RESPIRATORY SYSTEM

Introduction

The purpose of the chapter is to:

1. Describe the anatomy of the respiratory system
2. Understand the physiology of the respiratory system
3. Describe the events that cause inhalation, exhalation, and gas exchange
4. Learn how oxygen and carbon dioxide are transported in the blood

Breathing and Respiration

- Respiration is the exchange of gases between the atmosphere, blood, and cells
- The combination of 3 processes is required for respiration to occur
  - Ventilation (breathing)
  - External (pulmonary) respiration
  - Internal (tissue) respiration
- The cardiovascular system assists the respiratory system by transporting gases

Structures of the Respiratory System

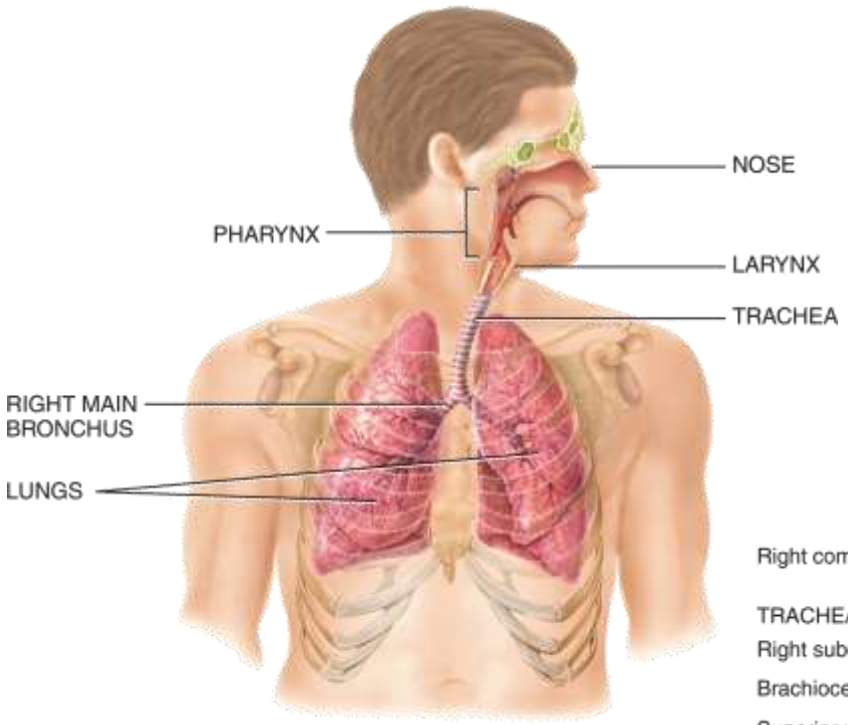
Structurally, the components of the respiratory system are divided into 2 parts:

1. Upper respiratory system
2. Lower respiratory system

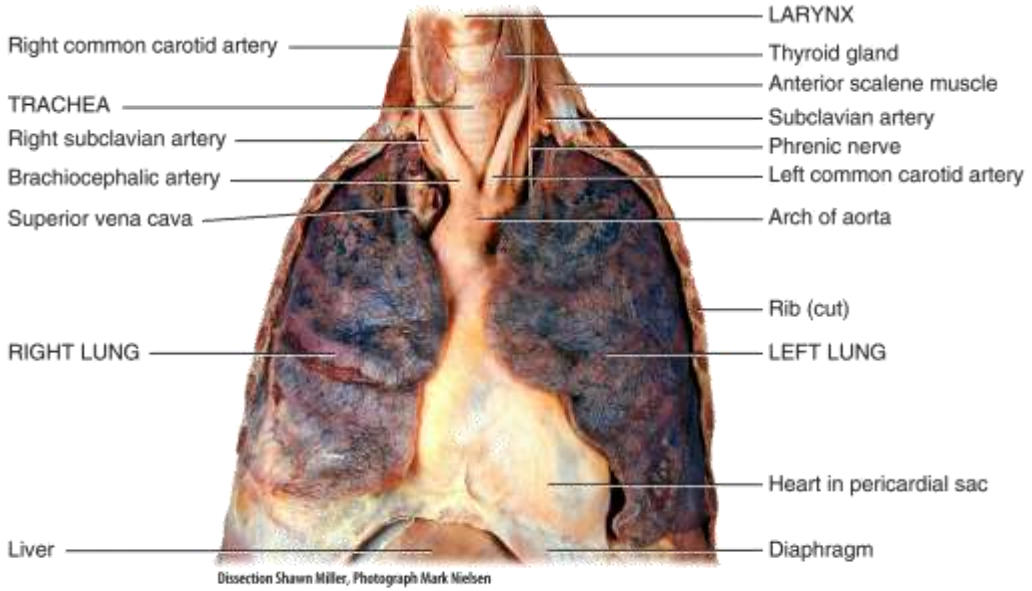
Functionally, the components of the respiratory system are divided into 2 zones:

1. Conducting zone
2. Respiratory zone

Structures of the Respiratory System



(a) Anterior view showing organs of respiration

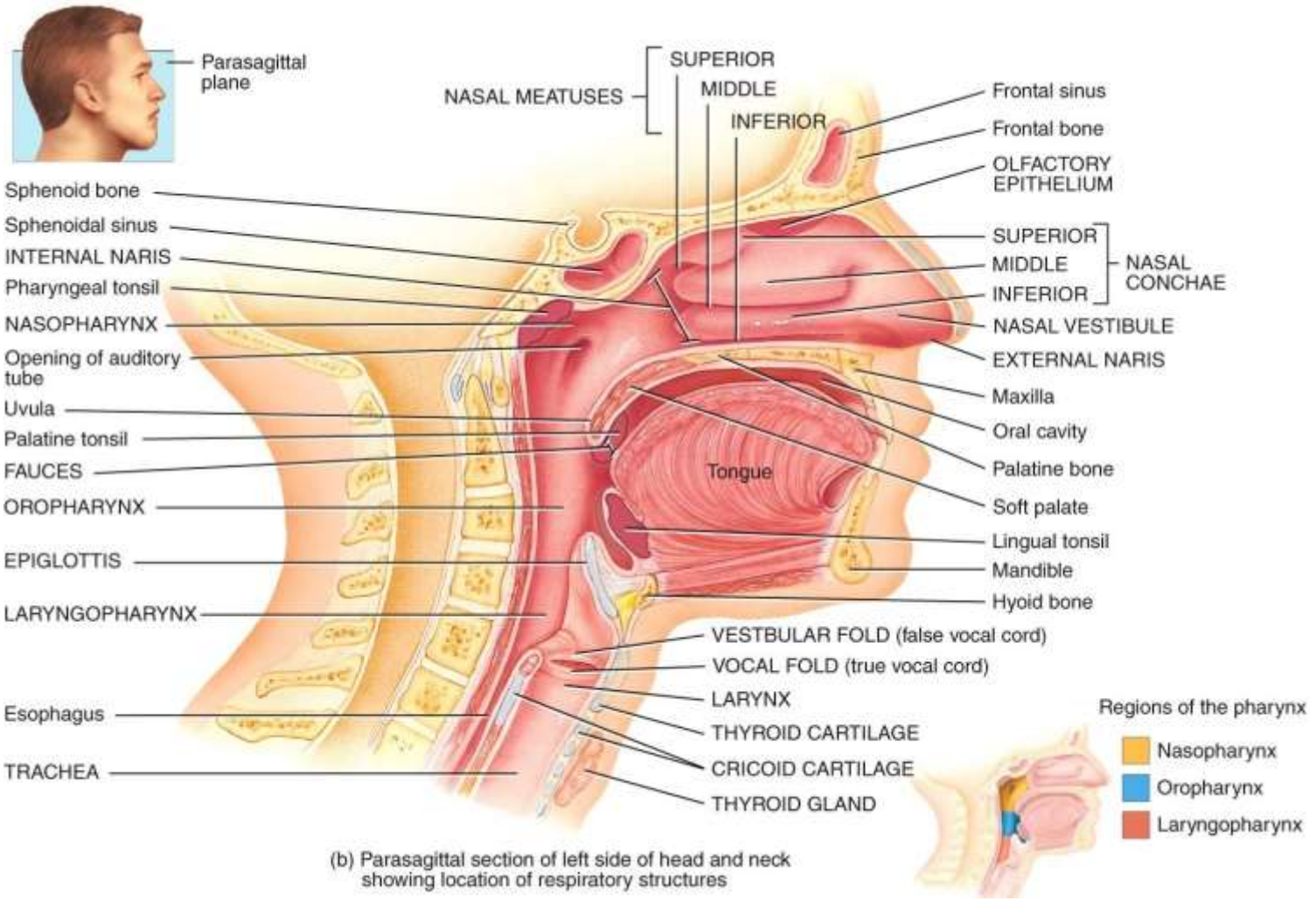


(b) Anterior view of lungs and heart after removal of the anterolateral thoracic wall and pleura

Respiratory System Anatomy

- The upper respiratory system consists of the nose, pharynx, and associated structures
- The lower respiratory system consists of the larynx, trachea, bronchi, and lungs

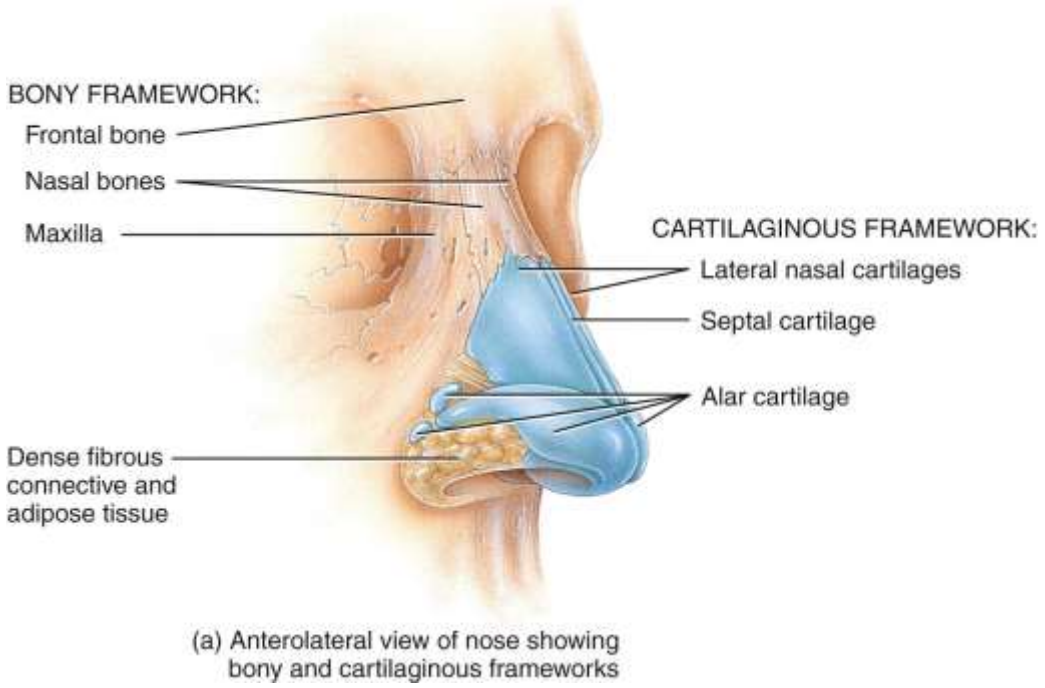
Overview: Nose, Pharynx, Larynx, and Trachea



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

Cartilaginous Framework of the Nose

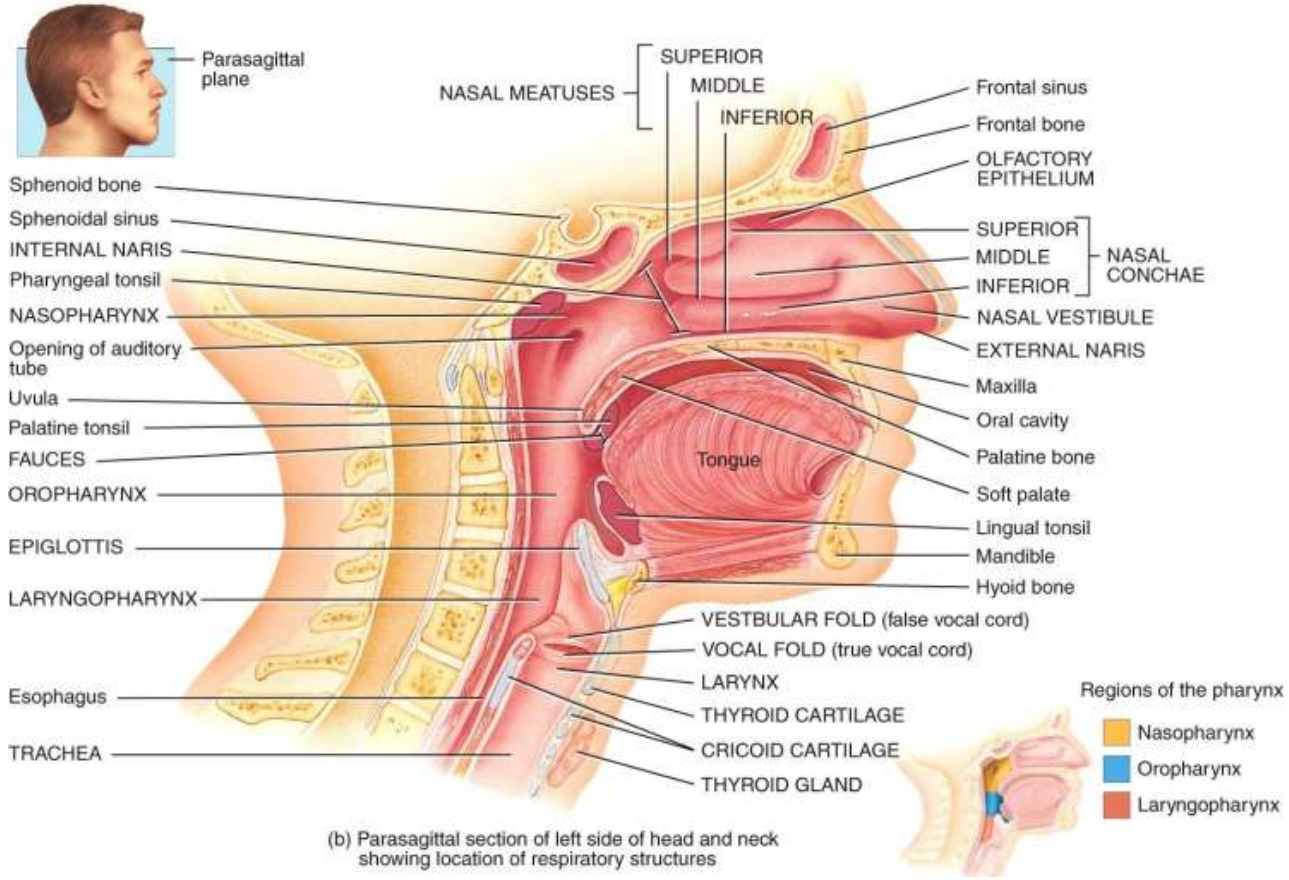
The external portion of the nose is made of cartilage and skin and is lined with mucous membrane



(a) Anterolateral view of nose showing bony and cartilaginous frameworks

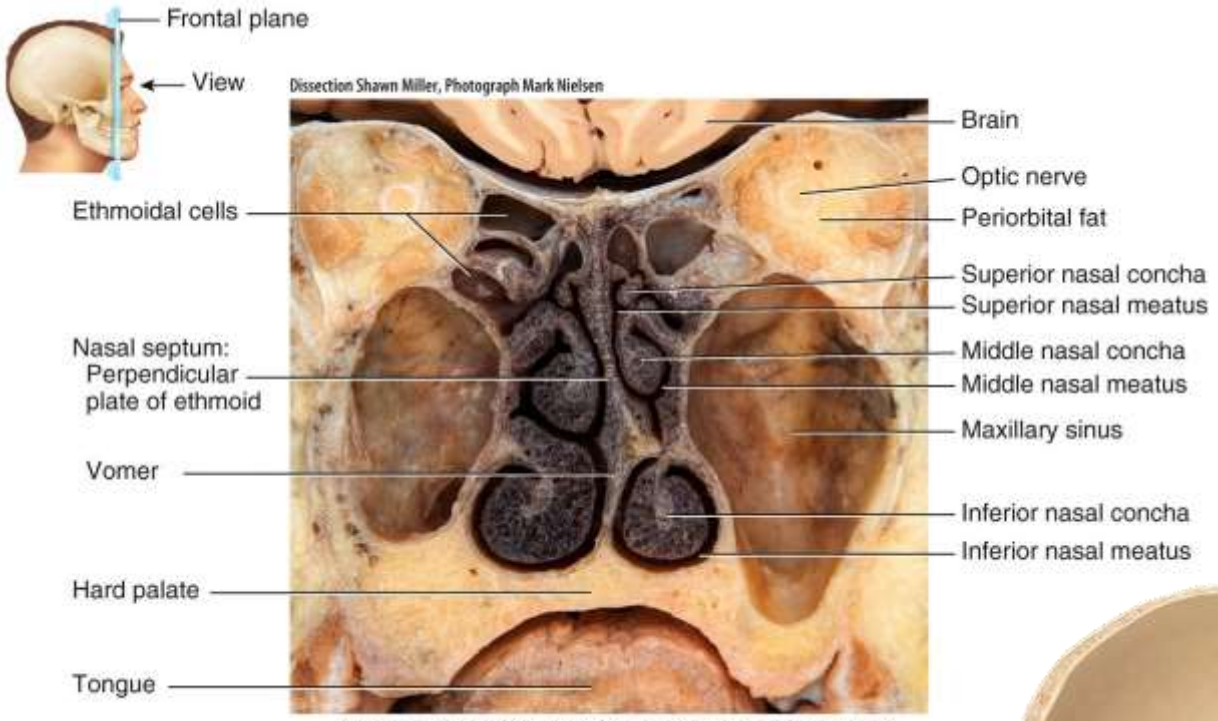
Internal Anatomy of the Nose

The bony framework of the nose is formed by the frontal, nasal, and maxillary bones

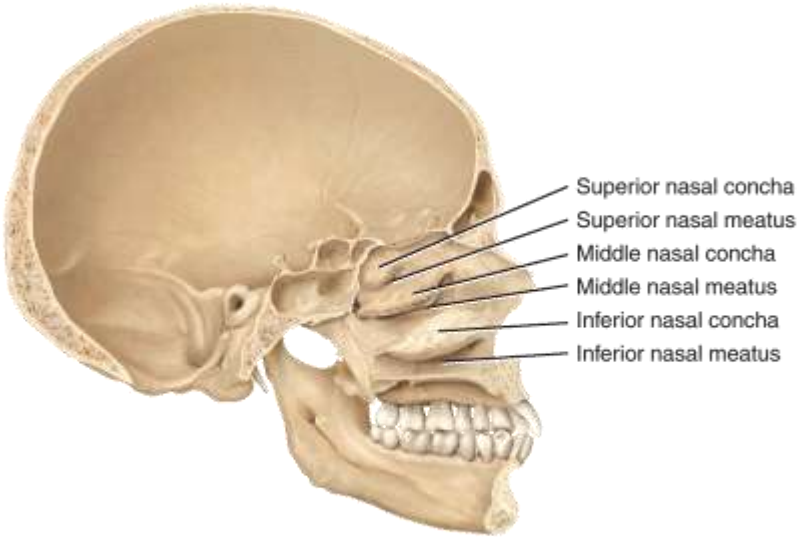


(b) Parasagittal section of left side of head and neck showing location of respiratory structures

Nasal Conchae and Meatuses



(c) Frontal section showing conchae and meatuses

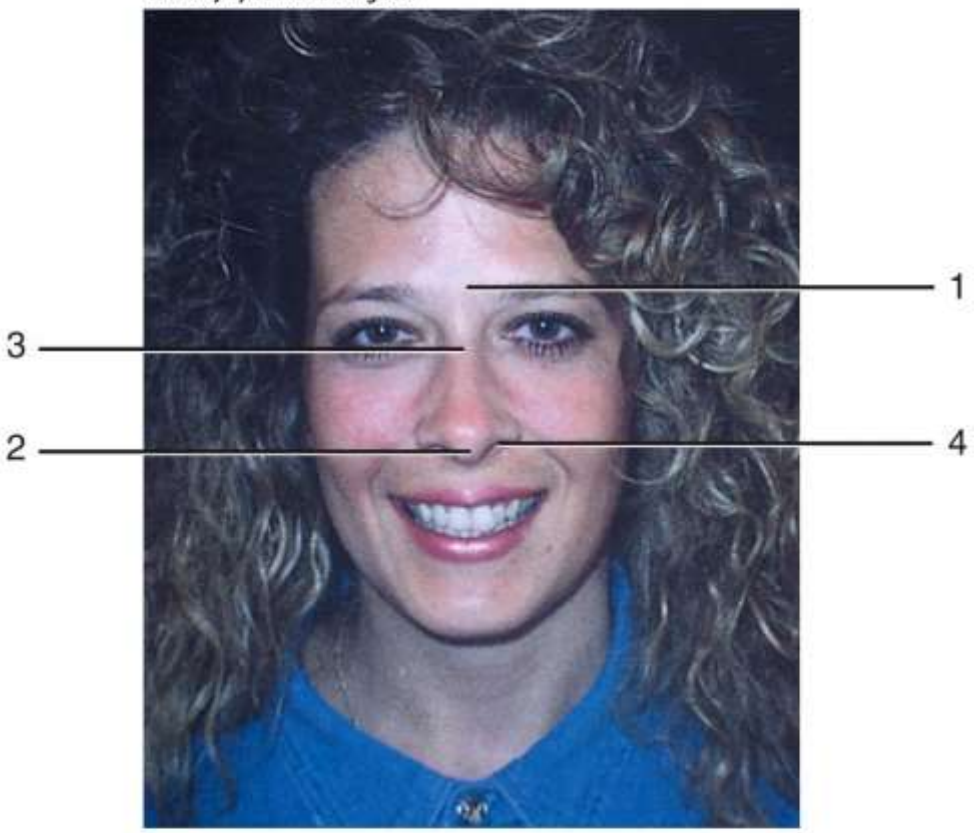


(d) Medial view of sagittal section

Surface Anatomy of the Nose

1. Root
2. Apex
3. Bridge
4. External naris

Courtesy Lyne Marie Borghesi

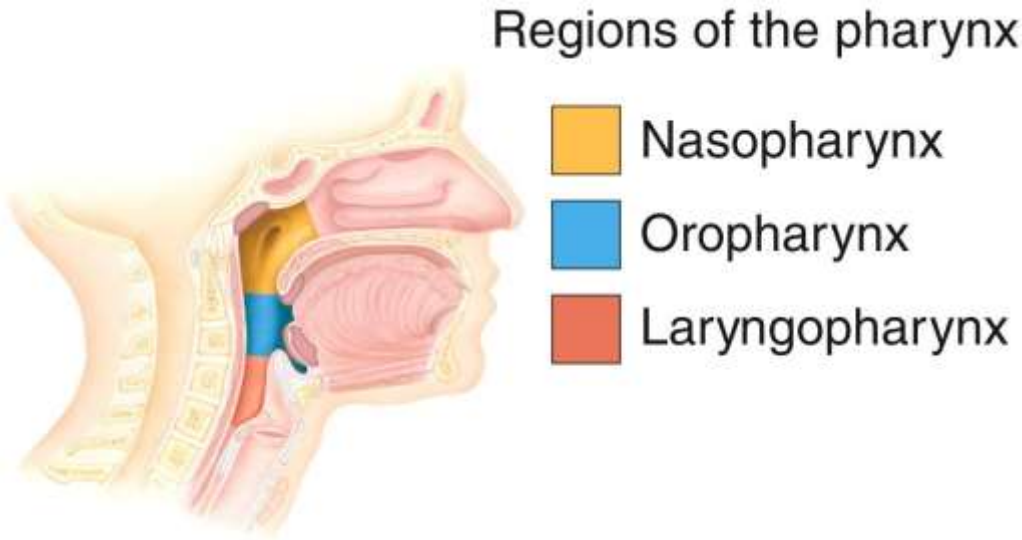


Anterior view

1. **Root**: Superior attachment of the nose to the frontal bone
2. **Apex**: Tip of nose
3. **Bridge**: Bony framework of nose formed by nasal bones
4. **External naris**: Nostril; external opening into nasal cavity

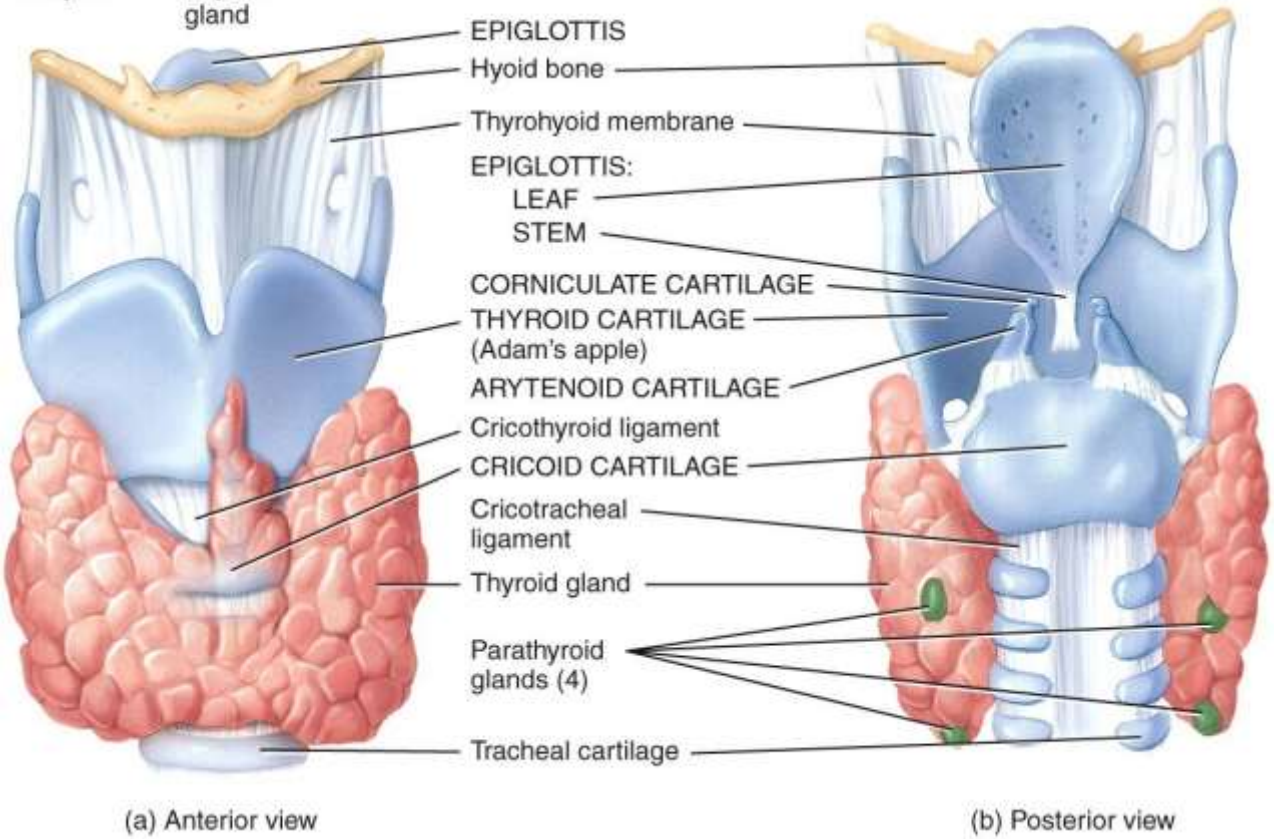
Pharynx

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



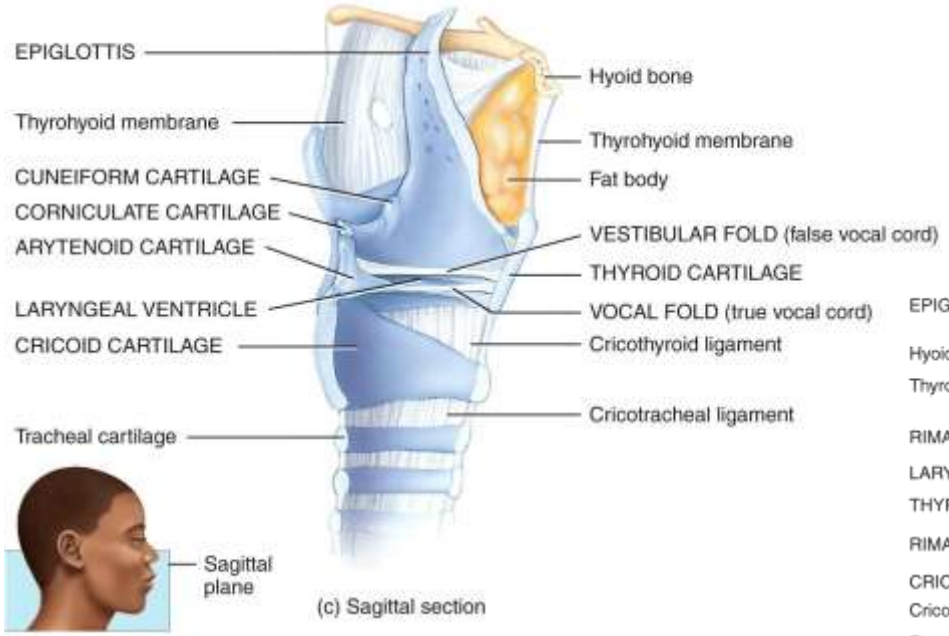
Larynx

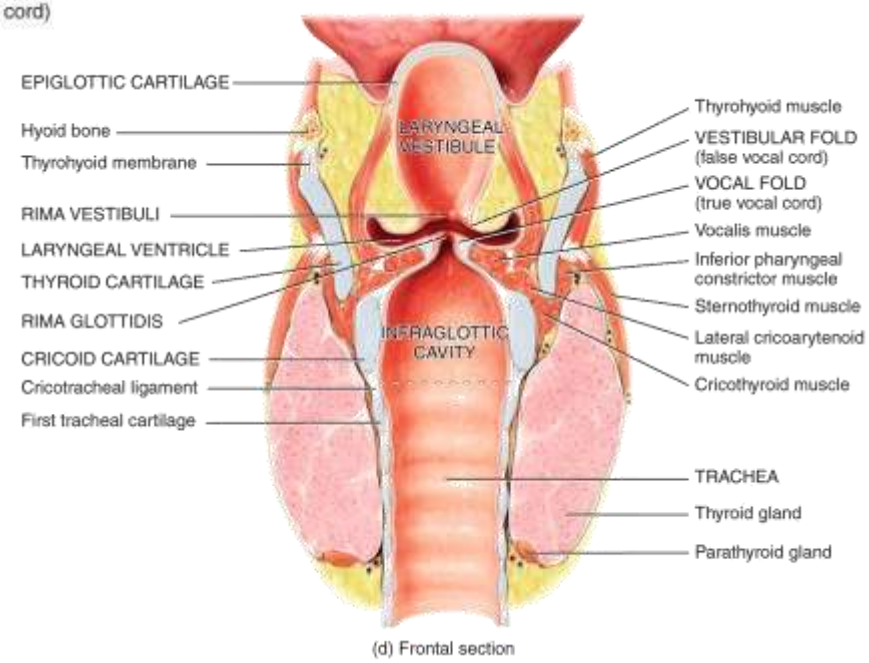
The larynx (voice box) is a passageway that connects the pharynx and trachea



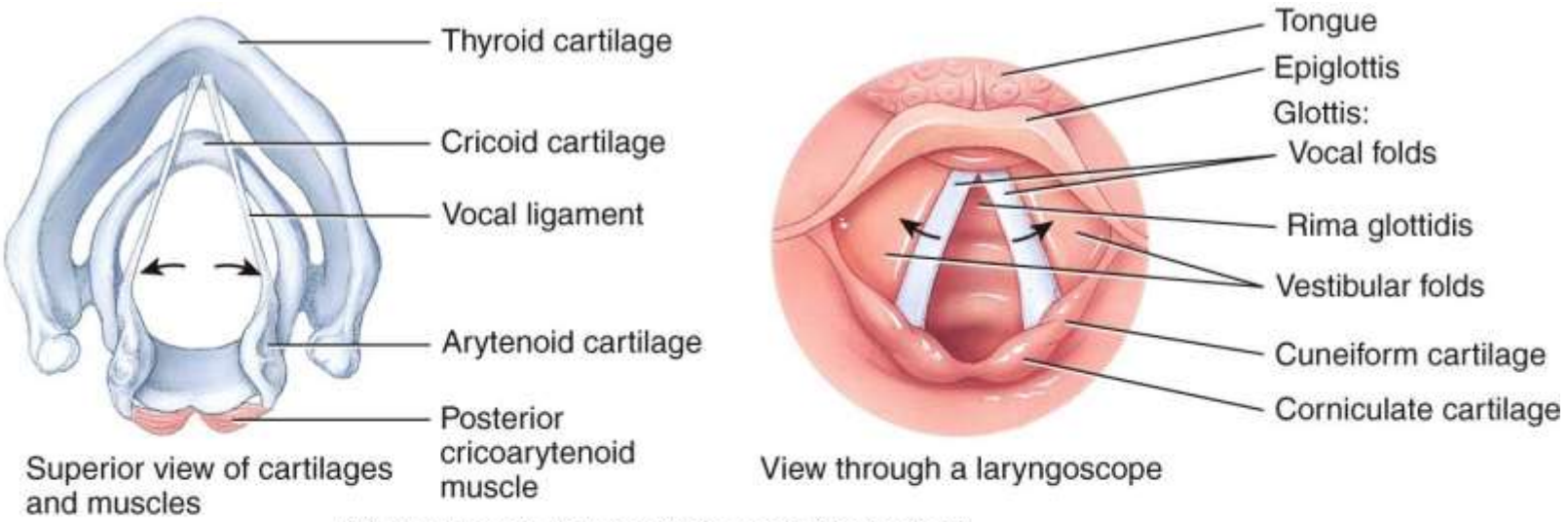
Larynx

The larynx contains vocal folds, which produce sound when they vibrate



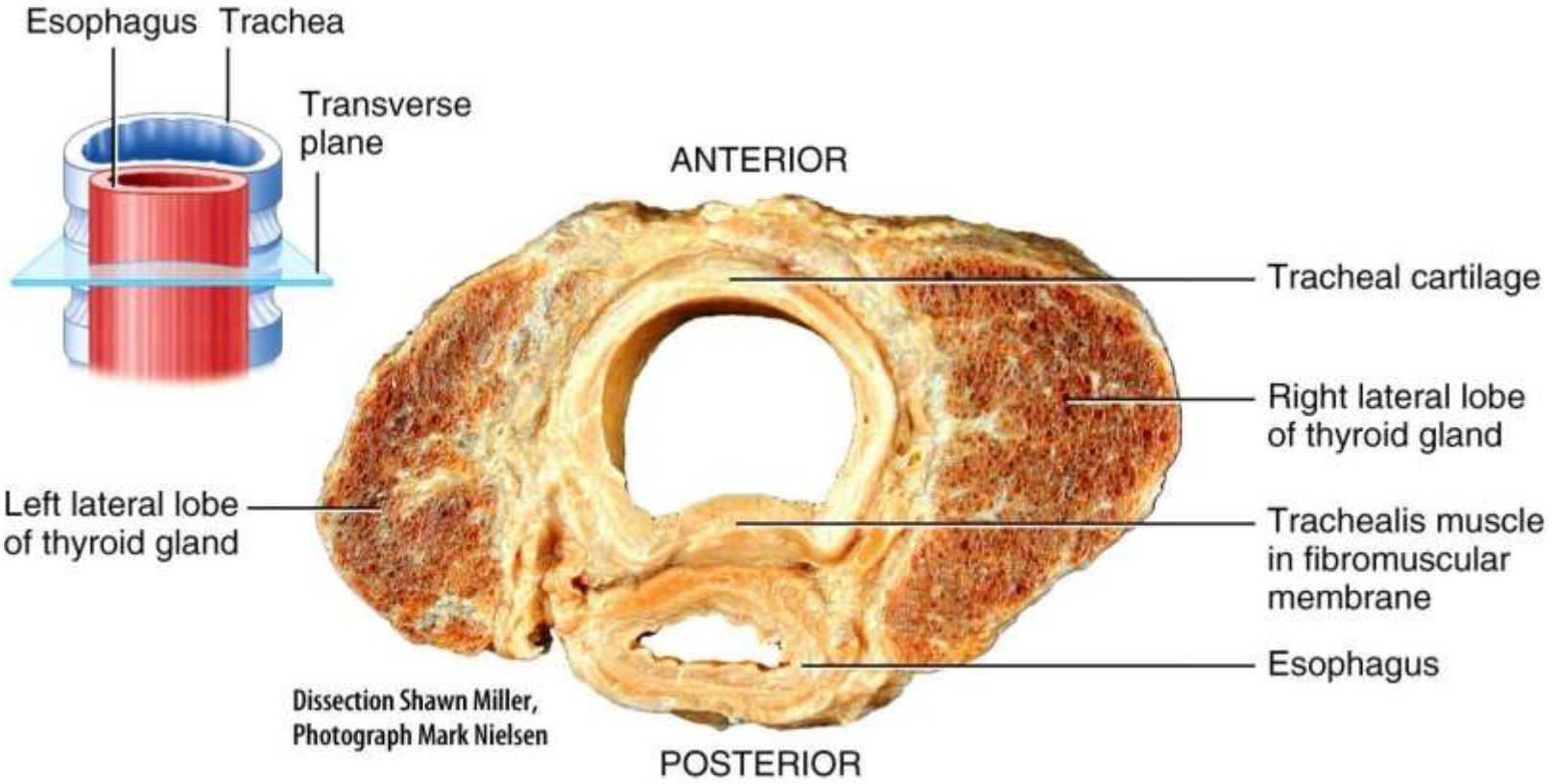


Structures of Voice Production



Trachea

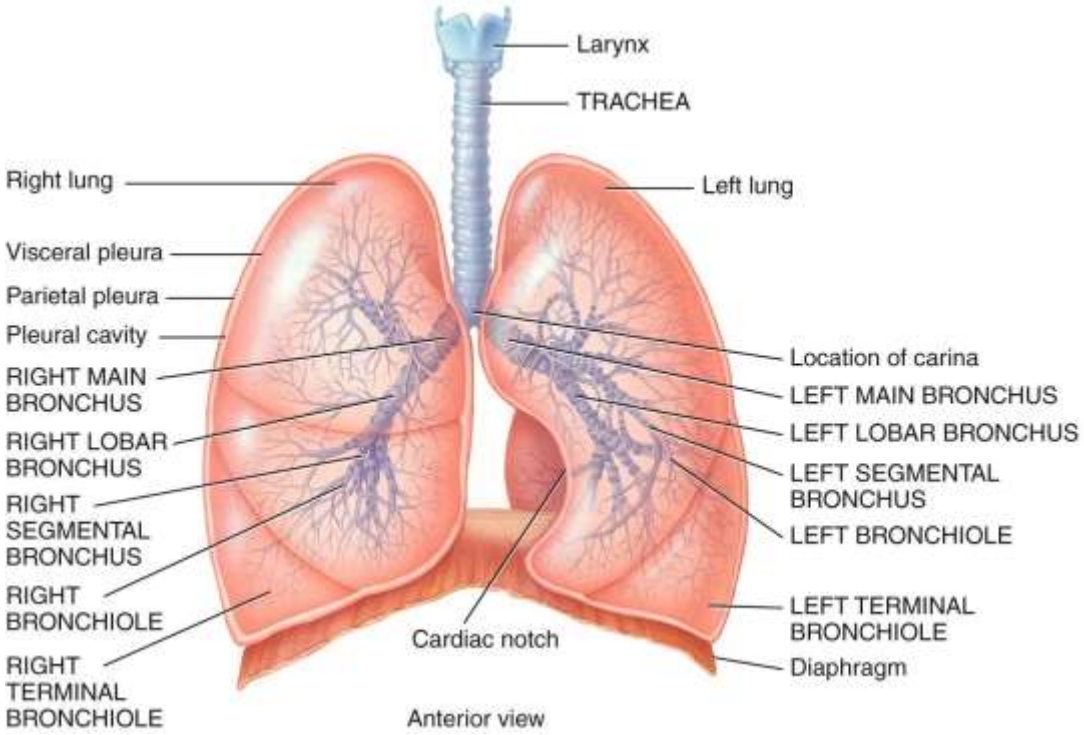
The trachea extends from the larynx to the primary bronchi



Superior view of transverse section of thyroid gland, trachea, and esophagus

Bronchi

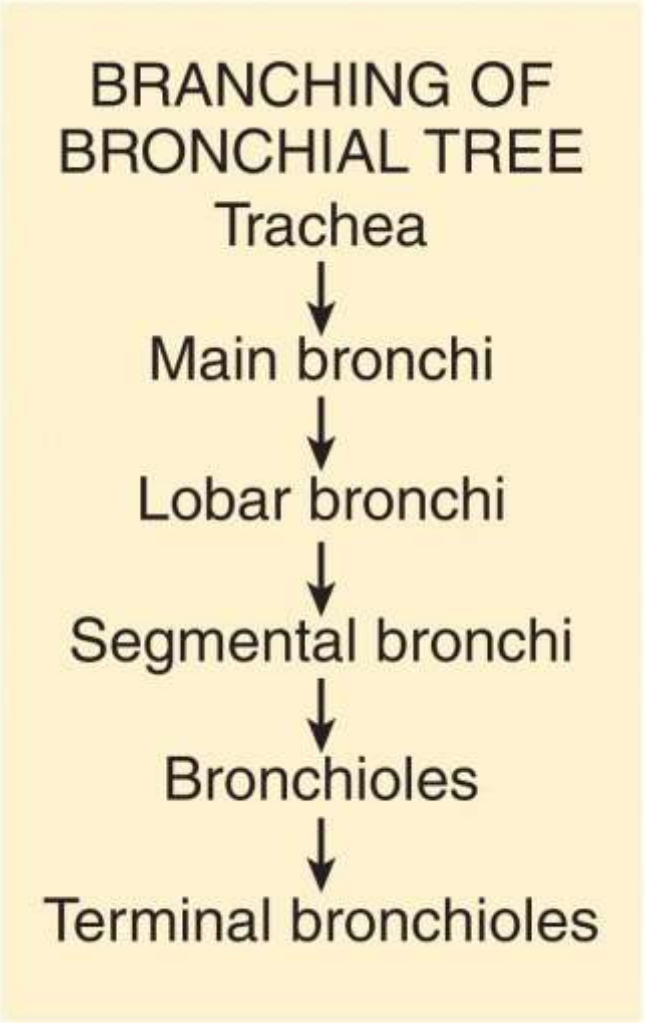
At the superior border of the 5th thoracic vertebrae, the trachea branches into a right primary bronchus which enters the right lung and a left primary bronchus which enters the left lung



Bronchi

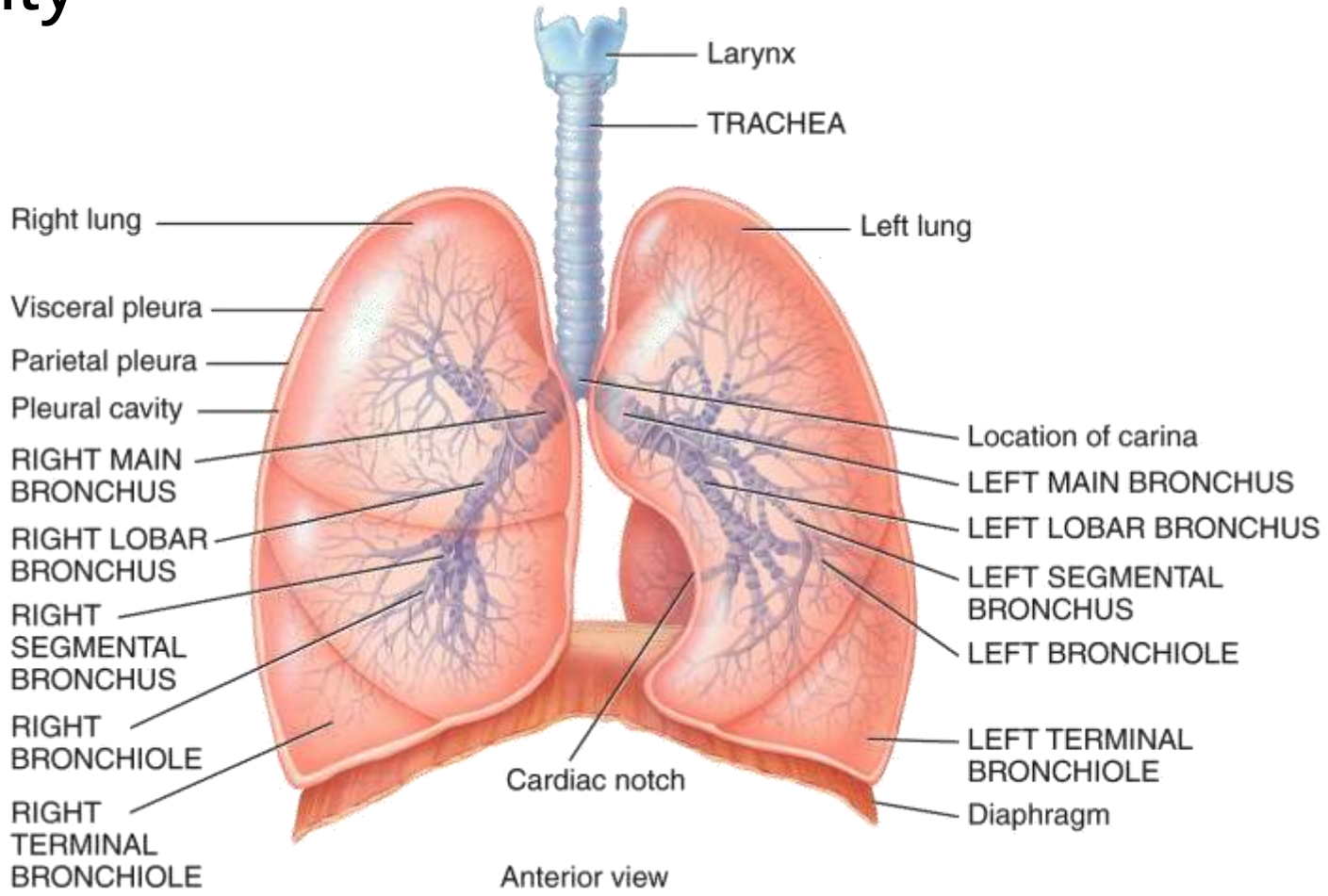
Upon entering the lungs, the primary bronchi further divide to form smaller and smaller diameter branches

- The terminal bronchioles are the end of the conducting zone



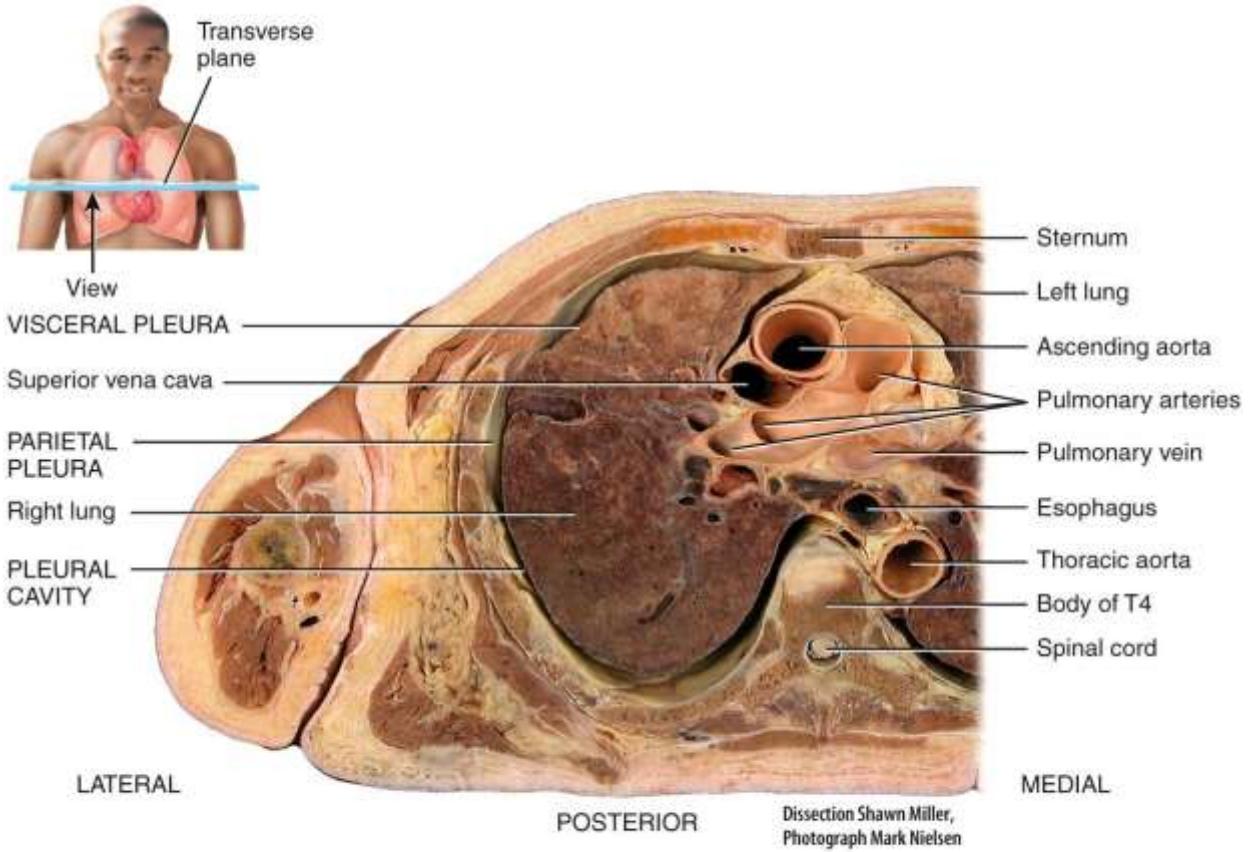
Lungs

The lungs are paired organs in the thoracic cavity



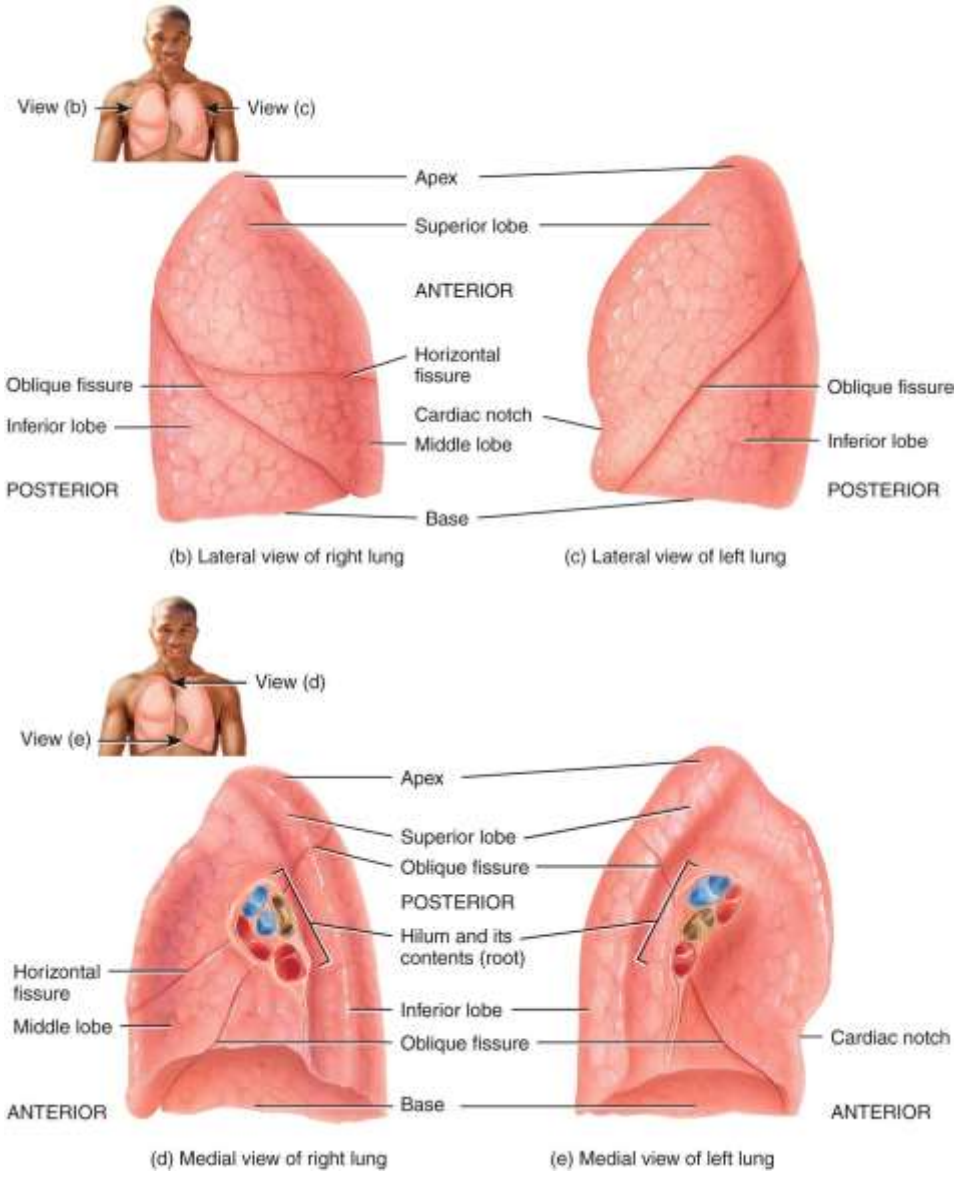
Lungs

The lungs are enclosed and protected by the pleural membrane



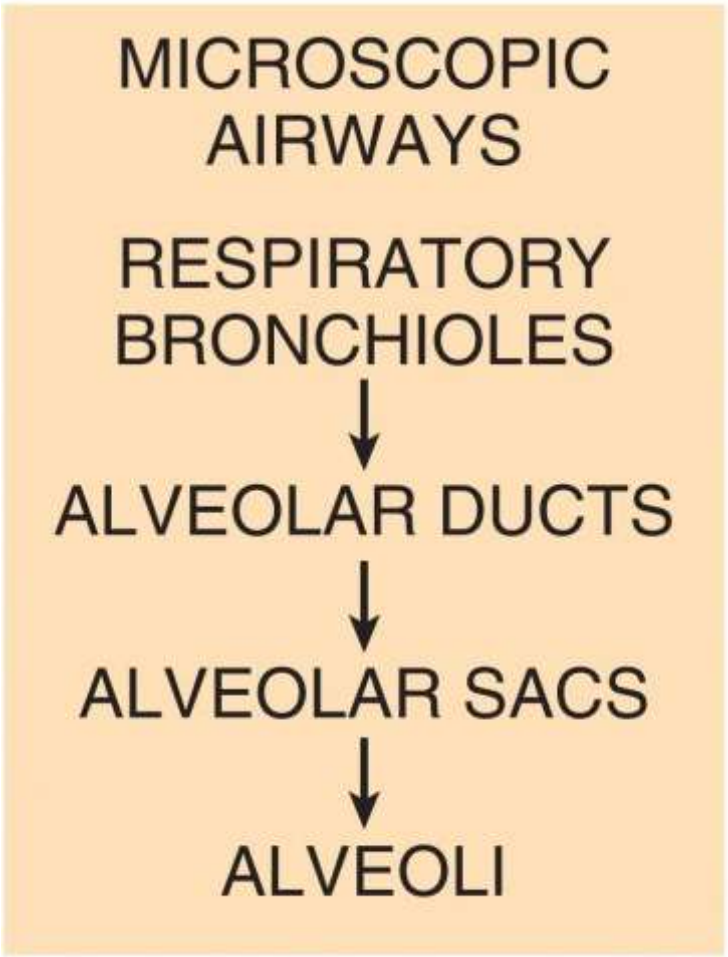
Inferior view of transverse section through thoracic cavity showing pleural cavity and pleural membranes

Lobes and Fissures of the Lungs



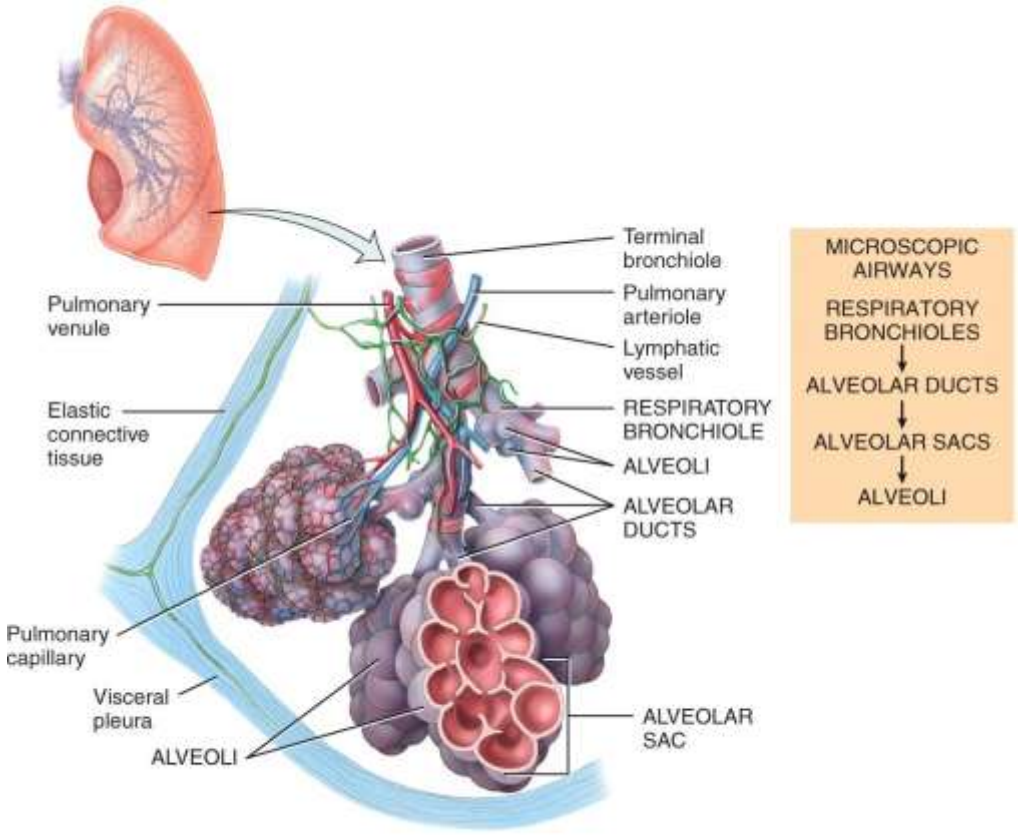
Alveoli

- When the conducting zone ends at the terminal bronchioles, the respiratory zone begins
- The respiratory zone terminates at the alveoli, the “air sacs” found within the lungs

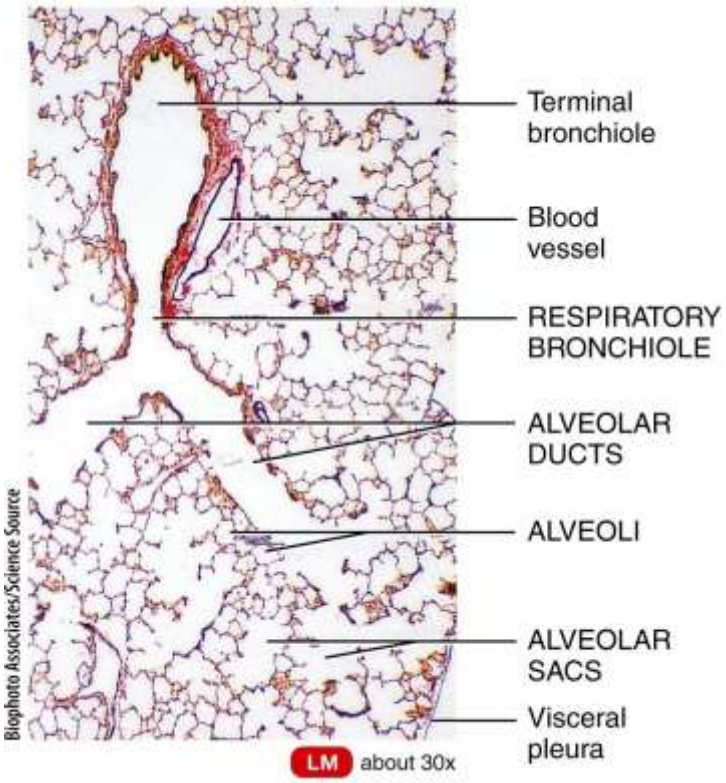


Alveoli in a Lobule of a Lung

Alveoli are sac-like structures



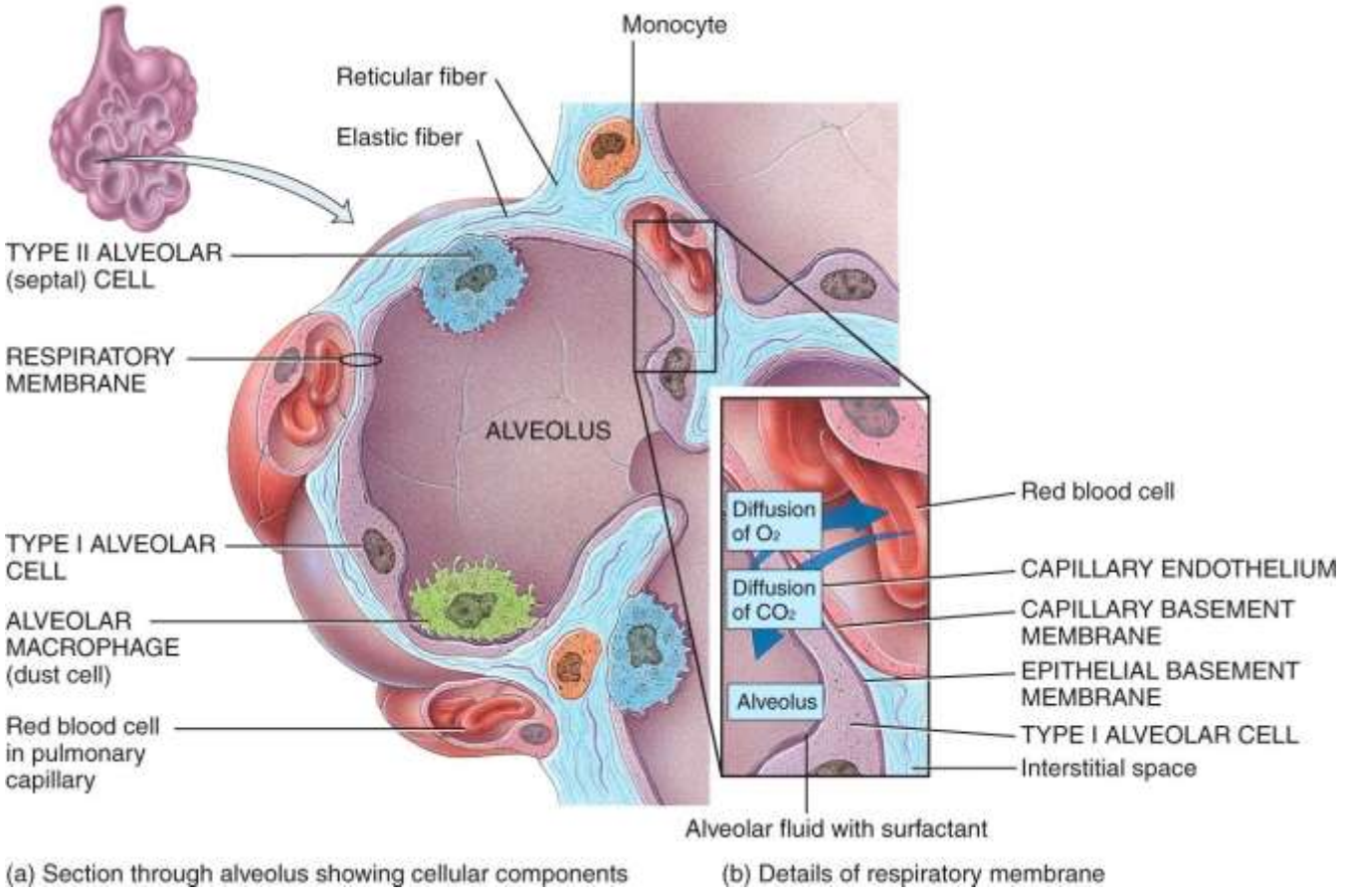
(a) Diagram of portion of lobule of lung



(b) Lung lobule

Alveolus

There are 2 kinds of alveolar cells, Type I and Type II



Respiratory Membrane

The respiratory membrane is composed of:

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

Blood Supply to the Lungs

- Blood enters the lungs via the pulmonary arteries (pulmonary circulation) and the bronchial arteries (systemic circulation)
- Blood exits the lungs via the pulmonary veins and the bronchial veins
- Ventilation-perfusion coupling
  - Vasoconstriction in response to hypoxia diverts blood from poorly ventilated areas to well ventilated areas

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.

Conducting structures Respiratory structures

TABLE 23.1

Summary of the Structures of the Respiratory System

STRUCTURE	EPITHELIUM	CILIA	GOBLET CELLS	SPECIAL FEATURES
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

Pulmonary Ventilation

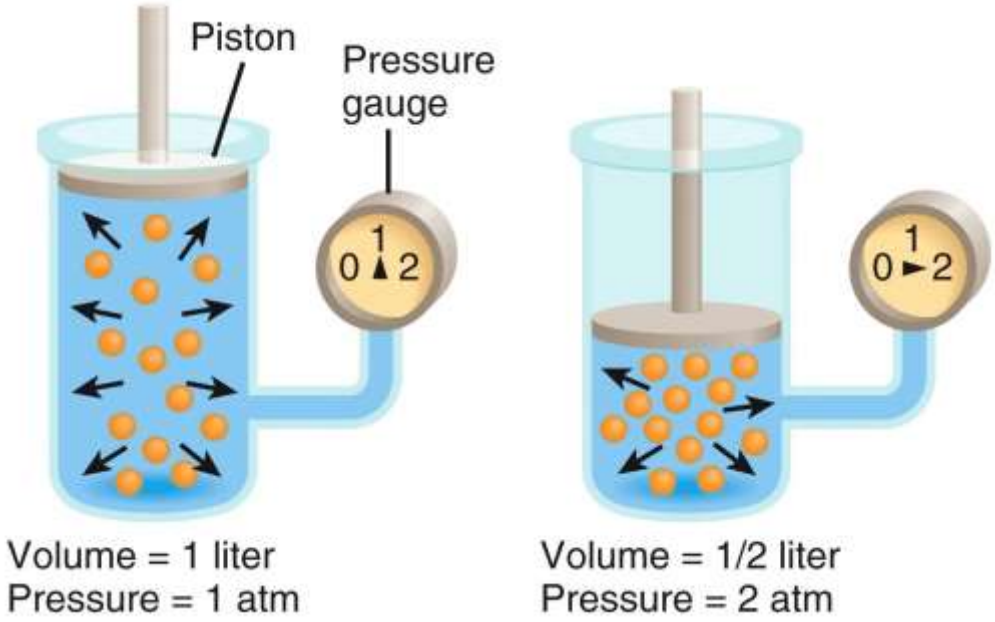
In pulmonary ventilation, air flows between the atmosphere and the alveoli of the lungs because of alternating pressure differences created by contraction and relaxation of respiratory muscles

- Inhalation
- Exhalation

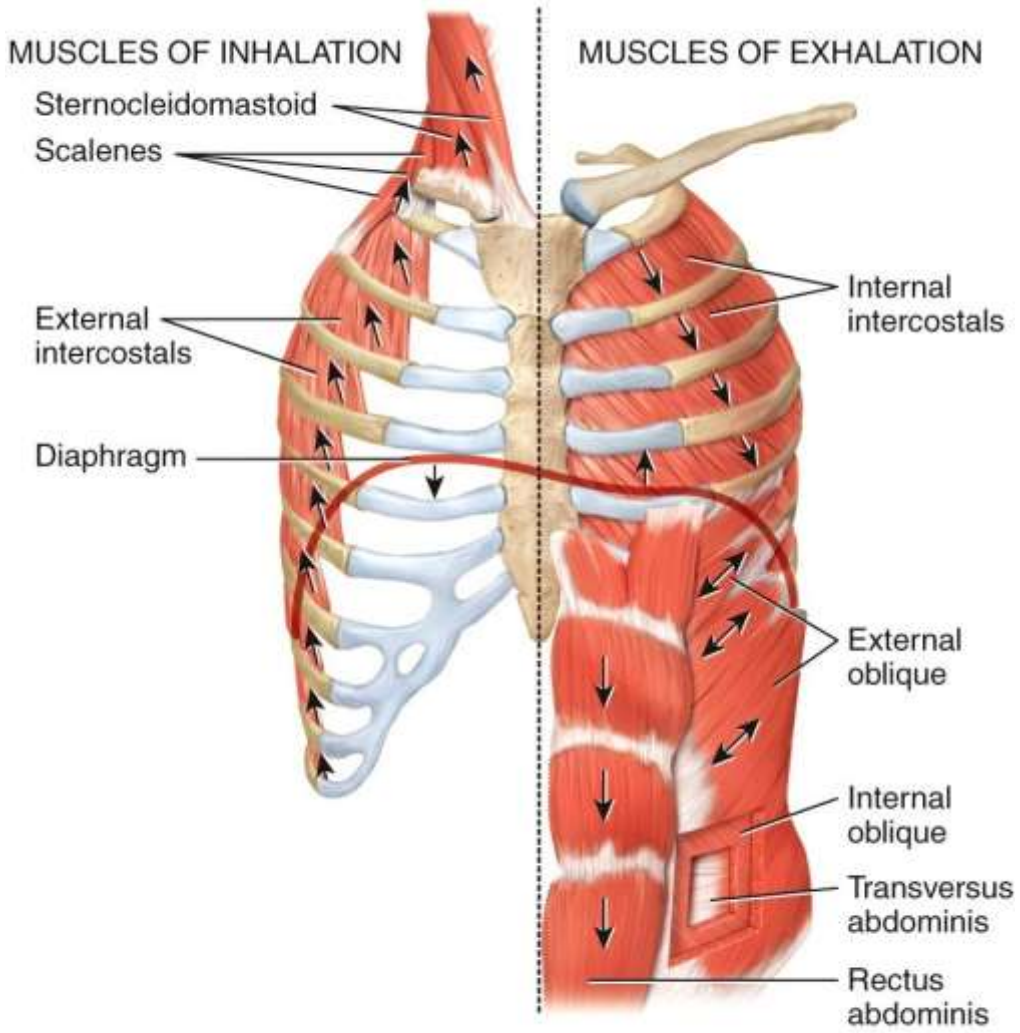
Boyle's Law

Pressure changes that drive inhalation and exhalation are governed, in part, by Boyle's Law

- The volume of a gas varies inversely with its pressure

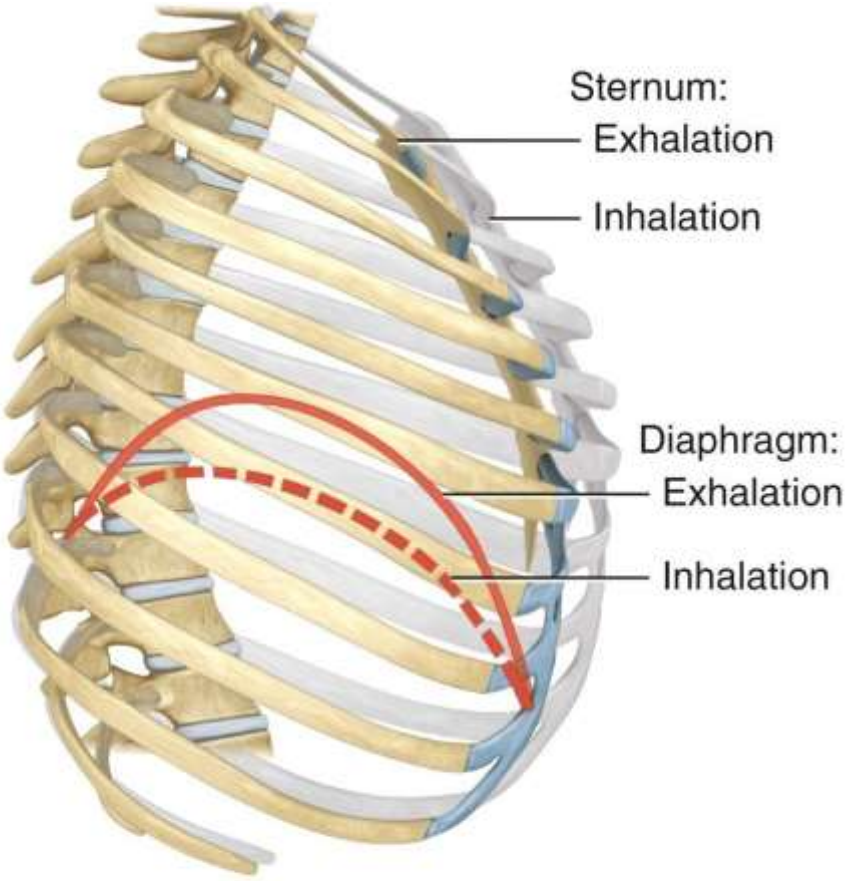


Muscles of Inhalation and Exhalation



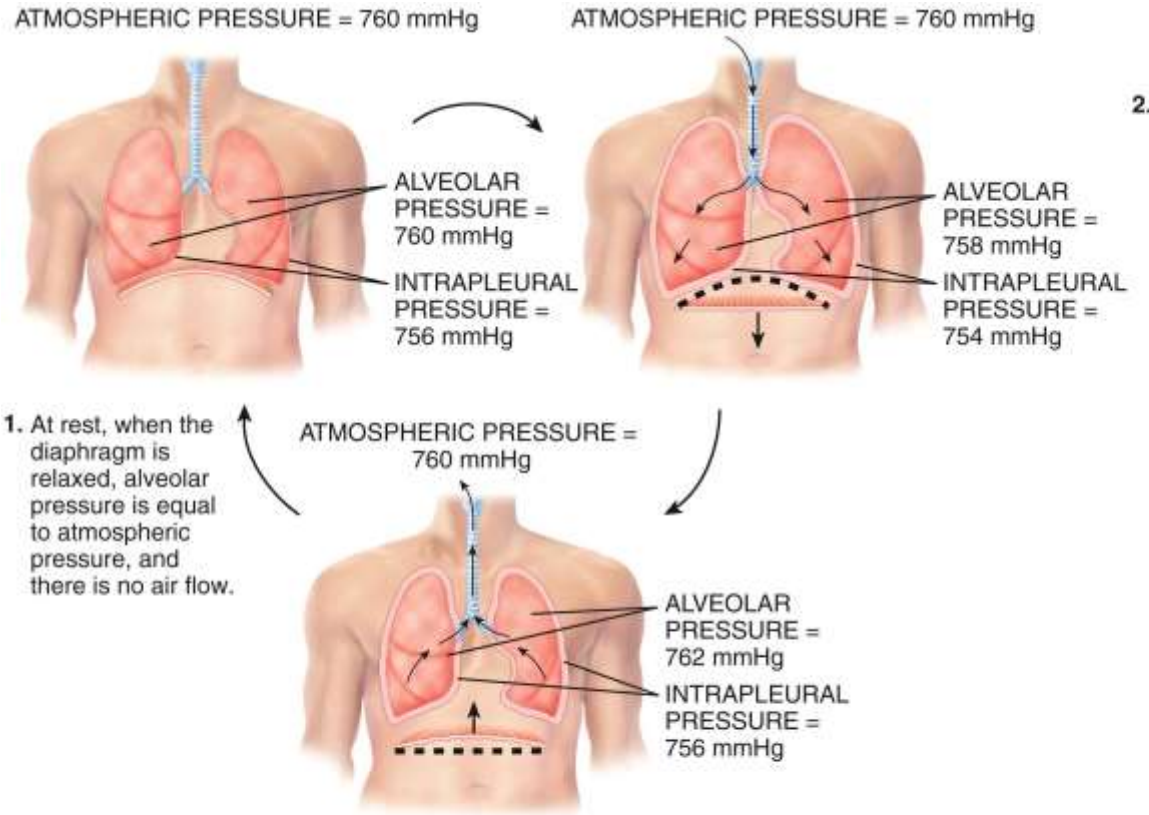
(a) Muscles of inhalation (left); muscles of exhalation (right); arrows indicate the direction of muscle contraction

Position of the Diaphragm During Inhalation and Exhalation



(b) Changes in size of thoracic cavity during inhalation and exhalation

Pressure Changes in Pulmonary Ventilation



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.

Other Factors Affecting Pulmonary Ventilation

Surface tension

- Inwardly directed force in the alveoli which must be overcome to expand the lungs during each inspiration

Elastic recoil

- Decreases the size of the alveoli during expiration

Compliance

- Ease with which the lungs and thoracic wall can be expanded

Breathing Patterns and Respiratory Movements

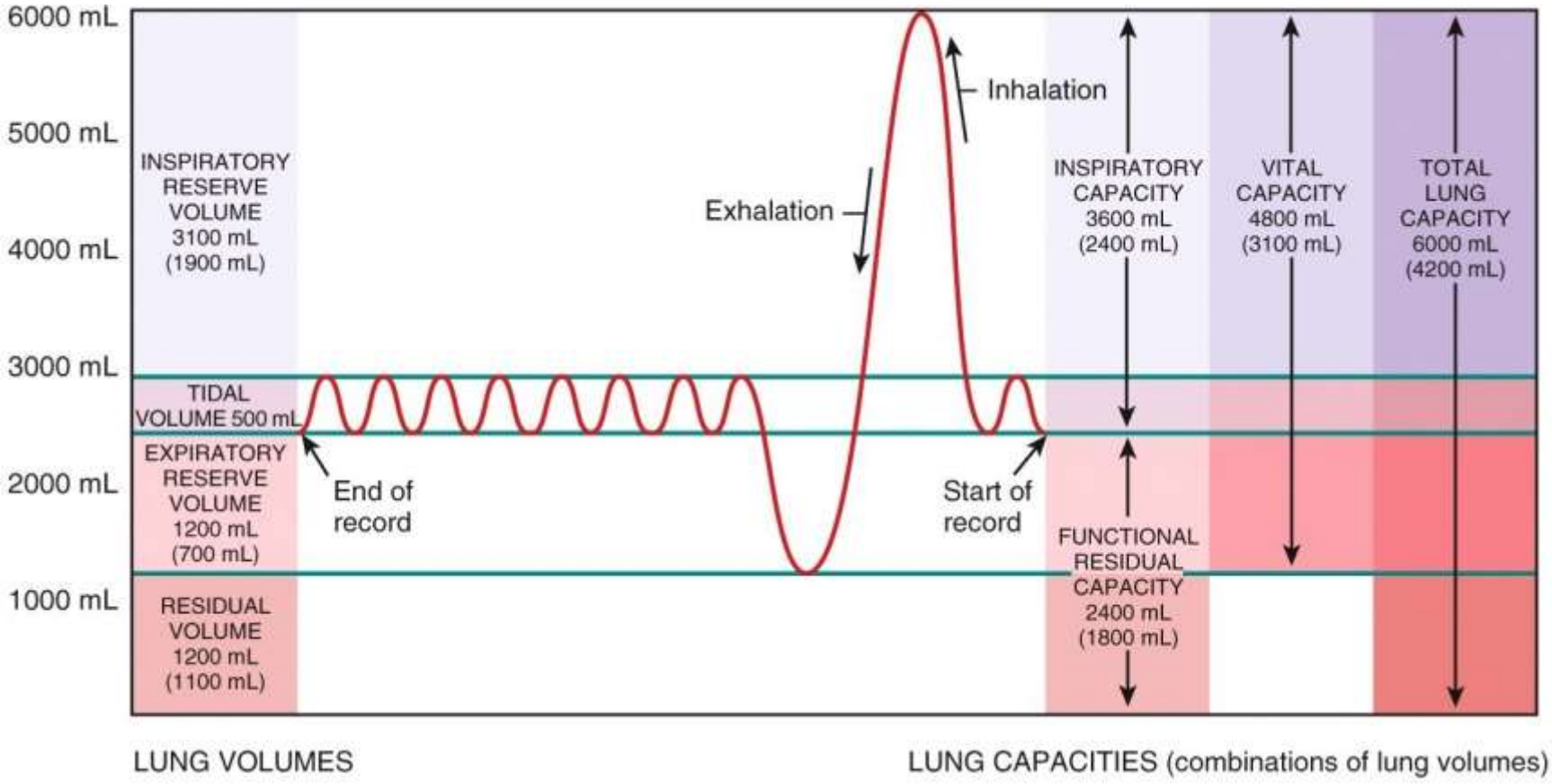
- Eupnea
- Apnea
- Dyspnea
- Tachypnea
- Costal breathing
- Diaphragmatic breathing

TABLE 23.2

Modified Breathing Movements

MOVEMENT	DESCRIPTION
Coughing	A long-drawn and deep inhalation followed by a complete closure of the rima glottidis, which results in a strong exhalation that suddenly pushes the rima glottidis open and sends a blast of air through the upper respiratory passages. Stimulus for this reflex act may be a foreign body lodged in the larynx, trachea, or epiglottis.
Sneezing	Spasmodic contraction of muscles of exhalation that forcefully expels air through the nose and mouth. Stimulus may be an irritation of the nasal mucosa.
Sighing	A long-drawn and deep inhalation immediately followed by a shorter but forceful exhalation.
Yawning	A deep inhalation through the widely opened mouth producing an exaggerated depression of the mandible. It may be stimulated by drowsiness, or someone else's yawning, but the precise cause is unknown.
Sobbing	A series of convulsive inhalations followed by a single prolonged exhalation. The rima glottidis closes earlier than normal after each inhalation so only a little air enters the lungs with each inhalation.
Crying	An inhalation followed by many short convulsive exhalations, during which the rima glottidis remains open and the vocal folds vibrate; accompanied by characteristic facial expressions and tears.
Laughing	The same basic movements as crying, but the rhythm of the movements and the facial expressions usually differ from those of crying. Laughing and crying are sometimes indistinguishable.
Hiccupping	Spasmodic contraction of the diaphragm followed by a spasmodic closure of the rima glottidis, which produces a sharp sound on inhalation. Stimulus is usually irritation of the sensory nerve endings of the gastrointestinal tract.
Valsalva (val-SAL-va) **maneuver**	Forced exhalation against a closed rima glottidis as may occur during periods of straining while defecating.
Pressurizing the middle ear	The nose and mouth are held closed and air from the lungs is forced through the auditory tube into the middle ear. Employed by those snorkeling or scuba diving during descent to equalize the pressure of the middle ear with that of the external environment.

Lung Volumes and Capacities



Exchange of Oxygen and Carbon Dioxide

Dalton's law

- Each gas in a mixture of gases exerts its own pressure as if no other gases were present

Henry's law

- The quantity of a gas that will dissolve in a liquid is proportional to the partial pressure of the gas and its solubility coefficient when the temperature remains constant

External and Internal Respiration

During external respiration, oxygen will diffuse from the alveoli into the pulmonary capillaries

- CO_2 moves in the opposite direction

During internal respiration, oxygen will diffuse from the systemic capillaries into the tissue

- CO_2 moves in the opposite direction

Gas Exchange

Interactions Animation:

- Gas Exchange

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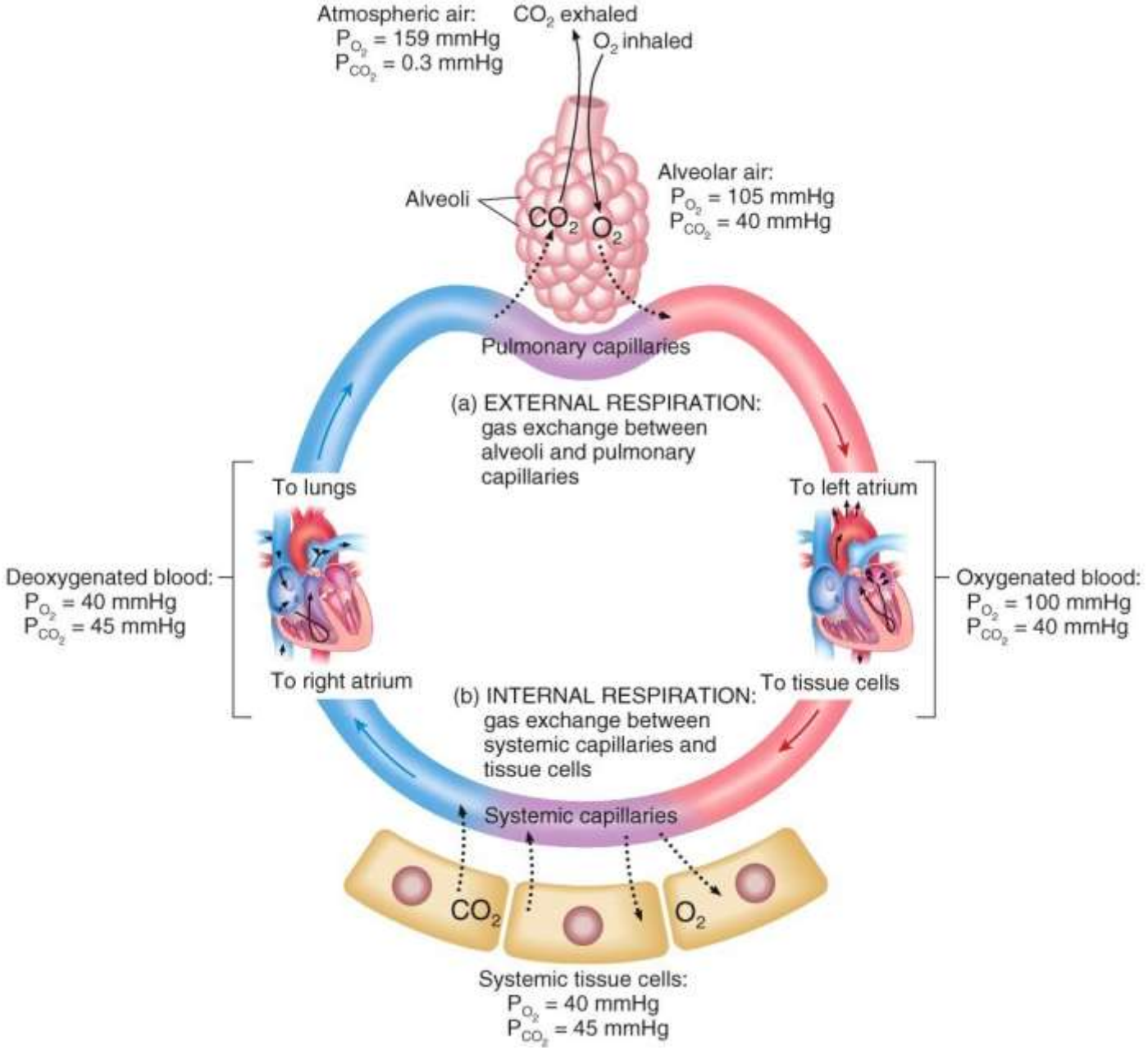


Transport of O_2 and CO_2 in the Blood

Oxygen:

- 1.5% of the O_2 is dissolved in the plasma
- 98.5% of the O_2 is carried by hemoglobin (Hb)

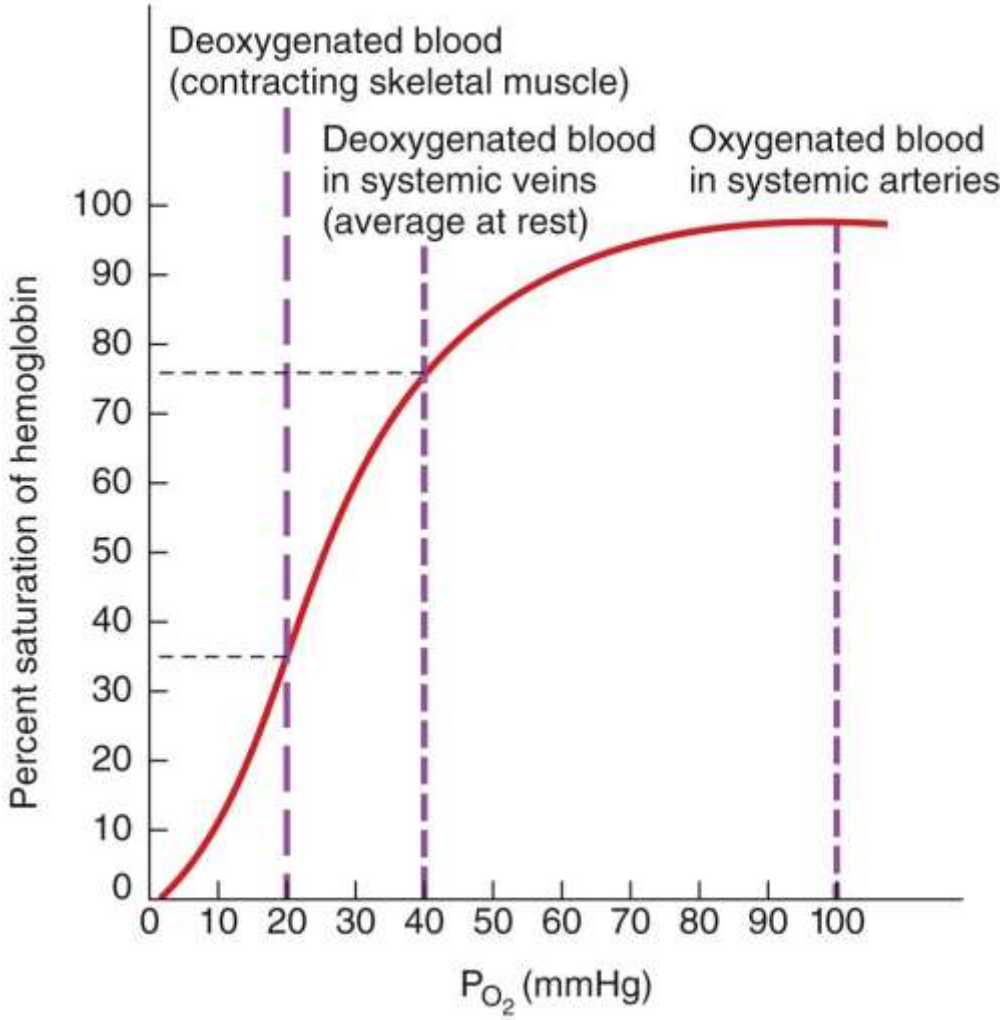
Carbon dioxide:

- 7% of the CO_2 is dissolved in the plasma
- 23% of the CO_2 is carried by Hb inside red blood cells as carbaminohemoglobin
- 70% of the CO_2 is transported as bicarbonate ions (HCO_3)

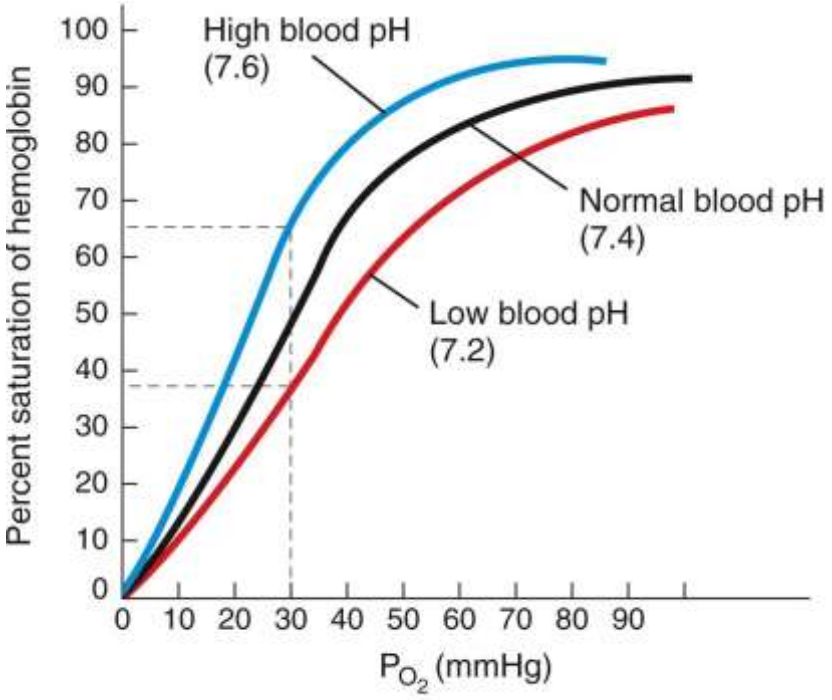
Factors Affecting the Affinity of Hb for O_2

- PO_2
- pH
- Temperature
- BPG
- Type of Hb

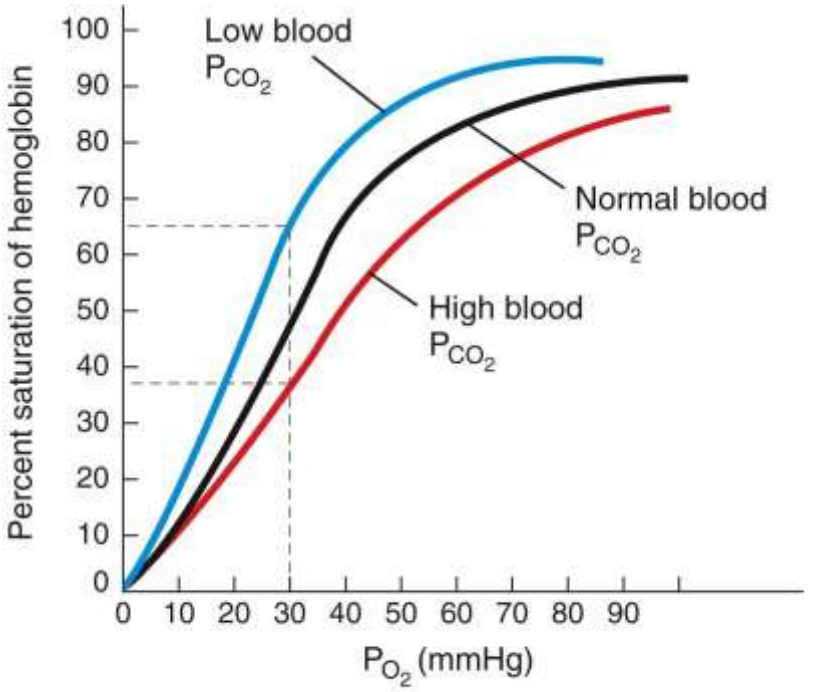
Factors Affecting the Affinity of Hb for O_2



Factors Affecting the Affinity of Hb for O_2

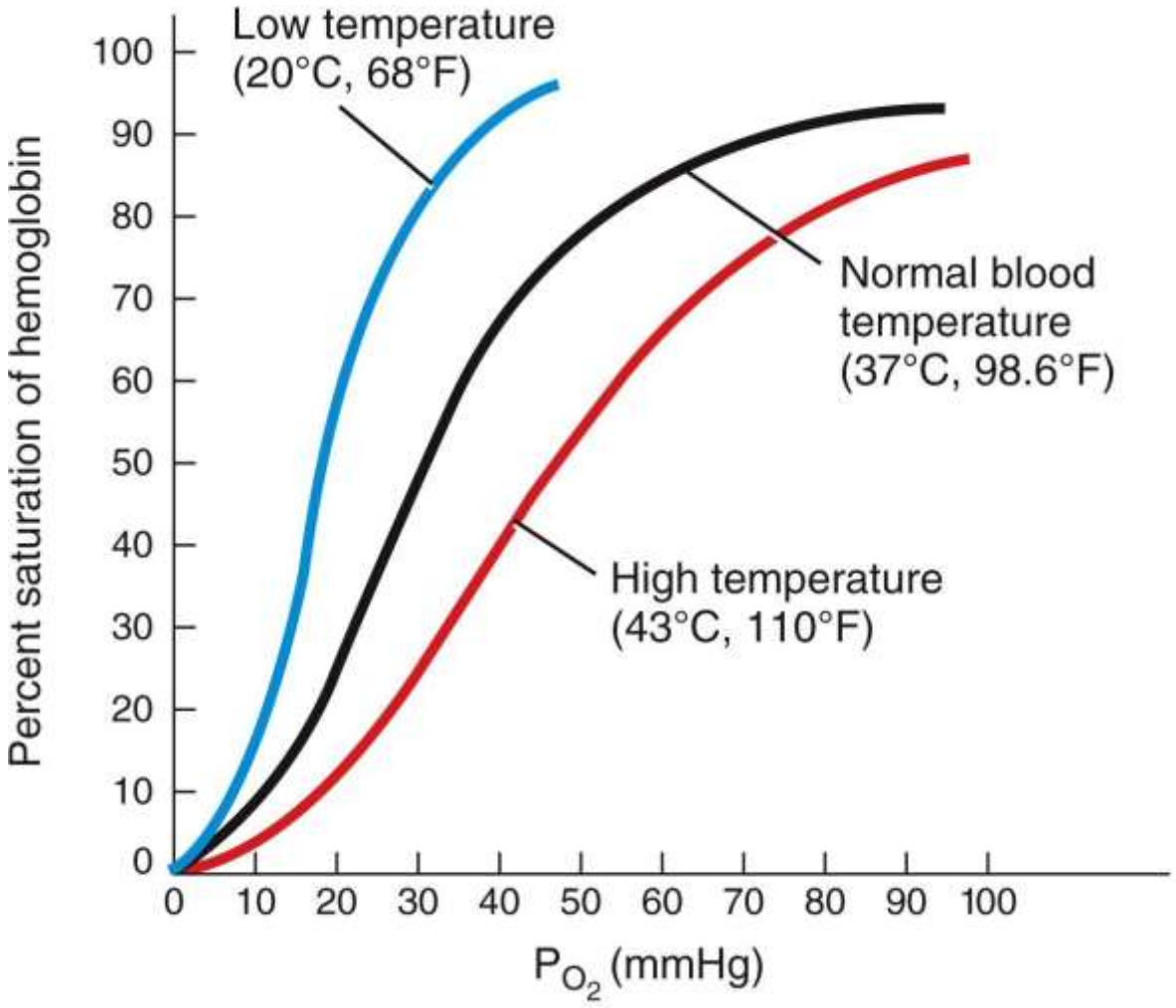


(a) Effect of pH on affinity of hemoglobin for oxygen

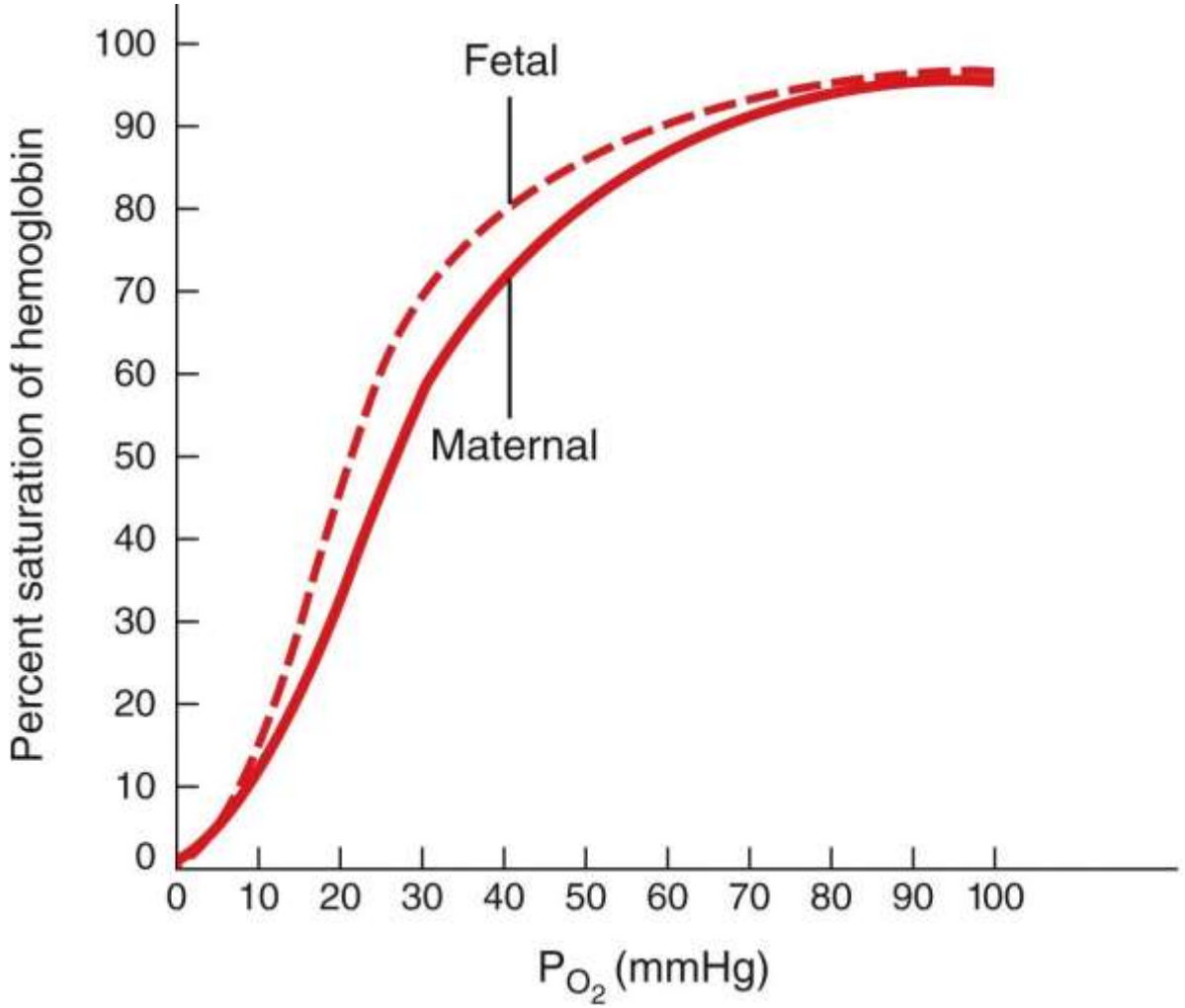


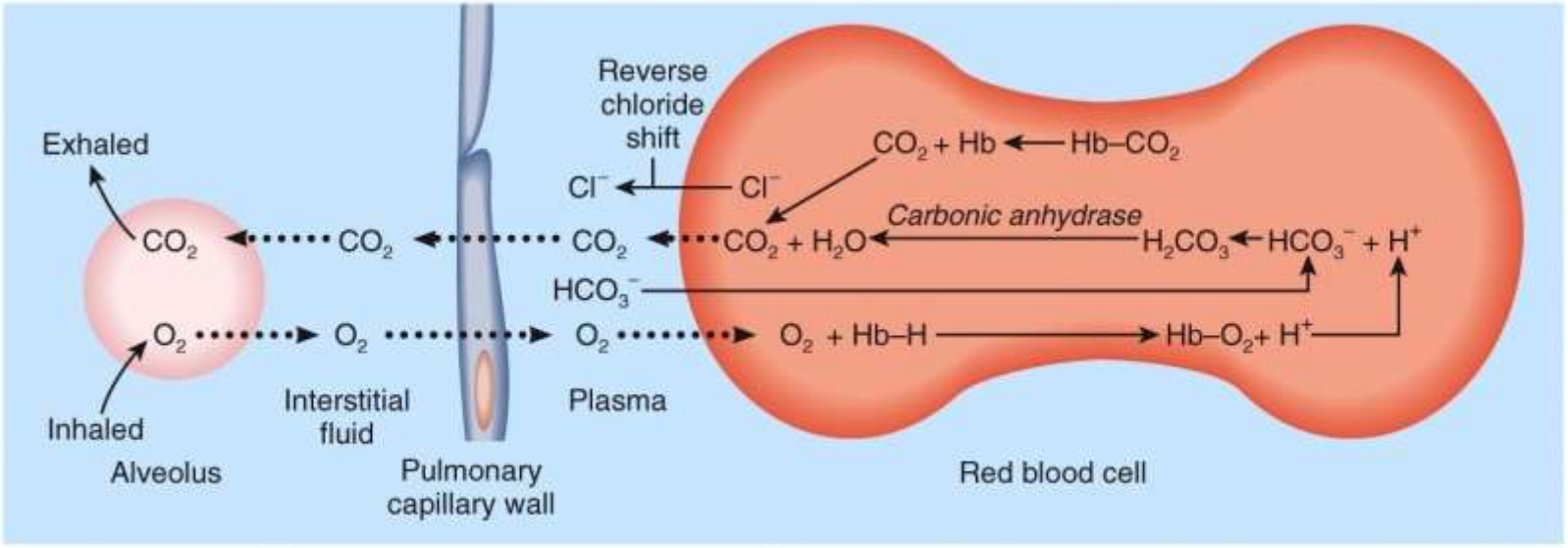
(b) Effect of P_{CO_2} on affinity of hemoglobin for oxygen

Factors Affecting the Affinity of Hb for O_2

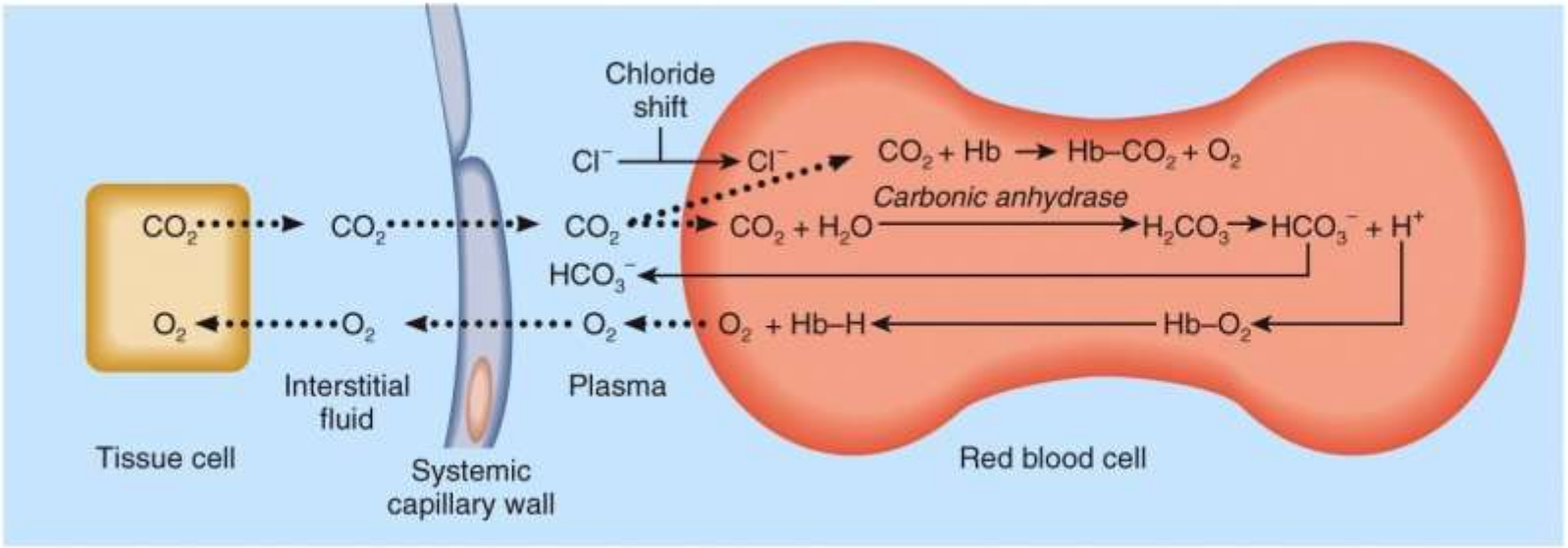


Factors Affecting the Affinity of Hb for O_2



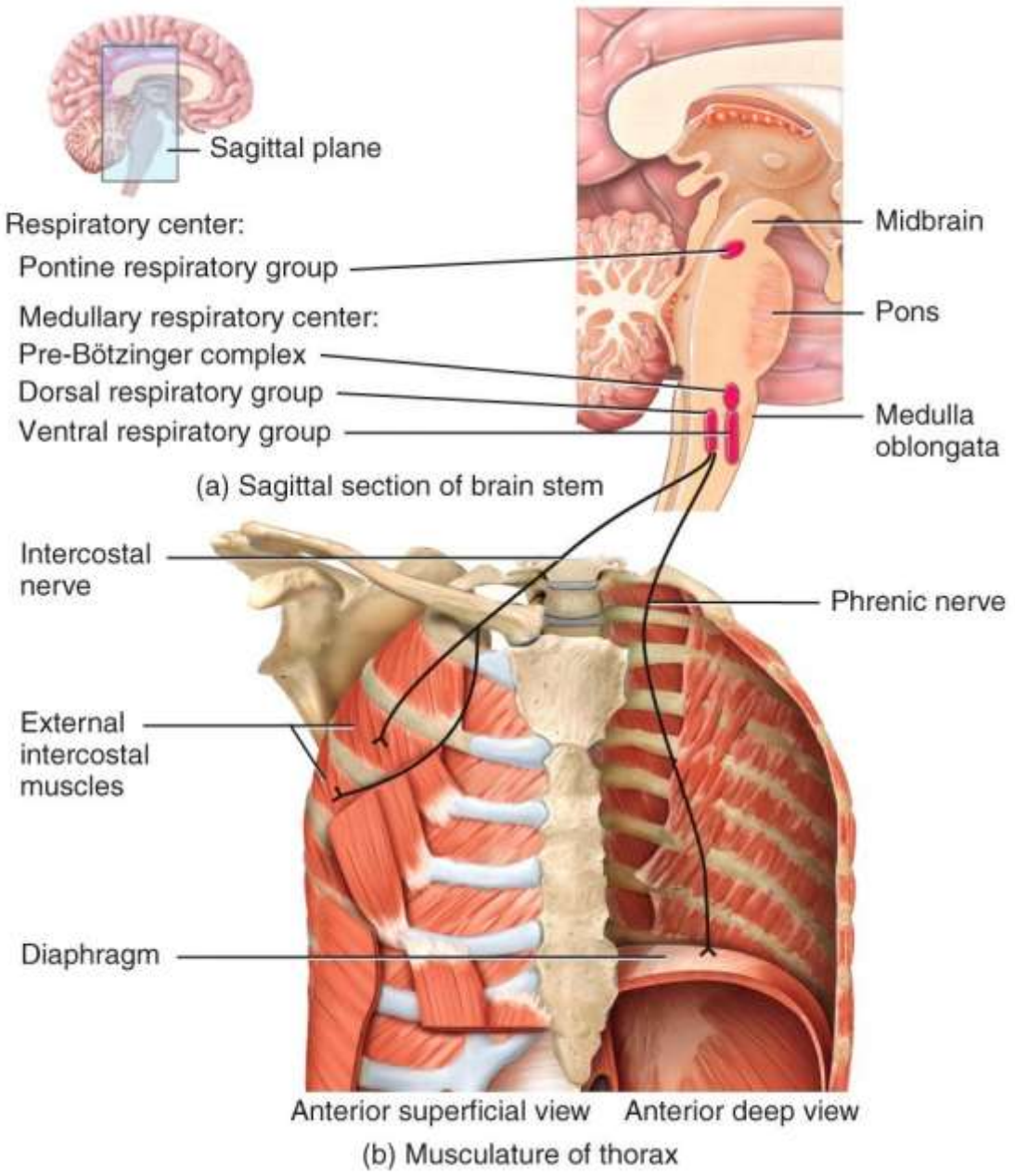


(a) Exchange of O_2 and CO_2 in pulmonary capillaries (external respiration)

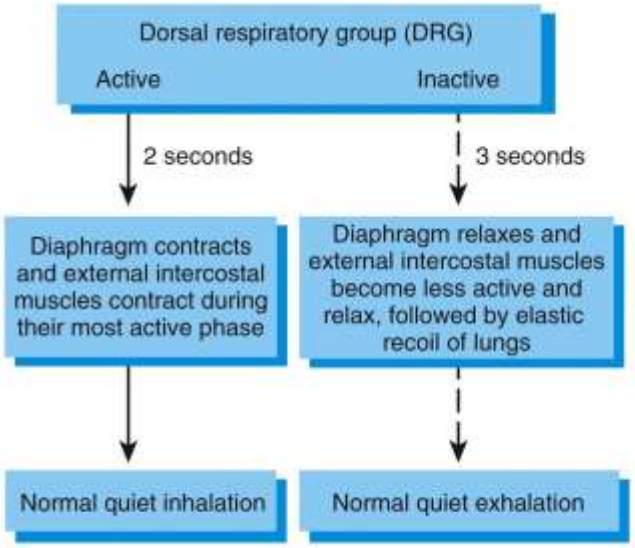


(b) Exchange of O_2 and CO_2 in systemic capillaries (internal respiration)

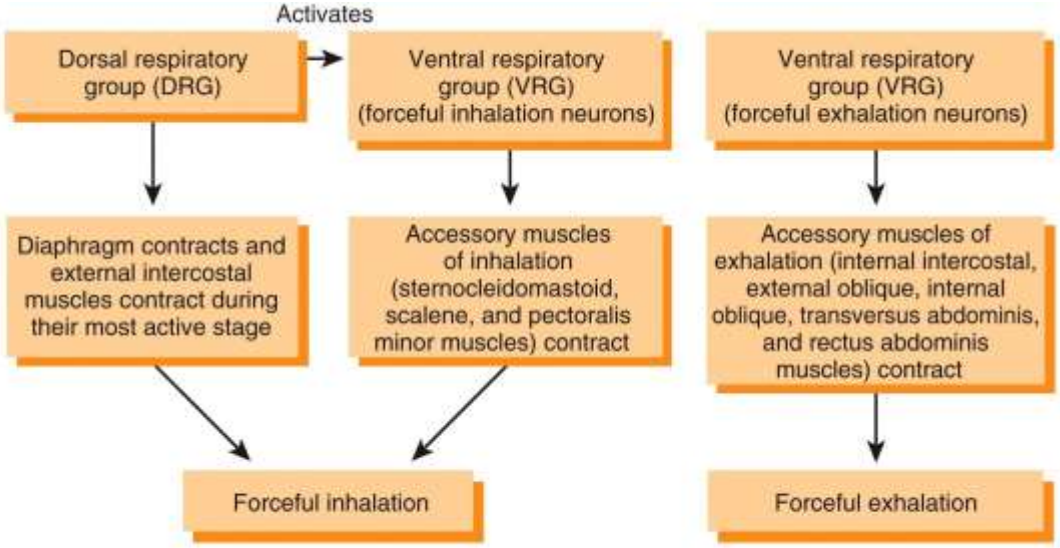
Control of Respiration



Control of Respiration



(a) During normal quiet breathing



(b) During forceful breathing

Control of Respiration

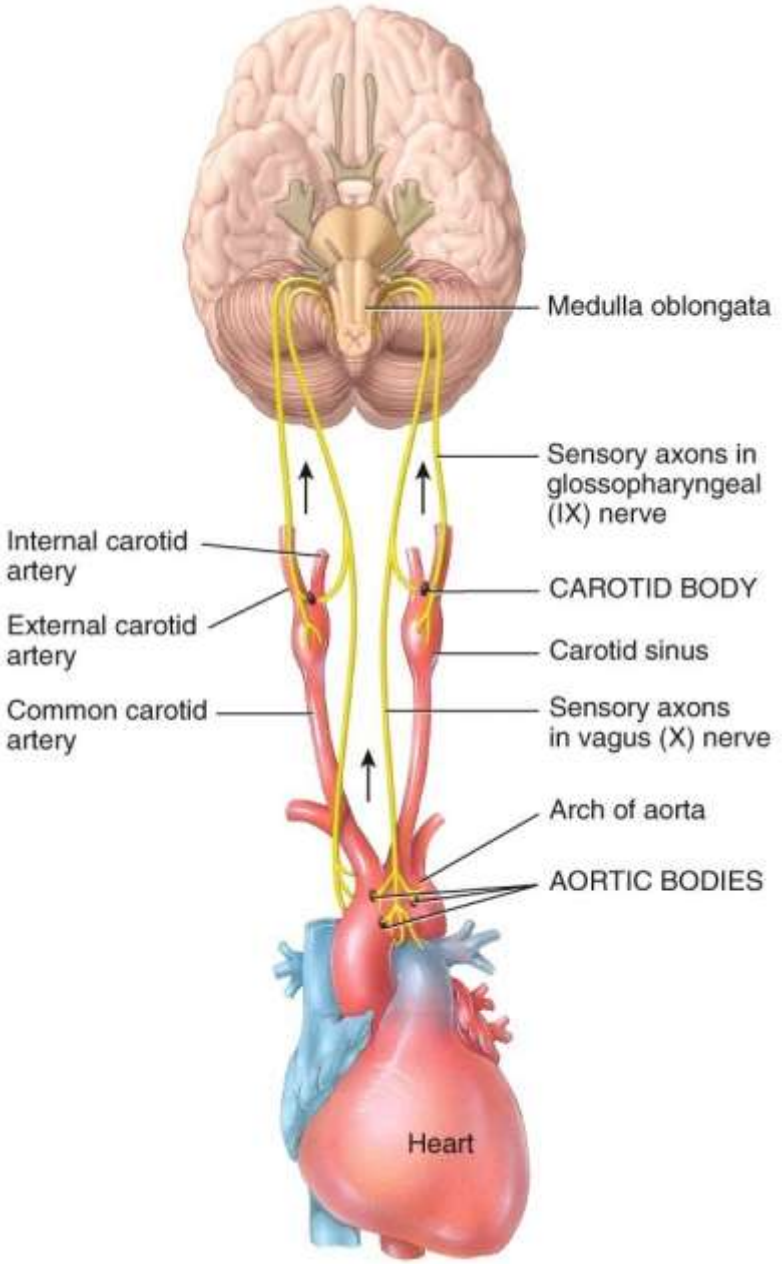
Cortical influences

- Allow conscious control of respiration that may be needed to avoid inhaling noxious gases or water

Chemoreceptor

- Central and peripheral chemoreceptors monitor levels of O_2 and CO_2 and provide input to the respiratory center

Control of Respiration



Control of Respiration

Hypercapnia

- A slight increase in PCO_2 (and thus H^+)
- Stimulates central chemoreceptors

Hypoxia

- Oxygen deficiency at the tissue level
- Caused by a low PO_2 in arterial blood due to high altitude, airway obstruction or fluid in the lungs

Control of Respiration

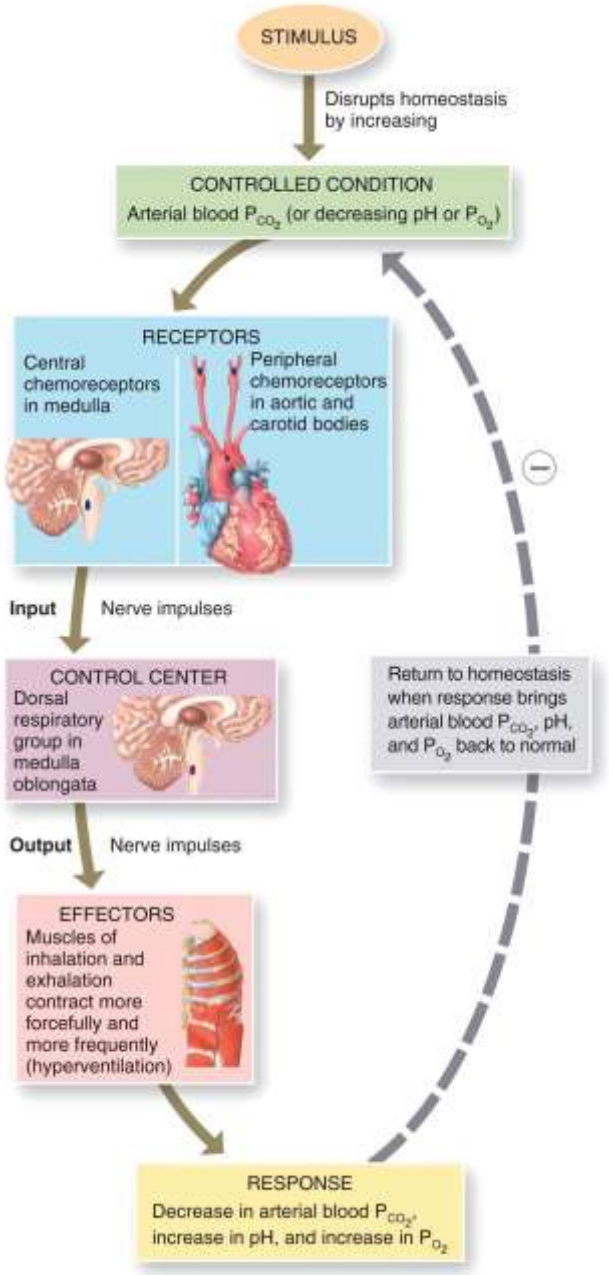


TABLE 23.3

Summary of Stimuli That Affect Breathing Rate and Depth

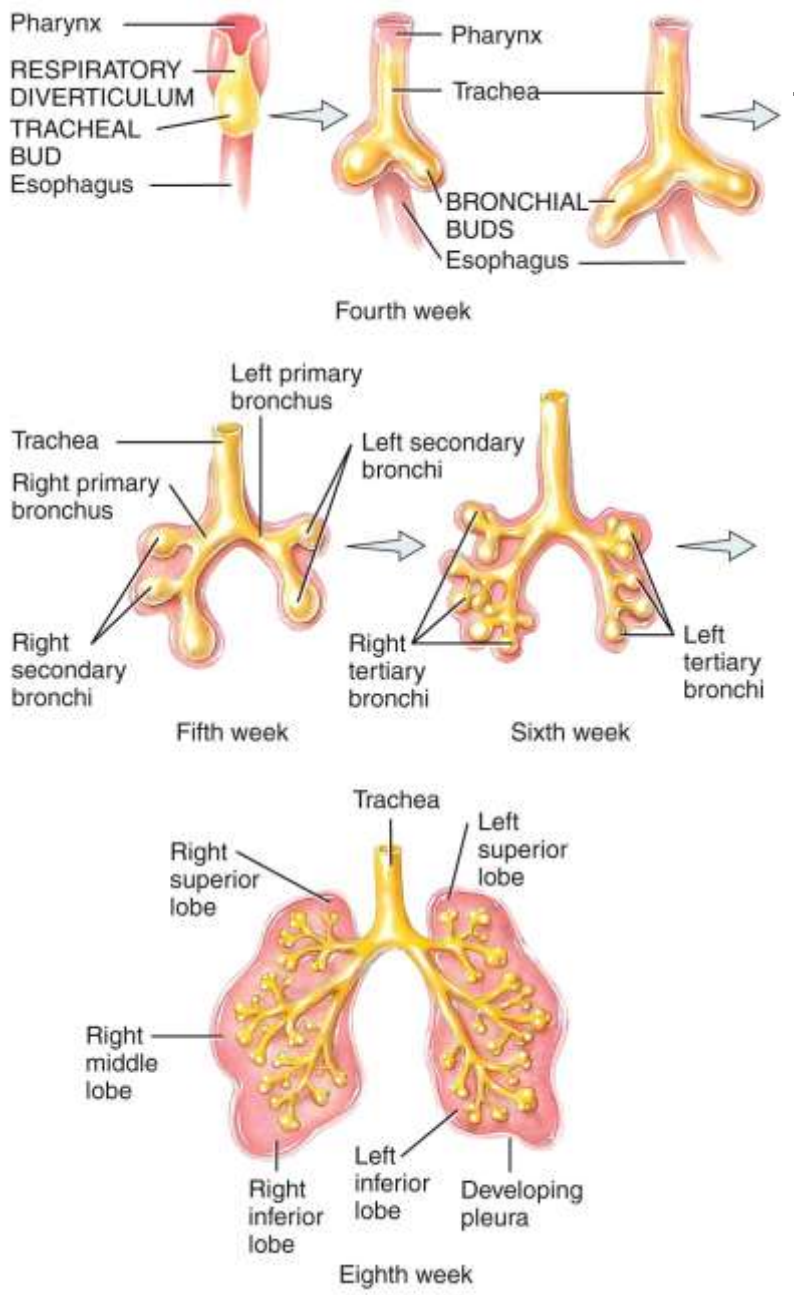
STIMULI THAT INCREASE BREATHING RATE AND DEPTH	STIMULI THAT DECREASE BREATHING RATE AND DEPTH
Voluntary hyperventilation controlled by cerebral cortex and anticipation of activity by stimulation of limbic system.	Voluntary hypoventilation controlled by cerebral cortex.
Increase in arterial blood P_{CO_2} above 40 mmHg (causes an increase in H^+) detected by peripheral and central chemoreceptors.	Decrease in arterial blood P_{CO_2} below 40 mmHg (causes a decrease in H^+) detected by peripheral and central chemoreceptors.
Decrease in arterial blood P_{O_2} from 105 mmHg to 50 mmHg.	Decrease in arterial blood P_{O_2} below 50 mmHg.
Increased activity of proprioceptors.	Decreased activity of proprioceptors.
Increase in body temperature.	Decrease in body temperature (decreases respiration rate), sudden cold stimulus (causes apnea).
Prolonged pain.	Severe pain (causes apnea).
Decrease in blood pressure.	Increase in blood pressure.
Stretching of anal sphincter.	Irritation of pharynx or larynx by touch or chemicals (causes brief apnea followed by coughing or sneezing).

Exercise and the Respiratory System

The respiratory and cardiovascular systems make adjustments in response to both the intensity and duration of exercise

- As cardiac output rises, the blood flow to the lungs, termed pulmonary perfusion, increases as well
- The O_2 diffusing capacity may increase threefold during maximal exercise so there is a greater surface area available for O_2 diffusion

Development of the Respiratory System



Aging and the Respiratory System

Aging results in decreased:

- Vital capacity
- Blood O_2 level
- Alveolar macrophage activity
- Ciliary action of respiratory epithelia

Consequently, elderly people are more susceptible to pneumonia, bronchitis, emphysema, and other issues

FOCUS on HOMEOSTASIS

CONTRIBUTIONS OF THE RESPIRATORY SYSTEM

FOR ALL BODY SYSTEMS

- Provides oxygen and removes carbon dioxide
- Helps adjust pH of body fluids through exhalation of carbon dioxide

MUSCULAR SYSTEM

- Increased rate and depth of breathing support increased activity of skeletal muscles during exercise

NERVOUS SYSTEM

- Nose contains receptors for sense of smell (olfaction)
- Vibrations of air flowing across vocal folds produce sounds for speech

ENDOCRINE SYSTEM

- Angiotensin-converting enzyme (ACE) in lungs catalyzes formation of the hormone angiotensin II from angiotensin I

CARDIOVASCULAR SYSTEM

- During inhalations, respiratory pump aids return of venous blood to the heart

LYMPHATIC SYSTEM and IMMUNITY

- Hairs in nose, cilia and mucus in trachea, bronchi, and smaller airways, and alveolar macrophages contribute to nonspecific resistance to disease
- Pharynx (throat) contains lymphatic tissue (tonsils)
- Respiratory pump (during inhalation) promotes flow of lymph

DIGESTIVE SYSTEM

- Forceful contraction of respiratory muscles can assist in defecation

URINARY SYSTEM

- Together, respiratory and urinary systems regulate pH of body fluids

REPRODUCTIVE SYSTEMS

- Increased rate and depth of breathing support activity during sexual intercourse
- Internal respiration provides oxygen to developing fetus

Disorders: Homeostatic Imbalances

- Asthma
- Chronic obstructive pulmonary disease
- Lung cancer
- Pneumonia
- Tuberculosis
- Common cold
- Pulmonary edema
- Cystic fibrosis
- Asbestos-related diseases
- Sudden infant death syndrome
- Acute respiratory distress