CHAPTER VIII

The Respiratory System: Take A Breath

LEARNING OBJECTIVES

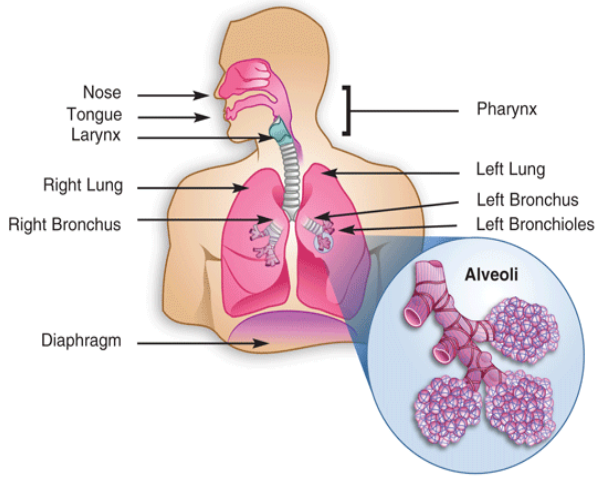
By the end of this class you should be able to:

- List the functions of the respiratory system and explain which organ is primarily involved in them
- Describe the structure of the lungs
- Explain where and how gas exchanges occur in the lungs.
- Explain the mechanisms of breathing
- Describe hemoglobin and its function
- Summarize diseases and conditions associated with the respiratory system.
- Know how to dissect the upper body of a rat specimen
- List and identify the organs in the neck and thoracic cavity

Introduction

Hold your breath. Really! See how long you can hold your breath as you continue reading…How long can you do it? Chances are you are feeling uncomfortable already. A typical human cannot survive without breathing for more than 3 minutes, and even if you wanted to hold your breath longer, your autonomic nervous system would take control. This is because every cell in the body needs oxygen to stay alive. Humans, at rest, breathe approximately 15 times per minute on average. This equates to about 900 breaths an hour or 21,600 breaths per day. With every breath taken, air fills the lungs. That air is doing more than just inflating the lungs in the chest cavity. The air contains oxygen that crosses the lung tissue, enters the bloodstream, and travels to organs and tissues. The air contains oxygen that crosses the lung tissue, enters the bloodstream, and travels to organs and tissues. Oxygen (O_2) enters the cells where it is used for metabolic reactions that produce ATP, a high-energy compound. At the same time, these reactions release carbon dioxide (CO_2) as a by-product. CO_2 is toxic and must be eliminated. Carbon dioxide exits the cells, enters the bloodstream, travels back to the lungs, and is removed out of the body during exhalation. A variety of diseases can affect the respiratory system, such as asthma, emphysema, chronic obstruction pulmonary disorder (COPD), and lung cancer. All of these conditions affect the gas exchange process and result in labored breathing and other difficulties. In this chapter as you discover more about your respiratory system, you will learn that lungs are about the size of a tennis court and that you produce and swallow more than a quart of mucus every day.

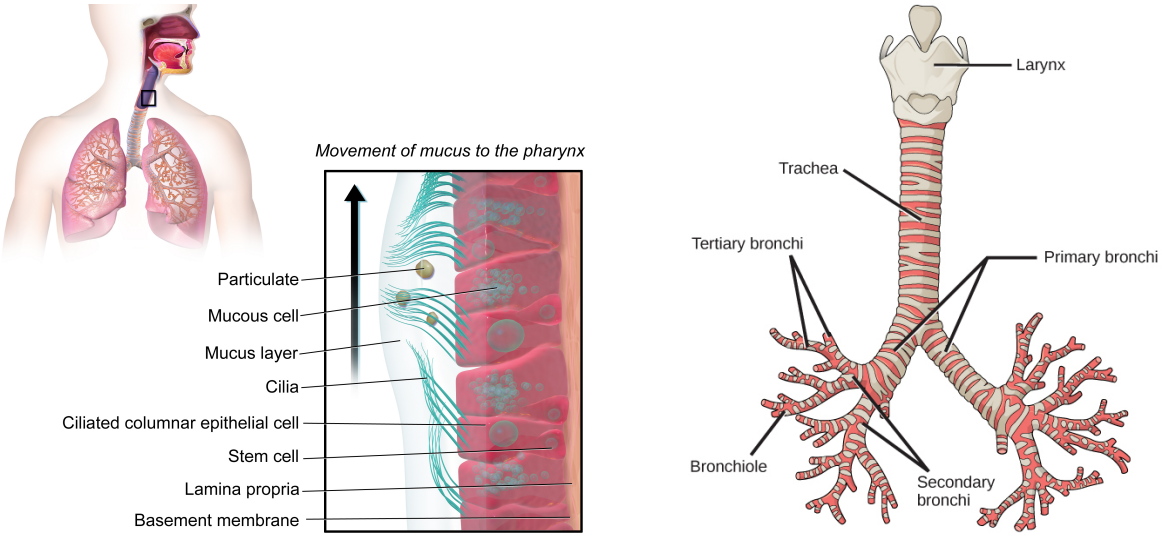
Organs and Structures of Our Respiratory System



The Human Respiratory System. (credit: UNSHAW CC BY-SA 4.0).

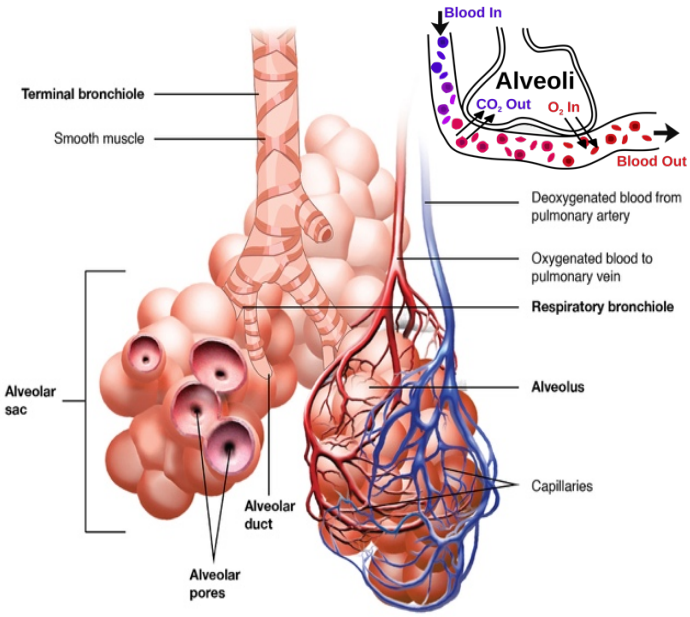
To reach the **lungs**, air travels through the **nasal cavity**, **pharynx**, **larynx**, **trachea**, **bronchi** (sing. *bronchus*) and **bronchioles**. Once in **alveoli** (sing. *alveolus*) of the lungs, oxygen from inhaled air, diffuses into the blood, in nearby capillaries, and is then distributed to cells throughout the body. Meanwhile, carbon dioxide brought from the cells moves from the blood to the lungs. During exhalation, the carbon dioxide is removed from the body and dispersed in Ithe atmosphere. In addition to its function in gas exchanges, the human respiratory system has roles in speech, temperature regulation and sense of smell**.**

As the air passes through the nasal cavity, the air is warmed to body temperature and humidified by moisture from mucous membranes. These processes help equilibrate the air to the body conditions, reducing any damage that cold, dry air can cause. Particulate matter that is floating in the air is removed in the nasal passages by hairs, mucus, and cilia. Air is also chemically sampled by the sense of smell.



The Trachea and Bronchi. The respiratory epithelium secretes mucus that traps particles; cilia swipe the mucus upwards towards the throat where it is swallowed (left; BruceBlaus, CC BY 3.0). The trachea and bronchi are made of incomplete rings of cartilage that provide strength and support to keep them open (right; credit: CNX OpenStax CC BY 4.0).

- From the nasal cavity, air passes through the **pharynx (throat)** and the **larynx (voice box)** as it makes its way to the trachea. The main function of the trachea is to funnel the air to and from the lungs. The human trachea is a cylinder, about 30 cm (11.8 in) long, which sits in front of the esophagus and extends from the pharynx into the chest cavity to the lungs. It is made of incomplete rings of cartilage and smooth muscle. The cartilage provides strength and support to the trachea to keep the passage open. The trachea is lined with cells that have cilia and secrete mucus, about 1.5 liters each day. The mucus catches particles that have been inhaled, and the cilia move the particles toward the pharynx where it is swallowed in the esophagus.
- The end of the trachea divides into two bronchi that enter the right and left lung. Air enters the lungs through the primary bronchi. The primary bronchus divides, creating smaller and smaller diameter bronchi until the passages are under 1 mm (.03 in) in diameter when they are called bronchioles as they split and spread through the lung. Like the trachea, the bronchus and bronchioles are made of cartilage and smooth muscle.
- The final bronchioles are the respiratory bronchioles. Alveolar ducts are attached to the end of each respiratory bronchiole. At the end of each duct are alveolar sacs, each containing 20 to 30 alveoli. Gas exchange occurs only in the alveoli. The alveoli are thin-walled and look like tiny bubbles within the sacs. The alveoli are in direct contact with capillaries of the circulatory system. Such intimate contact ensures that oxygen will diffuse from the alveoli into the blood. In addition, carbon dioxide will diffuse from the blood into the alveoli to be exhaled. The anatomical arrangement of capillaries and alveoli emphasizes the structural and functional relationship of the respiratory and circulatory systems.
- Lungs are spongy organs containing each about 300 million alveoli, making the respiratory surface of a lung close to that of half a tennis court (75-100 m^2). Alveoli are grouped in alveolar sacs surrounded by blood capillaries derived from the pulmonary artery. The barrier between the lumen (inside) of the alveolar sac and the lumen of a blood capillary is only about two cells layers thick, thus very thin, 0.2 to 2.5 µm. This allows for the rapid transport, by diffusion, of CO_2 and O_2 from air in the alveolar sac and blood.



The Respiratory Portion of the Lungs. Alveoli and alveolar sacs (). Gas exchange between alveoli and capillaries (credits OpenStax College CC BY 3.0 and helix84 CC BY-SA 3.0).

Activity 1. Lungs

1.1 - Explain why body cells constantly need oxygen.

1.2 - Explain why oxygen and carbon dioxide diffuse to and from tissues, blood and the alveoli.

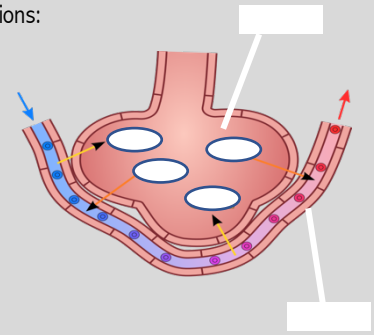
1.3 - Fill-in the blanks: Lungs participate in homeostasis because they remove ____, a metabolic waste, from the body resulting from the cells using ____.

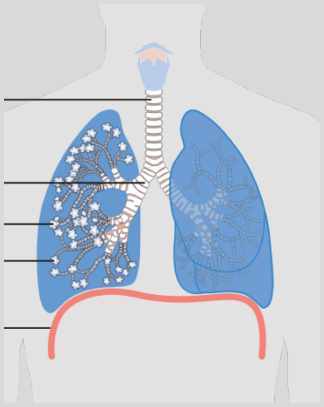
1.4 - The lungs also help maintain the _____ of the blood. They do so as they excrete CO_2.

1.5 - When is blood less acidic, when it carries more or less CO_2?

1.6 - Examine a prepared slide of a section of human lung. What type of tissue lines the alveoli? How does its structure match its function?

1.7 - Label the following illustrations:

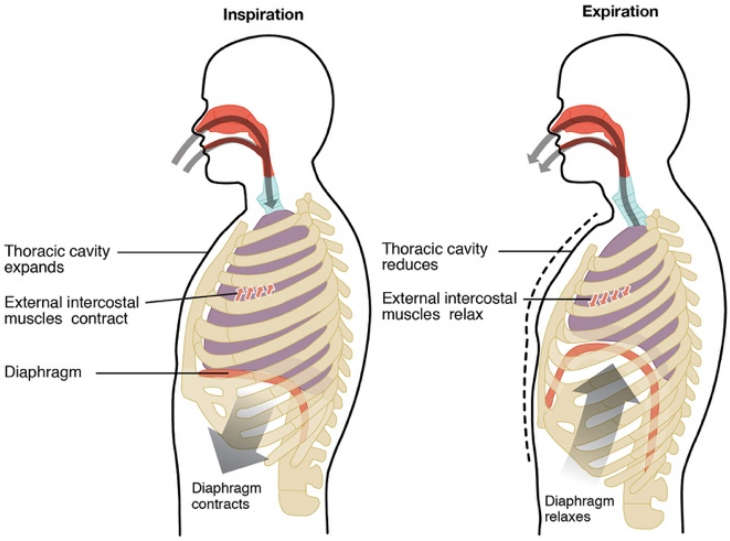




Respiratory Anatomy and Gas Exchanges (Credits: Left, Cancer Research UK CC BY-SA 4.0; right, Domdomegg, CC BY 4.0).

Breathing

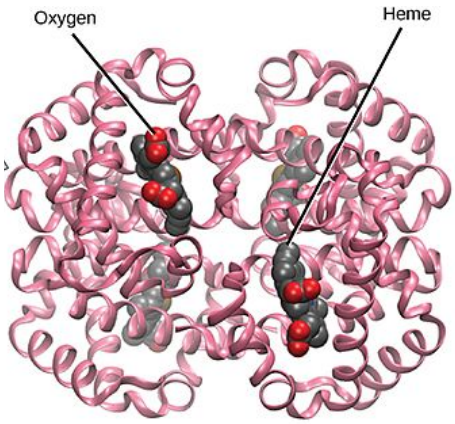
The human respiratory system consists of airways through which gases move to and from the **paired lungs**. Air is moved in and out of the lungs by the contraction and relaxation of the **diaphragm** and **intercostal (between the ribs) muscles**. **Inspiration** (inhalation) happens when the diaphragm contracts increasing the thoracic cavity volume. As this decreases the air pressure in the lungs, making it lower than the atmospheric air pressure, air flows in the lungs. **Expiration** (exhalation) results from the relaxation of the muscles which does the opposite: decrease the volume of the thoracic cavity and increase the air pressure in the lungs making the air flow out of the lungs where the pressure is lower. **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. The **respiratory rate** is the total number of breaths, or respiratory cycles, that occur each minute. Respiratory rate can be an important indicator of disease, as the rate may increase or decrease during an illness or in a disease condition. The respiratory rate is controlled by the respiratory center located within the brain, which responds primarily to changes in carbon dioxide, oxygen, and pH levels in the blood. The normal respiratory rate of a child decreases from birth to adolescence. A child under 1 year of age has a normal respiratory rate between 30 and 60 breaths per minute, but by the time a child is about 10 years old, the normal rate is closer to 18 to 30. By adolescence, the normal respiratory rate is similar to that of adults, 12 to 18 breaths per minute.



Breathing. Inspiration and expiration (right; credit: OpenStax College CC BY 3.0).

Hemoglobin

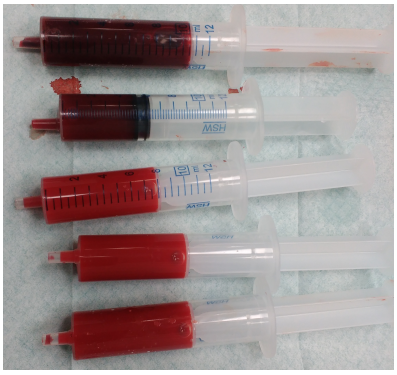
Hemoglobin, or Hb, is a protein molecule found in red blood cells (erythrocytes) made of four subunits: two alpha subunits and two beta subunits. Each subunit surrounds a central heme group that contains iron and binds one oxygen molecule, allowing each hemoglobin molecule to bind four oxygen molecules. Molecules with more oxygen bound to the heme groups are brighter red. As a result, oxygenated arterial blood where the Hb is carrying four oxygen molecules is bright red, while venous blood that is deoxygenated is darker red. Carbon dioxide is transported by three major mechanisms. The first mechanism of carbon dioxide transport is by blood plasma, as some carbon dioxide molecules dissolve in the blood. The second mechanism is transport in the form of bicarbonate (HCO_3^-), which also dissolves in plasma. The third mechanism of carbon dioxide transport is similar to the transport of oxygen by Hb. About 20 percent of carbon dioxide is bound by hemoglobin and is transported to the lungs. Though, carbon dioxide does not bind to iron as oxygen does.



Hemoglobin. The protein inside red blood cells that carries oxygen to cells and carbon dioxide to the lungs is hemoglobin. Hemoglobin is made up of four symmetrical subunits and four heme groups. Iron associated with the heme binds oxygen. It is the iron in hemoglobin that gives blood its red color (credit: Modified from OpenStax College CC BY 4.0).

Some diseases or compounds can decrease the blood's ability to deliver oxygen to tissues and its oxygen-carrying capacity:

- In sickle cell anemia, the shape of the red blood cell is crescent-shaped, elongated, and stiffened, reducing its ability to deliver oxygen. In this form, red blood cells cannot pass through the capillaries. This is painful when it occurs.
- Thalassemia is a rare genetic disease caused by a defect in either the alpha or the beta subunit of Hb. Patients with thalassemia produce a high number of red blood cells, but these cells have lower-than-normal levels of hemoglobin. Therefore, the oxygen-carrying capacity is diminished.
- Carbon monoxide has a greater affinity for hemoglobin than oxygen. Therefore, when carbon monoxide is present, it binds to hemoglobin preferentially over oxygen. As a result, oxygen cannot bind to hemoglobin, so very little oxygen is transported through the body. Carbon monoxide is a colorless, odorless gas and is therefore difficult to detect. It is produced by gas-powered vehicles and tools. Carbon monoxide can cause headaches, confusion, and nausea; long-term exposure can cause brain damage or death. Administering 100 percent (pure) oxygen is the usual treatment for carbon monoxide poisoning. Administration of pure oxygen speeds up the separation of carbon monoxide from hemoglobin.

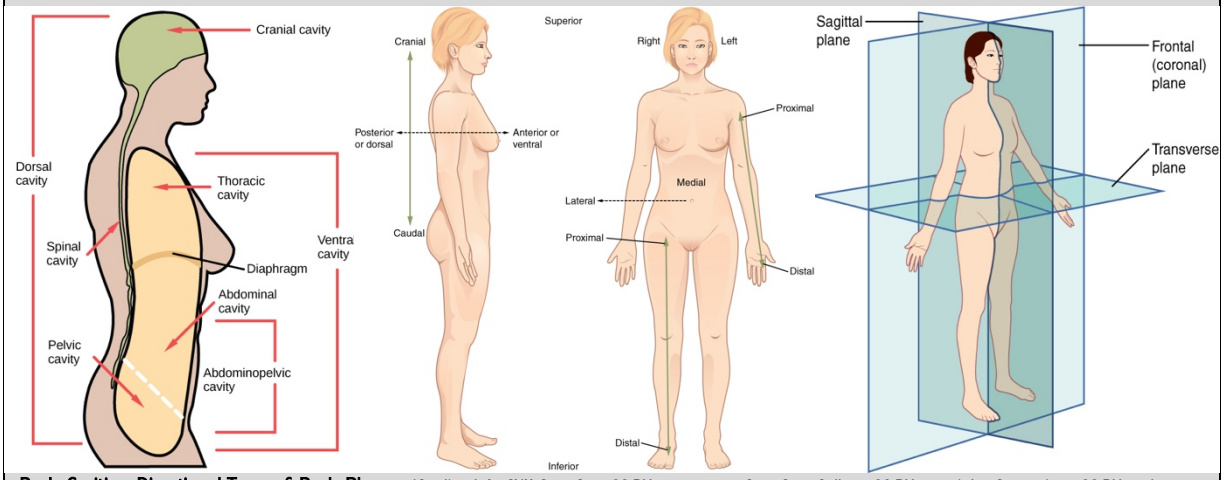


Blood and Oxygen. Left: Difference in hue between arterial (brighter) and venous (darker) blood (credit: Wesalius, CC BY SA 3.0). Right: Comparative morphology of normal red blood cells and sickle cells (credit: Public Domain).

Activity 2. Critical Thinking
Make an analogy between the respiratory system/circulatory system/oxygen and people using mass public transportation to and from work in a big city. What's the oxygen? The hemoglobin? Blood vessels? Lungs? Etc…

Activity 3. Terminology and Dissection Preparation

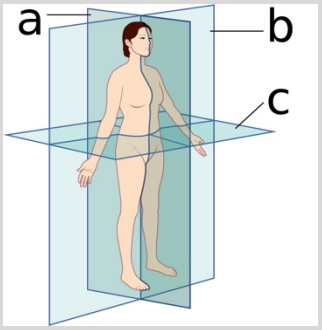
Many of the organs of mammals are located inside body cavities. The **diaphragm** (skeletal muscle) separates the upper **thoracic cavity** and a lower **abdominal cavity**. A **cranial cavity** holds the brain and a **spinal cavity** houses the spinal cord.
The piglet dissection will focus on the internal organs located in the ventral body cavity. Many **directional terms** are used to describe the location of organs, and incisions will follow the three common **body planes**, sagittal, frontal and transverse, associated with bilaterally symmetrical animals.

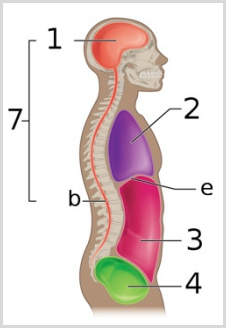


Body Cavities, Directional Terms & Body Planes. (Credits: left: CNX OpenStax CC BY 4.0; center: OpenStax College CC BY 4.0; right: Connexions CC BY 4.0).

The purpose of the dissection is to expose the various organs of the rat for study. This should be done in a manner causing minimal damage to the specimen. For this, **follow all instructions carefully and in sequence**. As you work in groups, have a member of your team reading the instructions, and description for each incision, entirely, before you attempt it. Use a scalpel when absolutely necessary, and **scissors for most of the incisions**. Do not probe with a scalpel, use tweezers and probes for this purpose. As the dissection is performed over different sessions, place the specimen in wet paper towel at the end of the first session and seal it in a plastic bag to prevent it from drying out, and use an identifying tag to recognize it on the next session. Use appropriate **protection**, lab coat, gloves and goggles and wash your hands at the end of the session.

3.1 - Identify the structures and planes on the two illustrations below.





Body Planes & Body Cavities. (Credits: left: Connections CC BY 4.0; right: OpenStax CC BY 3.0).

3.2 - Why are rats used for this lab? *Provide at least two reasons.*

3.3 - How should you proceed with the dissection? *Discuss the material needed, your behavior and approach.*

3.4 - Why is it important to point scissors up and not down when incising?

Activity 4. Rat External Anatomy

Rats are animals called vertebrates. Vertebrates are characterized by a **backbone**. We can classify our rat even further by recognizing that is a mammal. Mammals have **mammary glands**, **fur/hair** and **separate sexes**.

4.1 - Place your rat on a dissection pan and locate the following regions: **head (cranial region), neck (thoracic region), trunk (thorax, abdomen and pelvic girdle), forelimbs and hindlimbs, tail.**

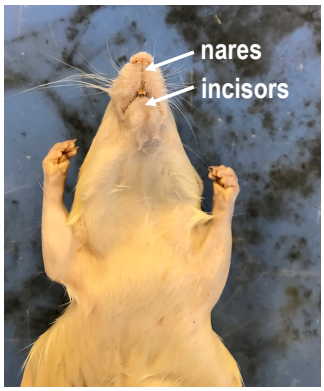
4.2 - Does your animal have fur? If so, where? Does the tail have fur? The tail acts as an important regulator of the rat's body temperature. What problems would a rat face if it lost its tail?

4.3 - Peeking out from the rat's mouth are the **incisors**. These teeth grow throughout the rat's lifetime, and are continually worn down by the gnawing actions of the animal. A rat kept in a domestic environment must be given items to gnaw on or the incisors will grow to a length which will impede normal feeding.

4.4 - The formal terminology for the nostrils is the **nares**. The whiskers, important sensory structures, are called the **vibrissae**. The external part of the ear is called the **pinna** (sing.) or pinnae (plur.).

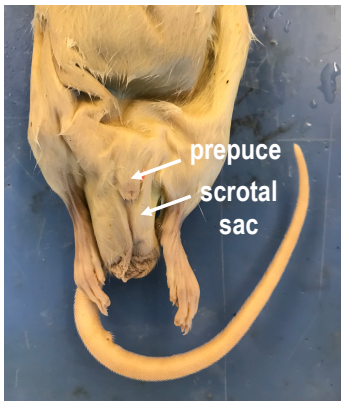
4.5 - Determine the sex of your rat locating the **vaginal opening** (female) or **scrotal sac** and **prepuce** (raised skin surrounding the penis) (male). The **anus** is positioned just underneath the tail in both sexes. We will learn more about the reproductive system in a later lecture. For now, be able to identify external structures. Keep in mind that the penis in the male rat serves as an exit point for both the reproductive system (release of sperm) AND for the urinary system (release of urine). In the female rat, the urinary system has its own separate exit from the body, a small hole anterior the vaginal opening.

4.6 - Locate and count the number of **mammae or nipples** on the ventral surface. What conclusion can you draw from the number of nipples? Do both sexes have nipples?

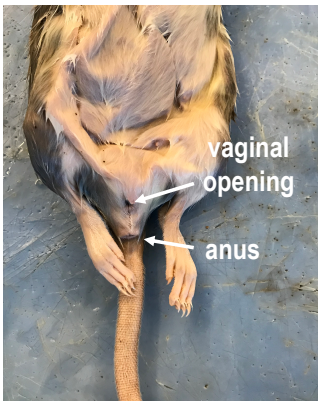


Rat: head region, ventral view. Nares (nostrils) and incisors (teeth for gnawing).

Rat: head region, dorsal view. Vibrissae (whiskers) and pinna (ear).



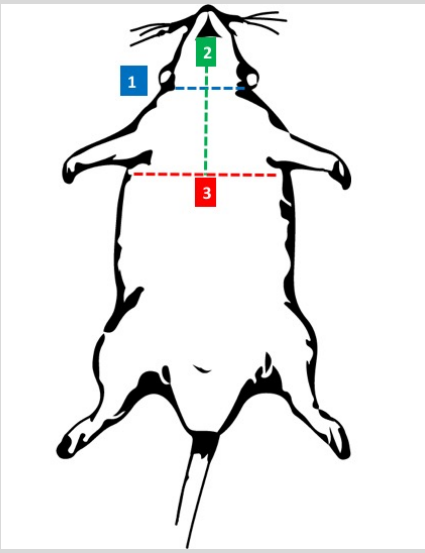
Male Rat: pelvic region, ventral view. Prepuce (skin around penis) and scrotal sac (anus is hidden underneath scrotal sac).



Female Rat: pelvic region, ventral view. Vaginal opening and anus. The opening of the urethra (urinary system) is anterior to the vaginal opening, but is not clearly visible in this picture.

Activity 5. Rat Neck Region

Tie your rat to the dissection pan, ventral side up. For this wrap and knot a 20 inch long string on one wrist, and run it under the pan and tie the other wrist. Proceed the same way with the ankles with another piece of string. The rat should be held tautely in place by the strings.



5.1 - Proceed with the first set of incisions 1, 2 and 3. Note that for cut two you will be cutting through the bones of the thoracic cavity. Cut 3 should be made just below the bottom of the rib cage. We are essentially creating a window that can be opened up to give us a clear view of the neck and thoracic regions.

5.2 - Move the skin apart and carefully cut through muscles and connective tissue to expose the underlying structures. A blunt probe is a great tool for gently clearing/scraping away soft tissue.

5.3 - With a probe or tweezers, separate the thymus lobes and other tissues, medially, beneath several layers of muscles until you expose the **larynx** and the **trachea** and **thyroid** sitting on the trachea.

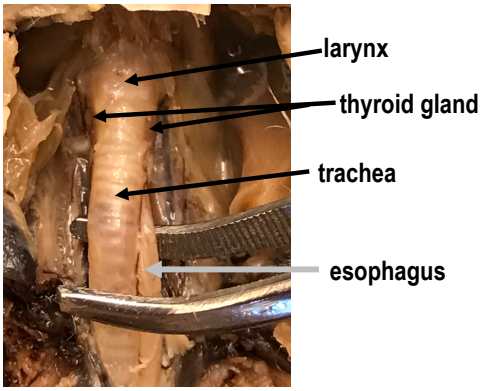
5.4 - With tweezers carefully move the trachea to the right of your animal to see the **esophagus**.

5.5 - How would do explain why the trachea is made of cartilage while the esophagus is not?

5.6 - Label the middle image below showing the neck structures listed above in bold and indicate what organ system they belong to:

Here, the skin has been opened up, but the bone and muscle still need to be cut and cleared away.

Now, the bone and muscle have been cleared. What structures can you identify?



Activity 6. Rat – Thoracic Cavity

5.1 - The incisions you made in Activity 5 should have already exposed the organs of the thoracic cavity. Make sure to clear away bone impeding your view. When cutting through the sternum and the ribs, be aware of (and try to preserve) the blood vessels going to and leaving the heart.

5.2 - Identify the **sternum, ribs and diaphragm**. Since the diaphragm separates the thoracic and abdominal cavities, dissection may disrupt some of its connections to the body wall. What type of tissue makes up the diaphragm?

5.3 - Observe the membrane lining the thoracic cavity, **the pleura**, then remove it to better see the **lungs**, and remove the **pericardium** to observe the **heart.**

5.4 - What organ system do the lungs belong to? List and observe the structures air travels into to reach the lungs.

5.5 - Observe the coronary vessels on the heart, the two flap-like structures of the atria and the larger, muscular, ventricles. What organ system does the heart belong to? After you have thoroughly observed the cardiac structures *in situ*, remove the heart to more clearly see the respiratory structures.

5.6 - When you are done with your dissection, wrap your rat in a damp paper towel, place it in a plastic bag and seal it. **Name and label your rat**, so that you will be able to use it for the next dissection.

After the sternum and ribs have been cleared, the heart and lungs will be visible.

We are looking at the posterior end of the thoracic cavity. The tweezers are resting on the diaphragm.

Take a closer look at the heart. Notice the remnants of the pericardial membrane on the heart's surface. One of the heart's atria is clearly visible, as is a ventricle, the apex of the heart, and coronary arteries. Can you find the aorta on your specimen? (Hint: yes you can! So, take a look for it.)

After looking at the heart's structures, remove it. Now the respiratory structures will be more clearly visible. Trace the trachea down to the bronchi which branch off into the lungs.

Review Questions

1. List all the structures a molecule of oxygen would travel through as you breath it in.
2. How does the structure of alveoli maximize gas exchange?
3. A smoker develops damage to several alveoli that then can no longer function. How does this affect gas exchange?
4. Outline the steps involved in quiet breathing.
5. What is the respiratory rate and how is it controlled?
6. What is hemoglobin?
7. What can affect the blood's ability to transport oxygen?
8. Where is the epiglottis? What problem someone without one would encounter?
9. Name a gland located in the neck area.
10. What organs do the esophagus connect? Where are they located?
11. What organs are located in the thoracic cavity?
12. The sheet of muscle that separates the thoracic and abdominal cavities is called _____ .
13. Mini Practicum: identify as many organs as possible on the pictures below:

With text modified from OpenStax Biology 2e, Anatomy and Physiology, Concepts of Biology