The Respiratory System
Chapter 23

Objectives

- Describe the primary functions of the respiratory system.
- Explain how the delicate respiratory exchange surfaces are protected from pathogens, debris, and other hazards.
- Identify the organs of the upper respiratory system, and describe their functions.
- Describe the structure of the larynx, and discuss its role in normal breathing and in the production of sound.
- Discuss the structure of the extrapulmonary airways.
- Describe the superficial anatomy of the lungs, the structure of a pulmonary lobule, and the functional anatomy of the alveoli.
- Define and compare the processes of external respiration and internal respiration.
- Describe the major steps involved in external respiration.
- Summarize the physical principles governing the movement of air into the lungs.
- Describe the origins and actions of the respiratory muscles responsible for respiratory movements.
- Summarize the physical principles governing the diffusion of gases into and out of the blood.
- Explain the important structural features of the respiratory membrane.
- Describe the partial pressures of oxygen and carbon dioxide in the alveolar air, blood, and systemic circuit.
- Describe how oxygen is picked up, transported, and released in the blood.
- Discuss the structure and function of hemoglobin.
- Describe how carbon dioxide is transported in the blood.
- Describe the factors that influence the respiration rate.
- Identify and discuss reflex respiratory activity and the brain centers involved in the control of respiration

Sequence:

This unit will be divided into the following areas:

**Part A: The Upper Respiratory System**
1. Nasal cavity, pharynx and larynx structure and function
2. Sound production

**Part B: The Lower Respiratory System**
1. The trachea structure and function
2. The primary bronchi

**Part C: The Lungs**
1. Gross lung anatomy
2. Blood supply
3. Movement of air
4. Measuring lung volumes and capacities

**Part D: Gas Exchange**
1. Gas laws
2. Oxygen and Carbon Dioxide transport
1. List and describe the five basic functions of the respiratory system:
   a. Provide extensive surface for gas exchange between air and blood
   b. Move air to and from the exchange surfaces of lungs to respiratory passages
   c. Protecting respiratory surfaces from dehydration, temperature changes, and other environmental factors
   d. Producing sounds for speaking, singing, and other forms of communication
   e. Facilitating detection of odor or smell

2. Describe in detail the relationship between the cardiovascular system and the respiratory system:
   Cardiovascular system transports gases exchanged in the respiratory system.

3. List the function of the upper respiratory system and, using the diagram on page 828, list all of the structures of the upper respiratory system:
   Passage ways, filter, warm, and humidify incoming air protecting delicate surfaces. Nose, nasal cavity, paranasal sinuses, pharynx (throat).

4. List the function of the lower respiratory system and, using the diagram on page 828, list all of the structures of the lower respiratory system:
   Larynx (voice box), trachea (windpipe), bronchi, bronchioles, alveoli of lungs.

5. Place the following parts of the respiratory system in order of air flow, beginning with the nose:
   Nasopharynx, Larynx, Nasal Vestibule, Trachea, Nasal Conchae, Pharynx, Bronchus, Internal Nares, Bronchioles, External Nares
   External Nares → Vestibule → Nasal Conchae → Internal Nares → Nasopharynx → Larynx → Trachea.
6. Label the following structures

7. Describe the nasal mucosa of the nasal cavity.
   Preparers inhaled air for arrival at the lower respiratory system. Lining propia
   contains lots of arteries, veins, and capillaries that bring nutrients to sensory cells.

8. Why should you breathe through your nose?
   Everything that is breathed in through your nose is
   filtered, warmed, and humidified for your lungs.
1. What provides the force needed behind a sneeze (particles can travel up to 15 feet)?

Irritation of the wall of nasal cavity.

2. What is apnea?

To stop breathing

3. Describe what happens during hyperventilation. How is Carbon Dioxide involved?

Rate and depth of resp exceeds oxygen demand = low CO2

4. Describe the effects of breathing into a bag for hyperventilation.

Blood becomes more alkaline & causes cerebral blood vessels to constrict / Dizzy / Faint - breath into paper bag to raise levels of CO2

5. What is bronchitis and what triggers it?

Swelling / inflammation of main air passages to the lungs.

Triggers: Smoking history, Lefornel breathing, coughing

6. What is emphysema and what causes it?

The air sacs in the inner wall of your lungs rupture.

7. What is cystic fibrosis? What are the chances of getting it?

Oversecretion of thick mucus in resp passages.

1 in every 2400 births (Genetic recessive)

8. What happens during asthma?

Chronically inflamed, hypersensitive bronchial passages. Response to irritants = dust mites, droppings, fungi;

Coughing, Wheezing, Dyspnea

9. List a smoking statistic that most surprises you.

Smoke contains 4800 chemicals

60 can cause cancer
10. List 4 things that are found in cigarettes that are toxic.

- Cadmium
- Arsenic
- Radon
- Nicotine

11. What does smoking do to your respiratory passages?

- Increases heart rate
- Constricts peripheral blood vessels
- Affects nose and brain

12. How does lung cancer compare to the numbers of deaths from other cancers?

It kills more than any other cancer.

13. Distinguish between the 3 main types of lung cancer and list any treatments available

Squamous Carcinoma (20-40%) in epithelium of large bronchi → form masses that hollow out and bleed
Define the following pulmonary volumes:

1. Resting Tidal Volume (TV): 
2. Expiratory Reserve Volume (ERV): 
3. Residual Volume (RV): 
4. Inspiratory Reserve Volume (IRV): 
5. Inspiratory Capacity (IC): 
6. Functional Residual Capacity (FRC): 
7. Vital Capacity (VC): 
8. Total Lung Capacity (TLC): 

Name: ________________________________

Chapter 23

Volume Relationships
Use the following list to label the picture below:

- a. External Nares
- b. Internal Nares
- c. Esophagus
- d. Nasal Concha
- e. Laryngopharynx
- ac. Nasopharynx
- ad. Oropharynx
- ae. Epiglottis
- bc. Glottis
- bd. Trachea
- be. Nasal Vestibule

1. Collectively known as
Follow the flow of air into the lungs. Match the labels to the appropriate location:

a. Secondary Bronchi  
   b. Oropharynx  
   c. Trachea  
   d. Terminal Bronchioles

   c. Nasal Concha  
   ab. Nasopharynx  
   ac. Alveoli  
   ad. Tertiary Bronchi

ae. Alveolar Duct

Nasal Vestibule → _9_ → Internal Nares → _10_ → _11_ → laryngopharynx →

Larynx → _12_ → Primary Bronchi → _13_ → _14_ → Bronchioles → _15_ →

Respiratory Bronchioles → _16_ → _17_

Label the following on the lungs below:

18. Which lung is the right lung?

19. Which lung would contain 3 lobar bronchi?

20. Which lung contains a cardiac notch?

21. Boyle's Law states that gas volume is
   a. Directly proportional to pressure
   b. Directly proportional to temperature
   c. Inversely proportional to pressure
   d. Inversely proportional to temperature

22. In quiet breathing...
   a. Inspiration and expiration involve muscular contractions
   b. Inspiration is passive and expiration involves ab muscle contractions
   c. Inspiration involves muscular contractions and expiration is passive
   d. None of the above

23. Each of the following muscles elevates the ribs except...
   a. Sternocleidomastoid
   b. External obliques
   c. Scalenes
   d. External intercostals

24. When the diaphragm and external intercostals contract (choose 2)
   a. The ribcage expands
   b. The ribcage contracts
   c. Inhalation occurs
   d. Exhalation occurs
25. Which of the following muscles contract in deep inhalation (choose all that apply)?
   a. Sternocleidomastoid  
   b. Internal Intercostals  
   c. Scalenes  
   d. External Intercostals

26. Which of the following muscles contract in quiet exhalation?
   a. Internal intercostals  
   b. External intercostals  
   c. Diaphragm  
   d. None of the above

Match the following terms to the descriptions below:
   a. external respiration  
   b. pulmonary ventilation  
   c. internal respiration

27. the movement of oxygen from the capillaries into muscle tissue  
28. inhalation  
29. exhalation  
30. the movement of carbon dioxide from the capillary to alveoli
C. Animal Dissection

If you are dissecting a cat or fetal pig to observe respiratory system structures, refer to the appropriate accompanying dissection manual.

The respiratory system organs of a cat or fetal pig are similar to those of the human. This dissection will illustrate the structure of the larynx and trachea, the relationship of respiratory organs to other organs in the mediastinum, and the connective tissues surrounding these organs.

PHYSIOLOGY OF THE RESPIRATORY SYSTEM

The respiratory system supplies oxygen needed by body cells to produce ATP for metabolism and removes the carbon dioxide produced by metabolic reactions. Respiration involves three steps and requires the cardiovascular system to transport oxygen and carbon dioxide throughout the body.

1. **Pulmonary ventilation**, or breathing, is the movement of air between the atmosphere and the lungs that occurs when we inhale (inspiration) and exhale (expiration).

2. **External respiration** is the movement of oxygen from the alveoli into the pulmonary capillaries and carbon dioxide from the pulmonary capillaries to the alveoli.

3. **Internal respiration** is the movement of oxygen from the capillaries into body cells and carbon dioxide from body cells into capillaries.

In this exercise we examine pulmonary ventilation and the role of carbon dioxide in controlling pulmonary ventilation.

A. Pulmonary Ventilation

During pulmonary ventilation, air moves from an area of higher pressure to an area of lower air pressure. Changes in air pressure in the lung (alveolar or intrapulmonic pressure) occur when lung volume changes. The relationship between pressure and volume is described by Boyle’s Law, which states that the pressure of a gas in a closed container is inversely proportional to the volume of the container. Therefore, when lung volume increases, the pressure of the air inside decreases and air flows into the lungs. When lung volume decreases, the pressure of the air inside increases and air flows out of the lungs.

1. **Changing Thoracic and Lung Volumes**

When the diaphragm and other respiratory muscles contract or relax, they change the size of the thorax which in turn changes lung volume. Normal inhalation is caused mainly by contraction of the diaphragm. The diaphragm is dome-shaped when relaxed and flattens when contracted. When the diaphragm flattens, the length of the thoracic cavity and its volume increase. During forced inhalation, contraction of the **external intercostals** further increases the width of the thoracic cage by raising the ribs. Contraction of the **sternocleidomastoid**, **scalenes**, and **pectoralis minor muscles** cause a greater increase in thoracic volume by elevating the rib cage and sternum, resulting in a greater volume of air inhaled.

Normal exhalation is a passive process involving relaxation of the diaphragm and elastic recoil of the chest wall and lungs. The diaphragm becomes dome-shaped and decreases the length of the thoracic cavity and thoracic volume. In forced exhalation, contraction of the **internal intercostals** depresses the rib cage. Contraction of the **abdominal muscles** (**external oblique**, **internal oblique**, **transverse abdominis**, and **rectus abdominis**) pushes the diaphragm superiorly, further decreasing thoracic volume and resulting in a greater volume of exhaled air.

### ACTIVITY 8 Respiratory Muscles and Volume Changes

1. Label the respiratory muscles in Figure 26.10. Refer to Exercise 12: Muscles, your textbook, or an atlas.
2. Identify the respiratory muscles on a model or anatomical chart.
3. Pronounce the muscle names as you point to them.
4. Complete Table 26.2 and circle the correct choice in the column “Effect on Thoracic Dimensions.”
5. Examine the radiographs in Figure 26.11. Decide whether a radiograph was taken after inhalation or exhalation, and put your answer in the appropriate blank.
FIGURE 26.10 Respiratory muscles.

(a) Anterior superficial view

(b) Anterior deep view

- diaphragm
- external intercostal
- external oblique
- internal intercostal
- internal oblique
- pectoralis minor (pect-or-A-lis)
- rectus abdominis
- scalenea (SKAY-lee-uh)
- sternocleidomastoid (ster-no-ki-doh MAS-toyd)
- transverse abdominis

1. sternocleidomastoid
2. scalenea
3. pectoralis minor
4. rectus abdominis
5. external intercostal
6. transverse abdominis
7. diaphragm
8. internal intercostal
9. internal oblique
10. external oblique

548 Exercise 26 Respiratory System Structure and Function
### TABLE 26.2 Respiratory Muscle Functions

<table>
<thead>
<tr>
<th>MUSCLE</th>
<th>FUNCTION</th>
<th>EFFECT ON THORACIC DIMENSIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>External intercostals</td>
<td>Elevate ribs</td>
<td>Increase or decrease diameter</td>
</tr>
<tr>
<td>Internal intercostals</td>
<td>Depress ribs</td>
<td>Increase or decrease diameter</td>
</tr>
<tr>
<td>Sternocleidomastoids</td>
<td>Elevate the sternum</td>
<td>Increase or decrease diameter</td>
</tr>
<tr>
<td>Scalenes</td>
<td>Elevate first and second ribs</td>
<td>Increase or decrease diameter</td>
</tr>
<tr>
<td>Pectoralis minors</td>
<td>Elevate third, fourth, and fifth ribs</td>
<td>Increase or decrease diameter</td>
</tr>
<tr>
<td>Diaphragm</td>
<td>Flattens when contracted</td>
<td>Increase or decrease length</td>
</tr>
<tr>
<td>Abdominal muscles</td>
<td>Compress abdominal contents, increase abdominal pressure, and force diaphragm superiorly</td>
<td>Increase or decrease length</td>
</tr>
</tbody>
</table>

**FIGURE 26.11** Radiographs of thorax taken either after inhalation or exhalation.

(a) Indicate whether the view shows inhalation or exhalation.

(a) __________

(b) __________

FIGURE 26.11 Radiographs of thorax taken either after inhalation or exhalation.
B. Lung Volumes and Capacities

Lung volumes and capacities are defined in Table 26.4. These values vary according to gender, age, height, and physical condition.

1. Measuring TV, ERV, and VC

A spirometer is an instrument used to measure lung volumes and capacities. There are different types of spirometers depending on how they measure air volumes and capacities. Some spirometers measure only expiratory volumes and capacities while others measure both inspiratory and expiratory volumes and capacities. In this activity, you will be using a dry, handheld spirometer. **Exhale only into this type of spirometer.** It does not measure inspiratory volumes. Spirometers that measure inspiratory air volumes must be cleaned or supplied with new filters when used by a different person to prevent spread of infection.

Your instructor will supply you with instructions if you are using a different type of spirometer than the dry, handheld spirometer.

### Table 26.4 Lung Volumes and Capacities

<table>
<thead>
<tr>
<th>VOLUME OR CAPACITY</th>
<th>ABBREVIATION</th>
<th>DEFINITION</th>
<th>AVERAGE VALUES FOR HEALTHY ADULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tidal volume</td>
<td>TV</td>
<td>Amount of air moved into lungs during inhalation or out of lungs during exhalation</td>
<td>500 ml</td>
</tr>
<tr>
<td>Inspiratory reserve volume</td>
<td>IRV</td>
<td>Maximum amount of air that can be inhaled after a normal inhalation</td>
<td>3100 ml</td>
</tr>
<tr>
<td>Expiratory reserve volume</td>
<td>ERV</td>
<td>Maximum amount of air that can be exhaled after a normal exhalation</td>
<td>1200 ml</td>
</tr>
<tr>
<td>Residual volume</td>
<td>RV</td>
<td>Amount of air that remains in the lungs after a maximal exhalation</td>
<td>1200 ml</td>
</tr>
<tr>
<td>Inspiratory capacity</td>
<td>IC</td>
<td>IC = TV + IRV</td>
<td>3600 ml</td>
</tr>
<tr>
<td>Functional residual capacity</td>
<td>FRC</td>
<td>FRC = RV + ERV</td>
<td>2400 ml</td>
</tr>
<tr>
<td>Vital capacity</td>
<td>VC</td>
<td>VC = IRV + TV + ERV</td>
<td>4800 ml</td>
</tr>
<tr>
<td>Total lung capacity</td>
<td>TLC</td>
<td>TLC = IRV + TV + ERV + RV</td>
<td>6000 ml</td>
</tr>
</tbody>
</table>

### Preparations for Activity 10

**Preparing dry, handheld spirometer:**
- Wipe the nozzle of the spirometer with 70% alcohol.
- Place a clean, disposable mouthpiece on the nozzle.
- Use a noseclip or your fingers to close your nostrils to prevent air leaking out of your nose.
- When blowing into the spirometer, hold it in a horizontal position with the face of the dial superior.
- With use, water will condense inside the dial. Follow instructions included with your spirometer for removing the condensation.

### Activity 10 Measuring Lung Volumes and Capacities

1. Measure tidal volume (TV)
   - Reset the dial on the spirometer to 0. If the dial is not calibrated between 0 to 1000, then set the dial to 1000 (do this for TV measurement only). Make sure you subtract 1000 from your measurement before recording the value.
   - Take two or three normal breaths then inhale normally, place the spirometer to your lips and exhale normally into the spirometer. Record value in Table 26.5. Repeat this process two more times, resetting the dial before each measurement. Calculate and record the average TV.
### Measured Lung Volumes and Capacities

<table>
<thead>
<tr>
<th>MEASUREMENT</th>
<th>VALUE 1</th>
<th>VALUE 2</th>
<th>VALUE 3</th>
<th>AVERAGE VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>TV</td>
<td>300</td>
<td>450</td>
<td>450</td>
<td>400</td>
</tr>
<tr>
<td>ERV</td>
<td>1400</td>
<td>1500</td>
<td>1000</td>
<td>1300</td>
</tr>
<tr>
<td>VC</td>
<td>3700</td>
<td>3400</td>
<td>3400</td>
<td>3333.33</td>
</tr>
</tbody>
</table>

2. Calculating IRV, IC, RV, FRC, and TLC

Dry hand-held spirometers cannot be used to measure inspiratory volumes and capacities. However, IRV and IC can be calculated using values for TV, ERV, and VC.

Clinically, FRC is measured indirectly with special equipment and RV is calculated using values for FRC and ERV. In this activity, RV will be calculated with equations that were developed using measured RV values from many individuals.

### Activity 11: Calculating Lung Volumes and Capacities

1. Calculate IRV and IC.
   - Use the equations for VC and IC in Table 26.4 to calculate IRV and IC. Rearrange the VC equation to formulate an equation to calculate IRV.
   - Calculate the values and record them in Table 26.7.

2. Calculate RV, FRC, and TLC.
   - Use the appropriate equation in Table 26.8 to calculate your RV based on gender and age, and record RV in Table 26.7.
   - Calculate your FRC and TLC using the equations in Table 26.4 and record the value in Table 26.7.

### Equations for Predicting Vital Capacity*

<table>
<thead>
<tr>
<th>AGE</th>
<th>EQUATION TO PREDICT VC (LITERS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female 11–19</td>
<td>VC = (0.0416 × height in cm) - 4.4470 + (0.0699 × age in years)</td>
</tr>
<tr>
<td>Female 20–69</td>
<td>VC = (0.0444 × height in cm) - 3.1947 - (0.0169 × age in years)</td>
</tr>
<tr>
<td>Female &gt;69</td>
<td>VC = (0.0313 × height in cm) - 0.1889 - (0.0296 × age in years)</td>
</tr>
<tr>
<td>Male 12–24</td>
<td>VC = (0.0590 × height in cm) - 6.8865 + (0.0739 × age in years)</td>
</tr>
<tr>
<td>Male &gt;24</td>
<td>VC = (0.0844 × height in cm) - 8.7818 - (0.0298 × age in years)</td>
</tr>
</tbody>
</table>

### Table 26.7 Calculated Lung Volumes and Capacities

<table>
<thead>
<tr>
<th>Volume or Capacity</th>
<th>Equation</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRV</td>
<td>VC + TV - ERV</td>
<td>7433.33</td>
</tr>
<tr>
<td>IC</td>
<td>TV + IRV - IC</td>
<td>2833.33</td>
</tr>
<tr>
<td>RV</td>
<td>(0.029 x H) - 9192</td>
<td>1.0818 x1000</td>
</tr>
<tr>
<td>FRC</td>
<td>RV + ERV</td>
<td>1301.08</td>
</tr>
<tr>
<td>TLC</td>
<td>IRV + TV + ERV + RV</td>
<td>4134.4</td>
</tr>
</tbody>
</table>

**Equation for Calculating Residual Volume**

**Gender** | **Age** | **Equation to Predict RV (Liters)**
---|---|---
Male or Female<19 | RV = (0.029 x height in inches) - 0.9192 |
Female | 19–99 | RV = (0.0813 x height in inches) + (0.009 x age in years) - 3.9 |
Male | 19–99 | RV = (0.0686 x height in inches) + (0.017 x age in years) - 3.45 |

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### 3. Timed Forced Expiratory Volumes

A timed forced expiratory volume is used to indicate whether someone has a condition in which air flow is obstructed or restricted. The subject is asked to inhale as much air as possible, then forcibly blow as much air as fast as possible into the spirometer. The volume of air forcibly expelled in the first second (forced expiratory volume in 1 second or FEV₁) and the total volume of forcibly expelled air (forced vital capacity (FVC)) are used to determine if a person has an obstructed air flow. The FEV₁/FVC ratio is used to indicate if a person has an obstructive disease such as chronic obstructive pulmonary disease (COPD). In COPD the airway is obstructed and it takes longer to move air out of the lungs, therefore the FEV₁ is reduced. During pregnancy, the thoracic volume is restricted so that FVC is reduced, but the ratio of FEV₁/FVC is normal (assumes no obstructive disease).

### Activity 12 Measuring FEV₁ and FVC

1. Measure FVC and FEV₁ in Figure 26.13 and record the value on the figure.
   - The graph illustrates the change in volume over time. The x-axis indicates time and the y-axis indicates volume.

   - Use the values on the y-axis to determine the maximum volume indicated by the curved line. This is the FVC.
   - Find 1 second on the x-axis. Using a ruler, draw a vertical line that intersects the curve. Using the ruler, find the corresponding volume on the y-axis. This is the FEV₁.

2. Calculate the FEV₁/FVC ratio and record the value on Figure 26.13.

<table>
<thead>
<tr>
<th>Volume (L)</th>
<th>Time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>6</td>
</tr>
</tbody>
</table>

**FIGURE 26.13** Timed forced expiratory volume.
Using your textbook, beginning on page 829, answer the following questions related to respiratory physiology.

1. Respiration includes which two processes? External and Internal

2. What is internal respiration?
   Gas exchange at the tissues / organs (cellular respiration)

3. What is external respiration?
   Gas exchange between blood and external environment
   (Pulmonary respiration)

4. What are the 3 main steps to external respiration?
   a. Pulmonary Ventilation - Physically moving air into the lungs.
   b. Gas Diffusion - Across the respiratory membrane between alveolar air spaces and alveolar capillaries.
   c. Transport of Oxygen and CO₂ - Between alveolar capillaries and capillary beds and other tissues.

5. What is pulmonary ventilation?
   The physical movement of air into the lungs and out of the respiratory tract.
   1 atm pressure = 760 mm Hg = 1 torr (respiratory therapists) = 133.3 cm water = 15 psi

6. Describe how carbon dioxide is related to pulmonary ventilation?
   Purpose = release CO₂

7. Describe Boyle’s Law
   Decrease volume of gas; pressure will increase.

How does Boyle’s Law relate to breathing?
   Pressure of air flow to lungs.
9. What is atmospheric pressure?
Weight of Earth's pressure compresses our bodies and everything around us.

10. How does pressure affect airflow into the lungs?
Air flow from high to low pressure, this directed air flow and pressure of Boyle's low provides by is of pulmonary ventilation.

11. What role does the diaphragm play in this process?
When the diaphragm contracts it tenses and moves inferiorly. This increases the volume of the thoracic cavity reducing pressure within it.

12. What happens to cause us to exhale?
When the rib cage returns to the upright position and diaphragm relaxes.

---

Ribs and sternum elevate
Diaphragm contracts

Pleural cavity
Cardiac notch

Pressure outside and inside are equal, so no air movement occurs

Volume increases
$P_{\text{outside}} > P_{\text{inside}}$
Pressure inside falls, so air flows in

Volume decreases
$P_{\text{outside}} < P_{\text{inside}}$
Pressure inside rises, so air flows out

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13. List the muscles that are responsible for...

a. Normal Inhalation→ **Diaphragm** (75 %) and **external intercostals** (25 %)

b. Deep Inhalation→ **sternomastoid** (sternum), **pectoralis minor** (ribs 3, 4, 5), **serratus anterior** (ribs 1 & 2) and the Serratus Anterior

c. Normal Exhalation→

d. Forced Exhalation→ **internal intercostals**, **rectus abdominus**.

**Muscles of Respiration**

- **Sternomastoids**
- **Scalenes**
- **Inspiratory Intercostals**
- **Expiratory Intercostals**
- **Diaphragm**
- **External Obliques**
- **Internal Obliques**
Physiology Review of the Respiratory System

A. Function of Respiratory Muscles
Match the respiratory muscles to the appropriate muscle function.

1. elevates third, fourth, and fifth ribs
2. elevates the sternum
3. depresses ribs (exhale)
4. compresses abdominal contents and increases abdominal pressure
5. elevates first and second ribs
6. elevates ribs
7. main inspiratory muscle
8. two muscles used in forced expiration

a. abdominal muscles
b. diaphragm
c. external intercostals
d. internal intercostals
e. pectoralis minor
f. scalenes
g. sternocleidomastoids

B. Volume and Pressure Changes During Pulmonary Ventilation
Indicate whether the volume or pressure increases or decreases during inspiration and expiration.

<table>
<thead>
<tr>
<th>VOLUME OR PRESSURE</th>
<th>INSPIRATION</th>
<th>EXPIRATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thoracic volume</td>
<td>1.</td>
<td>2.</td>
</tr>
<tr>
<td>Intrapleural cavity volume</td>
<td>3.</td>
<td>4.</td>
</tr>
<tr>
<td>Intrapleural pressure</td>
<td>5.</td>
<td>6.</td>
</tr>
<tr>
<td>Lung volume</td>
<td>7.</td>
<td>8.</td>
</tr>
<tr>
<td>Alveolar (intrapulmonic) pressure</td>
<td>9.</td>
<td>10.</td>
</tr>
</tbody>
</table>

C. Lung Volumes and Capacities
Match lung volumes and capacities with the appropriate definition or equation.

1. equal to TV + IRV + ERV + RV
2. equal to IC − TV
3. equal to FRC − ERV
4. equal to TV + IRV
5. volume of air remaining in lungs after normal expiration
6. maximum amount of air that can be exhaled after a normal expiration
7. maximum amount of air that can be exhaled after a maximal inspiration
8. equal to IC − IRV

a. expiratory reserve volume
b. functional residual capacity
c. inspiratory capacity
d. inspiratory reserve volume
e. residual volume
f. tidal volume
g. total lung volume
h. vital capacity
D. Control of Pulmonary Ventilation: The Role of Carbon Dioxide

True or False. If false circle the word(s) that are incorrect and correct them.

1. If blood carbon dioxide levels increase, then blood hydrogen ion levels will decrease. **False**

2. If blood carbon dioxide levels increase, then blood pH will decrease. **True**

3. Increasing blood carbon dioxide levels decreases breathing rate. **False**

**Diagram:**
- Inhale: External Intercostal, Diaphragm
- Deep Inhale: Sclones, Sterno, Pec, Minor
- Exhale: None
- Force Exhale: Internal Intercostal, Abdominal
**Figure 26.8 Pleura.**

- diaphragm
- parietal pleura
- pleural cavity
- visceral pleura

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</table>

- left lung
- pericardium
- parietal pleura
- pleural cavity
- right lung
- visceral pleura

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<td>9</td>
<td></td>
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<tr>
<td>10</td>
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</tr>
</tbody>
</table>
O₂

1. Dissolved in plasma
2. Hb + O₂ ⇌ HbO₂

Pressure, pH, temp

CO₂

1. Dissolved: CO₂ + H₂O → H₂CO₃
2. HbCO₂
3. Carbonic Acid: CO₂ + H₂O → H₂CO₃

↓ CO₂ = ↓ H⁺ = ↓ pH
↑ CO₂ = ↑ H⁺ = ↑ pH
FIGURE 26.7 Lung structures.
FIGURE 26.8 Pleura.

- diaphragm
- parietal pleura
- pleural cavity
- visceral pleura

1. Visceral pleura
2. Parietal pleura
3. Pleural cavity
4. Diaphragm

5. Left lung
6. Right lung
7. Pericardium
8. Pleural cavity
9. Parietal pleura
10. Visceral pleura

(b) Cross-section through thorax (inferior view)

(a) Anterior view
Anatomy Review of the Respiratory System

A. Air Flow
Trace the air flow through the respiratory system starting with the external nares. Number the structures 1 through 17.

1. alveolar duct
2. alveolar sac
3. alveolus
4. bronchiole
5. external nares
6. internal nares
7. larynx
8. laryngopharynx
9. nasal cavity
10. nasopharynx
11. oropharynx
12. primary bronchus
13. respiratory bronchiole
14. secondary bronchus
15. terminal bronchiole
16. tertiary bronchus
17. trachea

B. Structural Changes in the Respiratory Tree
Name three structural changes that occur in the bronchi as they branch into bronchioles.
1. From smaller passageways
2. Goes to each lobe
3. Each tertiary bronchi supplies air to a single broncho pulmonary segment

C. Explain why food or liquid in the mouth can be expelled from the nostrils if the mouth is closed when the person laughs.

The passageways are all connected
D. Structure and Function

Match the structure with the correct function.

1. tubular airways that begin the respiratory zone  
   a. alveolus  
2. connects the laryngopharynx with the trachea  
   b. bronchiole  
3. tubelike structure that conducts air from the larynx to the bronchi  
   c. epiglottis  
4. closes over the glottis during swallowing  
   d. larynx  
5. keep the trachea from collapsing  
   e. tracheal cartilages  
6. division of the bronchi that enter bronchopulmonary segments  
   f. oropharynx  
7. last division of the conducting zone  
   g. tertiary bronchus  
8. conducts air from the nasopharynx to the laryngopharynx  
   h. respiratory bronchiole  
9. small, round sacs where gas exchange occurs  
   i. terminal bronchiole  
10. small conduction airway that serves a lobule  
    j. trachea

E. Match the type of epithelium with its location in the respiratory system and its function.

Location:

1. nasal cavity through nasopharynx  
   a. pseudostratified ciliated columnar  
2. oropharynx through larynx above vocal cords  
   b. simple columnar  
3. larynx below vocal cords through primary bronchi  
   c. simple cuboidal  
4. secondary bronchi through tertiary bronchi  
   d. simple squamous  
5. bronchioles through beginning of respiratory bronchiole  
   e. stratified squamous  
6. end of respiratory bronchiole through alveoli

Function:

7. secretes mucus to trap and remove dust and debris  
   a. pseudostratified ciliated columnar  
8. diffusion of respiratory gases  
    b. simple columnar  
9. protects underlying tissues  
    c. simple cuboidal
Background:

Blood pressure, the pressure exerted by blood against blood vessel walls, is highest in the aorta and the larger elastic arteries and decreases as the arteries branch further away from the heart. By the time blood gets back to the right atrium, blood pressure has dropped to zero. Venous blood pressure therefore is low, and blood flow back to the heart (against gravity) is difficult. The difference in blood pressure between the aorta and right atrium causes blood to flow through the systemic circulation. The pressure difference between the pulmonary trunk and the left atrium causes the blood to flow through the pulmonary circuit.

With each contraction of the ventricles, blood pressure fluctuates in the large arteries. Blood pressure during contraction (systole) is higher than blood pressure during ventricular relaxation (diastole).

Arterial blood pressure is measured in mmHg and can be determined by using a blood pressure cuff or sphygmomanometer in any large artery. Clinically, the brachial artery is most often used. A pump is used to inflate the rubber cuff to a pressure greater than the systolic pressure. This puts pressure on the artery, flattens it and stops the blood flow. Pressure is slowly released by opening a valve.

When blood pressure is greater than the pressure in the cuff, the artery opens and blood flow resumes. A sound caused by the turbulent flow of blood can be heard until blood flow returns to normal. The first sound heard is the systolic pressure (average 120mmHg) and the last, faint sound heard is the diastolic pressure (average 80mmHg). Blood pressure is written as systolic pressure/diastolic pressure (average 120/80mmHg).

Venous blood pressure can also be determined by inserting a pressure transducer directly into a vein or indirectly as described in this activity. Average venous pressure is 16mmHg.

Procedure: Working in teams of two
Part I: Resting Blood Pressure

1. The subject should sit and rest for 5 minutes before measuring blood pressure.
2. Obtain a stethoscope and sphygmomanometer. Wipe the earpieces of the stethoscope clean with alcohol and completely deflate the blood pressure cuff.
3. Place the sphygmomanometer cuff around the arm so that the inflatable portion is over the anterior surface of the arm. The bottom of the cuff should be approximately 1 inch above the elbow.
4. Close the valve on the rubber bulb.
5. Place the large bell of the stethoscope over the brachial artery, insert the earpieces and listen for the pulse.
6. Inflate the cuff by squeezing the bulb until the pressure gauge reaches 160-180mmHg.
7. Immediately use the valve on the hand pump to slowly release air to deflate the cuff and listen for the first sound (systolic pressure).
8. Watch the pressure gauge and continue to listen. The sound will increase, then muffle and stop. The diastolic pressure is the last, faint sound.
9. Record your measurements in Table 1.
10. Deflate the cuff and have the subject rest for 2 minutes before repeating the measurement. Record the second measurement in Table 1.

Part II: Pulse Pressure and Mean Arterial Pressure

Calculate each of the following and record in Table 1

1. Pulse Pressure- the larger the pulse pressure, the greater the volume of blood will be from the ventricle
   \[ \text{Pulse Pressure} = \text{systolic} - \text{diastolic pressure} \]

2. Mean Arterial Pressure is the average blood pressure over the course of the cardiac cycle
   \[ \text{MAP} = \text{diastolic bp} + \left( \frac{\text{pulse pressure}}{3} \right) \]

Part III: Venous Pressure

1. Stand against the chalk board or white wall with arms hanging by the side and observe the blood pooling in the veins on the dorsal hand surface
2. Locate the approximate location of the right atrium (at the same level as the nipples). Use tape or chalk to indicate the location.
3. Abduct one arm and observe the veins become smaller and flatten as the arm is raised above the level of the right atrium.
4. Mark the location of the hand with tape or chalk
5. Measure the vertical distance between the right atrium mark and the point at which the veins flattened in millimeters.
6. Repeat this procedure and record results in Table 1
7. Each 12.88 mm elevation of the hand above the right atrium represents approximately 1mm rise in Hg.

\[ \text{Venous Pressure (mmHg)} = \frac{\text{mm measured}}{12.88 \text{ mm elevation/mmHg}} \]

Part IV: Regulation of Blood Pressure

Background:
The body maintains blood pressure to ensure adequate blood flow to the body tissues. If blood pressure is too low, tissues may not be provided with enough oxygen or nutrients, and, if the blood pressure is too high, it may cause damage to capillaries and the lining of blood vessels. Blood viscosity, total blood vessel length and blood vessel diameter all influence the mean arteriole pressure. Only blood vessel diameter can be changed to make immediate changes in blood pressure. Increasing blood vessel diameter (vasodilation) decreases resistance and lowers blood pressure, while decreasing blood vessel diameter (vasoconstriction) increases resistance and blood pressure rises

1. Observe the effect of body position on blood pressure and heart rate by measuring both in the supine position. Record in Table 2.
2. Take both measurements again immediately after standing and also after standing for 2 minutes. Record in Table 2.
3. Observe the effect of exercise on blood pressure by measuring the systolic and diastolic blood pressure and heart rate while standing at rest.
4. Re-measure both blood pressure and heart rate after exercising for 5 minutes (running in place, climbing stairs, etc.). Record all values in Table 3.
### Table 1: Resting Blood Pressure

<table>
<thead>
<tr>
<th>Subject</th>
<th>Systolic Pressure</th>
<th>Diastolic Pressure</th>
<th>Pulse Pressure</th>
<th>MAP</th>
<th>Venous Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject 1</td>
<td>1. 1/4</td>
<td>1. 1/4</td>
<td>1. 6/4</td>
<td>1. 1/4</td>
<td>1. 6/4</td>
</tr>
<tr>
<td></td>
<td>2. 6/4</td>
<td>2. 7/3</td>
<td>2. 9/3</td>
<td>2. 6/4</td>
<td>2. 6/4</td>
</tr>
<tr>
<td>Avg.</td>
<td>106.5</td>
<td>Avg. 8.5</td>
<td>Avg. 86.5</td>
<td>Avg. 107.18</td>
<td>Avg. 6.14</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Subject 2</th>
<th>Systolic Pressure</th>
<th>Diastolic Pressure</th>
<th>Pulse Pressure</th>
<th>MAP</th>
<th>Venous Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject 2</td>
<td>1. 1/4</td>
<td>1. 7/7</td>
<td>1. 5/2</td>
<td>1. 94.33</td>
<td>1. 5/3</td>
</tr>
<tr>
<td></td>
<td>2. 7/3</td>
<td>2. 5/5</td>
<td>2. 9/4</td>
<td>2. 6/2</td>
<td>2. 6/2</td>
</tr>
<tr>
<td>Avg.</td>
<td>120</td>
<td>Avg. 76</td>
<td>Avg. 54.5</td>
<td>Avg. 44.165</td>
<td>Avg. 5.775</td>
</tr>
</tbody>
</table>

### Table 2: Effect of Body Position on Blood Pressure

<table>
<thead>
<tr>
<th>Subject</th>
<th>Supine BP and HR</th>
<th>BP and HR after Standing</th>
<th>BP and HR after Standing 2 minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject 1</td>
<td>Systolic BP: 163</td>
<td>Systolic BP: 126</td>
<td>Systolic BP: 108</td>
</tr>
<tr>
<td></td>
<td>Diastolic BP: 77</td>
<td>Diastolic BP: 76</td>
<td>Diastolic BP: 66</td>
</tr>
<tr>
<td></td>
<td>HR: 78</td>
<td>HR: 80</td>
<td>HR: 84</td>
</tr>
<tr>
<td>Subject 2</td>
<td>Systolic BP: 105</td>
<td>Systolic BP: 117</td>
<td>Systolic BP: 115</td>
</tr>
<tr>
<td></td>
<td>Diastolic BP: 75</td>
<td>Diastolic BP: 83</td>
<td>Diastolic BP: 76</td>
</tr>
<tr>
<td></td>
<td>HR: 62</td>
<td>HR: 67</td>
<td>HR: 68</td>
</tr>
</tbody>
</table>

### Table 3: Effect of Exercise on Blood Pressure

<table>
<thead>
<tr>
<th>Subject</th>
<th>Resting Blood Pressure</th>
<th>Post Exercise Blood Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject 1</td>
<td>Systolic BP: 169</td>
<td>Systolic BP: 110</td>
</tr>
<tr>
<td></td>
<td>Diastolic BP: 77</td>
<td>Diastolic BP: 73</td>
</tr>
<tr>
<td></td>
<td>HR: 82</td>
<td>HR: 104</td>
</tr>
<tr>
<td>Subject 2</td>
<td>Systolic BP: 125</td>
<td>Systolic BP: 114</td>
</tr>
<tr>
<td></td>
<td>Diastolic BP: 73</td>
<td>Diastolic BP: 68</td>
</tr>
<tr>
<td></td>
<td>HR: 71</td>
<td>HR: 106</td>
</tr>
</tbody>
</table>

### Analysis Questions:

1. Describe the changes in blood pressure from supine to standing and also after exercise. Be specific.

   My numbers went down a little from supine to standing. They also went down again from standing to exercising.

2. What happens to the blood vessel diameter at the surface of the skin during exercise? Why does this occur?

   They expand so heart can leave the body.
Respiratory Physiology

10. Using the key choices, select the terms identified in the following descriptions by inserting the appropriate term or letter in the answer blanks.

**KEY CHOICES:**

A. Atmospheric pressure  
B. Intrapulmonary pressure  
C. Intrapleural pressure

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<tbody>
<tr>
<td>1. In healthy lungs, it is always lower than atmospheric pressure (that is, it is negative pressure)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Pressure of air outside the body</td>
<td></td>
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<tr>
<td>3. As it decreases, air flows into the passageways of the lungs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. As it increases over atmospheric pressure, air flows out of the lungs</td>
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<tr>
<td>5. If this pressure becomes equal to the atmospheric pressure, the lungs collapse</td>
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<tr>
<td>6. Rises well over atmospheric pressure during a forceful cough</td>
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</table>

11. Many changes occur within the lungs as the diaphragm (and external intercostal muscles) contract and then relax. These changes lead to the flow of air into and out of the lungs. The activity of the diaphragm is given in the left column of the following table. Several changes in condition are listed in the column heads to the right. Complete the table by checking (✓) the appropriate column to correctly identify the change that would be occurring relative to the diaphragm’s activity in each case.

<table>
<thead>
<tr>
<th>Activity of diaphragm</th>
<th>Changes in</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Internal volume of thorax</td>
<td>Internal pressure in thorax</td>
</tr>
<tr>
<td>(↑ = increased)</td>
<td>↑</td>
<td>↓</td>
</tr>
<tr>
<td>(↓ = decreased)</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Contracted, moves downward</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relaxed, moves superiorly</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Henry's law*
12. Use the key choices to respond to the following descriptions. Insert the correct term or letter in the answer blanks.

**KEY CHOICES:**

A. External respiration  
B. Expiration  
C. Inspiration  
D. Internal respiration  
E. Ventilation (breathing)

1. Period of breathing when air enters the lungs  
2. Exchange of gases between the systemic capillary blood and body cells  
3. Alternate flushing of air into and out of the lungs  
4. Exchange of gases between alveolar air and pulmonary capillary blood

13. Although normal quiet expiration is largely passive due to lung recoil, when expiration must be more forceful (or the lungs are diseased), muscles that increase the abdominal pressure or depress the rib cage are enlisted.

1. Provide two examples of muscles that cause abdominal pressure to rise. **Diaphragm**
2. Provide two examples of muscles that depress the rib cage. **Internal intercostal**

14. Four nonrespiratory movements are described here. Identify each by inserting your answers in the spaces provided. 

1. Sudden inspiration, resulting from spasms of the diaphragm. **HICcup, yawn**
2. A deep breath is taken, the glottis is closed, and air is forced out of the lungs against the glottis; clears the lower respiratory passageways. **Cough**
3. As just described, but clears the upper respiratory passageways. **Sneeze**
4. Increases ventilation of the lungs; may be initiated by a need to increase oxygen levels in the blood. **Breathe**
1. Describe the movement of oxygen from the alveoli to the surrounding capillaries (Be sure to provide partial pressures of oxygen in both locations).

   Oxygen diffuses to the location of a lower concentration.

   \[ \text{Alveolar} - P_{O_2} = 105 \]

2. Describe the movement of carbon dioxide from capillaries to surrounding tissues (Be sure to provide partial pressures of carbon dioxide in both locations).

   \[ P_{CO_2} = 45 \]

3. Describe the proportion of oxygen in the plasma to oxygen in red blood cells.

   There is a lot more in the RBC than in blood/plasma.

4. What is oxyhemoglobin? How is it formed?

   \[ \text{Hb} + \text{O}_2 \rightarrow \text{HbO}_2 \]

5. What is the relationship between the partial pressure of oxygen and the percent oxygen saturation (see Figure 23-21)?

   \[ P_{O_2} \rightarrow \% \text{OS} \]

6. What happens to the percent oxygen saturation if the amount of oxygen in the plasma decreases?

   Saturation decreases.
7. Describe the effect of...
   a. pH changes on oxygen-hemoglobin saturation
      \[ \text{pH} \downarrow \Rightarrow \text{Saturation} \downarrow \]
   b. temperature on oxygen-hemoglobin saturation
      \[ \text{Temp} \uparrow \]

8. How do carbon dioxide levels effect oxygen saturation?
   \[ \text{CO}_2 \uparrow \Rightarrow \text{pH} \downarrow \Rightarrow \text{Hb} \text{O}_2 \text{ Saturation} \]
   \[ \text{CO}_2 \downarrow \Rightarrow \text{pH} \uparrow \Rightarrow \text{Saturation} \downarrow \]

9. What are the three fates of carbon dioxide after it has been produced by the tissues and enters the bloodstream
   a. Carboxyhemoglobin
   b. Binds with hemoglobin (23%)
   c. Dissolves (7%)

10. Describe Carbonic Acid Formation. List the equation
    \[ \text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{Carbonic Acid} \rightleftharpoons \text{H}^+ + \text{Bicarbonate} \]

11. What is Carbaminohemoglobin? List the equation
ACTIVITY 5 Bronchial Tree

1 Label the structures in Figure 26.5(a) and (b) and Figure 26.6.
2 Locate the structures on a lung model.
3 Pronounce each term as you point to it on the model.
4 Palpate the sternal angle to locate where the trachea divides into the primary bronchi.
5 Observe the sheep pluck demonstration with the bronchial tree dissected.

- bronchus (BRON-key-oil)
- carina (ka-RIE-na)
- diaphragm
- larynx
- primary-bronchus, left
- primary-bronchus, right
- secondary-bronchus, right
- tertiary-bronchus, left
- trachea
- tracheal-cartilage

1 trachea
2 Right Primary bronchus
3 Carina
4 Right Secondary bronchus
5 Diaphragm
6 Tracheal cartilage
7 Larynx
8 Left Primary bronchus
9 Tertiary bronchus, left
10 Bronchiole

- alveolar-sac (al-VEE-oh-lur)
- primary-bronchus
- secondary-bronchus
- respiratory-bronchiole
- terminal-bronchiole
- tertiary-bronchus

11 Primary bronchus
12 Secondary bronchus
13 Tertiary bronchus
14 Terminal bronchiole
15 Respiratory bronchiole
16 Alveolar-sac

CLINICAL NOTE: The airways can be clinically divided into three areas according to size:

large airways—trachea and bronchi
medium airways—bronchioles and terminal bronchioles
small airways—respiratory bronchioles, alveolar ducts, alveolar sacs, and alveoli

Respiratory medicine uses these terms to identify the location of diseases. Bronchitis is a large airway disease, asthma is a middle airway disease, and emphysema is a disease of the small airways.
5. Lungs

The two lungs are divided into three lobes on the right side and two lobes on the left. The three right lobes are the superior, middle, and inferior lobes, and the left lobes are called the superior and inferior lobes. The rounded superior part of the lung is the apex and the broader inferior part is the base that rests on the diaphragm. The left lobe has a concave surface called the cardiac notch that has the apex of the heart projecting into it. Each lung has a hilus, an area surrounded with pleura, where the bronchi, blood and lymphatic vessels, and nerves enter or exit the medial side of the lung. The lungs are in the thoracic cavity and are separated from each other by the heart and the mediastinum. Parietal pleura lines the thoracic cavity wall, and visceral pleura covers the surface of each lung. The pleural cavity is the space between the two pleural layers that contains pleural fluid.

### Activity: Lungs

1. Label the parts of the lung in Figure 26.7(a), (b), (c), and (d).
2. Identify these structures on a lung model or anatomical chart.
3. Pronounce the terms as you point to them.
4. Label the parts of the pleura in Figure 26.8(a) and (b).