Essentials of Anatomy & Physiology, **4th Edition**

Martini / Bartholomew

15 The Respiratory System

PowerPoint® Lecture Outlines
prepared by Alan Magid, Duke University

Slides 1 to 85

Respiratory System Functions

Functions of Respiratory System

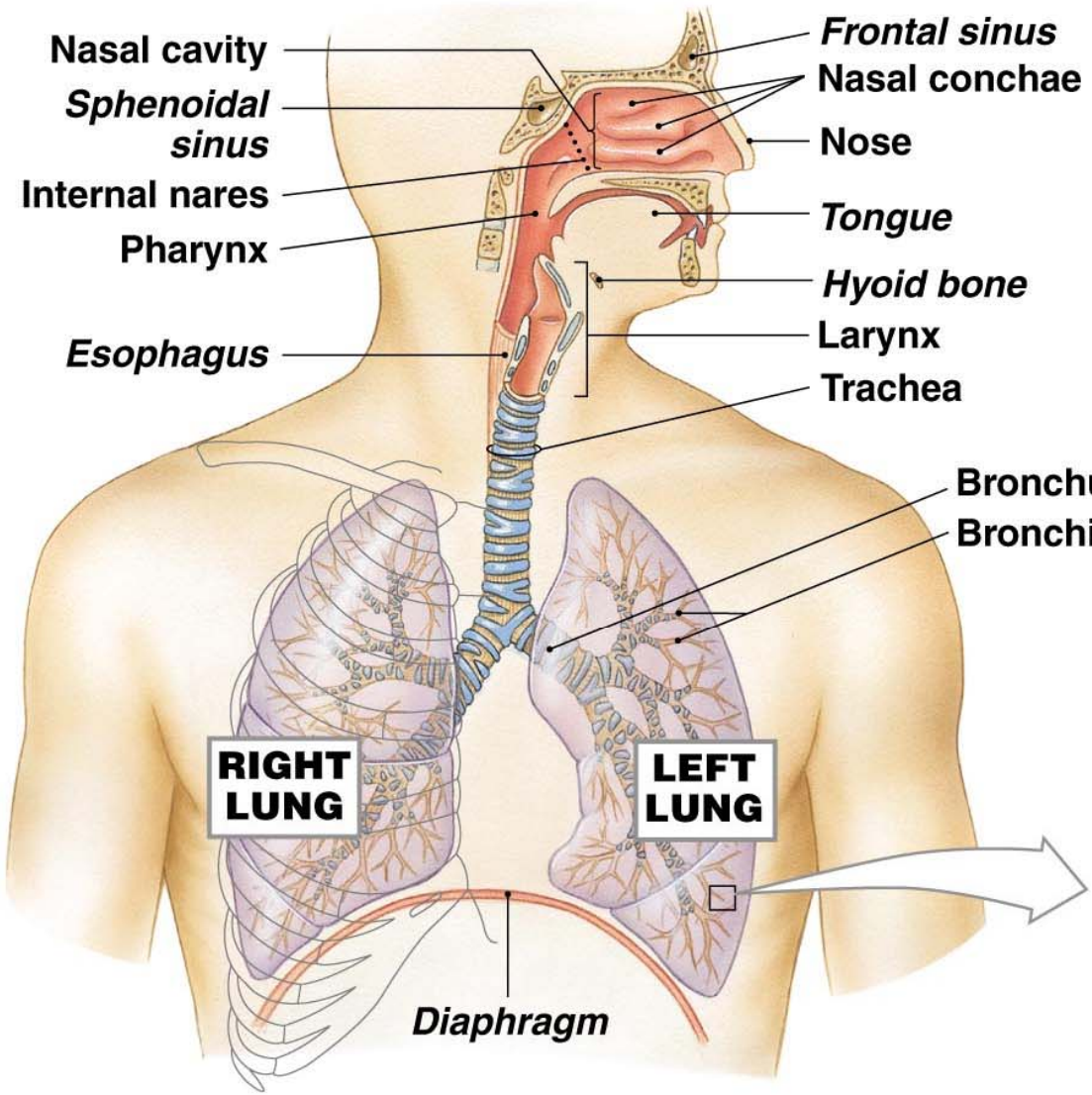
- Gas exchange between blood and air
- Move air to and from exchange surfaces
- Protect exchange surfaces from environmental variations and pathogens
- Produce sound
- Detect olfactory stimuli

Respiratory System Organization

Components of the Respiratory System

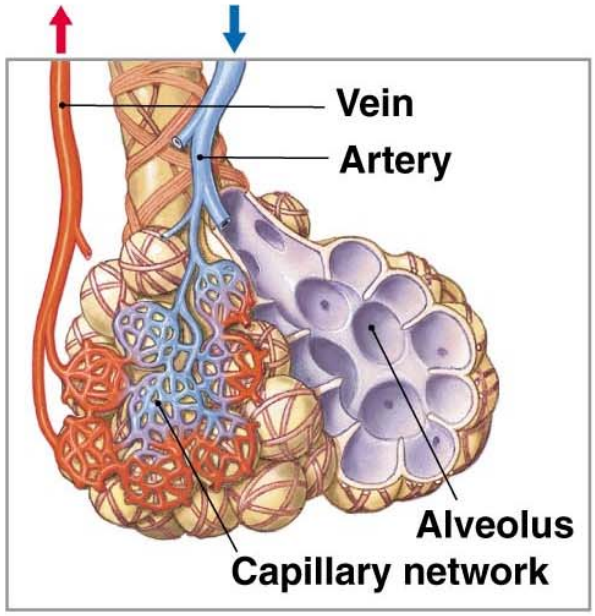
- Nose, nasal cavity, and paranasal sinuses
- Pharynx
- Larynx
- Trachea, bronchi
- Lungs
  - Bronchioles
  - Alveoli (gas exchange)

Respiratory System Organization



The Components of the Respiratory System

Figure 15-1



Respiratory System Organization

The Respiratory Tract

- Conducting portion
  - Conduct the air movement
  - From nares to small bronchioles
- Respiratory portion
  - Gas exchange region
  - Respiratory bronchioles and *alveoli*

PLAY The Respiratory Tract

Respiratory System Organization

The Nose

- External *nares* (nostrils) admit air
  - *Nasal vestibule* lined with hairs to filter air
- Vestibule opens into *nasal cavity*
  - Hard palate separates nasal and oral cavities
- Cavity continues through *internal nares* to *nasopharynx*
  - Soft palate underlies nasopharynx
- *Respiratory epithelium* lines the airways

Respiratory System Organization

The Nose, Nasal Cavity, and Pharynx

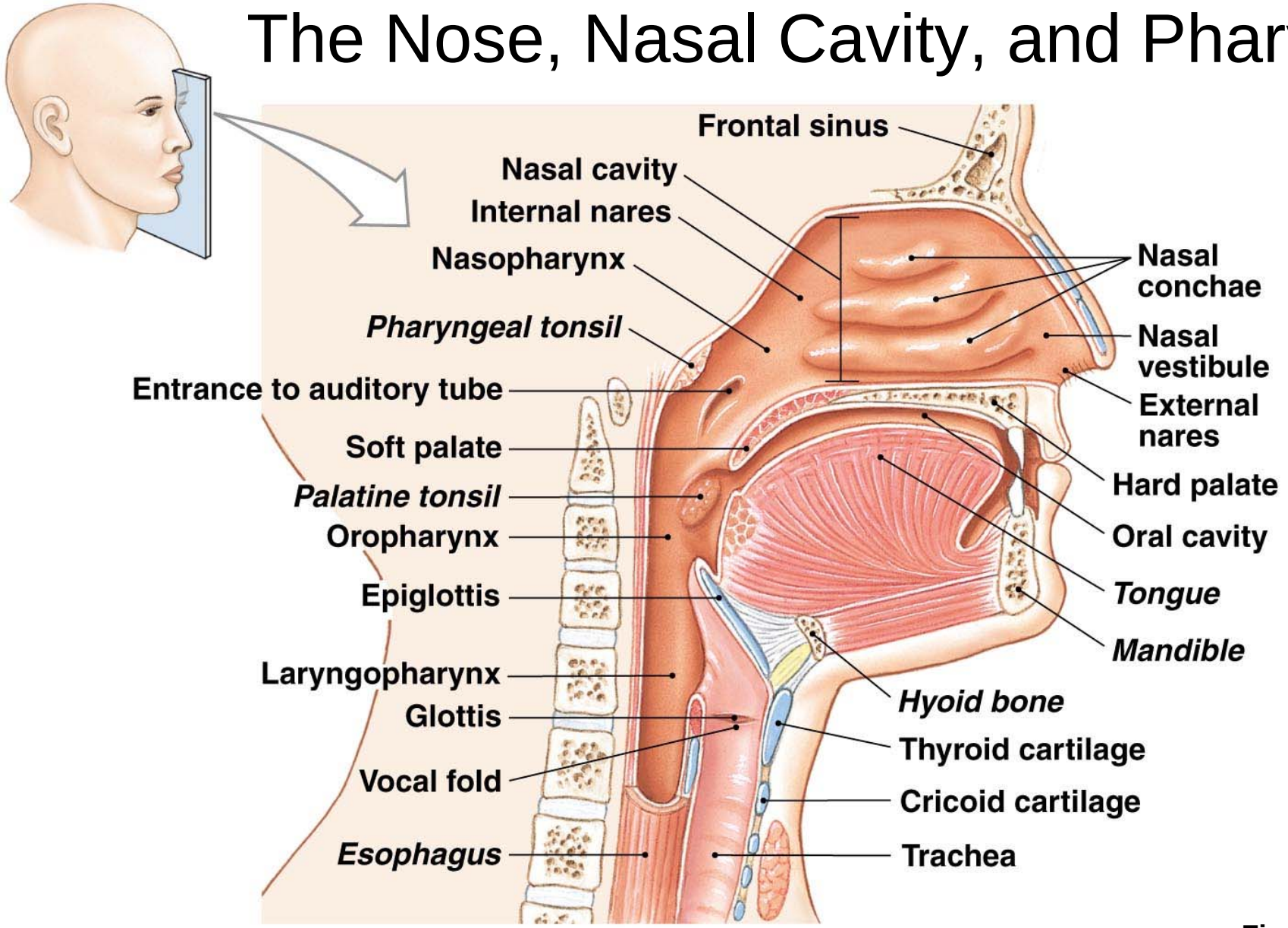


Figure 15-2

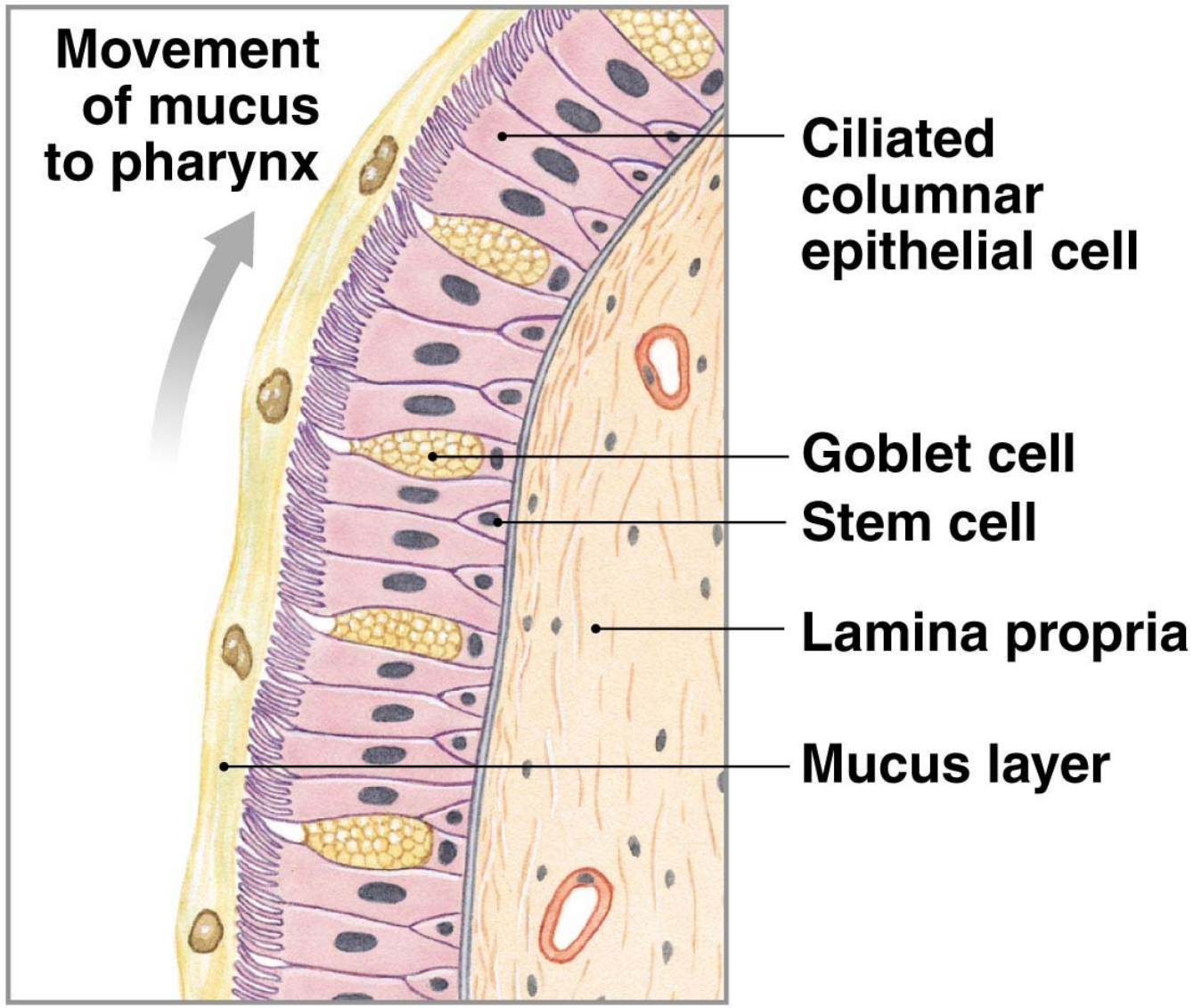
Respiratory System Organization

Respiratory Mucosa

- Respiratory epithelium plus supporting connective tissue with mucous glands
  - Lines nasal cavity and most of airways
  - Goblet and gland cells secrete mucus
  - Mucus traps inhaled dirt, pathogens, etc.
  - Ciliated cells sweep the mucus out of the airways into pharynx
  - Irritants stimulate secretion
    - Causes “runny nose”

Respiratory System Organization

The Respiratory Epithelium



(a)

Figure 15-3(a)

Respiratory System Organization

The Respiratory Epithelium

Figure 15-3(b) **(b)**

Respiratory System Organization

Three Regions of the Pharynx (Throat)

- Respiratory system only
  - *Nasopharynx*
- Shared with digestive system
  - *Oropharynx*
    - Opens into *both* esophagus and larynx
  - *Laryngopharynx*

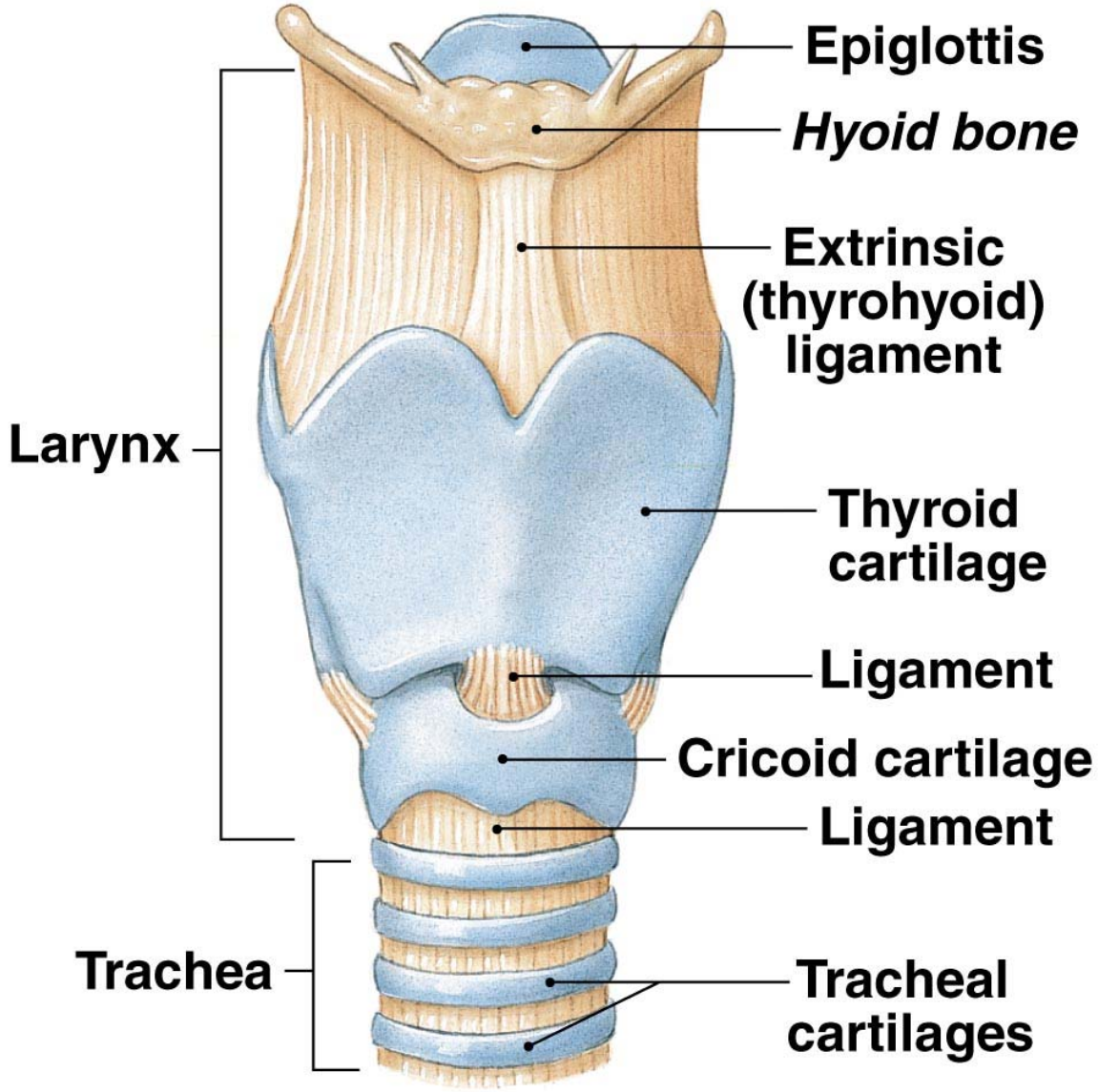
Respiratory System Organization

The Larynx

- Also called, “voice box”
- Made of nine cartilages
- Air passes through *glottis*
- Covered by *epiglottis* during swallowing
  - Keeps solids, liquids out of airways
  - Made of elastic cartilage
- Supports *true vocal cords*
  - Exhaled air vibrates them to make sound

Respiratory System Organization

The Anatomy of the Larynx and Vocal Cords



(a) Anterior view

Figure 15-4(a)

Respiratory System Organization

The Anatomy of the Larynx and Vocal Cords

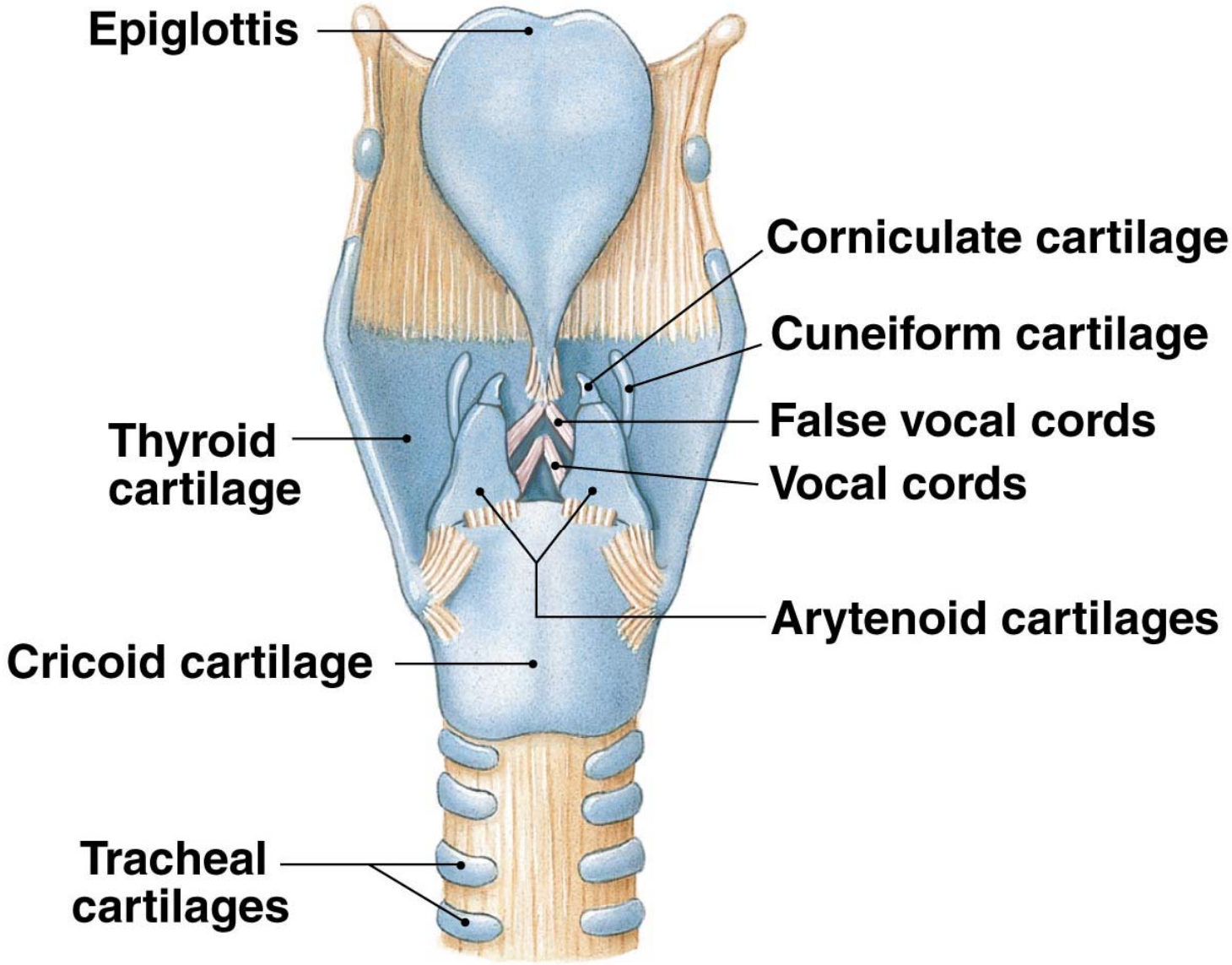
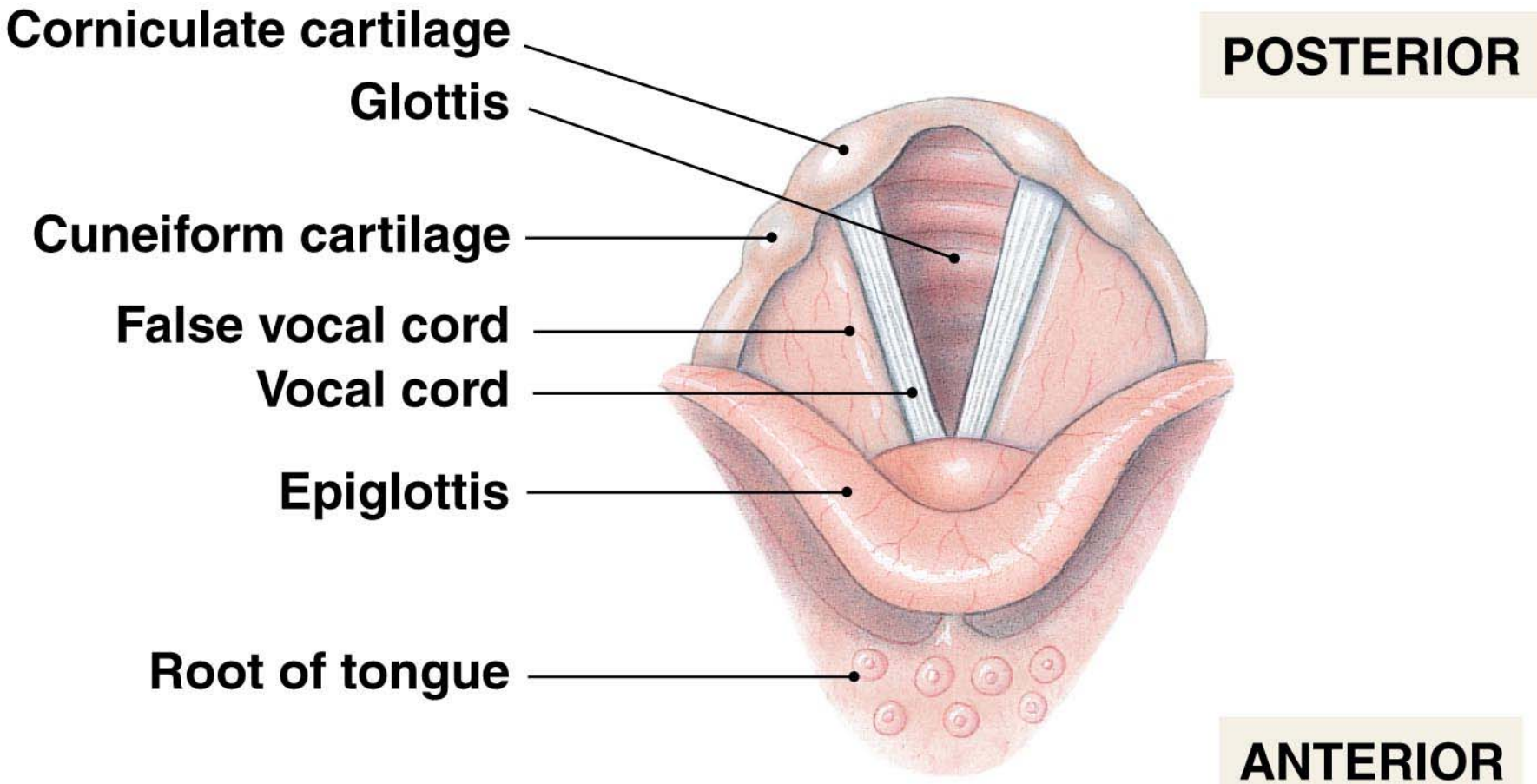


Figure 15-4(b)

Respiratory System Organization

The Anatomy of the Larynx and Vocal Cords



(c)

Figure 15-4(c)

Respiratory System Organization

The Anatomy of the Larynx and Vocal Cords

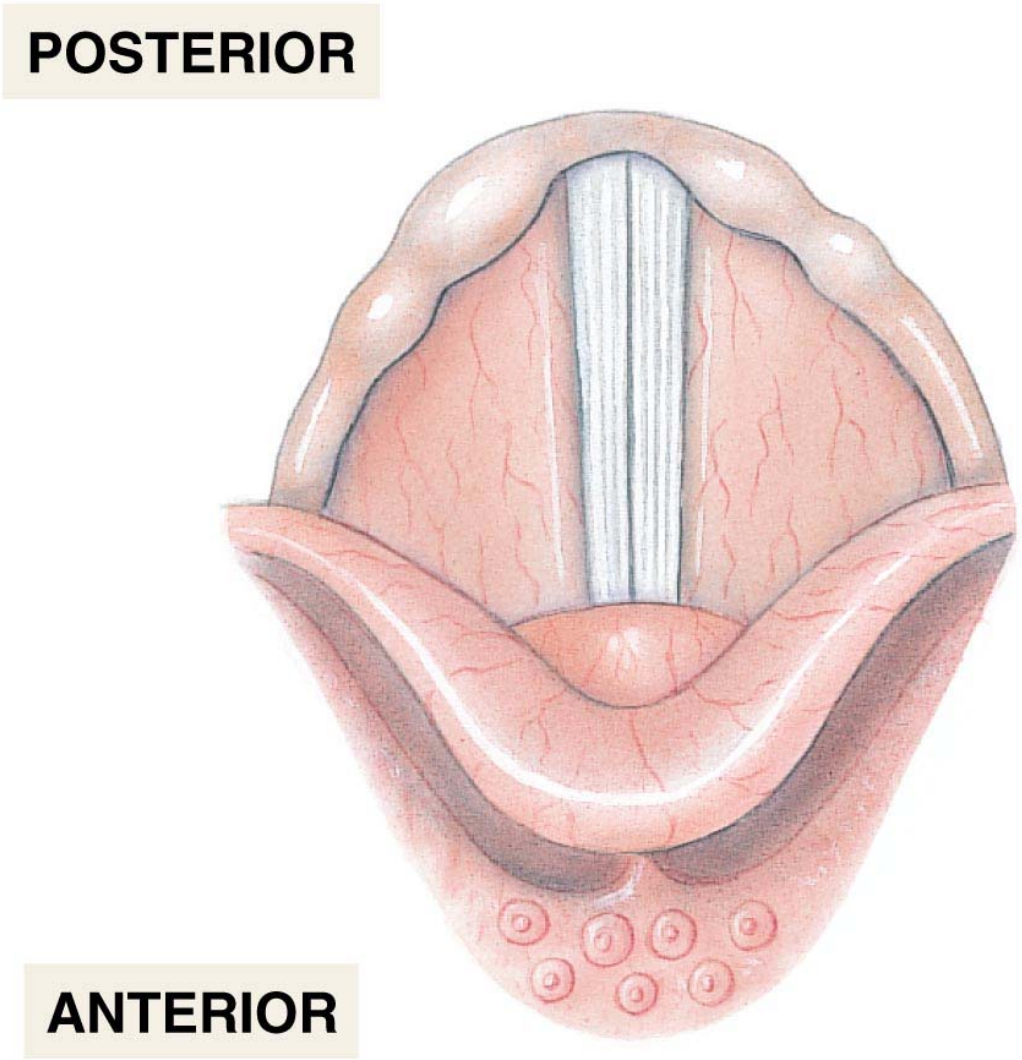


Figure 15-4(d)

(d)

Respiratory System Organization

The Anatomy of the Larynx and Vocal Cords

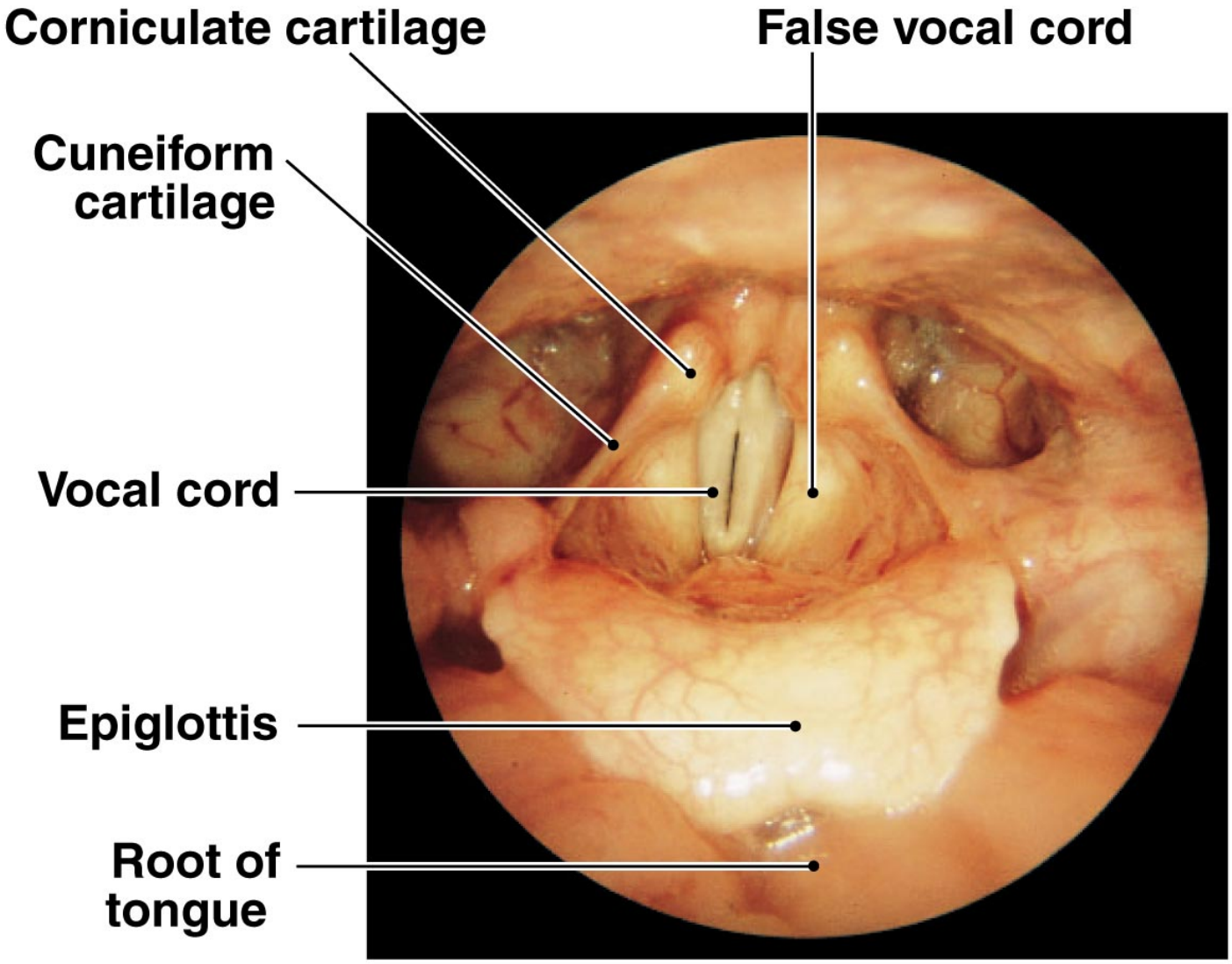


Figure 15-4(e)

Respiratory System Organization

The Trachea

- Also called “windpipe”
- Stiffened by C-shaped cartilage rings
- Esophagus stuck to posterior surface
  - Cartilage missing there
  - Trachea distorted by balls of food as they pass down esophagus to stomach

Respiratory System Organization

The Anatomy of the Trachea

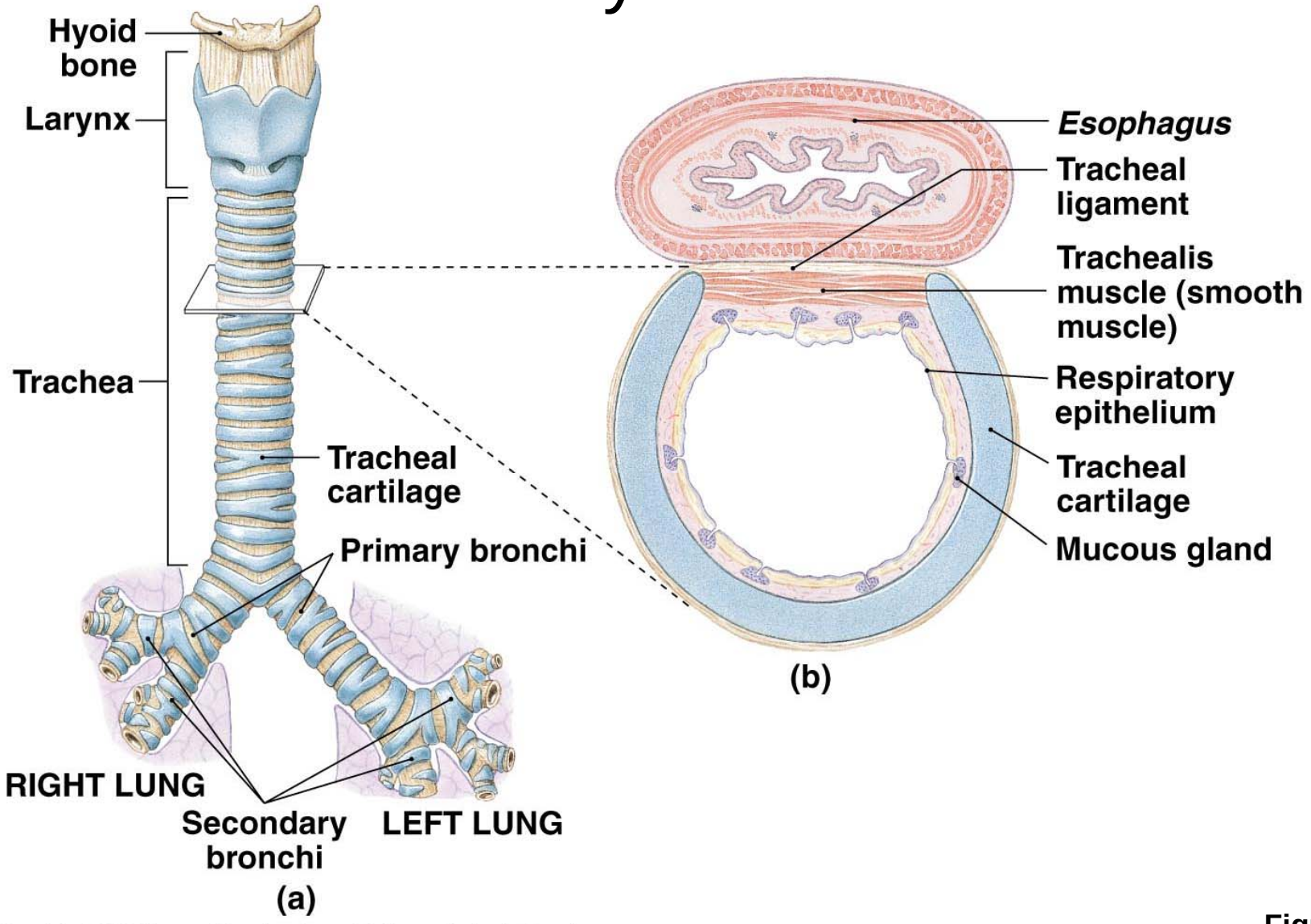


Figure 15-5

Respiratory System Organization

The Bronchi

- Trachea forms two branches
  - Right and left *primary bronchi*
- Primary bronchi branch
  - Form *secondary bronchi*
    - Each ventilates a *lobe*
- Secondary bronchi branch
  - Form *tertiary bronchi*
- Tertiary bronchi branch repeatedly
  - Cartilage decreases, smooth muscle increases

Respiratory System Organization

The Bronchioles

- Cartilage absent
- Diameter < 1.0 mm
- *Terminal bronchioles* deliver air to a single *lobule*
- Smooth muscle in wall controlled by ANS
  - Sympathetic causes *bronchodilation*
  - Parasympathetic causes *bronchoconstriction*
- Excess bronchoconstriction is *asthma*

Respiratory System Organization

The Bronchial Tree

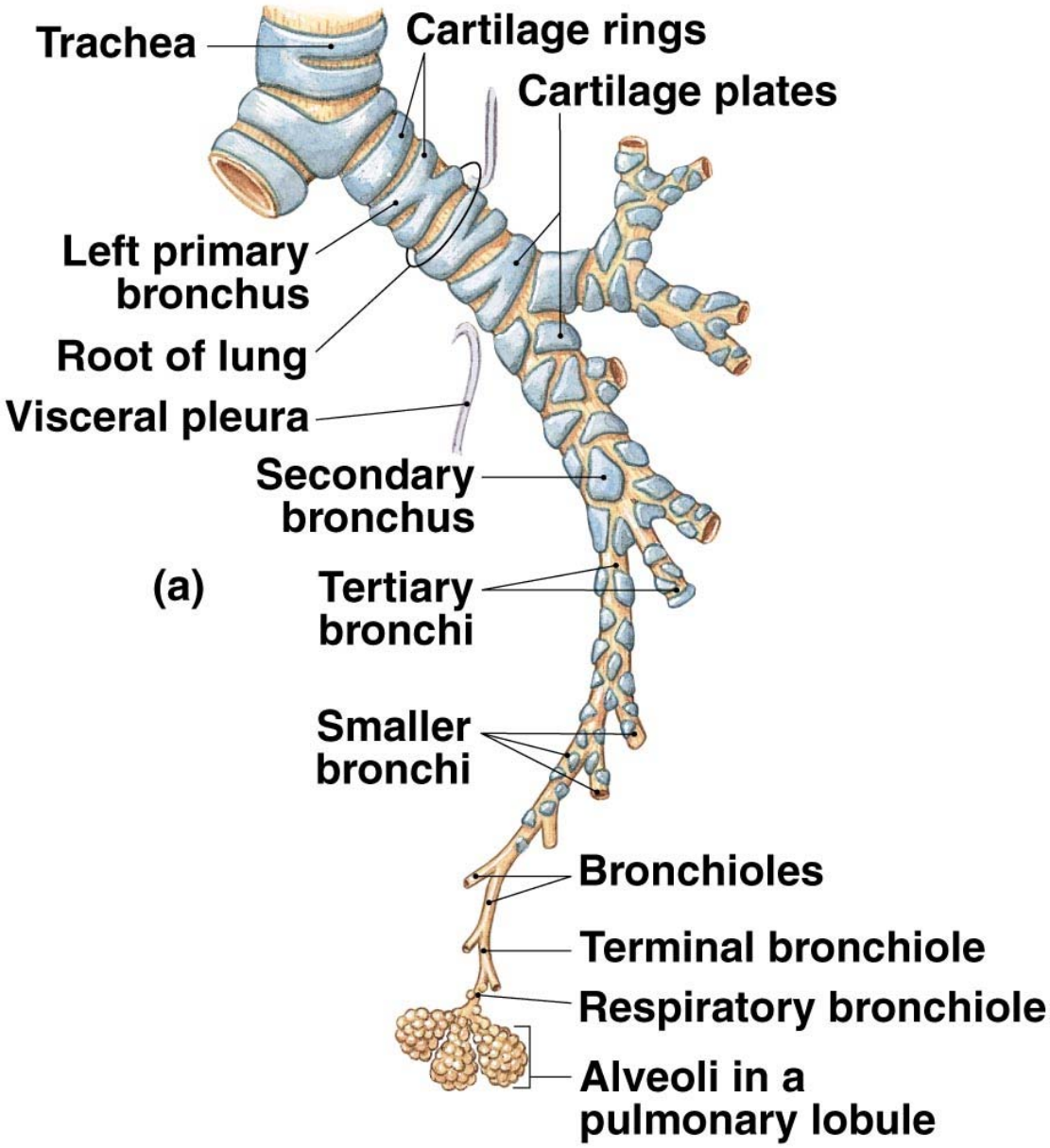


Figure 15-6(a)

Respiratory System Organization

The Alveolar Ducts and Alveoli

- Gas exchange regions of lung
- *Respiratory bronchioles* lead into *alveolar ducts*
- Ducts lead into *alveolar sacs*
- Sacs are clusters of interconnected *alveoli*
  - Gives lung an open, spongy look
  - About 150 million/lung

Respiratory System Organization

The Lobules of the Lung

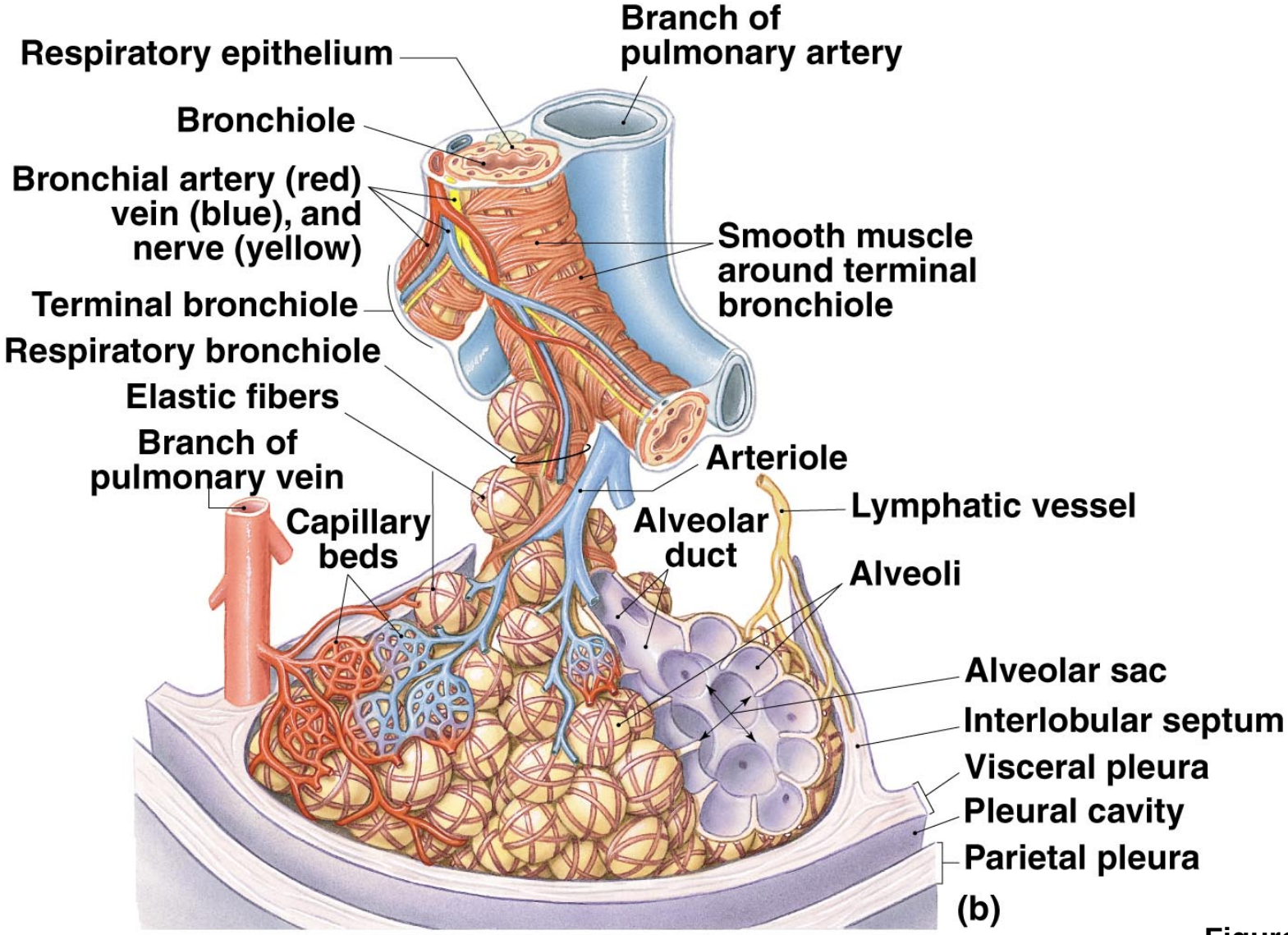
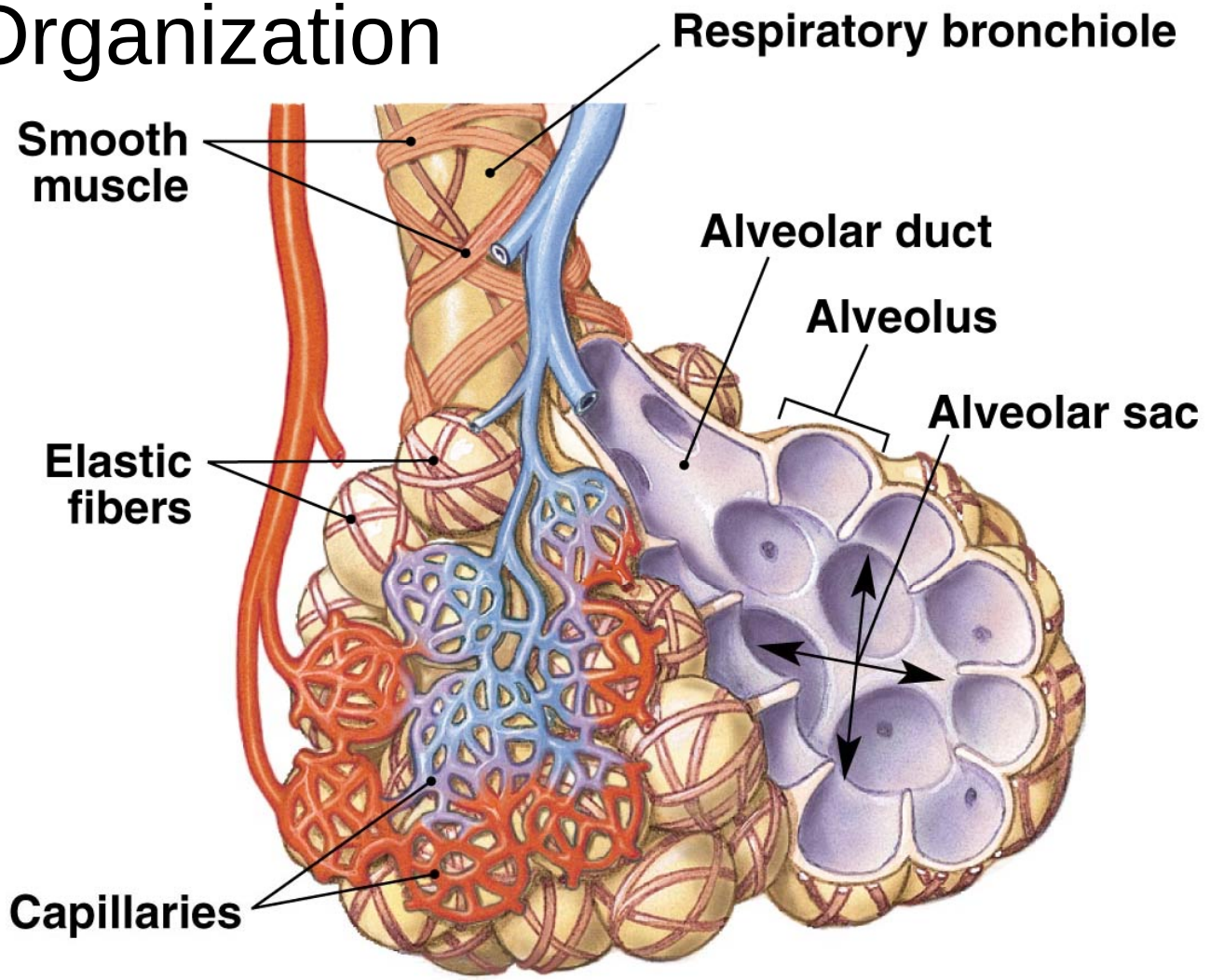


Figure 15-6(b)

Respiratory System Organization

Alveolar Organization

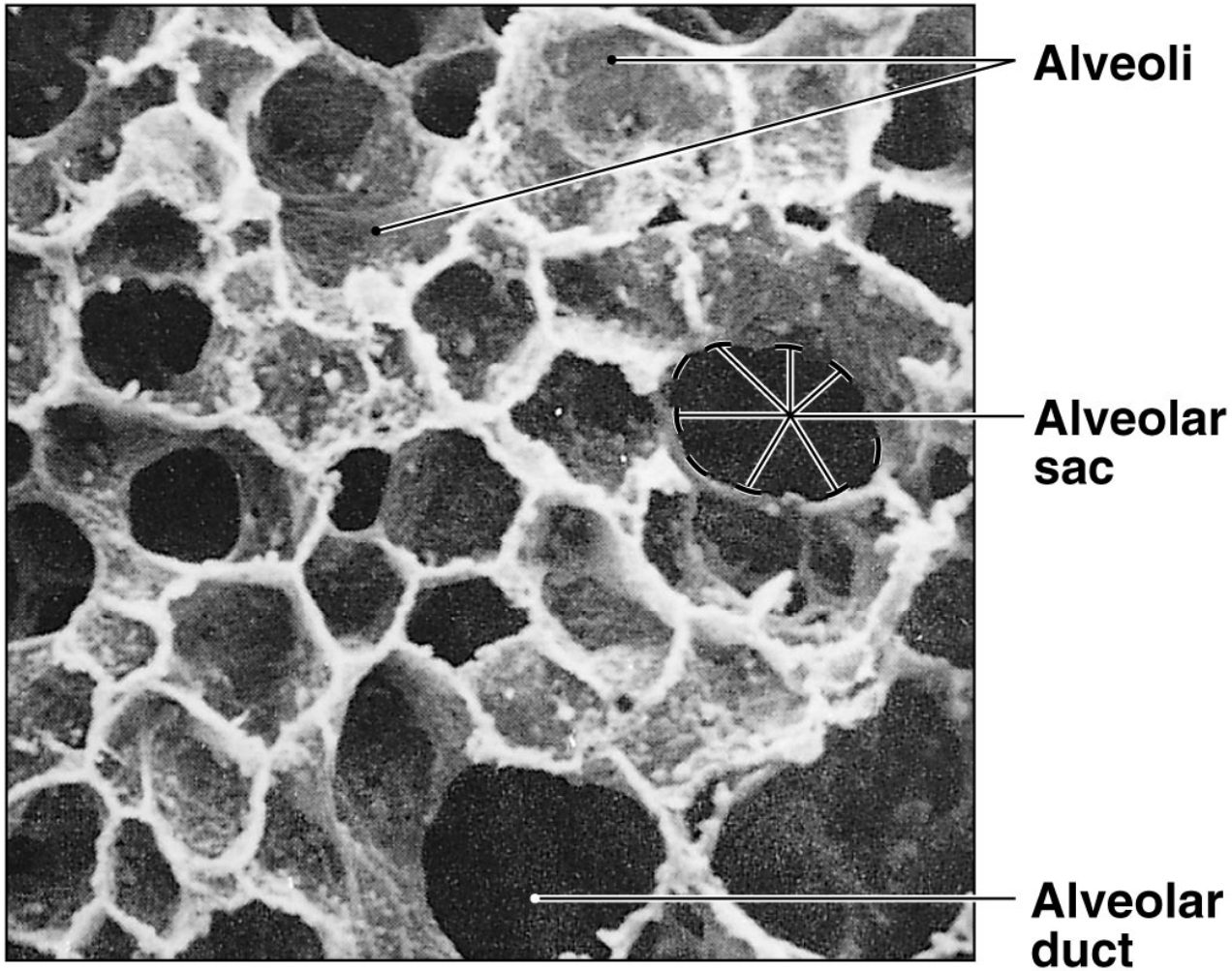


(a) Alveolar organization

Figure 15-7(a)

Respiratory System Organization

Alveolar Organization



(b) Alveolar ducts and alveoli

Figure 15-7(b)

Respiratory System Organization

Anatomy of the Alveolus

Respiratory membrane

- Simple squamous epithelium
- Capillary endothelium
- Shared basement membrane

- *Septal cells*
  - Produce *surfactant* to reduce collapse
- Alveolar macrophages
  - Engulf foreign particles

Respiratory System Organization

Alveolar Organization

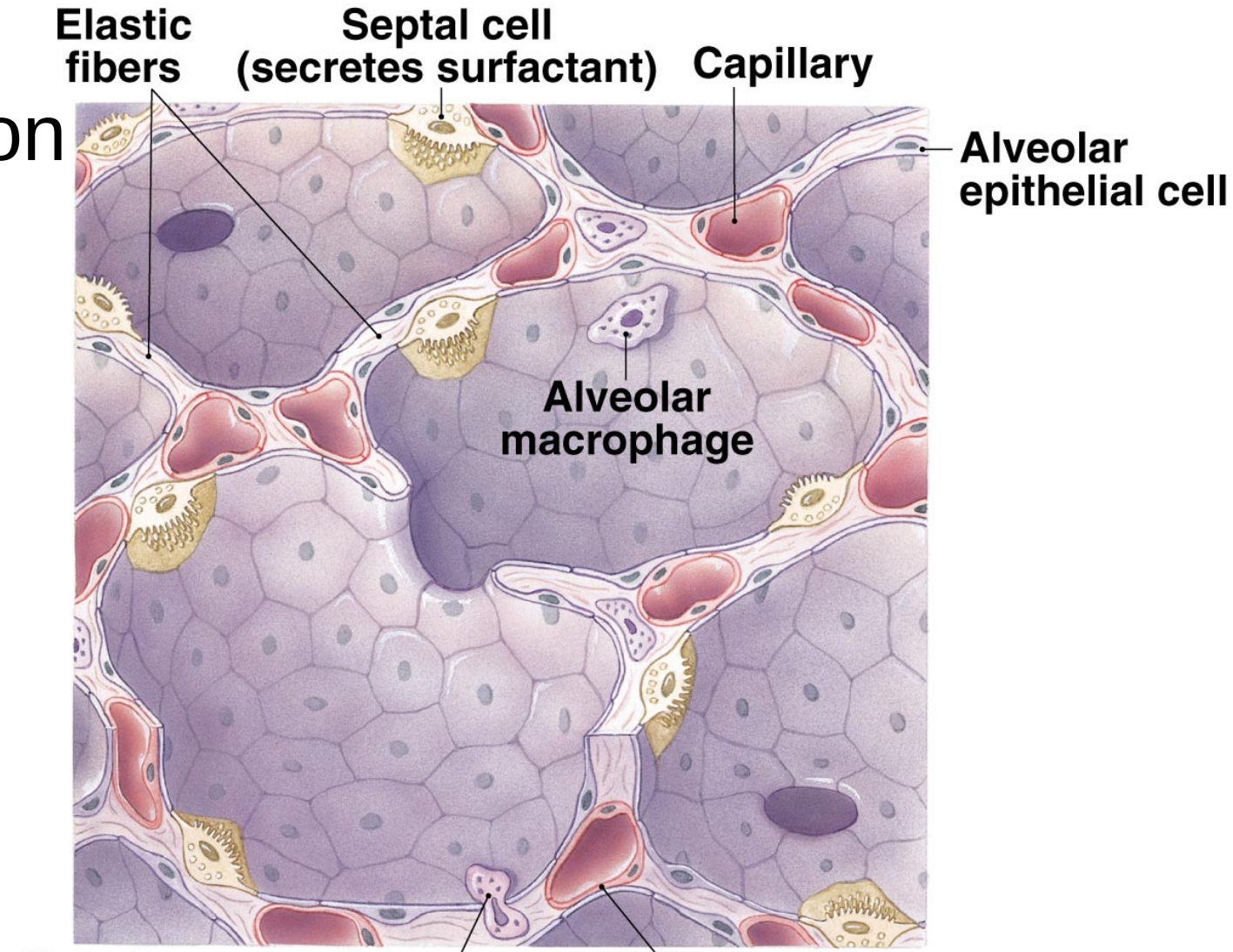
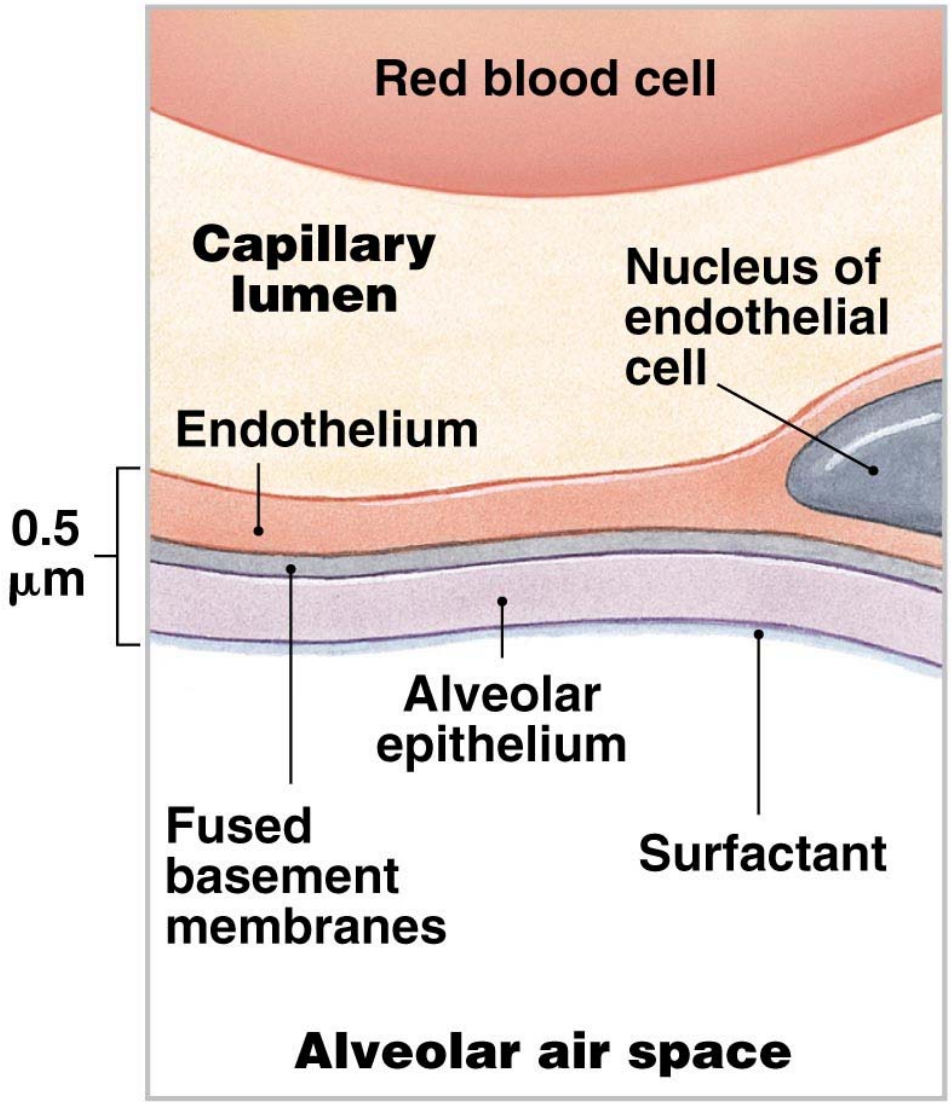


Figure 15-7(c)

Respiratory System Organization

Alveolar Organization



(d) The respiratory membrane

Figure 15-7(d)

Respiratory System Organization

Lung Gross Anatomy

- Lungs comprise five *lobes*
  - Separated by deep fissures
  - three lobes on right, two on left
- *Apex* extends above first rib
- *Base* rests on diaphragm
- Covered by a serous *visceral pleura*
- Lie with *pleural cavities*
  - Lined by a serous *parietal pleura*

Respiratory System Organization

The Gross Anatomy of the Lungs

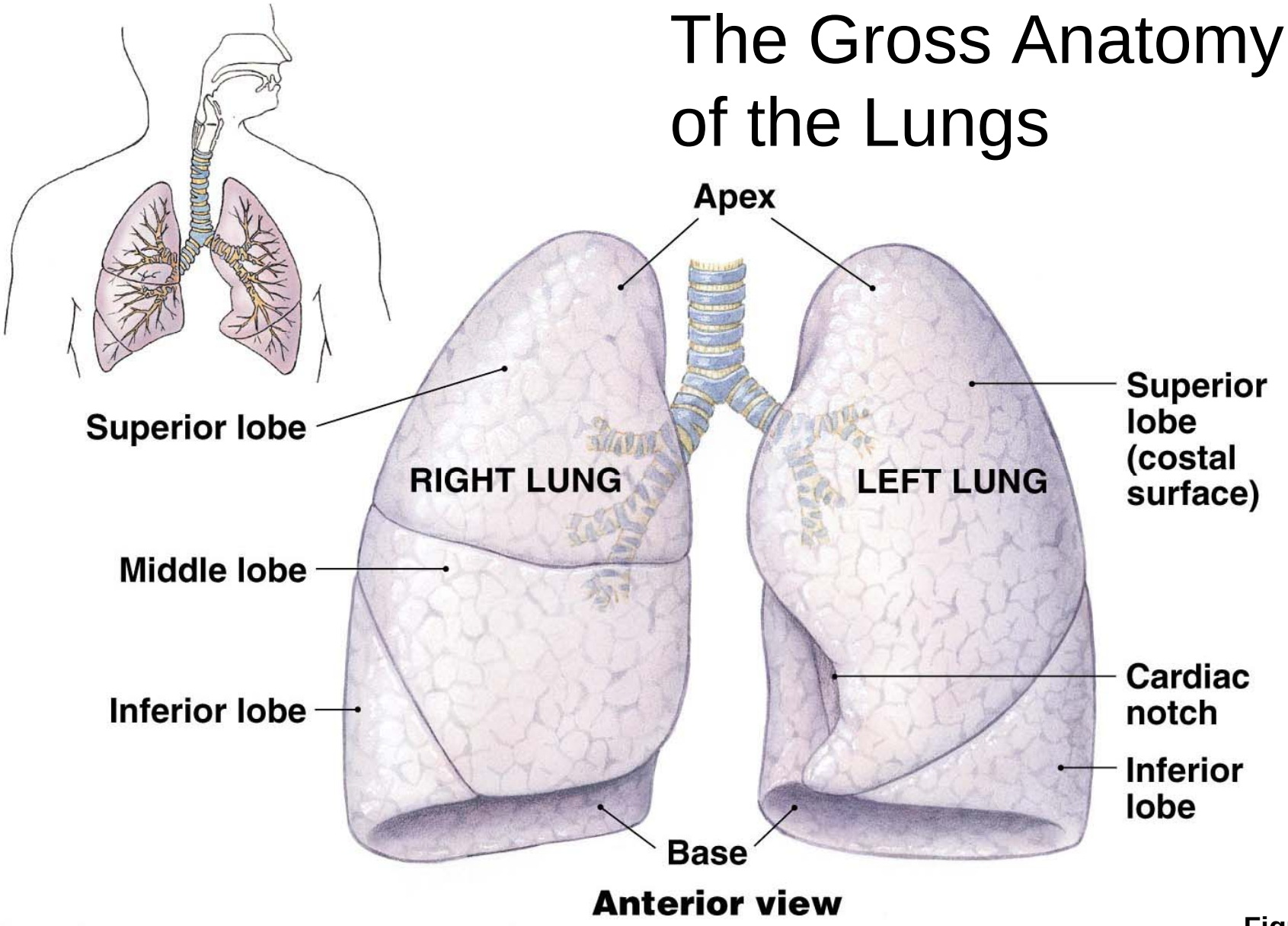
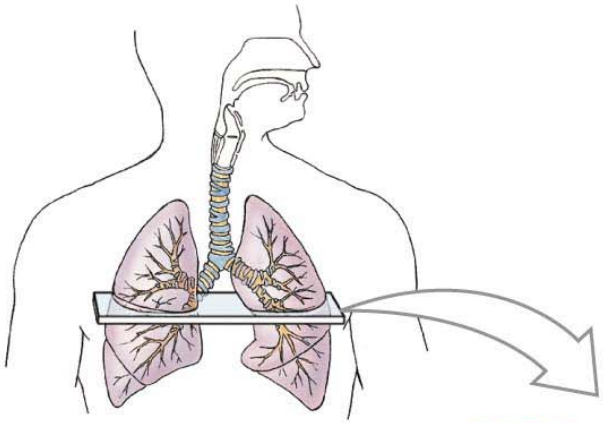
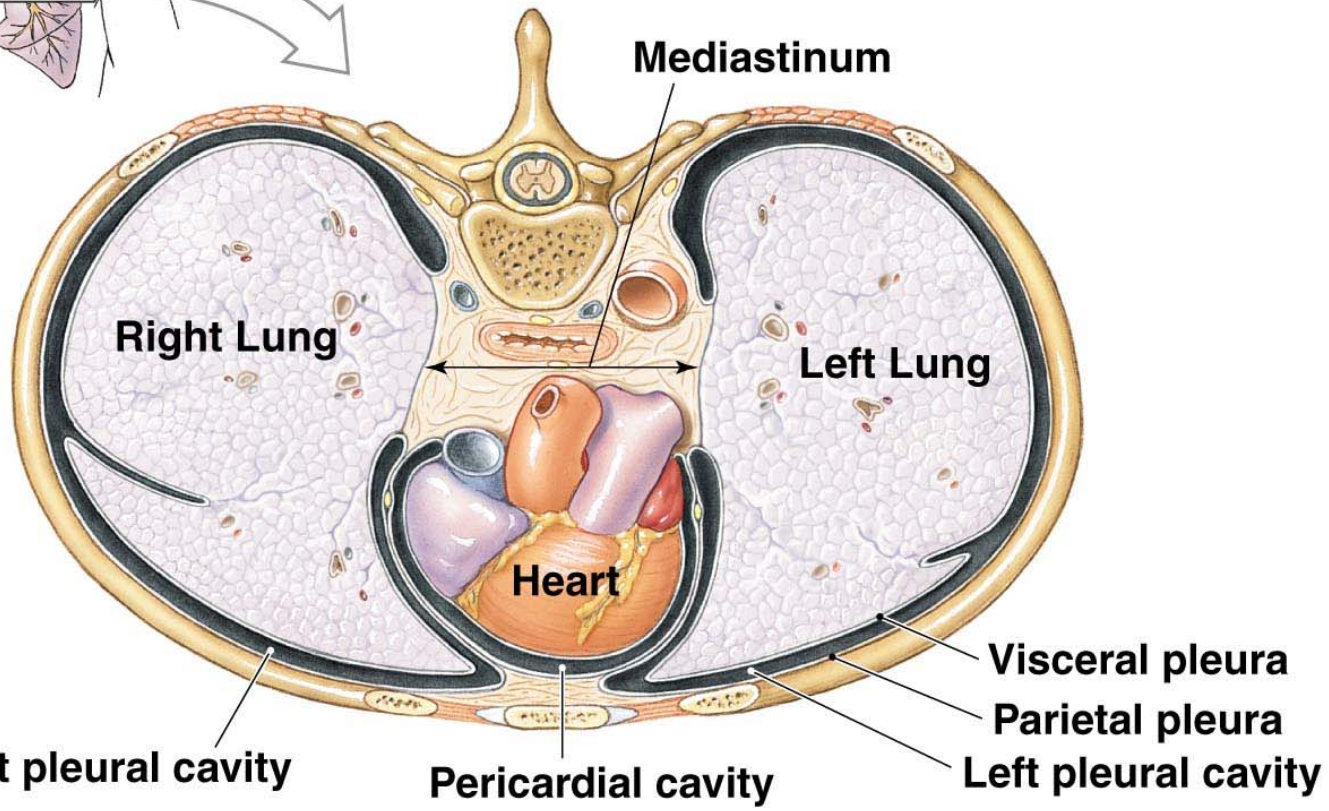


Figure 15-8

Respiratory System Organization

Anatomical Relationships in the Thoracic Cavity





PLAY Respiratory Movie

Figure 15-9

Respiratory Physiology

Three Integrated Processes

- *Pulmonary ventilation*—Moving air into and out of the respiratory tract; breathing
- *Gas exchange* —Diffusion between alveoli and circulating blood, and between blood and interstitial fluids
- *Gas transport*—Movement of oxygen from alveoli to cells, and carbon dioxide from cells to alveoli

Respiratory Physiology

Pulmonary Ventilation

- *Respiratory cycle*—A single breath consisting of *inspiration* (inhalation) and *expiration* (exhalation)
- *Respiratory rate*—Number of cycles per minute
  - Adult normal rate 12 to 18 breaths/minute
  - Child normal rate 18 to 20 breaths/minute
- *Alveolar ventilation*—Movement of air into and out of the alveoli

Respiratory Physiology

Key Note

The direction of air flow is determined by the relationship of atmospheric pressure and pressure inside the respiratory tract. Flow is always from higher to lower pressure.

Respiratory Physiology

Quiet *versus* Forced Breathing

- *Quiet breathing*—Diaphragm and external intercostals are involved. Expiration is *passive*.
- *Forced breathing*—Accessory muscles become active during the entire breathing cycle. Expiration is *active*.

Respiratory Physiology

Pressure and Volume Relationships in the Lungs

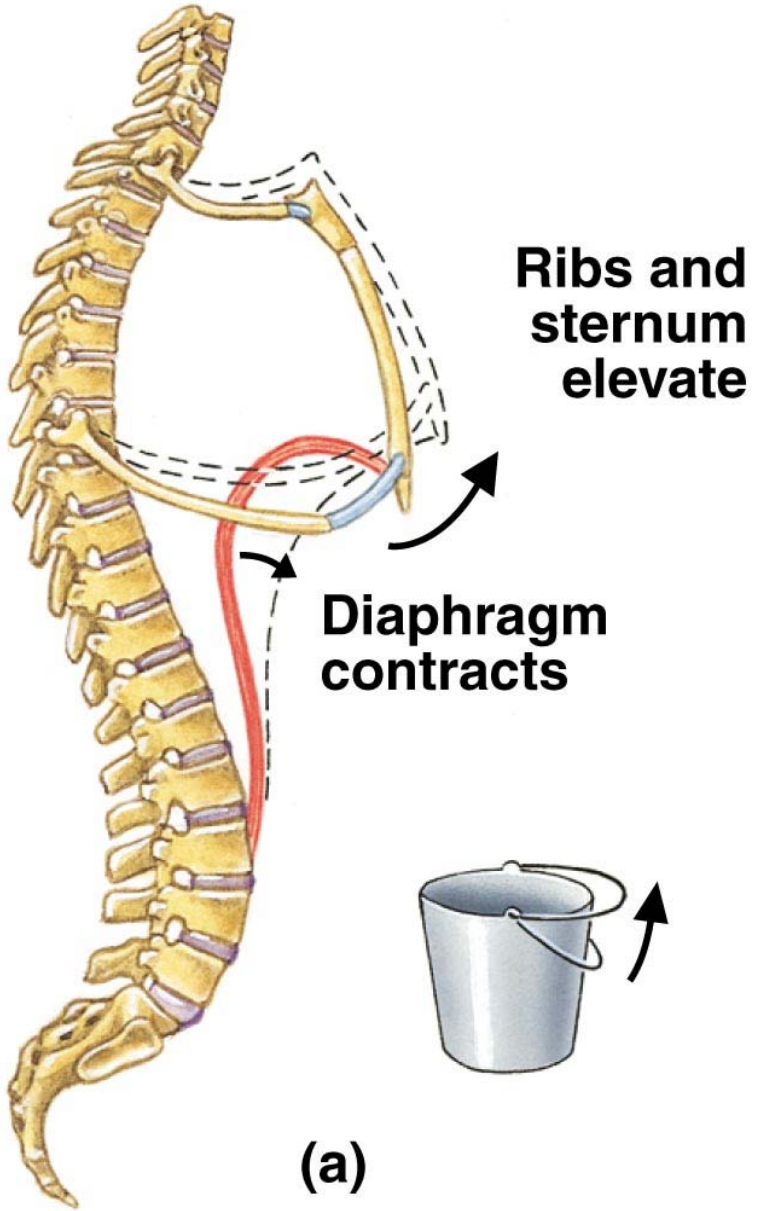
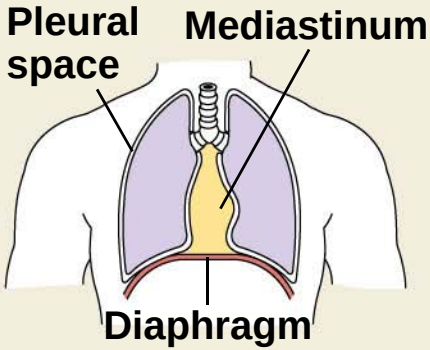


Figure 15-10(a)

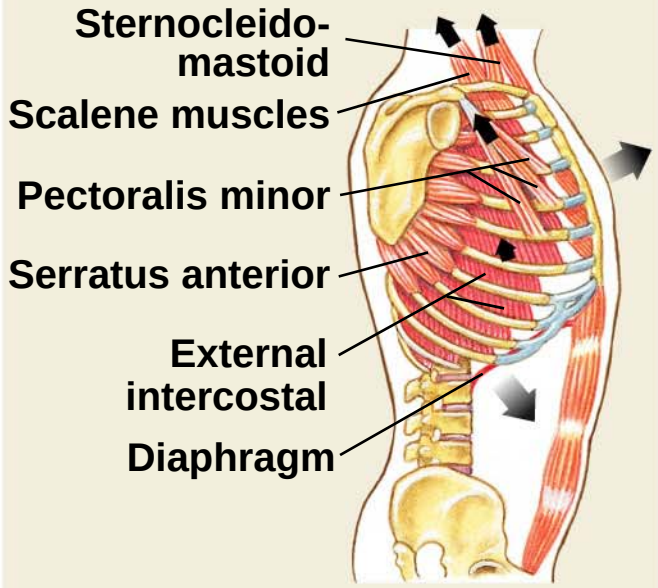
AT REST

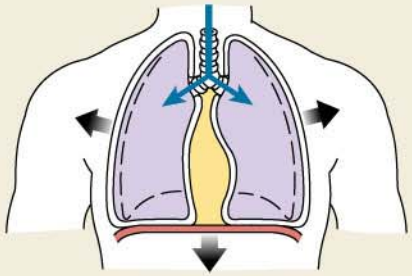


Pressure outside and inside are equal, so no movement occurs

$P_o = P_i$

INHALATION

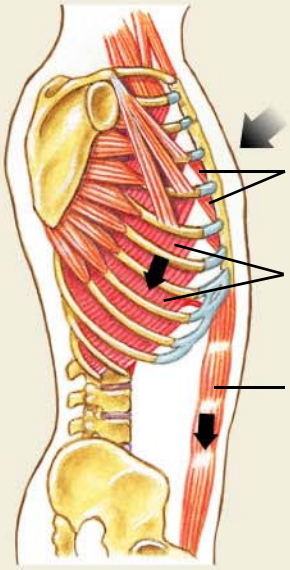




Volume increases
Pressure inside falls, and air flows in

$P_o > P_i$

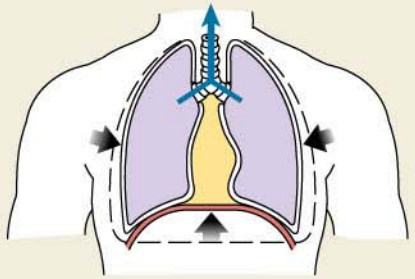
EXHALATION



Transversus thoracis

Internal intercostals

Rectal abdominis (other abdominal muscles not shown)

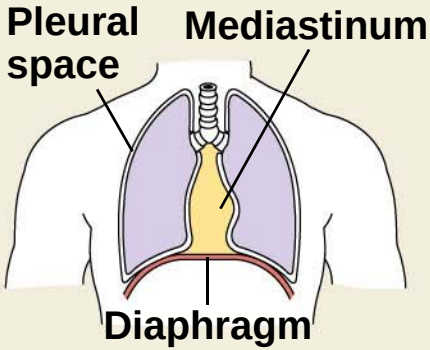


Volume decreases
Pressure inside rises, so air flows out

$P_o < P_i$

Figure 15-10(b)
1 of 4

AT REST

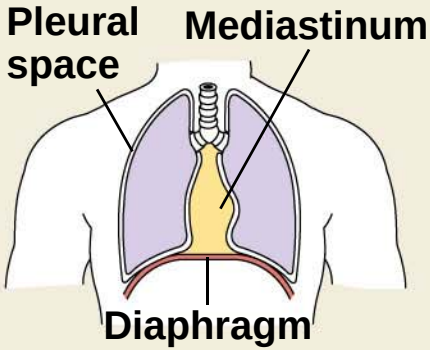


Pressure outside and inside are equal, so no movement occurs

$P_o = P_i$

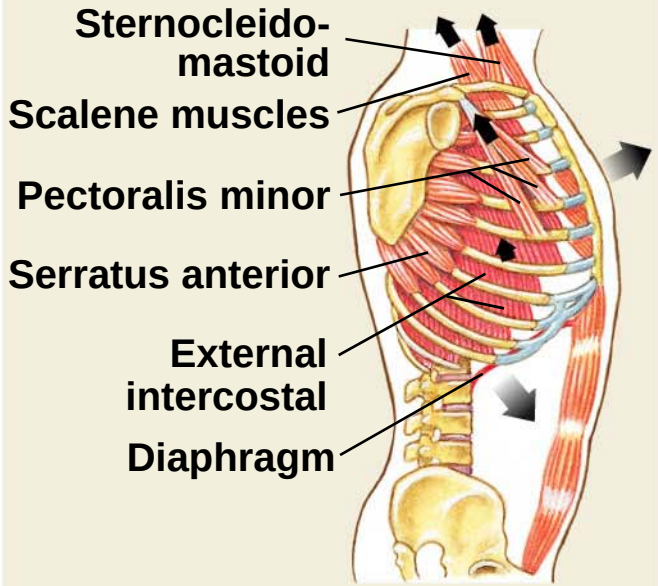
Figure 15-10(b)
2 of 4

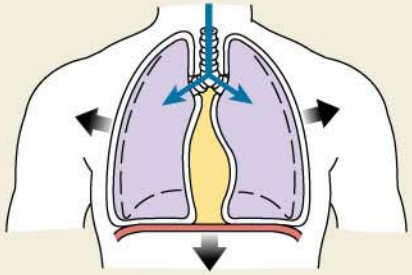
AT REST



Pressure outside and inside are equal, so no movement occurs
$P_o = P_i$

INHALATION

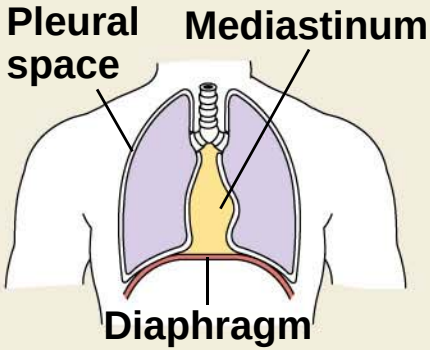




Volume increases
Pressure inside falls, and air flows in
$P_o > P_i$

Figure 15-10(b)
3 of 4

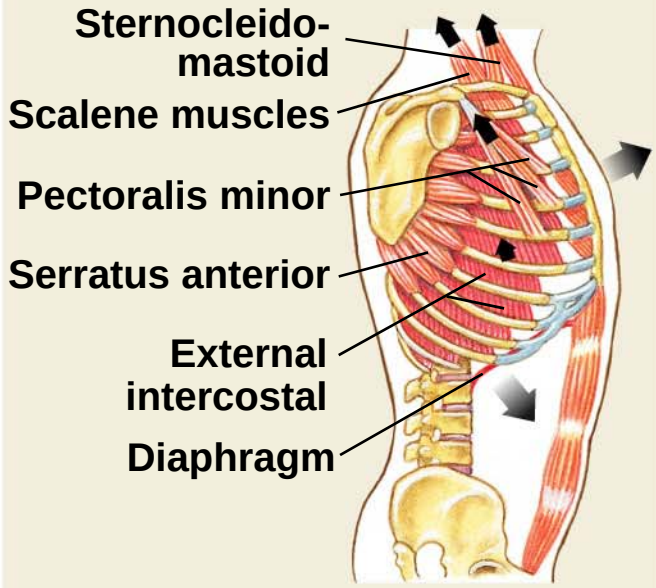
AT REST

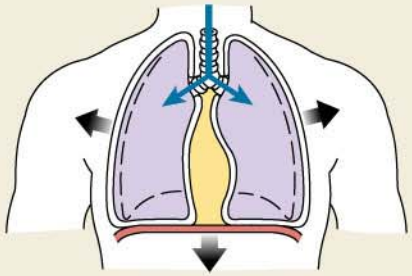


Pressure outside and inside are equal, so no movement occurs

$P_o = P_i$

INHALATION





Volume increases
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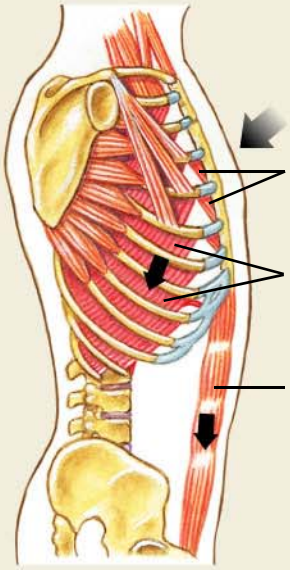
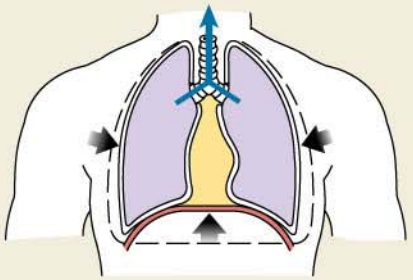
EXHALATION





Transversus thoracis

Internal intercostals

Rectal abdominis (other abdominal muscles not shown)

Volume decreases
Pressure inside rises, so air flows out

$P_o < P_i$

Figure 15-10(b)
4 of 4

Respiratory Physiology

Capacities and Volumes

- *Vital capacity*—Tidal volume + expiratory reserve volume + inspiratory volume

$$VC = TV + ERV + IRV$$

- *Residual volume*—Volume of air remaining in the lung after a forced expiration

Respiratory Physiology

Respiratory Volumes and Capacities

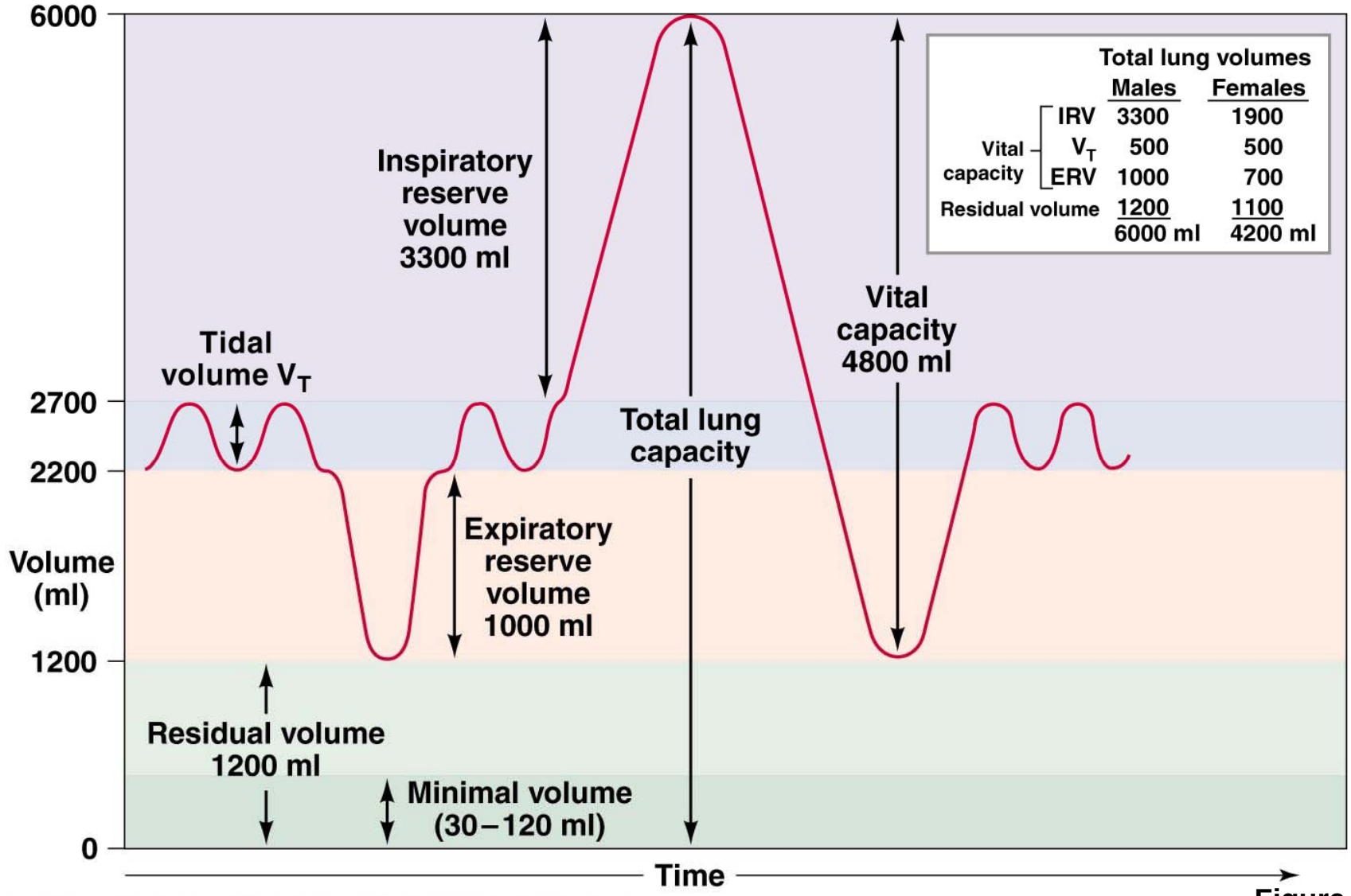


Figure 15-11

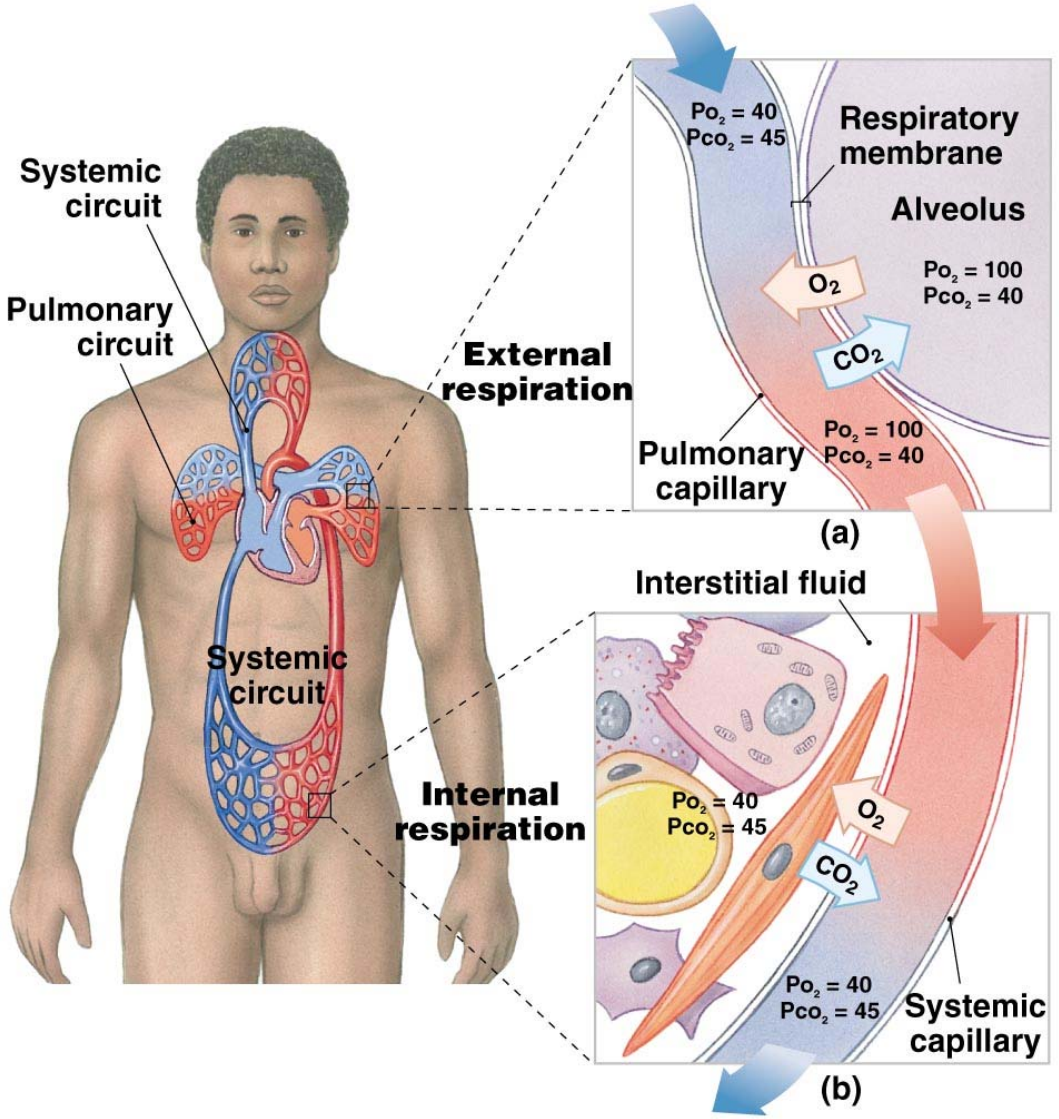
Respiratory Physiology

Gas Exchange

- *External respiration*—Diffusion of gases between alveolar air and pulmonary capillary blood across the respiratory membrane
- *Internal respiration*—Diffusion of gases between blood and interstitial fluids across the capillary endothelium

Respiratory Physiology

An Overview of Respiration and Respiratory Processes



PLAY Respiration: Gas Exchange

Figure 15-12

Respiratory Physiology

TABLE 15-1 *Partial Pressures (mm Hg) and Normal Gas Concentrations (%) in Air*

SOURCE OF SAMPLE	NITROGEN (N_2)	OXYGEN (O_2)	WATER VAPOR (H_2O)	CARBON DIOXIDE (CO_2)
Inhaled air (dry)	597 (78.6%)	159 (20.9%)	3.7 (0.5%)	0.3 (0.04%)
Alveolar air (saturated)	573 (75.4%)	100 (13.2%)	47 (6.2%)	40 (5.2%)
Exhaled air (saturated)	569 (74.8%)	116 (15.3%)	47 (6.2%)	28 (3.7%)

Respiratory Physiology

Gas Transport

- Arterial blood entering peripheral capillaries delivers oxygen and removes carbon dioxide
- Gas reactions with blood are completely reversible
- In general, a small change in plasma P_{O_2} causes a large change in how much oxygen is bound to hemoglobin

Respiratory Physiology

Key Note

Hemoglobin binds most of the oxygen in the bloodstream. If the P_{O_2} in plasma increases, hemoglobin binds more oxygen; if P_{O_2} decreases, hemoglobin releases oxygen. At a given P_{O_2} hemoglobin will release additional oxygen if the pH falls or the temperature rises.

PLAY Respiration: Carbon Dioxide and Oxygen Exchange

Respiratory Physiology

Carbon Dioxide Transport

- Aerobic metabolism produces CO_2
- 7% travels dissolved in plasma
- 23% travels bound to hemoglobin
  - Called *carbaminohemoglobin*
- 70% is converted to H_2CO_3 in RBCs
  - Catalyzed by *carbonic anhydrase*
  - Dissociates to H^+ and HCO_3^-
  - HCO_3^- enters plasma from RBC

Respiratory Physiology

Carbon Dioxide Transport in the Blood

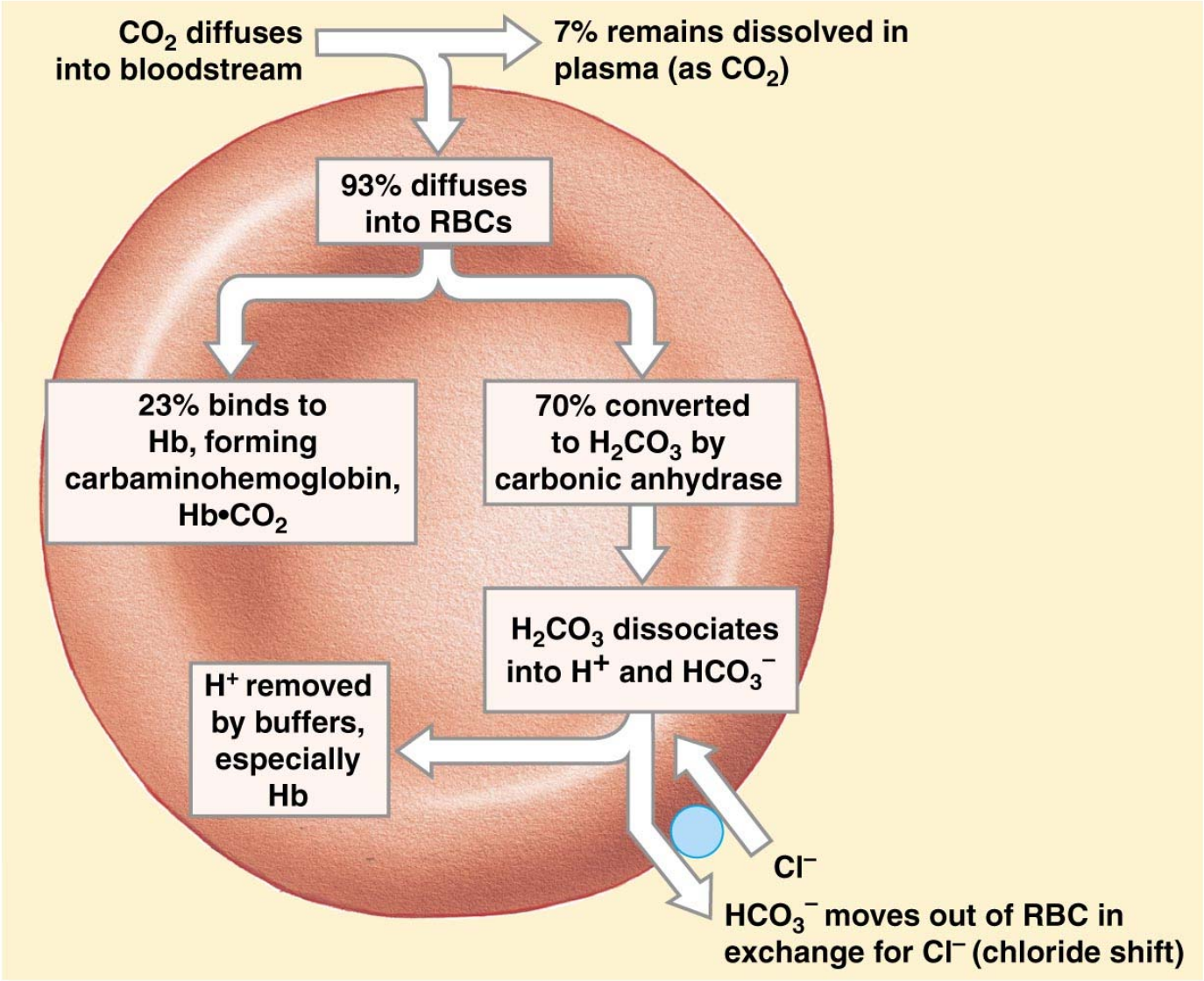


Figure 15-13

Respiratory Physiology

Key Note

Carbon dioxide (CO_2) primarily travels in the bloodstream as bicarbonate ions (HCO_3^-), which form through dissociation of the carbonic acid (H_2CO_3) produced by *carbonic anhydrase* inside RBCs. Lesser amounts of CO_2 are bound to hemoglobin or dissolved in plasma.

PLAY Respiration: Pressure Gradients

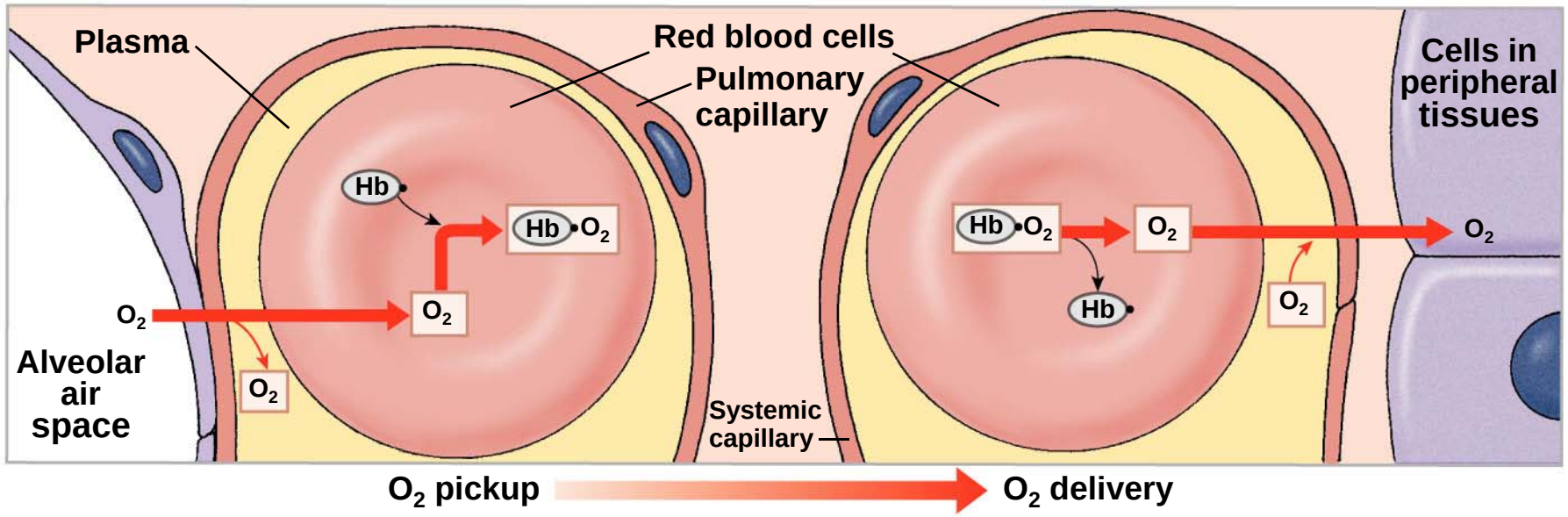
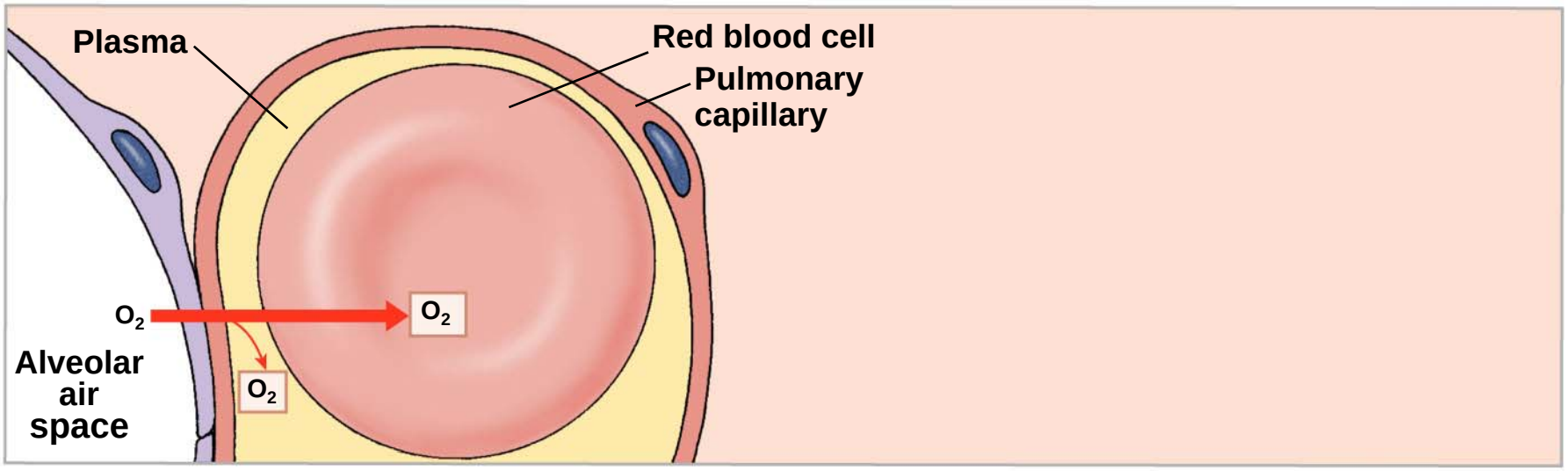


Figure 15-14(a)
1 of 5



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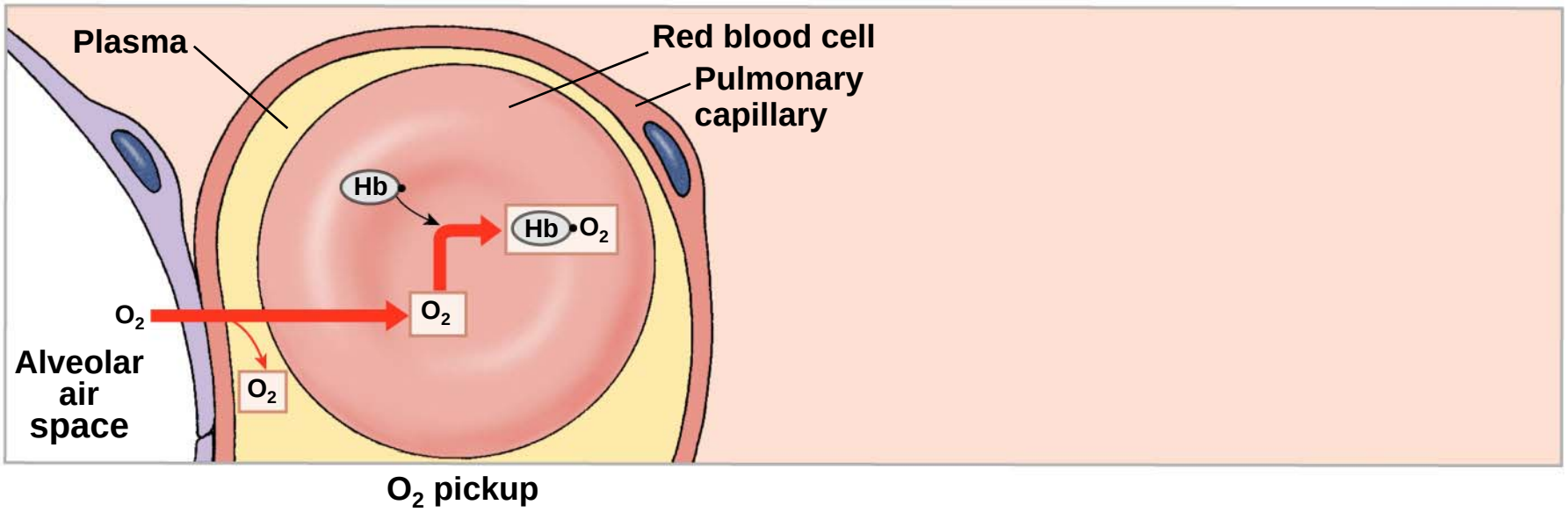
2 of 5



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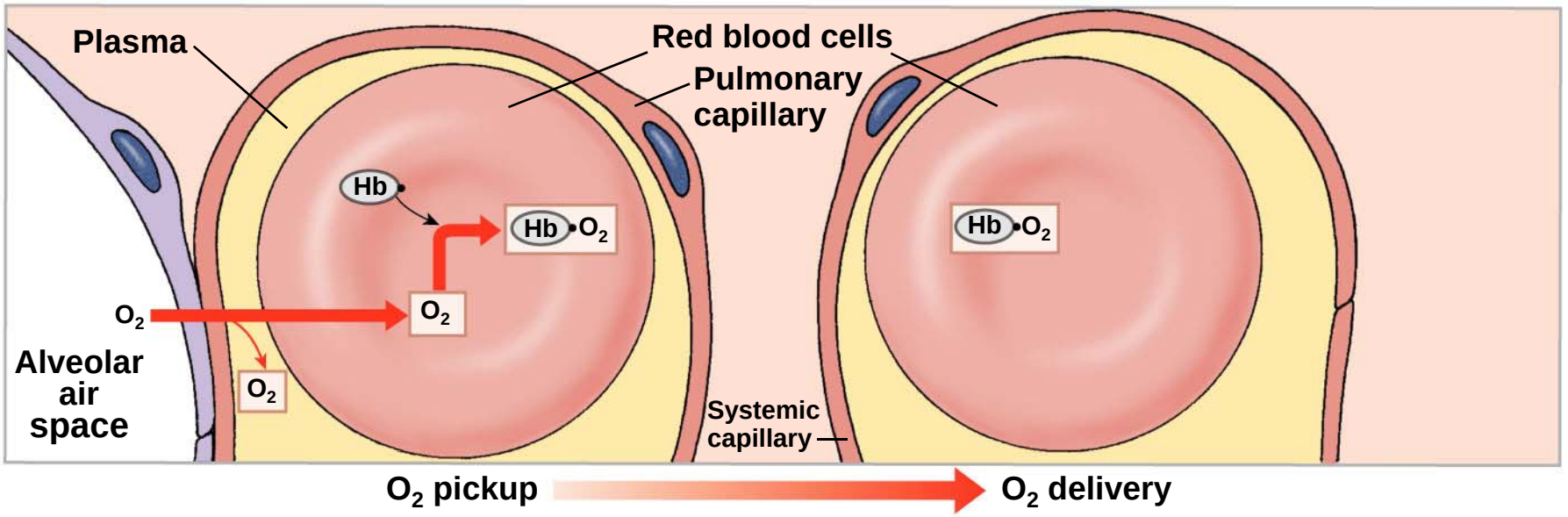

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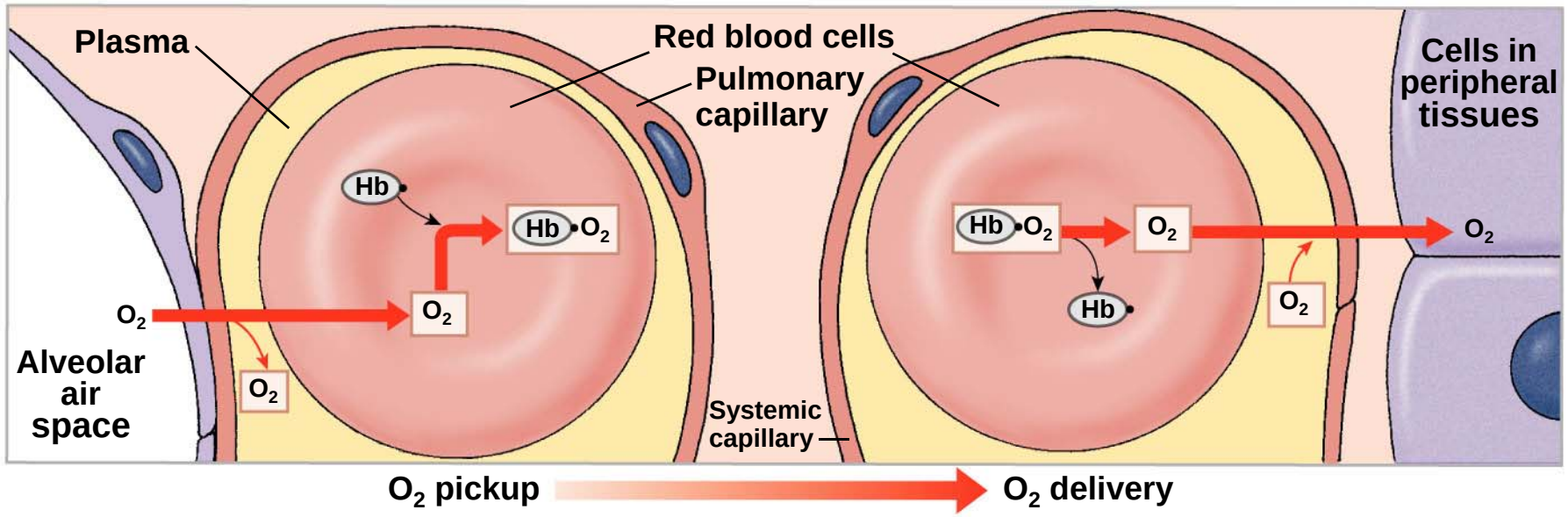

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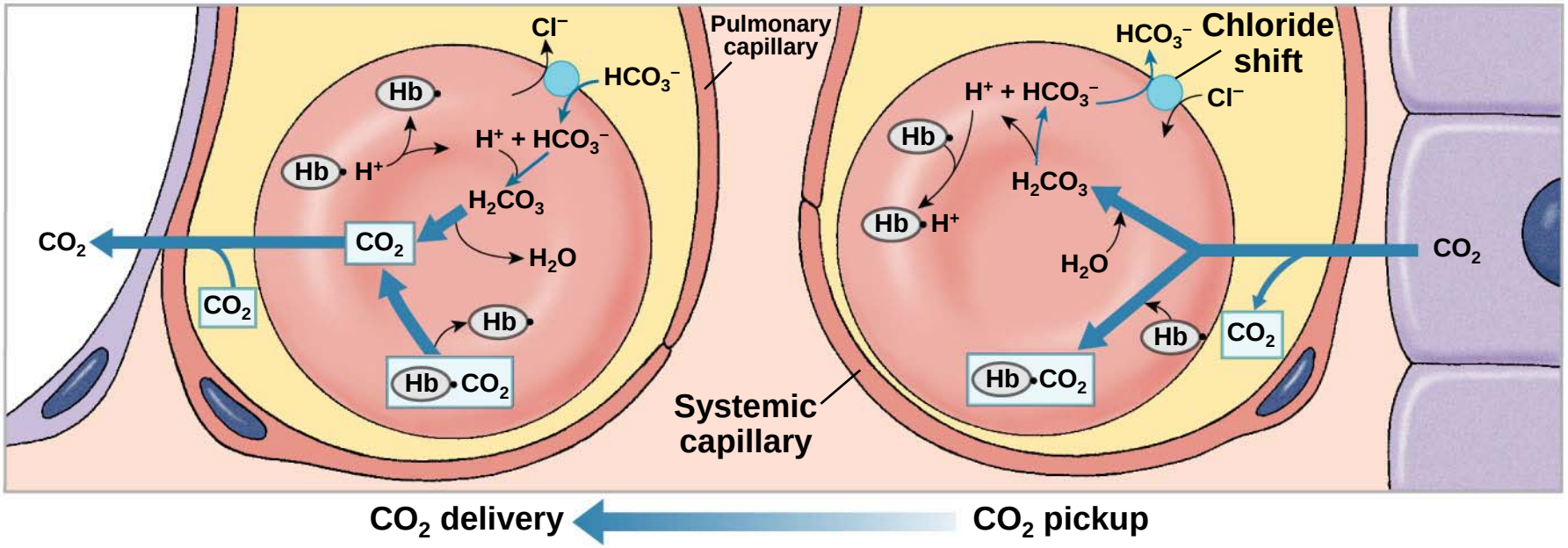
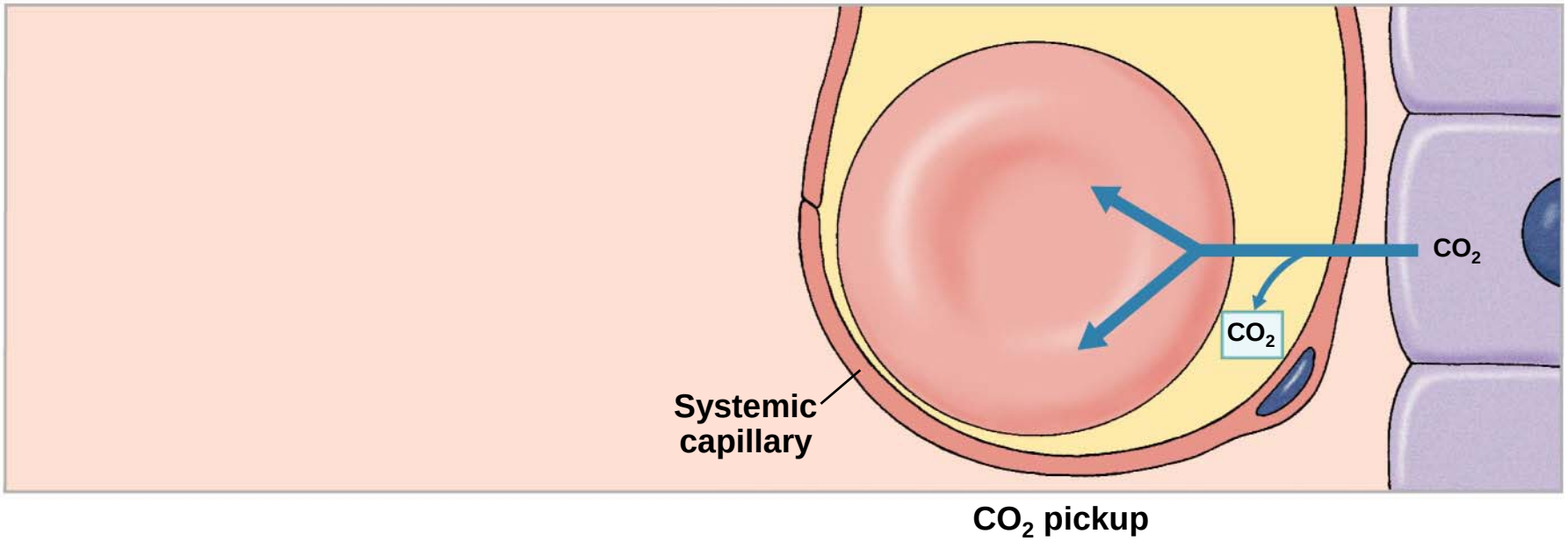


Figure 15-14(b)
1 of 7



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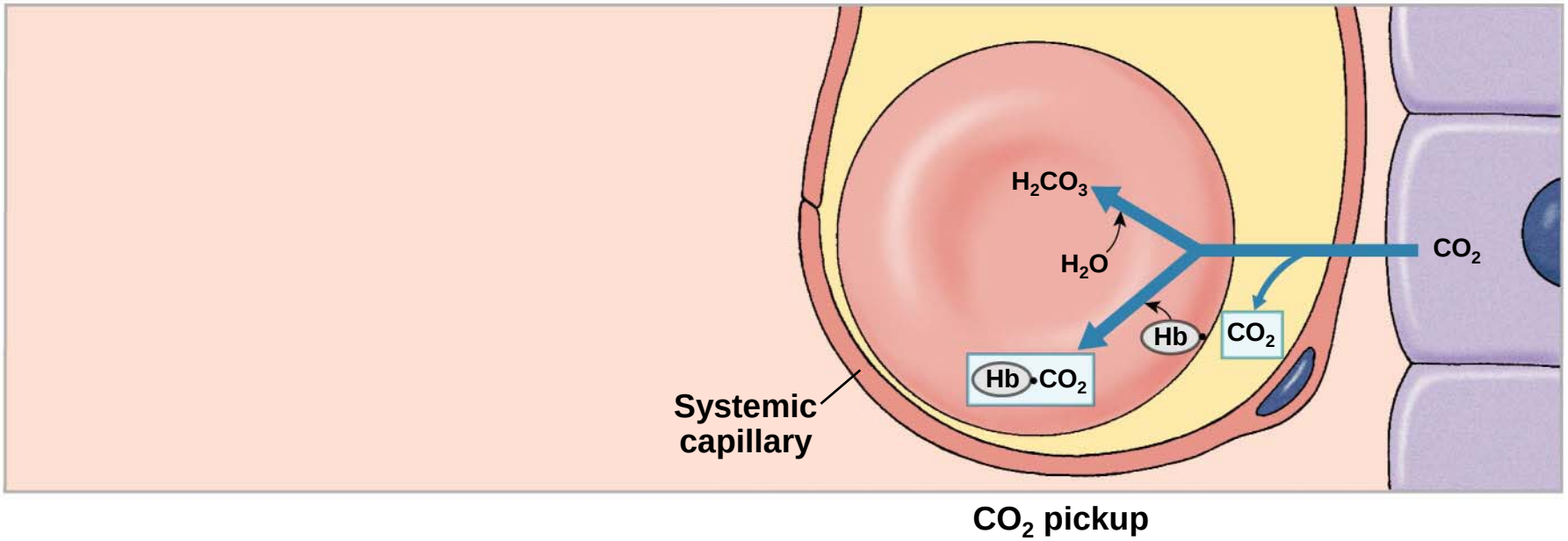
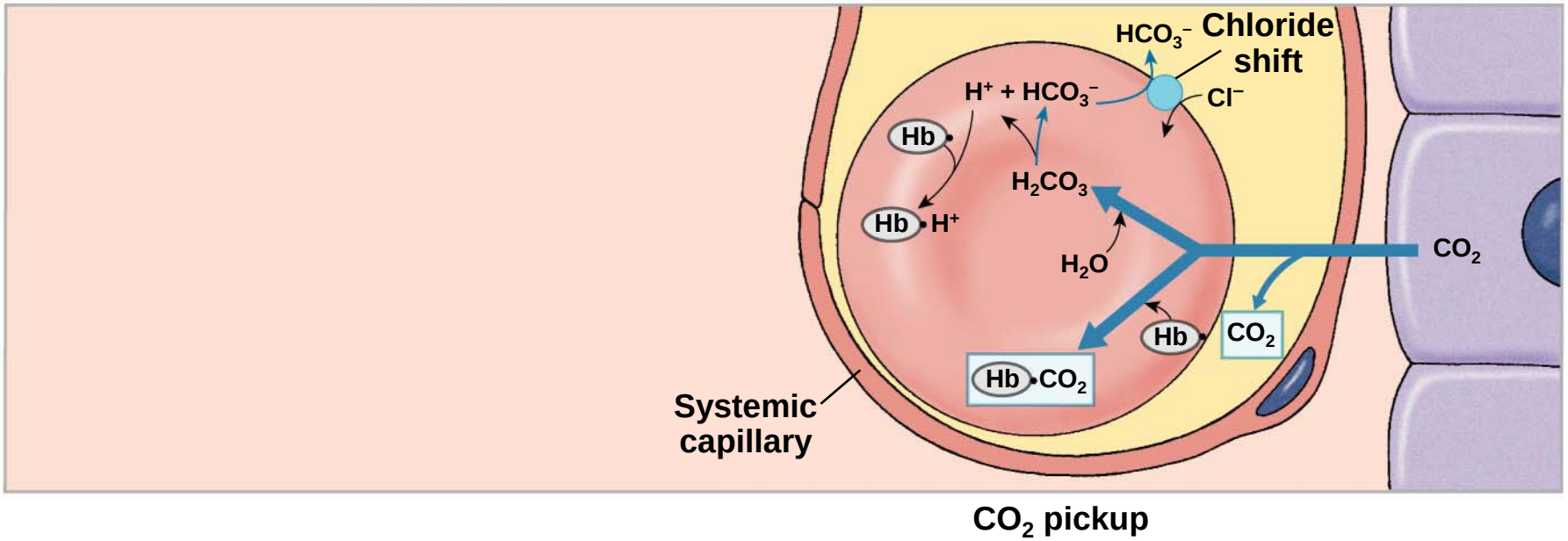


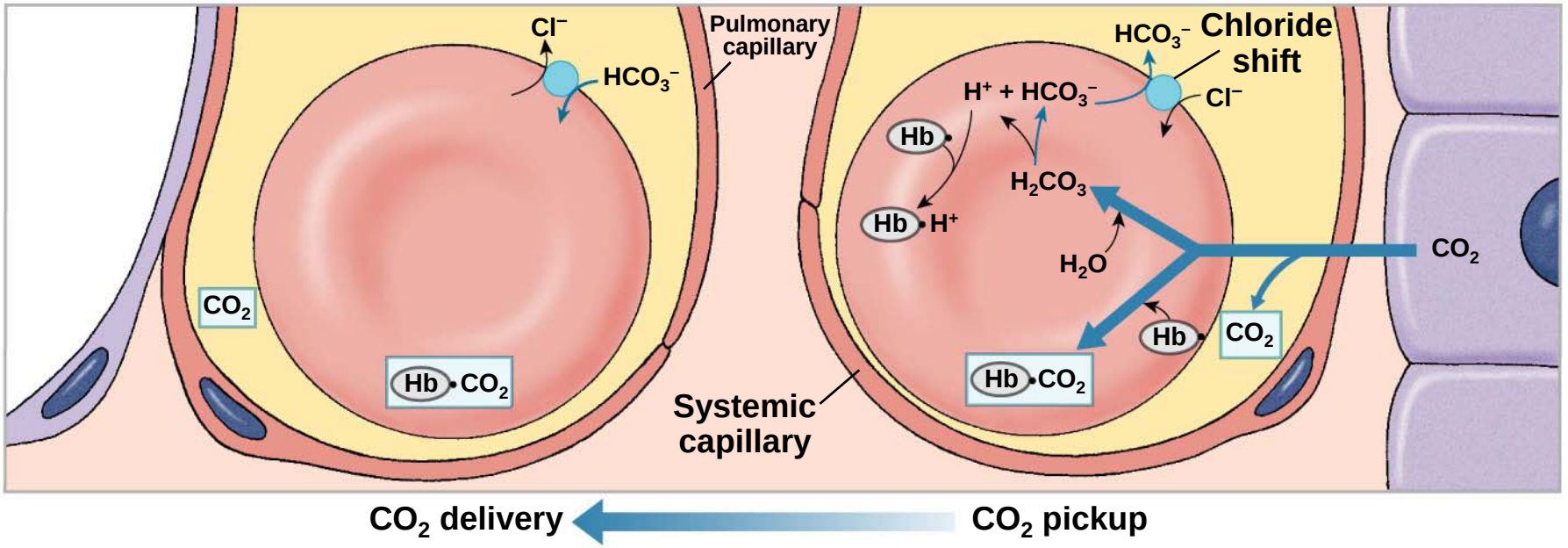
CO_2 pickup

Figure 15-14(b)
3 of 7



CO_2 pickup

Figure 15-14(b)
4 of 7



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5 of 7

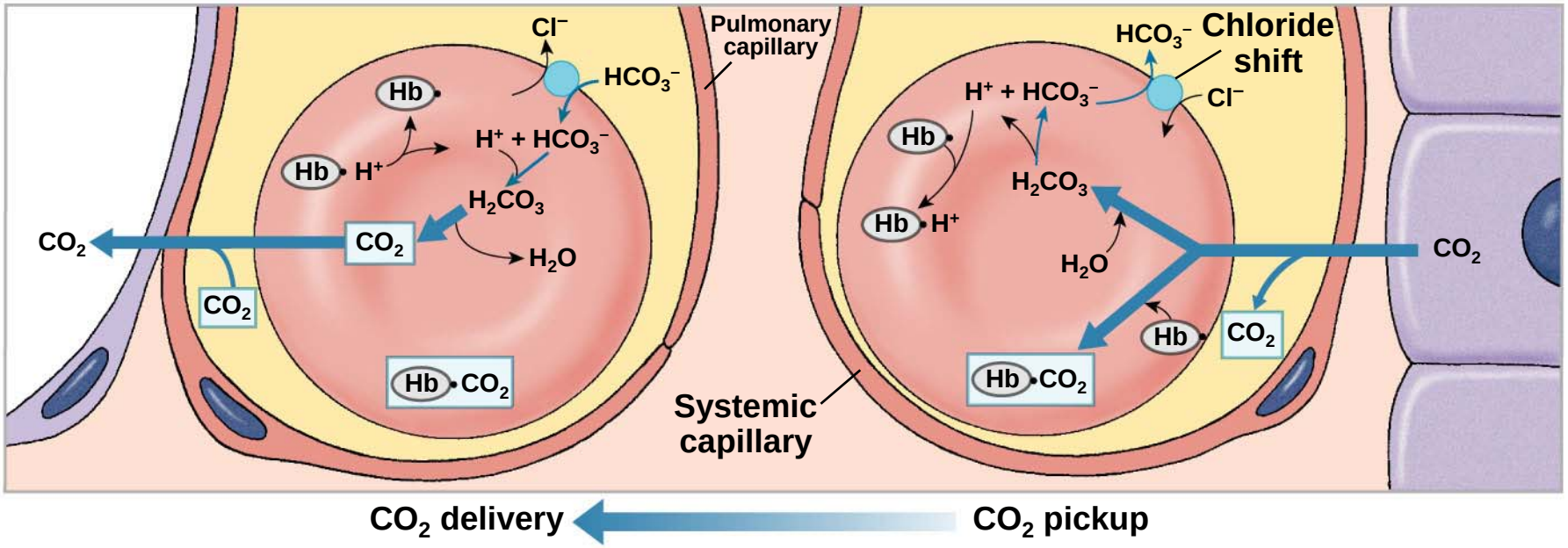

Figure 15-14(b)
6 of 7

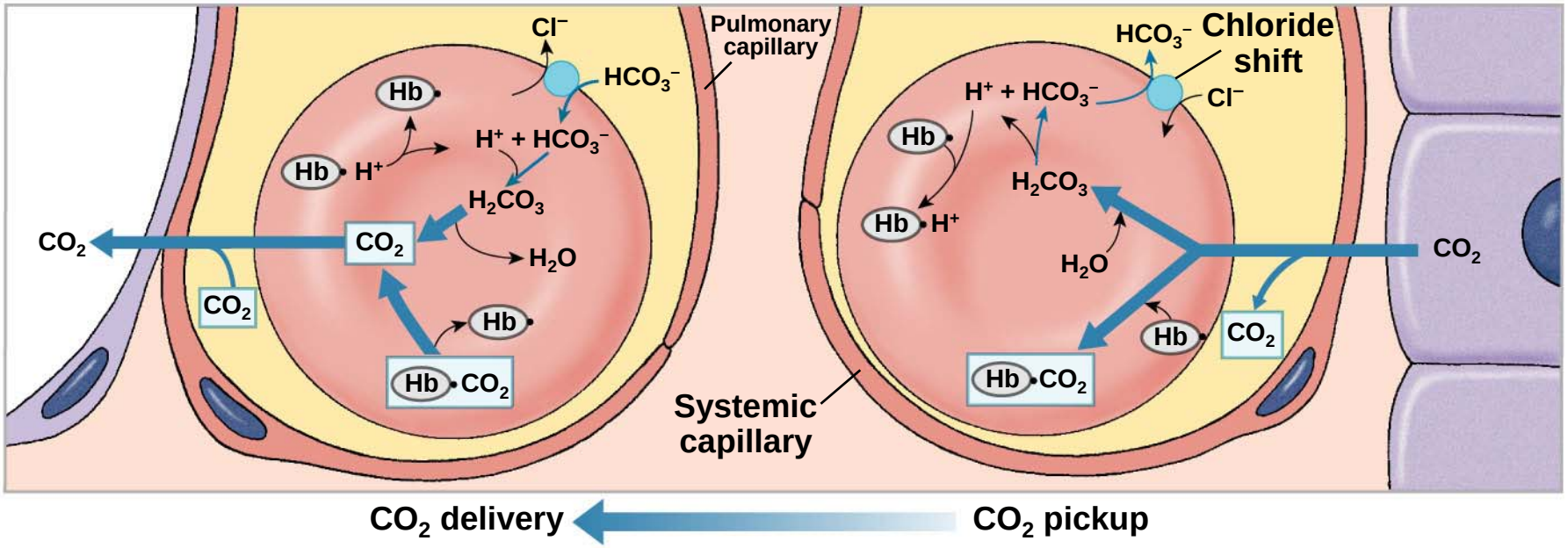

Figure 15-14(b)
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The Control of Respiration

Meeting the Changing Demand for Oxygen

- Requires integration cardiovascular and respiratory responses
- Depends on both:
  - Local control of respiration
  - Control by brain respiratory centers

The Control of Respiration

Local Control of Respiration

- Arterioles supplying pulmonary capillaries *constrict* when oxygen is low
- Bronchioles *dilate* when carbon dioxide is high

The Control of Respiration

Control by Brain Respiratory Centers

- Respiratory centers in brainstem
  - Three pairs of nuclei
    - Two pairs in *pons*
    - One pair in *medulla oblongata*
  - Control respiratory muscles
  - Set rate and depth of ventilation
  - Respiratory rhythmicity center in medulla
    - Sets basic rhythm of breathing

The Control of Respiration

Basic Regulatory Patterns of Respiration

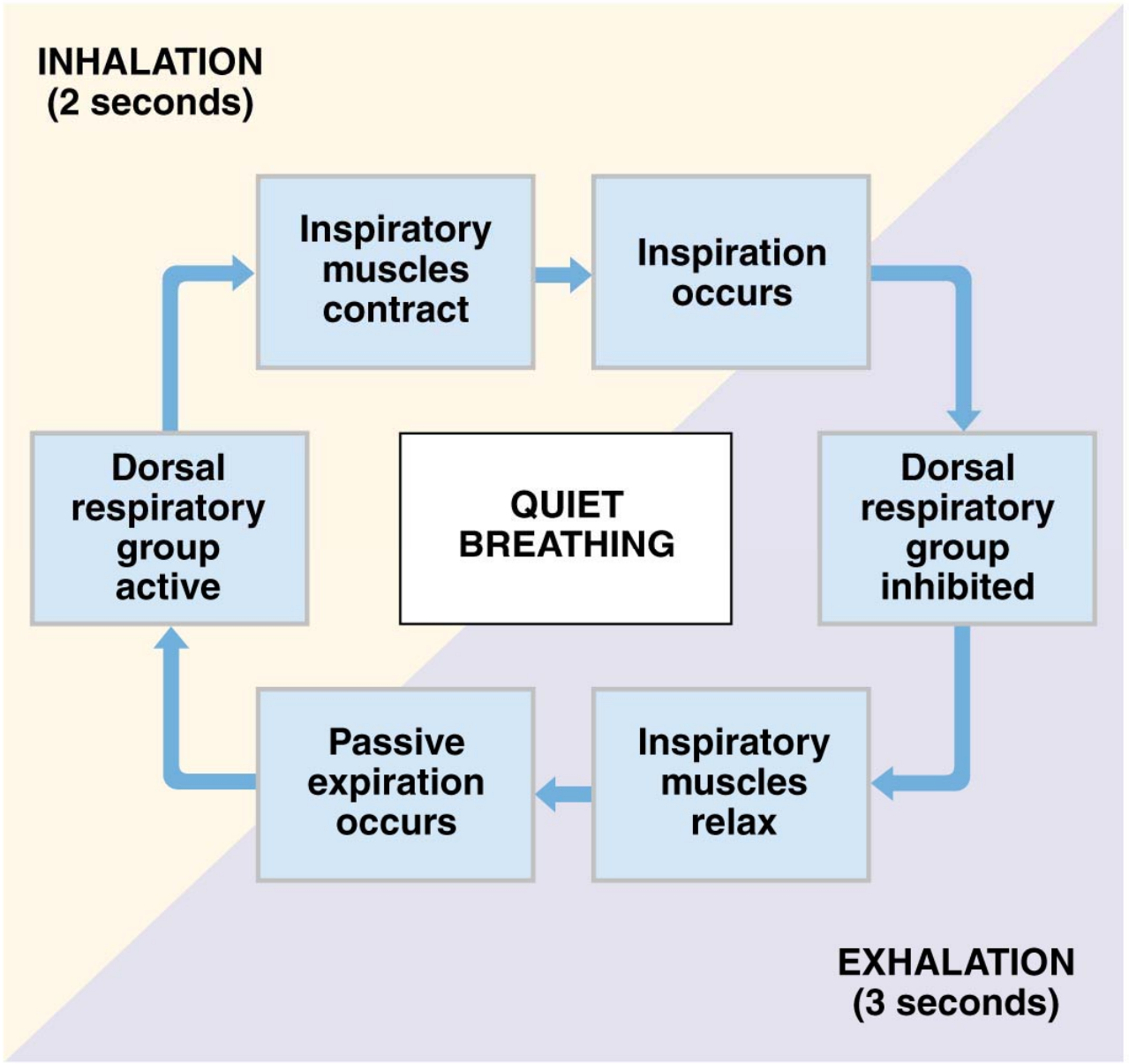


Figure 15-15(a) (a)

The Control of Respiration

Basic Regulatory Patterns of Respiration

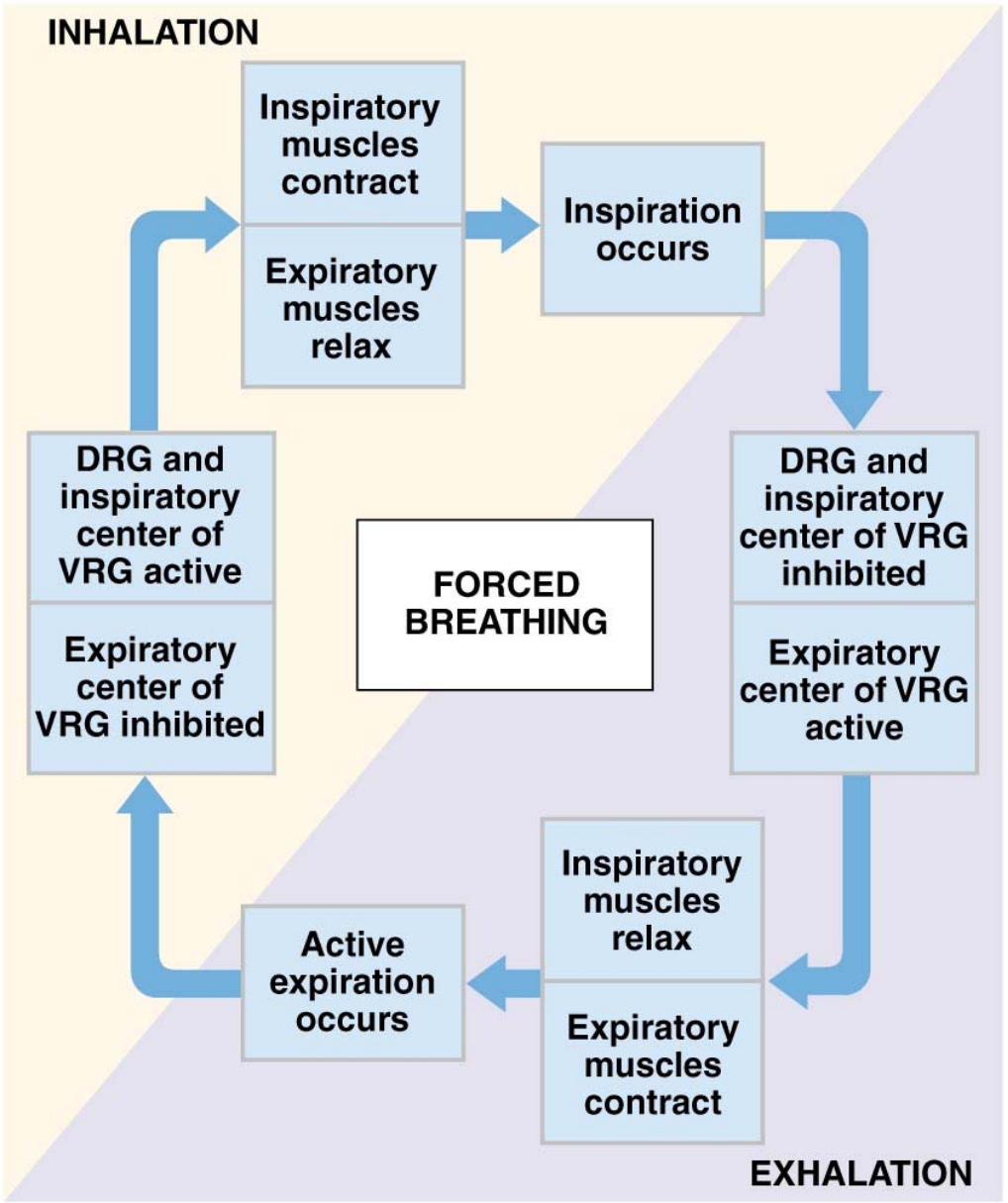


Figure 15-15(b)

The Control of Respiration

Reflex Control of Respiration

- Inflation reflex
  - Protects lungs from overexpansion
- Deflation reflex
  - Stimulates inspiration when lungs collapse
- Chemoreceptor reflexes
  - Respond to changes in pH, P_{O2}, and P_{CO2} in blood and CSF

The Control of Respiration

Control by Higher Centers

- Exert effects on pons or on respiratory motorneurons
  - Voluntary actions
    - Speech, singing
  - Involuntary actions through the limbic system
    - Rage, eating, sexual arousal

The Control of Respiration

Key Note

Interplay between respiratory centers in the pons and medulla oblongata sets the basic pace of breathing, as modified by input from chemo-receptors, baroreceptors, and stretch receptors. CO_2 level, rather than O_2 level, is the main driver for breathing. Protective reflexes can interrupt breathing and conscious control of respiratory muscles can act as well.

The Control of Respiration

The Control of Respiration

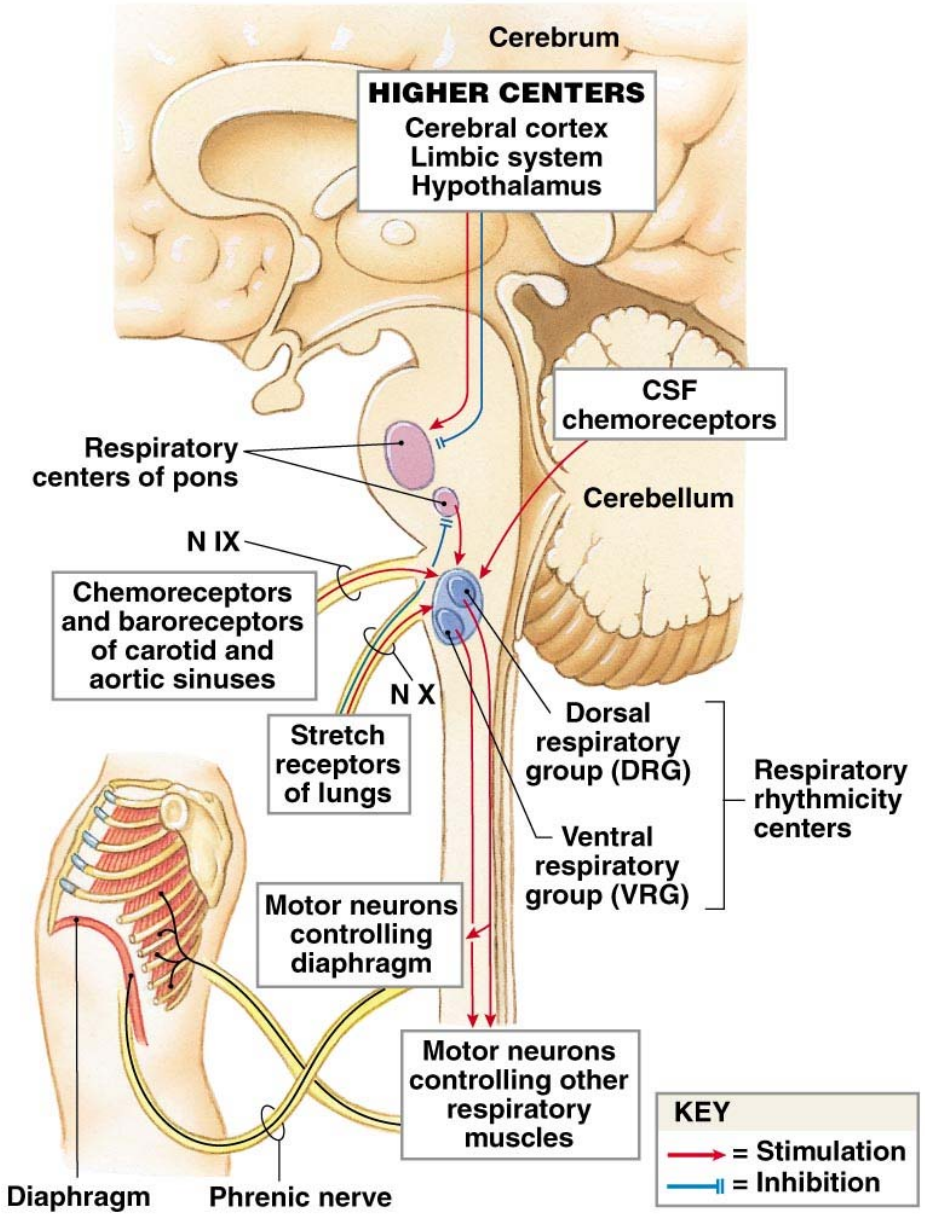


Figure 15-16

Respiratory Changes at Birth

Conditions Before Birth

- Pulmonary arterial resistance is high
- Rib cage is compressed
- Lungs are collapsed
- Airways, alveoli are filled with fluid

Conditions After Birth

- An *heroic* breath fills lungs with air, displaces fluid, and opens alveoli
- Surfactant stabilizes open alveoli

Respiratory System and Aging

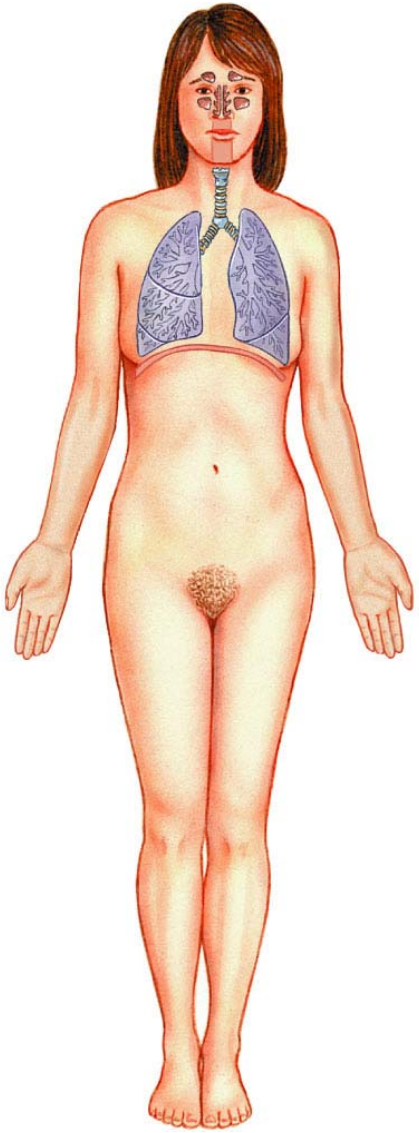
Respiratory System Loses Efficiency

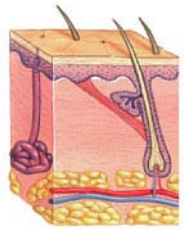
- Elastic tissue deteriorates
  - Lowers vital capacity
- Rib cage movement restricted
  - Arthritic changes
  - Costal cartilages loses flexibility
- Some emphysema usually appears

The Respiratory System in Perspective

FIGURE 15-17
Functional Relationships Between the Respiratory System and Other Systems

The Integumentary System

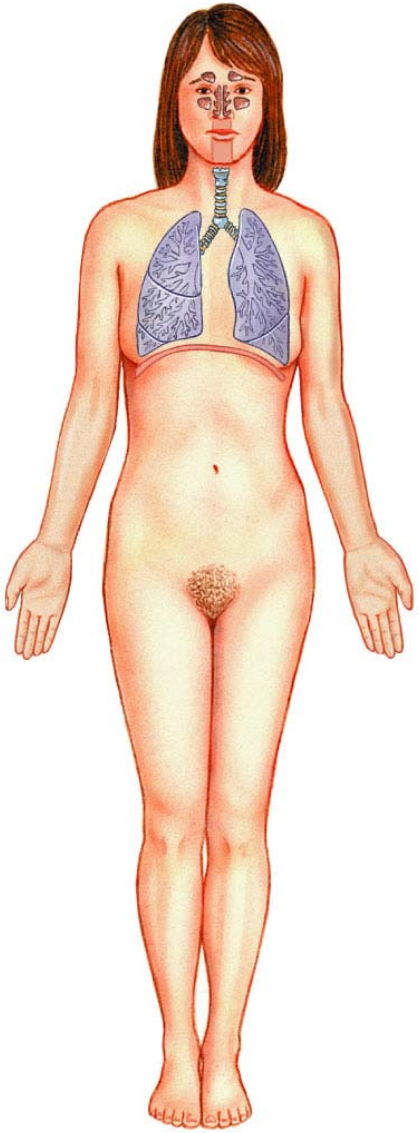




- Protects portions of upper respiratory tract; hairs guard entry to external nares

Figure 15-17
2 of 11

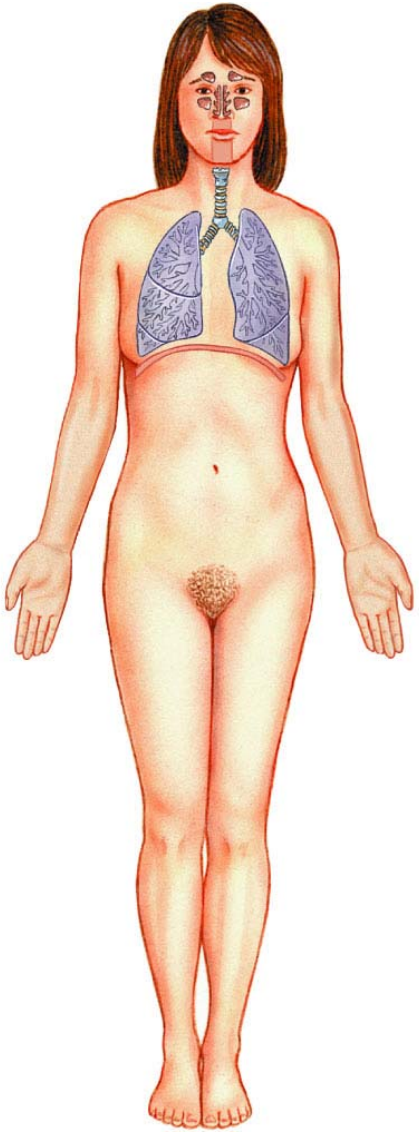
The Skeletal System

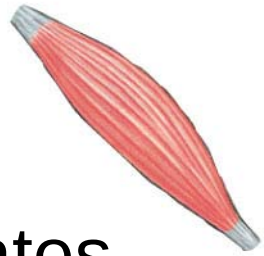


- Movements of ribs important in breathing; axial skeleton surrounds and protects lungs

Figure 15-17
3 of 11

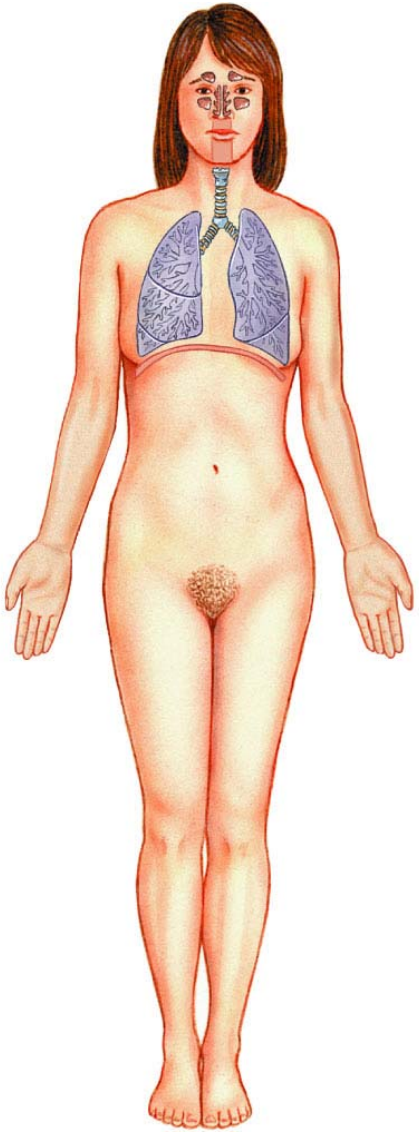
The Muscular System





- Muscular activity generates carbon dioxide; respiratory muscles fill and empty lungs; other muscles control entrances to respiratory tract; intrinsic laryngeal muscles control airflow through larynx and produce sounds

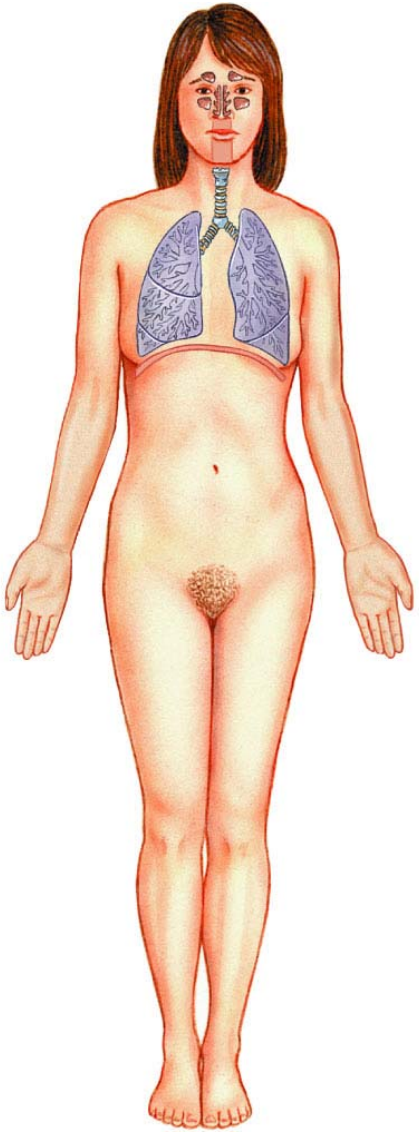
The Nervous System

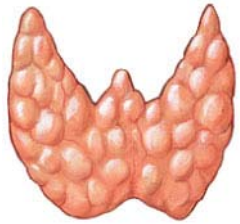


- Monitors respiratory volume and blood gas levels; controls pace and depth of respiration

Figure 15-17
5 of 11

The Endocrine System

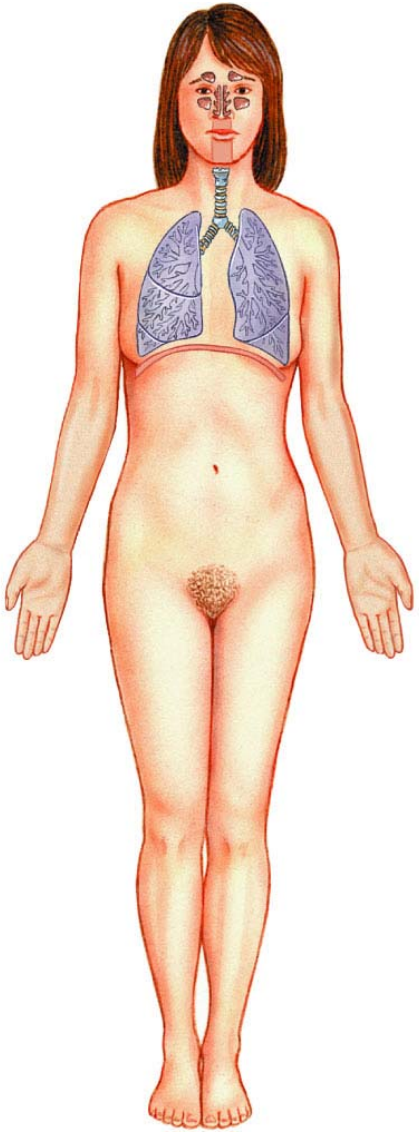


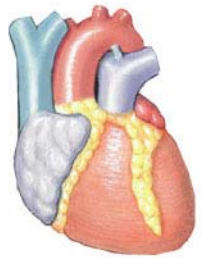


- Epinephrine and norepinephrine stimulate respiratory activity and dilate respiratory passageways

Figure 15-17
6 of 11

The Cardiovascular System

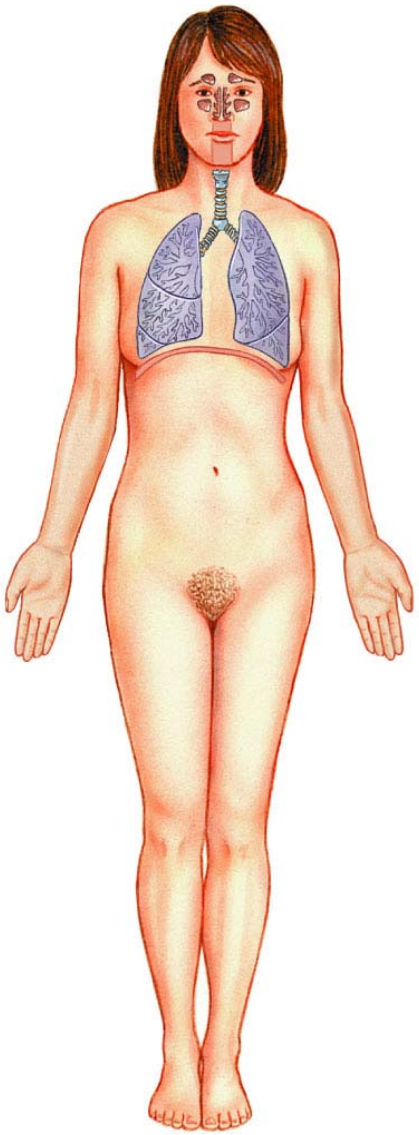




- Red blood cells transport oxygen and carbon dioxide between lungs and peripheral tissues
- Bicarbonate ions contribute to buffering capability of blood

Figure 15-17
7 of 11

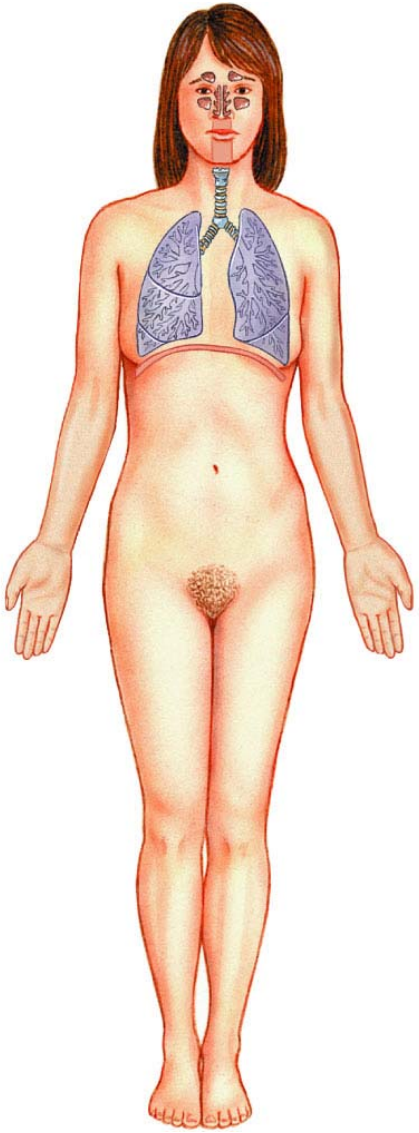
The Lymphatic System



- Tonsils protect against infection at entrance to respiratory tract; lymphatic vessels monitor lymph drainage from lungs and mobilize specific defenses when infection occurs
- Alveolar phagocytes present antigens to trigger specific defenses; mucous membrane lining the nasal cavity and upper pharynx traps pathogens, protects deeper tissues

Figure 15-17

The Digestive System



- Provides substrates, vitamins, water, and ions that are necessary to all cells of the respiratory system
- Increased thoracic and abdominal pressure through contraction of respiratory muscles can assist in defecation

Figure 15-17
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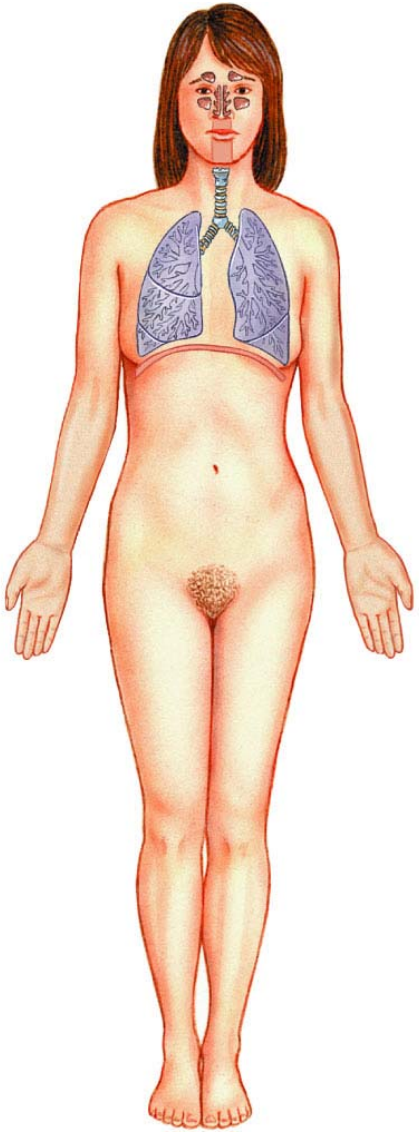
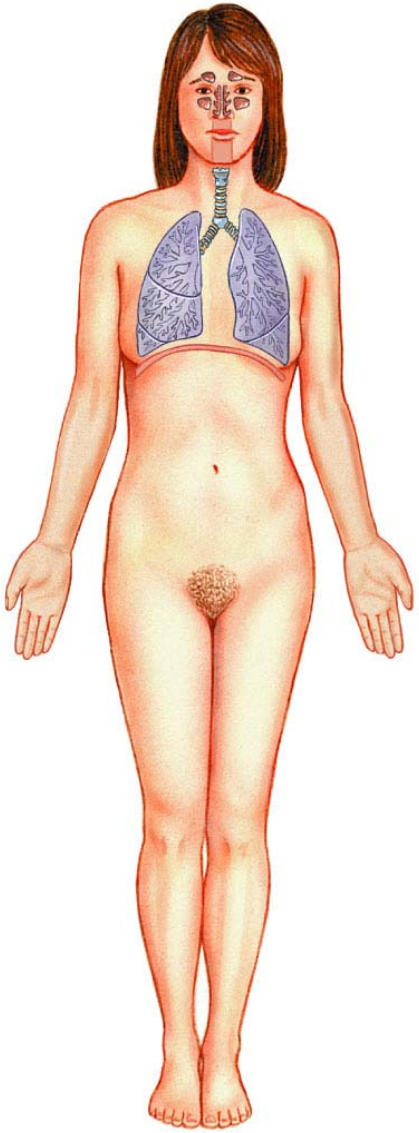
The Urinary System



- Eliminates organic wastes generated by cells of the respiratory system; maintains normal fluid and ion balance in the blood
- Assists in the regulation of pH by eliminating carbon dioxide

The Reproductive System



- Changes in respiratory rate and depth occur during sexual arousal

Figure 15-17
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