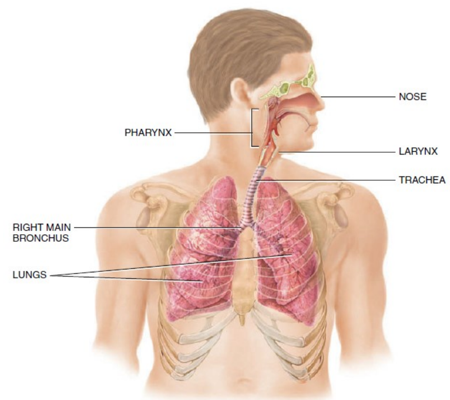

(a) Anterior view showing organs of respiration

FIG

ANATOMY AND PHYSIOLIGY OF RESPIRATORY SYSTEM

Course Name: Anatomy and Physiology 2

Course Code: 0521215

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Respiratory System Anatomy

- **O B J E C T I V E S**

- Describe the anatomy and histology of the nose, pharynx, larynx, trachea, bronchi, and lungs.

- Identify the functions of each respiratory system structure.

Respiratory System Anatomy (Introduction)

- The **respiratory system** (RES-pi-ra-tō-r-ē) consists of the nose, pharynx (throat), larynx (voice box), trachea (windpipe), bronchi, and lungs (Figure 23.1).
- Its parts can be classified according to either structure or function.

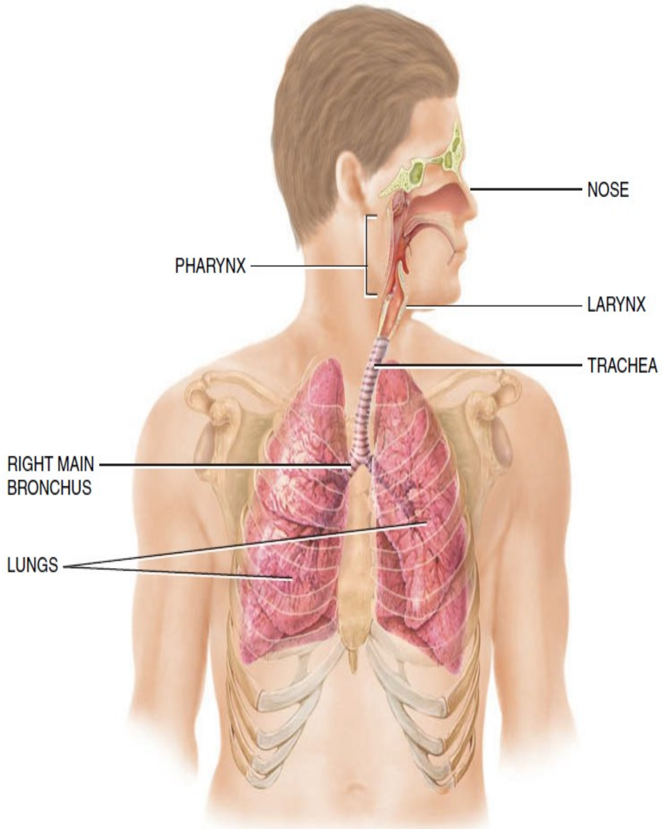
→ *Structurally,* the respiratory system consists of two parts:

(1)The **upper respiratory system** includes the nose, nasal cavity, pharynx, and associated structures

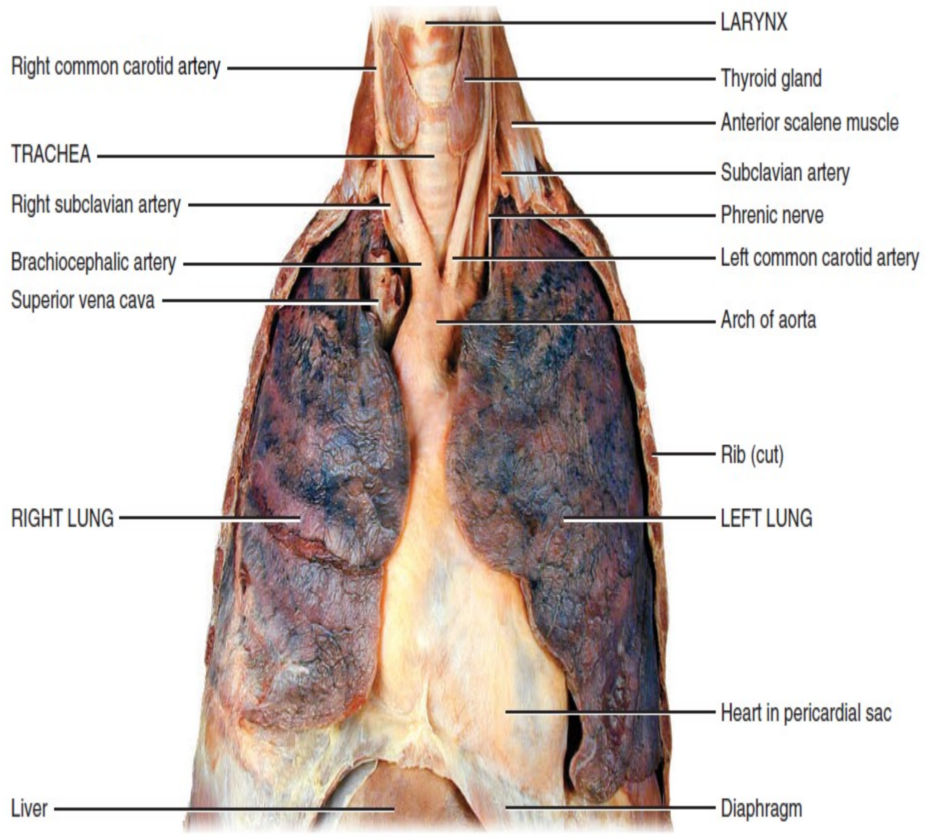
(2)The **lower respiratory system** includes the larynx, trachea, bronchi, and lungs.

Figure 23.1 Structures of the respiratory system.

The upper respiratory system includes the nose, nasal cavity, pharynx, the larynx and associated structures;
The lower respiratory system includes the trachea, bronchi, and lungs.



(a) Anterior view showing organs of respiration



(b) Anterior view of lungs and heart after removal of the anterolateral thoracic wall and pleura

Respiratory System Anatomy (Introduction; continued-1)

→ *Functionally,* the respiratory system also consists of two parts:

(1) The **conducting zone** consists of a series of interconnecting cavities and tubes both outside and within the lungs. These include the nose, nasal cavity, pharynx, larynx, trachea, bronchi, bronchioles, and terminal bronchioles; their function is to filter, warm, and moisten air and conduct it into the lungs.

(2) The **respiratory zone** consists of tubes and tissues within the lungs where gas exchange occurs. These include the respiratory bronchioles, alveolar ducts, alveolar sacs, and alveoli and are the main sites of gas exchange between air and blood.

Respiratory System Anatomy (Introduction; continued-2)

The branch of medicine that deals with the diagnosis and treatment of diseases of the ears, nose, and throat (ENT) is called **otorhinolaryngology** (ō-tō-rī-nō-lar-in-GOL-o-jē; *oto-* ear; -*rhino-* nose; -*laryngo-* voice box; -*logy* study of).

A **pulmonologist** (pul-mo-NOL-ō-jist) is a specialist in the diagnosis and treatment of diseases of the lungs.

Nose

- The **nose** is a specialized organ at the entrance of the respiratory system that consists of a visible external portion and an internal portion inside the skull called the nasal cavity.
- The **external nose** is the portion of the nose visible on the face and consists of a supporting framework of bone and hyaline cartilage covered with muscle and skin and lined by a mucous membrane.
- On the under surface of the external nose are two openings called the **external nares** (NĀ -rez; singular is **naris**) or *nostrils*.

The **interior structures** of the external nose have three functions:

(1) warming, moistening, and filtering incoming air;

(2) detecting olfactory stimuli;

(3) modifying speech vibrations as they pass through the large, hollow resonating chambers.

→ *Resonance* refers to prolonging, amplifying, or modifying a sound by vibration.

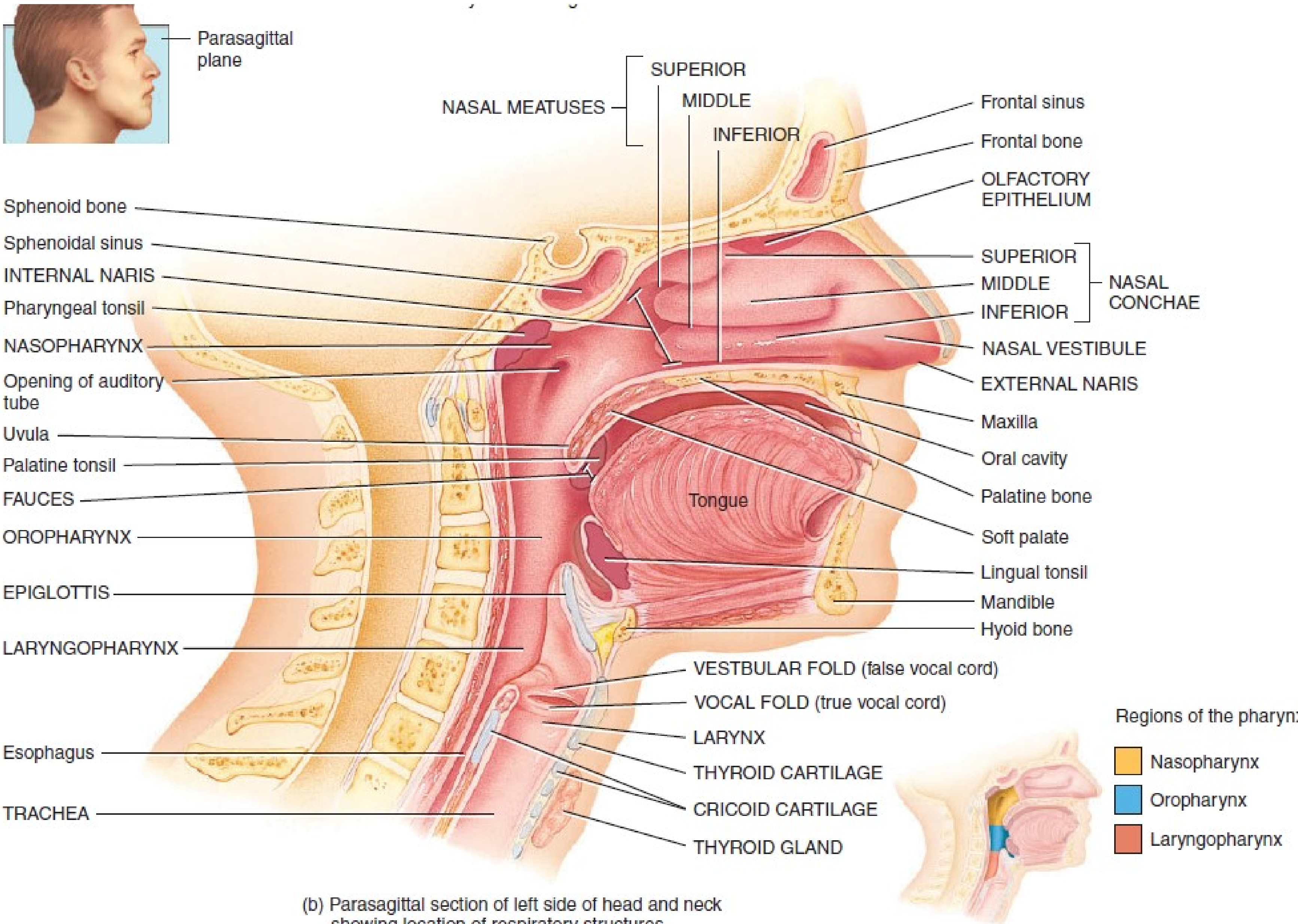
Nose (Continued-1)

- Anteriorly, the nasal cavity merges with the external nose, and posteriorly it communicates with the pharynx through two openings called the **internal nares** or *choanae* (ko¯-A¯ -ne¯) (see Figure 23.2b).
- Ducts from the *paranasal sinuses* (which drain mucus) and the *nasolacrimal ducts* (which drain tears) also open into the nasal cavity.

Nose (Continued-2)

- As inhaled air whirls around the conchae and meatuses, it is warmed by blood in the capillaries.
- Mucus secreted by the goblet cells moistens the air and traps dust particles.
- Drainage from the nasolacrimal ducts also helps moisten the air, and is sometimes assisted by secretions from the paranasal sinuses.
- The cilia move the mucus and trapped dust particles toward the pharynx, at which point they can be swallowed or spit out, thus removing the particles from the respiratory tract.
- The olfactory receptor cells, supporting cells, and basal cells lie in the respiratory region, which is near the superior nasal conchae and adjacent septum. These cells make up the **olfactory epithelium**. It contains cilia but no goblet cells.

Figure 23.2 Respiratory structures in the head and neck.
As air passes through the nose, it is warmed, filtered, and moistened; and olfaction occurs.



(b) Parasagittal section of left side of head and neck showing location of respiratory structures

Paranasal Sinuses

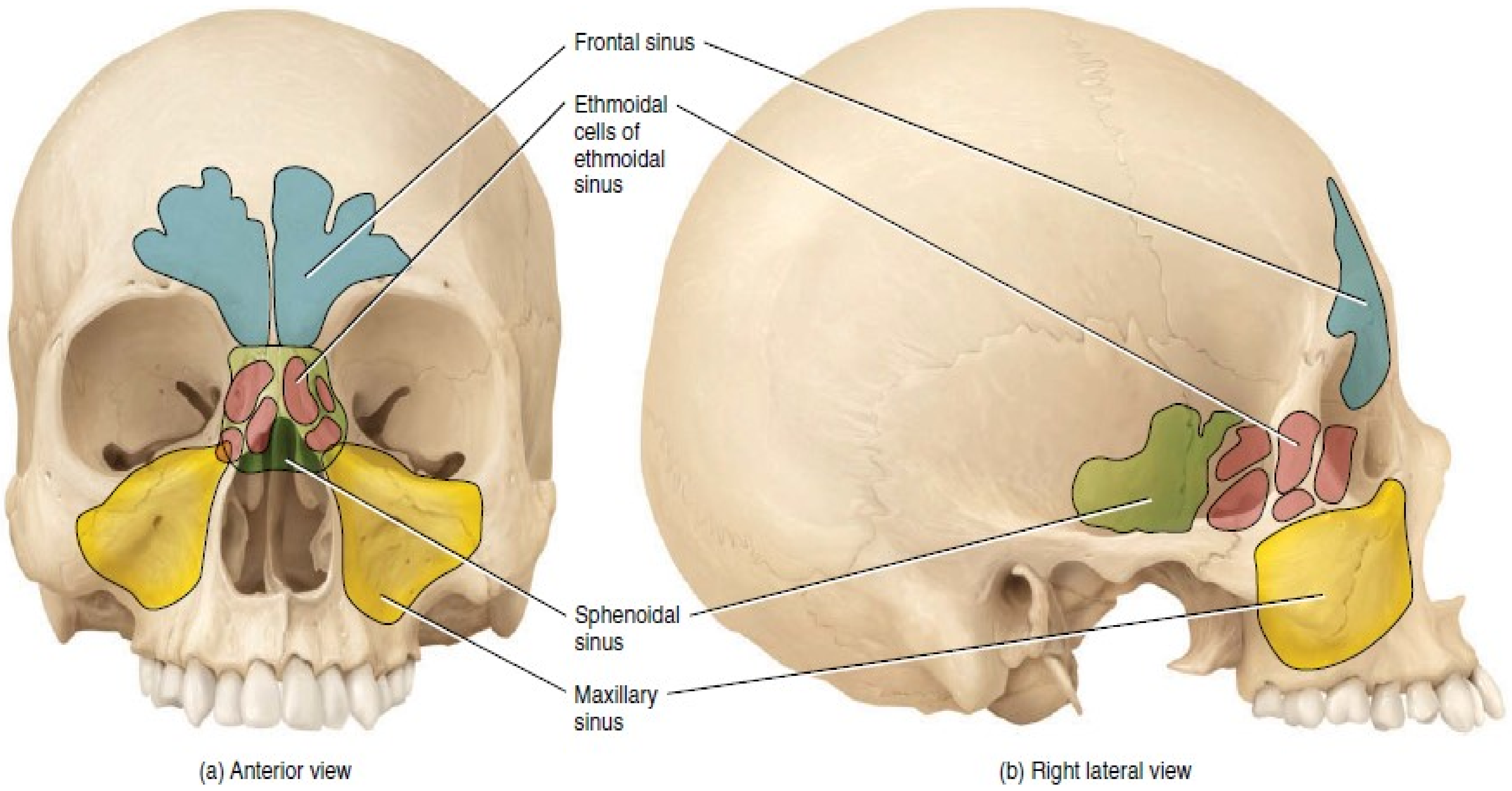
- The paranasal sinuses Paranasal sinuses are cavities in certain cranial and facial bones, lined with mucous membranes that are continuous with the lining of the nasal cavity.
- Secretions produced by the mucous membranes of the paranasal sinuses drain into the lateral wall of the nasal cavity.
- Paranasal sinuses are quite small or absent at birth, but increase in size during two periods of facial enlargement—during the eruption of the teeth and at the onset of puberty.
- They arise as outgrowths of the nasal mucosa that project into the surrounding bones.
- Skull bones containing the paranasal sinuses are the frontal, sphenoid, ethmoid, and maxillae.

Paranasal Sinuses (continued-1)

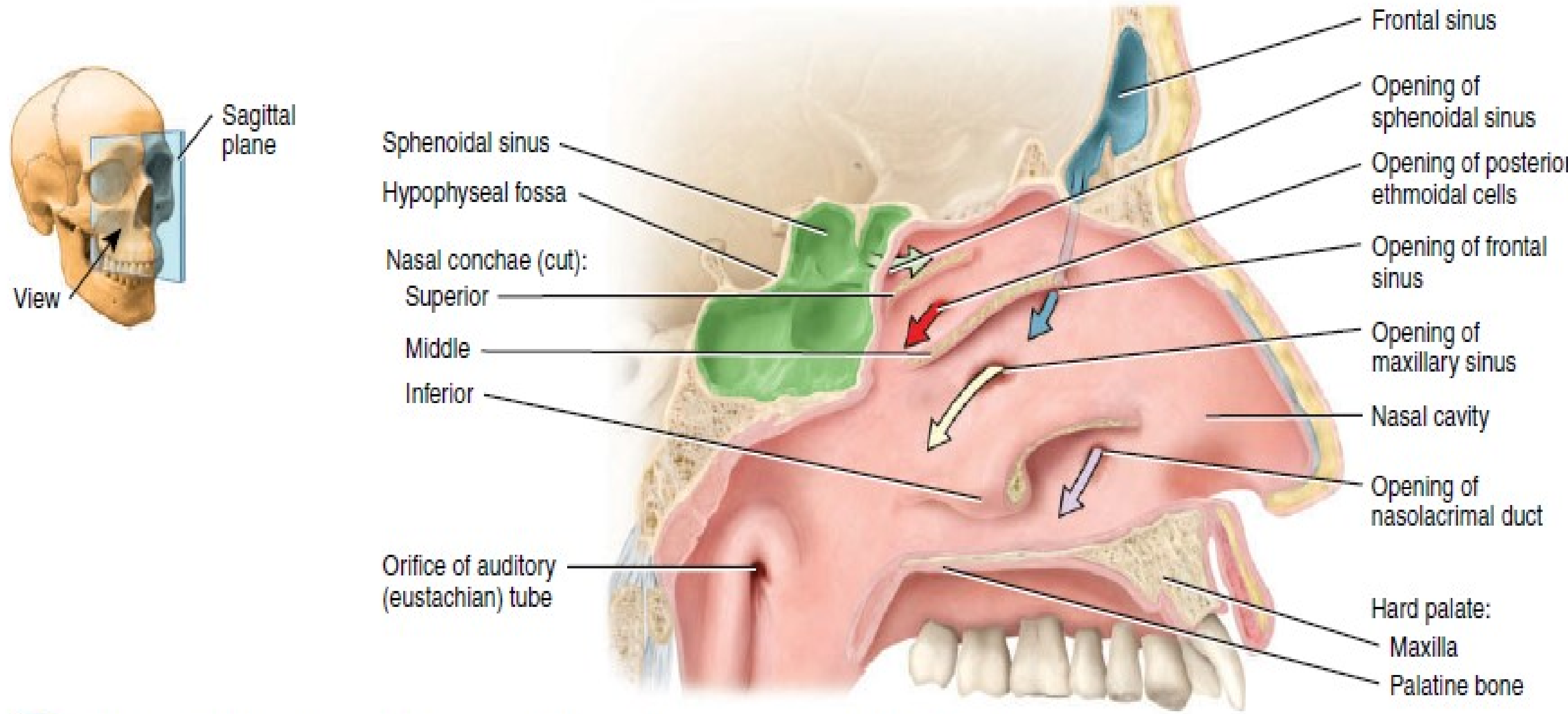
- The paranasal sinuses allow the skull to increase in size without a change in the mass (weight) of the bone.
- The paranasal sinuses increase the surface area of the nasal mucosa, thus increasing the production of mucus to help moisten and cleanse inhaled air.
- In addition, the paranasal sinuses serve as resonating (echo) chambers within the skull that intensify and prolong sounds, thereby enhancing the quality of the voice.
- The influence of the paranasal sinuses on your voice becomes obvious when you have a cold; the passageways through which sound travels into and out of the paranasal sinuses become blocked by excess mucus production, changing the quality of your voice.

Paranasal sinuses projected to the surface

Paranasal sinuses are mucous membrane–lined spaces in the frontal, sphenoid, ethmoid, and maxillary bones that connect to the nasal cavity.



Paranasal sinuses projected to the surface



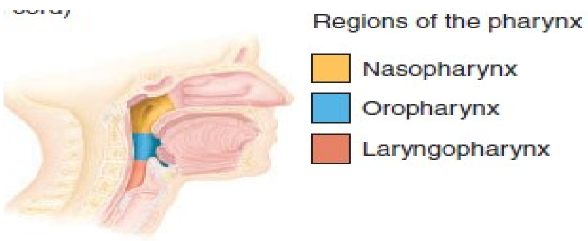
What are the functions of the paranasal sinuses?

(c) Sagittal section

Pharynx

- The **pharynx** (FAR-inks), or throat, is a funnel-shaped tube about 13 cm (5 in.) long that starts at the internal nares and extends to the level of the cricoid cartilage, the most inferior cartilage of the larynx (voice box) (see Figure 23.2b).
- The pharynx lies just posterior to the nasal and oral cavities, superior to the larynx, and just anterior to the cervical vertebrae.
- Its wall is composed of skeletal muscles and is lined with a mucous membrane.
- Relaxed skeletal muscles help keep the pharynx patent (OPEN).
- Contraction of the skeletal muscles assists in deglutition (swallowing).
- The pharynx functions as a passageway for air and food, provides a resonating chamber for speech sounds, and houses the tonsils, which participate in immunological reactions against foreign invaders.

Pharynx (continued-1)



- The muscles of the entire pharynx are arranged in two layers, an outer circular layer and an inner longitudinal layer.
- The pharynx can be divided into three anatomical regions:

(1) **NASOPHARYNX**, lies posterior to the nasal cavity and extends to the soft palate.

→There are five openings in its wall: two internal nares, two openings that lead into the *auditory* (*pharyngotympanic*) *tubes* (commonly known as the *eustachian tubes*), and the opening into the oropharynx.

- Lined with **pseudostratified ciliated columnar epithelium**, and the cilia move the mucus down toward the most inferior part of the pharynx.

→Nasopharynx also exchanges small amounts of air with the auditory tubes to equalize air pressure between the middle ear and the atmosphere.

- The posterior wall also contains the **pharyngeal tonsil** (fa-RIN-je-al), or *adenoid*.

Pharynx (continued-2)

(2) **OROPHARYNX**, This portion of the pharynx has both respiratory and digestive functions, serving as a common passageway for air, food, and drink.

→ Because the oropharynx is subject to abrasion by food particles, it is lined with **nonkeratinized stratified squamous epithelium**.

→ Two pairs of tonsils, the **palatine** and **lingual tonsils**, are found in the oropharynx.

(3) **LARYNGOPHARYNX**. (hypopharynx), begins at the level of the hyoid bone. At its inferior end it opens into the esophagus (food tube) posteriorly and the larynx (voice box) anteriorly.

→ lined with **nonkeratinized stratified squamous epithelium**.

Larynx (UPPER RESPIRATORY TRACT)

- The **larynx** (LAR-ingks), or voice box, is a short passageway that connects the laryngopharynx with the trachea. It lies in the midline of the neck anterior to the esophagus and the fourth through sixth cervical vertebrae (C4–C6).
- The lining of the larynx superior to the vocal folds is **nonkeratinized stratified squamous epithelium**.
- The lining of the larynx inferior to the vocal folds is **pseudostratified ciliated columnar epithelium** consisting of ciliated columnar cells, goblet cells, and basal cells. The mucus produced by the goblet cells helps trap dust not removed in the upper passages. The cilia in the upper respiratory tract move mucus and trapped particles *down* toward the pharynx; the cilia in the lower respiratory tract move them *up* toward the pharynx.

The Structures of Voice Production

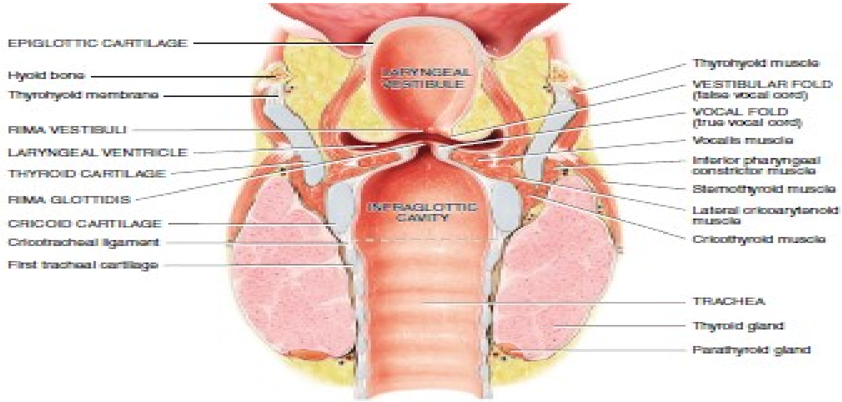
The mucous membrane of the larynx forms two pairs of folds

→ A superior pair called the **vestibular folds** (*false vocal cords*)

→ An inferior pair called the **vocal folds** (*true vocal cords*).

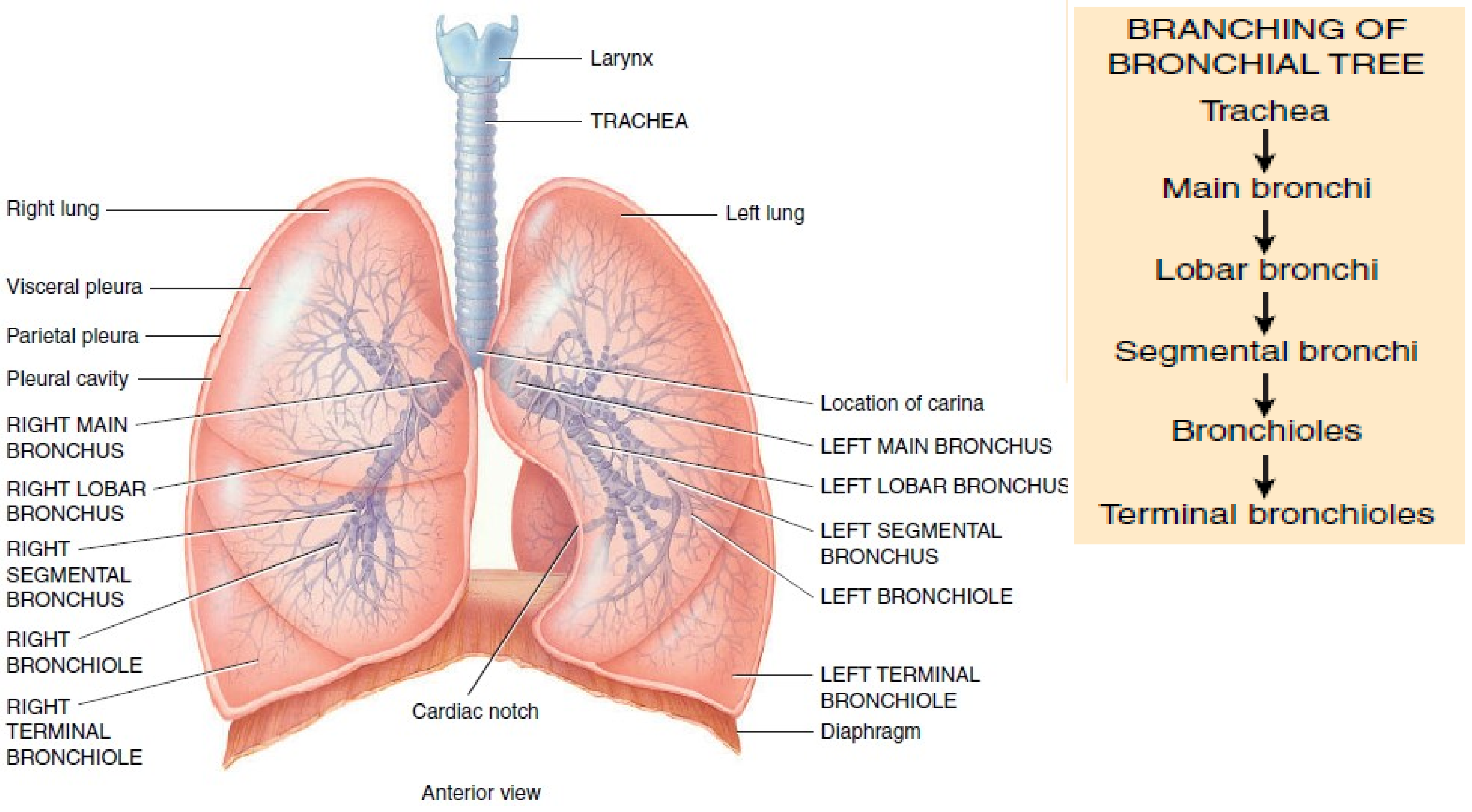
→ The space between the vestibular folds is known as the **rima vestibuli**.

→ The **laryngeal ventricle** is a lateral expansion of the middle portion of the laryngeal cavity inferior to the vestibular folds and superior to the vocal folds.



(d) Frontal section

Figure 23.7 Branching of airways from the trachea: the bronchial tree.



Trachea

- The **trachea** (TRA¯ -ke¯-a sturdy), or *windpipe*, is a tubular passageway for air that is about 12 cm (5 in.) long and 2.5 cm (1 in.) in diameter.
- It is located anterior to the esophagus and extends from the larynx to the superior border of the fifth thoracic vertebra (T5), where it divides into right and left primarybronchi.
- The layers of the tracheal wall, from deep to superficial, are the

(1) mucosa, (2) submucosa, (3) hyaline cartilage, and (4) adventitia (composed of areolar connective tissue).

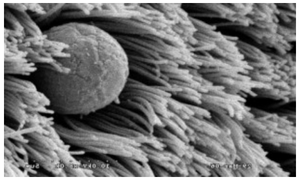
- The mucosa of the trachea consists of an epithelial layer of pseudostratified ciliated columnar epithelium and an underlying layer of lamina propria *(A type of connective tissue found under the thin layer of tissues covering a mucous membrane)* that contains elastic and reticular fibers.
- It provides the same protection against dust as the membrane lining the nasal cavity and larynx.
- The submucosa consists of areolar connective tissue that contains seromucous glands and their ducts.

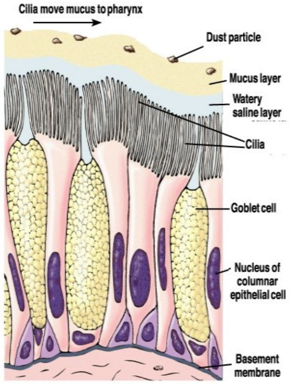
Bronchi

- The trachea divides into a **right main** (*primary*) **bronchus** (BRONGkus windpipe), which goes into the right lung, and a **left main** (*primary*) **bronchus**, which goes into the left lung.
- The right main bronchus is **more vertical**, **shorter**,
- and **wider than the left.** As a result, an aspirated object is more likely to enter and lodge in the right main bronchus than the left.
- Like the trachea, the main bronchi (BRONG-kī) contain incomplete rings of cartilage and are lined by <u>pseudostratified ciliated columnar epithelium</u>.
- At the point where the trachea divides into right and left main bronchi an internal ridge called the **carina** (ka-RĪ-na) is formed by a posterior and somewhat inferior projection of the last tracheal cartilage.
- The mucous membrane of the carina is one of the most sensitive areas of the entire larynx and trachea for triggering a cough reflex.

BRANCHING OF BRONCHIAL TREE

Trachea
↓
Main bronchi
↓
Lobar bronchi
↓
Segmental bronchi
↓
Bronchioles
↓
Terminal bronchioles



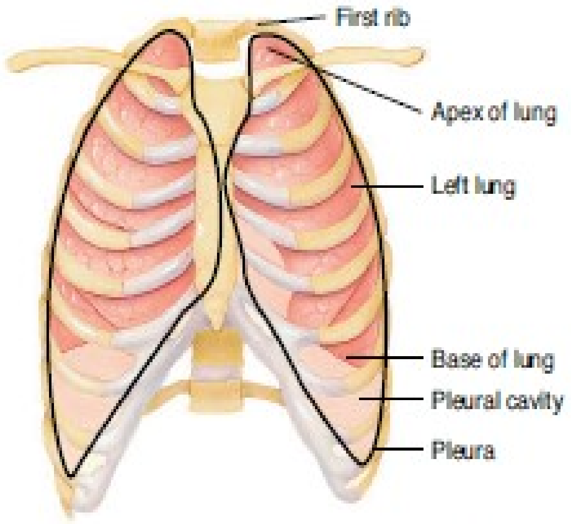


Lungs, Lobes, Fissures, and Lobules

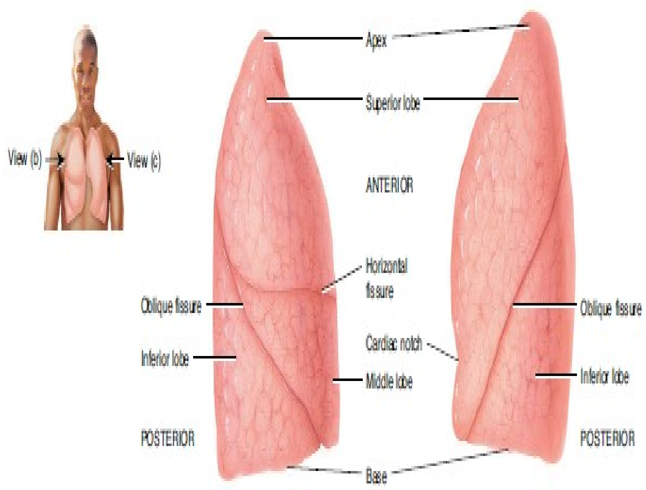
- The **lungs** (lightweights, because they float) are paired cone-shaped organs in the thoracic cavity.
- Each lung is enclosed and protected by a double-layered serous membrane called the **pleural membrane** (PLOOR-al; *pleur-* side). The superficial layer, called the **parietal pleura**, lines the wall of the thoracic cavity; the deep layer, the **visceral pleura**, covers the lungs themselves.
- In between the parietal and visceral pleura exists a cavity containing a thin fluid named **pleural cavity**.

- One or two **fissures** divide each lung into lobes.
- Both lungs have an **oblique fissure**, which extends inferiorly and anteriorly
- The right lung also has a **horizontal fissure**.
- Each bronchopulmonary segment of the lungs has many small compartments called **lobules**; each lobule is wrapped in elastic connective tissue and contains a lymphatic vessel, an arteriole, a venule, and a branch from a terminal bronchiole

Surface anatomy of the lungs.



(a) Anterior view of lungs and pleurae in thorax

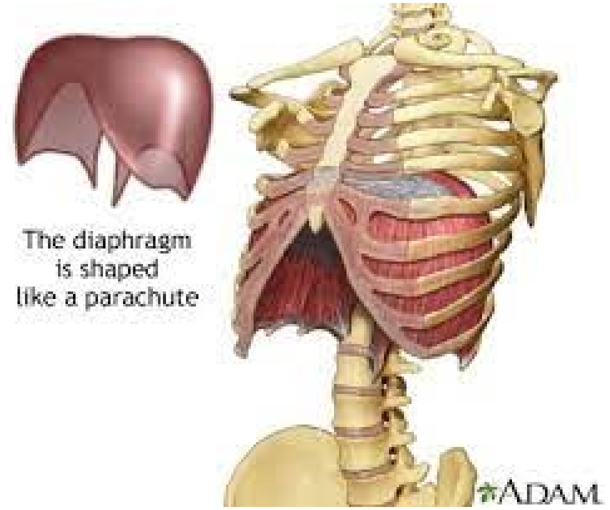


(b) Lateral view of right lung (c) Lateral view of left lung

The lung parenchyma is that portion of the lungs involved in gas exchange. The most prominent structure in this region is the alveolus.

Each alveolus in the lung parenchyma opens directly into an alveolar duct.

The diaphragm



- The diaphragm, located below the lungs, is the major muscle of respiration.
- It is a large, dome-shaped muscle that contracts rhythmically and continually, and most of the time, involuntarily.
- Upon inhalation, the diaphragm contracts and flattens and the chest cavity enlarges. This contraction creates a vacuum, which pulls air into the lungs.
- Upon exhalation, the diaphragm relaxes and returns to its domelike shape, and air is forced out of the lungs.

Alveoli

- An **alveolus** (al-VE¯-o¯-lus) is a cup-shaped outpouching lined by simple squamous epithelium and supported by a thin elastic basement membrane; an **alveolar sac** consists of two or more alveoli that share a common opening (Figure 23.10a, b).
- *The walls of alveoli consist of two types of alveolar epithelial cells (Figure 23.11).*

1- The more numerous **type I alveolar** (*squamous pulmonary epithelial*) **cells** are simple squamous epithelial cells that form a nearly continuous lining of the alveolar wall. → the main sites of gas exchange.

2- **Type II alveolar cells**, also called *septal cells*, are fewer in number and are found between type I alveolar cells. → secrete alveolar fluid, including **surfactant** a complex mixture of phospholipids and lipoproteins. Surfactant lowers the surface tension of alveolar fluid, which reduces the tendency of alveoli to collapse and thus maintains their patency.

3- **Alveolar macrophages** constitute a small percentage, but represent the main cellular host defense mechanism in the alveolar space. They are part of the mononuclear phagocyte system and are derived primarily from blood Monocytes.

Alveoli (continued)

Extending from the alveolar air space to blood plasma, the respiratory membrane consists of four layers (Figure 23.11b):

1. A layer of type I and type II alveolar cells and associated alveolar macrophages that constitutes the **alveolar wall**

2. An **epithelial basement membrane** underlying the alveolar wall

3. A **capillary basement membrane** that is often fused to the epithelial basement membrane

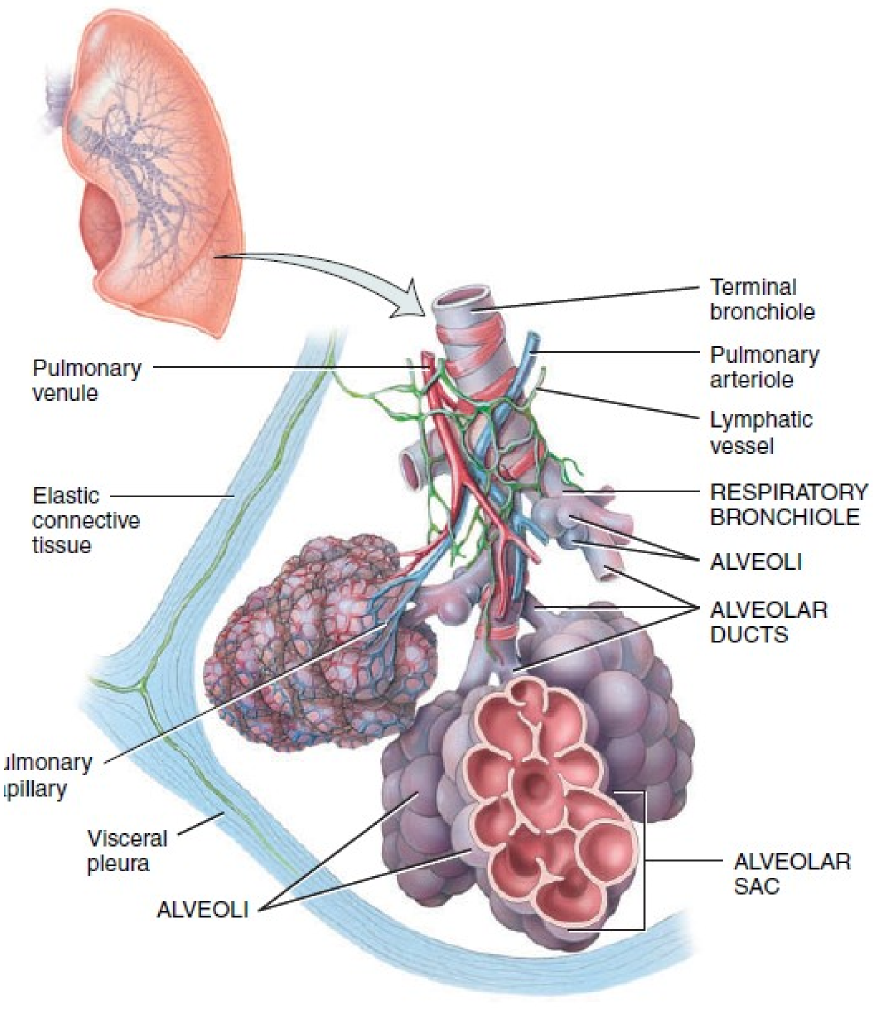
4. The **capillary endothelium**

- The exchange of O2 and CO2 between the air spaces in the lungs and the blood takes place by diffusion across the alveolar and capillary walls, which together form the **respiratory membrane**.

Figure 23.10 Microscopic anatomy of a lobule of the lungs.
Figure 23.11 Structural components of an alveolus.

MICROSCOPIC AIRWAYS

RESPIRATORY BRONCHIOLES
↓
ALVEOLAR DUCTS
↓
ALVEOLAR SACS
↓
ALVEOLI



(a) Diagram of portion of lobule of lung

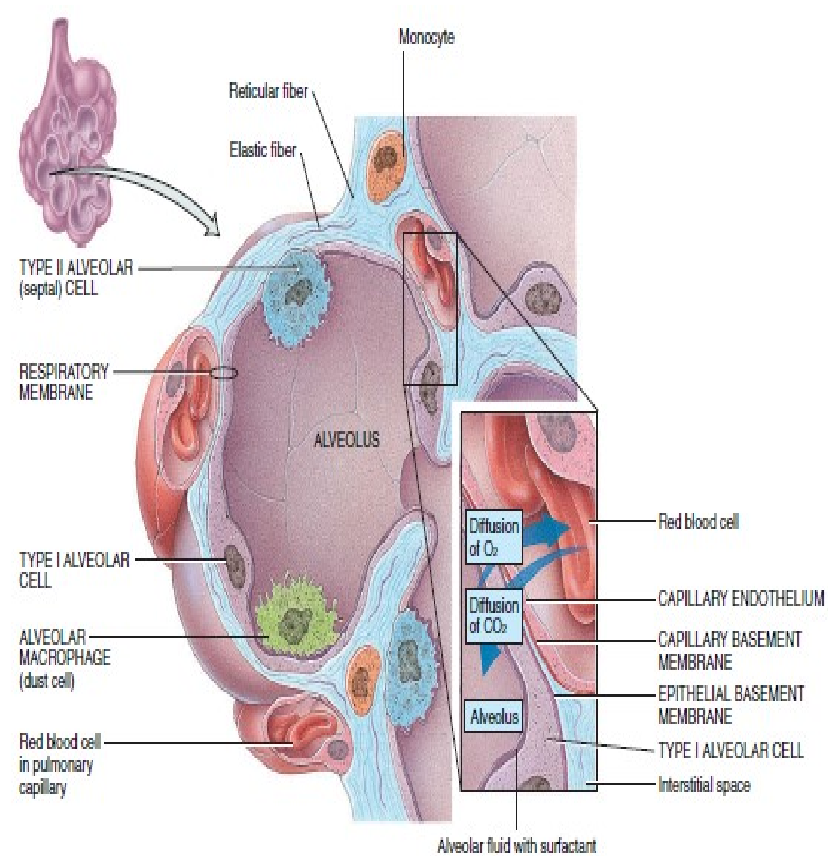


TABLE 23.1

Summary of the Structures of the Respiratory System

STRUCTURE	EPITHELIUM	CILIA	GOBLET CELLS	SPECIAL FEATURES
NOSE				
Vestibule	Nonkeratinized stratified squamous.	No.	No.	Contains numerous hairs.
Respiratory region	Pseudostratified ciliated columnar.	Yes.	Yes.	Contains conchae and meatuses.
Olfactory region	Olfactory epithelium (olfactory receptors).	Yes.	No.	Functions in olfaction.
PHARYNX				
Nasopharynx	Pseudostratified ciliated columnar.	Yes.	Yes.	Passageway for air; contains internal nares, openings for auditory tubes, and pharyngeal tonsil.
Oropharynx	Nonkeratinized stratified squamous.	No.	No.	Passageway for both air and food and drink; contains opening from mouth (fauces).
Laryngopharynx	Nonkeratinized stratified squamous.	No.	No.	Passageway for both air and food and drink.
LARYNX	Nonkeratinized stratified squamous above the vocal folds; pseudostratified ciliated columnar below the vocal folds.	No above folds; yes below folds.	No above folds; yes below folds.	Passageway for air; contains vocal folds for voice production.
TRACHEA	Pseudostratified ciliated columnar.	Yes.	Yes.	Passageway for air; contains C-shaped rings of cartilage to keep trachea open.
BRONCHI				
Main bronchi	Pseudostratified ciliated columnar.	Yes.	Yes.	Passageway for air; contain C-shaped rings of cartilage to maintain patency.
Lobar bronchi	Pseudostratified ciliated columnar.	Yes.	Yes.	Passageway for air; contain plates of cartilage to maintain patency.
Segmental bronchi	Pseudostratified ciliated columnar.	Yes.	Yes.	Passageway for air; contain plates of cartilage to maintain patency.
Larger bronchioles	Ciliated simple columnar.	Yes.	Yes.	Passageway for air; contain more smooth muscle than in the bronchi.
Smaller bronchioles	Ciliated simple columnar.	Yes.	No.	Passageway for air; contain more smooth muscle than in the larger bronchioles.
Terminal bronchioles	Nonciliated simple columnar.	No.	No.	Passageway for air; contain more smooth muscle than in the smaller bronchioles.
LUNGS				
Respiratory bronchioles	Simple cuboidal to simple squamous.	No.	No.	Passageway for air; gas exchange.
Alveolar ducts	Simple squamous.	No.	No.	Passageway for air; gas exchange; produce surfactant.
Alveoli	Simple squamous.	No.	No.	Passageway for air; gas exchange; produce surfactant to maintain patency.

Conducting structures   Respiratory structures

Blood Supply to the Lungs

- The lungs receive blood via two sets of arteries: pulmonary arteries and bronchial arteries.
- Deoxygenated blood passes through the pulmonary trunk, which divides into a left pulmonary artery that enters the left lung and a right pulmonary artery that enters the right lung.
- (The pulmonary arteries are the only arteries in the body that carry deoxygenated blood.) Return of the oxygenated blood to the heart occurs by way of the four pulmonary veins, which drain into the left atrium (see Figure 21.29).
- Bronchial arteries, which branch from the aorta, deliver oxygenated blood to the lungs. This blood mainly perfuses the muscular walls of the bronchi and bronchioles.
- Connections do exist between branches of the bronchial arteries and branches of the pulmonary arteries, however; most blood returns to the heart via pulmonary veins.
- Some blood drains into bronchial veins, branches of the azygos system, and returns to the heart via the superior vena cava.

→ Azygos system drain deoxygenated blood into one of your body's largest veins (superior vena cava).

Patency of the Respiratory System

These included:

1- The bony and cartilaginous frameworks of the nose,

2- Skeletal muscles of the pharynx,

3- Cartilages of the larynx,

4- C-shaped rings of cartilage in the trachea and bronchi,

5- Smooth muscle in the bronchioles,

6- Surfactant in the alveoli→ Gas must dissolve in liquid in order to enter or leave the cell. Therefore each alveolus is surrounded by a thin layer of tissue fluid. This will make potential problem in that it will make the walls of the alveolus stick together. Internally. Imagine a plastic bag that is wet inside. The walls will stick together because of water surface tension and inflation will be difficult. Surfactant will mix with tissue fluid and decreases its surface tension.

PHYSIOLIGY OF RESPIRATORY SYSTEM

Pulmonary Ventilation

The process of gas exchange in the body, called **respiration**, has three basic steps:

1. **Pulmonary ventilation** (*pulmon-* lung), or *breathing*, is the inhalation (inflow) and exhalation (outflow) of air and involves the exchange of air between the atmosphere and the alveoli of the lungs.
2. **External** (*pulmonary*) **respiration** is the exchange of gases between the alveoli of the lungs and the blood in pulmonary capillaries across the respiratory membrane. In this process, pulmonary capillary blood gains O2 and loses CO2.
3. **Internal** (*tissue*) **respiration** is the exchange of gases between blood in systemic capillaries and tissue cells. In this step the blood loses O2 and gains CO2. Within cells, the metabolic reactions that consume O2 and give off CO2 during the production of ATP are termed *cellular respiration*.

Pulmonary Ventilation (Continued)

- In pulmonary ventilation,

→ Air flows between the atmosphere and the alveoli of the lungs because of alternating pressure differences created by contraction and relaxation of respiratory muscles.

- The rate of airflow and the amount of effort needed for breathing are also influenced by:

→Alveolar surface tension

→Compliance of the lungs

→ Airway resistance.

Mechanics of Breathing (Pulmonary Ventilation)

Phases of Breathing:

1- *Inspiration* (Inhalation)

2- Expiration (Exhalation)

They are due to increasing and decreasing thorax and lungs volumes.

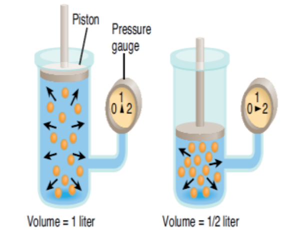
For <u>inspiration</u> to occur, lungs must be able to **expand/stretch** (*compliance*)*;* for <u>expiration</u> to occur, lungs must **get smaller** (*elasticity*). The tendency to get smaller is also aided by surfactant.

Increasing volumes by muscle contractions that lower the diaphragm and raise the ribs.

Pressure Changes during Pulmonary Ventilation → Introduction

Figure 23.12 Boyle's law.

The volume of a gas varies inversely with its pressure.



<u>**Boyle's law:**</u>

An inverse relationship between volume and pressure

The pressure of a gas in a closed container is <u>**inversely proportional**</u> to the volume of the container. (at fixed temperature).

→ This means that if the size of a closed container is **increased**, the pressure of the gas inside the container **decreases**, and that if the size of the container is decreased, then the pressure inside it increases.

<u>**During (inspiration)**</u>

Lung volume ⇧➔ intrapulmonary pressure ⇩ ➔ air goes in.

Create negative pressure in the thoracic cavity and lungs, and then air flows into the lungs.

Pressure Changes during Pulmonary Ventilation
→ *INHALATION (inspiration)*

- This condition is achieved by increasing the size of the lungs.
- For inhalation to occur, the lungs must expand, which increases lung volume and thus decreases the pressure in the lungs to below atmospheric pressure. The first step in expanding the lungs during normal quiet inhalation involves contraction of the main muscle of inhalation, the diaphragm, with resistance from external intercostals (Figure 23.13).
- The most important muscle of inhalation is the diaphragm, the dome-shaped skeletal muscle that forms the floor of the thoracic cavity. Contraction of the diaphragm is responsible for about 75% of the air that enters the lungs during quiet breathing.
- The next most important muscles of inhalation are the external intercostals. Contraction of the external intercostals is responsible for about 25% of the air that enters the lungs during normal quiet breathing.

Pressure Changes during Pulmonary Ventilation
→ *INHALATION (inspiration) - Continued-1*

- Just before each inhalation, the air pressure inside the lungs is equal to the air pressure of the atmosphere, which at sea level is about 760 millimeters of mercury (mmHg), or 1 atmosphere (atm). For air to flow into the lungs, the pressure inside the alveoli must become lower than the atmospheric pressure.
- During quiet inhalations, the pressure between the two pleural layers in the pleural cavity, called **intrapleural** (*intrathoracic*) **pressure**, is always subatmospheric (lower than atmospheric pressure). As the volume of the lungs increases in this way, the pressure inside the lungs, called the **alveolar** (*intrapulmonic*) **pressure**, drops.
- *During normal quiet inhalation*, the diaphragm descends about 1 cm (0.4 in.), producing a pressure difference of 1–3 mmHg and the inhalation of about 500 mL of air.
- *In strenuous breathing*, the diaphragm may descend 10 cm (4 in.), which produces a pressure difference of 100 mmHg and the inhalation of 2–3 liters of air.

Pressure Changes during Pulmonary Ventilation
→ *INHALATION (inspiration) - Continued-2*

- During **deep, forceful inhalations**, accessory muscles of inspiration also participate in increasing the size of the thoracic cavity.

The accessory muscles of inhalation include:

1- The **sternocleidomastoid** muscles, which elevate the sternum;

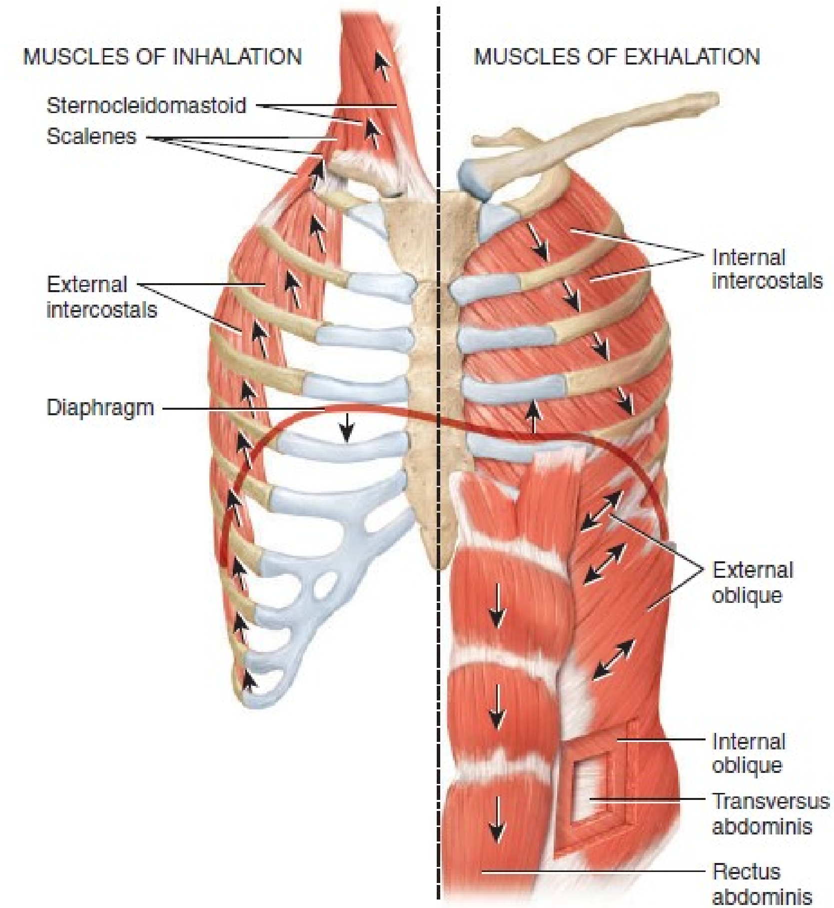
2- The **scalene** muscles, which elevate the first two ribs;

3- The **pectoralis minor** muscles, which elevate the third through fifth ribs.

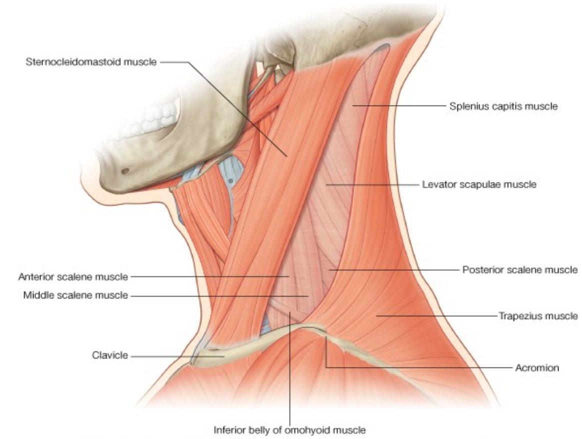
- Note: Because both normal quiet inhalation and inhalation during exercise or forced ventilation involve muscular contraction, the process of inhalation is said to be *active.*

Figure 23.13 Muscles of inhalation and exhalation

During normal, quiet inhalation, the diaphragm and external intercostals contract, the lungs expand, and air moves into the lungs; during normal, quiet exhalation, the diaphragm and external intercostals relax and the lungs recoil, forcing air out of the lungs.



(a) Muscles of inhalation (left); muscles of exhalation (right); arrows indicate the direction of muscle contraction



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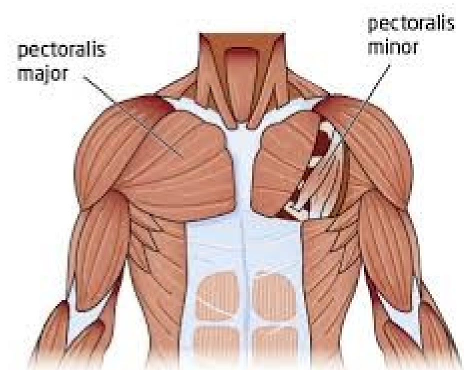


Pressure Changes during Pulmonary Ventilation
→ ***EXHALATION (Expiration)***

- Breathing out, called **exhalation** (*expiration*), is also due to a pressure gradient, but in this case the gradient is in the opposite direction: The pressure in the lungs is greater than the pressure of the atmosphere. Air then flows from the area of higher pressure in the alveoli (about 762 mmHg) to the area of lower pressure in the atmosphere.
- Normal exhalation during quiet breathing, unlike inhalation, is a *passive process* because no muscular contractions are involved.
- Instead, exhalation results from **elastic recoil** of the chest wall and lungs, both of which have a natural tendency to spring back after they have been stretched.

Movements decrease the diameters of the thoracic cavity, which decreases lung volume:

1- As the diaphragm relaxes, its dome moves superiorly owing to its elasticity.

2- As the external intercostals relax, the ribs are depressed.

- *Two inwardly directed forces contribute to elastic recoil:*

(1) the **recoil of elastic fibers** that were stretched during inhalation

(2) the **inward pull of surface tension** due to the film of alveolar fluid.

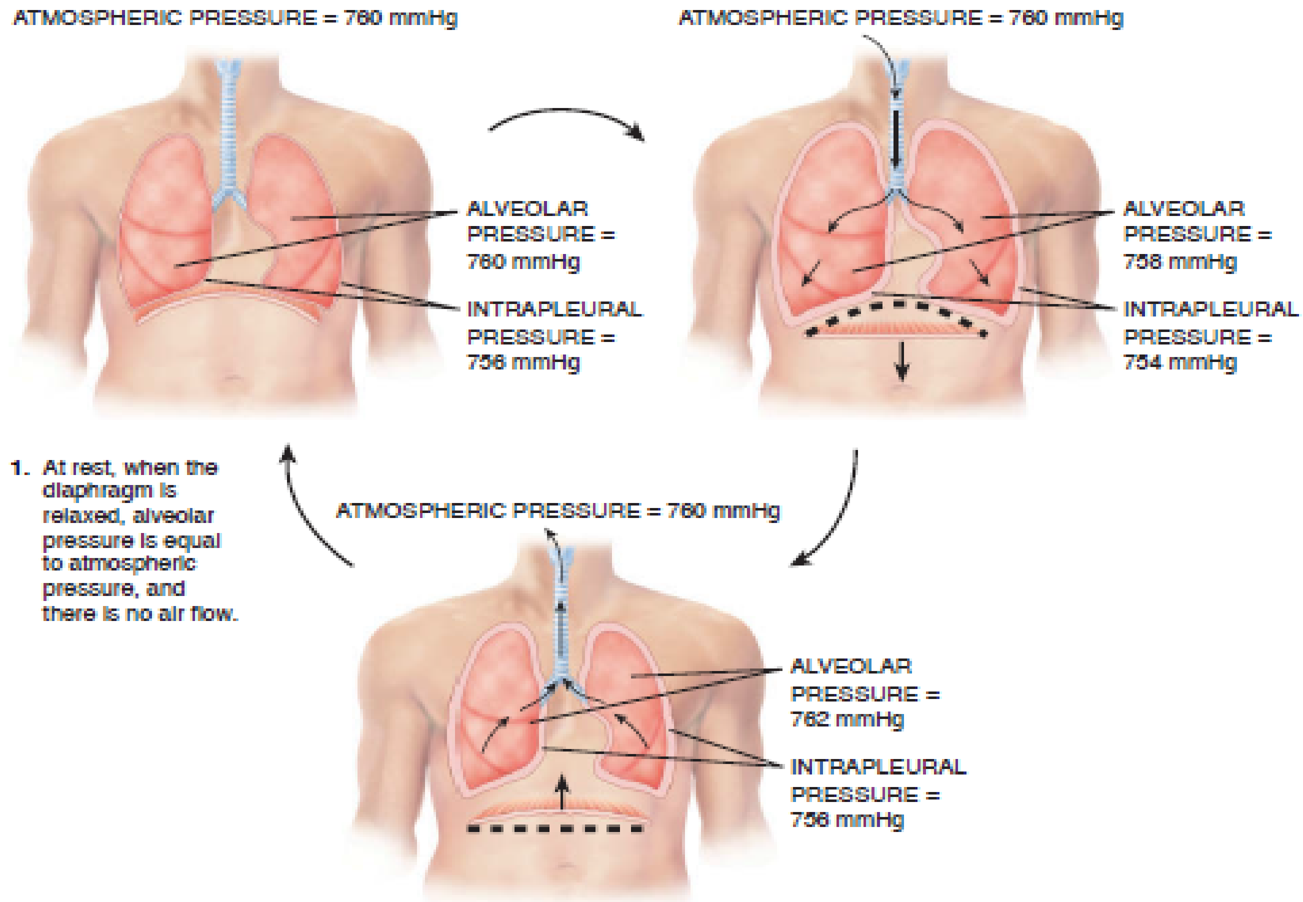
Pressure Changes during Pulmonary Ventilation
→ *EXHALATION (Expiration) continued*

- *Exhalation becomes active only during forceful breathing*, as occurs while playing a wind instrument or during exercise. During these times, muscles of exhalation—the abdominal and internal intercostals (see Figure 23.13a)—contract, which increases pressure in the abdominal region and thorax. Contraction of the abdominal muscles moves the inferior ribs downward and compresses the abdominal viscera, thereby forcing the diaphragm superiorly.

- **Although intrapleural pressure is always less than alveolar pressure, it may briefly exceed atmospheric pressure during a forceful exhalation, such as during a cough.**

Figure 23.14 Pressure changes in pulmonary ventilation. During inhalation, the diaphragm contracts, the chest expands, the lungs are pulled outward, and alveolar pressure decreases. During exhalation, the diaphragm relaxes, the lungs recoil inward, and alveolar pressure increases, forcing air out of the lungs.

→ *Air moves into the lungs when alveolar pressure is less than atmospheric pressure, and out of the lungs when alveolar pressure is greater than atmospheric pressure.*



1. At rest, when the diaphragm is relaxed, alveolar pressure is equal to atmospheric pressure, and there is no air flow.

2. During inhalation, the diaphragm contracts and the external intercostals contract. The chest cavity expands, and the alveolar pressure drops below atmospheric pressure. Air flows into the lungs in response to the pressure gradient and the lung volume expands. During deep inhalation, the scalene and sternocleidomastoid muscles expand the chest further, thereby creating a greater drop in alveolar pressure.

3. During exhalation, the diaphragm relaxes and the external intercostals relax. The chest and lungs recoil, the chest cavity contracts, and the alveolar pressure increases above atmospheric pressure. Air flows out of the lungs in response to the pressure gradient, and the lung volume decreases. During forced exhalations, the internal intercostals and abdominal muscles contract, thereby reducing the size of the chest cavity further and creating a greater increase in alveolar pressure.

? How does the intrapleural pressure change during a normal, quiet breath?

Other Factors Affecting Pulmonary Ventilation

1- **Surface Tension Of The Alveolar Fluid**

→ The surfactant (a mixture of phospholipids and lipoproteins) present in alveolar fluid reduces its surface tension below the surface tension of pure water.

2- **Compliance Of The Lungs**

→ Refers to how much effort is required to stretch the lungs and chest wall. High compliance means that the lungs and chest wall expand easily; low compliance means that they resist expansion.

3- **Airway Resistance**

→ The walls of the airways, especially the bronchioles, offer some resistance to the normal flow of air into and out of the lungs. Airway diameter is also regulated by the degree of contraction or relaxation of smooth muscle in the walls of the airways. Signals from the sympathetic division of the autonomic nervous system cause relaxation of this smooth muscle, which results in bronchodilation and decreased resistance.

Lung Volumes and Capacities

- The apparatus commonly used to measure the volume of air exchanged during breathing and the respiratory rate is a **spirometer** or *respirometer* The record is called a **spirogram**. Inhalation is recorded as an upward deflection, and exhalation is recorded as a downward deflection.

<u>The spirometer records the following:</u>

1- Lung volume

2- Lung capacity

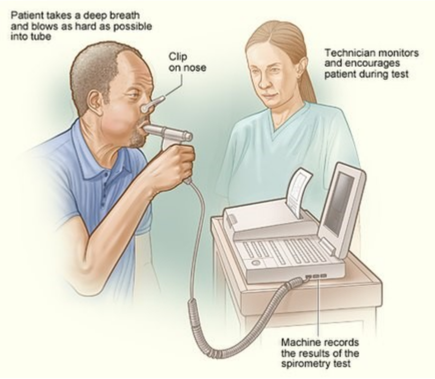
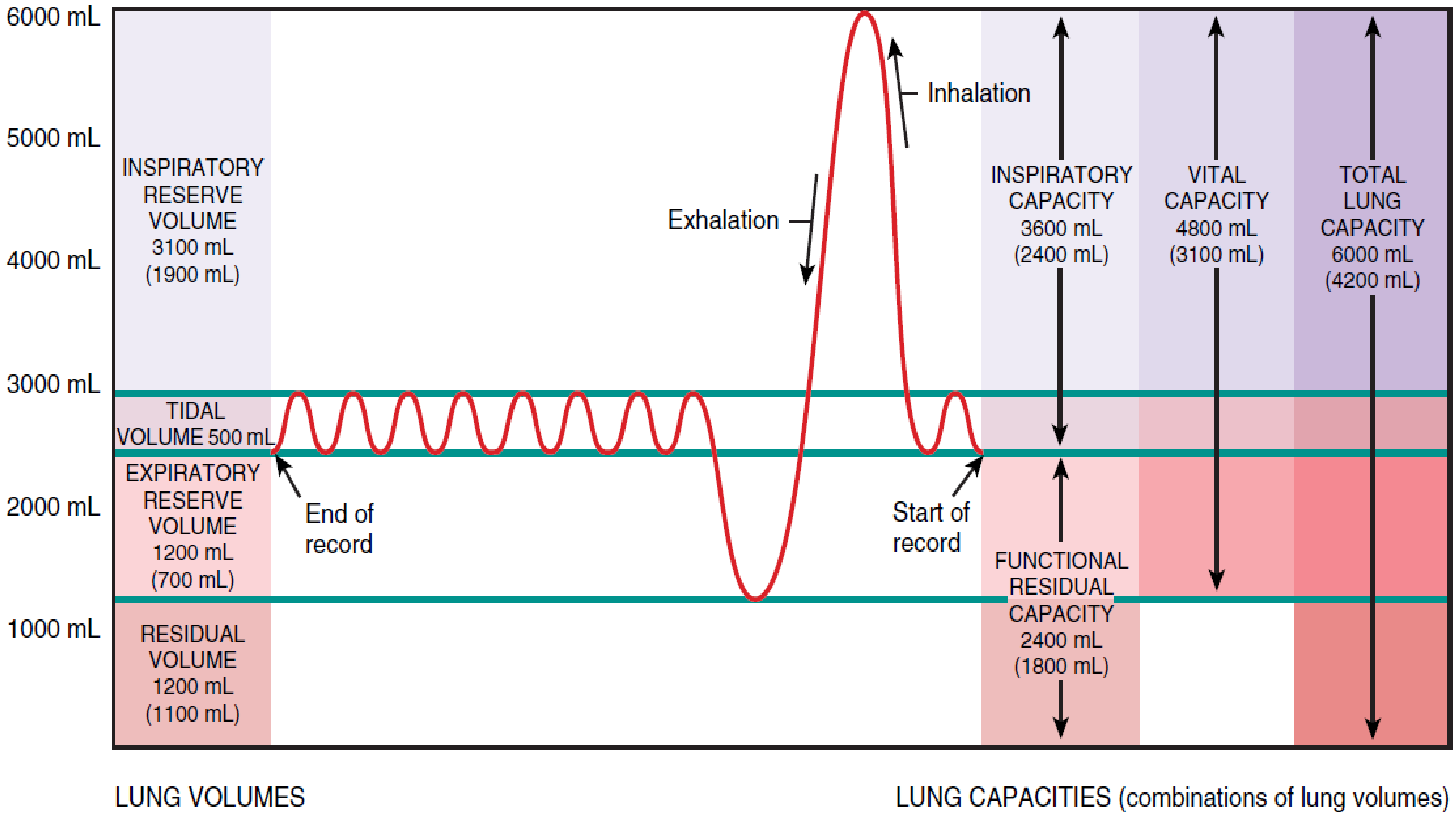


Figure 23.15 **Spirogram of lung volumes and capacities.** The average values for a healthy adult male and female are indicated, with the values for a female in parentheses. Note that the spirogram is read from right (start of record) to left (end of record).

→ Lung capacities are combinations of various lung volumes.



1- Lung Volumes

1- Tidal volume (TV; 500 ml):
Volume of gas inspired/expired of restful breathing.

2- Inspiratory reserve volume (IRV; 3000 ml):
Maximum volume that can be inspired during forced breathing other than tidal volume.

3- Expiratory reserve volume (ERV; 1300 ml):
Maximum volume of gas that can be expired during forced breathing other than tidal volume.

4- Forced Expiratory volume (FEV):
Amount of gas that can be expired forcedly in 1s, 2s, 3s.
i.e.: FEV1= Amount of gas that can be expired forcedly in 1s

5- Residual volume (RV; 1200 ml):

Volume of gas remaining in the lungs after vital capacity (VC) expiration → cannot be measured by spirometry.

2- Lung Capacity

1- Vital capacity (VC; 4700 ml):
Maximum air that can be expired after a maximum inspiration. (the sum of inspiratory reserve volume, tidal volume, and expiratory reserve volume)

2- Total Lung Capacities (6000 ml):
The sum of vital capacity and residual volume

3- Inspiratory capacity (3600 ml)
The sum of tidal volume and inspiratory reserve volume

4- Functional residual capacity (2400 ml)
The sum of residual volume and expiratory reserve volume

<u>MORE DEFINITIONS:</u>

- The **minute ventilation (MV)**—the total volume of air inhaled and exhaled each minute—is respiratory rate multiplied by tidal volume:
MV=12 breaths/min 500 mL/breath = 6 liters/min
- the conducting airways with air that does not undergo respiratory exchange are known as the **anatomic** (*respiratory*) **dead space**.
- The **alveolar ventilation rate** is the volume of air per minute that actually reaches the respiratory zone.

Exchange of Oxygen and Carbon Dioxide

- At sea level, one atmosphere = 760 mmHg (or 760 torr).

  → 760 mmHg is measured by Barometer.
- Atmospheric pressure is made of a mixture of gases so its pressure is equal to the sum of the pressures exerted by each gas.

- Dalton's law: In a mixture of gases, each gas exerts pressure (partial pressure; P) in proportion to its percentage in the total mixture.

- Since O_2 percentage in atmosphere is 21% then

$$PO_2 = 760 \times 21/100 = 160 \text{ mmHg}.$$

- At High altitudes: total atmospheric pressure is low (PO_2 is low)

Partial Pressures of Gases in Blood, Lungs and Tissues

✓ Alveoli air PO2 = 105 mmHg

→(only 60 mmHg O2 can saturate Hb) and PCO2 = 40 mmHg.

✓ Arterial blood PO2 = 100 mmHg; PCO2 = 40 mmHg.

✓ Peripheral tissue PO2 = 40 mmHg; PCO2 = 45 mmHg.

✓ Venous blood PO2 = 40 mmHg; PCO2 = 45 mmHg.

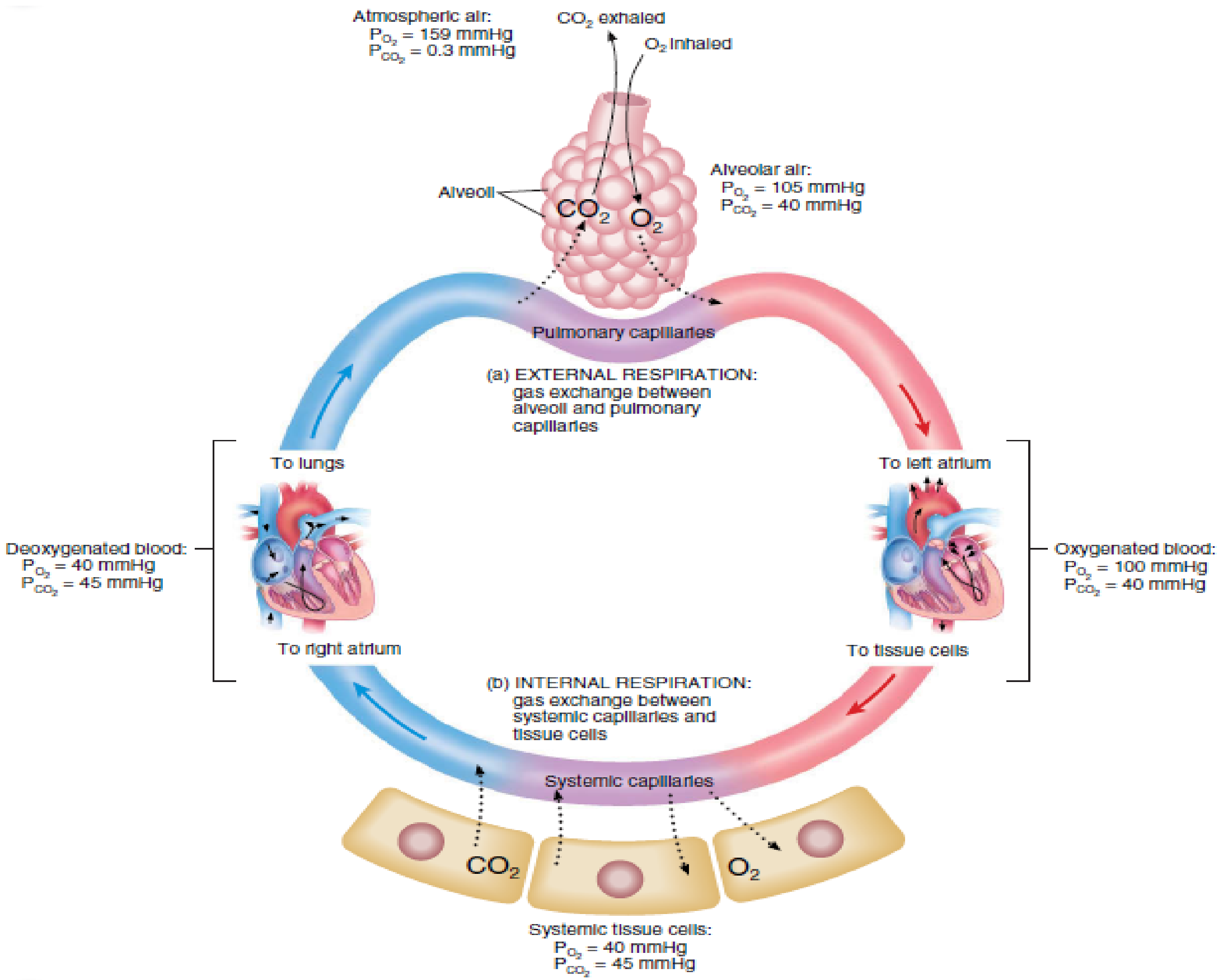
External and Internal Respiration (Reminder)!!

- **External respiration** or *pulmonary gas exchange* is the diffusion of O2 from air in the alveoli of the lungs to blood in pulmonary capillaries and the diffusion of CO2 in the opposite direction .

- **Internal respiration** or *systemic gas exchange* is the exchange of O2 and CO2 between systemic capillaries and tissue cells.

Figure 23.16 **Changes in partial pressures of oxygen and carbon dioxide (in mmHg) during external and internal respiration.**

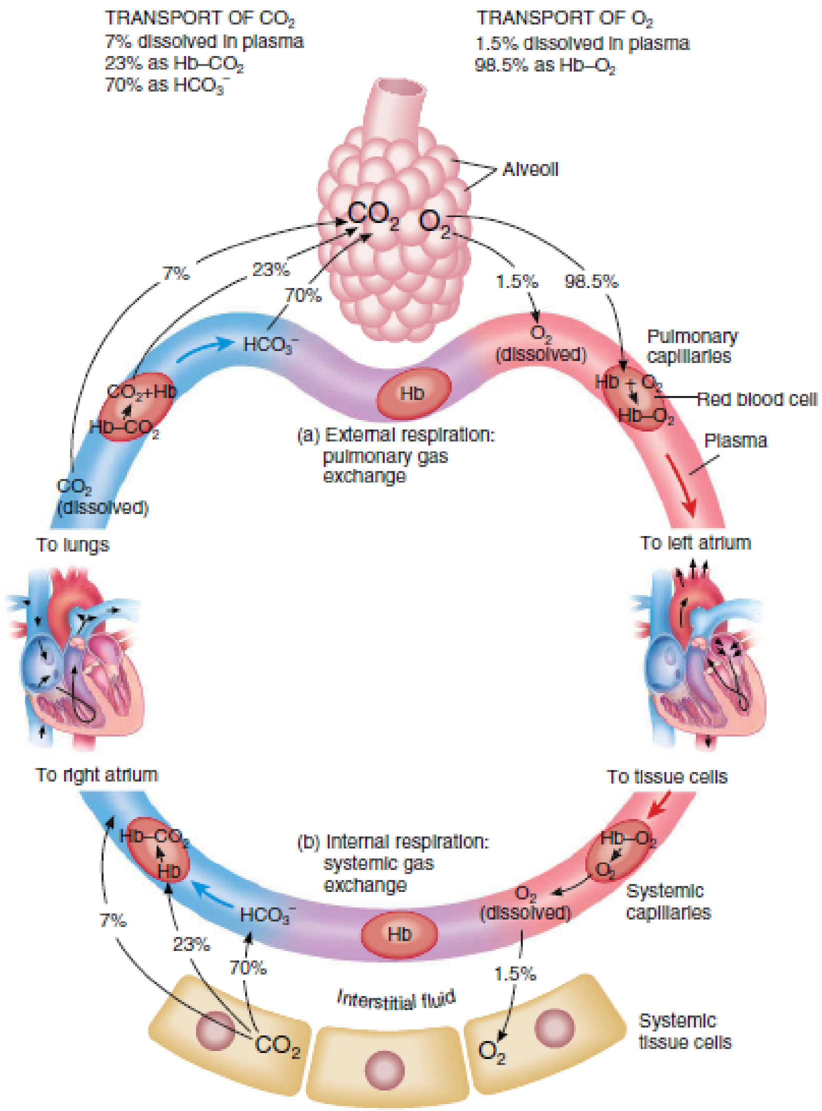
→ Gases diffuse from areas of higher partial pressure to areas of lower partial pressure



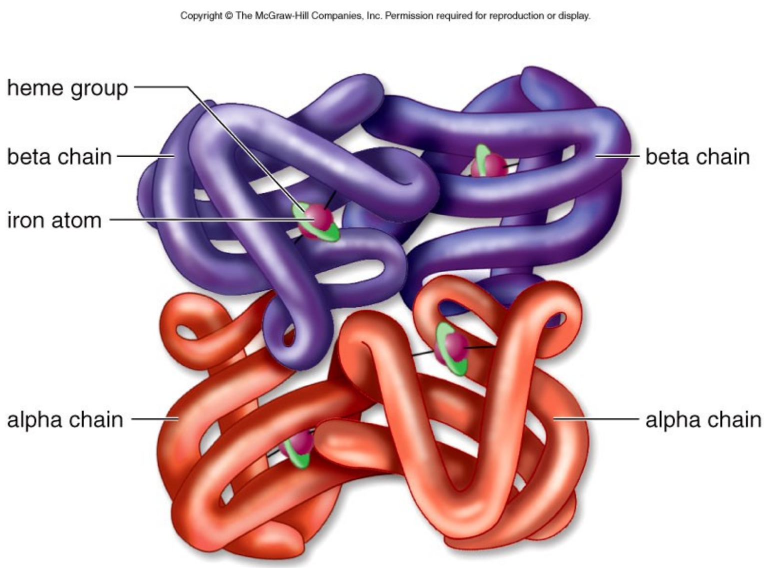
Transport of Oxygen and Carbon Dioxide

1. Gas exchange between the air in the alveoli and the blood in the pulmonary capillaries is primarily by diffusion.
2. Atmospheric air contains little CO2, but blood flowing in the pulmonary capillaries has a higher concentration of CO2.
3. CO2 diffuses from higher concentration in the blood across the walls of alveolar capillaries to lower concentration in the air in the alveoli.
4. The blood coming into pulmonary capillaries is oxygen poor and the alveolar air is oxygen-rich.
5. Oxygen diffuses from higher concentration in alveoli across the walls of the alveolar capillaries to the lower concentration in the blood.

Figure 23.17 Transport of oxygen (O2) and carbon dioxide (CO2) in the blood. Most O2 is transported by hemoglobin as oxyhemoglobin (Hb–O2) within red blood cells; most CO2 is transported in blood plasma as bicarbonate ions (HCO3).



Hemoglobin (Hb) & O2 Transport



In each 100 mL of oxygenated blood:

→ 1.5% of O2 is dissolved in plasma

→ 98.5% is bound to Hb; oxyhemoglobin (Hb-O2).

- ✓ Hb consists of: 4 polypeptides; 2 α-chains & 2 β-chains.
- ✓ Each chain contains a heme group with Fe2+ (ferrous iron).
- ✓ The iron atom of a heme group loosely binds with an O2 molecule.

Three Types of Hemoglobin

1- ***Oxyhemoglobin*** the normal, oxygen-carrying form of hemoglobin in which iron is in the reduced (ferrous) state.

2-Methemoglobin (met-Hb) : Oxidized Hb has iron in the oxidized (Fe^{3+}/ferric) state. Met-Hb thus lacks the e- it needs to form a bond with O_2 and cannot participate in O_2 transport. Blood normally contains only a small amount of met-Hb, but certain drugs can increase this amount.

3- Carboxyhemoglobin: the reduced heme is combined with CO instead of O_2. Since the bond with CO is 210 times stronger than the bond with O_2, CO remains attached to Hb.

Oxygen-binding ability of hemoglobin

a. The percentage of oxygen-binding sites of hemoglobin carrying O_2 varies with partial pressure of O_2 in the immediate environment.

b. At a normal partial pressure of O_2 in lungs, hemoglobin becomes practically saturated with O_2.

c. At the O_2 partial pressures in the tissues, oxyhemoglobin quickly unloads much of its O_2.

d. The acid pH and warmer temperature of the tissues also promote this dissociation.

Summary of Gas Exchange and Transport in Lungs and Tissues

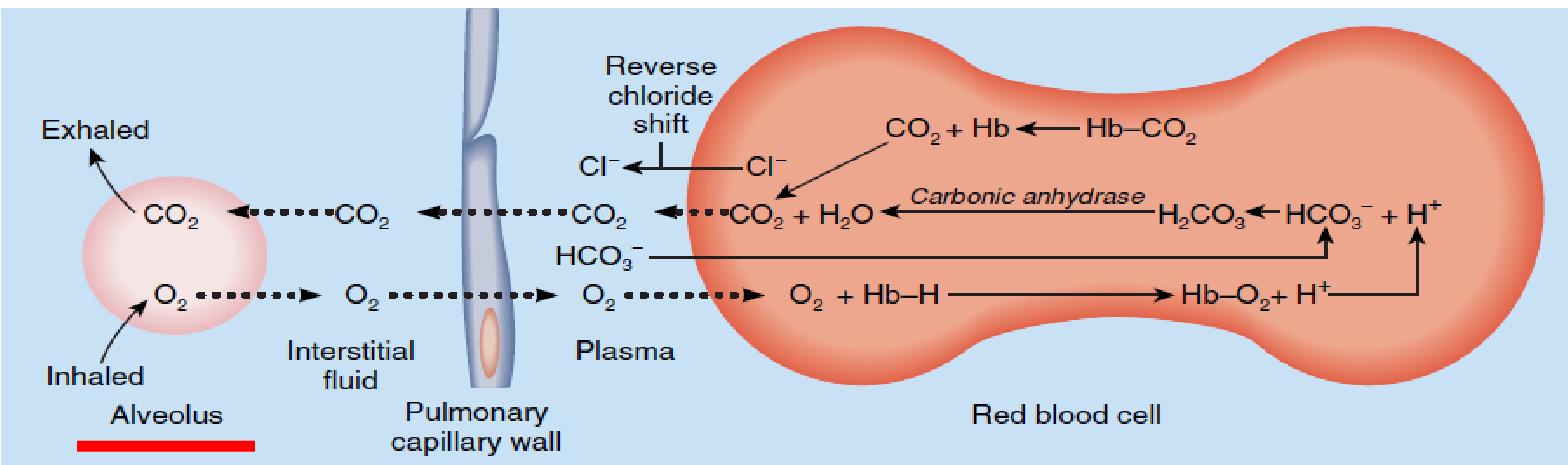
- Deoxygenated blood returning to the pulmonary capillaries in the lungs (Figure 23.22a) contains CO2 dissolved in blood plasma, CO2 combined with globin as carbaminohemoglobin (Hb–CO2), and CO2 incorporated into HCO3 within RBCs. The RBCs have also picked up H, some of which binds to and therefore is buffered by hemoglobin (Hb–H). As blood passes through the pulmonary capillaries, molecules of CO2 dissolved in blood plasma and CO2 that dissociates from the globin portion of hemoglobin diffuse into alveolar air and are exhaled.

- At the same time, inhaled O2 is diffusing from alveolar air into RBCs and is binding to hemoglobin to form oxyhemoglobin (Hb–O2). Carbon dioxide also is released from HCO3 when H combines with HCO3 inside RBCs. The H2CO3 formed from this reaction then splits into CO2, which is exhaled, and H2O. As the concentration of HCO3 declines inside RBCs in pulmonary capillaries, HCO3 diffuses in from the blood plasma, in exchange for Cl.
- In sum, oxygenated blood leaving the lungs has increased O2 content and decreased amounts of CO2 and H. In systemic capillaries, as cells use O2 and produce CO2, the chemical reactions reverse

Figure 23.22 Summary of chemical reactions that occur during gas exchange.

(a) As carbon dioxide (CO2) is exhaled, hemoglobin (Hb) inside red blood cells in pulmonary capillaries unloads CO2 and picks up O2 from alveolar air. Binding of O2 to Hb–H releases hydrogen ions (H).

- Bicarbonate ions (HCO3) pass into the RBC and bind to released H, forming carbonic acid (H2CO3). The H2CO3 dissociates into water (H2O) and CO2, and the CO2 diffuses from blood into alveolar air. To maintain electrical balance, a chloride ion (Cl) exits the RBC for each HCO3 that enters (reverse chloride shift).

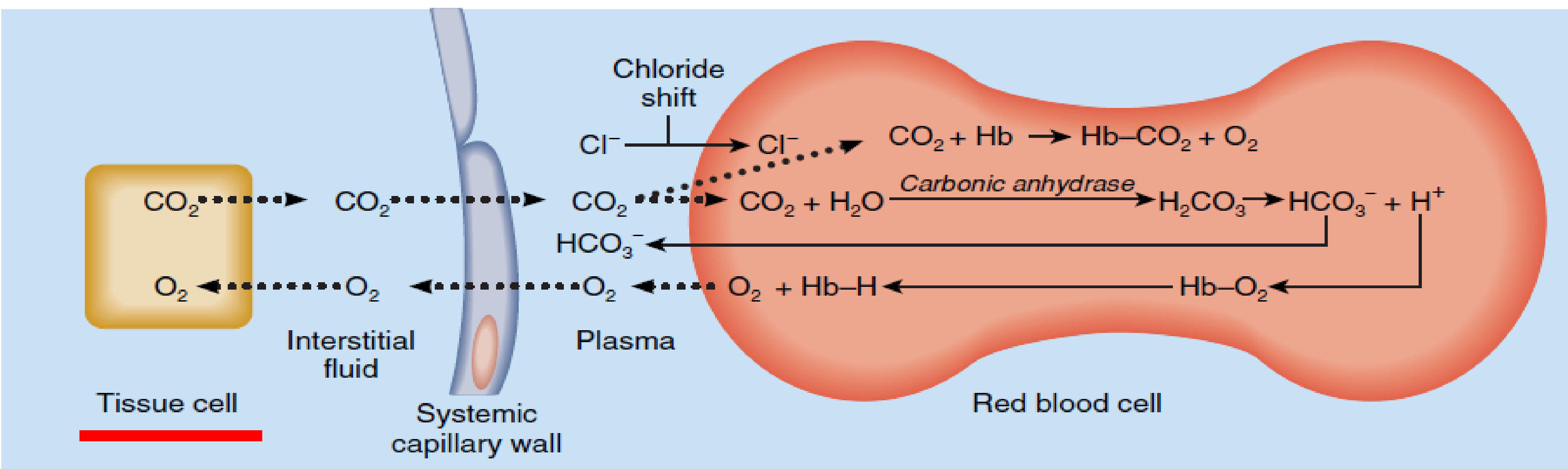


(a) Exchange of O_2 and CO_2 in pulmonary capillaries (external respiration)

Figure 23.22 Summary of chemical reactions that occur during gas exchange. (continued)

(b) CO2 diffuses out of tissue cells that produce it and enters red blood cells, where some of it binds to hemoglobin, forming carbaminohemoglobin (Hb–CO2). This reaction causes O2 to dissociate from oxyhemoglobin (Hb–O2).

- Other molecules of CO2 combine with water to produce bicarbonate ions (HCO3) and hydrogen ions (H). As Hb buffers H, the Hb releases O2 (Bohr effect). To maintain electrical balance, a chloride ion (Cl) enters the RBC for each HCO3 that exits (chloride shift).



(b) Exchange of O_2 and CO_2 in systemic capillaries (internal respiration)

Control of Breathing

Regulation of the Respiratory Center

1. ***Cortical Influences on Breathing***
2. ***Chemoreceptor Regulation of Breathing***
3. ***Proprioceptor Stimulation of Breathing***
4. ***The Inflation Reflex***
5. ***Other Influences on Breathing***

1- Cortical Influences on Breathing

→ **Voluntary**:

Because the cerebral cortex has connections with the respiratory center, we can voluntarily alter our pattern of breathing. Voluntary control is protective because it enables us to prevent water or irritating gases from entering the lungs. The ability to not breathe, however, is limited by the buildup of CO_2 and H in the body.

→ **Involuntary**

When PCO_2 and H concentrations increase to a certain level, the Dorsal respiratory group (DRG) neurons of the medullary respiratory center are strongly stimulated, nerve impulses are sent along the phrenic and intercostal nerves to inspiratory muscles, and breathing resumes, whether the person wants it to or not.

2- Chemoreceptor Regulation of Breathing

1- **Central chemoreceptors** are located in or near the medulla oblongata in the *central* nervous system. They respond to changes in H concentration or PCO2, or both, in cerebrospinal fluid.

2- **Peripheral chemoreceptors** are located in the **aortic bodies**, clusters of chemoreceptors located in the wall of the arch of the aorta, and in the **carotid bodies**, which are oval nodules in the wall of the left and right common carotid arteries where they divide into the internal and external carotid arteries. (The chemoreceptors of the aortic bodies are located close to the aortic baroreceptors, and the carotid bodies are located close to the carotid sinus baroreceptors).

2- Chemoreceptor Regulation of Breathing (continued-1)

Hypercapnia (increase of CO_2 in arterial blood).

→ ⇧ PCO_2 & ⇩ pH (due to formation of carbonic acid, which splits releasing H^+).

→ Thus, blood and other body fluids are more acidic (*Respiratory acidosis due to hypoventilation),* medulla respond by increasing ventilation.

→ Hypercapnia normally triggers a reflex which increases breathing and access to oxygen, such as arousal and turning the head during sleep. A failure of this reflex can be fatal, as in sudden infant death syndrome.

→ Hypercapnia can be accompanied by respiratory acidosis.

→ As a result, rapid and deep breathing, called **hyperventilation**, allows the inhalation of more O_2 and exhalation of more CO_2 until PCO_2 and H are lowered to normal.

2- Chemoreceptor Regulation of Breathing (continued-2)

Hypocapnia or *hypocarbia*

- If arterial PCO_2 is lower than 40 mmHg—the central and peripheral chemoreceptors are not stimulated, and stimulatory impulses are not sent to the Dorsal Respiratory Group (DRG).
- As a result, DRG neurons set their own moderate pace until CO_2 accumulates and the PCO_2 rises to 40 mmHg. DRG neurons are more strongly stimulated when PCO_2 is rising above normal than when PO_2 is falling below normal.
- ***Hypocapnia*** causes cerebral vasoconstriction, leading to cerebral hypoxia and this can cause transient dizziness, visual disturbances, and anxiety. A low partial pressure of carbon dioxide in the blood also causes alkalosis, leading to lowered plasma calcium ions and increased nerve and muscle excitability. This explains the other common symptoms of hyperventilation, muscle cramps and tetany in the extremities, especially hands and feet.
- Because the brain stem regulates breathing by monitoring the level of blood CO_2, hypocapnia can suppress breathing to the point of blackout from cerebral hypoxia.
- Respiratory alkalosis – occurs when the rate of respiration increases.

Figure 23.23 Locations of areas of the respiratory center.

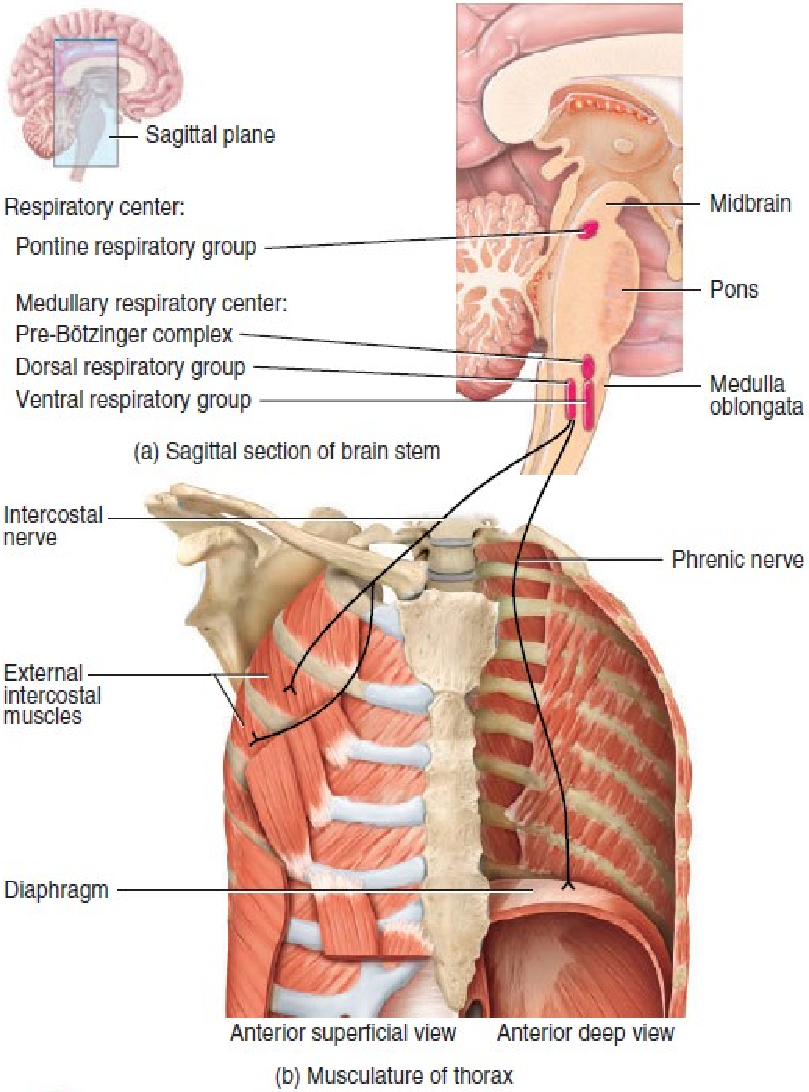
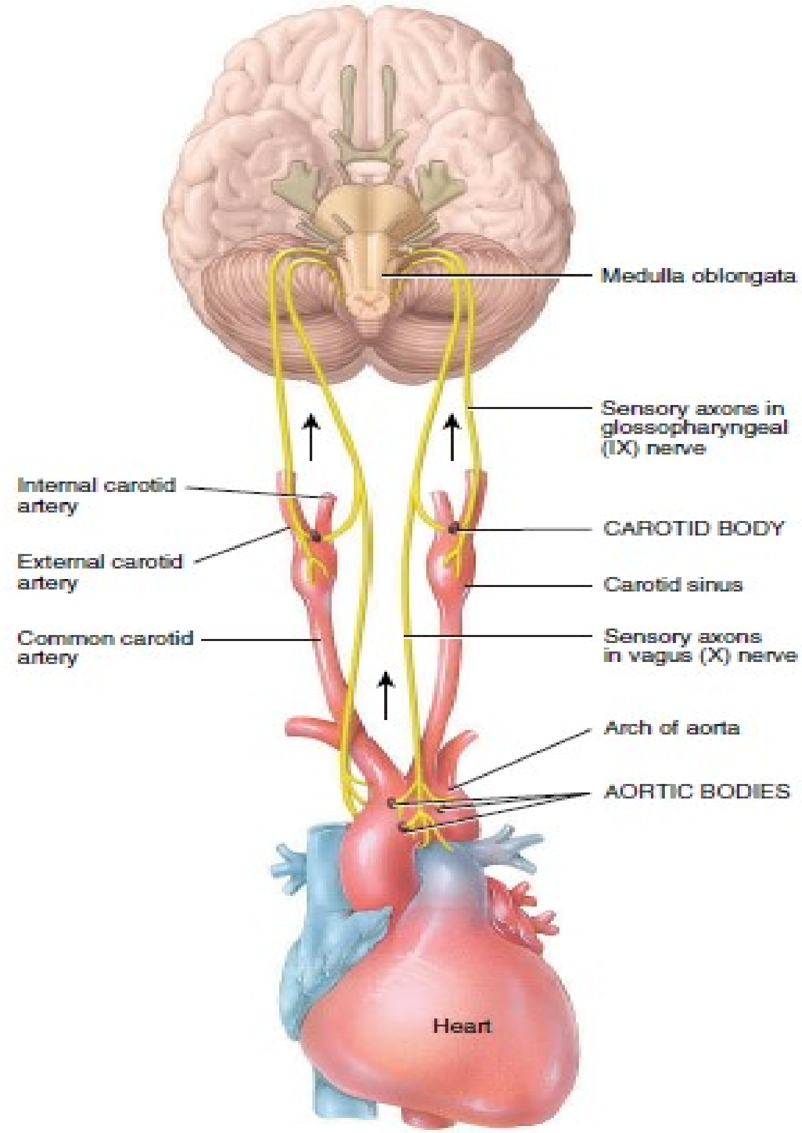
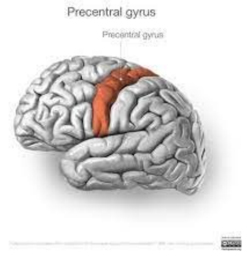


Figure 23.25 Locations of peripheral chemoreceptors.



3- Proprioceptor Stimulation of Breathing

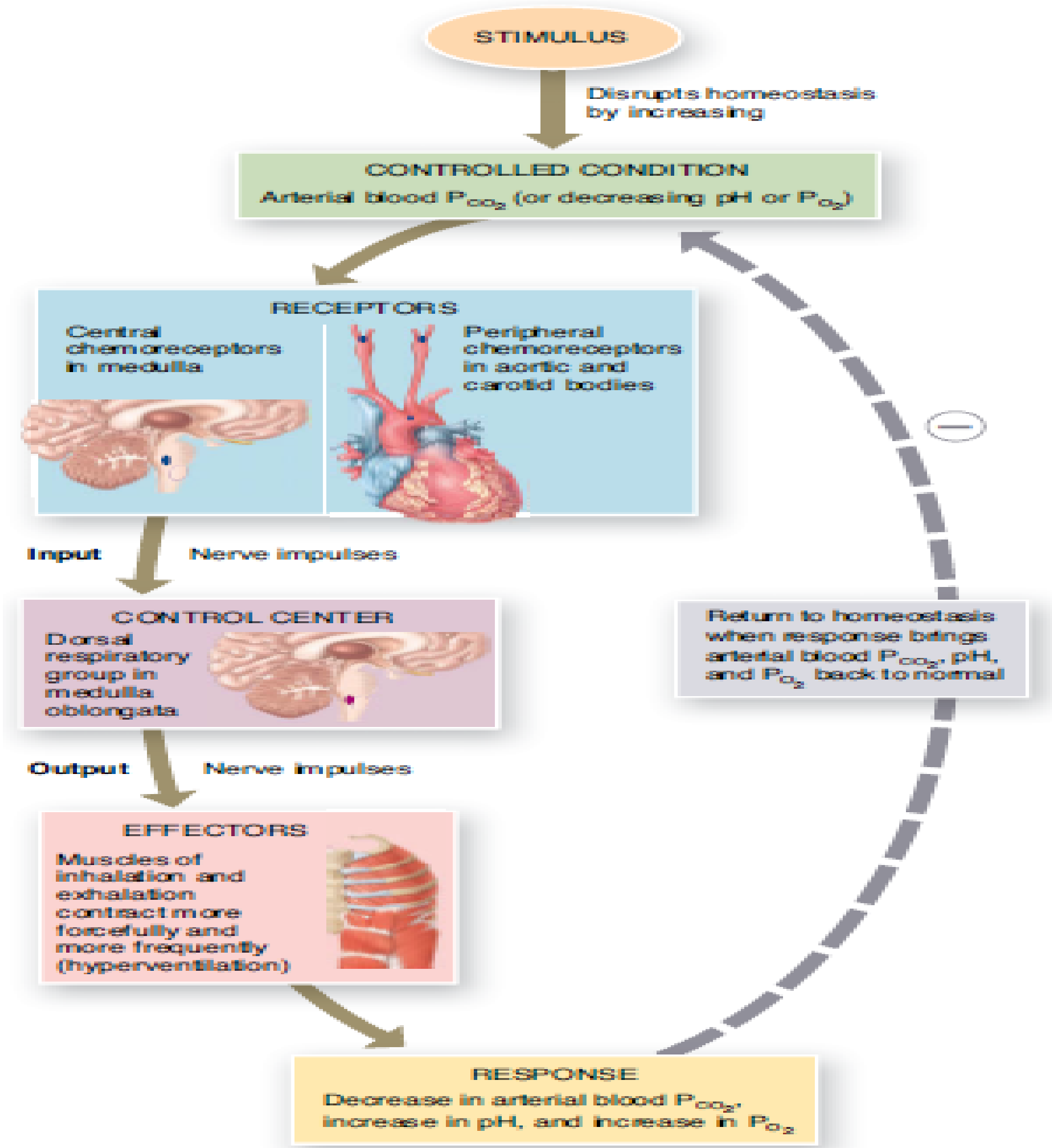
- As soon as you start exercising, your rate and depth of breathing increase, even before changes in PO2, PCO2, or H level occur.
- The main stimulus for these quick changes in respiratory effort is input from proprioceptors, which monitor movement of joints and muscles.
- Nerve impulses from the proprioceptors stimulate the DRG of the medulla.
- At the same time, axon collaterals (branches) of upper motor neurons that originate in the primary motor cortex (precentral gyrus) also feed excitatory impulses into the DRG.



4- The Inflation Reflex

- Similar to those in the blood vessels, stretch-sensitive receptors called **baroreceptors** or **stretch receptors** are located in the walls of bronchi and bronchioles.
- When these receptors become stretched during overinflation of the lungs, nerve impulses are sent along the vagus (X) nerves to the dorsal respiratory group (DRG) in the medullary respiratory center.
- In response, the DRG is inhibited and the diaphragm and external intercostals relax. As a result, further inhalation is stopped and exhalation begins. As air leaves the lungs during exhalation, the lungs deflate and the stretch receptors are no longer stimulated. Thus, the DRG is no longer inhibited, and a new inhalation begins.
- This reflex is referred to as the **inflation reflex** or *Hering–Breuer reflex* (HER-ing BROY-er).
- In infants, the reflex appears to function in normal breathing.
- In adults, however, the reflex is not activated until tidal volume (normally 500 mL) reaches more than 1500 mL.
- Therefore, the reflex in adults is a protective mechanism that prevents excessive inflation of the lungs, for example, during severe exercise, rather than a key component in the normal control of breathing.

Figure 23.26 **Regulation of breathing in response to changes in blood PCO2, PO2, and pH (H) via negative feedback control.**



5- Other Influences on Breathing

<u>Other factors that contribute to regulation of breathing include the following:</u>

- ✓ ***Limbic system stimulation.*** Anticipation of activity or emotional anxiety may stimulate the limbic system, which then sends excitatory input to the DRG, increasing the rate and depth of breathing.
- ✓ ***Temperature.*** An increase in body temperature, as occurs during a fever or vigorous muscular exercise, increases the rate of breathing. A decrease in body temperature decreases breathing rate. A sudden cold stimulus (such as plunging into cold water) causes temporary **apnea** (AP-nē-a; *a-* without; *-pnea* breath), an absence of breathing.
- ✓ ***Pain.*** A sudden, severe pain brings about brief apnea, but a prolonged somatic pain increases breathing rate. Visceral pain may slow the rate of breathing.
- ✓ ***Stretching the anal sphincter muscle.*** This action increases the breathing rate and is sometimes used to stimulate respiration in a newborn baby or a person who has stopped breathing.
- ✓ ***Irritation of airways.*** Physical or chemical irritation of the pharynx or larynx brings about an immediate cessation of breathing followed by coughing or sneezing.
- ✓ ***Blood pressure.*** The carotid and aortic baroreceptors that detect changes in blood pressure have a small effect on breathing. A sudden rise in blood pressure decreases the rate of breathing, and a drop in blood pressure increases the breathing rate.

References:

1. Principles of Anatomy and Physiology, 16th Edition by Gerard J. Tortora, Bryan H. Derrickson, Publisher: Wiley, (2020), ISBN: 978-1-119-66268-6

2. Introduction to Human physiology: Laura Sherwood; 9th edition; 2016; ISBN-13:978-0134399416