate volume from the flow reordering correctly, it is crucial that recording is started prior to breathing through the flow head. Also, make sure that the subject volunteer keeps the nose clip on and that they breathe through the mouthpiece for the entirety of the data collection.

Activities - Spirometry

In this exercise, you will record and analyze your own pulmonary function variables. This activity contributes to Learning Objectives 1, 2, and 7 identified at the beginning of the section.

Part 1: Zeroing the Spirometer Pod

Procedure

1. Leave the flow head apparatus undisturbed on the bench and select the “Zero Inputs” button. This will reset the offset of the Flow channel to zero.
2. Put the nose clip on the volunteer’s nose. If possible, leave the nose clip on for the entirety of the lesson to promote breathing through the mouth. This ensures that all air breathed passes through the mouthpiece, filter, and flow head. Ask the volunteer to breath normally.



3. Start recording. The mouthpiece can now be put into the volunteer’s mouth.
4. Hold the flow head carefully with two hands with the plastic tube pointed upwards.
5. Observe the incoming data. Select “Auto Scale” if required. **The signal should show a downward deflection on expiration.** If the signal deflects upward, stop recording and swap the tubular connections on either the back of the Spirometer Pod or the flow head.
6. When the volunteer has become accustomed to the apparatus and is breathing normally through it, “Stop” recording and proceed to the next page.

Part 2: Volume Correction and Calibration

The Spirometer Pod is susceptible to thermal drift of the baseline signal. In order to give appropriate volume measurements, it is important to always reset the baseline by clicking the “Zero Inputs” button prior to making any new recording.

Procedure

1. The subject should still be in the same setup as in Part 1.

2. Have the volunteer inhale and exhale normally through the flow head (i.e. normal tidal breathing) for one minute.
3. While recording continues **Add** the comment: "Volume correction procedure".
4. At the end of 1 minutes, **Stop** recording. The volunteer should keep breathing through the flow head and keep the nose clip on. This is to avoid repeatedly having to get used to the set up.
5. To begin calibration, adjust the "compression" of the Time axis so that you can see the normal tidal breathing.
6. Select the regular breathing data using the double "Data Handles". *Do not* select the areas of zero flow and the start and end of the recording.
7. In the "Spirometry panel", select **Calibrate**. This will apply the volume correction procedure to your data.

Part 3: Dynamic Pulmonary Function Tests

The question here is: "How long does it take to expire as much gas as possible from the lungs following maximal inspiration?" The answer to this question gives us important information about a person's respiratory function.

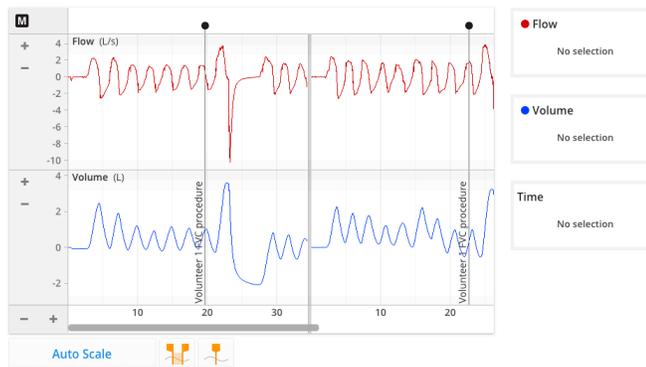
Before beginning

It is impossible to breathe normally when you are thinking about your breathing. **It is essential that the volunteer sits comfortably in a position from which the computer screen cannot be seen.** The volunteer may stare out a window or read a book as a distraction.

Procedure

1. **Start** recording. Once recording has started, as the volunteer to breathe normally through the flow head for 30 seconds. **Stop** recording and apply the "volume correction procedure".
2. **Start** recording. Have the volunteer breath normally for approximately 20 seconds.
3. Ask the volunteer to **inhale** as **forcefully** as possible. **Add** the comment: "PIF procedure". Resume normal breathing for 20 seconds.
4. Ask the volunteer to inhale (this **does not** need to be forcefully) and then **exhale** as **forcefully**, as **fully**, and for **as long** as possible, until nor more air can be expired. **Add** the comment "FVC procedure".
5. Allow the volunteer's breathing to return to normal, the **Stop** recording.
6. Your recording should resemble the model data, as shown below.

Example data showing the FVC procedure



7. Repeat this procedure twice more, so that you have three separate PIF and FCV recordings.

Analysis

Here you will analyze the pulmonary function variables. The FEV measurement (volume of air that can be forcibly exhaled in one second) gives us important information about the person's respiratory functions.

1. Examine the recordings in the **Flow channel**, and choose the recording that shows the highest Peak Inspiratory Flow.

Peak Inspiratory Flow (PIF)

2. By the comment "PIF", place the single Data Handle on the peak (maximum value) in the **Flow** channel. This is the maximum PIF (i.e. the most positive value). This will be displayed in the flow Value panel.
3. Enter this value into the "normal breathing" column of the table.

Peak Expiratory Flow (PEF)

4. Place the **single Data Handle** on the trough (minimum value) in the **Flow** channel. This is the maximum PEF (i.e. the most negative value).
5. Enter this value into the "normal breathing" column of the table.
6. In the **Volume channel**, determine which of the three recordings shows the greatest ("maximal") Forced Vital Capacity.

Forced Vital Capacity (FVC)

7. Place the Marker on the peak inhalation on the **Volume channel** and place the **single Data Handle** just as the maximal expiration (trough) value appears. The change in volume (FVC), and the time taken for expiration will be displayed in the volume and time **Value panels** respectively.
8. Enter these values into the appropriate cells in the table.

Forced expiratory volume in 1s (FEV₁)

Use the **same** recording that gave a maximal FVC.

9. Place the **Marker** on the peak inhalation in the **Volume channel**, and place the **single Data Handle** 1 second from the peak. The change in volume over this 1 second will be displayed in the volume **Value panel**.
10. Enter this value into the FEV₁ cell in the table. The ratio of FEV₁ to FVC expressed as a percentage will be calculated for you.

Check your understanding

1. In your own words describe the physiological significance of the FEV₁/FVC ratio.
2. Test your knowledge by categorizing the following conditions as a *lower* or *upper* airway obstruction: (fill in table)

Equipment List & Setup – Factors Influencing Rate and Depth of Respiration

Equipment List

- New partner
- Stop watch

Equipment Setup

No setup is required for this activity.

Activities – Factors Influencing Rate and Depth of Respiration

In this exercise, you will first determine the breathing rate of an individual when they are at rest. Then, the volunteer will perform a series of activities to see how each one effects the rate of respiration over time.

Part 1: Determining Resting (Quiet) Respiration Rate

Here, you will be determining the resting respiration rate of the subject. This will serve as a control to compare respiration rates to when you observe different activities.

Before beginning

Decide which partner will be the subject and which will be the recorder. You may switch spots later, if time allows. Initially, have the test subject sit quietly in a chair to perform the first part of this activity.

Procedure

1. The volunteer should sit comfortably and quietly in a chair for a minimum of one minute before recording begins.
2. Using the stop watch, the recorder should then count the number of breaths taken by the subject over a 1-minute time period.
3. Record this value in respirations/minute in the data Table 1 below.

Part 2: Factors Influencing Rate and Depth of Respiration

Before beginning

Again, have the test subject sit quietly in a chair to perform the first part of this activity. The same volunteer who you determined resting respiration rate for should also complete part 2.

Procedure

1. Have the volunteer perform each of the following activities listed in Table 1, below. The volunteer should perform each activity for a period of 1 minute.

2. During each activity, record the subject's breathing rate. Record this information in Table 1 as breaths/minute.
3. Record any other observations that you think are pertinent in the Table 1.

Part 3: Determining Respiration Rate During Various Activities

Before beginning

You may choose a different volunteer to complete Part 3 of the activity. To begin part 3, have the test subject sit quietly in a chair to perform the first part of this activity.

Procedure

Have the volunteer perform each of the following activities.

Quiet Respiration

1. Allow the subject to breathe normally for one minute.
2. After this initial period, record the subject's respiration rate (respirations/min.) during quiet inspiration. Enter the data in Table 2, below.

Deep Inhale

1. Allow the subject to breathe normally for two minutes.
2. After this initial period, have the subject deeply inhale and then hold their breath for as long as possible. Record (in seconds) how long the subject was able to hold their breath for. Enter this data in Table 2, below.
3. As soon as the subject exhales, record the respiratory rate for several minutes (this time may vary) until a normal, resting breathing pattern returns. Also record how long it took (recovery time) for the subject's breathing pattern to return to normal (in seconds).
4. Enter this data in Table 2, below.

Forced Exhale

1. Repeat the procedure for "Deep Inhale" above, but first the subject will inhale deeply, then exhale forcefully and completely, then hold their breath WITHOUT INHALING.
2. Record the length of time (in seconds) that their breath was held and the respiratory rate until the subject has recovered.
3. Enter this data in Table 2, below.

Hyperventilation

1. Have the subject to hyperventilate (breathe rapidly, about 1 breath/4 seconds) for approximately 30 seconds, then hold their breath for as long as possible.
2. Record the length of time (in seconds) that their breath was held and the respiratory rate until the subject has recovered.
3. Enter this data in Table 2, below.

Re-Breathing

1. Have the subject breath into a paper bag for 3 minutes. WATCH CAREFULLY for unusual or unwanted reactions or behaviors.
2. After this initial period, have the subject inhale as deeply as possible and then hold their breath for as long as possible. Record the length of time (in seconds) that their breath was held and the respiratory rate until the subject has recovered. Also record how long it took (recovery time) for the subject's breathing pattern to return to normal (in seconds).
3. Enter this data in Table 2, below.

Jogging In Place

1. Have the subject jog in place (or run up and down the stairs) for 2 minutes.
2. After this initial period, have the subject inhale as deeply as possible and then hold their breath for as long as possible. Record the length of time (in seconds) that their breath was held and the respiratory rate until the subject has recovered. Also record how long it took (recovery time) for the subject's breathing pattern to return to normal (in seconds).
3. Enter this data in Table 2, below.

Analysis

Table 1. Respiratory Rates During Various Activities

Tasks Performed	Observations and Rate of Breathing
Quiet respiration	
Talking	
Yawning	
Laughing	
Standing	
Concentrating	
Swallowing water	
Coughing	
Lying down	
Running in place	

Table 2. The Effect of Various Activities on Breath-Holding and Normal Recovery

Activity	Time Breath was held after activity (sec.)	Recovery time (sec.)	Respiratory rate during recovery
Quiet respiration			
Deep inhale and breath holding			
Deep inhale – forceful exhale and breath holding			
Hyperventilation			
Re-breathing (breathing into paper bag)			
Jogging in place			

Check your understanding

1. After inhaling and holding your breath, was your urge to inspire or exhale?
2. After exhaling and holding your breath, was your urge to inspire or exhale?
3. Explain your answers from questions 1 and 2.
4. Explain the effect that hyperventilation has on respiratory rate and recovery. (HINT: Think about the gases that are found in the plasma during hyperventilation.)

Equipment List & Setup – Respiration and Acid/Base Changes

Equipment List

- 100 mL beaker
- 50 mL 0.01M NaOH solution
- Phenolphthalein
- Unused straw
- Stop watch
- Safety goggles

Equipment Setup

1. Obtain a clean 100 mL beaker and place 50 mL of 0.01M NaOH solution in it.
2. Add one drop of phenolphthalein solution to the same beaker. Swirl gently to mix. The solution should turn pink-ish.
3. Place the straw so that the end is submerged in the NaOH solution.

Before beginning

You should work in groups of 4 to complete this activity. If you are suffering from a respiratory infection, do not volunteer to complete this experiment.

Activities – Respiration and Acid/Base Changes

In this exercise, you will observe the effects of increasing carbon dioxide levels in the blood, by observing color changes in a solution of NaOH.

Procedure

1. The subject should put the safety goggles on, if available.
2. Allow the subject to breathe normally for one minute.
3. Have the subject BLOW through the straw, into the solution, avoiding splashes or spills. The subject should continue blowing through the straw until the solution turns clear. IT IS BEST IF YOU HOLD YOUR NOSE AND BREATHE THROUGH YOUR MOUTH, BEING CAREFUL NOT TO SUCK THE SOLUTION INTO YOUR MOUTH.
4. Record the time required for the solution to change color in Table 3, below. This value will represent the time necessary while at rest.
5. Add a few drops of NaOH and phenolphthalein to your beaker. Add enough of each to turn the solution a pink-ish color again.
6. Have the subject jog in place (or run up and down the stairs) for 5 minutes.
7. At the end of this exercise period, have the subject BLOW through the straw, into the solution, avoiding splashes or spills. The subject should continue blowing through the straw until the solution turns clear.
8. Record the time required for the solution to change color in Table 3, below. This value will represent the time for color change after exercising.

Analysis

Table 3. Acid Base Changes in a NaOH Solution

Activity	Time to Color Change from Pink to Clear
At rest	
After exercising for 5 minutes	

Check your understanding

1. At the start of the experiment, is the solution acidic or basic?
2. What is being added to the solution when you blow into it?
3. Why is this substance changing the color of the solution?
4. Did you see a difference in the time required to change the color of the solution after exercising, when compared to at rest? Explain this difference.
5. What is the relationship between gases in the blood and pH?

The Digestive System: Anatomy

Introduction

The digestive system is responsible for taking large, complex foodstuffs and breaking them into small molecules that can be absorbed and used by the cells of the body. Mechanical digestion breaks large pieces into smaller pieces; chemical digestion breaks large molecules into smaller molecules. The organs of the digestive system are structured to do both. In these laboratory exercises, you will be studying the structure of the organs of the digestive system via models, diagrams, histology images, and preserved specimens.

Learning Objectives

By the end of this lesson you will be able to:

- Describe the overall function of the digestive system
- Describe the functions of the individual organs and structures of the digestive system
- Identify the individual organs of the alimentary canal on a model, in a picture or diagram or in a specimen, and to describe the function of each
- Identify (on a model, in a picture or diagram, or in a microscope slide) and describe the histologic structure of the alimentary canal, and the specific components (layers) that comprise it
 - Mucosa
 - Submucosa
 - Muscularis externa
 - Serosa or adventitia
- Identify the accessory organs of digestion on a model, in a picture or diagram, or in a specimen, and describe the function of each
- List and identify the histological specializations of the stomach and the small intestine, and describe how these specializations contribute to the function of each organ
- Identify the histologic structure of the salivary glands, stomach, small intestine, pancreas, liver
- List the digestive enzymes involved in the digestion of proteins, fats and carbohydrates, and to identify their site of origin
- Identify the end products of protein, fat and carbohydrate digestion
- Discuss the role of temperature and pH on digestive enzyme activity

- Identify the following structures of importance:

Alimentary canal – figure 23.3 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/23-1-overview-of-the-digestive-system	Oral cavity and esophagus – figure 23.9, 23.12 – 23.13 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/23-3-the-mouth-pharynx-and-esophagus
Mucosa: lamina propria, epithelium and muscularis mucosae	Hard and soft palates
Submucosa, muscularis externa, serosa / adventitia	Salivary glands; parotid, submandibular, sublingual
Duodenum, ileum, jejunum	Pharynx, including nasopharynx, oropharynx and laryngopharynx
Myenteric and submucosal nerve plexuses	Tonsils: lingual, palatine and pharyngeal
	Esophagus (be sure to distinguish it from the trachea)
	Labia (lips)
Stomach – figures 23.15 – 23.16 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/23-4-the-stomach	Microanatomy of the small intestine – figure 23.19 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/23-5-the-small-and-large-intestines
Gastroesophageal (or cardiac, or lower esophageal) and pyloric sphincters	Epithelium – simple columnar (with goblet and absorptive cells)
Cardiac and pyloric regions and body	Villi and microvilli
Fundus	Plicae circularis
Greater and lesser curvatures	Intestinal crypt (crypts of Lieberkuhn)
Layers of smooth muscle: oblique, circular and longitudinal	Lacteal and capillary beds
Rugae	Peyer’s patches
Gastric pits, including chief cells, parietal cells, mucus neck cells and gastric glands	
Omenta – greater and lesser	
Mesocolon	

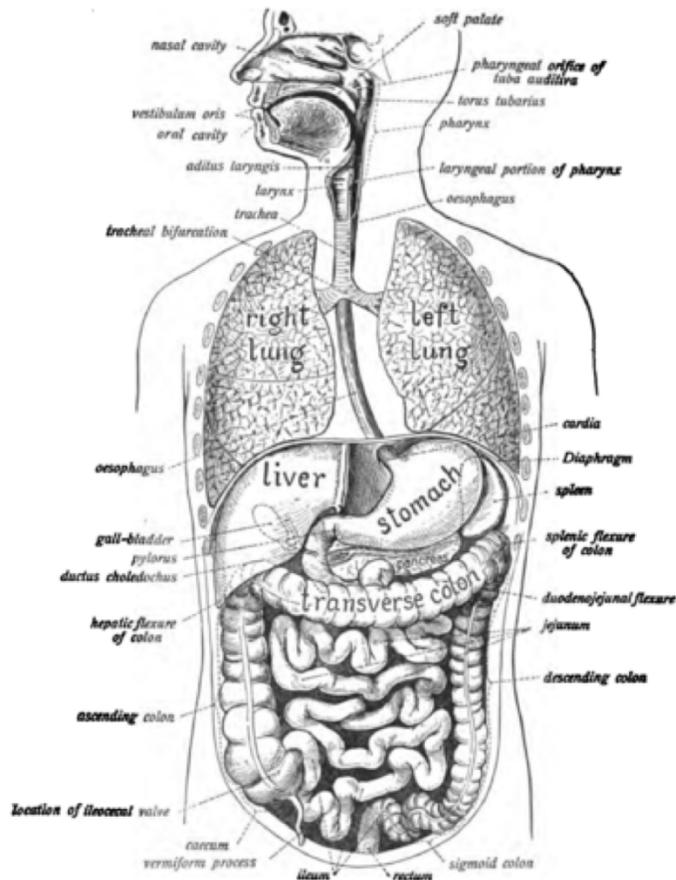
<p>Large Intestine – figures 23.1 – 23.3 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/23-5-the-small-and-large-intestines</p>	<p>Pancreas – figure 23.26 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/23-6-accessory-organs-in-digestion-the-liver-pancreas-and-gallbladder</p>
Ileocecal valve	Acinar cells and islet cells (islets of Langerhans)
Cecum and vermiform appendix; ascending, transverse and descending colon	Hepatopancreatic ampulla (Ampulla of Vater)
Taenia coli and epiploic appendages	Sphincter of Oddi
Haustrum (haustra)	Pancreatic duct
Rectum and anal canal	
External anal sphincter	
Epithelium – simple columnar (with goblet and absorptive cells)	
<p>Liver and gall bladder – figure 23.52, 23.27 in the OpenStax text: https://openstax.org/books/anatomy-and-physiology/pages/23-6-accessory-organs-in-digestion-the-liver-pancreas-and-gallbladder</p>	
Lobes: right, left, caudate and quadrate	
Falciform ligament	
Gall bladder, cystic duct, and bile duct	
Liver lobule	
Portal triad and central vein	
Hepatocytes and Kupffer cells	
Sinusoids	

Background Information

Overview of the Digestive System

The **alimentary canal (or gastrointestinal tract)**, a group of organs that form a long tube to conduct foodstuffs from the mouth to the anus, and **accessory organs**, which assist in mechanical or chemical digestion of foodstuffs, work together to break complex molecules in foodstuffs into simple substances that can be taken into cells efficiently and readily used. Organs of the alimentary canal include the mouth, the oropharynx and laryngopharynx, the esophagus, the stomach, the small intestine, and the large intestine. Accessory organs include the teeth, the tongue, the salivary glands, the liver and gallbladder, and pancreas.

The below 1906 engraving of the human body (from Wikipedia) shows the organs of the digestive system, from the mouth to the anus.



By Dr. Johannes Sobotta -
Sobotta's Atlas and Text-book of
Human Anatomy 1906, Public
Domain,
<https://commons.wikimedia.org/w/index.php?curid=29847467>

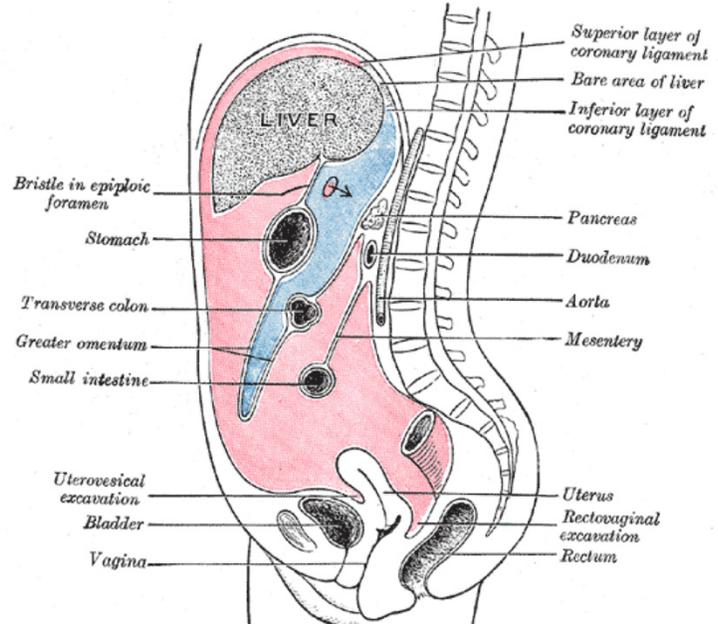
Membranes of the Digestive System: Peritoneum, Mesentery and Mesocolon

Much of the digestive system is enclosed in a double-layered **peritoneum**, a serous membrane. The picture at the right (from 1918) shows the abdomen in midsagittal view. The **parietal peritoneum** is fused to the abdominal wall, while the visceral peritoneum adheres to the organs. The **visceral peritoneum** folds over on itself to form the **mesentery**. This means that most of the organs in this cavity are surrounded by visceral peritoneum while suspended in the larger abdominal cavity bounded by the parietal peritoneum.

Two important folds of the peritoneum are the **lesser** and **greater omenta**. The **lesser omentum**, formed by an anterior fold of the serosa of the stomach and duodenum, connects the liver to the stomach and duodenum. The lesser omentum forms a pathway for blood vessels to enter the liver. The **greater omentum** is formed by a long drape of the visceral peritoneum descending from the stomach and covering much of the small intestine that doubles back on itself to end at the transverse colon. This forms an apron-like structure that often contains considerable amounts of adipose tissue that lying anterior to the other organs in the abdominal cavity. When an incision is made into the abdomen, during surgery for example, it is the first structure seen.

The **mesentery** is a third important fold of the peritoneum. It begins at the posterior abdominal wall and wraps around the small intestine, then returns to the abdominal wall. Blood vessels are found between the double layers here, and this thick membrane anchors the intestines to the abdominal wall. Two additional peritoneal folds, the **mesocolon**, attach the transverse and sigmoid colon to the posterior abdominal wall.

Wikipedia has several other good images. See the link:
https://en.wikipedia.org/wiki/Greater_omentum



By Henry Vandyke Carter - Henry Gray (1918) Anatomy of the Human Body (See "Book" section below)Bartleby.com: Gray's Anatomy, Plate 1035, Public Domain, <https://commons.wikimedia.org/w/index.php?curid=566980>

Histological Structure of the Gastrointestinal Tract (The Alimentary Canal)

The organs of the gastrointestinal tract, from the lower esophagus to the anal canal, have a common arrangement of four layers. These four layers are the **mucosa**, the **submucosa**, the **muscularis externa**, and the **serosa** (sometimes called **adventitia**). Variations are seen in this basic histological plan that correlate to the function of each organ. As one example, the stomach has an extra layer of smooth muscle tissue to promote churning/mechanical digestion.

The below image from OpenStax (Figure 23.3) depicts the arrangement of these four layers in the wall of the GI tract. The link is below:

<https://openstax.org/books/anatomy-and-physiology/pages/23-1-overview-of-the-digestive-system>

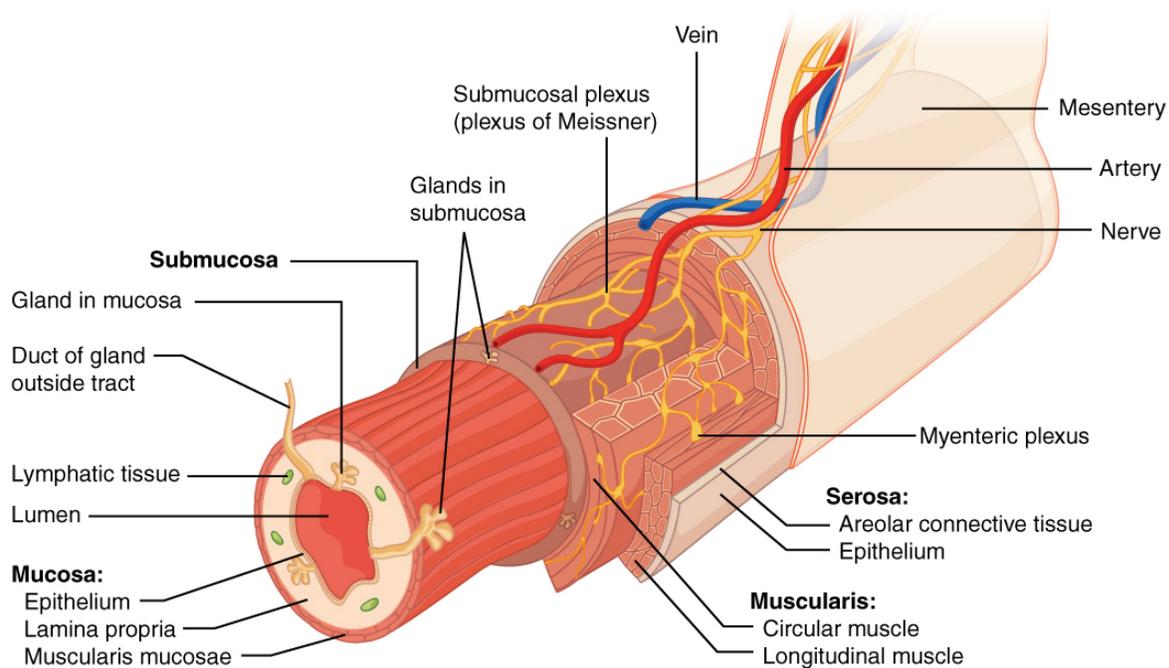


Figure 23.3 Layers of the Alimentary Canal The wall of the alimentary canal has four basic tissue layers: the mucosa, submucosa, muscularis, and serosa.

The **mucosa** is the deepest layer, lining the lumen of the alimentary canal. There are three tissues that make up the mucosa: epithelium that is in contact with the contents in the lumen; underlying connective tissue called the lamina propria; and a thin layer of smooth muscle called the muscularis mucosae.

The **submucosa** connects the mucosa to the next layer, the muscularis externa. The submucosa is areolar connective tissue, and this is where blood vessels, glands, nerves / nerve plexi and lymphatic tissue may be found.

The **muscularis externa** (sometimes called simply the muscularis) generally consists of two sheets or layers of smooth muscle tissue. The fibers of the innermost layer are arranged circularly (running at a 90° angle to the axis of the organ), while the fibers in the more superficial layer are longitudinal (running parallel to the axis of the organ).

The **serosa** surrounds all the digestive organs that are suspended in the abdominal cavity. As the name implies, the serosa is a serous membrane: two layers separated by a thin space filled with serous fluid. Each layer of the serosa is composed of a thin layer of connective tissue with a simple squamous epithelium. In the abdominal cavity, the serosa is also called the visceral peritoneum (discussed above). Some organs - those found outside the abdominal cavity like the esophagus - have only a single-layered membrane here called the **adventitia**.

The Alimentary Canal, From Mouth to Anus

Mouth and Pharynx

Mechanical and chemical digestion begins in the mouth, where foodstuffs are ingested. Structures and glands (like teeth and salivary glands) in the mouth contribute to the digestive functions there, and will be described in more detail with the accessory structures. The mouth is bounded superiorly by the **palate**, divided into the **hard palate** (which is a bony plate of the maxilla), and the **soft palate**, a fleshy extension that ends in the **uvula**.

The mouth leads to the **pharynx**, a funnel-shaped region that allows access to both the **esophagus** of the digestive system and the larynx / trachea of the respiratory system. A bolus of foodstuffs will encounter the oropharynx and the laryngopharynx when it is swallowed.

Images of the oral cavity (Figure 23.7) and the pharynx (Figure 23.12) from OpenStax are below:

<https://openstax.org/books/anatomy-and-physiology/pages/23-3-the-mouth-pharynx-and-esophagus>

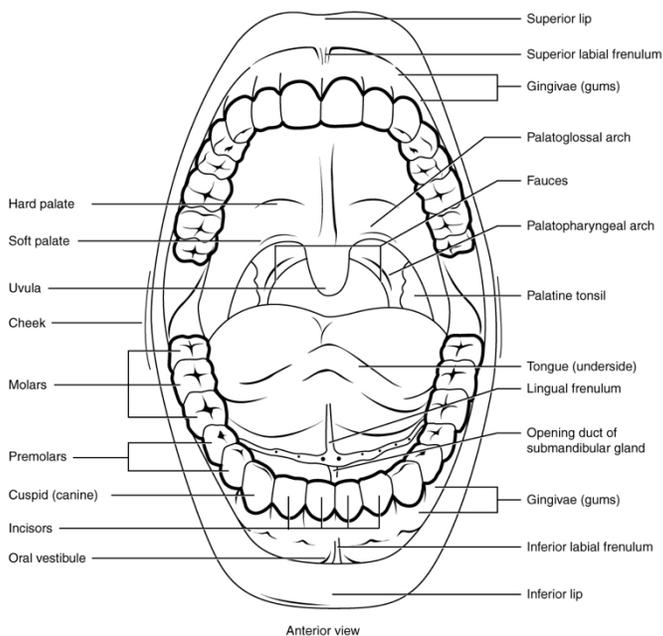


Figure 23.7 Mouth The mouth includes the lips, tongue, palate, gums, and teeth.

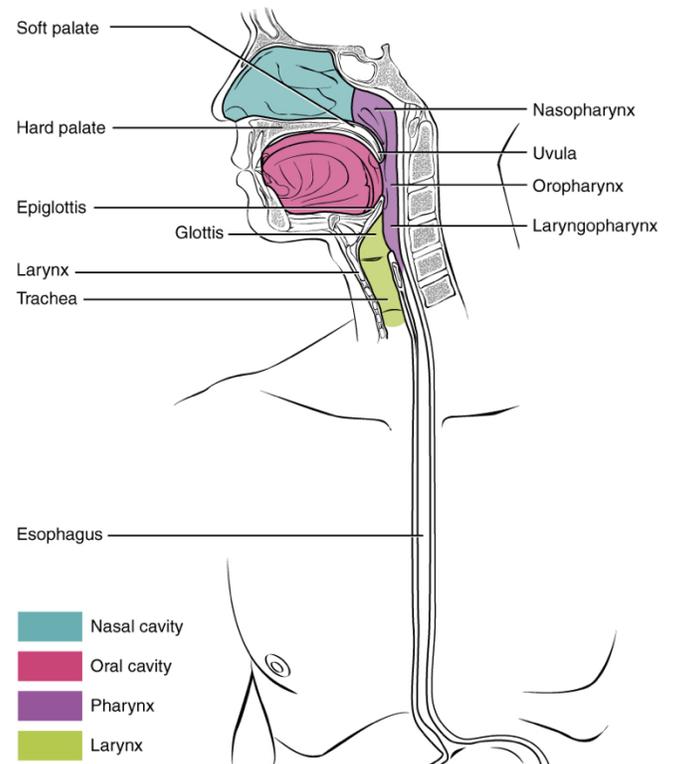


Figure 23.12 Pharynx The pharynx runs from the nostrils to the esophagus and the larynx.

Esophagus

The pharynx leads to the **esophagus**, a long muscular tube located between the trachea and the aorta. Smooth muscle contraction in the esophagus propels the bolus of foodstuffs toward the stomach. The esophagus is separated from the stomach by a ring of smooth muscle tissue called the **cardiac sphincter** (or the lower esophageal sphincter, or the gastroesophageal sphincter). This ring of smooth muscle tissue regulates the movement of foodstuffs between the esophagus and the stomach so that food moves in one direction only. It also prevents the contents of the stomach from splashing or re-entering the esophagus where they can do damage to those tissues.

The composition of the wall of the esophagus contributes to its function to conduct foodstuffs to the stomach for chemical digestion. The mucosa is composed of non-keratinized stratified squamous epithelium, a tissue that is suited to resisting friction because of the many cell layers. This protects the organ against the wear and tear associated with potentially abrasive food particles that are pushed through the esophagus to the stomach. The esophagus also lacks a serosa and instead is surrounded by a single-layered adventitia.

Stomach

The stomach is a muscular, sac-like organ shaped vaguely like a backwards C. The dome-shaped **fundus** extends superiorly, forming the top part of the C, while the **pylorus** extends laterally toward the small intestine like the tail of the letter. Other regions of the stomach are the **cardia**, located near the entrance of the esophagus, the main body of the stomach, and the **pyloric antrum** (pyloric region or pylorus), a straight-ish portion that leads to the **pyloric sphincter** and the duodenum. The inside part of the C-shaped organ is called the **lesser curvature** while the outer part is called the **greater curvature**. In the pylorus, there is another ring of smooth muscle called the **pyloric sphincter**. The pyloric sphincter serves the same function as the gastroesophageal sphincter: to ensure that there is one-way movement of foodstuffs through the alimentary canal.

The below image from the OpenStax text (Figure 23.15) shows the gross anatomical features of the stomach.

<https://openstax.org/books/anatomy-and-physiology/pages/23-4-the-stomach>

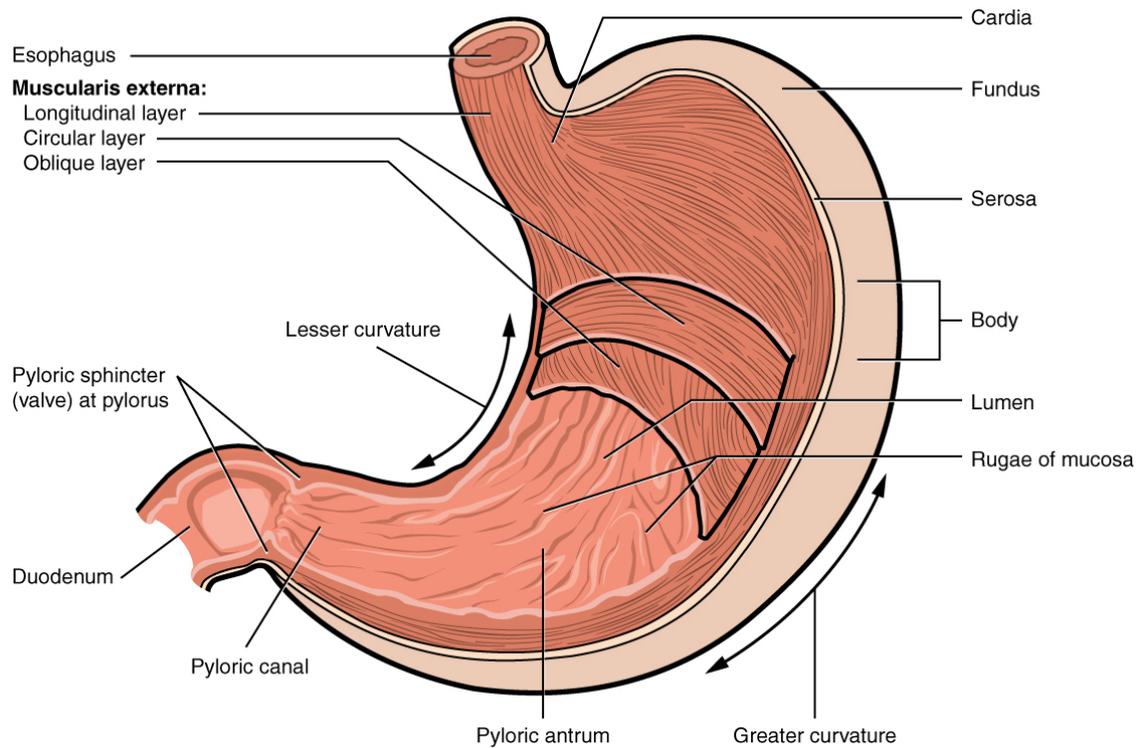


Figure 23.15 Stomach The stomach has four major regions: the cardia, fundus, body, and pylorus. The addition of an inner oblique smooth muscle layer gives the muscularis the ability to vigorously churn and mix food.

Small Intestine

Once foodstuffs have passed through the **pyloric sphincter**, it reaches the small intestine. The three divisions of the small intestine are the **duodenum** (Latin meaning “12 fingers,” the region closest to the stomach, and the shortest region); the **jejunum** (the middle region, which is much longer); and the **ileum** (the most distal region, which is the longest). While the duodenum looks slightly different from the rest of the small intestine, the differences between the jejunum and ileum are not evident with the naked eye. Important histological variations distinguish these two regions from one another.

Figure 23.18 from the OpenStax text shows the different regions of the small intestine in different colors. See the link:

<https://openstax.org/books/anatomy-and-physiology/pages/23-5-the-small-and-large-intestines>

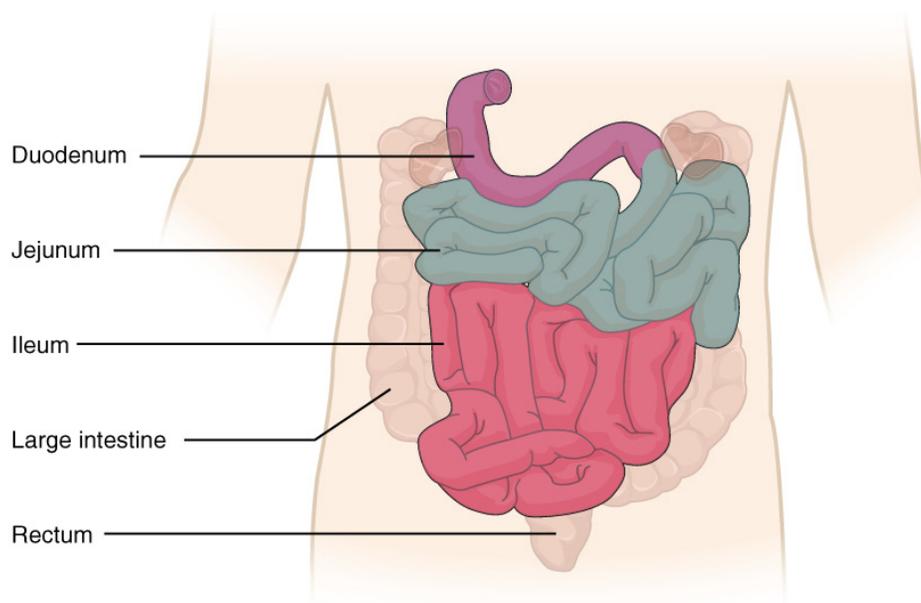


Figure 23.18 Small Intestine The three regions of the small intestine are the duodenum, jejunum, and ileum.

Large Intestine

Another smooth muscle sphincter, the **ileocecal sphincter**, regulates the flow of foodstuffs from the ileum to the proximal region of the **large intestine** (so named for its larger diameter than the small intestine). The large intestine has 4 main regions: **the cecum** (a bulbous blind-ended pouch from which the vermiform appendix extends); the colon, composed of **ascending, transverse and descending segments**; the **rectum**, a straight region; and the **anal canal**, which opens to the body exterior. The anal canal is closed by two sphincters: an **internal** (involuntary) and an **external** (voluntary) anal sphincter.

The below image (Figure 23.21 from the OpenStax text) shows the gross anatomical features of the large intestine:

<https://openstax.org/books/anatomy-and-physiology/pages/23-5-the-small-and-large-intestines>

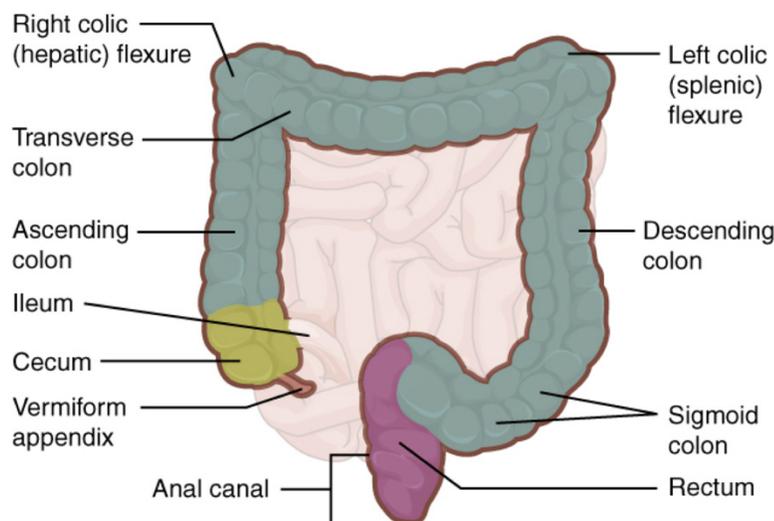
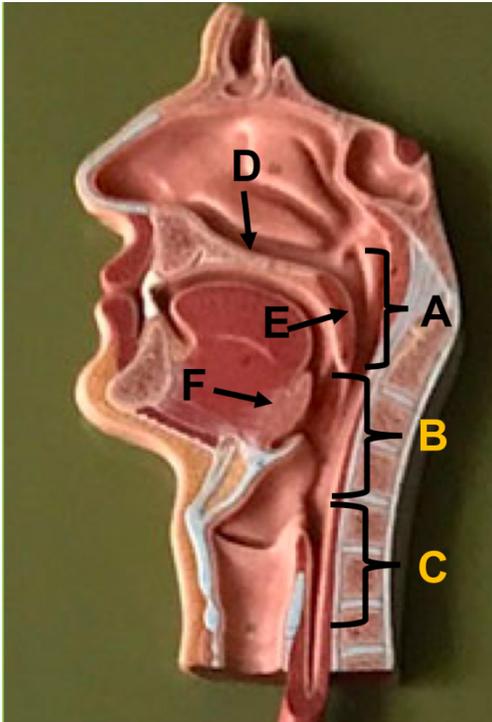


Figure 23.21 Large Intestine The large intestine includes the cecum, colon, and rectum.

Activity 1 – Identifying anatomical features of the mouth, pharynx and larynx.

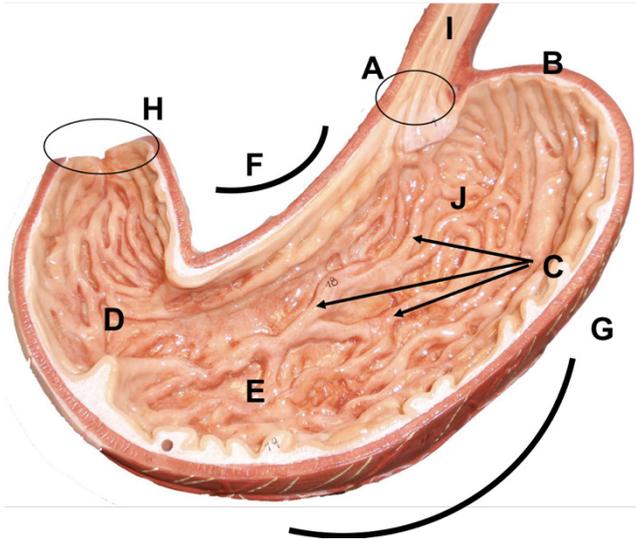
Fill in the table on the right with the name of the structure, region, feature, or organ that corresponds to each label on the model at the left.



Label	Structure, region, feature or organ
A	
B	
C	
D	
E	
F	

Activity 2 – Identifying anatomical structures of the stomach.

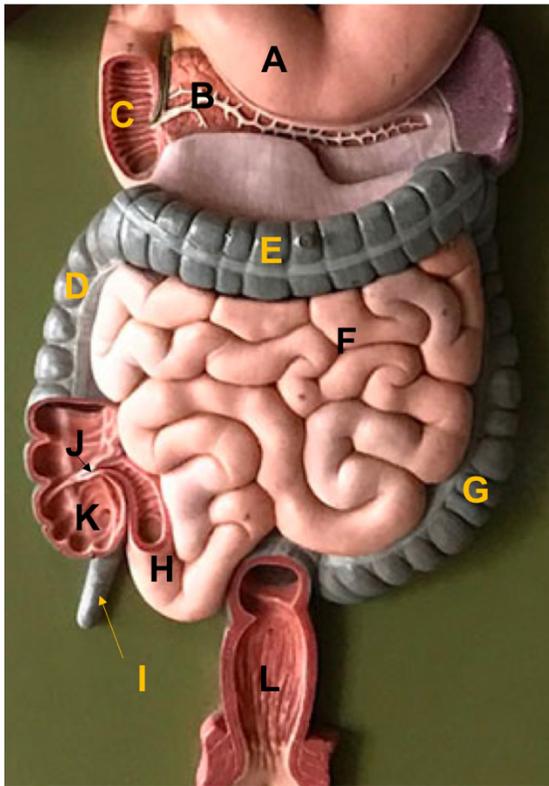
Fill in the table on the right with the name of the digestive system structure, region, feature, or organ that corresponds to each label on the model at the left.



Label	Structure, region, feature or organ
A	
B	
C	
D	
E	
F	
G	
H	
I	
J	

Activity 3 – Identifying anatomical features of the gastrointestinal tract.

Fill in the table on the right with the name of the digestive system structure, region, feature, or organ that corresponds to each label on the model at the left.



Label	Structure, region, feature or organ
A	
B	
C	
D	
E	
F	
G	
H	
I	
J	
K	
L	

Activity 4 – Functions of the organs of the gastrointestinal tract (alimentary canal).

Fill in the table with the functions of the alimentary canal / digestive system organs.

Organ	Function(s)
Mouth	
Esophagus	
Stomach	
Small Intestine	
Large Intestine	

Activity 5 - Histology of the Organs of the Alimentary Canal: Esophagus

The University of Michigan has a virtual histology site with numerous images of tissues in the organs of the digestive system. Here is a link to an image of the esophagus and the stomach:

http://virtuallides.med.umich.edu/Histology/Digestive%20System/Pharynx%20Esophagus%20and%20Stomach/153_HISTO_20X.svs/view.apml?cwidth=980&cheight=1045&chost=virtuallides.med.umich.edu&csis=1&listview=1

(NOTE - the stomach is the tissue on the left in the field of view, while the esophagus is on the right. Be sure that you can identify the lumen of the organ first, and it may not be in the place you think.)

In the space below, sketch or paste a low-power magnification image of the histology of the esophagus (ie, 2X or less). Label the layers of the wall of the esophagus (mucosa, submucosa, muscularis, serosa / adventitia).

Now, zoom in so you can see the mucosa. Sketch or paste a higher-power magnification image below. Label the mucosa, and classify the EPITHELIAL tissue there. What is the advantage of this tissue in the esophagus?

Activity 6 – Histology of the Organs of the Alimentary Canal: Stomach

The University of Michigan has a virtual histology site with numerous images of tissues in the organs of the digestive system. Here is a link to an image of the esophagus and stomach:

http://virtuallides.med.umich.edu/Histology/Digestive%20System/Pharynx%20Esophagus%20and%20Stomach/153_HISTO_20X.svs/view.apml?cwidth=980&cheight=1045&chost=virtuallides.med.umich.edu&csis=1&listview=1

(NOTE - the stomach is the tissue on the left in the field of view, while the esophagus is on the right. Be sure that you can identify the lumen of the organ first, and it may not be in the place you think.)

In the space below, sketch or paste a low-power magnification image of the histology of the stomach (ie, 2X or less). Label the layers of the wall of the stomach (mucosa, submucosa, muscularis, serosa / adventitia).

Sketch or paste a higher-power magnification image of the histology of the stomach where the epithelial layer of the mucosa is evident. Label the gastric pits and gastric glands, if you can see them. Write the classification of the EPITHELIAL tissue on your image.

What is the advantage of the epithelial tissue you identified in the stomach?

Activity 7 - Histology of the Organs of the Alimentary Canal: Small Intestine

The University of Michigan has a virtual histology site with numerous images of tissues in the organs of the digestive system. Here is a link to an image of the small intestine (ileum or jejunum):

http://virtualslides.med.umich.edu/Histology/Digestive%20System/Intestines/168_HISTO_40X.svs/view.apml?cwidth=980&cheight=1045&chost=virtualslides.med.umich.edu&csis=1&listview=1

In the space below, sketch or paste a low-power magnification image of the histology of the small intestine (ie, 2X or less). Label the layers of the wall of the small intestine (mucosa, submucosa, muscularis, serosa / adventitia). You may also be able to see the plicae circulares (circular folds) and villi at low power - label them also.

Sketch or paste a higher-power magnification image of the histology of the small intestine where the epithelial layer of the mucosa is evident. Label the villi, epithelial layer, lamina propria, and goblet cells if you can see them. Write the classification of the EPITHELIAL tissue on your image.

What is the advantage of the epithelial tissue you identified in the small intestine?

Activity 8 – Summary of epithelial tissues in the gastrointestinal tract (alimentary canal).

For each organ of the alimentary canal, identify / classify the epithelial tissue that is present in the mucosa. Give at least one other modification of the basic histological plan of the alimentary canal that is seen in each organ, and describe how this modification contributes to the function of that organ.

Organ	Epithelium?	Another modification of the histological plan, and how this modification contributes to the function of the organ
Esophagus		
Stomach		
Small Intestine		
Large Intestine		

Accessory Organs of the Digestive System – Gross Anatomy

Teeth and tongue

The functions of the teeth are to tear, grind and crush large foodstuffs into smaller particles. This increases the surface area of the food that is exposed to the action of enzymes and digestive juices. The tongue has many functions, including taste, speech, manipulation of food in the mouth and swallowing. The rough surface of the tongue aids in the breakdown of food there.

Salivary glands

There are 3 major pairs of salivary glands in the mouth: the **parotid glands**, found outside the mouth and superficial to masseter on both sides; the **submandibular glands**, located just below the jaw; and the **sublingual glands**, located under the tongue. All three pairs of salivary glands are exocrine, meaning they secrete saliva through ducts into the oral cavity. Saliva is a watery fluid that contains antibacterial compounds, enzymes, and mucus. Saliva is important in lubricating foodstuffs in the mouth so they pass smoothly through the esophagus to the stomach. The enzymes in saliva ensure that chemical digestion begins in the mouth.

Here is an image from the OpenStax text (Figure 23.9) showing the location of these glands in the oral cavity:

<https://openstax.org/books/anatomy-and-physiology/pages/23-3-the-mouth-pharynx-and-esophagus>

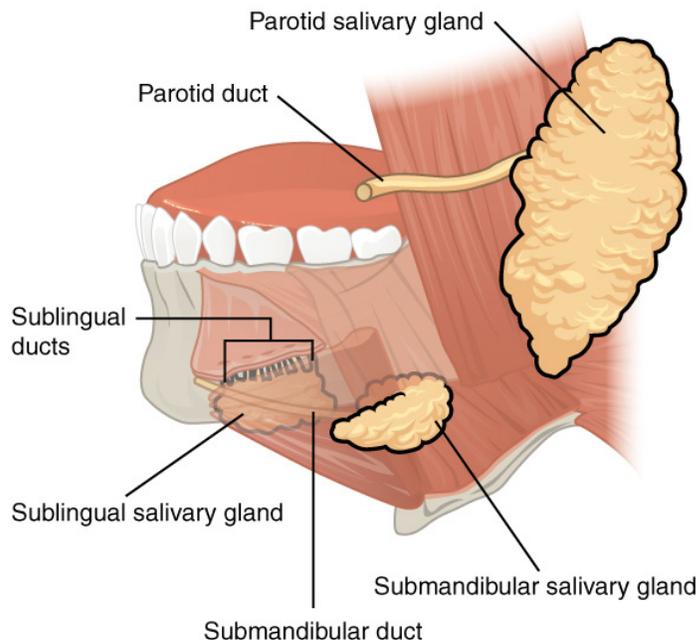
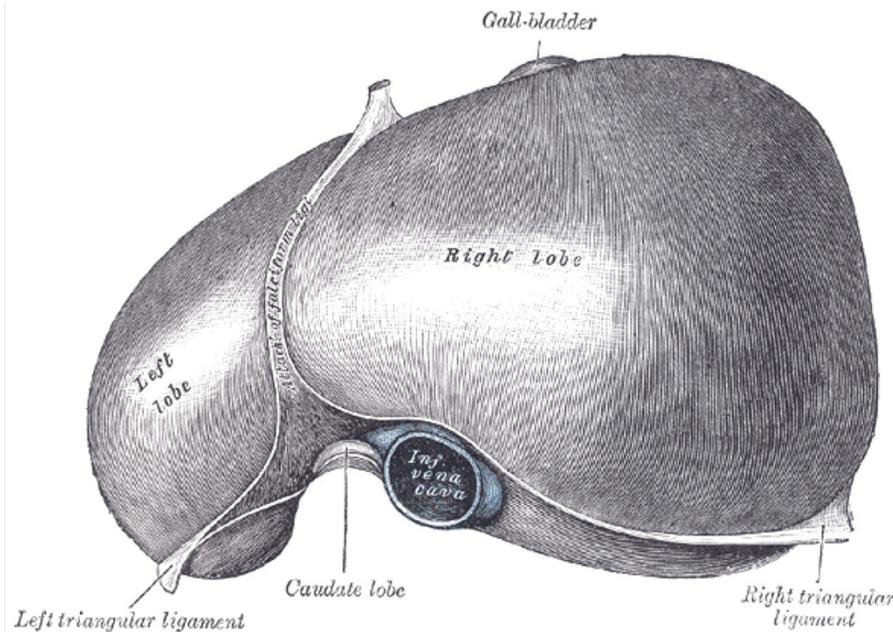


Figure 23.9 Salivary glands The major salivary glands are located outside the oral mucosa and deliver saliva into the mouth through ducts.

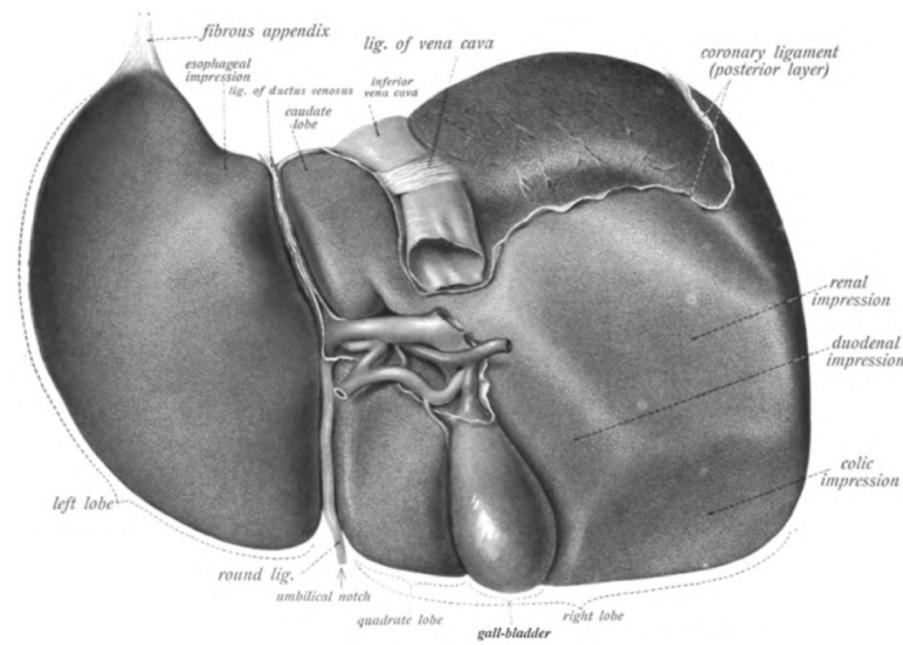
Liver and Gallbladder

The liver is the largest gland in the body and has many functions, mostly related to digestion. It can be divided into 4 lobes: the large **right** and smaller **left lobes** (separated by the **falciform ligament**, an incursion of the mesentery) and the smaller **quadrate** and **caudate lobes**, which can be seen in a posterior view. The **gallbladder**, a greenish sac-like structure, is tucked up inferiorly under the lobes of the liver. Its greenish hue comes in part from the **bile** that is stored within. Bile is made in the liver, and excess is stored in the **gallbladder**. Bile can be released to the small intestine to aid in the emulsification and digestion of fats.

The figures below, from early 20th century anatomy texts, show the liver and gallbladder in superior and inferior view.



By Henry Vandyke Carter - Henry Gray (1918) *Anatomy of the Human Body* (See "Book" section below) Bartleby.com: Gray's Anatomy, Plate 1085, Public Domain, <https://commons.wikimedia.org/w/index.php?curid=567039>



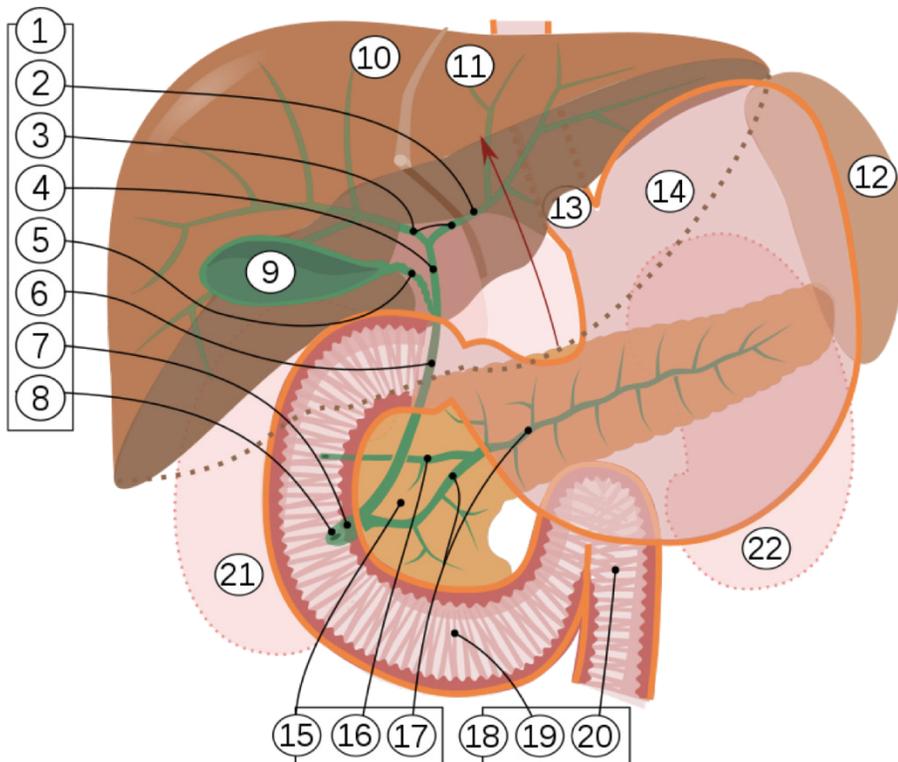
By Dr. Johannes Sobotta - Sobotta's Atlas and Text-book of Human Anatomy 1906, Public Domain, <https://commons.wikimedia.org/w/index.php?curid=29901575>

Bile that is made in the liver travels through small ductules until it reaches the **common hepatic duct**. Some bile will travel to the gallbladder through the **cystic duct**, where it is stored. When stimulated (by food reaching the duodenum), the gallbladder will contract and force bile through the cystic duct to the common bile duct, and then to the duodenum through the **ampulla of Vater** (the opening) in the **hepatopancreatic ampulla** (a nipple-like structure housing the opening). As the name implies, digestive secretions from the pancreas also enter the duodenum here.

Pancreas

The **pancreas** is a comma-shaped, somewhat spongy gland that is nestled into the curve of the duodenum. It is both exocrine and endocrine, meaning that its products are secreted both into the bloodstream (hormones like insulin and glucagon) and into the duodenum (pancreatic juice, enzymes and bicarbonate). The enzymes and components of the pancreatic juice are secreted into the **pancreatic duct**, and enter the duodenum by way of the **hepatopancreatic ampulla**.

The below image from Wikimedia / Wikipedia (see the link: <https://en.wikipedia.org/wiki/Gallbladder>) shows the relationship between the liver and pancreas, and the duct structures that deliver their products to the duodenum.

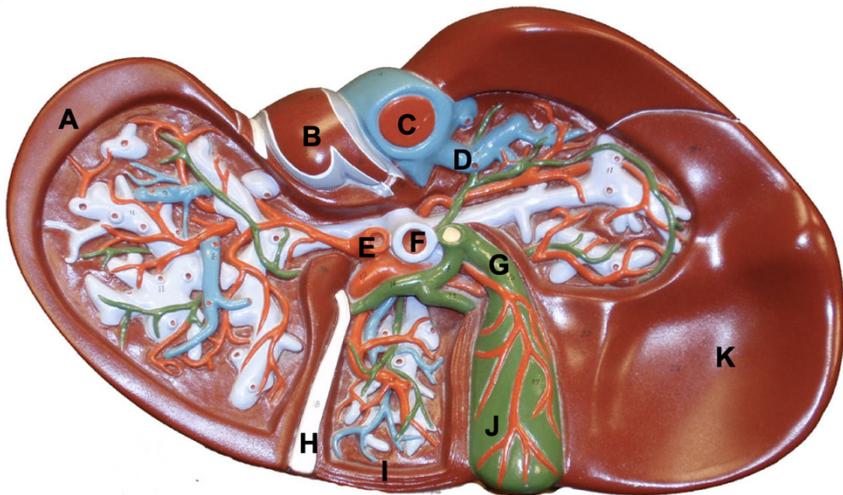


Label	Structure
1	Bile ducts
2	Intrahepatic ducts
3	R and L hepatic ducts
4	Common hepatic duct
5	Cystic duct
6	Common bile duct
7	Ampulla of Vater
8	Major duodenal papilla
9	Gallbladder
10 - 11	Right and left lobes of the liver
12	Spleen
13	Esophagus
14	Stomach
15	Pancreas
16	Accessory pancreatic duct
17	Pancreatic duct
18	Small intestine
19	Duodenum
20	Jejunum
21 - 22	Right and left kidneys

By Jmarchn - Own work, CC BY-SA 3.0,
<https://commons.wikimedia.org/w/index.php?curid=14612>
 350

Activity 9 – Identifying the anatomical features of the liver.

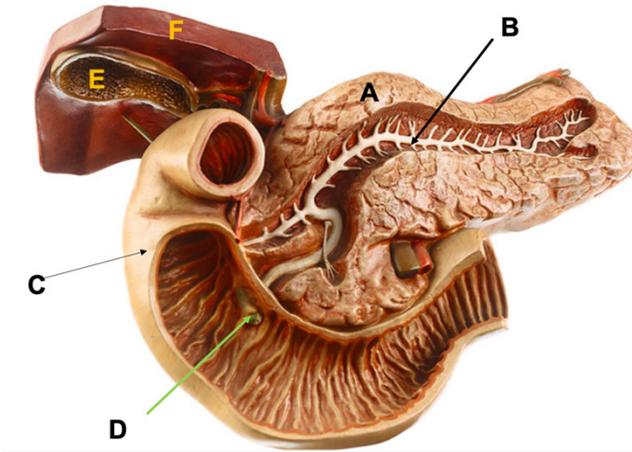
Fill in the table with the names of the labeled structures from the liver model on the left.
 (NOTE – the model is shown in the inferior view.)



Label	Structure, region, or feature
A	
B	
C	
D	
E	
F	
G	
H	
I	
J	
K	

Activity 10 – Identifying the features of the accessory organs in the digestive system

Fill in the table with the names of the labeled structures from the digestive system model on the left.



Label	Structure, region, feature or organ
A	
B	
C	
D	
E	
F	

Accessory Organs of the Digestive System: Histology of the Liver

The liver is responsible for numerous functions: synthesizing and releasing bile, detoxification of exogenous substances in the blood, synthesis of plasma proteins, storage of certain nutrients. The unique microanatomy of the liver begins with the functional unit called the **lobule**, a rough six-sided arrangement of **hepatocytes** (liver cells), blood vessels and bile canaliculi. At the corners of each lobule three vessels are found together: a branch of the hepatic portal vein, a branch of the hepatic artery, and a bile ductule. These three vessels together are called the **portal triad**. Oxygenated blood in the hepatic artery and deoxygenated blood in the hepatic portal vein leave those vessels and mix in the broad, leaky capillaries called **sinusoids**, which deliver blood to the **central vein** in the center of the lobule. From the central vein, blood then travels to the hepatic vein, and then to the inferior vena cava. Bile that is synthesized in the hepatocytes travels toward the bile ductule at the corners. As seen in the OpenStax image below (Figure 23.25, <https://openstax.org/books/anatomy-and-physiology/pages/23-6-accessory-organs-in-digestion-the-liver-pancreas-and-gallbladder>), the lobule resembles a bicycle wheel, with the central vein in the middle and the sinusoids / bile canaliculi / hepatocytes radiating outward like spokes. Although oxygenated and deoxygenated blood do mix in the lobule, the blood and the bile do not mix.

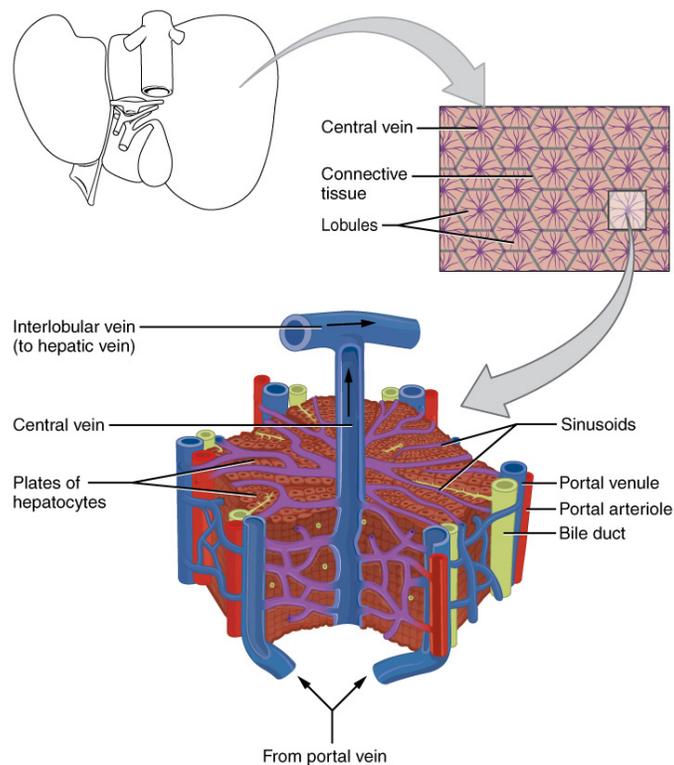


Figure 23.25 Microscopic Anatomy of the Liver The liver receives oxygenated blood from the hepatic artery and nutrient-rich deoxygenated blood from the hepatic portal vein.

Accessory Organs of the Digestive System: Histology of the Pancreas

The endocrine and exocrine portions of the pancreas can be seen in its microanatomy. The exocrine portion is composed of clusters of **acinar cells** and tiny **pancreatic ducts** that synthesize and release digestive enzymes, bicarbonate and other substances that are important for digestion of foodstuffs in the small intestine. Collectively, the digestive substances synthesized by the acinar cells is called (descriptively) **pancreatic juice**. The acinar cells resemble clusters of grapes. The endocrine portion is composed of discrete structures called **islets (or pancreatic islets)**, which synthesize and release hormones like insulin and glucagon. The islet cells are easily distinguished from the acinar cells on a microscope slide.

This OpenStax image (Figure 17.18) shows the relationship between the acinar cells, the pancreatic ducts, and the islet cells in the pancreas. A photomicrograph of pancreatic tissue showing both endocrine and exocrine tissue is also shown. See the link:

<https://openstax.org/books/anatomy-and-physiology/pages/17-9-the-endocrine-pancreas>

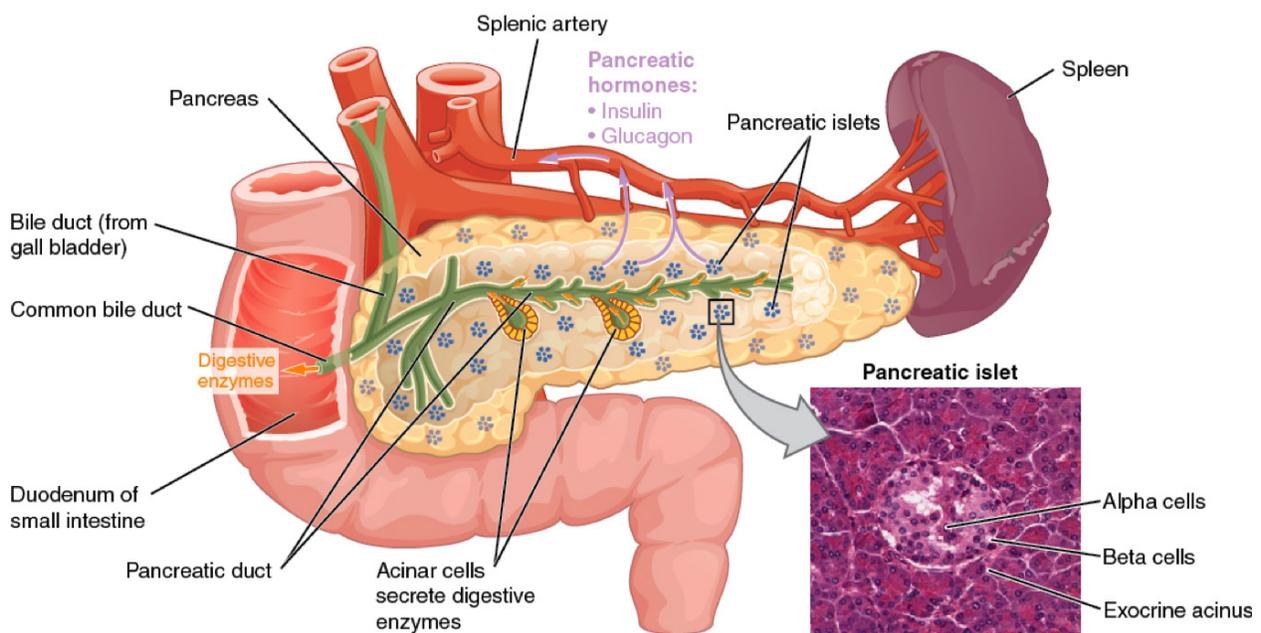


Figure 17.18 Pancreas The pancreatic exocrine function involves the acinar cells secreting digestive enzymes that are transported into the small intestine by the pancreatic duct. Its endocrine function involves the secretion of insulin (produced by beta cells) and glucagon (produced by alpha cells) within the pancreatic islets. These two hormones regulate the rate of glucose metabolism in the body. The micrograph reveals pancreatic islets. LM \times 760. (Micrograph provided by the Regents of University of Michigan Medical School \copyright 2012)

Activity 12 - Histology of the Accessory Organs of the Digestive System: Liver

The University of Michigan has a virtual histology site with numerous images of tissues in the organs of the digestive system. Here is a link to an image of the liver and gall bladder:

(NOTE – the large, round structure with the ruffled-looking border is the gallbladder. The liver tissue is all around this large structure.)

http://virtualslides.med.umich.edu/Histology/Digestive%20System/Liver%20and%20Pancreas/195M_HISTO_40X.svs/view.apml?cwidth=980&cheight=1045&chost=virtualslides.med.umich.edu&csis=1&listview=1

In the space below, sketch or paste a low-power magnification image of the histology of the small intestine (ie, 10X or less). Label the central vein, the portal triad, and sinusoids. (HINT – look for a hexagon-shaped lobule and central vein.)

Activity 13 - Histology of the Accessory Organs of the Digestive System: Pancreas

The University of Michigan has a virtual histology site with numerous images of tissues in the organs of the digestive system. Here is a link to an image of the pancreas:

http://virtuallides.med.umich.edu/Histology/Digestive%20System/Liver%20and%20Pancreas/188_HISTO_40X.svs/view.apml?cwidth=980&cheight=1045&chost=virtuallides.med.umich.edu&csis=1&listview=1

In the space below, sketch or paste a low-power magnification image of the histology of the pancreas (ie, 10X or less). Label the acinar cells and islets. (HINT – the round white structures appear to be artifacts of the tissue preparation and are NOT islets. The islets will show up as being more lightly stained than the acinar cells.)

Exit Ticket: Before you leave lab today, read the following scenario and fill in the blanks.

You are travelling through the digestive tract as far as the appendix. You gain easy entry to the subject's mouth on a piece of bread. You avoid being chewed and watch as a number of openings squirt fluid into the mouth.

- As the bread begins to disappear, you decide that the fluid, called _____ must contain the enzyme _____.
- You walk to the back of the oral cavity, and find yourself being carried along by a squeezing motion of the walls around you. This propelling motion is called _____.
- As you are carried helplessly downward, you see two openings, the _____ and the _____. Just as you are about to straddle the solid area between, the structure on your left moves upward quickly and a trapdoor-like structure called the _____ flaps over its opening
- Down you go, and the passage beneath you opens into a huge dark chamber with mountainous folds. This is the _____. The folds are very slippery because they are coated with _____.
- Juices begin to gurgle into the chamber from pits in the floor – this juice is very caustic and you suspect that it must contain _____ and _____.
- To protect yourself, you cover yourself in the slippery substance that is coating the rest of the organ.

- You move toward the far exit and squeeze through the _____ valve into the next organ. You can see lumps of undigested cellulose (starch) and globules of fat floating about.
- A wave of fluid pours into the chamber from an opening high in the wall above you. The fat globules begin to fall apart when they come into contact with this new fluid, and you decide that it must contain an enzyme called _____.
- The new fluid entering the organ passes through a duct called the _____ that comes from the _____.
- You find yourself on a roller-coaster ride through this organ. You are “stroked” by velvety projections from the wall that are called _____.
- The twisting, turning movement comes to an abrupt halt when you are catapulted through another opening called the _____ into the appendix.

The Digestive System: Enzyme Activity

Introduction

In this exercise, you will be studying the activity of enzymes (proteases, amylases, lipases) to digest proteins, starch and lipids. You'll be performing some simple tests to identify the presence or absence of substrates and products, and using the results of these tests to determine if digestion occurred or not.

Learning Objectives

By the end of this lesson you will be able to:

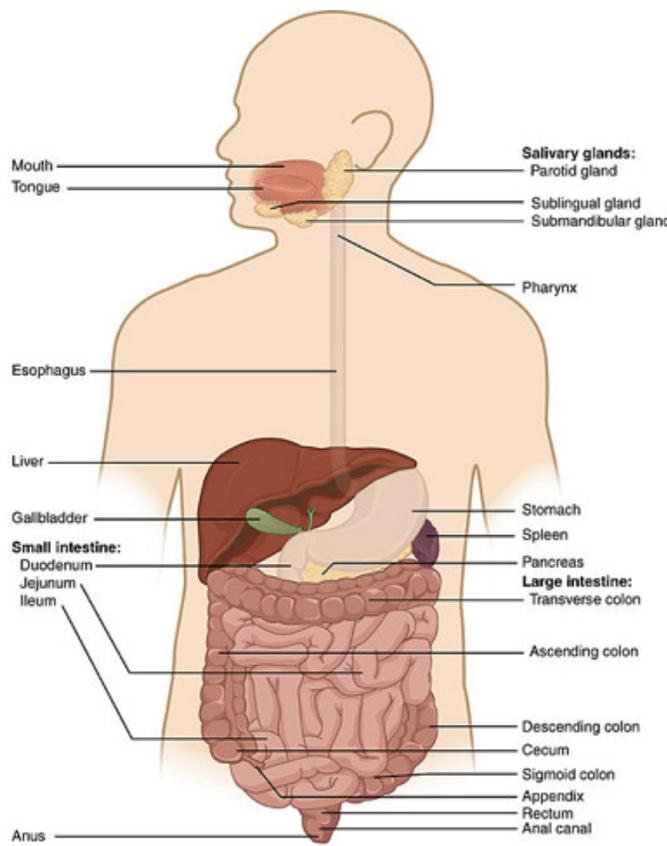
- List the digestive enzymes involved in the digestion of proteins, fats and carbohydrates, and to identify their site of origin
- Identify the end products of protein, fat and carbohydrate digestion
- Discuss the role of temperature and pH on digestive enzyme activity
- Identify or classify an enzyme based on the results of simple chemical tests that identify the presence of starch, protein, fat, simple sugars, amino acids and fatty acids

Background Information

The digestive system is composed of the alimentary canal (mouth, pharynx, esophagus, stomach, small intestine, large intestine), which is essentially a long tube that is open to the outside at both ends, and accessory organs (teeth, liver, gallbladder, pancreas) that aid in digestion of foodstuffs but are not directly part of the digestive tract. The accessory organs contribute secretions or provide other functions that serve to enhance the ability of the digestive tract to break down large complex molecules in foodstuffs into smaller molecules that cells can use. Breaking down large molecules into smaller molecules can occur by mechanical action (crushing, tearing, mixing) and by chemical action (hydrolysis). The digestive system does both.

The below image (Figure 23.2 in the OpenStax text) shows the arrangement of the digestive system organs in the body. See the link:

<https://openstax.org/books/anatomy-and-physiology/pages/23-1-overview-of-the-digestive-system>



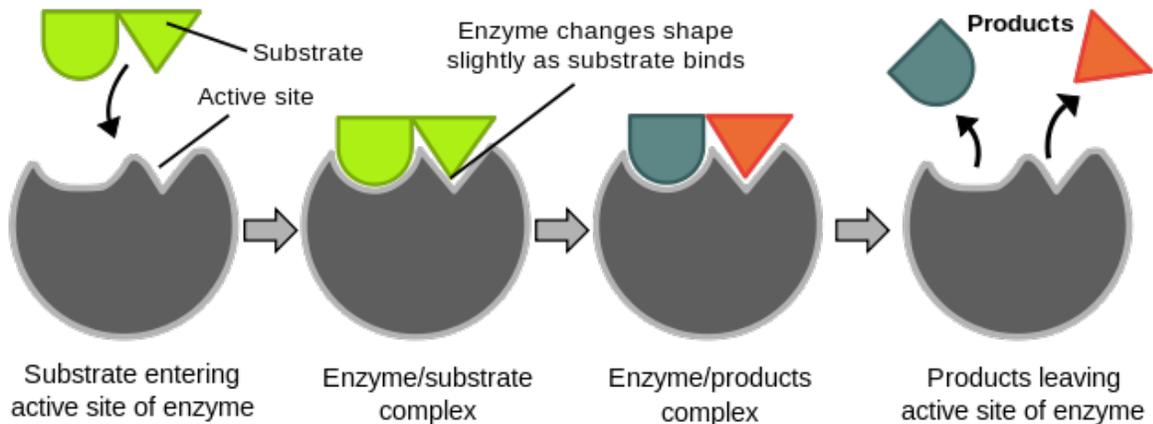
OpenStax College - Anatomy & Physiology, Connexions
Web site. <http://cnx.org/content/col11496/1.6/>, Jun 19, 2013.

Figure 23.2 Components of the Digestive System All digestive organs play integral roles in the life-sustaining process of digestion.

Chemical Digestion

Chemical digestion of foodstuffs occurs via enzymes that are located throughout the digestive system. Enzymes catalyze chemical reactions; most physiological processes are the result of enzyme action.

As an analogy, think about going to a furniture store to buy a bookcase. You'll need to take the bookcase home with you in your car, and get it into your house. A large bookcase won't fit in your car, or go through the front door. But, if you could disassemble the bookcase into smaller pieces that would lie flat, it would go into your car and through the door. You could bring the smaller pieces into your house, then assemble the pieces into the large functional bookcase. Digestion is like disassembling large bookcases so they'll go through the front door: large molecules are disassembled into smaller molecules that can enter cells and be used by them to create something functional. The below cartoon depicts a summary of this breakdown process:



By Created by TimVickers, vectorized by Fvasconcellos (Provided by TimVickers) [Public domain], via Wikimedia Commons

Enzymes that are participating in digestion interact in specific ways with particular substrates. We can classify enzymes according to the substrates they act on. See the below table for a summary of enzymatic digestion of the major foodstuffs.

Table 1. A Brief Summary of Enzyme Action in the Digestive System

Enzyme	Produced by	Site of action	Optimum pH	Digestion
CARBOHYDRATE DIGESTION				
Salivary amylase	Salivary glands	Mouth	neutral	Starch + H ₂ O → maltose
Pancreatic amylase	Pancreas	Small intestine	basic	Starch + H ₂ O → maltose
Maltase	Small intestine	Small intestine	basic	Maltose + H ₂ O → 2 glucose
Lactase	Small intestine	Small intestine	basic	Lactose + H ₂ O → glucose + galactose
PROTEIN DIGESTION				
Pepsin	Gastric glands	stomach	acidic	Protein + H ₂ O → peptides
trypsin	Pancreas	Small intestine	basic	Protein + H ₂ O → peptides
peptidases	Small intestine	Small intestine	basic	Peptide + H ₂ O → amino acids
FAT DIGESTION				
Lingual lipase	Tongue	Stomach	acidic	Triglycerides + 2H ₂ O → monoglycerides and 2 fatty acids
Pancreatic lipase	Pancreas	Small intestine	basic	Triglycerides + 2H ₂ O → monoglycerides and 2 fatty acids

In the laboratory activities that follow, you'll be incubating substrates (carbohydrates, proteins or lipids) in test tubes with enzymes, under various conditions of temperature and pH. The activity of the enzyme will be assessed by the appearance of the products of digestion (glucose and monosaccharides; peptides and amino acids; monoglycerides and fatty acids) in the test tube at the end of the incubation time.

Materials / Equipment Needed

Reagents

- Alka-Seltzer® tablets
- Starch solution
- Albumin solution
- 1% amylase solution
- 1% pepsin solution
- Pancreatin solution
- 1M HCl
- Litmus powder
- Milk or heavy cream
- Water

Test Reagents

- Lugol's solution
- Benedict's solution
- Biuret solution

NOTE – the solutions may contain heavy metals. You should dispose of them in approved containers only.

Miscellaneous supplies

- Small test tubes (microcentrifuge tubes will also work)
- Small beakers
- Wooden stirrers
- Plastic transfer pipets (if reagents are not in dropper bottles)
- Test tube holders or clamps (to move hot tubes) and test tube racks
- Sharpie markers

Other equipment

- Water bath (set to 37°C)
- Water bath (boiling, or 100°C)
- Ice bath
- Timer or stopwatch

Experiment 1 – Effect of Particle Size on the Rate of Digestion

Digestion of foodstuffs begins in the mouth. Mechanical digestion includes the physical breakdown of large foodstuffs into smaller pieces by the action of the teeth and tongue. This mechanical breakdown increases the surface area of the foodstuff, and increases the ability of the digestive enzymes to act on the food pieces.

In this activity, you'll be using Alka-Seltzer® tablets and the rate of their disappearance in water as a proxy for enzyme activity.

Procedure

1. Obtain 2 test tubes or small beakers. Add water to each.
2. Obtain 1 Alka-Seltzer® tablet, and break it in half.
3. Set aside one half of the Alka-Seltzer® tablet. Crush the other half (or break into smaller pieces) using the bottom of a beaker or a stirrer
4. Place the half-tablet into one test tube / beaker, recording the time when you place the tablet into the water. Swirl (or use a wooden stirrer) to mix the contents. Stop the timer when the tablet has dissolved.
5. Add the crushed half-tablet to the other test tube / beaker, starting a timer when you place the powder into the test tube. Swirl (or use a wooden stirrer) to mix the contents. Stop the timer when the powder has completely dissolved.

Record the time taken for the pieces to disappear in the table below.

Data Table – Dissolution time for Alka-Seltzer® tablets.

	Time to completely dissolve (sec)
Intact half-tablet	
Crushed tablet	

Check your understanding:

How can you explain these results?

Experiment 2 – Digestion of Starch

Digestion of starch begins in the mouth. Three pairs of salivary glands secrete about 1000-1500 mL of saliva into the mouth each day. The saliva contains mucus and salivary amylase which begins the breakdown of starch, converting it to maltose. Starch digestion continues in the small intestine, due to the secretion of pancreatic amylase into that organ. You will use either salivary amylase or pancreatic amylase for this experiment.

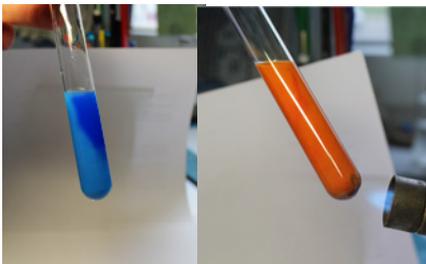
Amylases are enzymes that break starches into smaller molecules (monosaccharides or disaccharides)

Starch -----> mono- and disaccharides (sugars)

In this activity you'll be examining the effects of various conditions on the ability of amylase to break starch into smaller sugar molecules. You'll be using 2 tests: one that indicates the presence (or absence) of starch, and one that indicates the presence (or absence) of sugars.



The image at the left shows a positive IKI test (Lugol's, or iodine test) for starch on the left, and a negative test on the right.



The image at the left shows a negative Benedict's test, indicating that sugars are not present.

In the presence of certain kinds of sugars, the Benedict's reagent will turn a bright orange-red (in the presence of heat). The image on the right is a positive Benedict's test.

Kubawlo - Own work, CC BY-SA 4.0, <https://commons.wikimedia.org/w/index.php?curid=19455438>

Procedure

1. Mark 5 test tubes S1A - S5A (s = starch); Mark a second set of 5 test tubes S1B – S5B.
2. Prepare the tubes S1A – S5A according to the below table

Test tube	Starch solution	Water	1% amylase solution	Incubate at
S1	-----	3 drops	3 drops	37°C
S2	3 drops	3 drops		37°C
S3	3 drops		3 drops boiled enzyme	37°C
S4	3 drops	-----	3 drops	0°C
S5	3 drops	-----	3 drops	37°C

3. Place the prepared tubes in the corresponding incubation baths
 - S1A – S3A, S5A into 37°C waterbath
 - S4 into icebath
4. Incubate tubes for 60 minutes
5. At the end of the hour, remove a drop or two from each tube and place it into the corresponding labeled B test tube. **Use a clean pipet for each tube.** You'll now have 2 sets of tubes that have identical solutions.
 - **To each A test tube,** add 1 drop of Lugol's solution, which indicates the presence of starch
 - A positive Lugol's (or iodine) test is an inky blue-black color.
 - A negative Lugol's test is no color change, or the presence of a clear brownish color
 - **To each B test tube,** add 3 drops of Benedict's solution. Place each tube into the hot water (90 – 100°C) water bath for 3 – 5 minutes. Benedict's solution indicates the presence of sugars (specifically, reducing sugars)

- A positive Benedict's test is color change from clear blue to opaque green, orange or brick red
- A negative Benedict's test is no color change

Record your observations of the color changes in the table below.

Data Table – Lugol's and Benedict's test results after action of amylase.

Test tube	Starch solution	Water	1% amylase solution	Incubate at	Results – Lugol's test	Results – Benedict's test
S1	-----	3 drops	3 drops	37°C		
S2	3 drops	3 drops	-----	37°C		
S3	3 drops	-----	3 drops boiled enzyme	37°C		
S4	3 drops	-----	3 drops	0°C		
S5	3 drops	-----	3 drops	37°C		

Check your understanding

Which tubes tested positive for the presence of starch? Which tubes were negative for starch?

Which tubes tested positive for the presence of sugars? Which tubes were negative for sugars?

Were any tubes positive for BOTH sugars and starch?

What conditions appear to be the best for production of sugars from starch? Why do you say this?

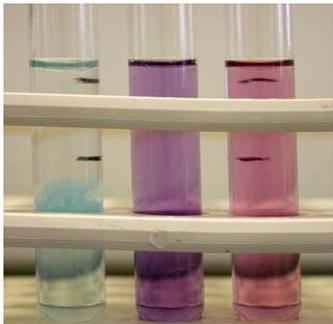
Experiment 3 - Digestion of Proteins

Protein digestion begins in the stomach with the action of pepsin, an enzyme secreted in an inactive form (as pepsinogen) by zymogenic cells in gastric pits. The inactive pepsinogen is activated in the presence of hydrochloric acid, secreted by parietal cells in the gastric pits. Proteins are also digested in the small intestine by the action of trypsin, an enzyme synthesized and stored in the pancreas then secreted into the duodenum by way of the pancreatic duct. Like pepsin, trypsin is secreted as an inactive precursor molecule (trypsinogen) that becomes activated when it reaches the duodenum.

Several kinds of proteases digest proteins into smaller fragments.

Protein -----> amino acids / peptides

In this activity, you'll be looking at the ability of a protease (pepsin) to act on a protein (albumin) in solution. The effect of pH on the activity of the enzyme will be examined. The presence of digested proteins, in the form of amino acids and peptides, will be marked by a color change in Biuret's solution.



A negative Biuret test is shown on the left, demonstrating no change in color in the Biuret reagent. A negative Biuret test means there are no proteins, amino acids or peptides present in the solution being tested.

The tubes in the middle and on the right show positive Biuret tests. A blue - violet color that results when the Biuret reagent reacts with peptides (middle), and smaller peptides produce a lavender – pink color (right).

<http://brilliantbiologystudent.weebly.com/biuret-test-for-protein.html>

Procedure

1. Mark 1 set of test tubes P1 – P3 (p = protein)
2. Prepare the tubes according to the below table.

Test tube	Protein (albumin) solution	Water	1% pepsin in H ₂ O	1M HCl	Incubate at
1	-----	24 drops	-----	-----	37°C
2	12 drops	12 drops	-----	-----	37°C
3	12 drops	-----	10 drops	2 drops	37°C

3. Place the prepared tubes in the 37°C water bath
4. Incubate tubes for 45 minutes
5. After incubation has completed, add 3 - 5 drops of Biuret reagent to each tube. Swirl each tube to mix the contents.
6. Using a white paper as a background, determine the color of the solution in each test tube. Look downward through the opening at the top of each test tube. **BLUE or PURPLE** color indicates the presence of proteins; **PINK-VIOLET** indicates the presence of short polypeptides, from partially digested proteins. Record your observations in the table below.

Test tube	Protein (albumin) solution	Water	1% pepsin in H ₂ O	1M HCl	Incubate at	Color seen after Biuret reagent was added
1	-----	24 drops	-----	-----	37°C	
2	12 drops	12 drops	-----	-----	37°C	
3	12 drops	-----	10 drops	2 drops	37°C	

Check your understanding:

Which tubes were positive for the presence of amino acids and peptides?

Which tubes were negative for the presence of amino acids and peptides?

What conditions appear to be the best for production of amino acids and peptides from proteins? Why do you say this?

Experiment 4 – Digestion of Lipids

Digestion of fats (lipids) begins in the stomach, but the bulk of fat digestion occurs in the small intestine. Lipases break lipids into fatty acids, and glycerol, which are the building blocks of these larger molecules.

Triglycerides ---→ fatty acids and glycerol

In this experiment, you'll be using "litmus milk," or "litmus cream," which is milk powder or cream with litmus powder stirred into it. The milk/cream provides the fat substrates while the litmus powder – like litmus paper – changes color in the presence of acids and bases. This "litmus milk" will be incubated with a pancreatin solution (pancreatic enzyme solution) that contains lipases.

Procedure

1. Mark 3 test tubes L1 – L3 (L – lipid). Prepare the tubes according to the below table.
2. Place the prepared tubes into the 37°C waterbath
3. At the end of the incubation time, examine each tube for possible color change, and enter your observations into the below table.
 - The litmus milk / cream may have a purplish color at the start. It produces a color change in response to changes in pH – more basic = blue while more acidic = red.

Test tube	Litmus milk (or cream)	1% pancreatin solution	2% bile salt solution	Water	Incubate at	Results - color
L1	12 drops	-----	-----	23 drops	37°C	
L2	12 drops	13 drops	-----	10 drops	37°C	

Check your understanding:

Which tubes were positive for the presence of fats?

Which tubes were negative for the presence of fats?

What conditions appear to be the best for the production of fatty acids and glycerol from fats?
Why do you say this?

Exit Ticket: Before you leave lab today, read the following scenarios and answer the questions.

Acidic chyme can denature and inactivate enzymes in the small intestine. Describe how an inability of the pancreas to produce or secrete bicarbonate (HCO_3^-) could lead to issues with digestion and absorption of nutrients.

Some weight-loss drugs and sugar-free foods contain substances that cannot be digested by the enzymes in the small intestine. A famous example was Olestra[®], a compound designed to be a fat substitute in snacks like crackers and chips. Because the Olestra[®] was not absorbed, it contributed no calories to the snack food. The FDA granted approval of use of Olestra[®] as a food additive, but foods prepared with Olestra[®] were required to have the following statement on their labels:

“Olestra may cause abdominal cramping and loose stools (anal leakage). Olestra inhibits the absorption of some vitamins and other nutrients. Vitamins [A](#), [D](#), [E](#), and [K](#) have been added”.

Why do you think that Olestra[®] inhibited the absorption of these particular vitamins?

The Urinary System: Anatomy

Introduction

In this laboratory, you will use models, diagrams and histological samples to study the anatomy of the urinary system. Specifically, you will examine the gross and microscopic anatomy of the system as it is represented in humans. As you study the anatomy, keep in mind that the urinary system functions to filter dissolved materials from the blood, regulate electrolytes and fluid volume, concentrate and release waste products, and reabsorb metabolically important substances.

Learning Objectives

By the end of this lesson you will be able to:

1. Describe the function of the urinary system.
2. Identify the organs of the urinary system on a model or a diagram and describe the function of each.
3. To identify the following on a dissected kidney:
 - a. Hilum
 - b. Cortex
 - c. Medulla
 - d. Medullary pyramids
 - e. Major and minor calyces
 - f. Pelvis
 - g. Renal columns
 - h. Renal capsule
4. Trace the blood supply of the kidney from the renal artery to the renal vein.
5. Describe the anatomy of a nephron.
6. Identify and describe the microanatomical features of the nephron. These should include:
 - a. Glomerulus
 - b. Glomerular capsule
 - c. Renal tubule
 - i. Proximal convoluted tubule
 - ii. Nephron loop
 - iii. Distal convoluted tubule
7. Describe the function of the nephron and the specific functions (filtration, reabsorption, secretion) that are associated with each region.
8. To compare the course and length of the urethra in males and females.
9. Identify the following structures of importance:

Organs of the Urinary System	Kidney Anatomy
Kidney	Cortex
Ureter	Medulla
Urinary bladder	Hilum
Urethra	Pelvis
	Renal artery and vein
Urinary bladder and urethra	Major and minor calyces
Detrusor muscle	Renal pyramid and columns
Ureter openings	Segmental arteries
Internal and external urethral sphincters	Interlobar arteries and veins
Membranous urethra (male only)	Arcuate arteries and veins
Spongy urethra (male only)	Cortical radiate (interlobar) arteries and veins
Prostate and prostatic urethra (male only)	
Bulbourethral gland (male only)	Nephron
Crus and bulb of penis (male only)	Renal corpuscle – glomerulus and Bowman's capsule
Erectile tissue of penis (male only)	Afferent and efferent arteriole
External and urethral orifice	Renal tubule
Trigone	Loop of Henle
	Proximal and distal convoluted tubules
Bladder microanatomy	Collecting duct
Transitional epithelium	Peritubular capillaries and vasa recta

Background Information

Overview of the Urinary System

The urinary system consists of two kidneys, two ureters, a single urinary bladder, and a single urethra. This system has roles that you may already be aware of, such as cleansing the blood and ridding the body of wastes probably come to mind. However, there are additional, equally important functions played by the system. Take for example, regulation of pH, a function shared with the lungs and the buffers within the blood. Additionally, the regulation of blood pressure is a role shared with the heart and blood vessels. What about regulating the concentration of solutes in the blood? Did you know that the kidney is important in determining the concentration of red blood cells?

Most importantly, the urinary system works to filter dissolved materials from the blood through the process of **filtration**. **Filtration** occurs when one or more substances pass through a selectively permeable membrane, while others are retained. Within the kidneys, filtration involves both metabolic waste products, such as urea or toxins, as well as materials that are beneficial to the body. Any filtered material that is not desirable though will be **excreted** from the body. If the kidneys fail, these functions are compromised or lost altogether, with devastating effects on homeostasis. Affected individuals may experience weakness, lethargy, shortness of breath, anemia, widespread edema (swelling), metabolic acidosis, rising potassium levels, heart arrhythmias, and more. Each of these functions is vital to your well-being and survival.

Source Material

OpenStax, 25.1 Physical Characteristics of Urine. OpenStax CNX. May 2, 2019 <http://cnx.org/contents/f01808b8-5784-470e-a451-f1c96a109bd1@7>.

The Kidneys

The kidneys lie on either side of the spine in the **retroperitoneal space**, between the parietal peritoneum and the posterior abdominal wall. This location ensures that the kidneys are well protected by muscle, fat, and the ribs. They are roughly the size of your fist, and the male kidney is typically a bit larger than the female kidney. The kidneys are well vascularized, receiving about 25 percent of the cardiac output at rest.

The left kidney is located at about the level of T12 to L3 vertebrae, whereas the right is slightly lower due to displacement by the liver. Upper portions of the kidneys are somewhat protected by the eleventh and twelfth ribs (**Figure 1**). They are about 11–14 cm in length, 6 cm wide, and 4 cm thick, and are covered by a fibrous **renal capsule** composed of dense, irregular connective tissue that helps to hold their shape and serve as protection (**Figure 2**). This capsule is covered by a shock-absorbing layer of adipose tissue known as the **renal fat pad**, which in turn is

encompassed by a tough renal fascia. The fascia and, to a lesser extent, the overlying peritoneum serve to firmly anchor the kidneys to the posterior abdominal wall in a retroperitoneal position.

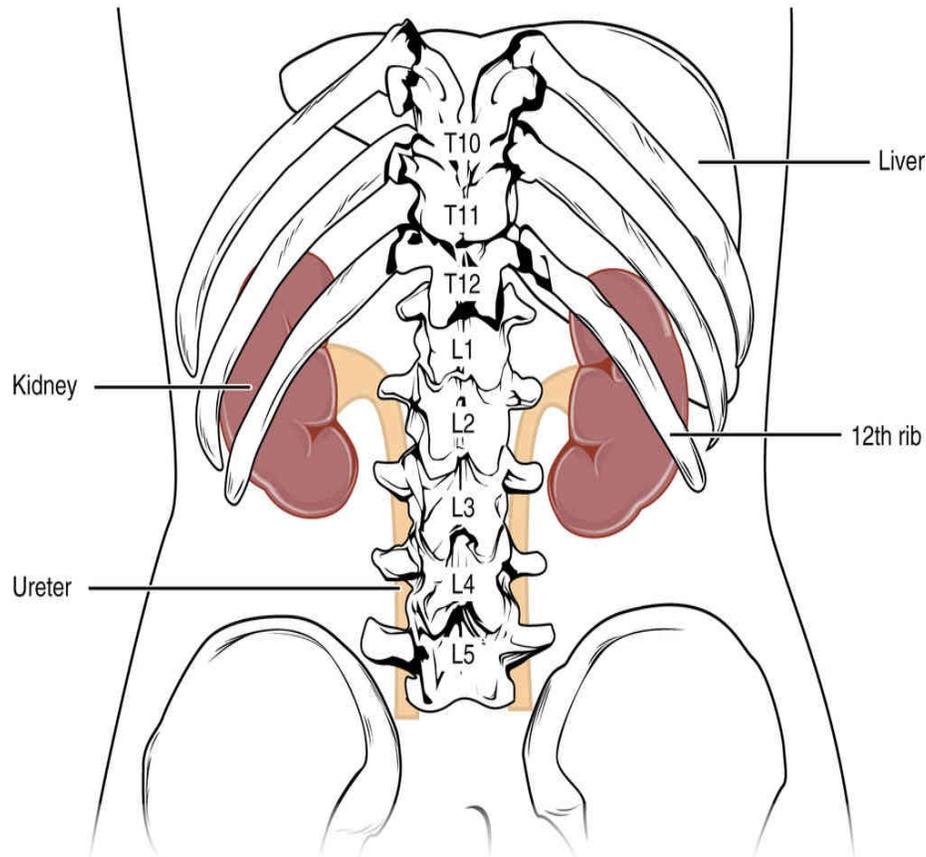


Figure 1. Location of the Kidneys

The kidneys are slightly protected by the ribs and are surrounded by fat for protection (not shown).

The **renal hilum** is the medial entry and exit site for structures that service the kidneys, including the vessels, nerves, lymphatics, and ureters (**Figure 2**). Internally, the hilum extends into a large cavity, the **renal sinus**, which is occupied by these vessels, nerves, and other supporting structures that enter or exit each kidney. Emerging and extending out from the hilum is the **renal pelvis**, which is formed from the **major** and **minor calyces** (singular = **calyx**) in the kidney, which are discussed below.

A frontal section through the kidney reveals an outer region called the **cortex** and an inner region called the **medulla**. The **renal columns** are connective tissue extensions that radiate downward from the cortex through the medulla to separate the most characteristic features of the medulla, the **renal pyramids**. The renal columns also serve to divide the kidney into 6–8 **lobes** and to provide a supportive framework for vessels that enter and exit the cortex. The

pyramids and renal columns taken together constitute the kidney lobes. Each of the renal pyramids end in a blunt point, called the **renal papillae**. The papillae are bundles of collecting ducts that transport urine made by nephrons to the **calyces** of the kidney for excretion. The urine first drips into the **minor calyces**, which enclose the renal papillae. These structures act somewhat like funnels. The minor calyces then lead to the **major calyces**, and these in turn, conduct urine into the large **renal pelvis** (**Figure 2**).

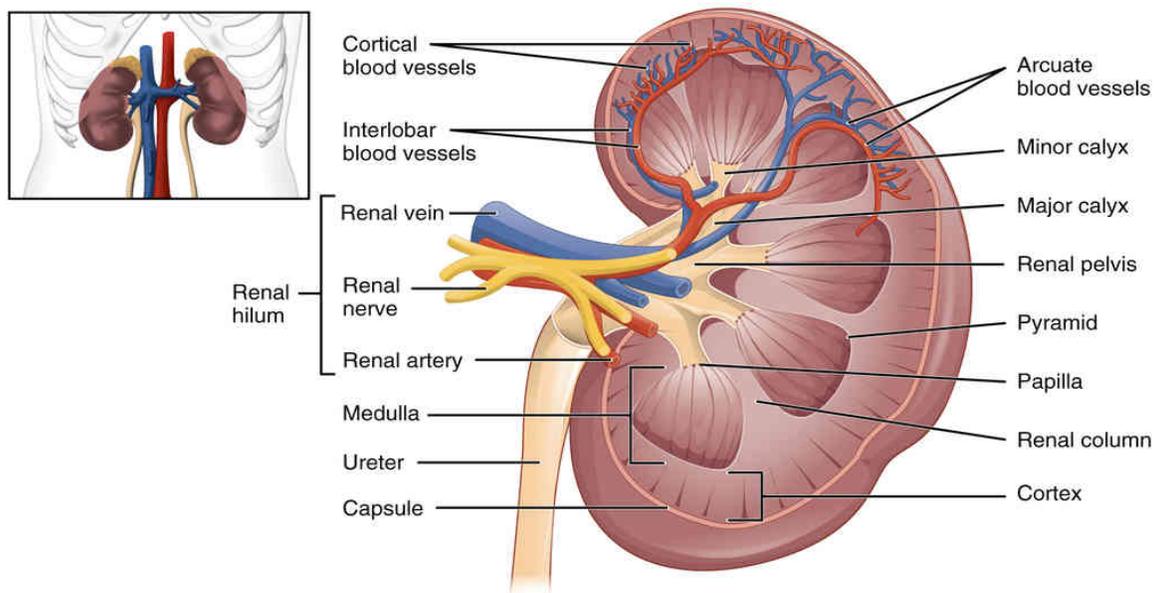


Figure 2. Gross Anatomy of the Left Kidney

Source Material

OpenStax, 25.3 Gross Anatomy of the Kidney. OpenStax CNX. May 2, 2019 <http://cnx.org/contents/ee5f4420-7ba2-44d6-86f1-85ff5a0e4ada@8>.

Blood Flow Through the Kidneys

The kidney filters material from the blood and returns important components such as water, glucose, and ions back into the blood. To ensure this, blood flow into and out of the kidneys is essential. The blood flow through the kidney forms a **portal system**, which is defined as a group of blood vessels in which blood flows from one capillary bed to another, with an arteriole or venule between them.

The first vessel to enter the kidney comes from the abdominal aorta, and this vessel is the **renal artery**. Once in the kidney, the renal artery first divides into **segmental arteries**, which are located within the renal sinus. As the segmental arteries continue to branch, blood flows into the **interlobar arteries**, which pass through the renal columns and extend to the cortex (**Figure 2** and **Figure 3**). Once the interlobar arteries reach the cortex, they bend abruptly and branch to form the **arcuate arteries**. These vessels are named because they form an arc located between

the medulla and cortex of the kidney. From here, the arteries become the **cortical radiate (interlobular) arteries**, which enter into the cortex.

The cortical radiate arteries then branch to form the **afferent arterioles**. The afferent arterioles will take blood to the **glomerulus**, a cluster of capillaries where filtration occurs. Blood then travels through the **efferent arterioles** and in to the **peritubular capillaries** (Figures 3 and 4). It is within the peritubular capillaries that **reabsorption** and **secretion** will take place. In some regions of the cortex, the efferent arterioles may also branch to give rise to the **vasa recta**. These vessels only represent a small number of capillaries within the kidney, but they are important for producing concentrated urine. Together, the **glomeruli** (single = **glomerulus**), the peritubular capillaries, and the vasa recta represent the three capillary beds of the kidney.

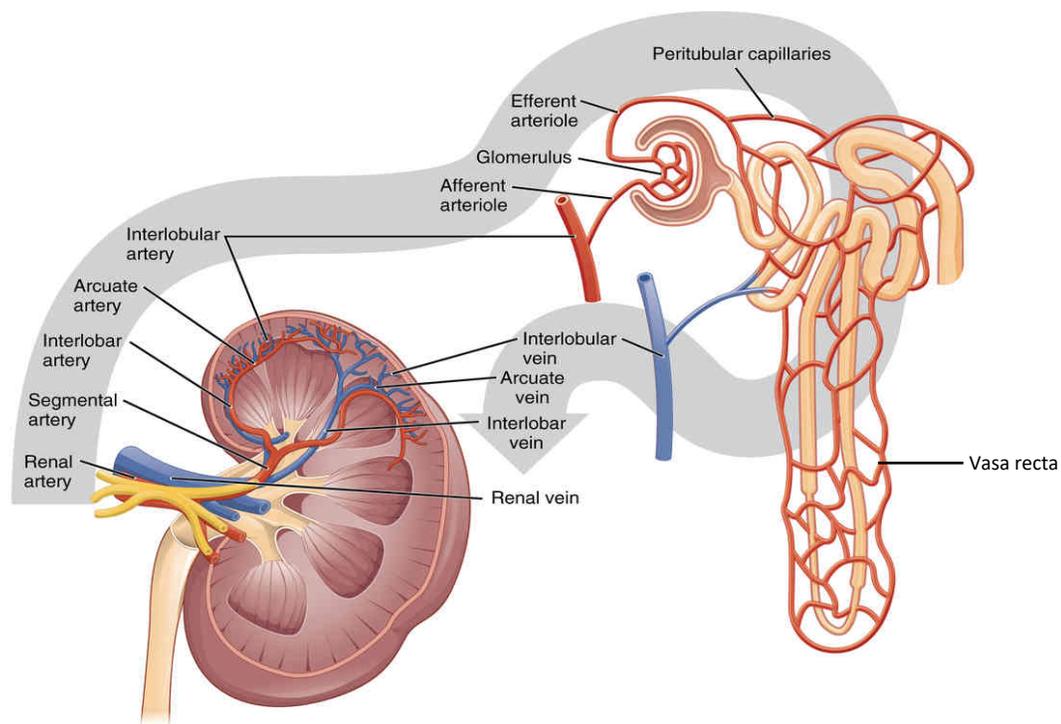


Figure 3. Blood Flow Through the Kidney

Whereas the renal arteries form directly from the descending aorta, the renal veins return cleansed blood directly to the inferior vena cava. Blood from the peritubular capillaries or vasa recta will first be directed to the **cortical radiate (interlobular) veins**. From here, the blood will be sent to the **arcuate veins**, to the **interlobar veins**, and then to the **renal vein**, which leads to the vena cava (Figure 3). Notice that this network of veins closely follows the paired arteries that were discussed earlier.

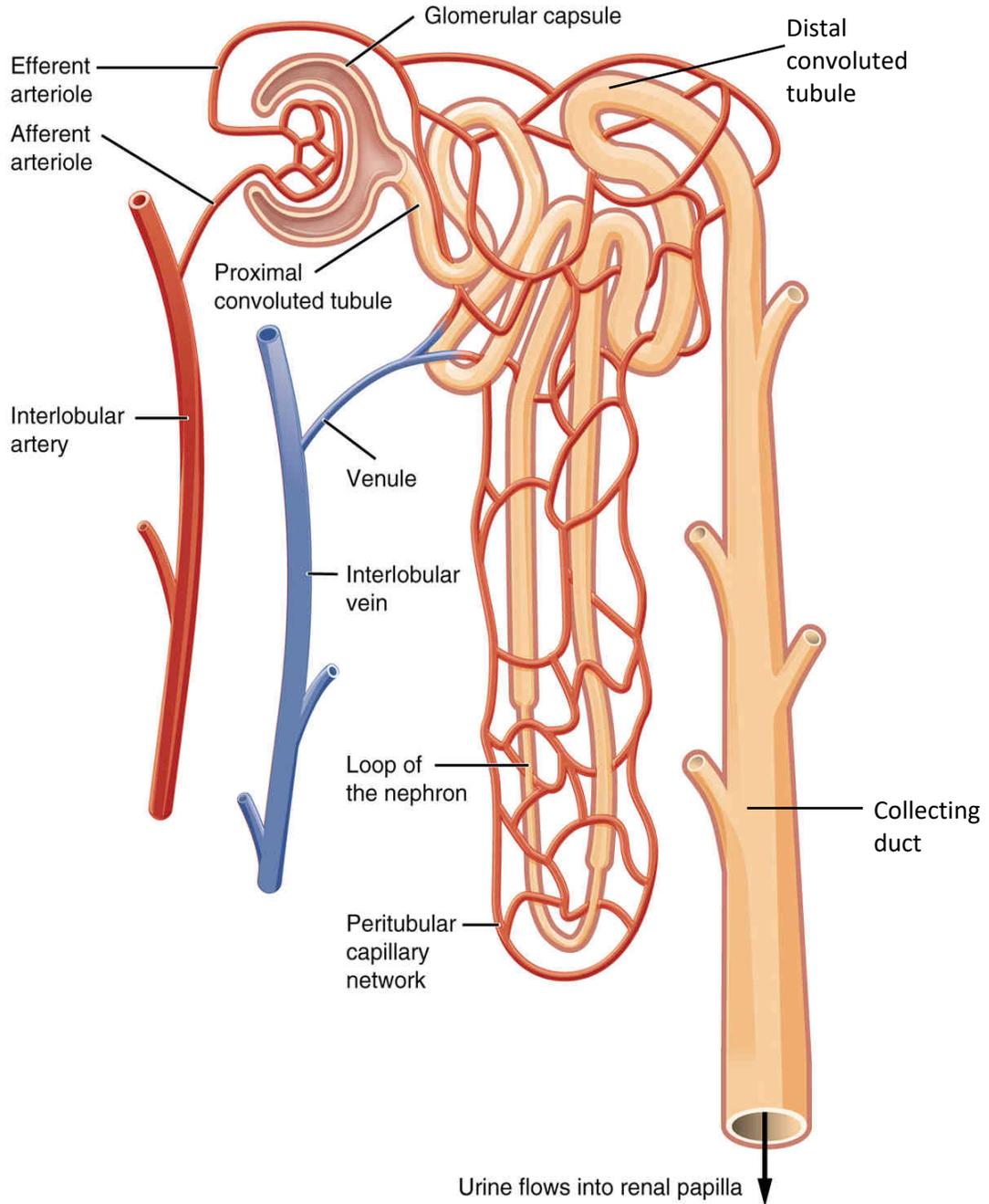


Figure 4. Blood Flow in the Nephron

Blood will enter into the nephron through the afferent arteriole, where it will be directed to the two capillary beds, which are shown in this figure. The efferent arteriole is the connecting vessel between the glomerulus and the peritubular capillaries and vasa recta. Blood flow will continue through the network of small vessels until leaves through the interlobular veins.

Source Material

OpenStax, 25.3 Gross Anatomy of the Kidney. OpenStax CNX. May 2, 2019 <http://cnx.org/contents/ee5f4420-7ba2-44d6-86f1-85ff5a0e4ada@8>.

Ultrastructure of the Kidneys

The renal structures that conduct the essential work of the kidney cannot be seen by the naked eye. Only a light or electron microscope can reveal these structures. Even then, serial sections and computer reconstruction are necessary to give us a comprehensive view of the functional anatomy of the nephron and its associated blood vessels.

Nephrons are the "functional units" of the kidney; they cleanse the blood and balance the constituents of circulation. These structures take a simple filtrate of the blood and modify it into urine. The system's ability to filter the blood resides in about 2 to 3 million **glomeruli**, which are distributed more or less equally between the two kidneys. Because glomeruli filter the blood based mostly on particle size, large elements like blood cells, platelets, antibodies, and albumen are excluded. All other solutes, such as ions, amino acids, vitamins, and wastes, are filtered to create a filtrate composition that is very similar to blood plasma. Overall, the principle task of the nephron population is to balance the plasma to homeostatic set points and excrete potential toxins in the urine. They do this by accomplishing three principle functions—**filtration**, **reabsorption**, and **secretion**. The functional regions that make up a single nephron include the renal corpuscle, proximal convoluted tubule, nephron loop, and distal convoluted tubule.

As the afferent arterioles enter into the nephron, they will form a tuft of high-pressure capillaries known as the **glomerulus**. Surrounding the glomerulus is a thin, double-walled capsule, known as the **glomerular capsule (Bowman's capsule)** and the space between each is known as the **capsular space**. Together, the glomerulus and capsule are known as the **renal corpuscle**, making up the proximal end of each nephron (**Figures 4 and 5**). This region is where **filtration** takes place. Through this process, water and some solutes in the blood plasma will pass from the capillaries of the glomerulus and into the capsular space of the nephron to begin filtrate production.

The remaining portion of the nephron consists of a continuous and sophisticated tubule system. As blood passes through the glomerulus, 10 to 20 percent of the plasma filters through small spaces between the cells of the glomerulus. This filtered fluid is then captured by the Bowman's capsule and funneled to the **proximal convoluted tubule (PCT)**. Simple cuboidal cells form this tubule with prominent microvilli on the luminal surface, forming a **brush border (Figure 5)**. These microvilli create a large surface area to maximize the **reabsorption** of some solutes (Na^+ , Cl^- , glucose, etc.) from the blood and **secretion** of these back into the tubule for disposal. This is one of the most essential functions of this region of the nephron. Once filtrate leaves the PCT, it is directed into the **nephron loop (Loop of Henle)**, which consists of two portions. The **descending** and **ascending** portions of the loop are simply continuations of the same tubule. They run adjacent and parallel to each other after having made a hairpin turn at the deepest point of their descent. The descending loop of Henle consists of an initial short, thick portion and long, thin portion, whereas the ascending loop consists of an initial short, thin portion followed by a long, thick portion. Fluid will then be directed to the last portion of the nephron,

known as the **distal convoluted tubule (DCT)** (**Figure 5**). These cells are not as active as those in the PCT; thus, there are fewer microvilli on the apical surface.

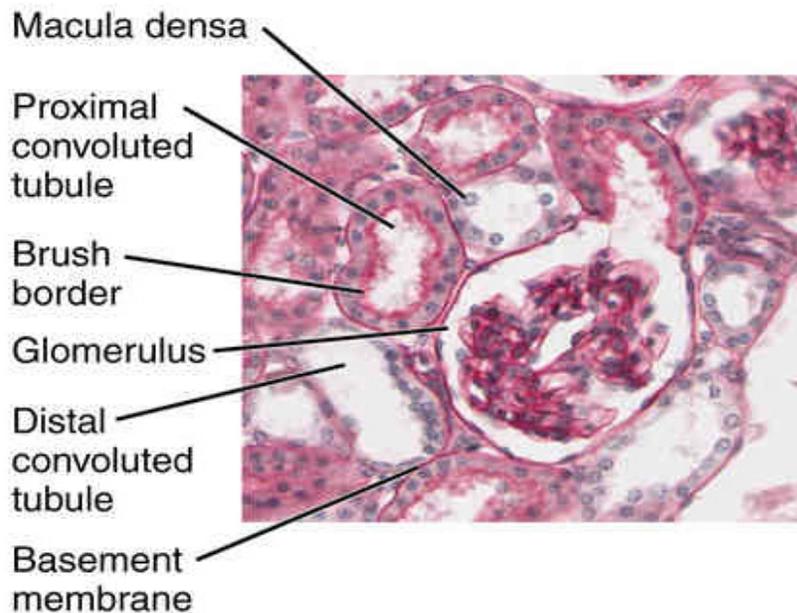


Figure 5. Photomicrograph of the Kidney Cortex

Overview of a single glomerulus and the surrounding regions of a nephron.

As fluid flows through this tubule system, water, glucose, and many electrolytes are returned to the blood. Any urea or other wastes that are collected are concentrated as they pass through the nephron and into the **collecting duct**, a tube that receives fluid from the nephrons (**Figures 4 and 6**). The collecting ducts are continuous with each nephron, but not technically part of it. In fact, each duct collects filtrate from several nephrons for final modification. Collecting ducts merge as they descend deeper in the medulla to form about 30 terminal ducts, which empty at a papilla.

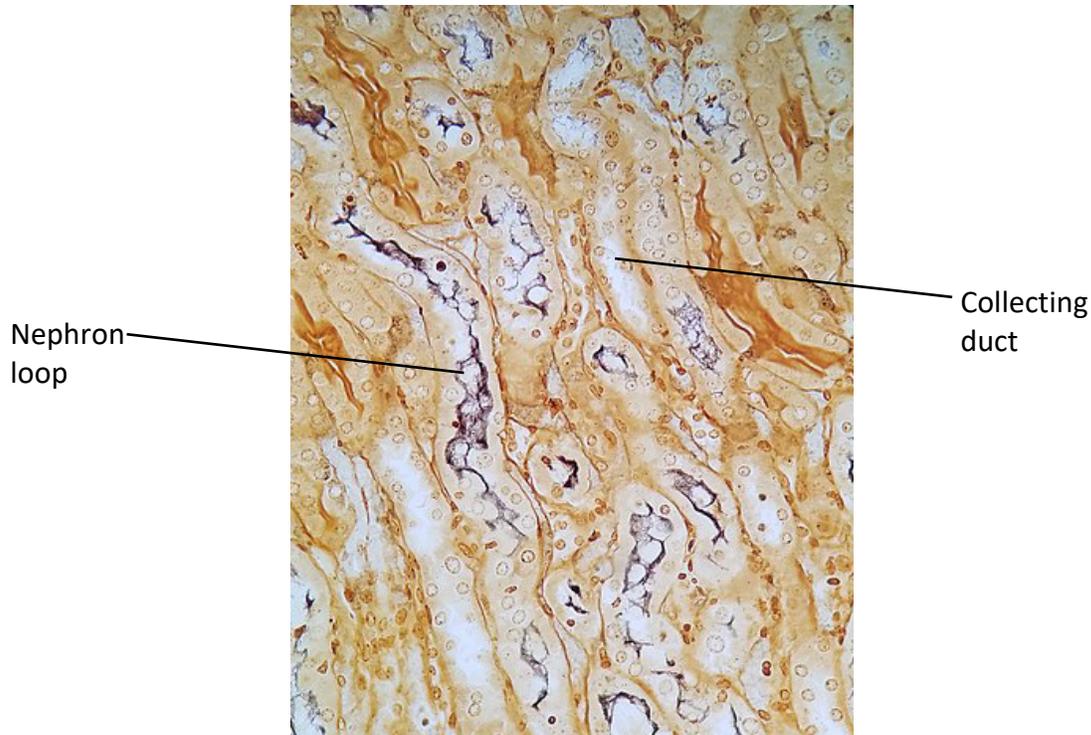


Figure 6. Photomicrograph of the Kidney Medulla

Source Material

OpenStax, 25.4 Microscopic Anatomy of the Kidney. OpenStax CNX. May 2, 2019
<http://cnx.org/contents/5c9bdf05-dd60-4769-a25a-e2958ff4c7a1@8>.

Wikimedia Commons contributors. File:Leptospira in kidney.jpg [Internet]. Wikimedia Commons, the free media repository; 2019 Mar 20, 09:51 UTC [cited 2019 Jun 13]. Available from:https://commons.wikimedia.org/w/index.php?title=File:Leptospira_in_kidney.jpg&oldid=343293348.

The Ureters

As urine is formed, it drains into the calyces of the kidney, which merge to form the funnel-shaped renal pelvis within each hilum. As the renal pelvis extends out of the hilum, it narrows to become the **ureter** of each kidney (**Figure 2**). As urine passes through the ureter, it does not passively drain into the bladder, but rather is propelled by waves of **peristalsis**. As the ureters exit the pelvis, they sweep laterally, hugging the pelvic walls. As they approach the bladder, they turn medially and pierce the bladder wall obliquely (**Figure 8**). This is important because it creates a one-way valve (a *physiological sphincter* rather than an *anatomical sphincter*) that allows urine into the bladder, but prevents the reflux of urine from the bladder back into the ureter.

The ureters are approximately 30 cm long and they consist of three tissue layers. The inner mucosa is lined with transitional epithelium and scattered goblet cells that secrete protective mucus. The thick muscular layer of the ureter consists of both longitudinal and circular smooth

muscles that create the peristaltic contractions to move the urine into the bladder without the aid of gravity. Finally, a loose, outer adventitial layer composed of collagen and fat anchors the ureters between the parietal peritoneum and the posterior abdominal wall (**Figures 7 and 8**).

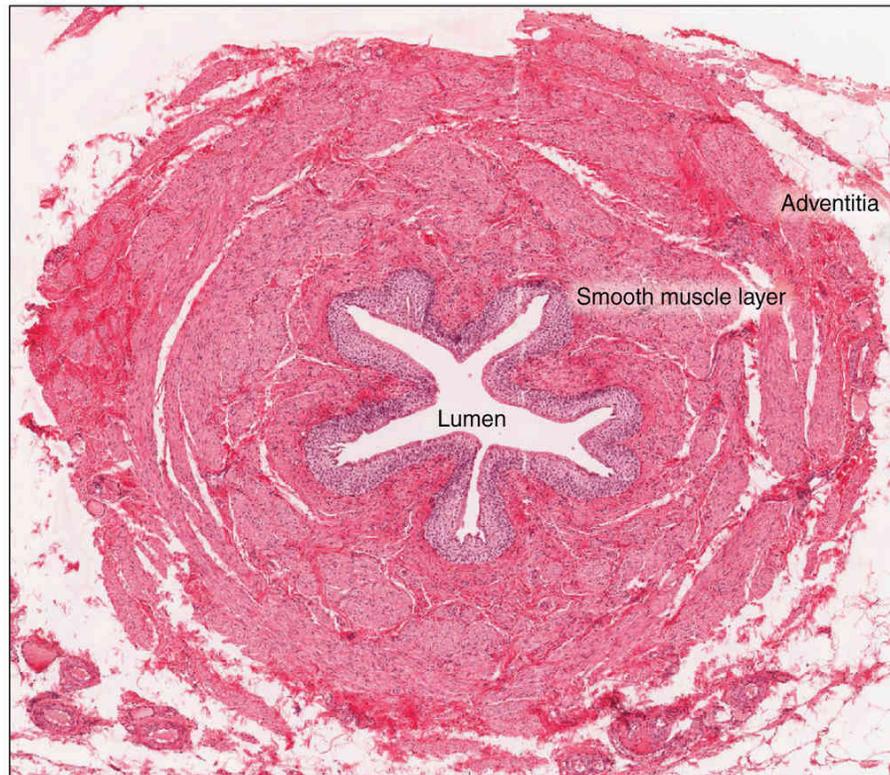


Figure 7. Cross-section Through the Ureter

Peristaltic contractions help to move urine through the lumen with contributions from fluid pressure and gravity. LM \times 128. (Micrograph provided by the Regents of the University of Michigan Medical School \textcopyright 2012)

Source Material

OpenStax, 25.2 Gross Anatomy of Urine Transport. OpenStax CNX. May 2, 2019 <http://cnx.org/contents/41e169f3-d147-4074-bf7e-788a2ae28caf@10>.

Urinary Bladder

The urinary bladder is the primary organ that collects urine from both ureters (**Figure 8**). In females, the bladder lies anterior to the uterus, posterior to the pubic bone and anterior to the rectum (**Figure 9**). During late pregnancy, its capacity is reduced due to compression by the enlarging uterus, resulting in increased frequency of urination. In males, the anatomy is similar, minus the uterus, and with the addition of the prostate inferior to the bladder (**Figure 9**). The bladder is partially **retroperitoneal** (outside the peritoneal cavity) with its peritoneal-covered "dome" projecting into the abdomen when the bladder is distended with urine (**Figure 8**).

The bladder is unique in the fact that it is a highly distensible organ comprised of irregular crisscrossing bands of smooth muscle, collectively called the **detrusor muscle**. The interior

surface is made of transitional epithelium that is structurally suited for the large volume fluctuations of the bladder. When empty, its cells resemble columnar epithelia, but when stretched, it "transitions" (hence the name) to a squamous appearance (**Figure 8**). The volume of urine that the adult bladder can collect and hold can range from nearly zero to 600 mL, so the makeup of this tissue must allow it to be adaptable.

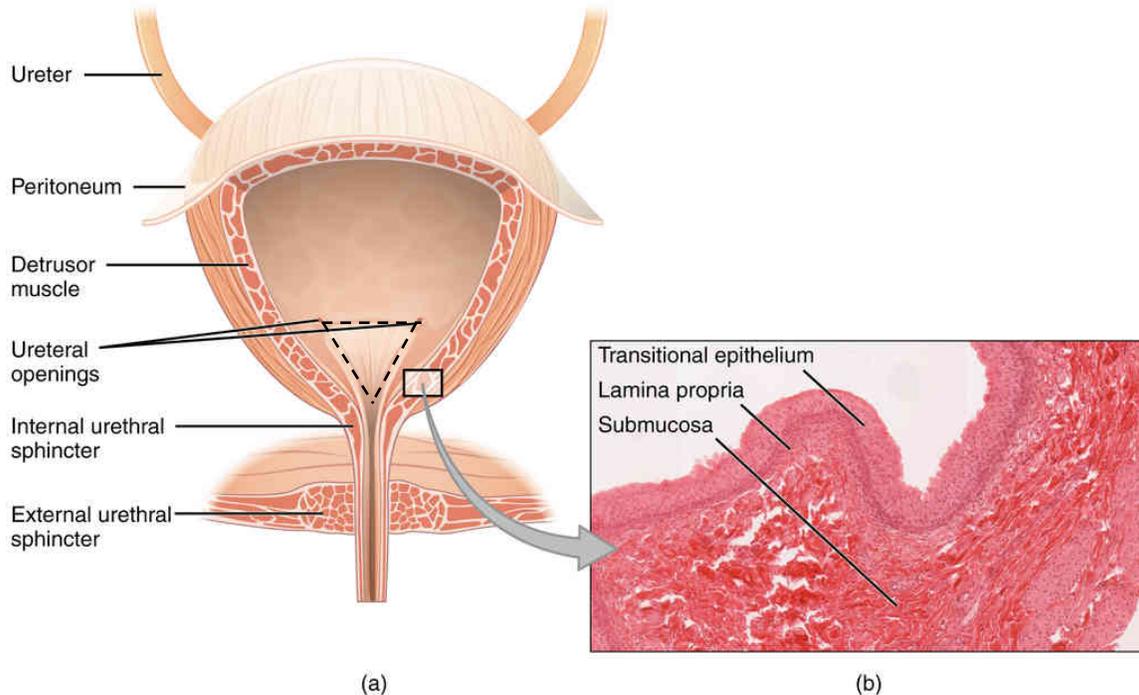


Figure 8. The Bladder

(a) Anterior cross section of the bladder. (b) The detrusor muscle of the bladder (source: monkey tissue) LM \times 448. (Micrograph provided by the Regents of the University of Michigan Medical School \copyright 2012)

In addition to its elasticity, the detrusor muscle can contract with significant force in the young. Though the bladder's strength can significantly diminish with age, voluntary contractions of abdominal skeletal muscles can increase intra-abdominal pressure to promote more forceful bladder emptying. Such voluntary contraction is also used in forceful defecation and childbirth.

Source Material

OpenStax, 25.2 Gross Anatomy of Urine Transport. OpenStax CNX. May 2, 2019 <http://cnx.org/contents/41e169f3-d147-4074-bf7e-788a2ae28caf@10>.

Urethra

The terminal organ of the urinary system is the **urethra**, which transports urine from the bladder to the outside of the body for disposal. The urethra is the only urologic organ that shows any significant anatomic difference between males and females; all other urine transport structures are identical (**Figure 9**).

The urethra in both males and females begins inferior and central to the two ureteric openings in the bladder. Together, these structures form the three points of a triangular-shaped area at the base of the bladder, known as the **trigone** (triangle in **Figure 8** and **Figure 10**). In both males and females, the proximal urethra is lined by transitional epithelium, whereas the terminal portion is a nonkeratinized, stratified squamous epithelium. In the male, pseudostratified columnar epithelium lines the urethra between these two cell types. Voiding is regulated by an involuntary autonomic nervous system-controlled **internal urinary sphincter**, which consists of smooth muscle, and a second voluntary **external urinary sphincter** that is made of skeletal muscle (**Figure 10**).

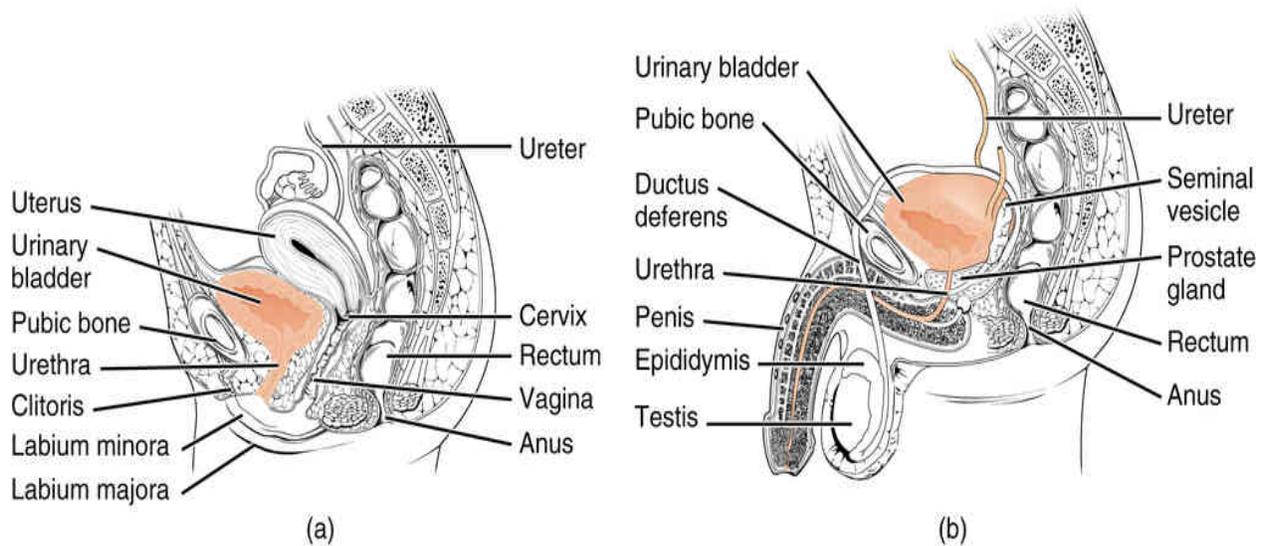


Figure 9. The Female and Male Urethras

The urethra transports urine from the bladder to the outside of the body in both systems. This image shows (a) a female urethra and (b) a male urethra.

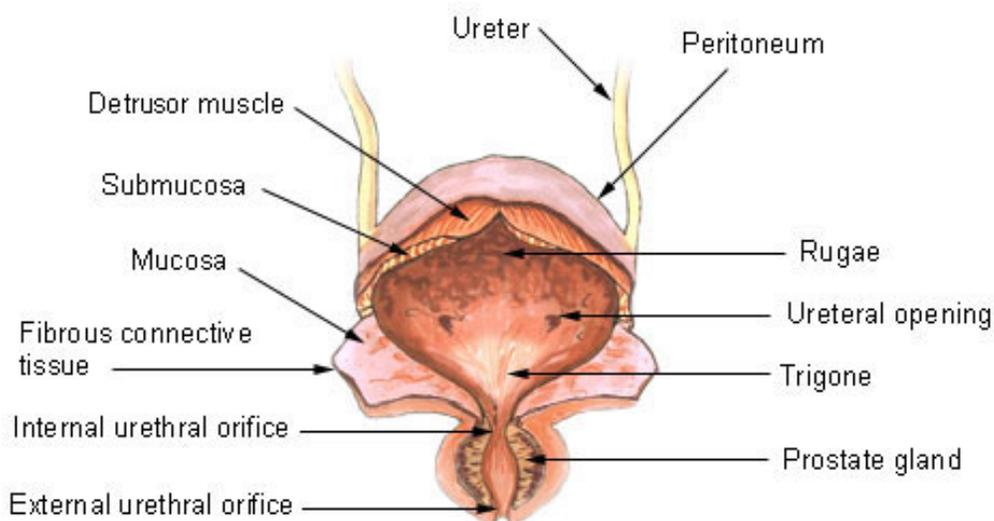


Figure 10. The Bladder, Coronal sections

Regions of a male bladder and the urethral orifices that control urine elimination.

Source Material

OpenStax, 25.2 Gross Anatomy of Urine Transport. OpenStax CNX. May 2, 2019 <http://cnx.org/contents/41e169f3-d147-4074-bf7e-788a2ae28caf@10>.

Wikimedia Commons contributors. File:Illu bladder.jpg [Internet]. Wikimedia Commons, the free media repository; 2019 Apr 22, 09:28 UTC [cited 2019 Jun 26]. Available from: https://commons.wikimedia.org/w/index.php?title=File:Illu_bladder.jpg&oldid=346860409.

Female Urethra

The female urethra is approximately 3 to 4 cm long and it passes from the urinary bladder to the **external urethral orifice (Figure 9a)**. The external urethral orifice is embedded in the anterior vaginal wall, inferior to the clitoris, superior to the vaginal opening, and medial to the labia minora. Its short length is less of a barrier to fecal bacteria than the longer male urethra and is the best explanation for the greater incidence of urinary tract infections (UTIs) in women. Voluntary control of the external urethral sphincter is a function of the pudendal nerve. It arises in the sacral region of the spinal cord, traveling via the S2–S4 nerves of the sacral plexus.

Source Material

OpenStax, 25.2 Gross Anatomy of Urine Transport. OpenStax CNX. May 2, 2019 <http://cnx.org/contents/41e169f3-d147-4074-bf7e-788a2ae28caf@10>.

Male Urethra

The male urethra is much longer than the female urethra, averaging 20 cm in length. After leaving the urinary bladder, the urethra passes through the prostate gland, which is positioned inferior to the bladder, before passing below the pubic symphysis (**Figure 9b**). It is divided into three regions: the **prostatic urethra**, the **membranous urethra**, and the **spongy (penile) urethra**. The first region of the urethra is the **prostatic urethra** and it passes through the prostate gland. During sexual intercourse, it receives sperm via the ejaculatory ducts and secretions from the seminal vesicles. Paired **bulbourethral glands** produce and secrete mucus into the urethra to buffer urethral pH during sexual stimulation. The mucus neutralizes the usually acidic environment and lubricates the urethra, decreasing the resistance to ejaculation. The prostatic urethra continues as the **membranous urethra**, which passes through the deep muscles of the perineum, where it is invested by the overlying urethral sphincters. Finally, the **spongy urethra** exits at the tip (**external urethral orifice**) of the penis, after passing through the **erectile tissue (corpus spongiosum)** of the penis (**Figure 11**). Mucous glands are found along much of the length of the urethra, ultimately helping to protect the urethra from the extreme pH of urine. Innervation is the same in both males and females.

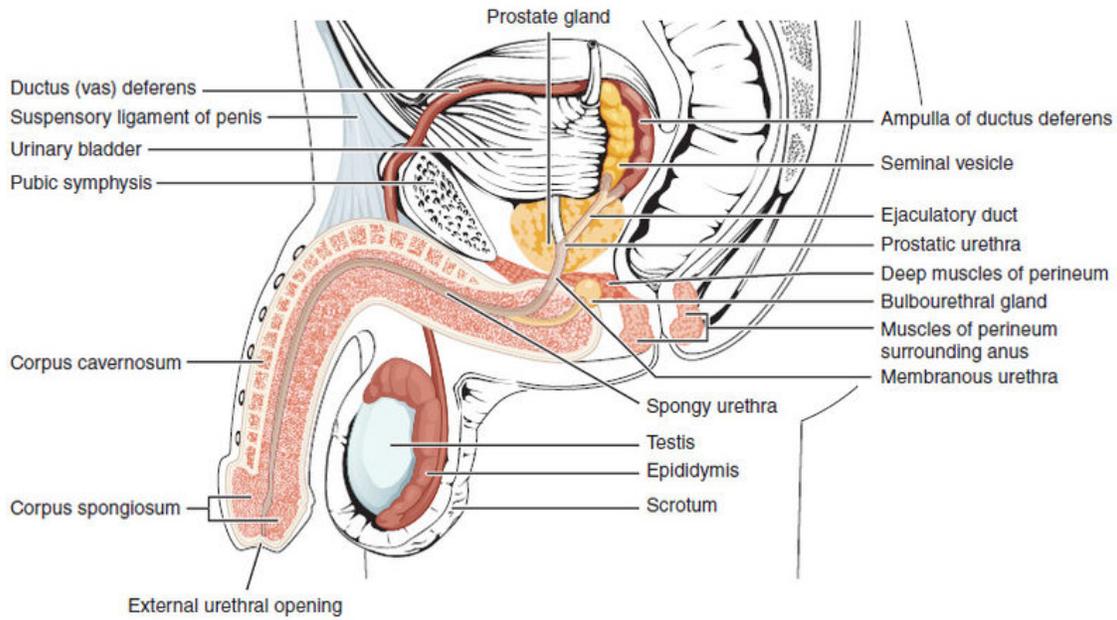


Figure 11. The Male Urethra

Source Material

OpenStax, 25.2 Gross Anatomy of Urine Transport. OpenStax CNX. May 2, 2019 <http://cnx.org/contents/41e169f3-d147-4074-bf7e-788a2ae28caf@10>.

Wikimedia Commons contributors. File:Penis lateral cross section.jpg [Internet]. Wikimedia Commons, the free media repository; 2019 Apr 30, 13:22 UTC [cited 2019 Jun 13]. Available from: https://commons.wikimedia.org/w/index.php?title=File:Penis_lateral_cross_section.jpg&oldid=347903355.

Pre-Assessment

1. Where are the kidneys located within the body?
2. What is the process of filtration?
 - a. Where does filtration take place within the urinary system?
3. Trace the pathway that urine would take once it is produced in the renal tubules to when it is released through the process of urination (micturition).

Equipment List & Setup – Anatomy

Equipment List

- Models and charts of the urinary system
- Models and illustrations of the kidney
- Models and illustrations of the kidney's nephron system
- Microscope
- Prepared slides or histological images of:
 - Kidney
 - Bladder
 - Renal calculi (if available)
- Preserved specimens of sheep or other mammalian kidney
- Dissecting pan
- Scalpel
- Blunt probe
- Protective gloves
- Laboratory coat
- Waste container

Equipment Setup

Identify the location of the necessary equipment needed to complete the activities. Models will be spread throughout the lab, so familiarize yourself to their locations. Any preserved specimens will be available for use in the cadaver lab room.

Activities – Anatomy

In this exercise, you will study the anatomy and organization of the urinary system. This activity contributes to each of the Learning Objectives identified at the beginning of the section.

Part 1: Overview of the Urinary System

Procedure

1. Look at the charts and models of the urinary system for a general orientation and compare them to Figures 1 and 8. Locate the following structures:
 - a. Kidney(s)
 - b. Ureter(s)
 - c. Urinary bladder
 - d. Urethra

Part 2: Gross Anatomy of the Kidneys

Procedure

1. Examine a model of the kidney and compare it to Figure 2.
2. Locate the following regions on the kidney: the outer **renal capsule**, a tough connective tissue layer; the outer **cortex**; and the inner **medulla**.
3. On the medial side of the kidney, locate the **hilum**. This depression is located where the renal artery enters the kidney and the renal vein and **ureter** exit the kidney.
4. Using a model and Figure 2, examine a coronal section of the kidney. Within the medulla, find the **medullary (renal)** pyramids, which are separated by the **renal columns**. Notice that each pyramid ends in a blunt point, the renal papilla, an area where urine will drip from toward the middle of the kidney.
5. Using the same model or figure, identify the **minor** and **major calyces** (singular, *calyx*), which enclose each renal papilla. The minor calyces will collect urine from the papillae and direct it to the major calyces.
6. Now, locate and identify the **renal pelvis**. This structure is a large tube-like structure that collects urine from the major calyces. The pelvis is found in the deepest region of the kidney, known as the **renal sinus**. You can think of the renal pelvis as a glove in a coat pocket; the pocket is the renal sinus and the thin membrane-like glove that occupies the space is the pelvis.
7. Using the model and figure, follow the renal pelvis on the medial side of the kidney. The pelvis is connected to the **ureter**, which leads out of the medial side of each kidney.
8. Now, examine models or charts and look at the renal vascular system in Figure 3. Trace the flow of blood from when it enters the kidney through the **renal artery** to when it leaves through the **renal vein**. This pathway should include the following vessels:
 - a. Renal artery
 - b. Segmental arteries
 - c. Interlobar arteries

- d. Arcuate arteries
 - e. Cortical radiate (interlobular) arteries
 - f. Afferent arterioles
 - g. Glomerulus
 - h. Efferent arterioles
 - i. Peritubular capillaries
 - j. Cortical radiate (interlobular) veins
 - k. Arcuate veins
 - l. Interlobar veins
 - m. Renal vein
 - n. Vena cava
9. Using Figure 3, identify the **vasa recta**, which are found within the cortex in association with the **juxtamedullary nephrons**. These represent a small number of capillaries, but are important for concentrating urine through the process of reabsorption and secretion of water.

Part 3: Microanatomy of the Kidneys

Procedure

1. Before you examine the histological preparations of the kidney, you must first become familiar with the structure of the **nephron**. Examine a model of the nephron and compare what you see to Figure 4. The nephron consists of multiple structures, including the renal corpuscle, proximal convoluted tubule, nephron loop, and the distal convoluted tubule.
2. Locate and identify the regions of the **renal tubule**. These include the **glomerular (Bowman's) capsule**, the **glomerulus**, the **proximal convoluted tubule**, the **nephron loop (loop of Henle)**, and the **distal convoluted tubule**. The glomerulus and the glomerular capsule are collectively known as the **renal corpuscle**.
3. When blood reaches the glomerulus, the plasma is filtered by blood pressure, forcing fluid through the capillary membranes. This process occurs along the series of structures that you identified in step 2. This filtered fluid is known as **filtrate (tubular filtrate)**, which is concentrated as it passes through the nephron. Using the provided models and Figure 4, locate the **collecting duct**. This tube-like structure receives filtrate from the distal convoluted tubule portion of the nephron, allowing it to be directed to the minor calyces, by way of the **papillary duct**.
4. Using the provided models and figures to trace the flow of filtrate through the structures that you identified in the steps above.
5. Examine a histological section (prepared slide and provided images) of the kidney. You should be able to see the cortex, which includes multiple glomeruli, as well as parallel collecting ducts. Compare this section to Figure 5.
6. Now, examine the section under higher magnification. Locate the glomerulus and the glomerular corpuscle. If you look around the slide within the cortex, you should be able to identify the proximal and distal convoluted tubule. Notice that the proximal

convoluted tubule appears fuzzy; this is due to the presence of a **brush border**, or microvilli on the inner edge of the tubule. The distal convoluted tubule does not exhibit this, so the cells should appear to have darker nuclei and relatively clear cytoplasm.

Compare what you see in this section to Figure 5.

7. Examine the medulla of the kidney under high magnification and locate the thin-walled nephron loop and the larger collecting ducts. Use Figure 6 to help you compare and identify these structures.

Part 4: Dissection of the Sheep Kidney

This dissection will take place in the cadaver lab. Make sure that you are properly prepared for this portion of the activity by wearing long pants, close-toed shoes, and having your hair pulled back (if it is long).

Procedure

1. Enter the cadaver lab and immediately put on a lab coat, correctly-sized pair of gloves, and a pair of safety glasses (optional).
2. Obtain sheep kidney from your TA on a dissecting pan.
3. Examine the outer **capsule** of the kidney. You may see some other tubes extending out of the **hilum** of the kidney. These structures are the **renal artery**, **renal vein**, and the **ureter**. The artery will have a smaller diameter and thicker walls than the renal vein. The ureter can be identified as the tube which exhibits an expanded portion near the hilum.
4. Using the scalpel, make an incision in the sheep kidney a little off-center in the coronal plane. This plane-of-section will allow you to better see the interior structures of the kidney.
5. Locate the **renal cortex** and the **renal medulla**. Within the medulla, try to identify the triangular **renal pyramids**. At the tip of each pyramid you should be able to see the **papilla**.
6. Remember that urine will drip from each papilla into a **minor calyx**. Locate and identify the minor calyces, each which will lead to a **major calyx**. Follow the major calyx to identify the **renal pelvis**.
7. Lift the renal pelvis somewhat to pull it away to identify the **renal sinus**. This space in the kidney may be filled with adipose tissue. Also examine the exit of the renal pelvis as it becomes the **ureter**.
8. When you are finished with the dissection and your observations, place the material in the proper waste container provided.
9. Wash and store any pans, scalpels, probes, etc. that you used during the dissection.

Part 5: Anatomy of the Ureters and Urinary Bladder

Procedure

1. Locate and examine the **ureters** and **bladder** on the provided models in the lab. Compare these structures to what you see in Figures 1 and 8.

2. On the models, locate and follow the ureters as they leave the kidney and extend to the urinary bladder.
3. On the outer surface of the bladder, locate where each ureter enters on the superior aspect of the bladder. In Figure 8a, locate each **ureter opening** on the inside of the bladder.
4. Using the models and Figures 8, 9 and 10, identify the exit location of the **urethra**, which is located on the inferior aspect of the bladder. The urethra and superior entrances of the ureters create a triangular region of the bladder, which is known as the **trigone**. Compare the models to Figures 8 and 10 to identify and locate this region.
5. Examine Figure 8 of the bladder closely. Notice that the wall of the bladder contains the **detrusor muscle**, a smooth muscle located within the bladder wall. This muscle remains relaxed to allow for the collection and storage of urine, but contracts during the process of urination.
6. Transitional epithelium lines the inner surface of the bladder wall. This epithelium is specialized to allow for significant stretching (distention) when the bladder fills with urine. Obtain a prepared slide or histological image of transitional epithelium and compare it to Figure 8b.
7. On the image, look at the inner surface of the section for the epithelial layer. These cells will be shaped like teardrops and they can be distinguished from squamous epithelial cells because the surface of transitional epithelia does not flatten in the empty bladder.
8. Using the provided image in Figure 8, identify the **lamina propria**, the connective tissue layer oriented deep to the transitional epithelium.
9. Examine the smooth muscle layers of the urinary bladder that contribute to the detrusor muscle.

Part 6: Anatomy of the Urethra

Procedure

1. The terminal organ of the urinary system is the **urethra**. This structure is approximately 3 cm long in females and about 20 cm long in males. Using the provided models and figures 9, locate and identify the urethra in both the male and female examples.
2. In both models, note that the bladder opens into the urethra through the **internal urethral orifice**. On the outer margin of this opening, the **internal urethral sphincter** is located. This smooth muscle surrounds the urethra to regulate when urine will leave the bladder. Identify the orifice and sphincter.
3. Examine the model of the female system and identify the following structures. In females, the urethra passes from the urinary bladder to the **external urethral orifice**, which is located anterior to the vagina and posterior to the clitoris. On the outer aspect of the urethra an **external urethral sphincter** is also present to regulate voluntary release of urine.
4. Now, examine the model of the male system and figures 10 and 11. In males, the urethra begins at the urinary bladder and passes through the **prostate gland** as the **prostatic urethra**. Just as was seen in the female urinary tract, the bladder will initially

- open into the urethra through the **internal urethral orifice**. On the outer margin of this opening, the **internal urethral sphincter** is located. Identify these structures in figure 10.
5. Using the models and provided figures, follow the urethra as it passes through the body wall as the **membranous urethra**, which then exits through the penis to the external urethral orifice at the tip of the glans penis. This terminal portion of the urethra is known as the **spongy urethra**.

Check your understanding

1. The smallest functional unit of the kidney is known as what?
2. The renal corpuscle is comprised of what two components?
3. Name the four regions of the renal tubule:
4. Trace the pathway that urine would take once it is produced in the renal tubules to when it is released through the process of urination (micturition).

The Urinary System: Physiology

Introduction

Urinalysis is an important study in the clinical assessment of an individual's physical condition. Traces of blood or other substances in the urine can indicate the presence of kidney stones or even issues with other organs. In this laboratory, you will analyze a small sample of urine for materials dissolved in the urine or suspended in it.

Learning Objectives

By the end of this lesson you will be able to:

1. Identify the physical characteristics of urine.
2. Identify the normal pH and specific gravity ranges of urine.
3. Identify the different substances that can appear in the urine using simple chemical tests.
4. Define the following terms and describe their meaning with respect to urinalysis:
 - a. Calculi/ casts
 - b. Glycosuria/albuminuria/ketonuria/hematuria/hemoglobinuria/pyuria
5. Describe possible causes of the above defined conditions.

Background Information

Overview of Urinalysis

Introduction

Urine is formed through the purification of plasma by glomerular filtration, tubular absorption, and secretion. The characteristics of the urine change, depending on influences such as water intake, exercise, environmental temperature, nutrient intake, and other factors. Some of the characteristics such as color and odor are rough descriptors of your state of hydration. For example, if you exercise or work outside, and sweat a great deal, your urine will turn darker and produce a slight odor, even if you drink plenty of water (**Figure 1**). Athletes are often advised to consume water until their urine is clear. This is good advice; however, it takes time for the kidneys to process body fluids and store it in the bladder. Another way of looking at this is that the quality of the urine produced is an average over the time it takes to make that urine. Producing clear urine may take only a few minutes if you are drinking a lot of water or several hours if you are working outside and not drinking much. In a normal, healthy individual, about 0.6 – 2.5 L of urine may be produced daily.

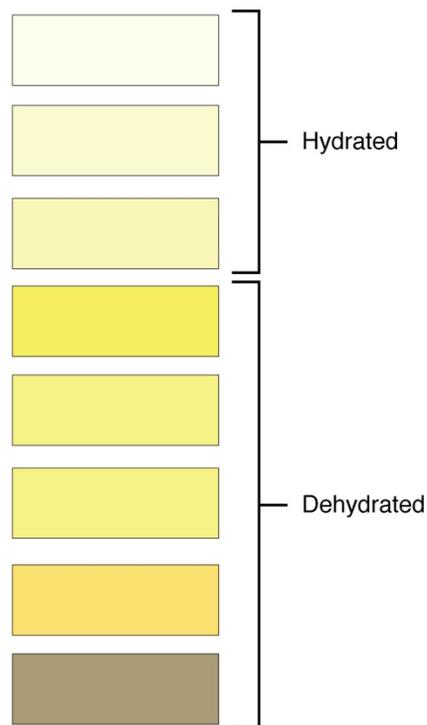


Figure 1. Variation of Urine Color

The color, clarity, and components of urine provide clues to the health and function of the kidneys and the body in general. The color of urine is determined mostly by the breakdown products of red blood cell destruction. The "heme" of hemoglobin is converted by the liver into water-soluble forms that can be excreted into the bile and indirectly into the urine. This yellow

pigment is **urochrome**. Some foods (ex. beets, berries, or rhubarb), as well as some vitamins and drug therapies may alter the color of one's urine. Dehydration may produce darker, more concentrated urine that may also possess the slight odor of ammonia. Most of the ammonia produced from protein breakdown is converted into urea by the liver, so ammonia is rarely detected in fresh urine. The strong ammonia odor you may detect in bathrooms or alleys is due to the breakdown of urea into ammonia by bacteria in the environment. About one in five people detect a distinctive odor in their urine after consuming asparagus; other foods such as onions, garlic, and fish can impart their own aromas! These food-caused odors are harmless though. While freshly voided urine is usually clear, it will become cloudy upon standing due to bacterial growth. Persistently cloudy (**turbid**) urine may indicate an infection. The waste products of metabolism (CO₂, urea, uric acid, creatinine, NaCl, ammonia) are all normal constituents of urine. However, the presence of substances like albumin, glucose, or ketones, or changes in pH or urine output are key factors in identifying renal diseases or other metabolic disorders.

Various tests (both physical and chemical) have been developed for routine urinalysis. Some of these tests and their procedures are described below (tests for pH, specific gravity, glucose, protein, and ketones). Recently, the dipstick method has been developed to replace many of these individual tests, and is commonly used in most doctors' offices. These test strips can not only detect many substances (ex. blood, bilirubin, protein, ketones, pH, glucose, and nitrites), but also their relative amounts.

Source Material

OpenStax, 25.1 Physical Characteristics of Urine. OpenStax CNX. May 2, 2019 <http://cnx.org/contents/f01808b8-5784-470e-a451-f1c96a109bd1@7>.

pH

Freshly voided urine usually has a pH around 6.0, but the pH of normal urine samples can range from 4.7 – 7.5. Urine pH is highly influenced by a person's diet. A high-protein diet often results in acidic urine, while a vegetable-rich diet results in more alkaline urine. The pH is also subject to diurnal fluctuations. Urine samples that are 24 hours old or older gradually become more alkaline due to the bacterial breakdown of urea. Urine that is consistently acidic is indicative of metabolic or respiratory acidosis, methanol poisoning, or metabolic disorders such as **phenylketonuria** (PKY). At the other end of the spectrum, production of consistently alkaline urine is a sign of metabolic or respiratory alkalosis or a urinary tract infection. It can also result from urine retention in the bladder, anemia, alkaline therapy, or obstructing gastric ulcers.

Source Material

OpenStax, 25.1 Physical Characteristics of Urine. OpenStax CNX. May 2, 2019 <http://cnx.org/contents/f01808b8-5784-470e-a451-f1c96a109bd1@7>.

Ketones

Ketones are intermediary products of fat metabolism and are not usually present in urine in any detectable amount. Finding ketones in the urine suggests that the body is using fat as an energy source in preference to glucose. Conditions leading to insufficient carbohydrate reserves will cause elevated levels of acetoacetic acid, acetone, and beta hydroxybutyric acid in the blood and urine, also known as **ketonuria**. Ketonuria can be brought on by hypothermia, dietary imbalances (starvation or inadequate carbohydrate intake), diabetes mellitus, or genetically or chemically-induced metabolic disorders. Diabetes mellitus is the most common disorder associated with urine ketones. Progressive **ketosis**, a state of raised ketone levels, can lead to coma and death.

Source Material

OpenStax, 25.1 Physical Characteristics of Urine. OpenStax CNX. May 2, 2019 <http://cnx.org/contents/f01808b8-5784-470e-a451-f1c96a109bd1@7>.

Proteins

Due to their large size, protein molecules are usually restricted to the glomerular capillaries during the filtration process in the nephron. This means that only trace amounts of protein should be found in a normal urine, approximately 10 mg/100 mL in a random sample. However, under certain physiological and pathological conditions, increased levels of proteins can be detected in the urine. **Pathologic albuminuria** is found in cases of glomerular damage, febrile diseases, anemia, hypertension, and toxemia of pregnancy. Excessive protein ingestion, excessive muscular exertion, prolonged exposure to cold and acute abdominal diseases may lead to a condition known as **physiologic albuminuria**.

Source Material

OpenStax, 25.1 Physical Characteristics of Urine. OpenStax CNX. May 2, 2019 <http://cnx.org/contents/f01808b8-5784-470e-a451-f1c96a109bd1@7>.

Glucose

Under normal conditions, urine will also contain only trace amounts of glucose (≤ 30 mg per 100 mL of urine). When glucose levels exceed this, the condition is known as **glucosuria**. This is found in cases of diabetes mellitus, pregnancy, excess stress, renal tubule damage, or brain damage. The renal threshold for glucose is about 160 mg/100 mL. In cases of glucosuria, blood glucose levels will exceed this amount and as a result, the excess glucose cannot be absorbed by the kidneys and it will “spill” into the urine. Incidentally, excess Vitamin C (ascorbic acid) contamination of the urine (> 400 mg/L) can give a false positive result for this test.

Source Material

OpenStax, 25.1 Physical Characteristics of Urine. OpenStax CNX. May 2, 2019 <http://cnx.org/contents/f01808b8-5784-470e-a451-f1c96a109bd1@7>.

Specific Gravity

Specific gravity is a measure of the quantity of solutes per unit volume of a solution and is traditionally easier to measure than osmolarity. Urine will always have a specific gravity greater than pure water (water = 1.00) due to the presence of solutes. Distilled water is generally used as a reference for calibrating a **urine hydrometer** and determining the specific gravity of urine samples. Normally, the specific gravity of a urine sample is between 1.015 and 1.025, however, normal samples can vary anywhere from 1.002 – 1.030. As the amount of dissolved solid in a urine solution increases, so does the specific gravity. The production of consistently dilute urine (specific gravity < 1.015) results in a condition called **hyposthenuria**. This state is usually indicative of conditions such as chronic nephritis, diabetes insipidus, or cardiovascular problems. Urine which is consistently concentrated (specific gravity > 1.030) results in **hypersthenuria**. This condition is indicative of such disorders as acute nephritis and diabetes mellitus.

Source Material

OpenStax, 25.1 Physical Characteristics of Urine. OpenStax CNX. May 2, 2019 <http://cnx.org/contents/f01808b8-5784-470e-a451-f1c96a109bd1@7>.

Pre-Assessment

1. What are the normal and healthy characteristics of urine?
2. How are you going to analyze different samples of urine?

Equipment List & Setup – Urinalysis

Equipment List

- Sterile urine collection containers
- Marker or wax pencil
- Four Chemstrip or Multistix 10SG urine test strips
- Four pH test strips
- Four small, clean cups OR conical centrifuge tubes
- Four disposable pipets
- Test tube rack
- 10 mL artificial urine sample from each of four “patients”
- Protective gloves

Equipment Setup

Before beginning

You should work in groups of 2-4 to complete this activity. Make sure that you thoroughly clean your workspace before and after the activity to ensure that you do not contaminate your samples or leave a mess behind.

Activities – Urinalysis

In this exercise, you will use artificial urine samples to analyze the dissolved and suspended components. This activity contributes to each of the Learning Objectives identified at the beginning of the section.

Part 1: Physical Characteristics of Urine

Procedure

1. Obtain four clean cups or conical centrifuge tubes. Using the marker or wax pencil, label each tube with the name or number of each urine sample.
2. Record your observations of the physical characteristics of each sample (color, clarity and smell) in Table 1, below.
 - a. For color: urine is normally a pale yellow. This is due to a pigment called **urochrome**, which is a metabolic product of hemoglobin breakdown. High levels of vitamin B may cause urine to artificially be bright yellow, while low fluid intake may cause urine to be a deep yellow color.
 - b. For clarity: fresh urine is typically clear or slightly cloudy. Urine turbidity (clarity) is often affected when red blood cells, white blood cells, epithelial cells, bacteria, mucus, lipids, or crystals. Crystals generally make urine cloudy or opaque.
 - c. For smell: urine should have a faint, but characteristic odor. Consumption of certain food, such as asparagus, may produce compounds, leading to stronger odors.

3. Once all of your observations are recorded, keep your samples, as you will reuse them for Part 2 of the activity.

Part 2: Chemical Composition of Urine

Procedure

1. Dip an unused pH paper into each urine sample. Use a new pH paper for each sample.
2. Using the comparison chart provided on the bottle of pH papers, identify and record the pH of each sample in Table 2, below.
3. Dip a ChemStrip into each sample. Use a new strip for each. Alternatively, you may need to squirt the sample onto the ChemStrip, if you do not have enough volume to completely submerge the strip. To do so, gently squirt each sample onto a new ChemStrip. New pipets should be used for each sample.
4. Compare the color changes on your sample strip to the comparison chart on the bottle.
5. Record your observations for Protein, Glucose, and Ketones in Table 2, below.

Analysis

Table 1. Physical Characteristics of Urine

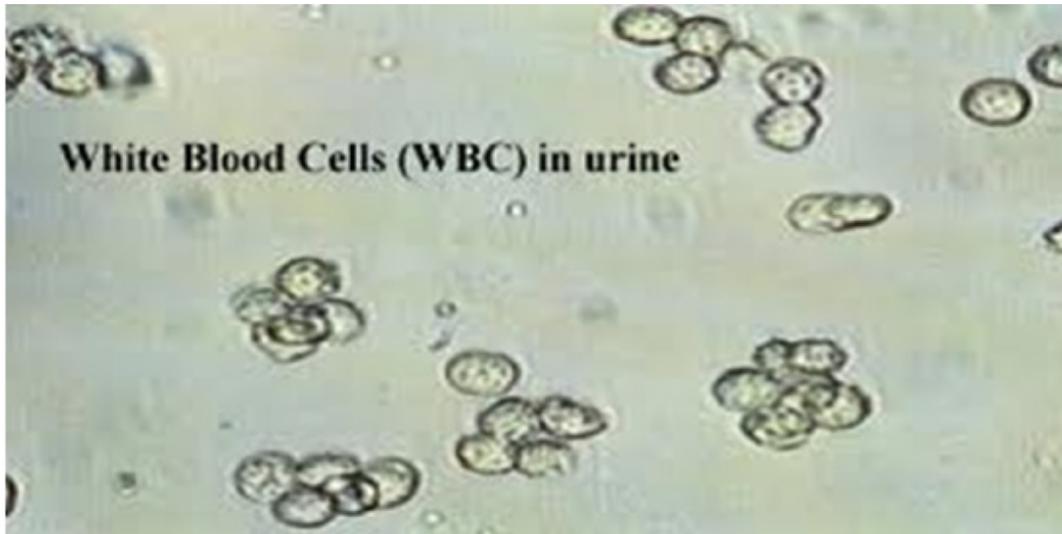
Sample	Color	Clarity	Smell
Patient #1 (Jeff Jones)			
Patient #2 (Mr. Thompson)			
Patient #3 (Ms. Smith)			
Patient #4 (Normal Control)			

Table 2. Chemical Composition of Urine

Sample	pH	Glucose	Protein	Ketones
Patient #1 (Jeff Jones)				
Patient #2 (Mr. Thompson)				
Patient #3 (Ms. Smith)				
Patient #4 (Normal Control)				

3. Ms. Smith (Patient #3) is 27 years old and has been experiencing painful and difficult urination (**dysuria**). She also complains that she feels the need to urinate more frequently and urgently. Her urine has a milky color. She is running a fever today and feels ill, which may be signs of an infection.

Microscopic examination of her urine reveals the following:



- a. What disorder does Ms. Smith appear to have? Explain.

The Female Reproductive System

Introduction

In this laboratory, you will use models, diagrams and histological samples to study the anatomy of the female reproductive system. As you study this organization, remember that a female's reproductive system is responsible for not just producing female **gametes** and receiving sperm from a male, but it also provides a space and nutrients for a developing **embryo**. Finally, the female reproductive system will allow for the delivery of a child into the outer environment. Based upon these functions, it should not be surprising that the female reproductive system is functionally more complex than the male reproductive system.

Learning Objectives

By the end of this lesson you will be able to:

1. Identify the general functions of the female reproductive tract.
2. Identify and describe the structures and functions that contribute to the female reproductive system. You will have to identify each on a model, diagram, or in a specimen.
3. Follow the pathway taken by an ovum from its site of formation to the body's exterior.
4. Discuss the microanatomy of the structures of the female reproductive tract and explain the importance of this organization to reproduction.
5. Understand the microanatomical organization of the ovary and ovum.
6. Identify the phases of mitosis and meiosis and describe the events that occur during each.
7. Compare and contrast the events of mitosis and meiosis.
8. Understand and explain the phases of the menstrual cycle and ovarian cycles.
 - a. Describe the changes in follicles that occur.
 - b. Identify and describe the functions of the corpus luteum and corpus albicans.
9. List and describe the hormones regulating the production of the ovum and identify their origin.
10. Identify the following structural and functional components of importance:

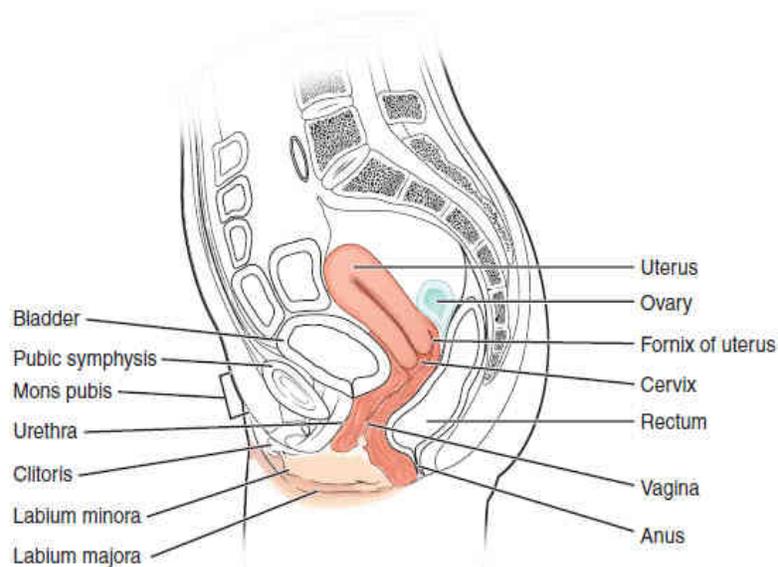
Female Reproductive System	Ovary microanatomy
Mons pubis	Follicle
Clitoris <ul style="list-style-type: none"> • Prepuce of clitoris 	Oocyte
Vestibule	Corona radiata
Labia <ul style="list-style-type: none"> • Majora • Minora 	Follicles <ul style="list-style-type: none"> • Primary • Secondary • Graafian
Urethral orifice	Antrum
Vaginal orifice	Corpus luteum

Hymen	Corpus albicans
Broad ligament	
Cervix	Mitosis and Meiosis
Suspensory ligament	Prophase <ul style="list-style-type: none"> • I and II
Ovary	Metaphase <ul style="list-style-type: none"> • I and II
Uterine (fallopian) tube	Anaphase <ul style="list-style-type: none"> • I and II
Fimbriae	Telophase <ul style="list-style-type: none"> • I and II
Mesosalpinx	Cytokinesis
Round ligament	Chiasmata
Uterus	Homologues
Vagina	Sister chromatids
Female Breast and Mammary Tissue	Oogenesis
Lobe	Oogonium
Areola	Oocytes <ul style="list-style-type: none"> • Primary • Secondary
Nipple	Polar bodies
Lactiferous sinus and duct	Ovulation
Alveoli of lobule	Ovum
Menstrual Cycle and Uterus	
Endometrium <ul style="list-style-type: none"> • Stratum functionalis • Stratum basalis 	Ovarian cycle
Myometrium	Luteal phase
Phases – menstrual, proliferative, secretory	Follicular phase
	Ovulation
Hormones	
Follicle stimulating hormone	
Luteinizing hormone	
Estrogen	
Progesterone	

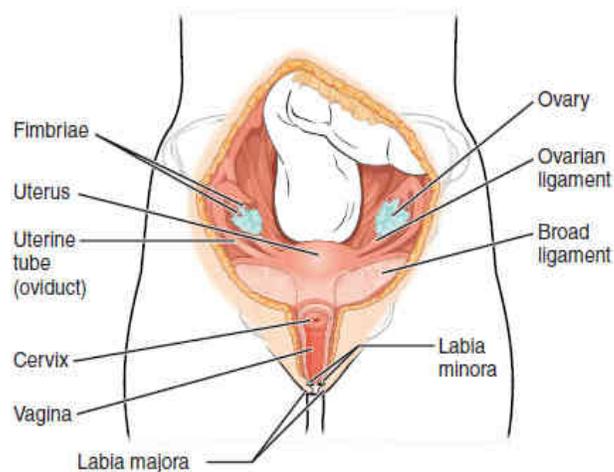
Background Information

Overview of the Female Reproductive System

The female reproductive system functions to produce gametes and reproductive hormones, just like the male reproductive system; however, it also has the additional task of supporting a developing fetus and delivering it to the outside world. Unlike its male counterpart, the female reproductive system is located primarily inside the pelvic cavity (**Figure 1**). Recall that the **ovaries** are the female **gonads** and the gamete that is produced is called an **oocyte**.



(a) Human female reproductive system: lateral view



(b) Human female reproductive system: anterior view

Figure 1. Female Reproductive System

The major organs of the female reproductive system are located inside the pelvic cavity.

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Ovaries

The **ovaries** are the female gonads (**Figure 1** and **Figure 2**). Paired ovals, they are each about 2 to 3 cm in length, about the size of an almond. The ovaries are located within the pelvic cavity, and are supported by the mesovarium, an extension of the peritoneum that connects the ovaries to the **broad ligament**. Extending from the mesovarium itself is the **suspensory ligament** that contains the ovarian blood and lymphatic vessels. Finally, the ovary itself is attached to the uterus via the **ovarian ligament**.

The ovary consists of multiple layers of tissue. The outer-most covering of cuboidal epithelium called the ovarian surface epithelium sits just superficial to a dense connective tissue layer, known as the **tunica albuginea**. Beneath the tunica albuginea is the **cortex**, or outer portion, of the organ itself. The cortex is composed of a tissue framework called the ovarian stroma that forms the bulk of the adult ovary. Oocytes develop within the outer layer of this stroma, each surrounded by supporting cells. This grouping of an oocyte and its supporting cells is called a **follicle** (**Figure 2**). The growth and development of ovarian follicles will be described shortly. Beneath the cortex lies the inner ovarian **medulla**, where the majority of blood vessels, lymphatic vessels, and the nerves of the ovary are localized to.

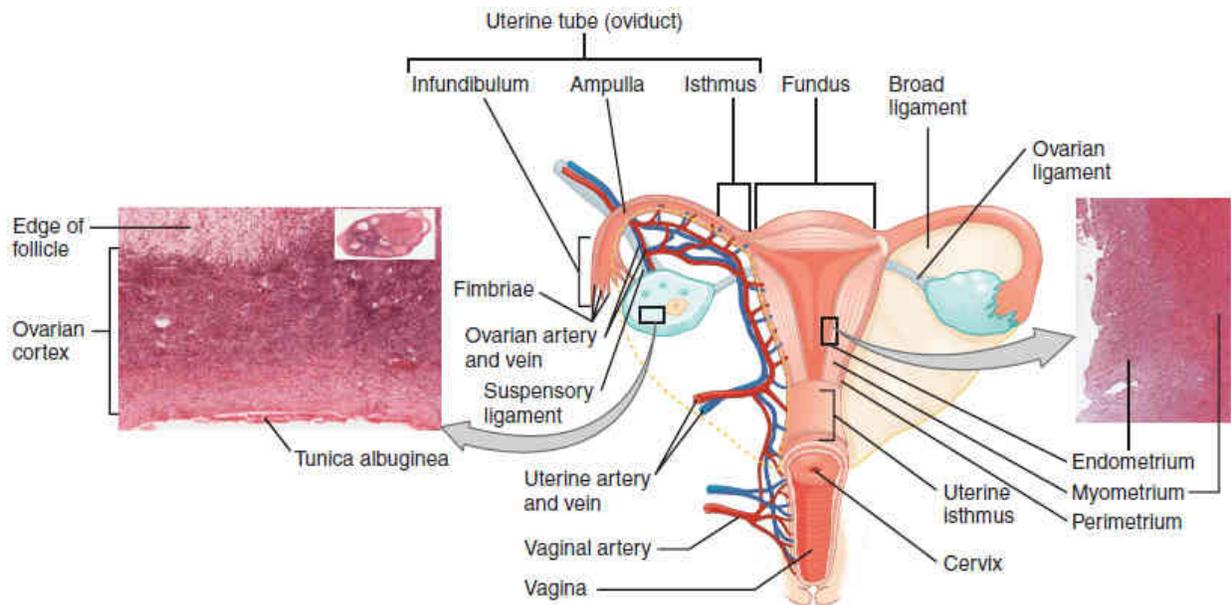


Figure 2. The Ovaries, Uterine Tubes, and Uterus

This anterior view shows the relationship of the ovaries, uterine tubes (oviducts), and uterus. From left to right, LM $\times 400$, LM $\times 20$. (Micrographs provided by the Regents of University of Michigan Medical School \copyright 2012)

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The Ovarian Cycle and Oogenesis

The **ovarian cycle** is a set of predictable changes in a female's oocytes and ovarian follicles. During a woman's reproductive years, it is a roughly 28-day cycle that can be correlated with, but is not the same as, the **menstrual cycle**. The cycle includes two interrelated processes: **oogenesis** (the production of female gametes) and **folliculogenesis** (the growth and development of ovarian follicles).

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Oogenesis

Gametogenesis in females is called **oogenesis**. The process begins with ovarian stem cells, or **oogonia** (plural: **oogonium**) (**Figure 3**). Oogonia are formed during fetal development, and divide via **mitosis**, much like spermatogonia in the testis. Unlike spermatogonia, however, oogonia form **primary oocytes** in the fetal ovary prior to birth. These primary oocytes are then arrested in prophase of meiosis I, only to resume it years later, beginning at **puberty** and continuing until the woman is near **menopause** (the cessation of a woman's reproductive functions). The number of primary oocytes present in the ovaries declines from one to two million in an infant, to approximately 400,000 at puberty, to zero by the end of menopause.

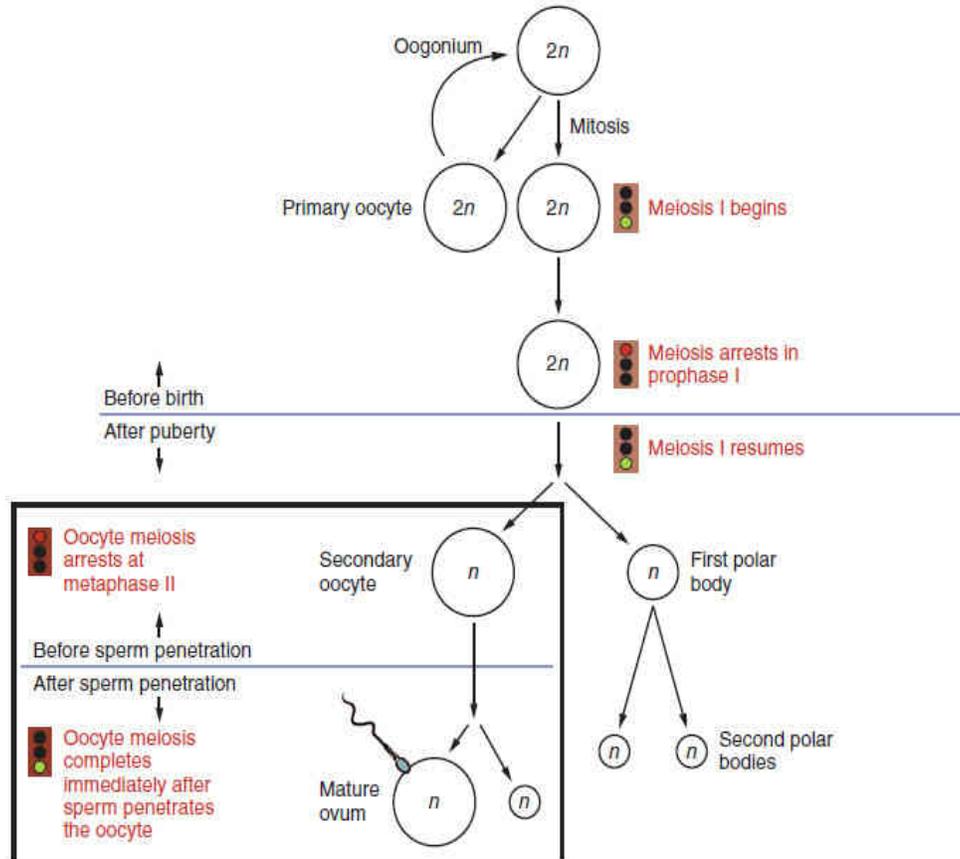


Figure 3. Oogenesis

The unequal cell division of oogenesis produces one to three polar bodies that later degrade, as well as a single haploid ovum, which is produced only if there is penetration of the secondary oocyte by a sperm cell.

The initiation of **ovulation**, the release of an oocyte from the ovary, marks the transition from puberty into reproductive maturity for women. From the onset of ovulation and throughout a woman's reproductive years, ovulation occurs approximately once every 28 days. Just prior to ovulation, a surge of **luteinizing hormone** triggers the resumption of meiosis in a primary oocyte. This initiates the transition from primary to **secondary oocyte**. However, as you can see in **Figure 3**, this cell division does not result in two identical cells. Instead, the cytoplasm is divided unequally, and one daughter cell is much larger than the other. This larger cell, the **secondary oocyte**, eventually leaves the ovary during ovulation. The smaller cell, called the first **polar body**, may or may not complete meiosis and produce second polar bodies; in either case, it eventually disintegrates. Therefore, even though oogenesis produces up to four cells, only one survives.

A question still remains though: How does the diploid secondary oocyte become an **ovum** —the haploid female gamete? Meiosis of a secondary oocyte is completed *only if a sperm succeeds in penetrating its barriers*. If union of a secondary oocyte and a sperm is successful, only then will meiosis II resume. This fusion will produce one haploid ovum that, at the moment of fertilization by a (haploid) sperm, becomes the first diploid cell of the new offspring (a **zygote**).

Thus, the ovum can be thought of as a brief, transitional, haploid stage between the diploid oocyte and diploid zygote.

The larger amount of cytoplasm contained in the female gamete is used to supply the developing zygote with nutrients during the period between fertilization and implantation into the uterus. Interestingly, sperm contribute only DNA at fertilization—not cytoplasm. Therefore, the cytoplasm and all of the cytoplasmic organelles in the developing embryo are of maternal origin.

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Folliculogenesis

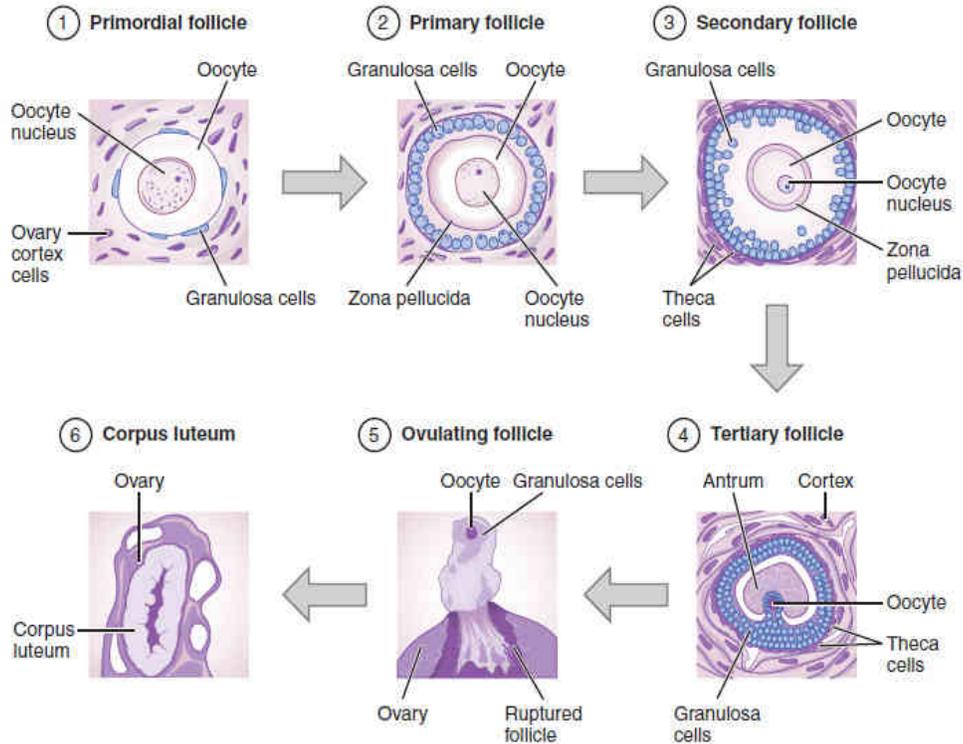
Remember, ovarian **follicles** are oocytes and their supporting cells. They grow and develop in a process called **folliculogenesis**, which typically leads to ovulation of one follicle approximately every 28 days, along with death to multiple other follicles. The death of ovarian follicles is called **atresia**, and can occur at any point during follicular development. Recall that, a female infant at birth will have one to two million oocytes within her ovarian follicles, and that this number declines throughout life until menopause, when no follicles remain. As you'll see next, follicles progress from **primordial**, to **primary**, to **secondary** and finally **tertiary** stages prior to ovulation—with the oocyte inside the follicle remaining as a primary oocyte until right before ovulation.

Folliculogenesis begins with follicles in a resting state. These small **primordial follicles** are present in newborn females and are the prevailing follicle type in the adult ovary (**Figure 4**). Primordial follicles have only a single flat layer of supporting cells, called **granulosa cells**, that surround the primary oocyte, and they can stay in this resting state for years—some until right before menopause.

After puberty, a few primordial follicles will respond to a recruitment signal each day, and will join a pool of immature growing follicles called **primary follicles**. Primary follicles start with a single layer of granulosa cells, but the granulosa cells then become active and transition from a flat or squamous shape to a rounded, cuboidal shape as they increase in size and proliferate. As the granulosa cells divide, the follicles—now called **secondary follicles (Figure 4)**—increase in diameter, adding a new outer layer of connective tissue, blood vessels, and **theca cells**—cells that work with the granulosa cells to produce estrogens. Within the growing secondary follicle, the primary oocyte now secretes a thin acellular membrane called the **zona pellucida** that will play a critical role in fertilization. A thick fluid, called follicular fluid, that has formed between the granulosa cells also begins to collect into one large pool, the **antrum**. Follicles in which the antrum has become large and fully formed are considered **tertiary follicles (or antral follicles)**. Several follicles reach the tertiary stage at the same time, and most of these will undergo atresia. The one that does not die will continue to grow and develop until ovulation, when it

will expel its secondary oocyte surrounded by several layers of granulosa cells from the ovary. Keep in mind that most follicles don't make it to this point. In fact, roughly 99 percent of the follicles in the ovary will undergo atresia, which can occur at any stage of folliculogenesis.

(a) Stages of Folliculogenesis



(b) A Secondary Follicle

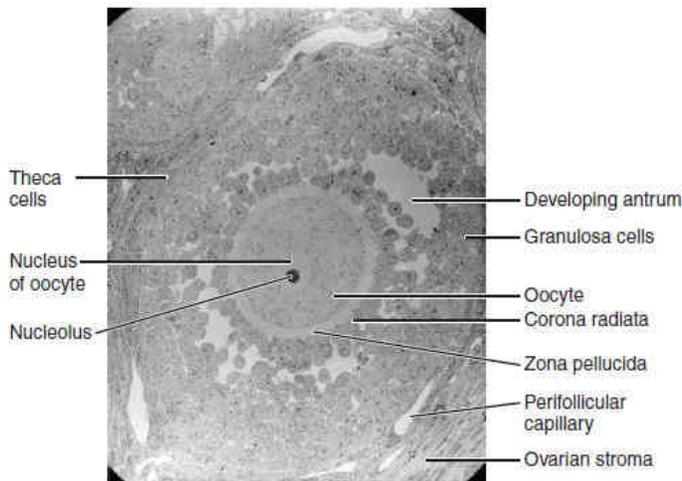


Figure 4. Folliculogenesis

(a) The maturation of a follicle is shown in a clockwise direction proceeding from the primordial follicles. FSH stimulates the growth of a tertiary follicle, and LH stimulates the production of estrogen by granulosa and theca cells. Once the follicle is mature, it ruptures and releases the oocyte. Cells remaining in the follicle then develop

into the corpus luteum. (b) In this electron micrograph of a secondary follicle, the oocyte, theca cells (thecae folliculi), and developing antrum are clearly visible. EM \times 1100. (Micrograph provided by the Regents of University of Michigan Medical School © 2012)

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Hormonal Control of the Ovarian Cycle

The process of development that we have just described, from primordial follicle to early tertiary follicle, takes approximately two months in humans. The final stages of development of a small cohort of tertiary follicles, ending with ovulation of a secondary oocyte, occur over a course of approximately 28 days. These changes are regulated by many of the same hormones that regulate the male reproductive system, including **GnRH**, **LH**, and **FSH**.

As in men, the hypothalamus produces GnRH, a hormone that signals the anterior pituitary gland to produce the gonadotropins FSH and LH (**Figure 5**). These gonadotropins leave the pituitary and travel through the bloodstream to the ovaries, where they bind to receptors on the granulosa and theca cells of the follicles. FSH stimulates the follicles to grow (hence its name of follicle-stimulating hormone), and the five or six tertiary follicles expand in diameter. The release of LH also stimulates the granulosa and theca cells of the follicles to produce the sex steroid hormone **estradiol**, a type of **estrogen**.

This phase of the ovarian cycle, when the tertiary follicles are growing and secreting estrogen, is known as the **follicular phase**. The more granulosa and theca cells a follicle has (that is, the larger and more developed it is), the more estrogen it will produce in response to LH stimulation. As a result of these large follicles producing large amounts of estrogen, systemic plasma estrogen concentrations increase. Following a classic negative feedback loop, the high concentrations of estrogen will stimulate the hypothalamus and pituitary to reduce the production of GnRH, LH, and FSH. Because the large tertiary follicles require FSH to grow and survive at this point, this decline in FSH caused by negative feedback leads most of them to die (atresia) (**Figure 5, step 1**). Typically, only one follicle, now called the **dominant follicle**, will survive this reduction in FSH, and this follicle will be the one that releases an oocyte. Scientists have studied many factors that lead to a particular follicle becoming dominant: size, the number of granulosa cells, and the number of FSH receptors on those granulosa cells all contribute to a follicle becoming the one surviving dominant follicle.

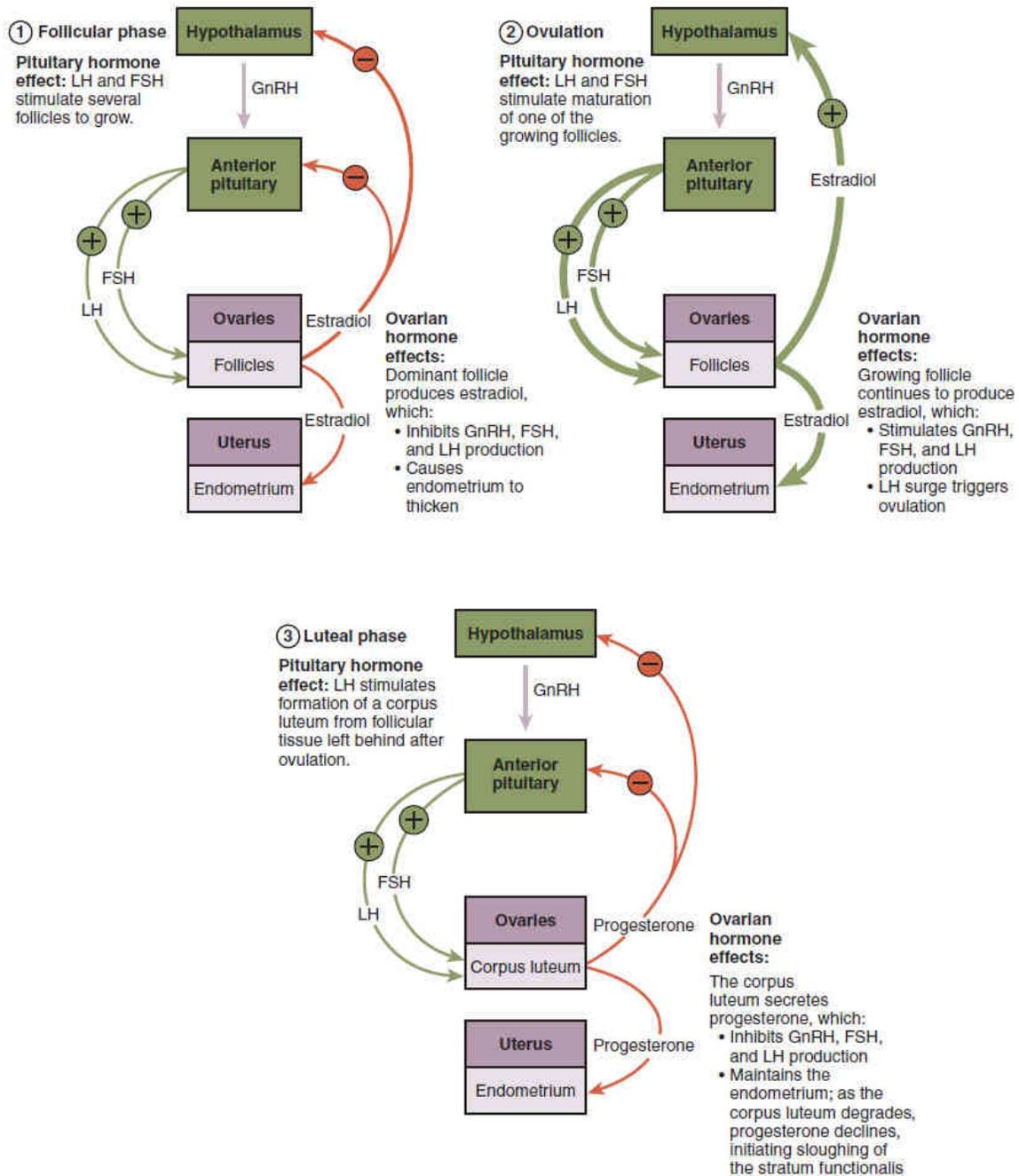


Figure 5. Hormonal Regulation of Ovulation

The hypothalamus and pituitary gland regulate the ovarian cycle and ovulation. GnRH activates the anterior pituitary to produce LH and FSH, which stimulate the production of estrogen and progesterone by the ovaries.

When only the dominant follicle remains in the ovary, it again begins to secrete estrogen. It produces more estrogen than all of the developing follicles did together before the negative feedback occurred. It produces so much estrogen that the normal negative feedback doesn't occur. Instead, these extremely high concentrations of systemic plasma estrogen trigger a regulatory switch in the anterior pituitary that responds by secreting large amounts of LH and FSH into the bloodstream (Figure 5, step 2).

The positive feedback loop by which more estrogen triggers release of more LH and FSH only occurs at this point in the cycle. It is this large burst of LH (called the LH surge) that leads to ovulation of the dominant follicle. The LH surge induces many changes in the dominant follicle, including stimulating the resumption of meiosis of the primary oocyte to a secondary oocyte. As noted earlier, the polar body that results from unequal cell division simply degrades. The LH surge also triggers proteases (enzymes that cleave proteins) to break down structural proteins in the ovary wall on the surface of the bulging dominant follicle. This degradation of the wall, combined with pressure from the large, fluid-filled antrum, results in the expulsion of the oocyte surrounded by granulosa cells into the peritoneal cavity. This release is **ovulation**.

There is one more important event that occurs in the ovarian cycle. The surge of LH also stimulates a change in the granulosa and theca cells that remain in the follicle after the oocyte has been ovulated. This change is called **luteinization** and it transforms the collapsed follicle into a new endocrine structure called the **corpus luteum**, a term meaning "yellowish body" (**Figure 4**). Instead of estrogen, the luteinized granulosa and theca cells of the corpus luteum begin to produce large amounts of the sex steroid hormone **progesterone**, a hormone that is critical for the establishment and maintenance of pregnancy. Progesterone triggers negative feedback at the hypothalamus and pituitary, which keeps GnRH, LH, and FSH secretions low, so no new dominant follicles develop at this time. This post-ovulatory phase of progesterone secretion is known as the **luteal phase** of the ovarian cycle (**Figure 5, step 3**). If pregnancy does not occur within 10 to 12 days, the corpus luteum will stop secreting progesterone and degrade into the **corpus albicans**, a nonfunctional "whitish body" that will degenerate in the ovary over a period of several months. During this time of reduced progesterone secretion, FSH and LH are once again stimulated, and the follicular phase begins again with a new cohort of early tertiary follicles beginning to grow and secrete estrogen.

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Uterine (Fallopian) Tubes

The **uterine tubes** (also called **fallopian tubes** or **oviducts**) serve as the conduit of the oocyte from the ovary to the uterus (**Figure 2**). Each of the two uterine tubes is close to, but not directly connected to, the ovary and each is divided into sections. The **isthmus** is the narrow medial end of each uterine tube that is connected to the uterus. The wide distal **infundibulum** flares out with slender, finger-like projections called **fimbriae**. The middle region of the tube, called the **ampulla**, is where fertilization often occurs. The uterine tubes also have three layers of tissue: an outer serosa, a middle smooth muscle layer, and an inner mucosal layer. In addition to its mucus-secreting cells, the inner mucosa contains ciliated cells that beat in the direction of the uterus, producing a current that will be critical to move the oocyte.

Following ovulation, the secondary oocyte surrounded by a few granulosa cells is released into the peritoneal cavity. The nearby uterine tube, either left or right, receives the oocyte. Unlike

sperm, oocytes lack flagella, and therefore cannot move on their own. So how do they travel into the uterine tube and toward the uterus? High concentrations of estrogen that occur around the time of ovulation induce contractions of the smooth muscle along the length of the uterine tube. These contractions occur every 4 to 8 seconds, and the result is a coordinated movement that sweeps the surface of the ovary and the pelvic cavity. As a result of these mechanisms, the oocyte–granulosa cell complex is pulled into the interior of the tube. Once inside, the muscular contractions and beating cilia move the oocyte slowly toward the uterus. When fertilization does occur, sperm typically meet the egg while it is still moving through the ampulla.

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Uterus

The **uterus** is the muscular organ that nourishes and supports the growing embryo (**Figure 2**). Its average size is approximately 5 cm wide by 7 cm long when a female is not pregnant. It has three sections: the portion of the uterus superior to the opening of the uterine tubes is called the **fundus**, the middle section of the uterus is called the **body** or **corpus**, and the **cervix** is the narrow inferior portion of the uterus that projects into the vagina.

The wall of the uterus is made up of three layers (**Figure 2** and **Figure 6**). The most superficial layer is the serous membrane, or **perimetrium**, which consists of epithelial tissue that covers the exterior portion of the uterus. The middle layer, or **myometrium**, is a thick layer of smooth muscle responsible for uterine contractions. Most of the uterus is myometrial tissue, and the muscle fibers run horizontally, vertically, and diagonally, allowing the powerful contractions that occur during labor and the less powerful contractions (or cramps) that help to expel menstrual blood during a woman's period.

The innermost layer of the uterus is called the **endometrium**. Structurally, the endometrium consists of two layers: the **stratum basalis (basal layer)** and the **stratum functionalis (functional layer)**. The stratum basalis layer lies adjacent to the myometrium; this layer does not shed during menses. In contrast, the thicker stratum functionalis layer contains the glandular endothelial tissues that line the uterine lumen. It is the stratum functionalis that grows and thickens in response to increased levels of estrogen and progesterone. In the luteal phase of the menstrual cycle, special branches off of the uterine artery called **spiral arteries** supply the thickened stratum functionalis (**Figure 6**). This inner functional layer provides the proper site of implantation for a fertilized egg, and—should fertilization not occur—it is only the functional layer of the endometrium that sheds during menstruation.

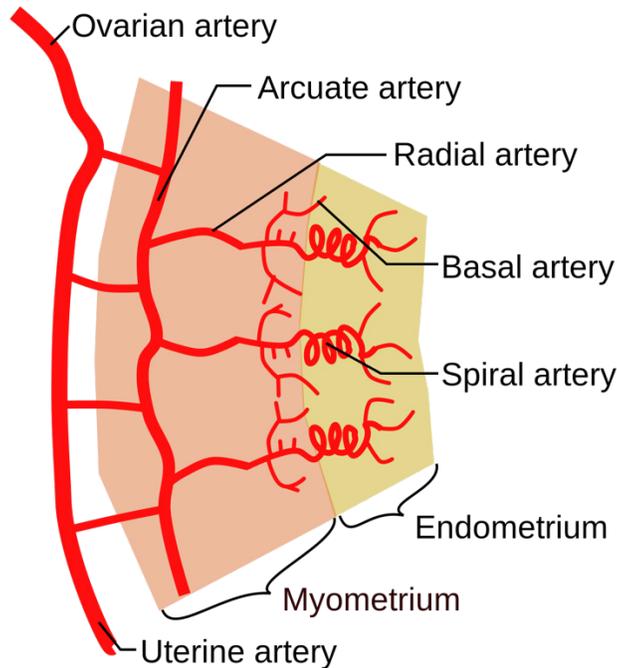


Figure 6. Layers of the Uterus

The wall of the uterus consists of 3 layers: the outer perimetrium (not shown), the myometrium, and the endometrium.

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Ligaments

Several ligaments maintain the position of the uterus within the abdominopelvic cavity (**Figure 2**). The **broad ligament** is a fold of peritoneum that serves as a primary support for the uterus, extending laterally from both sides of the uterus and attaching it to the pelvic wall. The **round ligament** attaches to the uterus near the uterine tubes, and extends to the labia majora.

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Vagina

The **vagina**, shown at the bottom of **Figure 1** and in **Figure 7**, is a muscular canal (approximately 10 cm long) that serves as the entrance to the reproductive tract. It also serves as the exit from the uterus during menses and childbirth. The outer walls of the anterior and posterior vagina are formed into longitudinal columns, or **ridges**, and the superior portion of the vagina—called the **fornix**—meets the protruding uterine cervix. The walls of the vagina are lined with an outer, fibrous adventitia, a middle layer of smooth muscle, and an inner mucous membrane with transverse folds called **rugae**. Together, the middle and inner layers allow the expansion of the vagina to accommodate intercourse and childbirth. A thin, perforated **hymen** can partially surround the opening to the **vaginal orifice (opening)**.

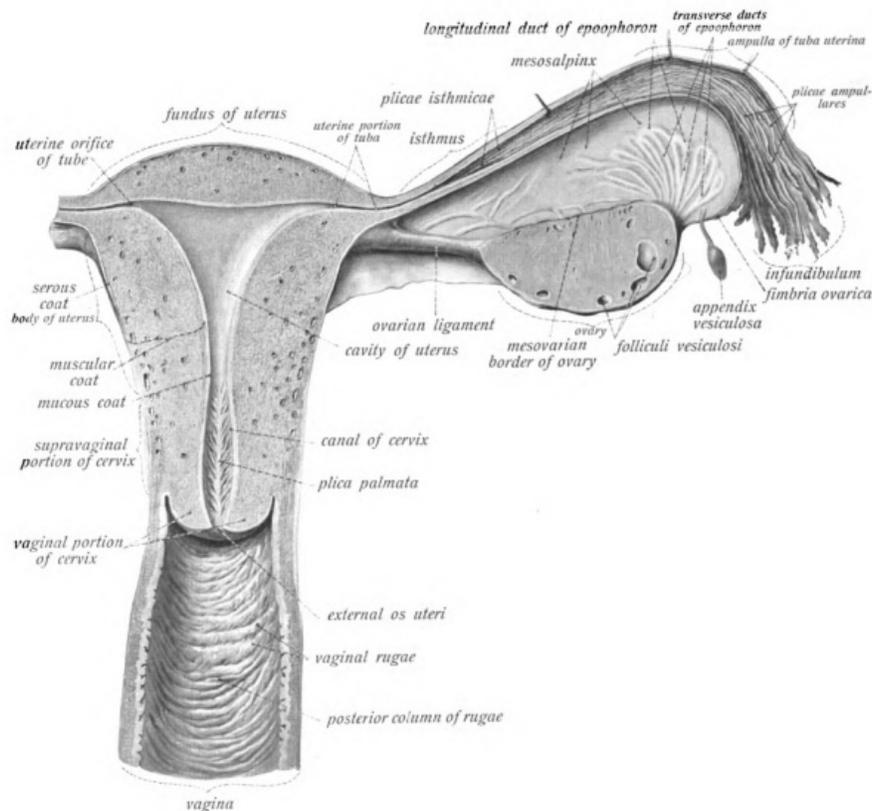


Figure 7. Cross-section of the Vagina

An illustration showing a cross-section through the vagina and upper female genital tract (only one ovary and fallopian tube shown). Circular folds (also called rugae) of vaginal mucosa can be seen.

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Menstrual Cycle

Now that we have discussed the maturation of the cohort of tertiary follicles in the ovary, the build-up and then shedding of the endometrial lining in the uterus, and the function of the uterine tubes and vagina, we can put everything together to talk about the three phases of the **menstrual cycle** —the series of changes in which the uterine lining is shed, rebuilt, and prepared for implantation.

The timing of the menstrual cycle starts with the first day of **menses**, referred to as day one of a woman's period. Cycle length is determined by counting the days between the onset of bleeding in two subsequent cycles. Because the average length of a woman's menstrual cycle is 28 days, this is the time period used to identify the timing of events in the cycle. However, the length of the menstrual cycle varies among women, and even in the same woman from one cycle to the next, typically from 21 to 32 days.

Just as the hormones produced by the granulosa and theca cells of the ovary "drive" the follicular and luteal phases of the ovarian cycle, they also control the three distinct phases of the menstrual cycle. These are the **menses (menstrual) phase**, the **proliferative phase**, and the **secretory phase**, each of which will be discussed in further detail below.

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Menstrual Phase

The **menstrual** or **menses phase** of the menstrual cycle is the phase during which the lining of the uterus is shed; that is, the days that the woman **menstruates**. Although it averages approximately five days, the menses phase can last from 2 to 7 days, or longer. As shown in **Figure 8** below, the menses phase occurs during the early days of the follicular phase of the ovarian cycle, when progesterone, FSH, and LH levels are low. Recall that progesterone concentrations decline as a result of the degradation of the corpus luteum, marking the end of the luteal phase. This decline in progesterone triggers the shedding of the stratum functionalis of the endometrium.

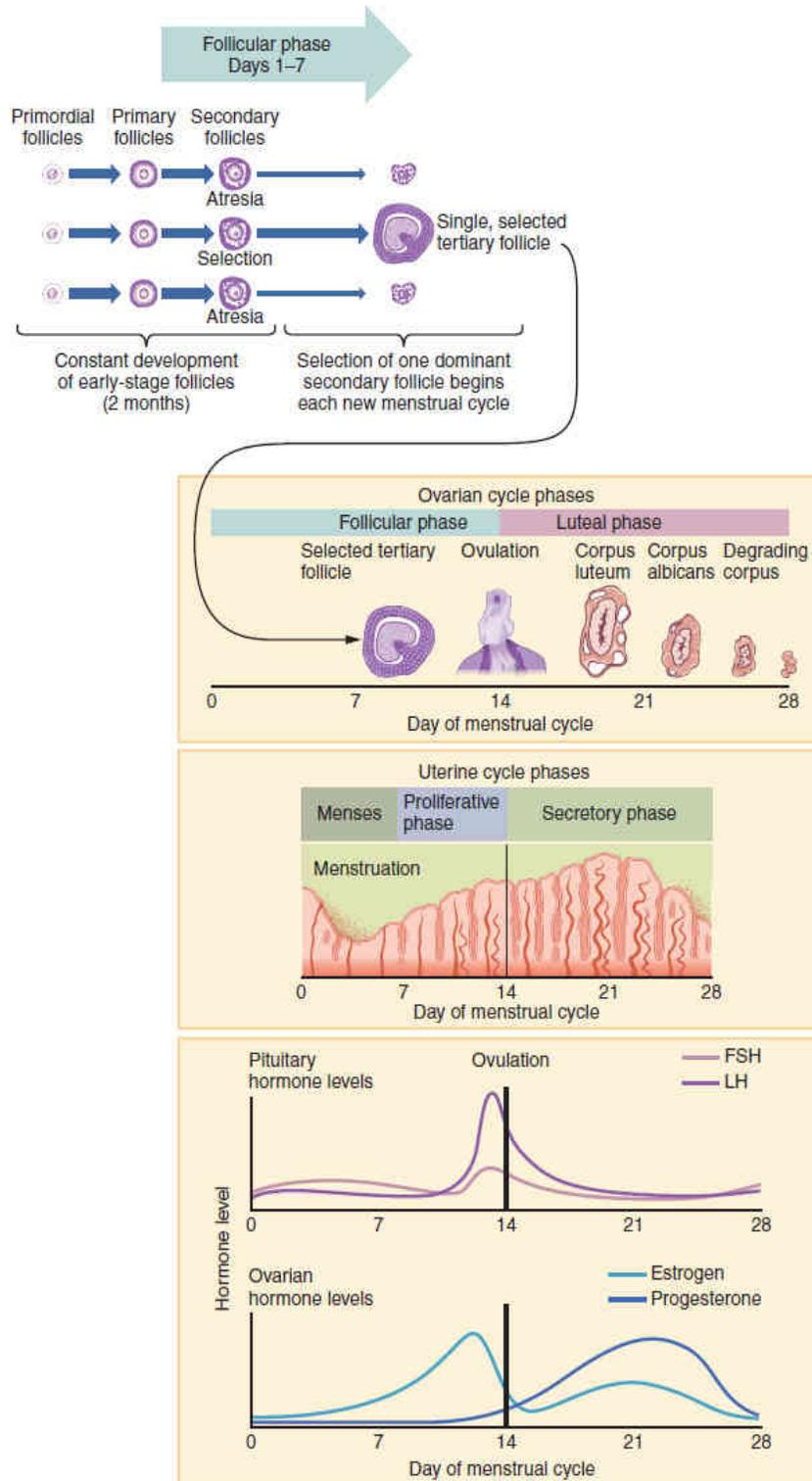


Figure 8. Hormone Levels in Ovarian and Menstrual Cycles

The correlation of the hormone levels and their effects on the female reproductive system is shown in this timeline of the ovarian and menstrual cycles. The menstrual cycle begins at day one with the start of menses. Ovulation occurs around day 14 of a 28-day cycle, triggered by the LH surge.

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Proliferative Phase

Once menstrual flow ceases, the endometrium begins to proliferate again, marking the beginning of the **proliferative phase** of the menstrual cycle (**Figure 8**). It occurs when the granulosa and theca cells of the tertiary follicles begin to produce increased amounts of estrogen. These rising estrogen concentrations stimulate the endometrial lining to rebuild. Recall that the high estrogen concentrations will eventually lead to a decrease in FSH as a result of negative feedback, resulting in atresia of all but one of the developing tertiary follicles. The switch to positive feedback—which occurs with the elevated estrogen production from the dominant follicle—then stimulates the LH surge that will trigger ovulation. In a typical 28-day menstrual cycle, ovulation occurs on day 14. Ovulation marks the end of the proliferative phase as well as the end of the follicular phase.

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Secretory Phase

In the ovary, the luteinization of the granulosa cells of the collapsed follicle forms the progesterone-producing corpus luteum, marking the beginning of the **luteal phase** of the ovarian cycle. In the uterus, progesterone from the corpus luteum begins the **secretory phase** of the menstrual cycle, in which the endometrial lining prepares for implantation (**Figure 8**). Over the next 10 to 12 days, the endometrial glands secrete a fluid rich in glycogen. If fertilization has occurred, this fluid will nourish the ball of cells now developing from the zygote. At the same time, the spiral arteries will develop to provide blood to the thickened stratum functionalis.

If no pregnancy occurs within approximately 10 to 12 days, the corpus luteum will degrade into the corpus albicans. Levels of both estrogen and progesterone will fall, and the endometrium will grow thinner. Prostaglandins will be secreted that cause constriction of the spiral arteries, reducing oxygen supply and the endometrial tissue will die, resulting in menses—or the first day of the next cycle.

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External Genitalia

The external female reproductive structures are referred to collectively as the **vulva** (**Figures 1 and 9**) and they include the structures that will be discussed next. The **mons pubis** is a pad of fat that is located anteriorly, over the pubic bone. After puberty, it becomes covered in pubic hair. The **labia majora** (labia = "lips"; majora = "larger") are folds of hair-covered skin that begin just posterior to the mons pubis. The thinner and more pigmented **labia minora** (labia = "lips"; minora = "smaller") extend medial to the labia majora and the space between labia minora is known as the **vestibule**. Although they naturally vary in shape and size from woman to woman, the labia minora serve to protect the female urethra and the entrance to the female reproductive tract.

The superior, anterior portions of the labia minora come together to encircle the **clitoris** (or **glans clitoris**), an organ that originates from the same cells as the glans penis, and has abundant nerves that make it important in sexual sensation and orgasm. The **hymen** is a thin membrane that sometimes partially covers the entrance to the vagina. The vaginal opening, also known as the **vaginal orifice**, is located between the opening of the urethra and the anus. It is flanked by outlets to the *Bartholin's glands* (or greater vestibular glands) (**Figure 9**).

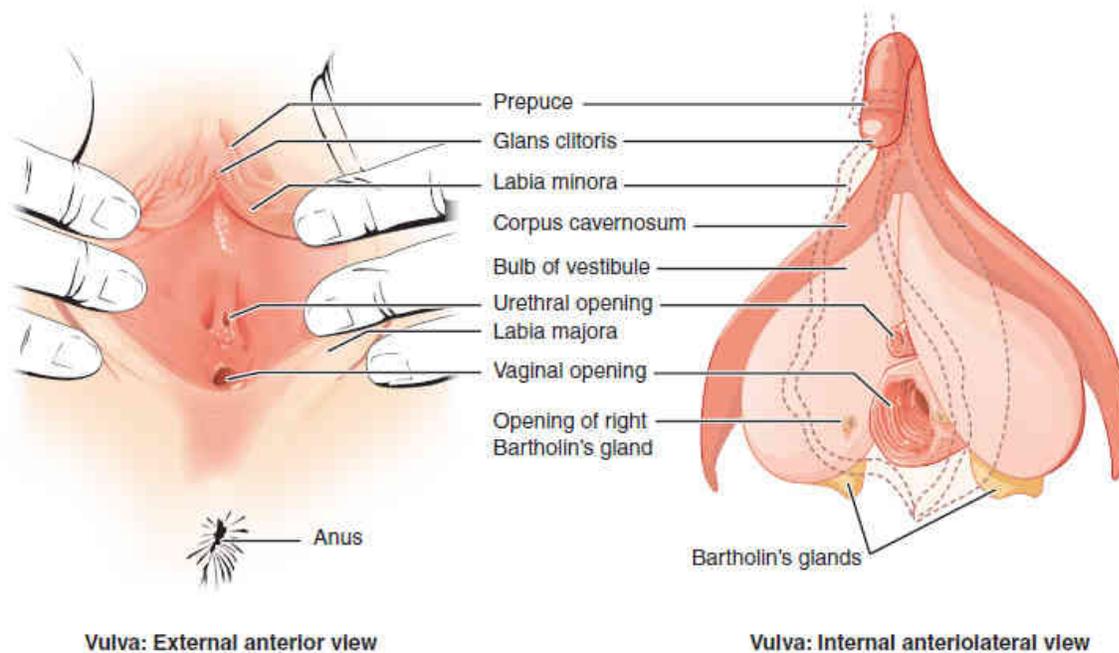


Figure 9. The Vulva

The external female genitalia are referred to collectively as the vulva.

Source Material

OpenStax, 27.2 Anatomy and Physiology of the Female Reproductive System. OpenStax CNX. May 2, 2019
<http://cnx.org/contents/9cccba49-6490-4e5b-a366-9991b7dbc56c@9>.

The Breast

Whereas the breasts are located far from the other female reproductive organs, they are considered accessory organs of the female reproductive system. The function of the breasts is to supply milk to an infant in a process called **lactation**. The external features of the breast include a **nipple** surrounded by a pigmented **areola (Figure 10)**, whose coloration may deepen during pregnancy. The areolar region is characterized by small, raised areolar glands that secrete lubricating fluid during lactation to protect the nipple from chafing.

Internally, breast milk is produced by the **mammary glands**, which are modified sweat glands. The milk itself exits the breast through the nipple via 15 to 20 **lactiferous ducts** that open on the surface of the nipple. These lactiferous ducts each extend to a **lactiferous sinus** that connects to a glandular lobe (**lobule**) within the breast itself that contains groups of milk-secreting cells in clusters called **alveoli (Figure 10)**. Once milk is made in the alveoli, stimulated myoepithelial cells that surround the alveoli contract to push the milk to the lactiferous sinuses. From here, a baby can draw milk through the lactiferous ducts by suckling. The lobules themselves are surrounded by fat tissue, which determines the size of the breast; breast size differs between individuals and does not affect the amount of milk produced. Supporting the breasts are multiple bands of connective tissue called **suspensory ligaments** that connect the breast tissue to the dermis of the overlying skin.

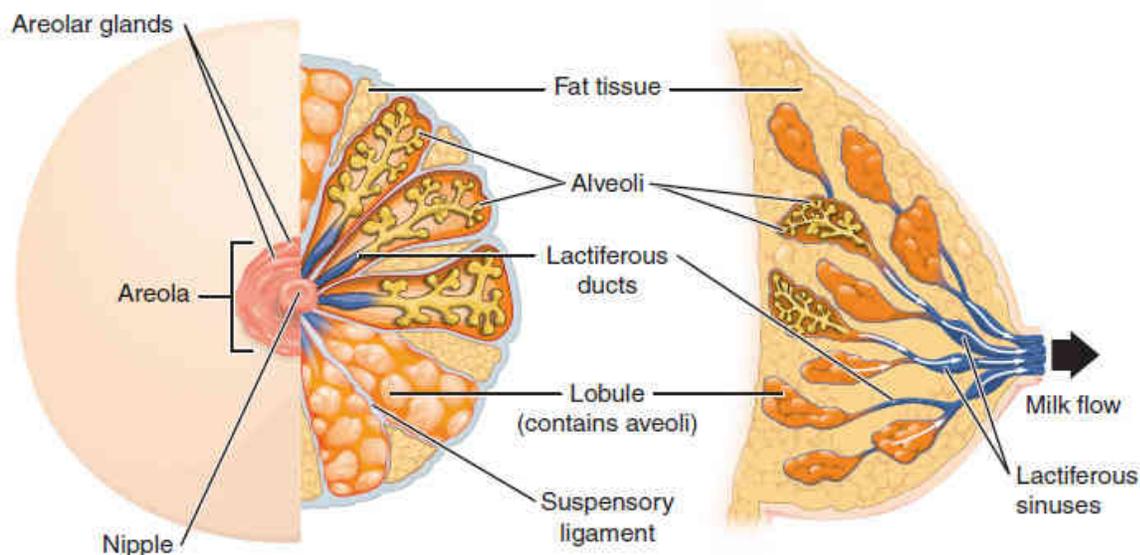


Figure 10. Anatomy of the Breast

During lactation, milk moves from the alveoli through the lactiferous ducts to the nipple. During the normal hormonal fluctuations in the menstrual cycle, breast tissue responds to changing levels of estrogen and progesterone, which can lead to swelling and breast tenderness in some individuals, especially during the secretory phase. If pregnancy occurs, the increase in hormones leads to further development of the mammary tissue and enlargement of the breasts.

Source Material

OpenStax, 27.2 Anatomy and Physiology of the Female Reproductive System. OpenStax CNX. May 2, 2019 <http://cnx.org/contents/9cccba49-6490-4e5b-a366-9991b7dbc56c@9>.

Cellular Division: Mitosis and Meiosis

The **cell cycle** is an ordered series of events involving cell growth and cell division that produces two new daughter cells. Cells on the path to cell division proceed through a series of precisely timed and carefully regulated stages of growth, DNA replication, and division that produces two identical (clone) cells. The cell cycle has two major phases: **interphase** and the **mitotic phase (mitosis)**. During **interphase**, the cell grows and DNA is replicated. During the **mitotic phase**, the replicated DNA and cytoplasmic contents are separated, and the cell divides.

Source Material

OpenStax, The Cell Cycle. OpenStax CNX. Jun 5, 2013 <http://cnx.org/contents/d6d279e4-eb7a-4e64-8d53-8710b4c50e81@7>.

Interphase

During interphase, the cell undergoes normal growth processes while also preparing for cell division. In order for a cell to move from interphase into the mitotic phase, many internal and external conditions must be met. The three stages of interphase are called G₁, S, and G₂.

Source Material

OpenStax, The Cell Cycle. OpenStax CNX. Jun 5, 2013 <http://cnx.org/contents/d6d279e4-eb7a-4e64-8d53-8710b4c50e81@7>.

G₁ Phase (First Gap)

The first stage of interphase is called the **G₁ phase** (first gap) because, from a microscopic aspect, little change is visible. However, during the G₁ stage, the cell is quite active at the biochemical level. The cell is accumulating the building blocks of chromosomal DNA and the associated proteins, as well as accumulating sufficient energy reserves to complete the task of replicating each chromosome in the nucleus.

Source Material

OpenStax, The Cell Cycle. OpenStax CNX. Jun 5, 2013 <http://cnx.org/contents/d6d279e4-eb7a-4e64-8d53-8710b4c50e81@7>.

S Phase (Synthesis of DNA)

Throughout interphase, nuclear DNA remains in a semi-condensed chromatin configuration. In the **S phase**, DNA replication can proceed through the mechanisms that result in the formation of identical pairs of DNA molecules—**sister chromatids**—that are firmly attached at the centromeric region. The centrosome is also duplicated during the S phase. The two

centrosomes will then give rise to the **mitotic spindle**, the apparatus that orchestrates the movement of chromosomes during mitosis.

Source Material

OpenStax, The Cell Cycle. OpenStax CNX. Jun 5, 2013 <http://cnx.org/contents/d6d279e4-eb7a-4e64-8d53-8710b4c50e81@7>.

G₂ Phase (Second Gap)

In the **G₂ phase**, the cell replenishes its energy stores and synthesizes proteins necessary for chromosome manipulation. Some cell organelles are duplicated, and the cytoskeleton is dismantled to provide resources for the mitotic phase. There may be additional cell growth during G₂. The final preparations for the mitotic phase must be completed before the cell is able to enter the first stage of mitosis.

Source Material

OpenStax, The Cell Cycle. OpenStax CNX. Jun 5, 2013 <http://cnx.org/contents/d6d279e4-eb7a-4e64-8d53-8710b4c50e81@7>.

The Mitotic Phase

The mitotic phase is a multistep process during which the duplicated chromosomes are aligned, separated, and move into two new, identical daughter cells. The first portion of the mitotic phase is called **karyokinesis**, or nuclear division. The second portion of the mitotic phase, called **cytokinesis**, is the physical separation of the cytoplasmic components into the two daughter cells.

Source Material

OpenStax, The Cell Cycle. OpenStax CNX. Jun 5, 2013 <http://cnx.org/contents/d6d279e4-eb7a-4e64-8d53-8710b4c50e81@7>.

Mitosis

Karyokinesis, also known as **mitosis**, is divided into a series of phases—prophase, prometaphase, metaphase, anaphase, and telophase—that result in the division of the cell nucleus. Each of these phases is shown in **Figure 11** and described in further detail below.

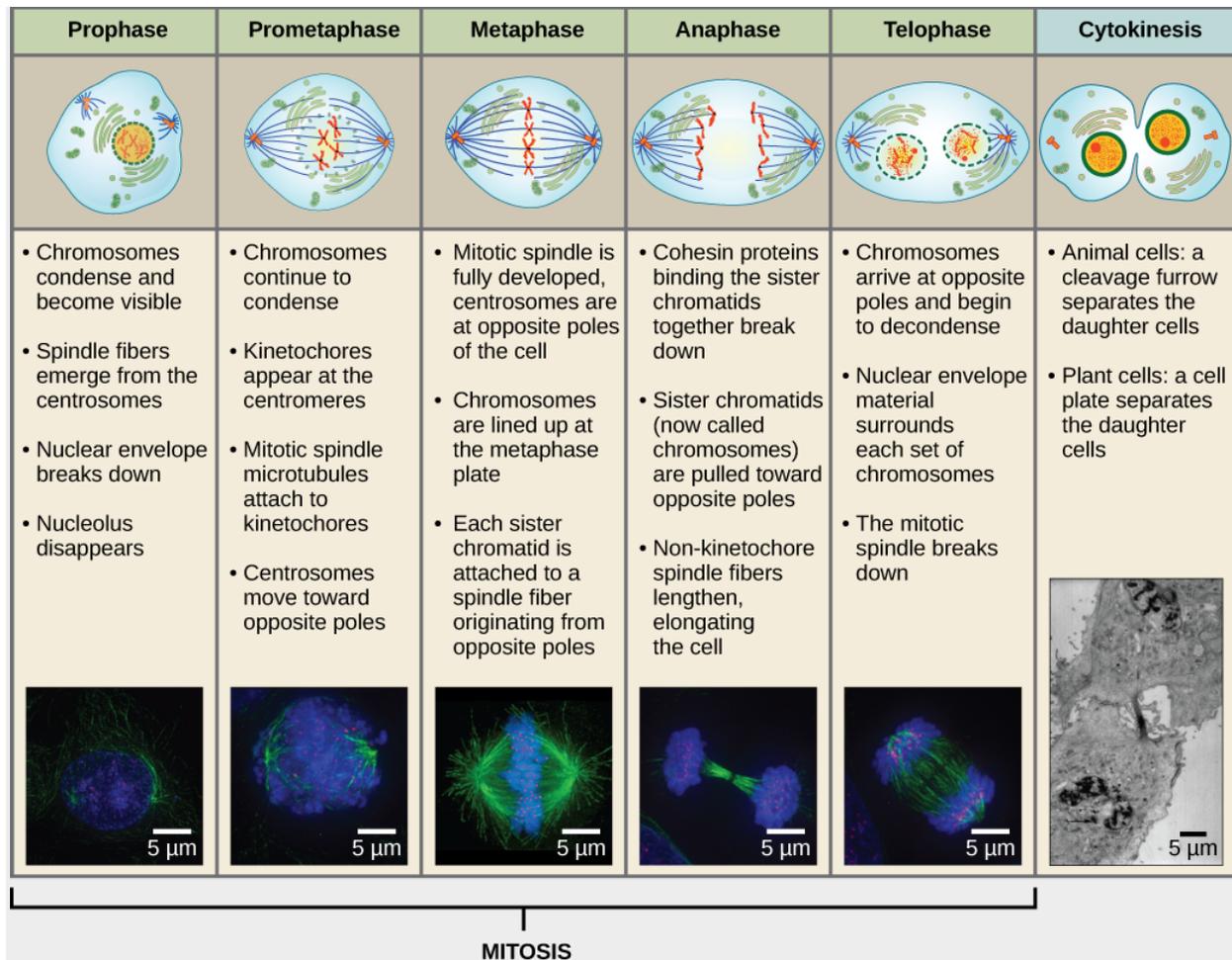


Figure 11. The Stages of Mitosis

Blue fluorescence indicates DNA (chromosomes) and green fluorescence indicates microtubules (spindle apparatus). Credit “mitosis drawings”: modification of work by Mariana Ruiz Villareal; credit “micrographs”: modification of work by Roy van Heesbeen; credit “cytokinesis micrograph”: Wadsworth Center/New York State Department of Health; scale-bar data from Matt Russell.

During **prophase**, the “first phase,” the nuclear envelope starts to dissociate into small vesicles, and the membranous organelles (such as the Golgi complex or Golgi apparatus, and endoplasmic reticulum) fragment and disperse toward the periphery of the cell. The nucleolus disappears (disperses) and the centrosomes begin to move to opposite poles of the cell. Microtubules that will form the mitotic spindle extend between the centrosomes and the sister chromatids begin to coil more tightly and become visible under a light microscope.

During **prometaphase**, the “first change phase,” many processes that were begun in prophase continue to advance. The remnants of the nuclear envelope fragment. The mitotic spindle continues to develop and chromosomes become more condensed and discrete. Each sister chromatid develops a protein structure called a **kinetochore** in the centromeric region (**Figure 12**). The proteins of the kinetochore attract and bind mitotic spindle microtubules. As the spindle microtubules extend from the centrosomes, some of these microtubules come into

contact with and firmly bind to the kinetochores. Once a mitotic fiber attaches to a chromosome, the chromosome will be oriented until the kinetochores of sister chromatids face the opposite poles. Eventually, all of the sister chromatids will be attached via their kinetochores to microtubules from opposing poles. *Often times, the events of prophase and prometaphase will be combined and simply known as prophase.*

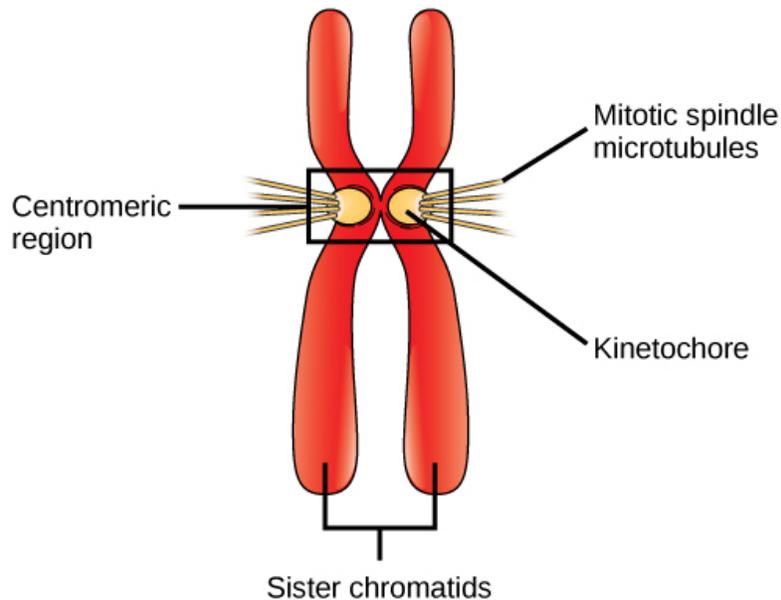


Figure 12. Organization of a replicated chromosome

During prometaphase, mitotic spindle microtubules from opposite poles attach to each sister chromatid at the kinetochores. In anaphase, the connection between the sister chromatids breaks down, and the microtubules pull the chromosomes toward opposite poles.

During **metaphase**, the “change phase,” all of the chromosomes are aligned in a plane called the **metaphase plate** midway between the two poles of the cell. The sister chromatids are still tightly attached to each other by specialized proteins called cohesin. At this time, the chromosomes are maximally condensed.

In **anaphase**, the “upward phase,” the cohesin proteins degrade, and sister chromatids separate at the centromere. Each chromatid, now called a **chromosome**, is pulled rapidly toward the centrosome to which its microtubule is attached. The cell becomes visibly elongated (oval shaped).

During **telophase**, the “distance phase,” as the mitotic spindles shorten toward their associated centrosome, the chromosomes reach opposite poles of the enlarging cell and begin to decondense (unravel), relaxing into a chromatin configuration. The mitotic spindles are then broken down and used to assemble cytoskeletal components for each daughter cell. Nuclear envelopes form around each set of chromosomes, and nucleosomes appear within the nuclear area.

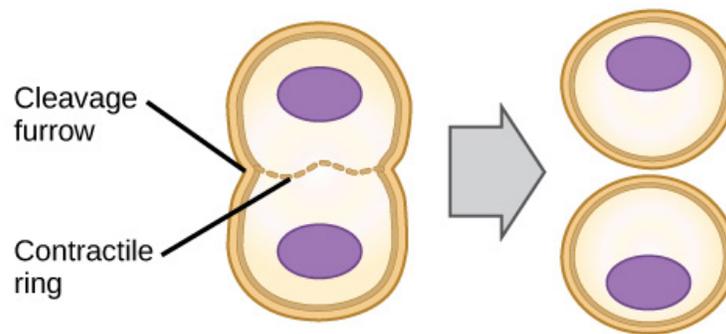
Source Material

OpenStax, The Cell Cycle. OpenStax CNX. Jun 5, 2013 <http://cnx.org/contents/d6d279e4-eb7a-4e64-8d53-8710b4c50e81@7>.

Cytokinesis

Cytokinesis, or “cell motion,” is the second main stage of the mitotic phase, during which cell division is completed via the physical separation of the cytoplasmic components into two daughter cells. Division is not complete until the cell components have been apportioned and completely separated into these two daughter cells.

In cells such as animal cells that lack cell walls, cytokinesis is initiated following the onset of anaphase. To begin, a contractile ring composed of actin filaments forms just inside the plasma membrane at the former metaphase plate. The actin filaments pull the equator of the cell inward, forming a fissure. This fissure, or “crack,” is called the **cleavage furrow**. The furrow deepens as the actin ring contracts, and eventually the membrane is cleaved in two (**Figure 13**).

**Figure 13. Formation of a Cleavage Furrow**

During cytokinesis in animal cells, a ring of actin filaments forms at the metaphase plate. The ring contracts, forming a cleavage furrow, which divides the cell in two.

Source Material

OpenStax, The Cell Cycle. OpenStax CNX. Jun 5, 2013 <http://cnx.org/contents/d6d279e4-eb7a-4e64-8d53-8710b4c50e81@7>.

Meiosis

Without mutation, or changes in the DNA, the daughter cells produced by mitosis receive a set of genetic instructions that is identical to that of the parent cell. Because changes in genes drive both the unity and diversity of life, organisms without genetic variation cannot evolve through natural selection. Evolution occurs only because organisms have developed ways to vary their genetic material. This occurs through mutations in DNA, recombination of genes during **meiosis**, and meiosis followed by fertilization in sexually reproducing organisms.

Sexual reproduction requires that **diploid** ($2n$) organisms produce **haploid** ($1n$) cells through meiosis and that these haploid cells fuse to form new, diploid offspring. The union of these two

haploid cells, one coming from each parent, is **fertilization**. Although the processes of meiosis and mitosis share similarities, their end products are significantly different. Recall that eukaryotic DNA is contained in chromosomes, and that chromosomes occur in **homologous pairs (homologues)**. At fertilization, the male parent contributes one member of each homologous pair to the offspring, and the female parent contributes the other. With the exception of the sex chromosomes, homologous chromosomes contain the same genes, but these genes can have different versions, called **alleles**. For example, you might have inherited an allele for brown eyes from your father and an allele for blue eyes from your mother. Similar to the preparation for mitosis, homologous chromosomes are duplicated during the S-stage (synthesis) of interphase. However, unlike mitosis, in which there is just one nuclear division, meiosis has two complete rounds of nuclear division—meiosis I and meiosis II. These result in four nuclei and (usually) four daughter cells, each with half of the original number of chromosomes as the parent cell ($1n$). The first division, **meiosis I**, separates homologous chromosomes, and the second division, **meiosis II**, separates sister chromatids. Each of these phases is shown in **Figure 14** and described in further detail below.

Stage	Event	Outcome
INTERPHASE	<p>S phase</p> <p>Centrosomes (with centriole pairs) Nuclear envelope Chromatin</p>	Chromosomes are duplicated during interphase. The resulting sister chromatids are held together at the centromere. The centrosomes are also duplicated.
	<p>Prophase I</p> <p>Sister chromatids Spindle Chiasmata Tetrad</p>	Chromosomes condense, and the nuclear envelope fragments. Homologous chromosomes bind firmly together along their length, forming a tetrad. Chiasmata form between non-sister chromatids. Crossing over occurs at the chiasmata. Spindle fibers emerge from the centrosomes.
MEIOSIS I	<p>Prometaphase I</p> <p>Centromere (with kinetochore)</p>	Homologous chromosomes are attached to spindle microtubules at the fused kinetochore shared by the sister chromatids. Chromosomes continue to condense, and the nuclear envelope completely disappears.
	<p>Metaphase I</p> <p>Microtubule attached to kinetochore Metaphase plate</p>	Homologous chromosomes randomly assemble at the metaphase plate, where they have been maneuvered into place by the microtubules.
	<p>Anaphase I</p> <p>Sister chromatids remain attached Homologous chromosomes separate</p>	Spindle microtubules pull the homologous chromosomes apart. The sister chromatids are still attached at the centromere.
	<p>Telophase I and Cytokinesis</p> <p>Cleavage furrow</p>	Sister chromatids arrive at the poles of the cell and begin to decondense. A nuclear envelope forms around each nucleus and the cytoplasm is divided by a cleavage furrow. The result is two haploid cells. Each cell contains one duplicated copy of each homologous chromosome pair.
	<p>Prophase II</p>	Sister chromatids condense. A new spindle begins to form. The nuclear envelope starts to fragment.
MEIOSIS II	<p>Prometaphase II</p>	The nuclear envelope disappears, and the spindle fibers engage the individual kinetochores on the sister chromatids.
	<p>Metaphase II</p>	Sister chromatids line up at the metaphase plate.
	<p>Anaphase II</p> <p>Sister chromatids separate</p>	Sister chromatids are pulled apart by the shortening of the kinetochore microtubules. Non-kinetochore microtubules lengthen the cell.
	<p>Telophase II and Cytokinesis</p> <p>Haploid daughter cells</p>	Chromosomes arrive at the poles of the cell and decondense. Nuclear envelopes surround the four nuclei. Cleavage furrows divide the two cells into four haploid cells.

Figure 14. Phases of Meiosis.

An animal cell with a diploid number of four ($2n = 4$) proceeds through the stages of meiosis to form four haploid daughter cells.

Source Material

OpenStax, The Process of Meiosis. OpenStax CNX. Jun 13, 2017 <http://cnx.org/contents/198652dc-30cf-4065-9bbf-80fe4e1f123b@9>.

Meiosis I

Just like mitosis, **meiosis** is preceded by an **interphase** consisting of the G_1 , S, and G_2 phases, which are nearly identical to the phases preceding mitosis. The G_1 phase is the first phase of the interphase and is focused on cell growth. The S phase is the second phase, during which the DNA of the chromosomes is replicated. During DNA duplication, each chromosome is replicated to produce two identical copies, called **sister chromatids**, that are held together at the centromere by cohesin proteins (**Figure 14**). Cohesin holds the chromatids together until anaphase II. The centrosomes also replicate. This prepares the cell to enter prophase I, the first meiotic phase. Finally, the G_2 phase occurs when the cell undergoes the final preparations for meiosis.

Source Material

OpenStax, The Process of Meiosis. OpenStax CNX. Jun 13, 2017 <http://cnx.org/contents/198652dc-30cf-4065-9bbf-80fe4e1f123b@9>.

Prophase I

Early in **prophase I**, before the chromosomes can be seen clearly, homologous chromosomes are attached at their tips to the nuclear envelope by proteins. As the nuclear envelope begins to break down, these proteins bring the chromosome pairs close to each other. The tight pairing of the homologous chromosomes is called **synapsis** (**Figure 15**). In synapsis, the genes on the chromatids of the homologous chromosomes are aligned with each other. This organization supports the exchange of chromosomal segments between non-sister homologous chromatids, in a process called **crossing over**. Crossing over can be observed visually after the exchange as **chiasmata** (singular: **chiasma**) (**Figure 16**). At the end of prophase I, these pairs of homologues are called **tetrads** because the four sister chromatids of each pair of homologous chromosomes are now visible (**Figure 15**).

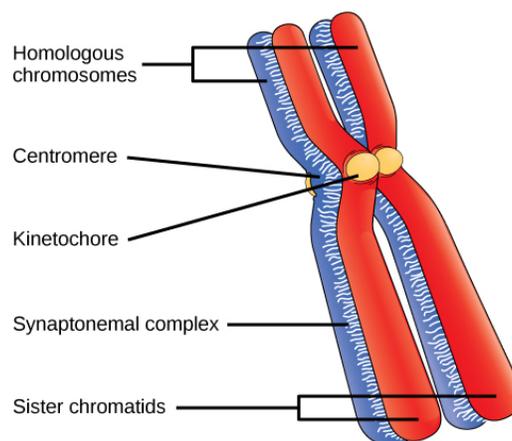


Figure 15. Homologous Pair of Chromosomes in Prophase I

Early in prophase I, homologous chromosomes come together to form a synapse. The chromosomes are bound tightly together and in perfect alignment by a protein lattice called a synaptonemal complex and by cohesin proteins at the centromere.

The crossover events are the first source of genetic variation in the nuclei produced by meiosis. A single crossover event between homologous non-sister chromatids leads to a reciprocal exchange of equivalent DNA between a maternal chromosome and a paternal chromosome. Then, when that sister chromatid is moved into a gamete cell, it will carry some DNA from one parent and some DNA from the other parent. The sister recombinant chromatid has a combination of maternal and paternal genes that did not exist before the crossover. Multiple crossovers in an arm of the chromosome have the same effect, exchanging segments of DNA to create recombinant chromosomes.

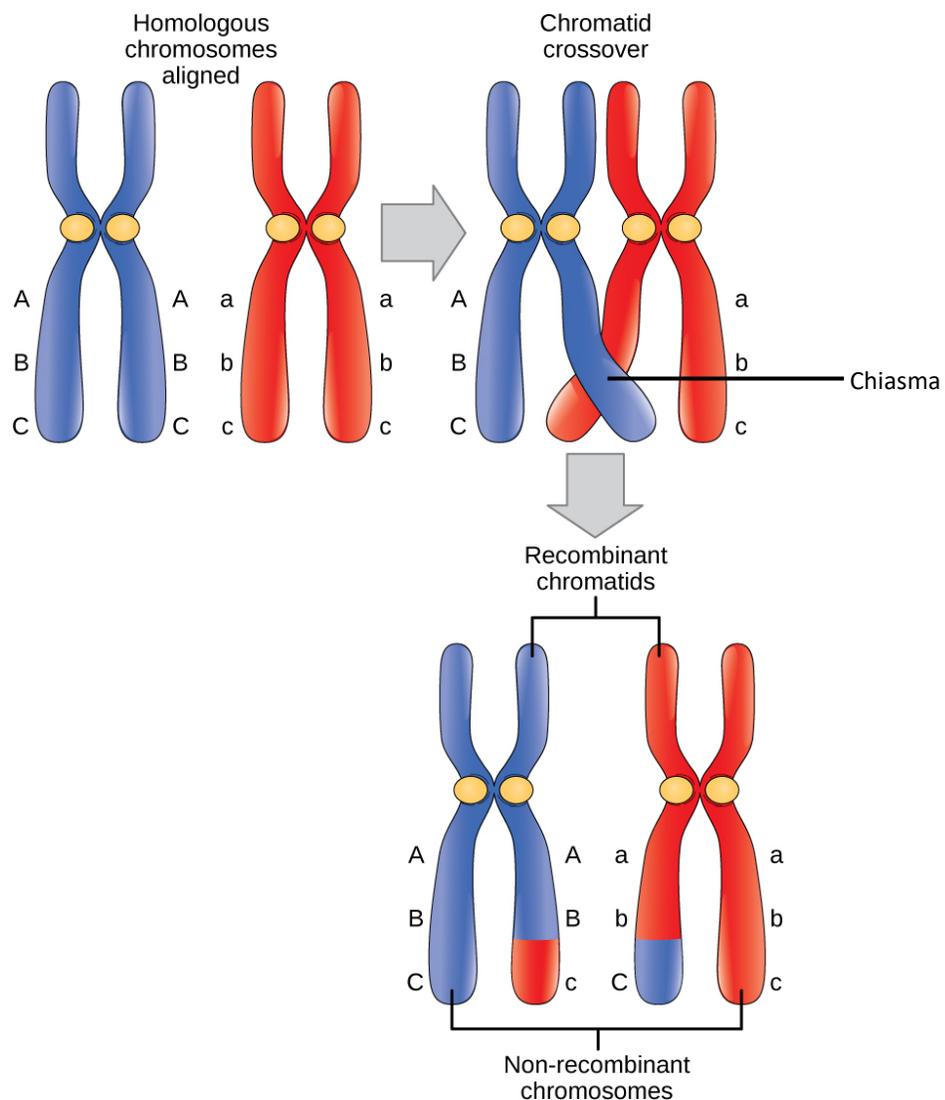


Figure 16. Crossover Occurring Between Non-Sister Chromatids of Homologous Chromosomes

The result of this interaction is an exchange of genetic material between homologous chromosomes. Here, think of the blue chromosomes representing paternal DNA and the red as representing maternal DNA.

Source Material

OpenStax, The Process of Meiosis. OpenStax CNX. Jun 13, 2017 <http://cnx.org/contents/198652dc-30cf-4065-9bbf-80fe4e1f123b@9>

Prometaphase I

The key event in **prometaphase I** is the attachment of the spindle fiber microtubules to the kinetochore proteins at the centromeres of each chromosome. As in mitosis, microtubules grow from centrosomes placed at opposite poles of the cell. The microtubules move toward the middle of the cell and attach to one of the two fused homologous chromosomes. With each member of the homologous pair attached to opposite poles of the cell, in the next phase, the microtubules can pull the homologous pair apart. At the end of prometaphase I, the nuclear membrane has broken down entirely.

Source Material

OpenStax, The Process of Meiosis. OpenStax CNX. Jun 13, 2017 <http://cnx.org/contents/198652dc-30cf-4065-9bbf-80fe4e1f123b@9>.

Metaphase I

During **metaphase I**, the homologous chromosomes are arranged in the center of the cell with the kinetochores facing opposite poles. The homologous pairs orient themselves randomly at the equator. This is important in determining the genes carried by a gamete, as each will only receive one of the two homologous chromosomes. Recall that homologous chromosomes are not identical; they contain slight differences in their genetic information, causing each gamete to have a unique genetic makeup. This event—the random assortment of homologous chromosomes at the metaphase plate—is the second mechanism that introduces variation into gametes.

Source Material

OpenStax, The Process of Meiosis. OpenStax CNX. Jun 13, 2017 <http://cnx.org/contents/198652dc-30cf-4065-9bbf-80fe4e1f123b@9>.

Anaphase I

In **anaphase I**, the microtubules pull the linked chromosomes apart. The sister chromatids remain tightly bound together at the centromere though. The chiasmata are broken in anaphase I as the microtubules attached to the fused kinetochores pull the homologous chromosomes apart and towards opposite poles of the cell (**Figure 17**).

Source Material

OpenStax, The Process of Meiosis. OpenStax CNX. Jun 13, 2017 <http://cnx.org/contents/198652dc-30cf-4065-9bbf-80fe4e1f123b@9>.

Telophase I and Cytokinesis

In **telophase I**, the separated chromosomes arrive at opposite poles and the remainder of the typical telophase events generally occur, depending on the species. In nearly all species of animals, **cytokinesis** separates the cell contents via a cleavage furrow.

Two haploid cells are the end result of this first meiotic division. The cells are haploid because at each pole, there is just one of each pair of the homologous chromosomes. Therefore, only one full set of the chromosomes is present in each daughter cell. This is why the cells are considered haploid—there is only one chromosome set, even though each homolog still consists of two sister chromatids. Recall that sister chromatids are merely duplicates of one of the two homologous chromosomes (except for the changes that occurred during crossing over). In meiosis II, these two sister chromatids will separate, creating four haploid daughter cells.

Source Material

OpenStax, The Process of Meiosis. OpenStax CNX. Jun 13, 2017 <http://cnx.org/contents/198652dc-30cf-4065-9bbf-80fe4e1f123b@9>.

Meiosis II

In some species, cells enter a brief interphase, or **interkinesis**, before entering **meiosis II**. Interkinesis lacks an S phase, so chromosomes are not duplicated. The two cells produced in meiosis I go through the events of meiosis II in synchrony. During meiosis II, the sister chromatids within the daughter cells separate, forming four new haploid gametes. The mechanics of meiosis II are similar to mitosis, except that each dividing cell has only one set of homologous chromosomes.

Source Material

OpenStax, The Process of Meiosis. OpenStax CNX. Jun 13, 2017 <http://cnx.org/contents/198652dc-30cf-4065-9bbf-80fe4e1f123b@9>.

Prophase II

At the beginning of **prophase II**, if the chromosomes decondensed in telophase I, they will condense again. If nuclear envelopes were formed, they fragment into vesicles. If centrosomes were duplicated during interkinesis, they will move away from each other toward opposite poles, and new spindles form. If centrosomes were not duplicated though, the remaining centrosomes from meiosis I will simply split and migrate to opposite poles of the cells.

Source Material

OpenStax, The Process of Meiosis. OpenStax CNX. Jun 13, 2017 <http://cnx.org/contents/198652dc-30cf-4065-9bbf-80fe4e1f123b@9>.

Prometaphase II

In **prometaphase II**, the nuclear envelopes are completely broken down, and the spindle is fully formed. Each sister chromatid forms an individual kinetochore that attaches to microtubules from opposite poles.

Source Material

OpenStax, The Process of Meiosis. OpenStax CNX. Jun 13, 2017 <http://cnx.org/contents/198652dc-30cf-4065-9bbf-80fe4e1f123b@9>.

Metaphase II

In **metaphase II**, sister chromatids are maximally condensed and aligned at the equator of the cell.

Source Material

OpenStax, The Process of Meiosis. OpenStax CNX. Jun 13, 2017 <http://cnx.org/contents/198652dc-30cf-4065-9bbf-80fe4e1f123b@9>.

Anaphase II

In **anaphase II** the sister chromatids are pulled apart by the kinetochore microtubules and move toward opposite poles (**Figure 17**).

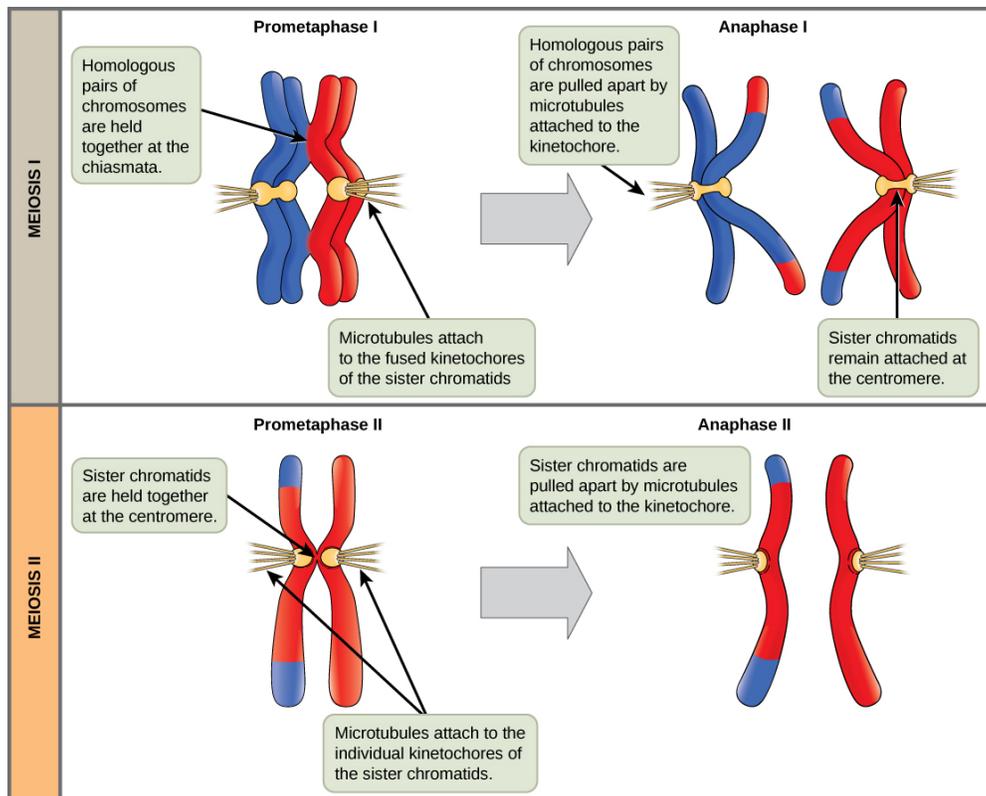


Figure 17. Chromosome Alignment Differs Between Meiosis I and Meiosis II.

In prometaphase I, microtubules attach to the fused kinetochores of homologous chromosomes, and the homologous chromosomes are arranged at the midpoint of the cell in metaphase I. In anaphase I, the homologous chromosomes are separated. In prometaphase II, microtubules attach to the kinetochores of sister chromatids, and the sister chromatids are arranged at the midpoint of the cells in metaphase II. In anaphase II, the sister chromatids are separated.

Source Material

OpenStax, The Process of Meiosis. OpenStax CNX. Jun 13, 2017 <http://cnx.org/contents/198652dc-30cf-4065-9bbf-80fe4e1f123b@9>.

Telophase II and Cytokinesis

During **telophase II** of meiosis, the chromosomes arrive at opposite poles and begin to decondense. Nuclear envelopes form around these chromosomes and cytokinesis separates the two cells into four unique haploid cells. At this point, the newly formed nuclei are both haploid. The cells produced are genetically unique because of the random assortment of paternal and maternal homologs and because of the recombining of maternal and paternal segments of chromosomes (with their sets of genes) that occurs during crossing over.

Source Material

OpenStax, The Process of Meiosis. OpenStax CNX. Jun 13, 2017 <http://cnx.org/contents/198652dc-30cf-4065-9bbf-80fe4e1f123b@9>.

Pre-Assessment

1. What are the primary functions of the female reproductive system? How does this compare to the male reproductive system?
2. Compare mitosis and meiosis.

Equipment List & Setup – Female Anatomy

Equipment List

- Models and charts of the female reproductive system
- Microscope
- Prepared slides or histological images of:
 - Ovary
 - Uterus
- Charts and models of human development

Equipment Setup

Identify the location of the necessary equipment needed to complete the activities. Models will be spread throughout the lab, so familiarize yourself to their locations.

Activities – Anatomy

In this exercise, you will study the anatomy and organization of the female reproductive system. This activity contributes to Learning Objectives 1-5 and 10, which were identified at the beginning of the section.

Part 1: Overview of the Female Reproductive System

Procedure

1. Look at the charts and models of the female reproductive system for a general orientation and compare them to Figures 1 and 2 from the Background material. Locate the following structures:
 - a. Ovary
 - b. Uterine (fallopian) tube
 - c. Uterus
 - d. Vaginal canal
 - e. Clitoris
 - f. Labia minora (singular, *labium minus*)
 - g. Labia majora (singular, *labium majus*)

Part 2: Ovaries

Procedure

1. Examine a model of the **ovary** and compare it to Figures 1 and 2 from the Background. The **ovaries** are the paired gonads, located within the pelvic cavity of a female.
2. These organs produce **oocytes**, which are released from during the process of **ovulation**. Locate the presence of any oocytes in Figure 2 (small circles in the ovary) and on the model.
3. Using the above figures and models, identify the **uterine (fallopian)** tube, which lead away from each ovary. This structure will carry oocytes from the ovary and into the **uterus** during ovulation.

Part 3: Microanatomy of the Ovaries

Procedure

1. Obtain a prepared slide or a histological section of the ovary. If using a microscope, observe the sample on low power.
2. Using the slide or provided image, locate the **medulla**, the highly vascularized tissue in the middle of each ovary. Once identified, look for circular structures within this region. These circles are **ovarian follicles**.
3. Locate the **primordial follicles** in your preparation and compare them to the follicles shown in Figure 4 from the Background material. These follicles contain **primary oocytes**, while more mature follicles will have **secondary oocytes**.

4. Now observe your slide under high magnification. Using your prepared sample or image, locate the **primary, secondary, and tertiary follicles**. Some follicles may contain oocytes. Primary follicles will have a single layer of follicular cells surrounding an oocyte; secondary follicles will have multiple layers of follicular cells surrounding an oocyte; tertiary follicles contain significant amounts of fluid in the region known as the **antrum**. Compare what you see to Figure 4.
5. Using your sample and Figure 4, try to identify a **mature ovarian (Graafian) follicle**; these will be the largest follicles present.
6. Draw an example of what you see on a clean sheet of paper. Then, photograph, upload, and annotate your drawing in the provided space below.
7. After ovulation, the remains of the mature follicle develop into the **corpus luteum**. If pregnancy does not occur, the corpus luteum decreases in size, giving rise to the **corpus albicans**. Examine your preparation of the ovary and identify these two structures. Compare what you see to what is shown in Figure 4.

Part 4: Uterine (Fallopian) Tubes

Procedure

1. Examine a model of the reproductive system and locate the **uterine (fallopian) tube(s)**. Compare each model to Figures 1 and 2 from the Background section.
2. On the model and in the figures, identify the **fimbriae**, small fringe-like structures on the distal region of the tube, located closest to the ovaries. These finger-like projections attach to the expanded region of the tube known as the **infundibulum**.
3. Follow the uterine tube as it extends toward the uterus. Just proximal to the infundibulum is an enlarged region known as the **ampulla**. This region will continue and give rise to the narrowest portion of the tube, known as the **isthmus**. Locate and identify these three regions on the model and in Figure 2.

Part 5: Uterus

Procedure

1. Examine a model of the **uterus** and compare it to Figures 2 and 6 from the Background material.
2. The uterus is a pear-shaped organ with a domed **fundus**; a **body**; and an inferior end known as the **cervix**. Identify each of these regions on the model. The cervix is the cylindrical portion of the uterus, where it connects to the vagina.
3. Locate where the uterine tubes enter the uterus. This junction occurs where the fundus meets the body of the uterine wall.
4. The uterine wall consists of three layers of tissue. Using the model and Figure 6, identify the outer **perimetrium**, the **myometrium**, and the innermost (deepest) **endometrium**. Whereas the perimetrium forms the serosa of the uterus, the myometrium will make up the bulk of the thick middle, smooth muscle layer. The endometrium forms the mucosa of the uterus.

Part 6: Microanatomy of the Uterus

Procedure

1. Obtain a prepared slide or a histological section of the uterus. If using a microscope, observe the sample on low power.
2. Using the slide or provided image, locate the three layers of the uterus that were identified in Part 5 above. Compare what you see to Figure 2 from the Background.
3. Now, examine the endometrium under higher power magnification. You should be able to identify two layers, including the **functional layer** and the **basal layer**. The functional layer will be the more superficial layer that is shed during **menstruation**, while the basal layer is deeper and will be retained.
4. Using the same preparation or image, locate the myometrium. This layer will sit just deep to the endometrial tissue and it can be distinguished by the presence of smooth muscle.
5. Draw an example of what you see on a clean sheet of paper and label your drawing.

Part 7: The Ligaments

The uterus and ovaries are suspended within the pelvic cavity by a number of connective tissue sheaths, called **ligaments**.

Procedure

1. Examine a model of the female reproductive system. Try to identify the fibrous ligaments that extend from the ovaries and uterus.
2. Locate the **broad ligament**, which anchors the uterus to the lateral pelvic wall. Also using the model and Figures 1 and 2 from the Background section, identify the **mesosalpinx**, a portion of the broad ligament that helps connect the ovary to the uterine tube.
3. The **round ligament** attaches the uterus to the anterior body wall, at about the level of the inguinal canal. Try to locate this structure on a model; a model showing a sagittal view of the system may be required for this observation.
4. Use the model to locate the **ovarian** and **suspensory ligaments**. The ovarian ligament attaches the ovary to the uterus directly, while the suspensory ligament attaches each ovary to the lumbar region.
5. Identify each of these ligaments in Figure 2 and compare what you see to what you observed on the model.

Part 8: Vagina

Procedure

1. Obtain a model of the **vagina** and compare it to what you see in Figures 2 and 7 from the Background. The vagina is about 8-10 cm long and it is located between the urethra on the anterior side, and the rectum, which sits posteriorly.
2. Once you locate the vagina, identify the **vaginal canal** and the **vaginal orifice**. The vaginal canal is a tough, muscular tube that meets the cervix at a region known as the **fornix** and extends to the opening of the vagina (vaginal orifice).
3. Using the model and Figure 7, identify the **vaginal rugae**, lateral ridges that line the vaginal canal.

Part 9: The External Genitalia

The external reproductive structures of the female are called the external genitalia and they are collectively referred to as the **vulva**.

Procedure

1. Use the provided models and Figures 1 and 9 from the Background material to locate and observe the external anatomy of the female. Located at the anterior end of the vulva you can find the **mons pubis**. This structure consists of an adipose pad that overlies the pubic symphysis in females.
2. Posterior to the mons pubis is the **clitoris**, a cylinder of erectile tissue that embeds into the wall of the body cavity and terminates anterior to the urethral orifice as the **glans clitoris**. The body of the clitoris is curved, while the glans is the terminal portion, as can be found on the model and in Figure 9.
3. Using the model and Figure 9, identify the **prepuce** of the vagina, an extension of the labia minora. This structure encloses the glans of the clitoris.
4. Posterior to the clitoris is the external urethral orifice and posterior to this structure is the vaginal orifice. The vaginal orifice is also partially enclosed by the **hymen**, a mucous membrane. Identify each of these structures on the provided models and figures.
5. Locate the labia minora and labia major externally. These structures sit laterally to the vaginal orifice. Using the models and Figure 9, identify the **vestibule**, the space separating the two labia.

Part 10: The Breast

The primary structure of the breast is derived from the integumentary system, but the role of the breast in reproduction is important as a source of nourishment for offspring.

Procedure

1. Observe the external anatomy of the breast on the provided models and Figure 10 within the Background. The major external features of the breast include the pigmented

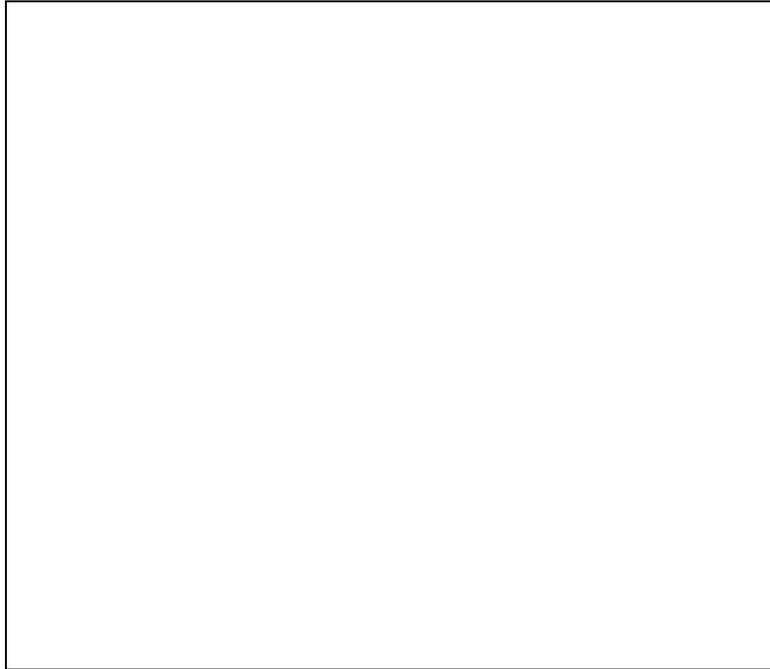
areola, the protruding **nipple**, the **body** of the breast, and the **axillary tail**. Identify each of these structures in the provided materials.

2. Use the provided models and charts to locate the internal structures of the breast. Much of the breast is composed of adipose tissue and embedded **mammary glands**. These glands are responsible for producing milk in lactating females.
3. Identify the mammary gland and the following associated structures on the figure and compare them to Figure 10. Each gland consists of clusters of 15-20 **lobes**. Each lobe contains groups of milk-secreting cells in clusters called **alveoli**. These clusters can change in size depending on the amount of milk in the alveolar lumen. In nursing females, the mammary glands increase in size and lead to **lactiferous ducts**, which collect and direct milk to the **lactiferous sinuses**. Together, the ducts and sinuses collect and direct milk to exit the breast through the nipple.

Analysis

Microanatomy of the ovary

Draw what you see as you observe the microanatomy of the ovary. You should include the primary, secondary, tertiary, and mature (Graafian) follicles.



Check your understanding

1. The _____ is the inner epithelial lining of the uterus.
2. A follicle is comprised of _____ cells, _____ cells, and the _____.
3. The finger-like structures on the fallopian tube that help sweep the ovum into the ampulla are called _____.
4. The layer of cells surrounding the ovulated ovum are called the _____.
5. The _____ holds the uterus and ovaries in place within the body.
6. The _____ separates the uterus from the vagina.
7. The _____ is the layer of the endometrium that is shed every month.

Equipment List & Setup – Mitosis and Meiosis

Equipment List

- Charts and models of mitosis
- Charts and models of meiosis
- 5 Single pipe cleaners, blue
- 3 Double pipe cleaners, blue (form X's)
- 5 Single pipe cleaners, pink
- 3 Double pipe cleaners, pink (form X's)
- 1 Mitosis sheet
- 1 Meiosis sheet
- 1 Summary sheet

Equipment Setup

Identify the location of the necessary equipment needed to complete the activities. Models will be spread throughout the lab, so familiarize yourself to their locations.

Activities – Mitosis and Meiosis

In this exercise, you will study the sequence of events that occur during the processes of cell division. Whereas mitosis consists of a single round of cell division, giving rise to two identical daughter cells, meiosis involves two rounds of division which result in four, genetically unique sex cells. This activity contributes to each of the Learning Objectives 6, 7, and 10, which were identified at the beginning of the section.

Part 1: Mitosis

Mitosis is a continuous event that is divided into four distinct phases. During this process, cellular division of genetic material is completed, producing two identical **daughter cells**. The four phases of mitosis include **prophase**, **metaphase**, **anaphase**, and **telophase**.

Procedure

1. **Interphase** is a stage in a cell's life when a cell undergoes growth and replication of DNA. This is a period when the cell also prepares to undergo division through the process of mitosis. During this phase, cells have distinct nuclei, with the genetic information dispersed in the nucleus as **chromatin**. Using the provided models and diagrams, identify a cell that is in interphase.
2. Using the provided models and diagrams, study the four phases of mitosis. As you study these stages, make sure that you identify the major structural changes and components that occur. You should be able to observe the events described below:
 - a. **Prophase** – chromatin thicken and condense, presence of mitotic apparatus, spindle fibers extending (may not be visible)
 - b. **Metaphase** – chromosomes are aligned along the **metaphase plate** (at the midline of the cell)
 - c. **Anaphase** – **chromatids** separate at the **centromere** and are pulled to opposite poles of the cell
 - d. **Telophase** – chromosomes are at opposite poles of the cell, chromosomes begin to unwind, and nuclear envelopes begin to reform
3. At the end of mitosis, a cell's cytoplasm must split into two parts, in a stage known as **cytokinesis**. A constriction around a cell's midline, known as a **cleavage furrow**, will be visible during this stage of division. Use the provided images and diagrams to identify a cell going through this stage. As this constriction tightens, the stage will result in two identical daughter cells. At this point, the cytoplasm and other organelles are effectively divided between the two resulting cells.
4. Examine a slide of whitefish blastula and look for the phases of mitosis in the preparation. If a prepared slide is not available, observe a set of images instead.
5. On a clean sheet of paper or in the Analysis section that follows, draw an example of what you see during interphase and each phase of mitosis. Then photograph, upload and annotate your drawing in Lt. You should include and label any important structures and changes in your drawing.

Part 2: Meiosis

Although the processes of meiosis and mitosis share similarities, their end products are different. Unlike mitosis, in which there is just one nuclear division, **meiosis** has two complete rounds of nuclear division—**meiosis I** and **meiosis II**. Together, the events of meiosis I and II give rise to four daughter cells, each with half the number of chromosomes as the parent cell. The first division, meiosis I, separates **homologous chromosomes**, and the second division, meiosis II, separates **sister chromatids**.

Procedure

1. Similar to mitosis, **meiosis** is preceded by an **interphase** consisting of the G₁, S, and G₂ phases. During DNA replication in the S phase, each chromosome is replicated to produce two identical copies, called **sister chromatids**, that are held together at the centromere. This prepares the cell to enter **prophase I**, the first meiotic phase. Using the provided models and diagrams, identify a cell that is in interphase.
2. Using the provided models and diagrams, study the eight phases of meiosis. As you study these stages, make sure that you identify the major structural changes and components that occur. You should be able to observe the events described below:
 - a. **Prophase I** – chromatin thicken and condense, nuclear envelope breaks down, presence of mitotic apparatus, spindle fibers extending (may not be visible), **homologous chromosomes (homologues)** pair up. Cross-over events may be seen as **chiasmata**.
 - b. **Metaphase I** – homologous pairs of chromosomes align along the **metaphase plate** (at the midline of the cell).
 - c. **Anaphase I** – homologues separate and are pulled to opposite poles of the cell.
 - d. **Telophase I** – chromosomes are at opposite poles of the cell, chromosomes begin to unwind, and nuclear envelopes begin to reform. Cytokinesis usually occurs at the same time as telophase I, forming two haploid daughter cells.
 - e. **Prophase II** – chromosomes thicken and condense, nuclear envelope breaks down, presence of mitotic apparatus, spindle fibers extend (may not be visible). Microtubules attach to each sister chromatid.
 - f. **Metaphase II** – chromosomes align along the **metaphase plate** (at the midline of the cell).
 - g. **Anaphase II** – sister chromatids separate at the **centromere** and are pulled to opposite poles of the cell.
 - h. **Telophase II** – chromosomes are at opposite poles of the cell, chromosomes begin to unwind, and nuclear envelopes begin to reform. Cytokinesis splits the chromosome sets into new cells, forming the final products of meiosis: four haploid cells in which each chromosome has just one chromatid.
6. On a clean sheet of paper or in the Analysis section that follows, draw an example of what you see during interphase and each phase of meiosis. Then photograph, upload

and annotate your drawing in Lt. You should include and label any important structures and changes in your drawing.

Part 3: Comparing Mitosis and Meiosis

Although the processes of meiosis and mitosis share similarities, their end products are different. In part 3, you will be modeling the processes of mitosis and meiosis. This will help you visualize critical differences between these two division processes.

Procedure

1. Locate all of your pipe cleaner chromosomes. Familiarize yourself with what each pipe cleaner represents.
 - a. Single, blue pipe cleaners – one chromosome inherited from the father
 - b. Double, blue pipe cleaners – one duplicated chromosome from the father, held together by the **centromere**
 - c. Single, pink pipe cleaners – one chromosome inherited from the mother
 - d. Double, pink pipe cleaners – one duplicated chromosome from the mother, held together by the centromere
 - e. Based upon the supplies that you were given, what is the diploid number ($2n$) of this organism? _____

Carry out each of the following steps from memory and understanding so far; think of each stage as a frame in a movie film of the process:

2. Arrange the pieces on the **Mitosis** sheet, showing the essential chromosome arrangements that occur during this process. Note: you won't need all of the pieces for this part.
3. Copy the arrangements of chromosomes that you modeled in step 2 onto your Summary sheet. Use colored pencils to help represent maternal vs. paternal chromosomes.
4. Photograph, upload and annotate your chromosome arrangement into Lt. You should include and label any important structures and changes in your drawing.
5. Remove all pieces and proceed to arrange them on the two **Meiosis** sheets, with the Meiosis I sheet placed above the Meiosis II sheet, so that the arrows flow sheet-to-sheet. Remember to show the essential differences between mitosis and meiosis. Note: You should use all of the pieces for meiosis.
6. Copy the arrangements of chromosomes that you modeled in step 5 onto your Summary sheet. Use colored pencils to help represent maternal vs. paternal chromosomes. Also, photograph, upload and annotate your chromosome arrangement into Lt. You should include and label any important structures and changes in your drawing.
7. Once completed, count all pieces back into the provided container.

Analysis

Stages of Mitosis

Draw what you see as you observe the different stages of mitosis. You should include and label any important structures and changes in your drawing.

Interphase	Prophase	Metaphase	Anaphase	Telophase	Cytokinesis

Stages of Meiosis

Draw what you see as you observe the different stages of meiosis. You should include and label any important structures and changes in your drawing.

Interphase	Prophase I	Metaphase I	Anaphase I	Telophase I	Cytokinesis I

Prophase II	Metaphase II	Anaphase II	Telophase II	Cytokinesis II

Check your understanding

1. What is the primary function of mitosis?
2. What are the two main functions of meiosis?
3. What are the three main differences between mitosis and meiosis?
4. What would happen if homologous chromosomes or sister chromatids did not correctly separate during anaphase of mitosis or meiosis? What is this scenario called?

The Male Reproductive System

Introduction

In this laboratory, you will use models, diagrams and histological samples to study the anatomy of the male reproductive system. As you study this organization, remember that a male's reproductive system is responsible for not just producing male **gametes**, but also transporting for these gametes to the female reproductive tract, as well as secreting the reproductive hormone **testosterone**.

Learning Objectives

By the end of this lesson you will be able to:

1. Identify the general functions of the male's reproductive tract.
2. Identify and describe the structures and functions that contribute to the male's reproductive system. You will have to identify each on a model, diagram, or in a specimen.
3. Follow the pathway taken by sperm from its site of formation to the body's exterior.
4. Discuss the microanatomy of the structures of the male reproductive tract and explain the importance of this organization to reproduction.
5. Understand the microanatomical organization of the testis and sperm.
6. Understand, explain, and compare the processes of spermiogenesis and spermatogenesis.
 - a. Describe the roles of the nurse/Sertoli and interstitial/Leydig cells in these processes.
7. List and describe the hormones regulating the production of the sperm and identify their origin.
8. Identify the following structural and functional components of importance:

Male Reproductive System	Reproductive Microanatomy
Urethra <ul style="list-style-type: none"> • Prostatic • Membranous • Spongy (penile) 	Sperm <ul style="list-style-type: none"> • Head • Mid-piece • Tail
Ejaculatory duct	Spermatid
Vas deferens	Spermatocytes
Corpus cavernosum	Sertoli (sustenacular) cells
Corpus spongiosum	Interstitial (Leydig) cells
Seminal vesicle	
Prostate gland	Spermatogenesis
Ampulla	Spermatogonium
Bulbourethral gland	Spermatocyte

	<ul style="list-style-type: none"> • Primary • Secondary
Epididymis	Spermatid
Testis	Spermiogenesis
Glans penis	Sperm
Prepuce	Sertoli and Leydig cells
Spermatic cord	
Rete testis	Hormones
Seminiferous tubule	Testosterone
Lobule	Luteinizing hormone
Tunica albuginea	Follicle stimulating hormone
Scrotal sac (scrotum)	
Dartos	

Background Information

Overview of the Male Reproductive System

The function of the male reproductive system is to produce **male gametes**, known as **sperm**, to transfer these to the female reproductive tract, and to secrete the hormones that support male reproductive physiology. The paired **gonads**, or gamete-producing structures, are the **testes** (singular, *testis*) and they are a crucial component of the male's reproductive system. While the testes produce both sperm and **androgens**, several accessory organs and ducts aid in the process of sperm maturation and transport of the sperm and other seminal components to the **penis**, which delivers sperm to the female reproductive tract.

The structures of the male reproductive system include the **testes**, the **epididymis**, and the **penis**, as well as the ducts and glands that produce and carry semen (**Figure 1**).

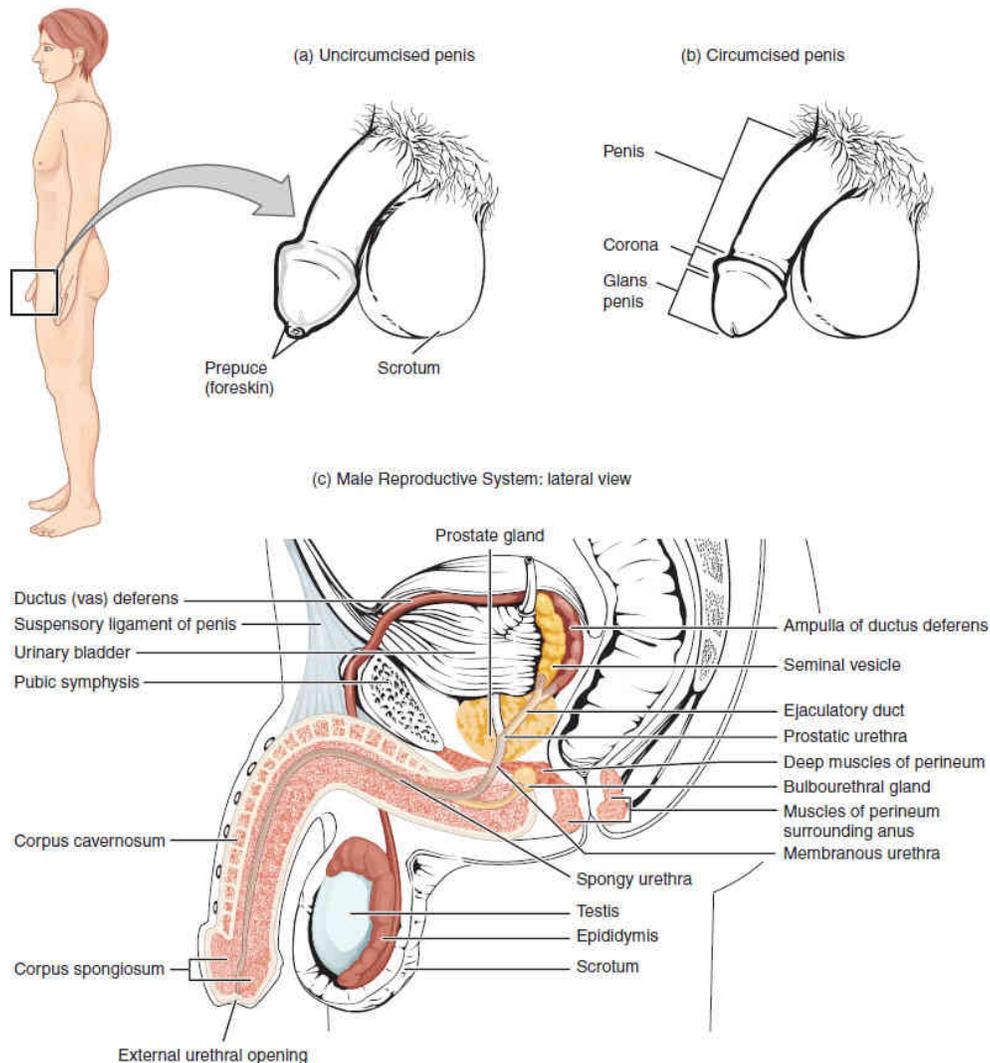


Figure 1. Structures and Organization of the Male Reproductive System

Source Material

OpenStax, 27.1 Anatomy and Physiology of the Male Reproductive System. OpenStax CNX. May 2, 2019
<http://cnx.org/contents/370d6d11-8e11-4b2b-8fa4-a70c14b0554b@13>.

Scrotum and Testes

The **testes** (singular, **testis**) are located in a skin-covered, highly pigmented, muscular sack called the **scrotum**. The scrotum extends from the body behind the penis (**Figure 1**). This location is important to sperm production, which occurs within the testes. The scrotum helps to regulate the temperature of the testes and maintains it around 35 degrees Celsius (95 degrees Fahrenheit). Temperature control is accomplished by the smooth muscles of the scrotum moving the testes either closer to or further away from the abdomen, dependent upon the ambient temperature. This regulatory action is accomplished by the **cremaster muscle** in the abdomen and the **dartos fascia** (muscular tissue under the skin) within the scrotum.

The **dartos muscle** makes up the subcutaneous muscle layer of the scrotum (**Figure 2**). It continues internally to make up the scrotal septum, a wall that divides the scrotum into two compartments, each housing one testis. Descending from the internal oblique muscle of the abdominal wall are the two **cremaster muscles**, which cover each testis like a muscular net. By contracting simultaneously, the dartos and cremaster muscles can elevate the testes in cold weather (or water), moving the testes closer to the body and decreasing the surface area of the scrotum to retain heat. Alternatively, as the environmental temperature increases, the scrotum relaxes, moving the testes farther from the body core and increasing scrotal surface area, which promotes heat loss. Externally, the scrotum has a raised medial thickening on the surface called the raphe (**Figure 2**).

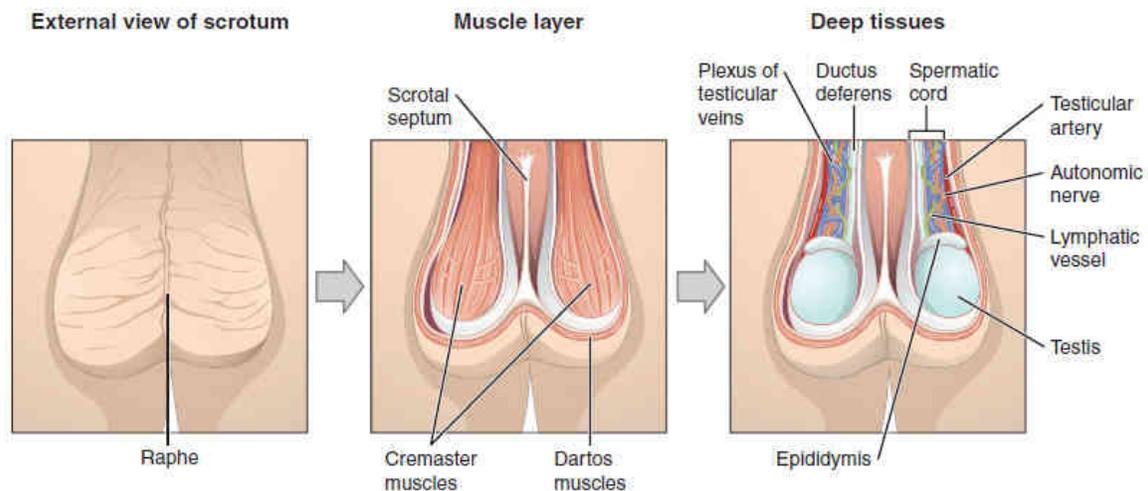


Figure 2. The Scrotum and Testes

This anterior view shows the structures of the scrotum and testes.

The **testes** are the male **gonads** —that is, the male reproductive organs. They produce both **sperm** and **androgens**, such as **testosterone**, and are active throughout the reproductive lifespan of the male.

Paired ovals, the testes are each approximately 4 to 5 cm in length and are housed within the scrotum (**Figures 1 and 2**). They are surrounded by two distinct layers of protective connective tissue (**Figure 3**). The outer **tunica vaginalis** is a double-layered serous membrane. Beneath the tunica vaginalis is the **tunica albuginea**, a tough, white, dense connective tissue layer covering the testis itself. Not only does the tunica albuginea cover the outside of the testis, it also invaginates to form septa that divide the testis into 300 to 400 structures called **seminal vesicle lobules** (or just **lobules**). Within each lobule, sperm develop in tube-like structures known as the **seminiferous tubules**.

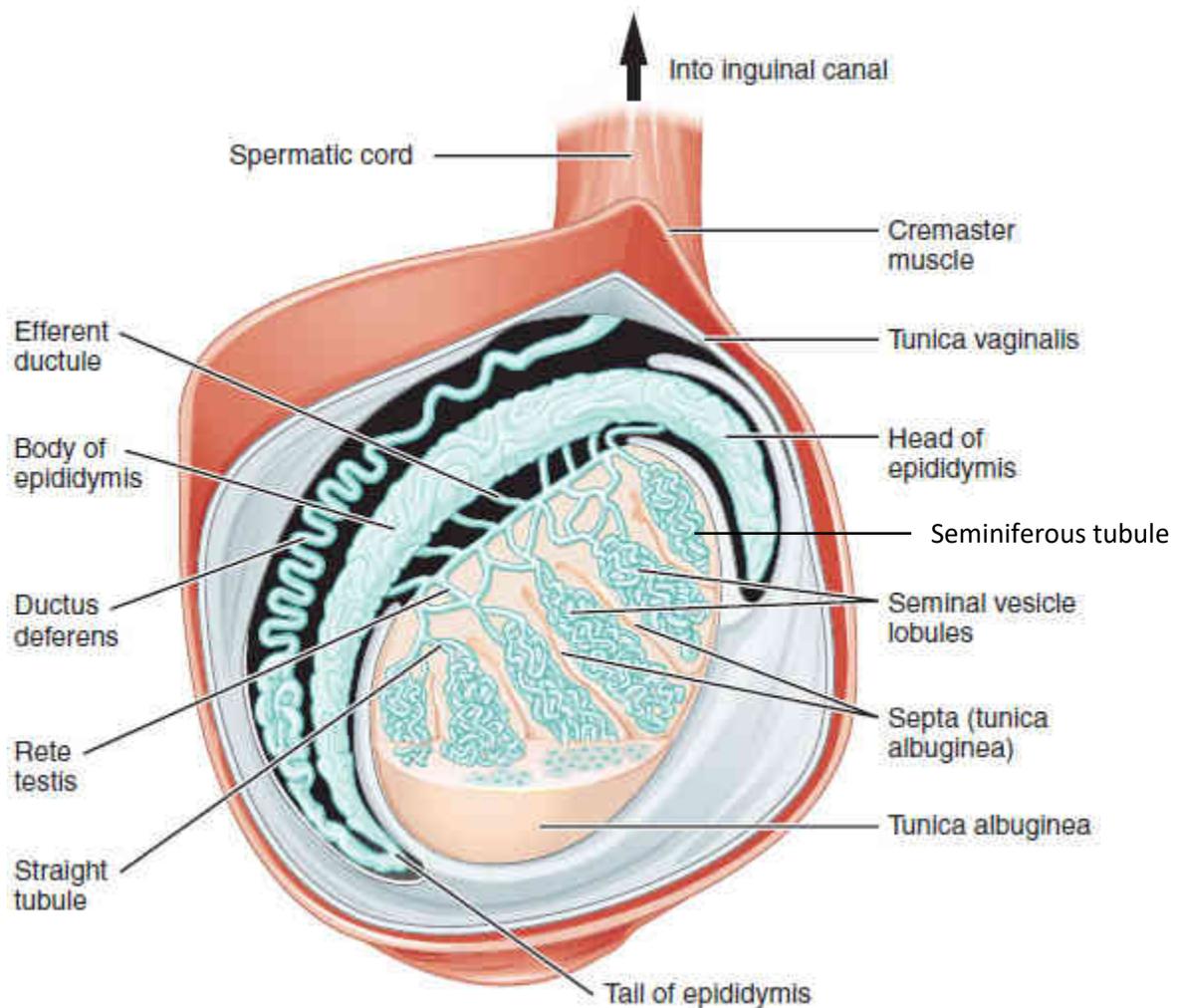


Figure 3. Anatomy of the Testis

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<http://cnx.org/contents/370d6d11-8e11-4b2b-8fa4-a70c14b0554b@13>.

Microanatomy of the Testes

The sagittal view of the testes, shown in **Figure 3**, identifies the **seminiferous tubules**, which serve as the primary site of sperm production. These tightly coiled tubules form the bulk of each testis. Each seminiferous tubule is composed of developing sperm cells surrounding a lumen, where formed sperm are released into the duct system of the testis (**Figure 4**). Specifically, from the lumens of each seminiferous tubule, sperm move into the straight tubules (or tubuli recti), and from there into a fine meshwork of tubules called the **rete testes** (**Figure 3**). Sperm leave the rete testes, and the testis itself, through the 15 to 20 efferent ductules that cross the tunica albuginea. Sperm are then transferred to the **epididymis**, where they will mature. Eventually, the sperm leave the epididymis during the process of **ejaculation** via the **ductus (vas) deferens** (**Figure 3**).

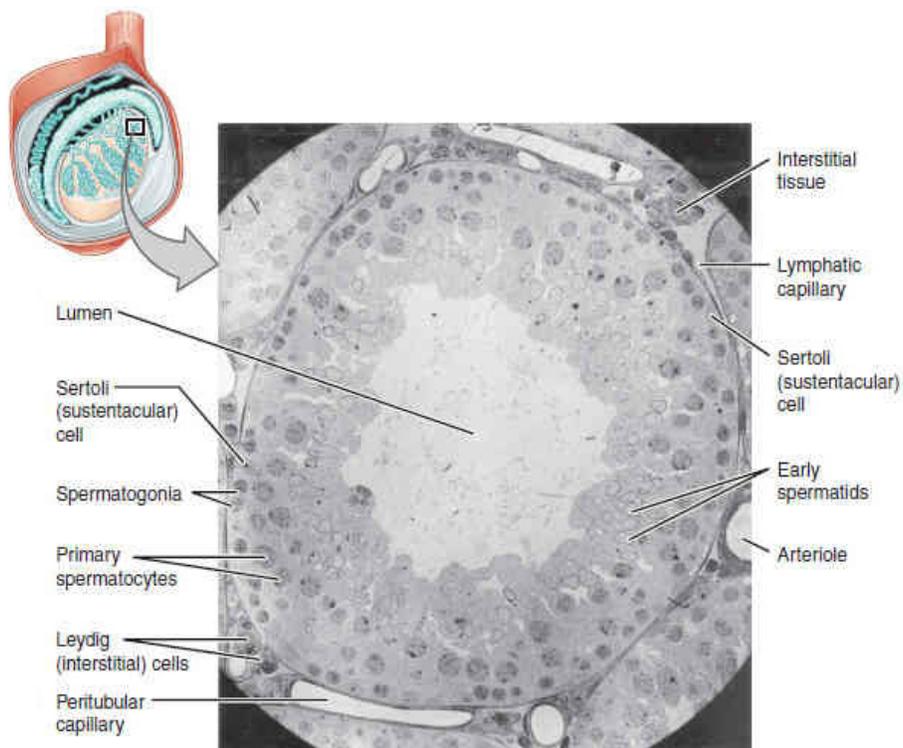


Figure 4. Histology of the Testis: Cross section of a seminiferous tubule

An electron micrograph of a cross-section of a seminiferous tubule from a rat. The lumen is the light-shaded area in the center of the image. The location of the primary spermatocytes is near the basement membrane, and the early spermatids are approaching the lumen (tissue source: rat). (Micrograph provided by the Regents of University of Michigan Medical School © 2012)

Inside the seminiferous tubules are six different cell types. These include supporting cells called **sustentacular (Sertoli) cells**, hormone producing **interstitial (Leydig) cells**, as well as five types

of developing sperm cells called **germ cells**. Germ cell development progresses from the basement membrane—at the perimeter of the tubule—toward the lumen. Let's look more closely at these cell types.

The least mature germ cells, the **spermatogonia** (singular; **spermatogonium**), line the basement membrane just inside the tubule. Spermatogonia are the stem cells of the testis, meaning that they are still able to differentiate into a variety of different cell types throughout adulthood. Spermatogonia initially divide to produce **primary** and then **secondary spermatocytes**, then **spermatids**, which will finally produce mature **sperm**. The process that begins with spermatogonia and concludes with the production of sperm is called **spermatogenesis**, which will be discussed next.

Source Material

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<http://cnx.org/contents/370d6d11-8e11-4b2b-8fa4-a70c14b0554b@13>.

Spermatogenesis

As just noted, **spermatogenesis** occurs within the seminiferous tubules of each testis (**Figures 3 and 4**). The process begins at puberty, after which time sperm are produced constantly throughout a man's life. One production cycle, from spermatogonia to mature sperm, takes approximately 64 days. A new cycle begins every 16 days, although this timing is not synchronous across all seminiferous tubules.

The process of spermatogenesis initially begins with **mitosis** of a diploid **spermatogonia** (**Figure 5**). Since these cells are **diploid (2n)**, they each have a complete copy of the father's genetic material, or 46 chromosomes. However, mature gametes are **haploid (1n)**, containing only 23 chromosomes—meaning that daughter cells of spermatogonia must undergo a second cellular division through the process of **meiosis**.

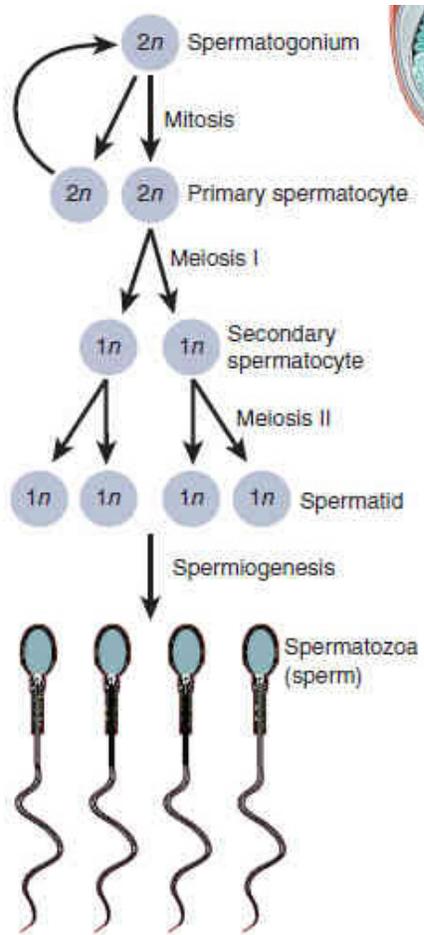


Figure 5. Spermatogenesis

Mitosis of a spermatogonial stem cell involves a single cell division that results in two identical, diploid daughter cells (spermatogonia to primary spermatocyte). Meiosis then follows and has two rounds of cell division: primary spermatocyte to secondary spermatocyte, and then secondary spermatocyte to spermatid. This produces four haploid daughter cells (spermatids).

Initially, mitosis of the spermatogonia will result in two identical diploid cells; one of these cells remains a spermatogonium, and the other becomes a **primary spermatocyte**, the next stage in the process of spermatogenesis. Unlike the process of mitosis, DNA is not replicated in a primary spermatocyte, and the cell undergoes **meiosis**, a type of cell division that separates the chromosome pairs. This division will produce two **secondary spermatocytes**. A second meiotic division of each secondary spermatocyte will result in a total of four daughter cells with only half of the original number of chromosomes. Each of these new cells is known as a **spermatid**. Although haploid, early spermatids look very similar to cells in the earlier stages of spermatogenesis, with a round shape, central nucleus, and large amount of cytoplasm (**Figure 5**).

A process called **spermiogenesis** transforms these early spermatids into mature **sperm (spermatozoa)**. This transformation occurs by reducing the amount of cytoplasm and beginning

the formation of the parts of a mature sperm. The fifth and final stage of germ cell formation—spermatozoa, or mature sperm—is the end result of this process, which occurs in the portion of the tubule nearest to the lumen. Eventually, the sperm are released into the lumen and are moved along a series of ducts in the testis toward the epididymis for the next step of sperm maturation.

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<http://cnx.org/contents/370d6d11-8e11-4b2b-8fa4-a70c14b0554b@13>.

Spermiogenesis and the Structure of a Mature Sperm

Sperm are smaller than most cells in the body; in fact, the volume of a sperm cell is 85,000 times less than that of the female gamete. Approximately 100 to 300 million sperm are produced each day, whereas women typically ovulate only one oocyte per month. As is true for most cells in the body, the structure of sperm cells speaks to their function. Sperm have a distinctive **head**, **mid-piece**, and **tail** region (**Figure 6**).

The head of the sperm contains the extremely compact haploid nucleus with very little cytoplasm. These qualities contribute to the overall small size of the sperm (the head is only 5 μm long). A structure called the **acrosome** covers most of the head of the sperm cell as a "cap" that is filled with lysosomal enzymes important for preparing sperm to participate in fertilization. Tightly packed mitochondria fill the mid-piece of the sperm. ATP produced by these mitochondria will power the **flagellum**, which extends from the neck and the mid-piece through the tail of the sperm, enabling it to move the entire sperm cell.

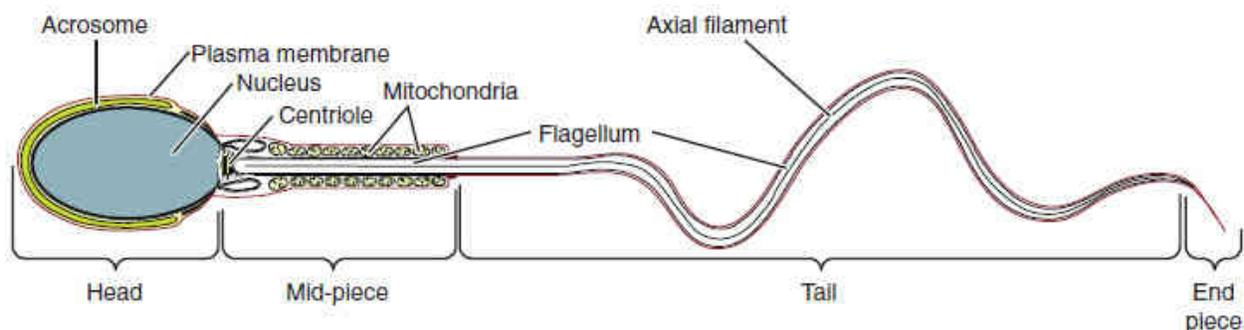


Figure 6. Structure of a Mature Sperm Cell

Sperm cells are divided into a head, containing DNA; a mid-piece, containing mitochondria; and a tail, providing motility. The acrosome is oval and somewhat flattened.

Source Material

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<http://cnx.org/contents/370d6d11-8e11-4b2b-8fa4-a70c14b0554b@13>.

Epididymis

To fertilize an egg, sperm must be moved from the seminiferous tubules in the testes, through the epididymis, and—later during ejaculation—along the length of the penis and out into the female reproductive tract.

From the lumen of the seminiferous tubules, immotile sperm are surrounded by testicular fluid and moved to the **epididymis** (plural; **epididymides**), a coiled tube attached to the testis where newly formed sperm continue to mature (**Figure 4**). Though the epididymis does not take up much room in its tightly coiled state, it would be approximately 6 m (20 feet) long if straightened. It takes an average of 12 days for sperm to move through the coils of the epididymis, with the shortest recorded transit time in humans being one day. Sperm enter the **head** of the epididymis and are moved along predominantly by the contraction of smooth muscles lining the epididymal tubes. As they are moved along the length of the epididymis, a region known as the **body**, the sperm further mature and acquire the ability to move under their own power. Once inside the female reproductive tract, they will use this ability to move independently toward the unfertilized egg. The more mature sperm are then stored in the **tail** of the epididymis (the final section) until ejaculation occurs.

Source Material

OpenStax, 27.1 Anatomy and Physiology of the Male Reproductive System. OpenStax CNX. May 2, 2019
<http://cnx.org/contents/370d6d11-8e11-4b2b-8fa4-a70c14b0554b@13>.

Spermatic cord

During ejaculation, sperm exit the tail of the epididymis and are pushed by smooth muscle contraction to the **ductus deferens** (also called the **vas deferens**). The **vas deferens** is a thick, muscular tube that is bundled together inside the scrotum with connective tissue, blood vessels, and nerves, forming a structure known as the **spermatic cord** (see **Figure 1** and **Figure 2**). Since the ductus deferens is physically accessible within the scrotum, surgical sterilization to interrupt sperm delivery can be performed by cutting and sealing a small section of the ductus (vas) deferens. This procedure is called a **vasectomy**, and it is an effective form of male birth control.

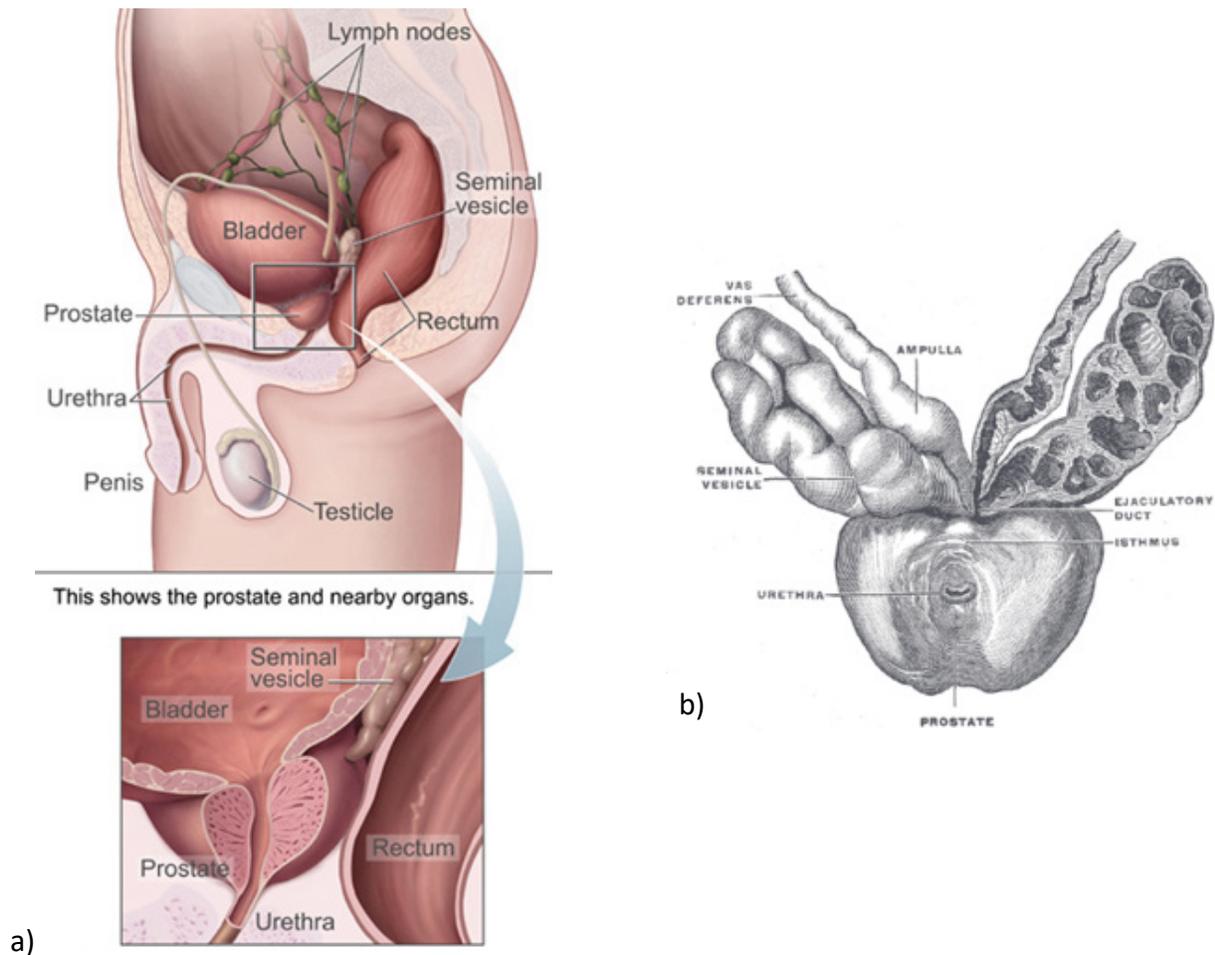
As sperm pass through the **ampulla** (enlarged region) of the ductus deferens at ejaculation, they mix with fluid from the associated **seminal vesicles** (**Figure 1** and **Figure 7**). The paired seminal vesicles are glands that contribute approximately 60% of the semen volume. Seminal vesicle fluid contains large amounts of fructose, which is used by the sperm mitochondria to generate ATP to allow movement through the female reproductive tract. The fluid, now containing both sperm and seminal vesicle secretions, next moves into the associated **ejaculatory duct**, a short structure formed from the ampulla of the ductus deferens and the duct of the seminal vesicle. The paired ejaculatory ducts transport the seminal fluid into the next structure, the prostate gland.

Source Material

OpenStax, 27.1 Anatomy and Physiology of the Male Reproductive System. OpenStax CNX. May 2, 2019
<http://cnx.org/contents/370d6d11-8e11-4b2b-8fa4-a70c14b0554b@13>.

Prostate Gland

As shown in Figure 7, the centrally located **prostate gland** sits anterior to the rectum at the base of the bladder surrounding the **prostatic urethra** (the portion of the urethra that runs within the prostate). About the size of a walnut, the prostate is formed of both muscular and glandular tissues. It excretes an alkaline, milky fluid into the passing seminal fluid—now called **semen**.

**Figure 7. Organization of the Spermatic Cord and the Prostate Gland**

a) Organization of the spermatic cord structures. An enlarged cross-section through some of these structures is found in the bottom portion of the image. b) Posterior view of the seminal vesicles and the prostate. The region of the urethra found here is known as the prostatic urethra.

Source Material

OpenStax, 27.1 Anatomy and Physiology of the Male Reproductive System. OpenStax CNX. May 2, 2019
<http://cnx.org/contents/370d6d11-8e11-4b2b-8fa4-a70c14b0554b@13>.

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Wikimedia Commons contributors. File:Prostatelead.jpg [Internet]. Wikimedia Commons, the free media repository; 2018 Dec 5, 09:31 UTC [cited 2019 Jun 21]. Available from: <https://commons.wikimedia.org/w/index.php?title=File:Prostatelead.jpg&oldid=330345378>.

Bulbourethral Glands

The final addition to semen is made by two **bulbourethral glands (Cowper's glands)** that release a thick, salty fluid that lubricates the end of the urethra and the vagina, and helps to clean urine residues from the **penile urethra**. The fluid from these accessory glands is released after the male becomes sexually aroused, and shortly before the release of the semen.

Source Material

OpenStax, 27.1 Anatomy and Physiology of the Male Reproductive System. OpenStax CNX. May 2, 2019
<http://cnx.org/contents/370d6d11-8e11-4b2b-8fa4-a70c14b0554b@13>.

The External Genitalia

The **penis** is the male organ of **copulation** (sexual intercourse). It is flaccid for non-sexual actions, such as **urination**, and turgid and rod-like with sexual arousal. When erect, the stiffness of the organ allows it to penetrate into the vagina and deposit semen into the female reproductive tract.

The **shaft** of the penis surrounds the urethra (**Figure 8**). Internally, the shaft is composed of three column-like chambers of erectile tissue that span the length of the shaft. Each of the two larger lateral chambers is the **corpus cavernosum** (plural; **corpora cavernosa**). Together, these make up the bulk of the penis. The **corpus spongiosum**, which can be felt as a raised ridge on the erect penis, is a smaller chamber that surrounds the **spongy**, or **penile, urethra**.

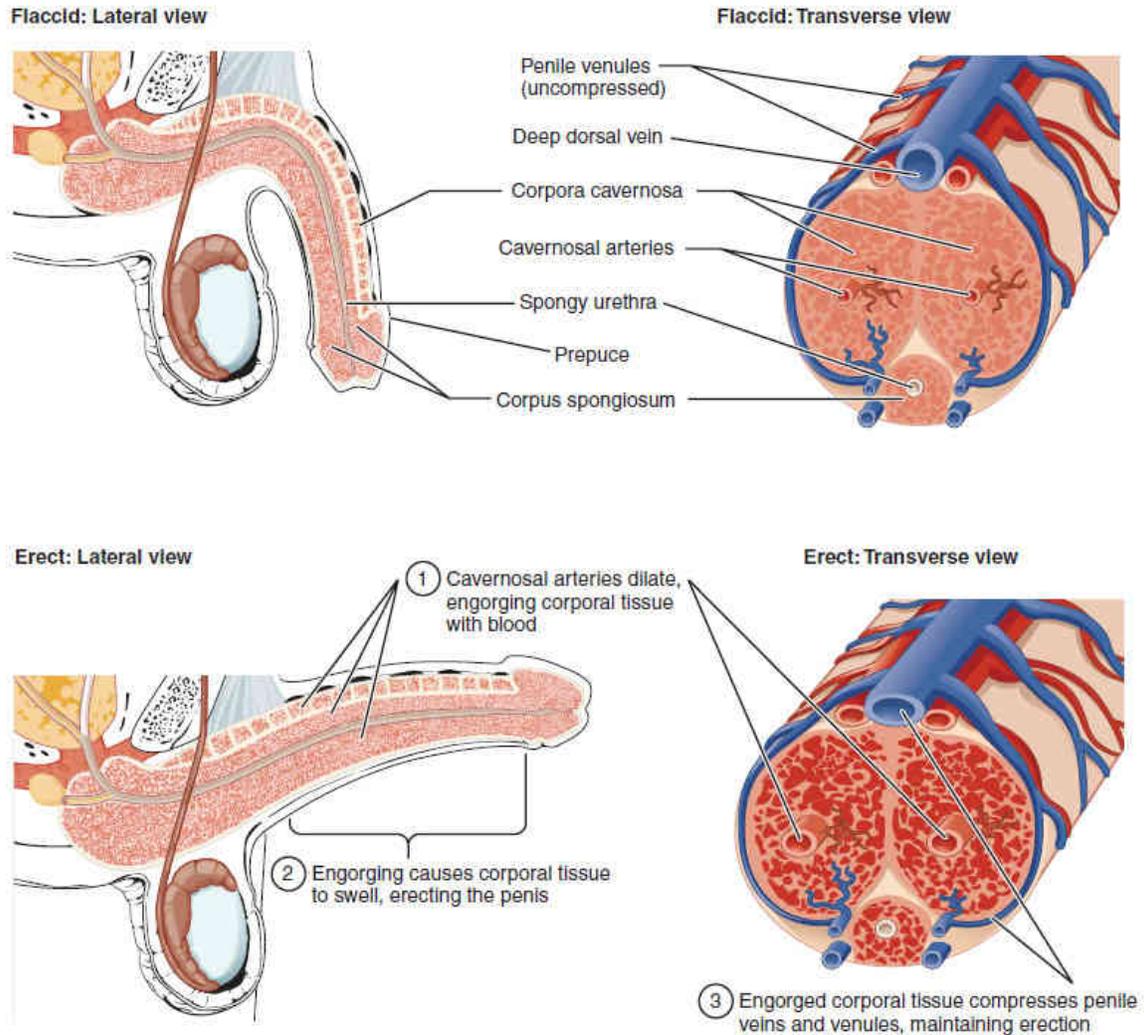


Figure 8. Cross-Sectional Anatomy of the Penis

Three columns of erectile tissue make up most of the volume of the penis.

The end of the penis, called the **glans penis**, has a high concentration of nerve endings, resulting in very sensitive skin that influences the likelihood of ejaculation (**Figure 1**). The skin from the shaft extends down over the glans and forms a collar called the **prepuce** or **foreskin** (**Figure 1** and **Figure 8**). The foreskin also contains a dense concentration of nerve endings, and both lubricate and protect the sensitive skin of the glans penis. A surgical procedure called circumcision, often performed for religious or social reasons, removes the prepuce, typically within days of birth.

Both sexual arousal and REM sleep (during which dreaming occurs) can induce an erection. Penile erections are the result of engorgement of the tissues because more arterial blood flows into the penile tissues than is leaving through the veins. To initiate this process during sexual arousal, nitric oxide (NO) is released from nerve endings near these blood vessels within the corpora cavernosa and spongiosum. Release of the NO activates a pathway that results in relaxation of the smooth muscles that surround the penile arteries, causing them to dilate. This

dilation increases the amount of blood that can enter the penis and induces the endothelial cells in the penile arterial walls to also secrete NO and perpetuate the vasodilation. This rapid increase in blood volume fills the erectile chambers, and the increased pressure of the filled chambers compresses the thin-walled penile venules, preventing venous drainage of the penis. The result of this increased blood flow to the penis and reduced blood return from the penis is erection (**Figure 8**).

Source Material

OpenStax, 27.1 Anatomy and Physiology of the Male Reproductive System. OpenStax CNX. May 2, 2019
<http://cnx.org/contents/370d6d11-8e11-4b2b-8fa4-a70c14b0554b@13>.

Hormones of the Male Reproductive System

Testosterone, an androgen, is a steroid hormone produced by **Leydig cells**. The alternate term for **Leydig cells**, **interstitial cells**, reflects their location between the seminiferous tubules in the testes. In male embryos, testosterone is secreted by Leydig cells by the seventh week of development, with peak concentrations reached in the second trimester. This early release of testosterone results in the anatomical differentiation of the male sexual organs. In childhood, testosterone concentrations are low, though they increase during puberty, activating characteristic physical changes and initiating spermatogenesis.

The continued presence of testosterone is necessary to keep the male reproductive system working properly, and Leydig cells produce approximately 6-7 mg of testosterone per day. Maintaining these normal concentrations of testosterone promotes spermatogenesis, whereas low levels of testosterone can lead to infertility. The regulation of testosterone concentrations throughout the body is critical for male reproductive function, requiring an intricate interplay between the endocrine system and the reproductive system. The relationship between these two systems is shown in **Figure 9**.

Together, the hypothalamus and pituitary gland regulate the production of testosterone and the cells that assist in spermatogenesis. Initially, **gonadotropin-releasing hormone (GnRH)** from the hypothalamus activates the anterior pituitary to produce **luteinizing hormone (LH)** and **follicle stimulating hormone (FSH)**, which in turn stimulate Leydig cells and Sertoli cells, respectively. The system also establishes a negative feedback loop because the end products of the pathway, testosterone and inhibin, interact with the activity of GnRH to inhibit their own production (**Figure 9, steps 2 and 3**).

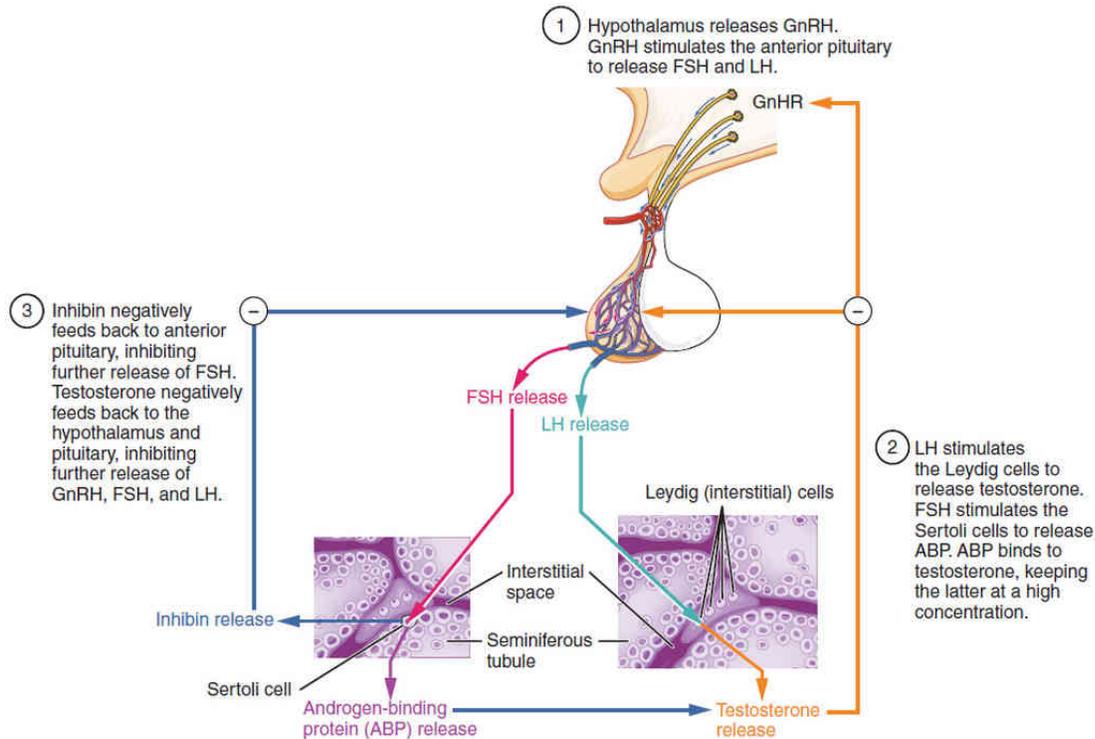


Figure 9. Regulation of Testosterone Production

The regulation of Leydig cell production of testosterone begins outside of the testes. The hypothalamus and the pituitary gland in the brain integrate external and internal signals to control testosterone synthesis and secretion. Pulsatile release of GnRH from the hypothalamus stimulates the endocrine release of hormones from the pituitary gland. Binding of GnRH to its receptors on the anterior pituitary gland stimulates release of the two gonadotropins: LH and FSH. These two hormones are critical for reproductive function in both men and women. In men, FSH binds predominantly to the Sertoli cells within the seminiferous tubules to promote spermatogenesis. FSH also stimulates the Sertoli cells to produce hormones called inhibins, which function to inhibit FSH release from the pituitary, thus reducing testosterone secretion. In men, LH binds to receptors on Leydig cells in the testes and upregulates the production of testosterone. As previously noted, a negative feedback loop predominantly controls the synthesis and secretion of both of these hormones and testosterone.

In addition to intra-testicular secretion, testosterone is also released into the systemic circulation and plays an important role in muscle development, bone growth, the development of secondary sex characteristics, and maintaining **libido** (sex drive) in both males and females. In females, the ovaries secrete small amounts of testosterone, although most is converted to estradiol. A small amount of testosterone is also secreted by the adrenal glands in both sexes.

Source Material

OpenStax, 27.1 Anatomy and Physiology of the Male Reproductive System. OpenStax CNX. May 2, 2019
<http://cnx.org/contents/370d6d11-8e11-4b2b-8fa4-a70c14b0554b@13>

Pre-Assessment

1. Sperm are formed within which structure located within the testes?
2. The process by which primordial germ cells become mature sperm is known as what?
3. _____ is the process by which the spermatid become more streamline, forming a flagellum, and an acrosome.
4. What are the three regions of the spermatozoa?

Equipment List & Setup – Anatomy

Equipment List

- Models and charts of the male reproductive system
- Microscope
- Prepared slides or histological images of:
 - Testis
 - Sperm

Equipment Setup

Identify the location of the necessary equipment needed to complete the activities. Models will be spread throughout the lab, so familiarize yourself to their locations.

Activities – Anatomy

In this exercise, you will study the anatomy and organization of the male reproductive system. This activity contributes to each of the Learning Objectives identified at the beginning of the section.

Part 1: Overview of the Male Reproductive System

Procedure

1. Look at the charts and models of the male reproductive system for a general orientation and compare them to Figures 1 and 7 from the Background material. Locate the following structures:
 - a. Testis
 - b. Epididymis
 - c. Scrotal sac (scrotum)
 - d. Ductus (vas) deferens
 - e. Seminal vesicle
 - f. Prostate gland
 - g. Bulbourethral gland
 - h. Penis
 - i. Urethra

Part 2: Gross Anatomy of the testes

Procedure

1. Examine a model of the testes and compare it to Figures 1 and 2 from the Background. The **testes** are paired organs, sitting outside of the body.
2. Using the models and Figures 2 and 3 from the Background material, identify the **tunica albuginea**, a tough connective sheath that surrounds the testes. Locate the invaginations of the membrane, where it invaginates to form many **lobules** within each testis.
3. Located superficial to the tunica, is the **scrotal sac (scrotum)** (Figure 2). This structure keeps the testes on the exterior of the body, where temperature tends to be cooler and more supportive to **spermatozoa (sperm)** production.
4. Using Figure 2, locate the **dartos muscle**, a component of the scrotal sac. When the testes are cold, the muscle contracts, tightening the sac and bringing the testes closer to the body. The opposite actions occur when the environment is warm.

Part 3: Microanatomy of the Testes

Procedure

1. Obtain a prepared slide or a histological section of the testes. Identify the **seminiferous tubules** and compare what you see to Figure 4 from the Background material. Multiple tubules may be identifiable in the preparation. It is within these structures where sperm are produced.
2. Using Figure 4, look for the triangular clusters of cells in between each tubule. These are the **interstitial (Leydig) cells**. They will produce the male sex hormone, **testosterone**.
3. Now examine the seminiferous tubules under high magnification. Look at Figure 4, if slides are not available. You should be able to see an outer row of cells, known as the **spermatogonia**. These cells will divide by the process of mitosis, giving rise to **primary spermatocytes**.
4. The primary spermatocytes will then undergo meiosis, or reduction division, to eventually produce **spermatozoa**. To do so, primary spermatocytes will initially divide to form **secondary spermatocytes**, which are found closer to the lumen of the seminiferous tubules. These cells will then become **spermatids**. Ultimately, the spermatids will lose their remaining cytoplasm and mature into functional **spermatozoa**. Compare this developmental process to what you see in Figure 5 from the Background and locate the primary and secondary spermatocytes, spermatids, and spermatozoa. You may be able to see **sustentacular (Sertoli) cells**, which help nourish, support, and move the sperm during development.
5. Draw an example of what you see in the space provided in the “Analysis” section below.

Part 4: Sperm

Procedure

1. Examine a prepared slide of sperm and compare it to what you see in Figure 6.
2. Using the slide and the provided image, identify the different components of the sperm cell. Each sperm consists of a **head, midpiece, and tail**.

Part 5: Epididymis

Procedure

1. Using the provided models and Figures 1 and 3, locate and identify the **epididymis**.
2. Sperm from each testis will travel from the seminiferous tubules to the epididymis, where they will be stored and mature. Locate and trace this pathway in Figure 3.
3. Each epididymis has a blunt, rounded **head**, an elongated **body**, and a tapering **tail** that leads to the **ductus (vas) deferens**. Identify each of these structures in the provided figures and compare them to what you observe in the provided models and charts.

Part 6: Spermatic Cord

Procedure

1. As you just saw, sperm travel from the epididymis into the ductus deferens. The ductus deferens is enclosed in the **spermatic cord**, a complex cable including the vas deferens, the testicular artery and vein, the testicular nerves, and the cremaster. The cord tends to be longer on the left side of the body, so the left testis is slightly lower than the right. Locate the structures of the spermatic cord in Figure 2 or on other provided diagrams.
2. Using the provided models and Figure 1 or Figure 7, trace the course of the vas deferens until it reaches the inferior portion of the bladder. Here, the vas deferens enlarge slightly, forming the **ampulla** of the vas deferens.
3. Each ductus then joins with the **seminal vesicle**, which will add fluid to the sperm travelling through. In Figure 7, locate where these two structures unite. Together, the vas deferens and the seminal vesicle form the **ejaculatory duct**.
4. As the ejaculatory duct leads away from the vas deferens, it will extend to the inferior portion of the bladder, where it will join with the **urethra**. The urethra will then extend through the **prostate gland**, which sits just inferior to the urinary bladder. This is the region of the urethra known as the **prostatic urethra**. Locate these structures on the models and in Figure 1.
5. Using the models and Figures 1, follow the urethra as it continues, giving rise to the **membranous urethra**.
6. Near the membranous region of the urethra, use Figures 1 and 7 to locate the paired **bulbourethral glands**. These structures contribute lubricant fluid to passing the **seminal fluid**.
7. Seminal fluid, or **semen**, consists of secretions from the seminal vesicles, prostate gland, bulbourethral glands, and spermatozoa from the testes. On Figure 1 and the models, follow the passage that seminal fluid will take as it passes out of the body cavity through the spongy urethra of the penis.

Part 7: The External Genitalia

In addition to the testes, which are housed within the scrotum, the penis is considered to contribute to the external genitalia of a male's reproductive system.

Procedure

1. Use the provided models and Figure 1 from the Background to locate and observe the external anatomy of the penis. The penis consists of the **root**, **bulb**, an elongated **shaft**, and a distally expanded region known as that **glans penis**. The glans is covered with the prepuce, or **foreskin**. Make sure that you identify the all of these structures.
2. Now, examine a model or chart of a cross section of the penis and compare it to Figure 8 within the Background section. Notice that the penis contains three distinct cylinders of erectile tissue that are anchored to the body proximally. Identify the **corpus**

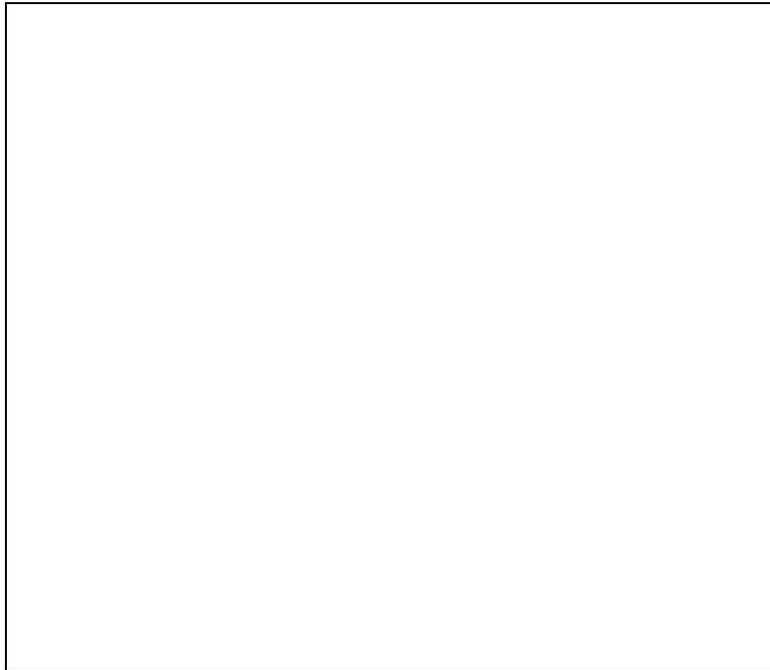
spongiosum, the cylinder of erectile tissue that contains the **spongy (penile) urethra**. Located dorsal to the spongiosum, two cylinders of **corpus cavernosa** are located.

3. Follow the corpus spongiosum as it extends distally. At the most distal region of the penis, this tissue expands to form the glans penis. Note the **dorsal arteries** and **deep (cavernosal) arteries** in Figure 8. Together, these vessels take blood to the penis. When these vessels dilate, the erectile tissue of the penis engorge with blood, making the penis erect.
4. Also locate the **dorsal vein** and **venules** of the penis in Figure 8. These vessels will remove blood from the penis, except for when the penis is erect. At this point, these vessels are compressed, preventing venous drainage of the penis.

Analysis

Microanatomy of the testes

Draw what you see as you observe the microanatomy of the testis. You should include the interstitial cells, seminiferous tubules, spermatogonia, spermatocytes, spermatids, and spermatozoa.



Check your understanding

1. The _____ is a tube that allows sperm cells to travel from the testes to the urethra.
2. Which cells are responsible for the production of testosterone in response to LH from the anterior pituitary?
3. Which cells aid in the process of spermatogenesis by providing nourishment to the developing germ cells?
4. The _____, _____, and _____, provide important fluids to the sperm before ejaculation.
5. Identify the three regions of the male urethra.
6. True or False: warmer temperatures (above body temp) are essential for spermatogenesis.
7. The majority of the erectile tissue within the penis is comprised of the _____ and _____.