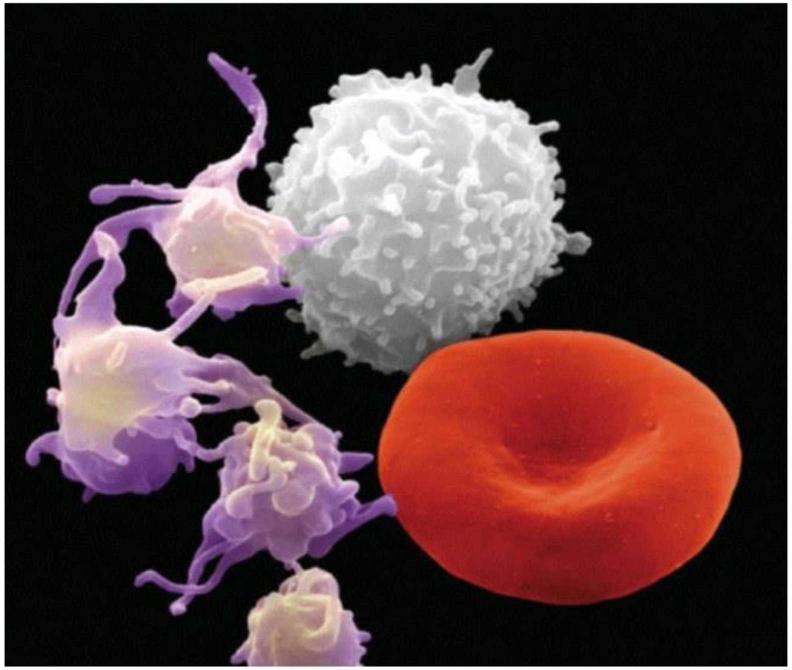
Unit 9
Cardiorespiratory Systems
Ms. Randall



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Lesson 1: Blood

Objective:

- Identify the primary functions of blood, its fluid and cellular components, and its physical characteristics
- Describe the anatomy of erythrocytes and the function of hemoglobin
- Classify leukocytes according to their lineage, their main structural features, and their primary functions
- Identify the basic structure and function of platelets

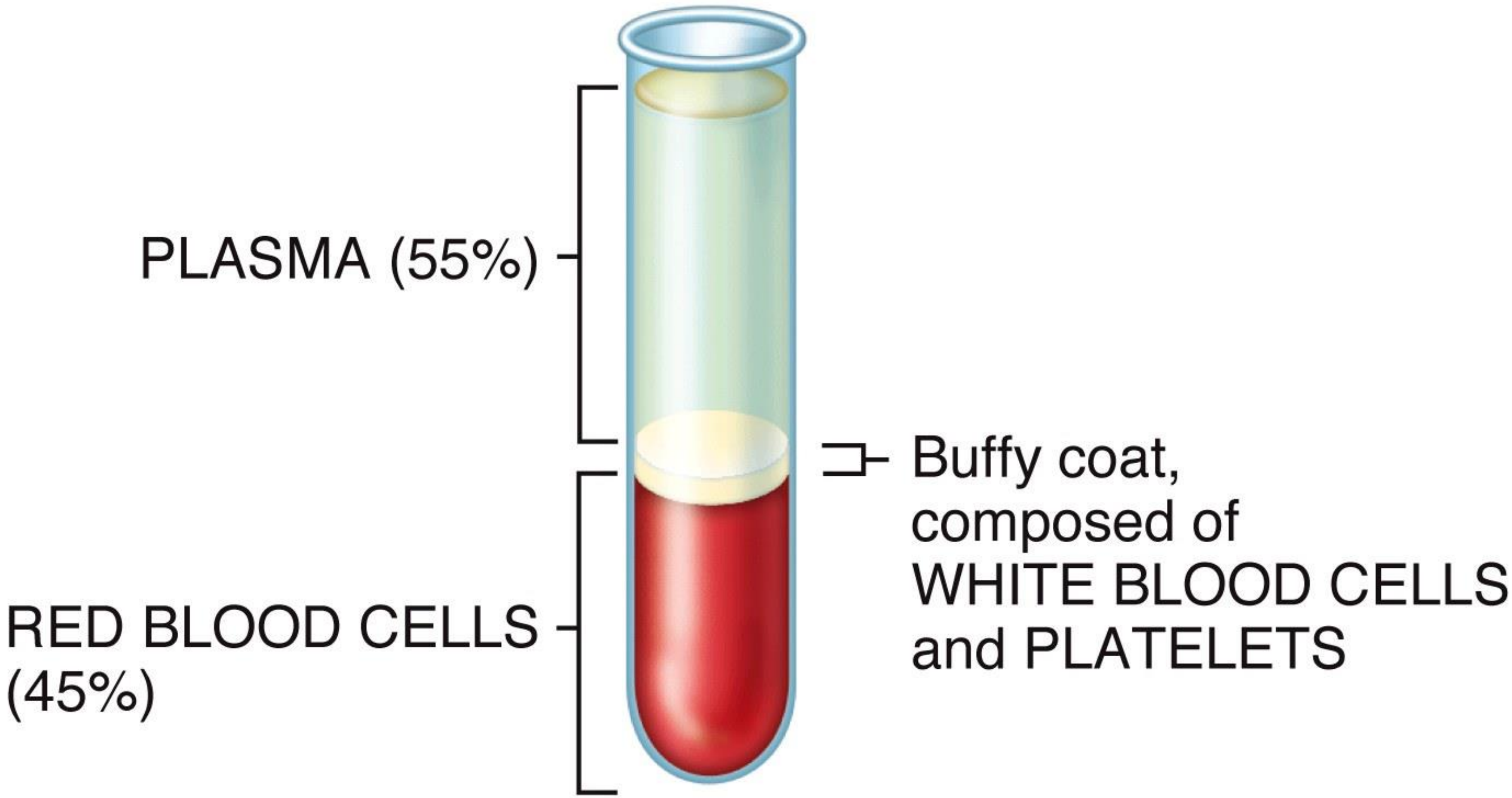
Functions of Blood

- Transports oxygen, carbon dioxide, nutrients, hormones, heat, and metabolic wastes
- Helps regulate pH, body temperature, and water content of cells
- Protects through clotting and by combating toxins and microbes through certain phagocytic white blood cells or specialized blood plasma proteins

Physical Characteristics of Blood

- More viscous and denser than water
- Slightly alkaline (pH 7.35 – 7.45)
- Temperature slightly higher (+1° C) than oral or rectal body temperature
- Average volume 5-6 liters male and 4-5 liters female
- About 8% of total body weight
- Whole blood is composed of plasma with dissolved solutes (55%) and formed elements (45%)

Physical Characteristics of Blood



(a) Appearance of centrifuged blood

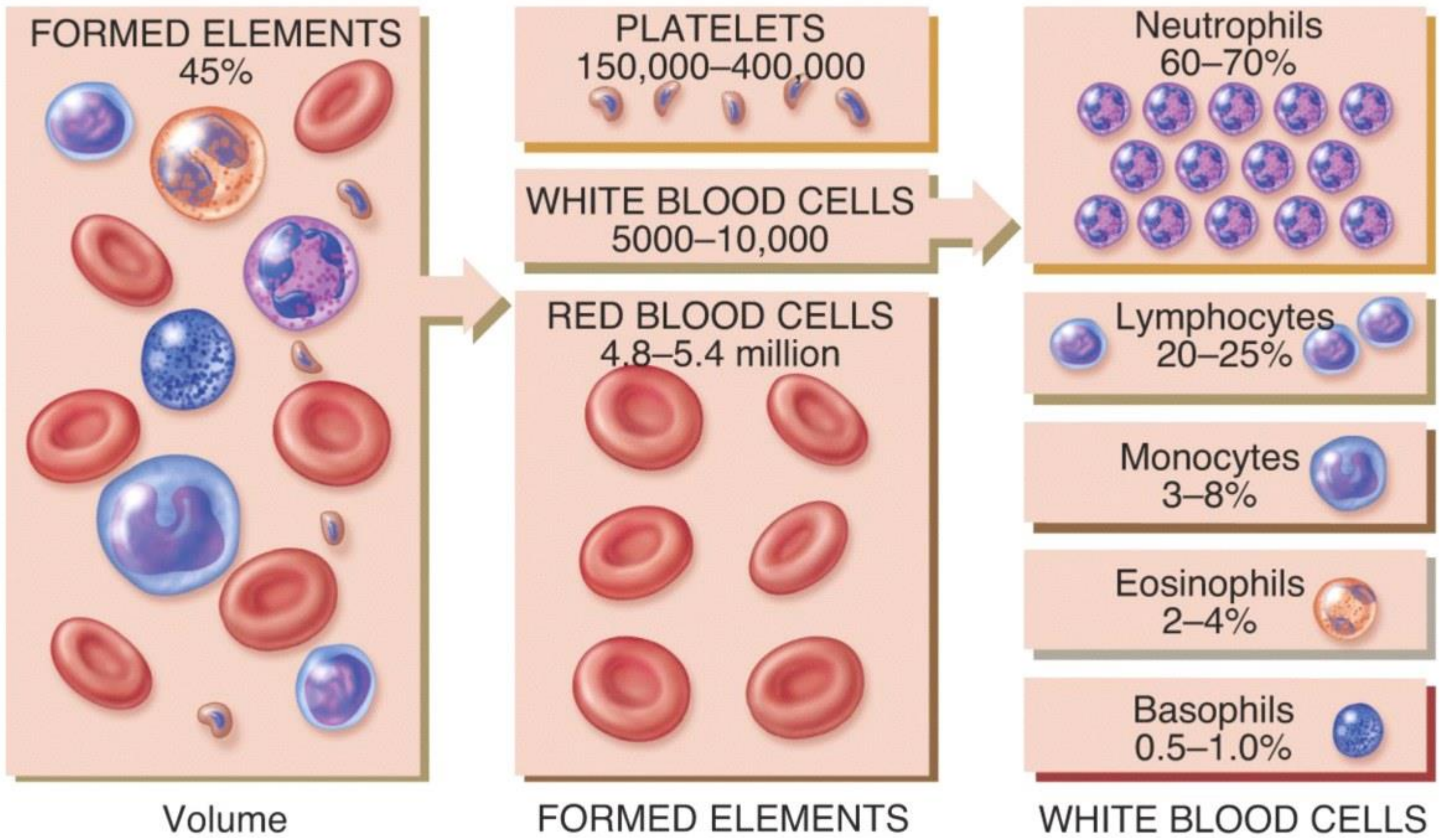
Components of Blood: Plasma

- 91.5% water and 8.5% solutes
- Plasma proteins mainly from liver cells (7%)
  - Albumins: 54%; maintain blood osmotic pressure
  - Globulins: 38%; includes antibodies for immunity
  - Fibrinogen: 7%; key for blood clotting
- Other solutes (1.5%)
  - Electrolytes
  - Nutrients
  - Gases
  - Regulatory enzymes, hormones, and vitamins
  - Waste products

Components of Blood: Formed Elements

- Red blood cells (RBCs; 99%)
- White blood cells (WBCs; less than 1%)
  - Neutrophils
  - Lymphocytes
  - Monocytes
  - Eosinophils
  - Basophils
- Platelets – cell fragments

Components of Blood: Formed Elements

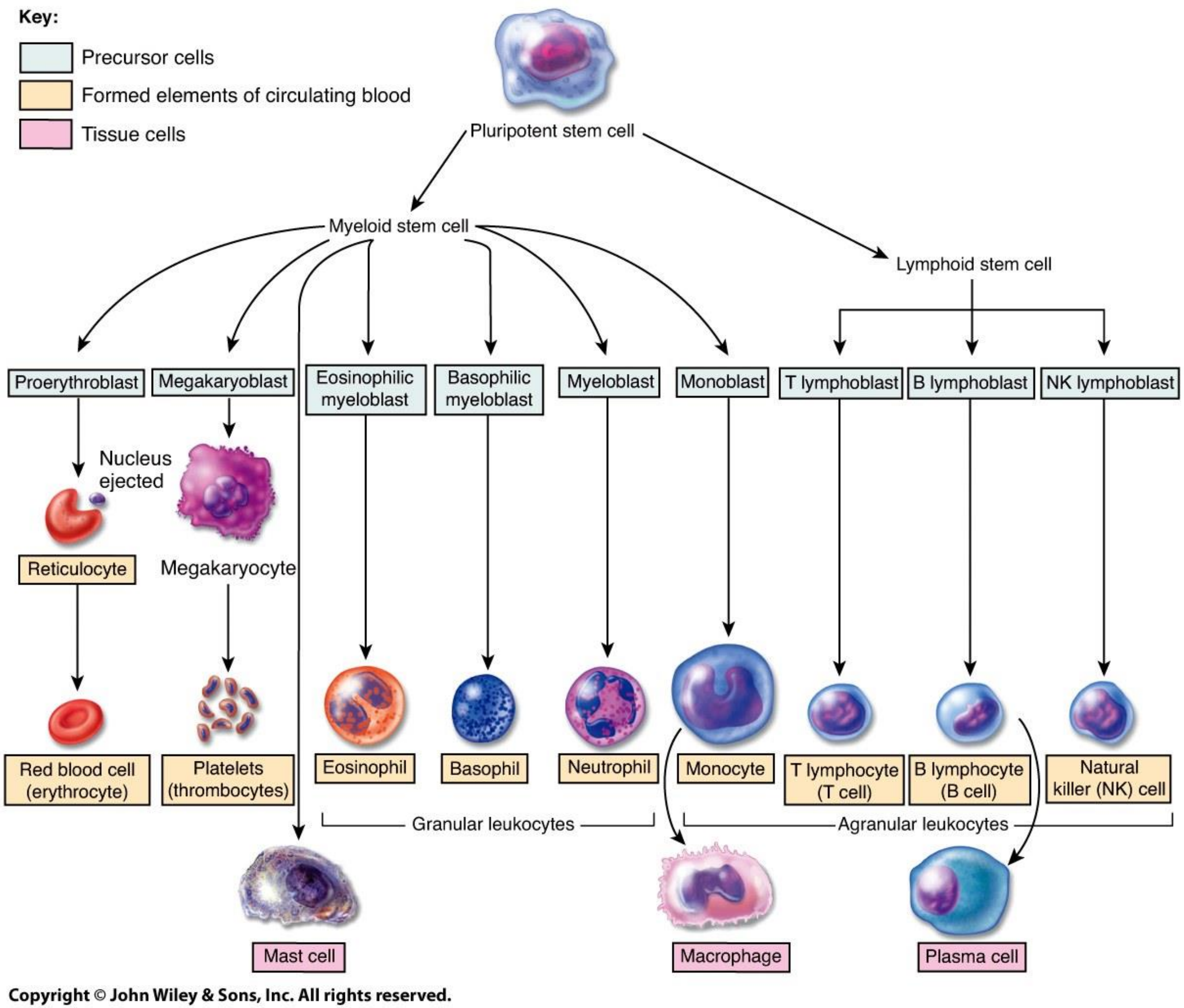


(b) Components of blood

Hemopoiesis

- Formation of blood cells from hemopoietic stem cells in red bone marrow controlled by hormones
  - Erythropoietin, thrombopoietin, cytokines, and other hemopoietic growth factors
- Pluripotent stem cells give rise to two kinds of stem cells
  - Myeloid stem cells – differentiate into precursor cells (blasts) for RBCs, platelets, three kinds of granulocytes, and monocytes
  - Lymphoid stem cells – differentiate into precursor cells (lymphoblasts) for two kinds of lymphocytes in red bone marrow, then complete development in lymphatic tissues

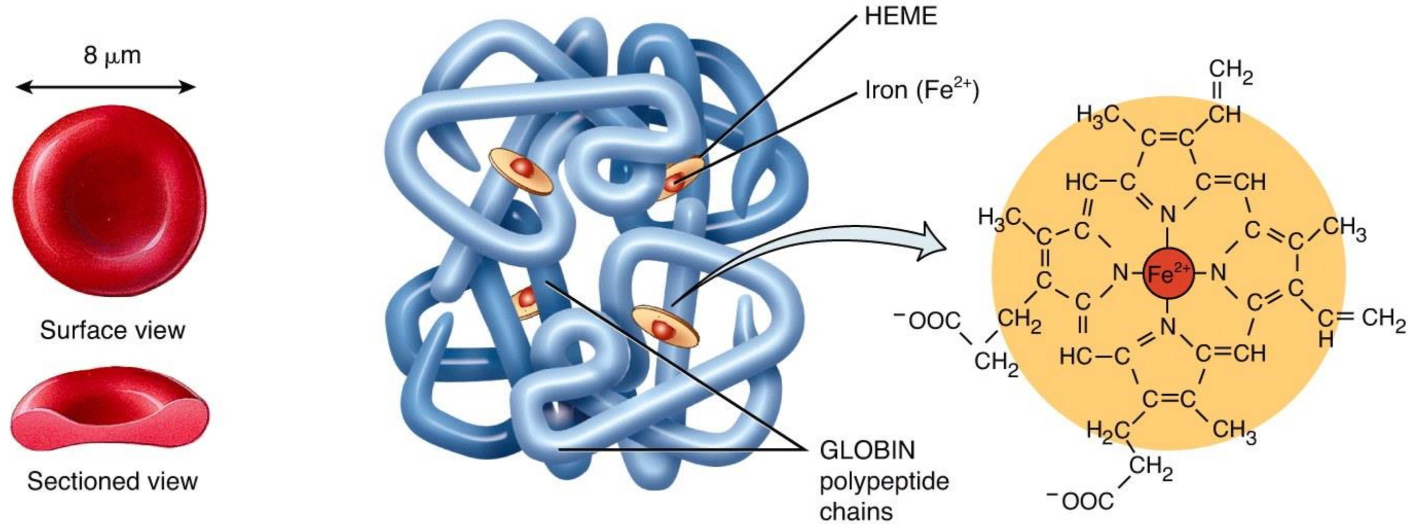
Hemopoiesis



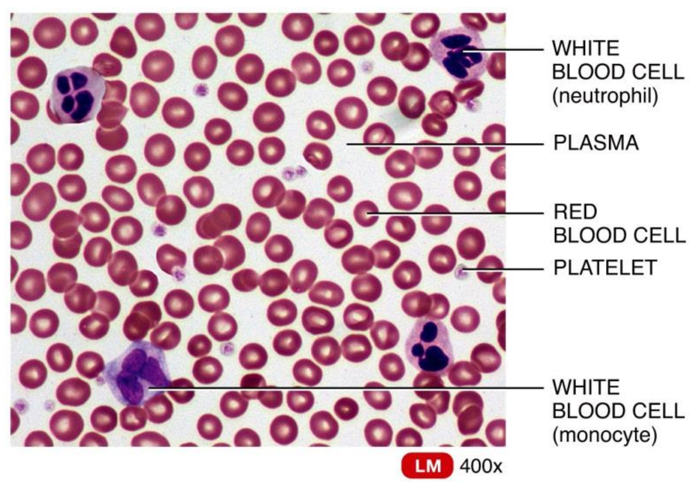
Erythrocytes (RBCs)

- Mature cells are biconcave discs that lack nuclei and other major organelles, so cannot undergo mitosis or extensive metabolic activities
- Contain oxygen-carrying hemoglobin
  - Gives RBCs their red color
  - Globin part of molecule is four polypeptide chain protein that can bind and transport carbon dioxide
  - Heme part of molecule is ring-like nonprotein pigment with iron that binds to oxygen
- Produced and enter circulation at same rate destroyed (about 2 million per second)

Erythrocytes (RBCs)



(a) Erythrocyte shape (b) Hemoglobin molecule (c) Iron-containing heme



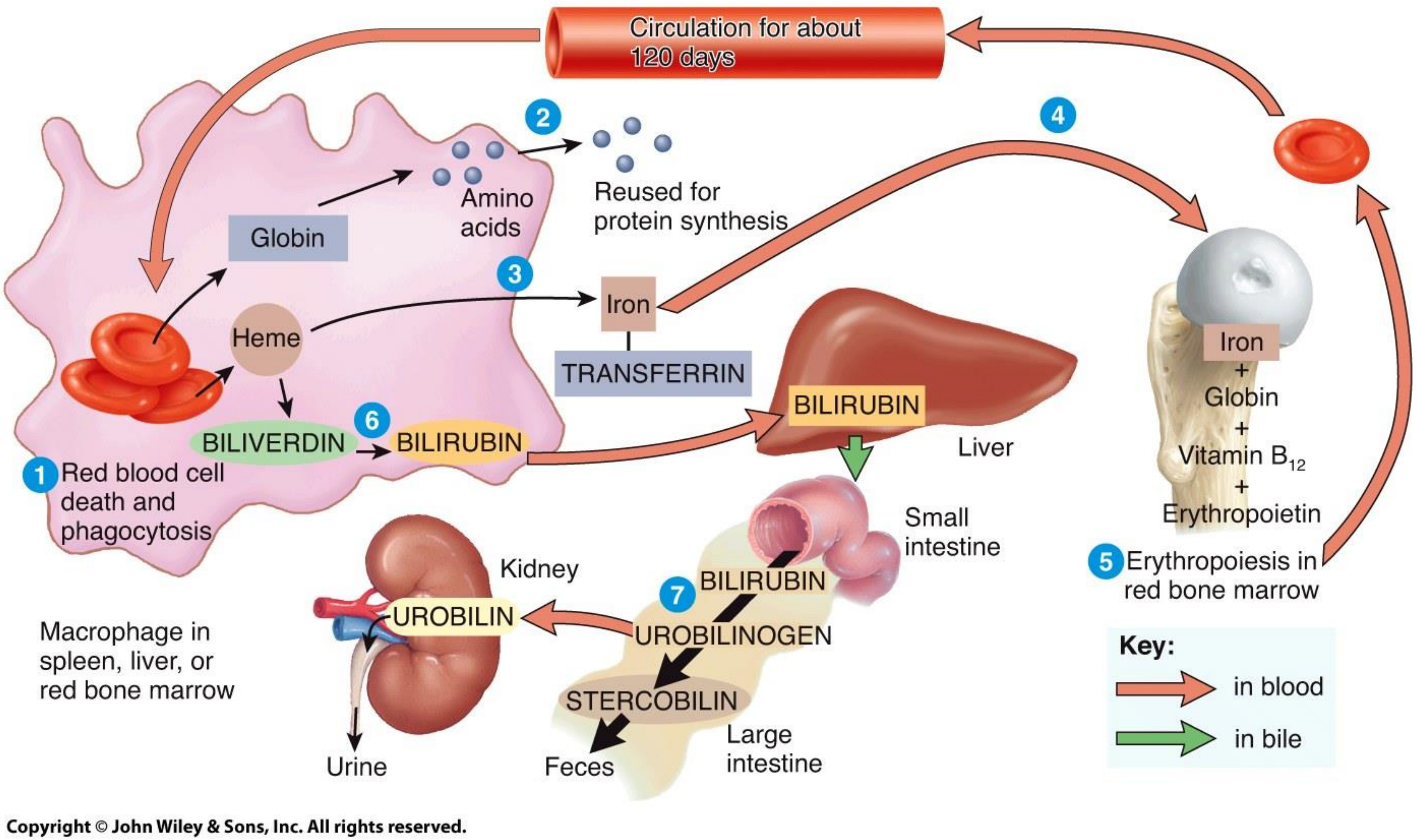
(b) Blood smear (thin film of blood spread on glass slide)

Mark Nielsen

Life Cycle of Erythrocytes (RBCs)

- Live only about 120 days
  - Fragile, old, or damaged RBCs destroyed by phagocytic macrophages in spleen and liver
- Hemoglobin is broken down and recycled
  - Amino acids from globin are used to make proteins
  - Iron from heme is transported by transferrin to red bone marrow to be used to synthesize hemoglobin for new RBCs
  - Non-iron portion of heme is eventually converted to bilirubin and secreted into bile that passes into the intestines

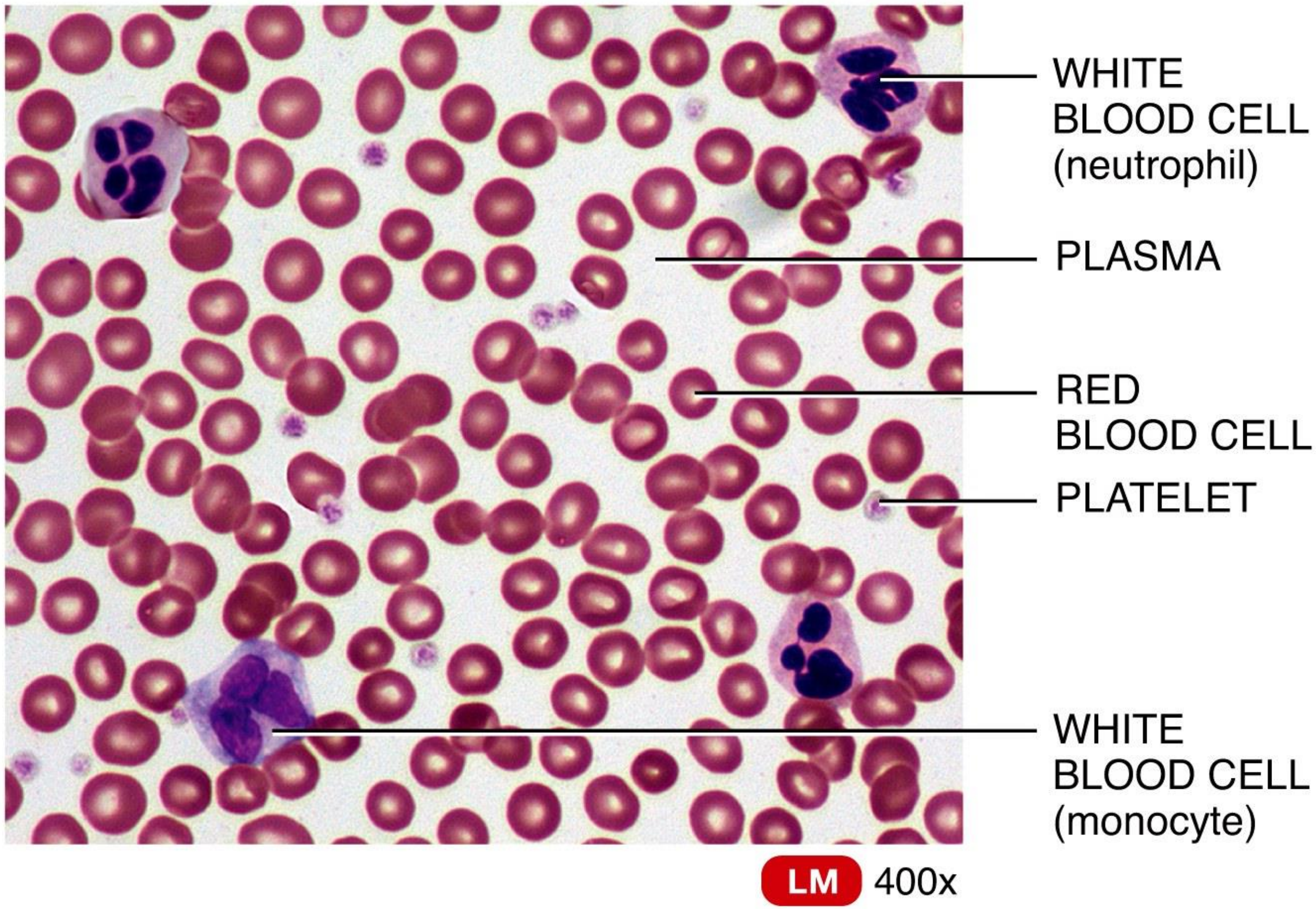
Life Cycle of Erythrocytes (RBCs)



Leukocytes (WBCs)

- Have a nucleus
- Lack hemoglobin
- Classified based on presence or absence of visible cytoplasmic granules (vesicles)
  - Granulocytes – differential staining visible in light microscope
    - Neutrophil (also called polymorphonuclear leukocytes PMNs)
    - Eosinophil
    - Basophil
  - Agranulocytes – granules present, but small and don’t stain, so not visible under light microscope
    - Lymphocyte
    - Monocyte

Leukocytes (WBCs)



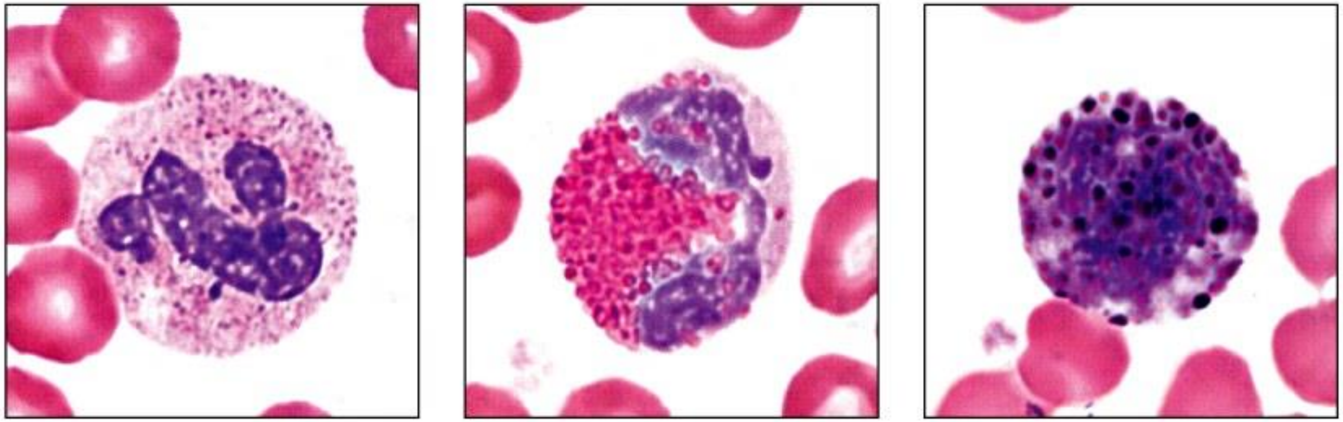
(b) Blood smear (thin film of blood spread on glass slide)

Mark Nielsen

Granulocytes

- Neutrophil
  - Phagocytosis of pathogens
  - Destroy with lysozyme, oxidants, and defensins
- Eosinophil
  - Stop the effect of histamine and other inflammation mediators in allergic reactions
  - Also attack parasitic worms and antigen-antibody complexes
- Basophil
  - Release heparin, histamine, and serotonin to intensify the inflammatory response
  - Involved in hypersensitivity of allergic reactions

Granulocytes



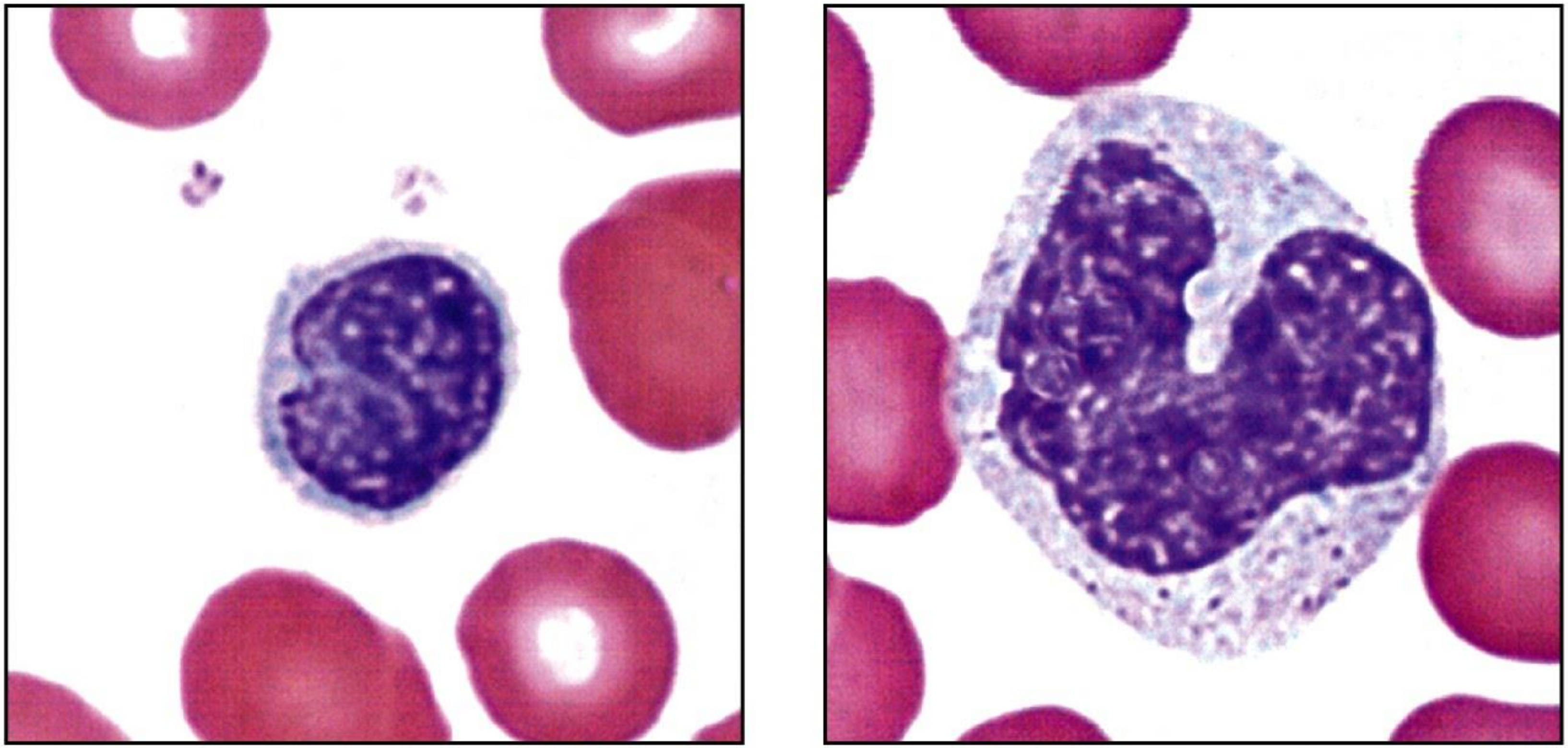
(a) Neutrophil (b) Eosinophil (c) Basophil

Courtesy Michael Ross, University of Florida

Agranulocytes

- Lymphocyte
  - Function in immune responses
    - B cells produce antibodies, effective on bacteria
    - T cells combat viruses, fungi, transplanted cells, cancer cells and some bacteria
  - Continually recirculate from blood to interstitial fluid and lymph, and back
- Monocyte
  - Migrate into tissues, enlarge and differentiate into macrophages – fixed or wandering
  - Phagocytosis of microbes, with many lysosomes
  - Also clean up cellular debris

Agranulocytes

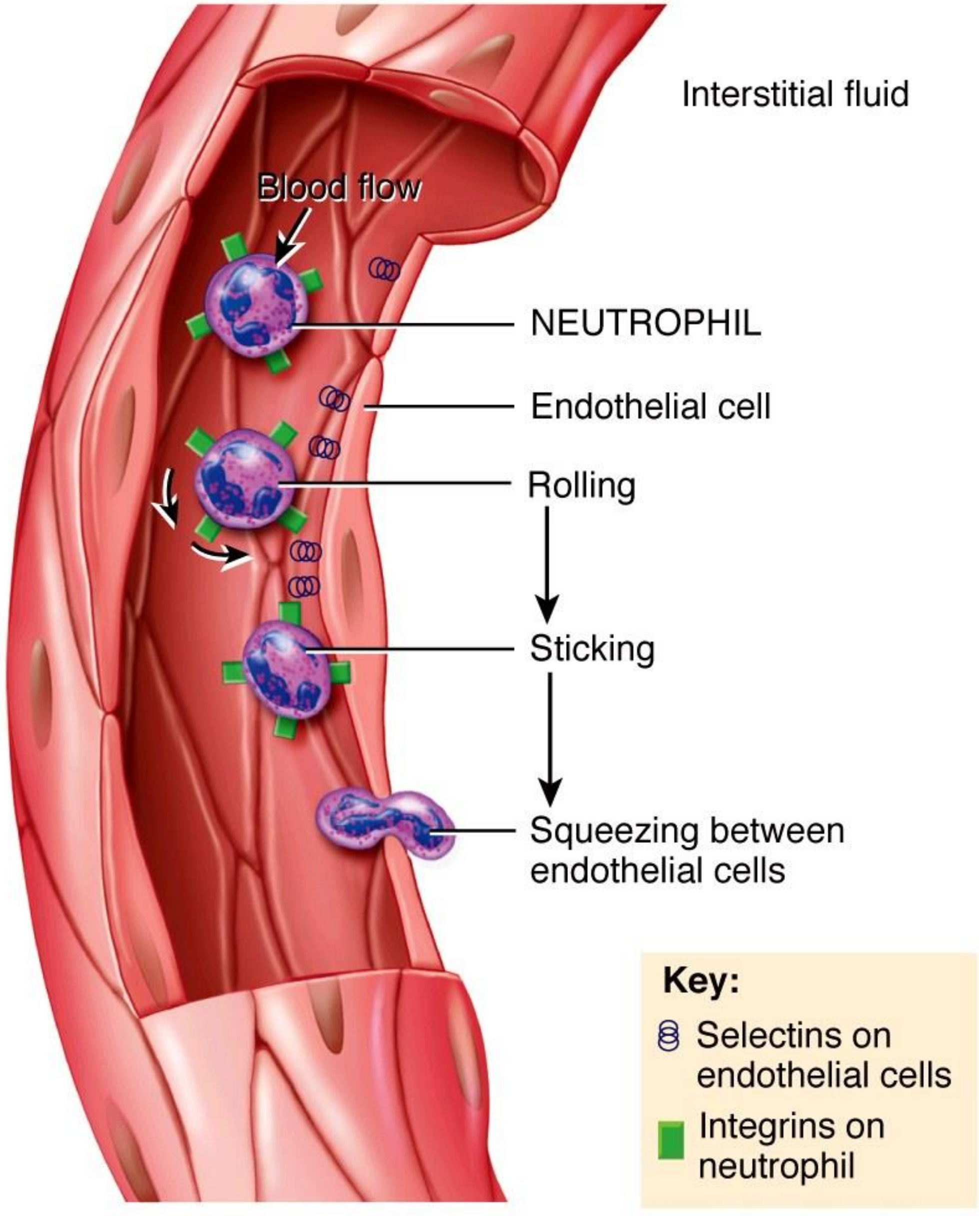


Courtesy Michael Ross, University of Florida

Leukocyte (WBC) Function

- Unlike RBCs, WBCs able to leave bloodstream by emigration or diapedesis
  - Adhesion molecules slow down select WBC with receptors to assist movement through capillary wall
  - Except for lymphocytes, once leave blood vessel do not return to blood vessel
- Chemotaxis
  - Pathogens and inflamed tissue release chemicals that attract phagocytic cells
  - Neutrophils respond most rapidly to infection site, and monocytes arrive later but in large numbers

Leukocyte (WBC) Function



Leukocyte (WBC) Life Cycle

- Most live only a few days
  - During infection, some live only a few hours
  - Some lymphocytes (B and T cells) can live for several months or years
- Differential white blood cell count
  - Measures number of each type of WBC in a sample of 100 WBCs
  - Because each type of WBC plays a different role in immune response, determining percentage of each type in the blood at a particular time can assist in diagnosing the condition

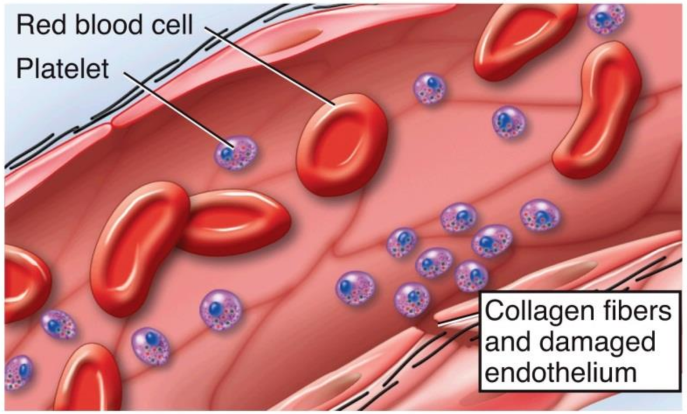
Platelets (Thrombocytes)

- Disc shaped cell fragments that lack a nucleus
- Develop from megakaryoblasts under influence of hormone thrombopoietin
- Stop blood loss in damaged vessels
  - Form a platelet plug in the vessel wall
  - Release chemicals that promote blood clotting
- Life span of 5 to 9 days
- Aged and dead platelets removed by fixed macrophages in spleen and liver

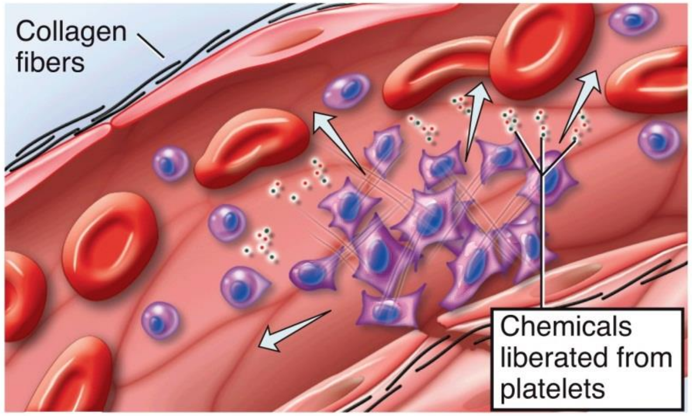
Hemostasis

- Sequence of responses to stop blood loss from a damaged blood vessel
- Quick, localized to region of damage, and carefully controlled by positive feedback
- Three mechanisms
  - Vascular spasm
  - Platelet plug formation
  - Blood clotting

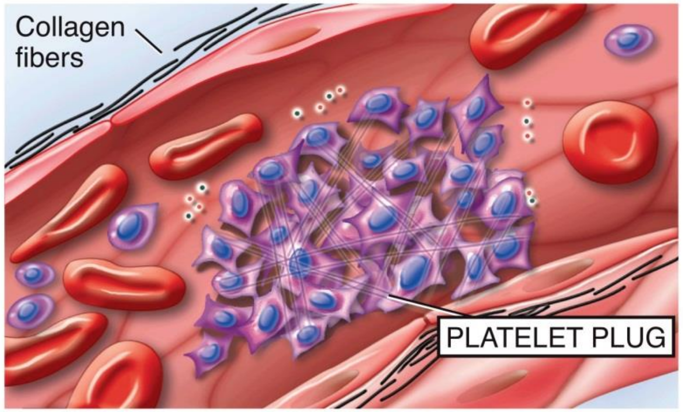
Vascular Spasm and Platelet Plug Formation



1 Platelet adhesion



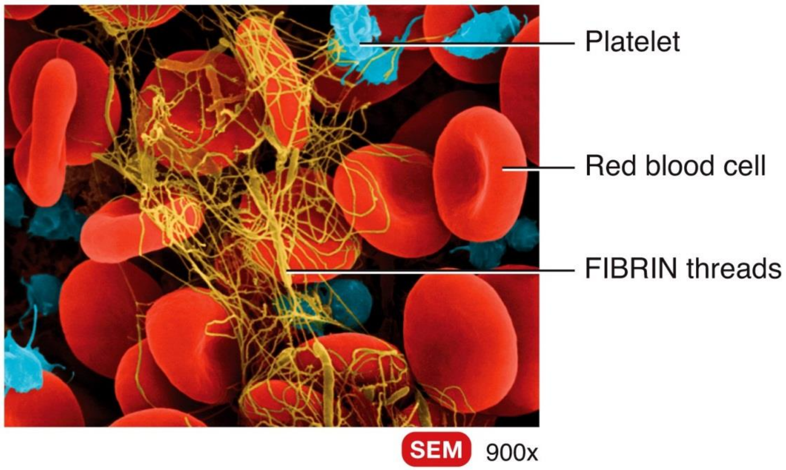
2 Platelet release reaction



3 Platelet aggregation

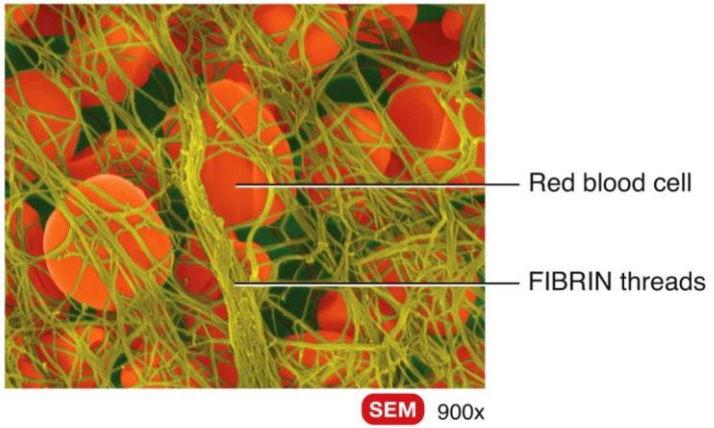
Blood Clotting (Coagulation)

- Clot is a thickened gel of blood with a network of insoluble protein fibers that trap formed elements
- Cascade of reactions involving calcium ions and clotting factors that activate one another
- Clot retraction pulls blood vessel edges together



(a) Early stage

Dennis Kunkel Microscopy, Inc./Phototake



(b) Last stage showing red blood cells trapped in fibrin threads

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Lesson 2: Blood Typing

Objective:

- Explain the significance of AB and Rh blood groups in blood transfusions

Blood Groups and Types

- Based on genetically determined cell surface protein antigens called agglutinogens
- Plasma typically contains antibodies called agglutinins, which react with antigens not on RBC surface
- Blood groups based on presence or absence of antigen, including ABO and Rh groups, but also several others
- With each group, two or more different blood types

Blood Groups and Types

TABLE 18.2

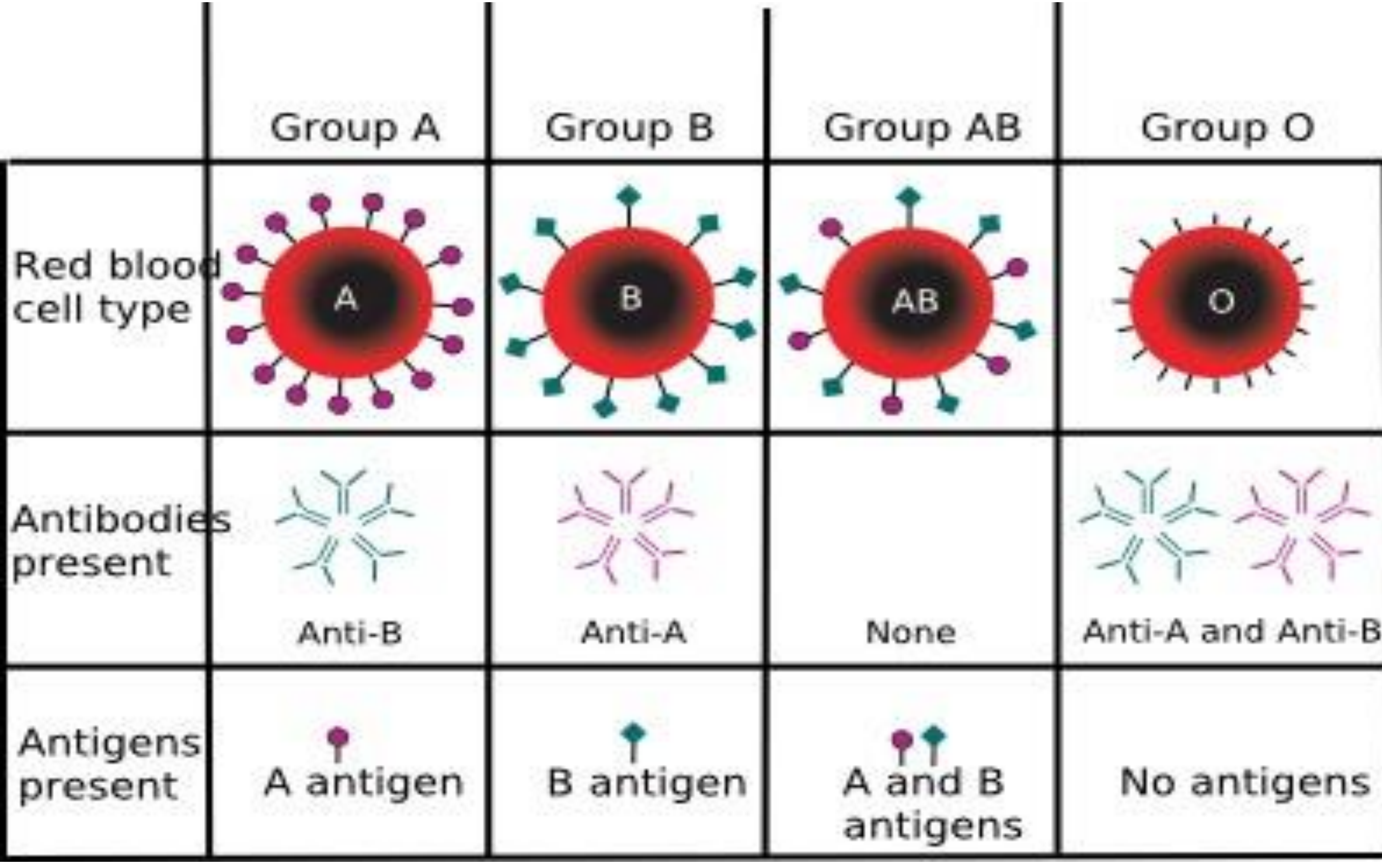
Blood Types in the United States

POPULATION GROUP	BLOOD TYPE (PERCENTAGE)				
	O	A	B	AB	RH^+
European-American	45	40	11	4	85
African-American	49	27	20	4	95
Korean-American	32	28	30	10	100
Japanese-American	31	38	21	10	100
Chinese-American	42	27	25	6	100
Native American	79	16	4	1	100

ABO Blood Group

- Based on presence or absence of antigen A and antigen B
- Plasma contains antibodies to antigen not found on cells
- Blood types
  - Type A blood – antigen A; anti-B antibodies
  - Type B blood –antigen B; anti-A antibodies
  - Type AB blood – both antigen A and antigen B; no antibodies
  - Type O blood – neither antigen; both anti-A and anti-B antibodies

ABO Blood Group



Blood Transfusions

- Incompatible when the recipient's antibodies (agglutinins in plasma) bind to antigens on the donated blood's RBCs, which causes agglutination (clumping) and hemolysis (RBC rupture)
  - Universal recipients – Type AB: in theory can receive blood from donors of all 4 blood types because they have no antibodies to attack the donated RBCs
  - Universal donor – Type O: in theory can donate blood to all 4 blood types because no antigens on RBCs to trigger transfusion reaction
- To avoid mismatches, recipient's blood is typed, then cross-matched to potential donor

Blood Groups

- **Type AB: (Universal Recipient)**
  - RBC’s have both A and B antigens.
  - Cen receive from A, B, AB, and O types.
  - Can donate to AB type only.

- **Type O: (Universal Donor)**
  - RBC’s have NO antigens.
  - Can receive from O type only.
  - Can donate to A, B, AB and O types.

- **Type A:**
  - RBC’s have A antigens only.
  - Can receive from A and O types.
  - Can donate to A and AB types.

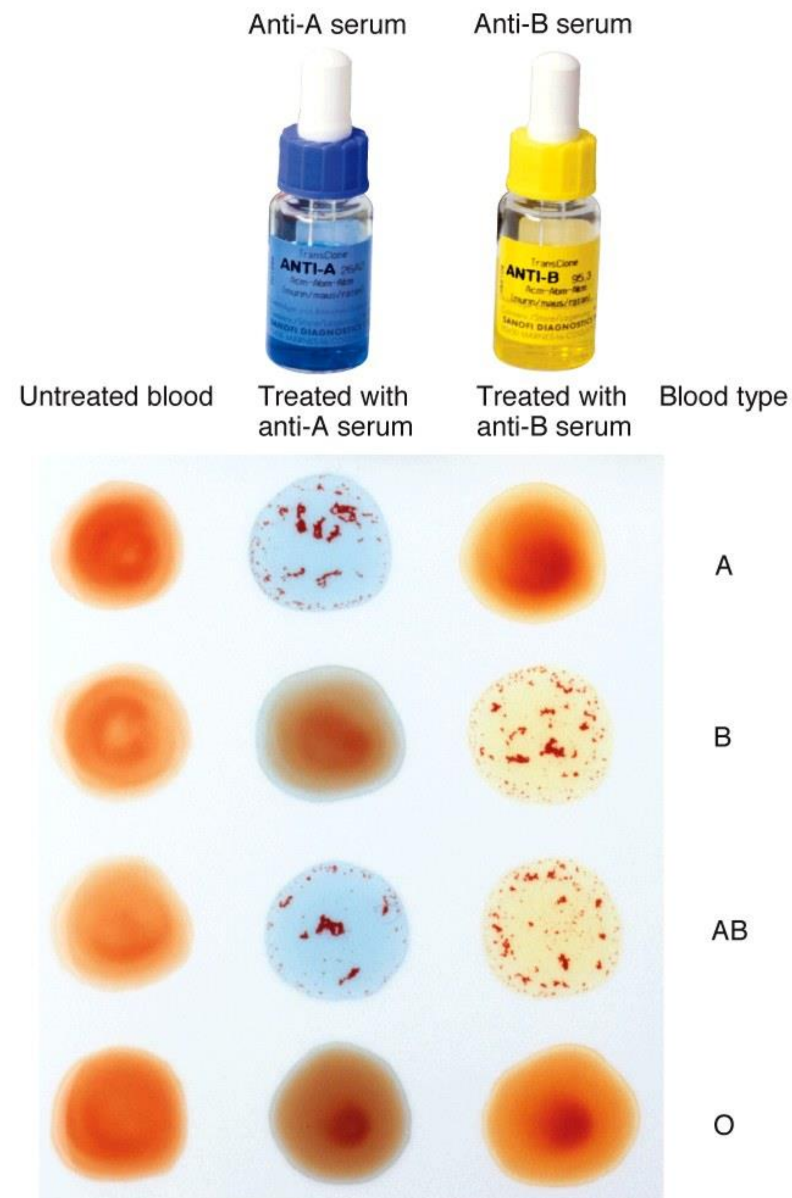
- **Type B:**
  - RBC’s have B antigens only.
  - Can receive from B and O types.
  - Can donate to B and AB types.

Blood Transfusions

TABLE 18.3

ABO Blood Group Interactions

CHARACTERISTIC	BLOOD TYPE A	BLOOD TYPE B	BLOOD TYPE AB	BLOOD TYPE O
Antigen (agglutinogen) on RBC	A	B	Both A and B	Neither A nor B
Antibody (agglutinin) in plasma	Anti-B	Anti-A	Neither anti-A nor anti-B	Both anti-A and anti-B
Compatible donor blood types (no hemolysis)	A, O	B, O	A, B, AB, O	O
Incompatible donor blood types (hemolysis)	B, AB	A, AB	–	A, B, AB



Jean Claude Revy/Phototake

Rh Blood Group

- Based on the presence (+) or absence (-) of the Rh antigen, first discovered in the *Rhesus* monkey
- Blood Types
  - Type Rh+ blood - has antigen
  - Type Rh- blood – no antigen; only produce anti-Rh antibodies in plasma if exposed to Rh+ antigen, such as during incompatible blood transfusion, sharing hypodermic needles, or when a pregnant Rh- woman is carrying an Rh+ fetus (hemolytic disease of the newborn)

Lesson 3: Structure of the Heart

Objective:

- Identify and describe the interior and exterior parts of the human heart
- Relate the structure of the heart to its function as a pump
- Compare systemic circulation to pulmonary circulation
- Identify the veins and arteries of the coronary circulation system
- Trace the pathway of oxygenated and deoxygenated blood thorough the chambers of the heart

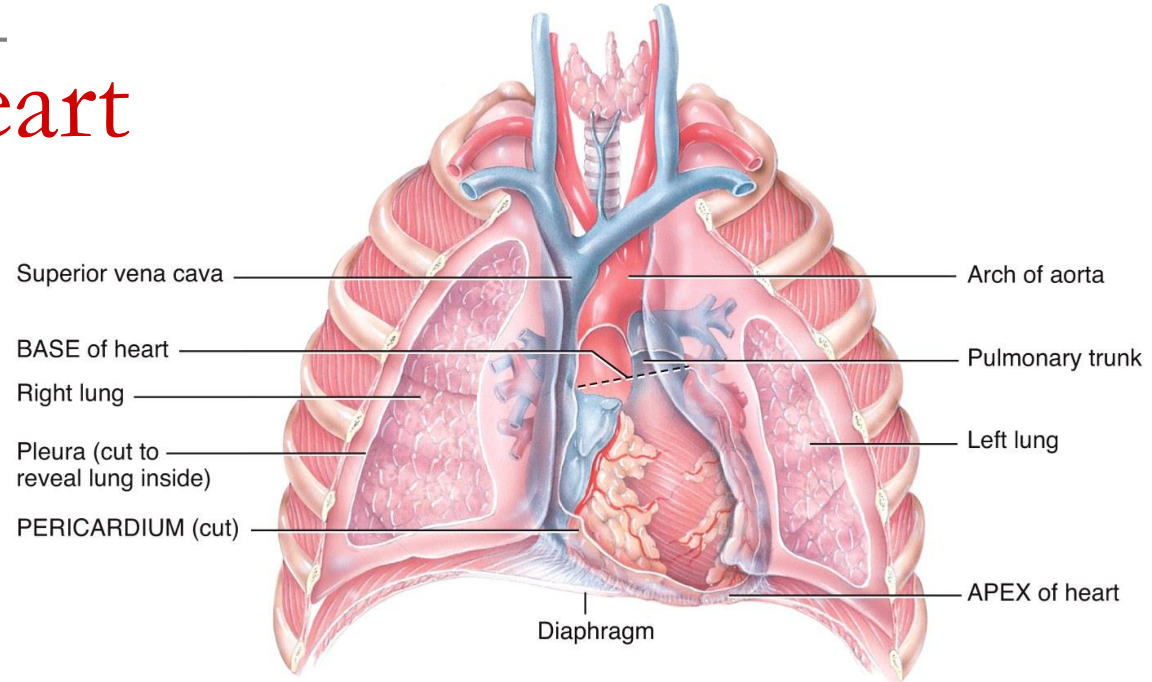
Introduction

- For blood to reach body cells and exchange materials with them, it must constantly be pumped by the heart through the body’s blood vessels
- The heart is a double pump
  - The left side pumps blood through miles of blood vessels in body
  - The right side pumps blood through the lungs, so it can pick up oxygen and unload carbon dioxide

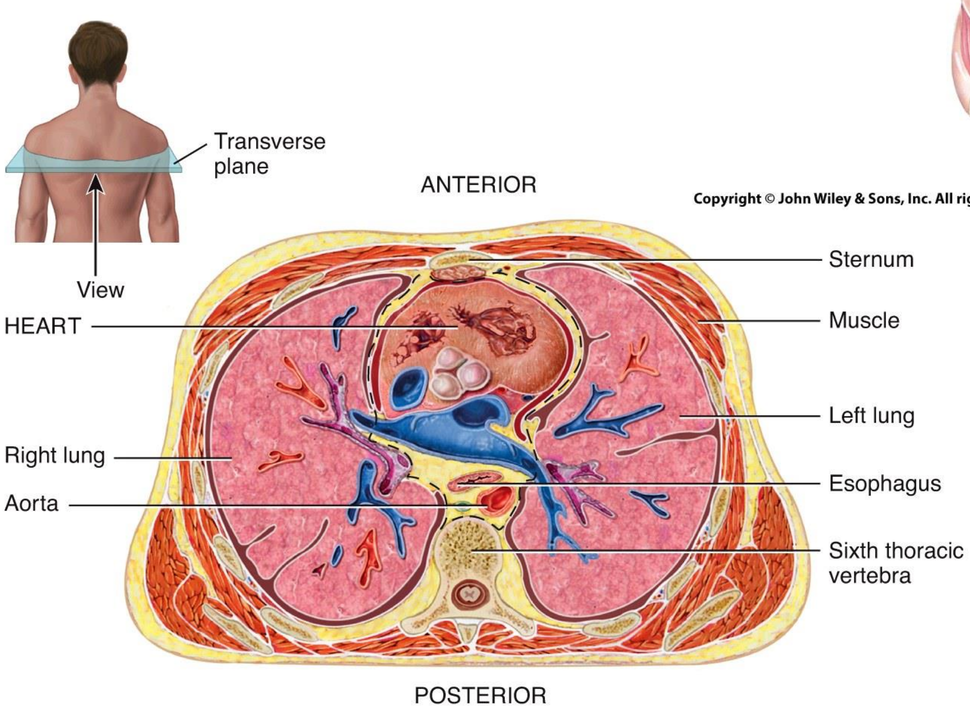
Location of Heart

- Mediastinum of thoracic cavity
  - Anatomical region between the lungs that extends from the sternum to the vertebral column
- Situated obliquely
  - Apex (pointed end) directed inferiorly to the left
  - Base positioned superiorly to the right

Location of Heart



(b) Anterior view of heart in thoracic cavity

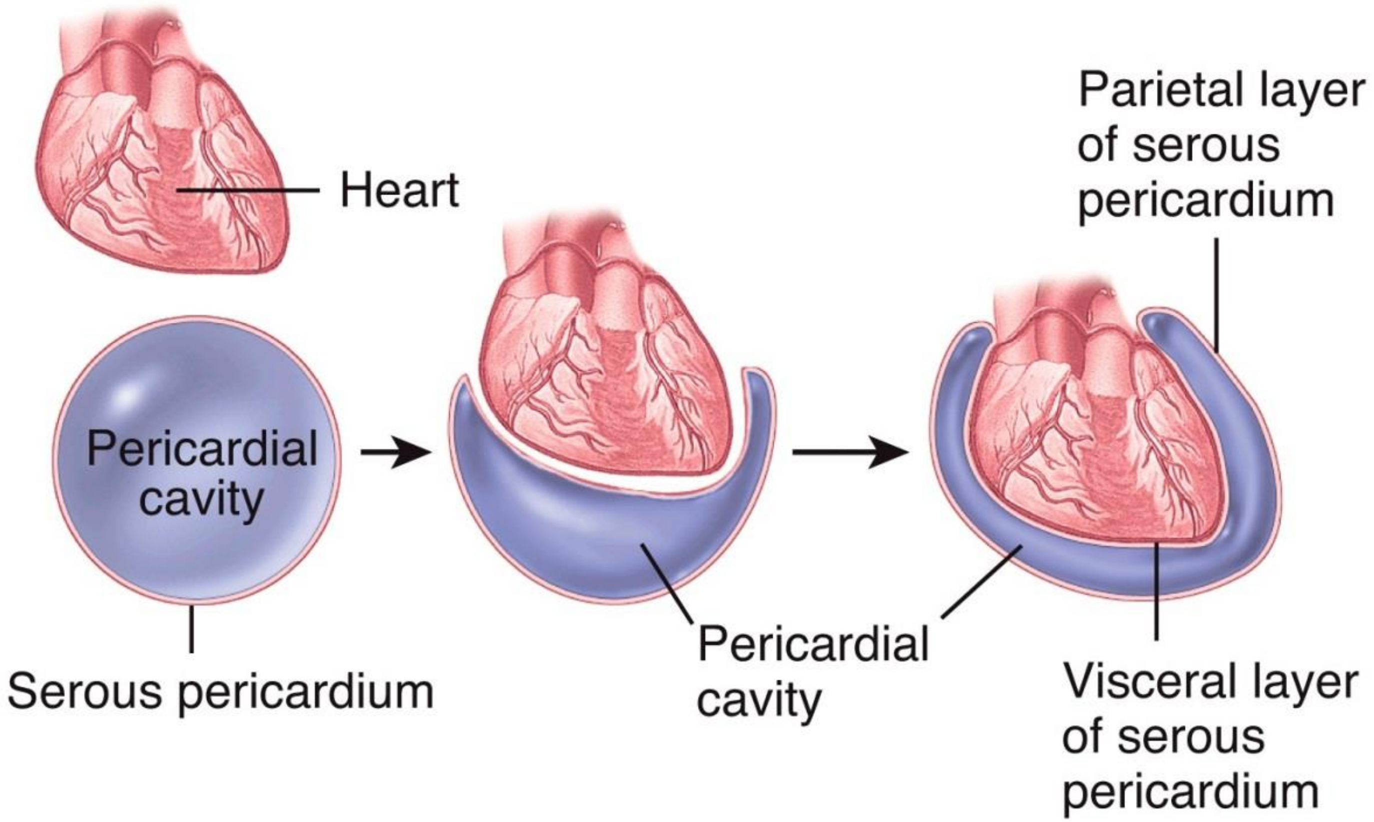


(a) Inferior view of transverse section of thoracic cavity showing heart in mediastinum

Pericardium

- Protective membrane structure that surrounds the heart
- Two principal parts
  - Fibrous pericardium – tough, dense irregular connective tissue, prevents overstretching and anchors heart in mediastinum
  - Serous pericardium – delicate, double layer serous membranes with serous fluid in thin cavity between membranes

Pericardium

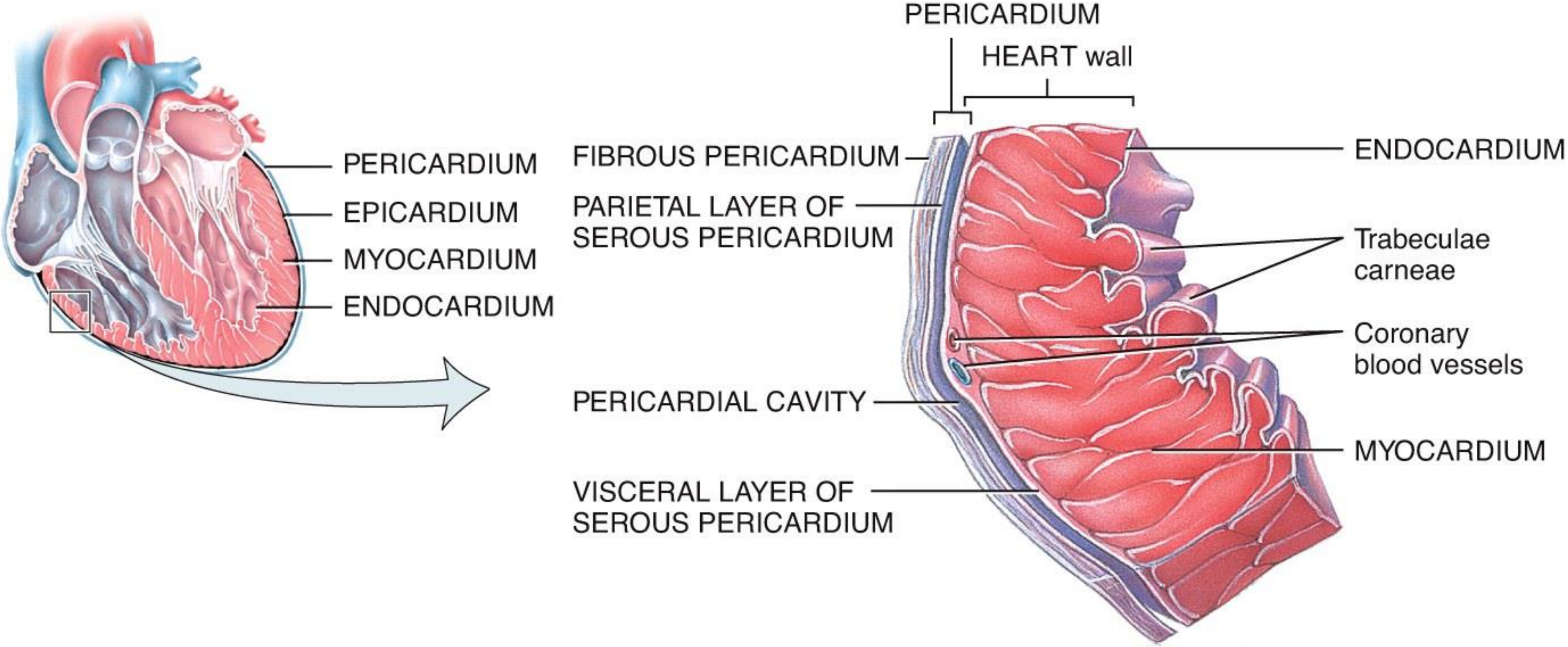


(b) Simplified relationship of serous pericardium to heart

Layers of Heart Wall

- Epicardium
  - Superficial, visceral layer of the pericardium
  - Contains blood and lymphatic vessels that supply the heart muscle
- Myocardium
  - Middle, cardiac muscle tissue layer
  - Involuntary cardiac muscle fibers organized in bundles that swirl diagonally around the heart
- Endocardium
  - Endothelium layer overlying connective tissue
  - Lines heart chambers, heart valves
  - Continuous with endothelia lining blood vessels

Layers of Heart Wall

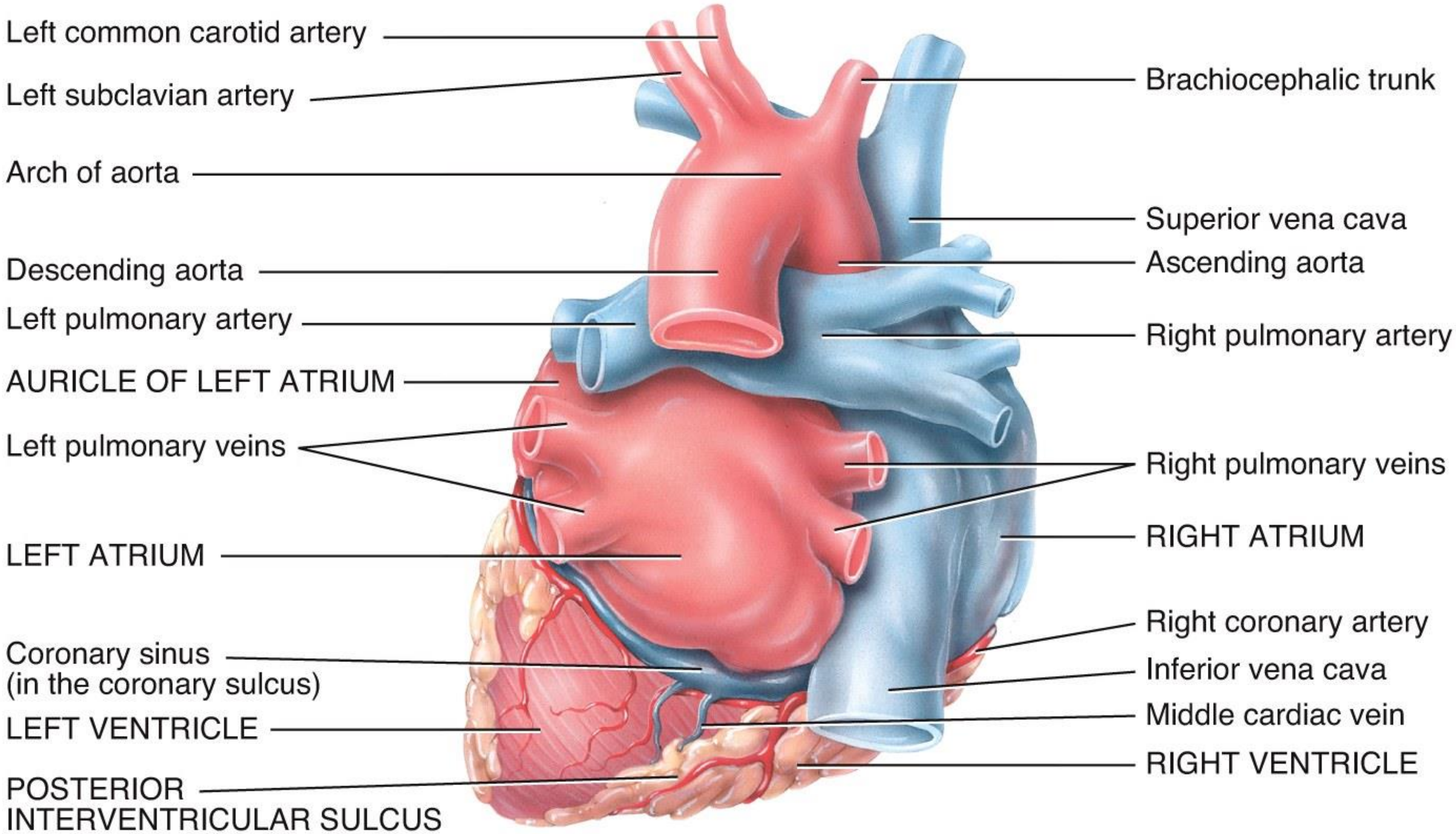


(a) Portion of pericardium and right ventricular heart wall showing divisions of pericardium and layers of heart wall

Heart Chambers

- Two atria
  - Upper chambers receive blood from veins
  - Pouchlike auricle on anterior surface increases blood volume capacity
- Two ventricles
  - Lower chambers pump blood into arteries
- Sulci – surface grooves containing blood vessels and fat
  - Coronary sulcus
  - Anterior interventricular sulcus
  - Posterior interventricular sulcus

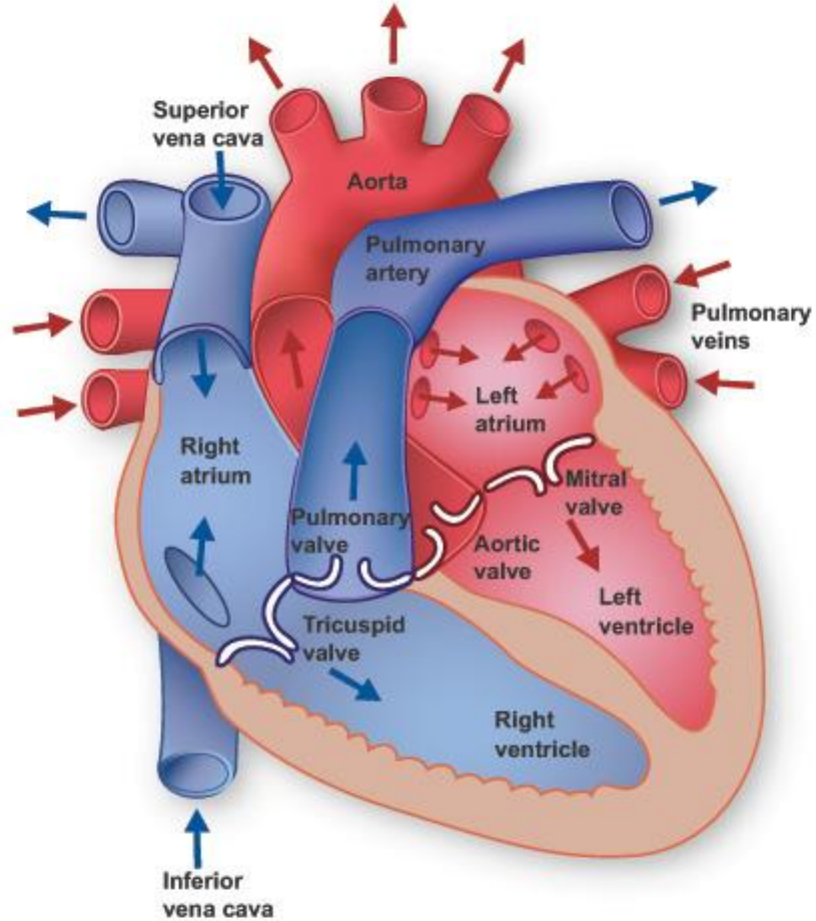
Heart Chambers



(c) Posterior external view showing surface features

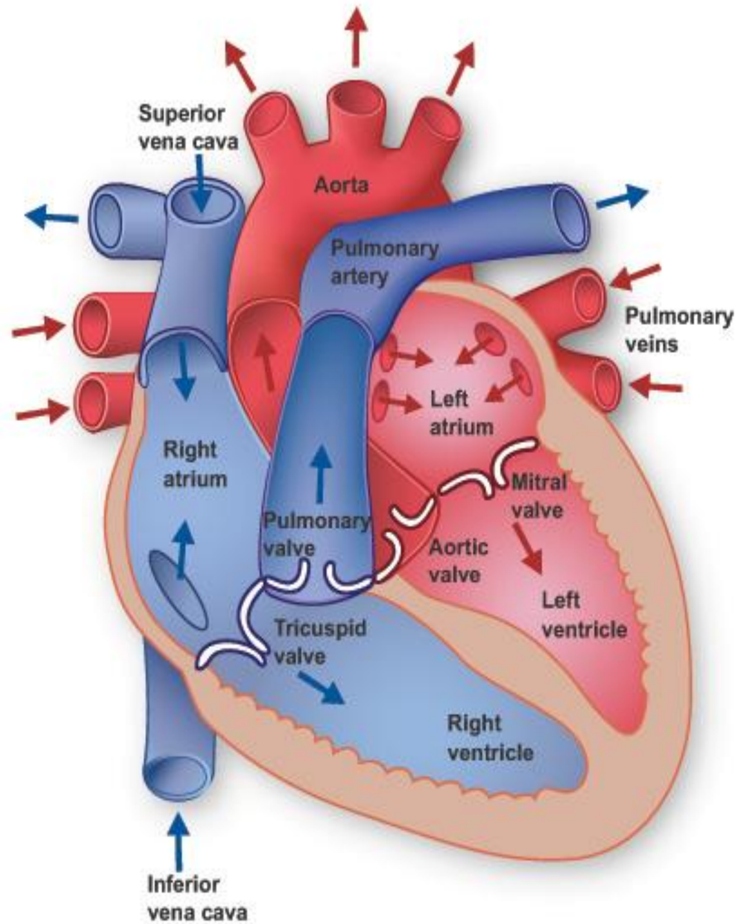
Right Atrium

- Receives blood from
  - Superior vena cava
  - Inferior vena cava
  - Coronary sinus
- Separated internally from left atrium by interatrial septum
- Blood passes through the tricuspid valve (right atrioventricular valve) into right ventricle



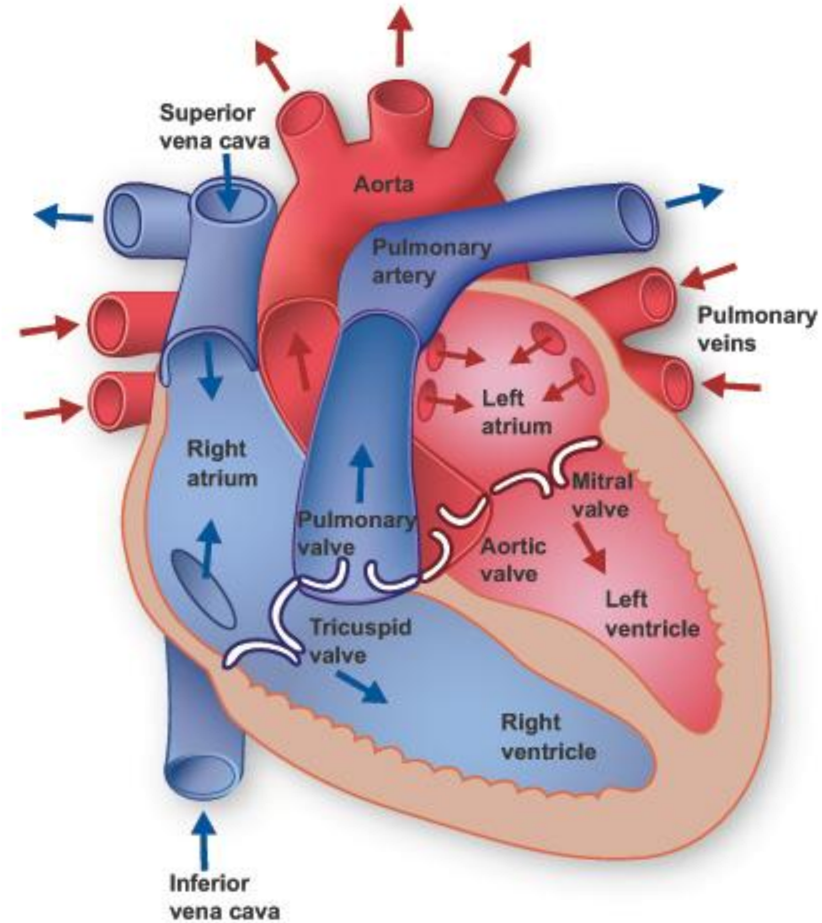
Right Ventricle

- Receives blood from the right atrium
- Separated internally from the left ventricle by interventricular septum
- Pumps blood through the pulmonary valve (semi-lunar valve) into the pulmonary trunk that carries blood to the lungs



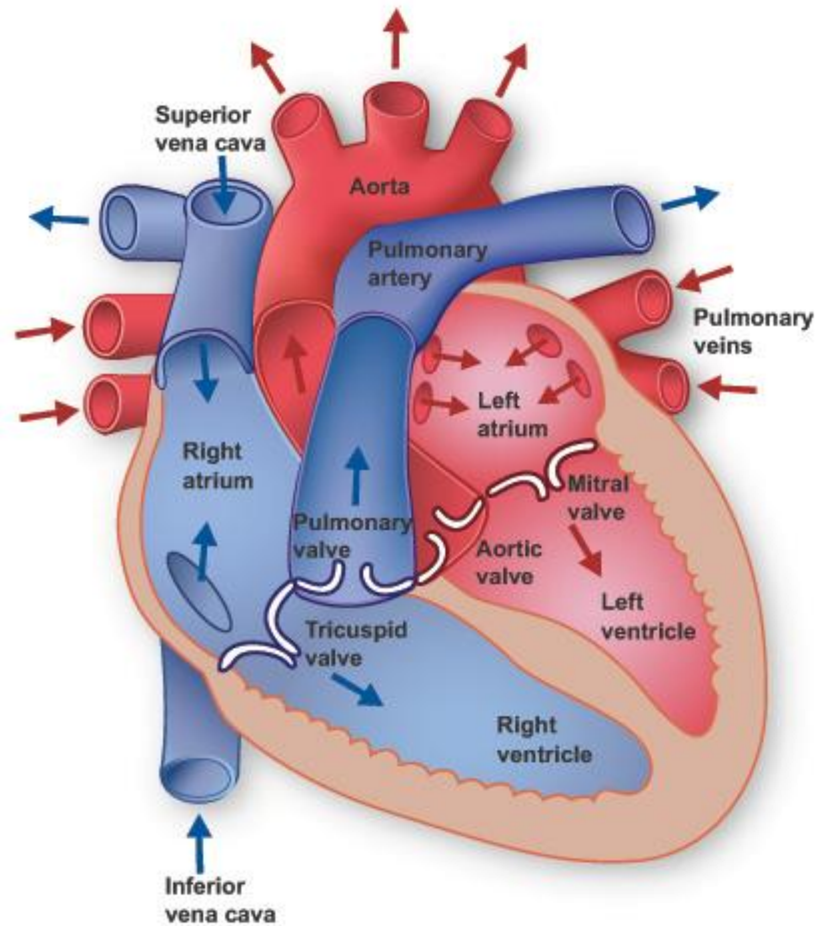
Left Atrium

- Receives blood from four pulmonary veins
- Other side of interatrial septum and same arrangement of pectinate muscles
- Blood passes through the bicuspid or mitral valve (left atrioventricular valve) into the left ventricle



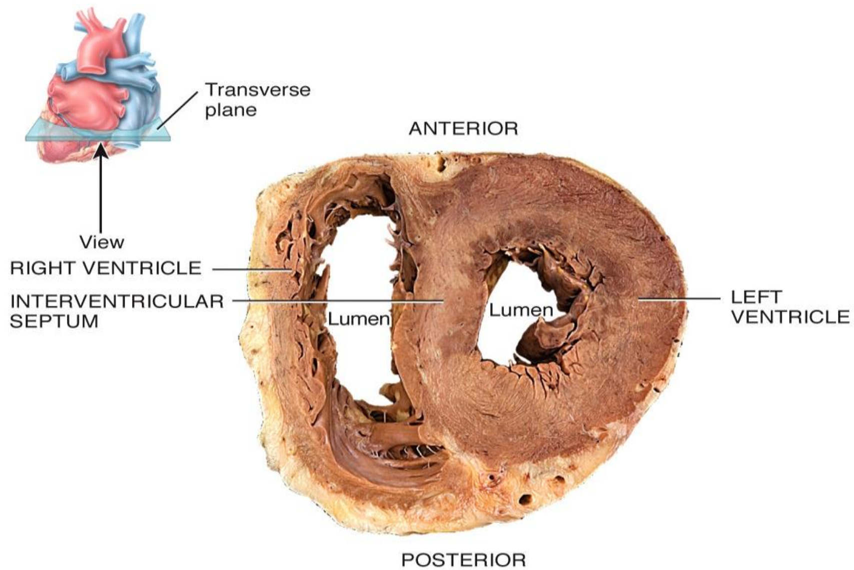
Left Ventricle

- Receives blood from left atrium
- Pumps blood through the aortic valve (semi-lunar valve) into the ascending aorta that carries blood to the heart wall and to the rest of the body



Myocardial Thickness and Function

- Atrial walls thinner than ventricular walls, delivering blood to ventricles with gravity assist
- Left ventricle wall thicker than right ventricle wall, pumping blood great distances to all parts of the body in systemic circulation, while right only pumps to lungs a short distance through pulmonary circulation



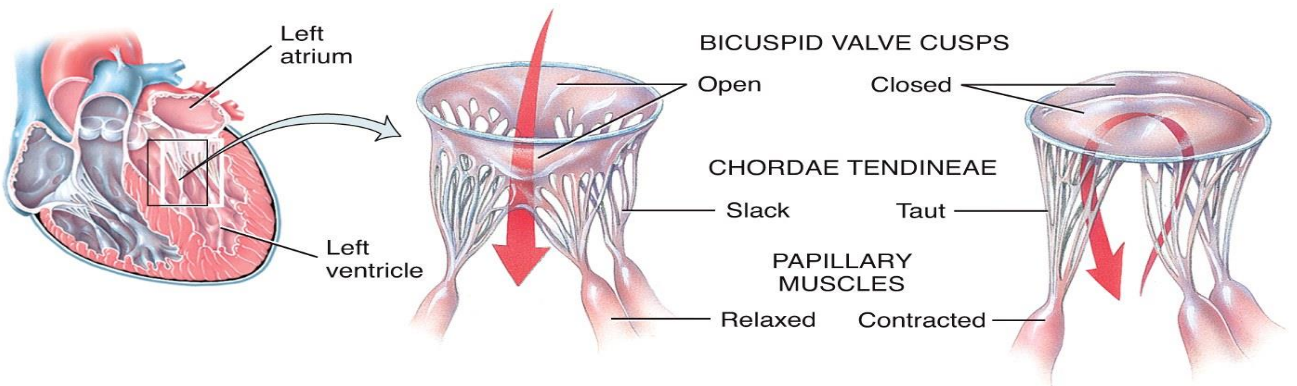
(c) Inferior view of transverse section showing differences in thickness of ventricular walls

Heart Valves

- Open and close in response to pressure differences across the valves created when chamber of heart contracts or relaxes
  - Blood flows from areas of high to low pressure
  - Contraction of chamber increases pressure
- Valves ensure one-way flow of blood
  - Atrioventricular valves – between atrium and ventricle
  - Semi-lunar valves – between ventricle and artery

Atrioventricular Valves (AV)

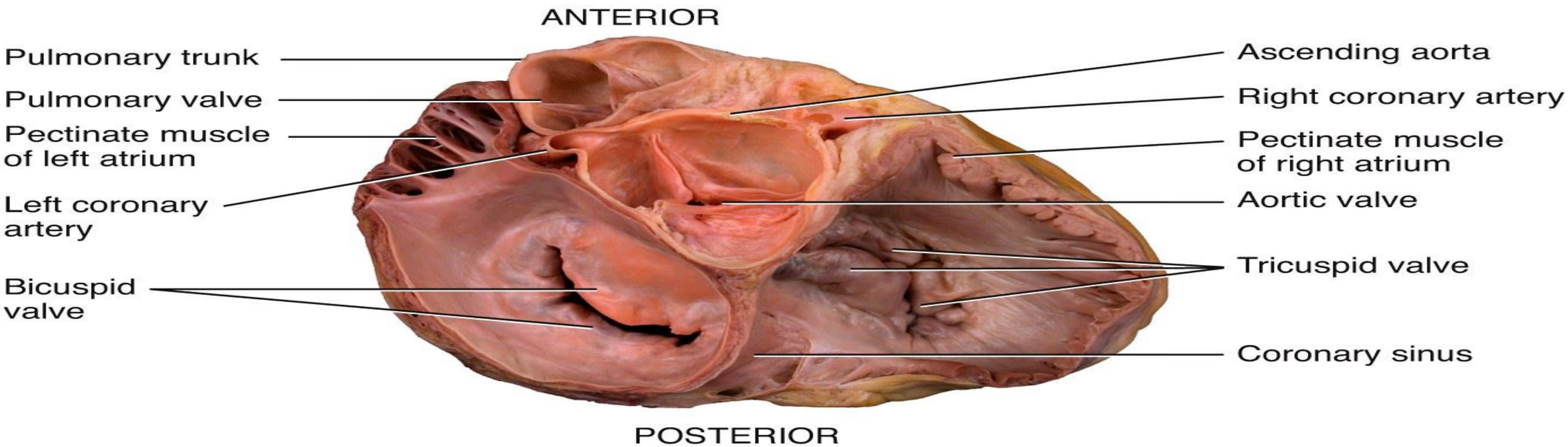
- Tricuspid (right) and bicuspid (left) valves
- When open, rounded ends of cusps project into ventricle chamber
  - Blood moves through from higher pressure in atria
- Close when ventricle contracts
  - Pressure of blood in chamber drives cusps upward until edges meet and close valve



(a) Bicuspid valve open (b) Bicuspid valve closed

Semi-Lunar Valves (SL)

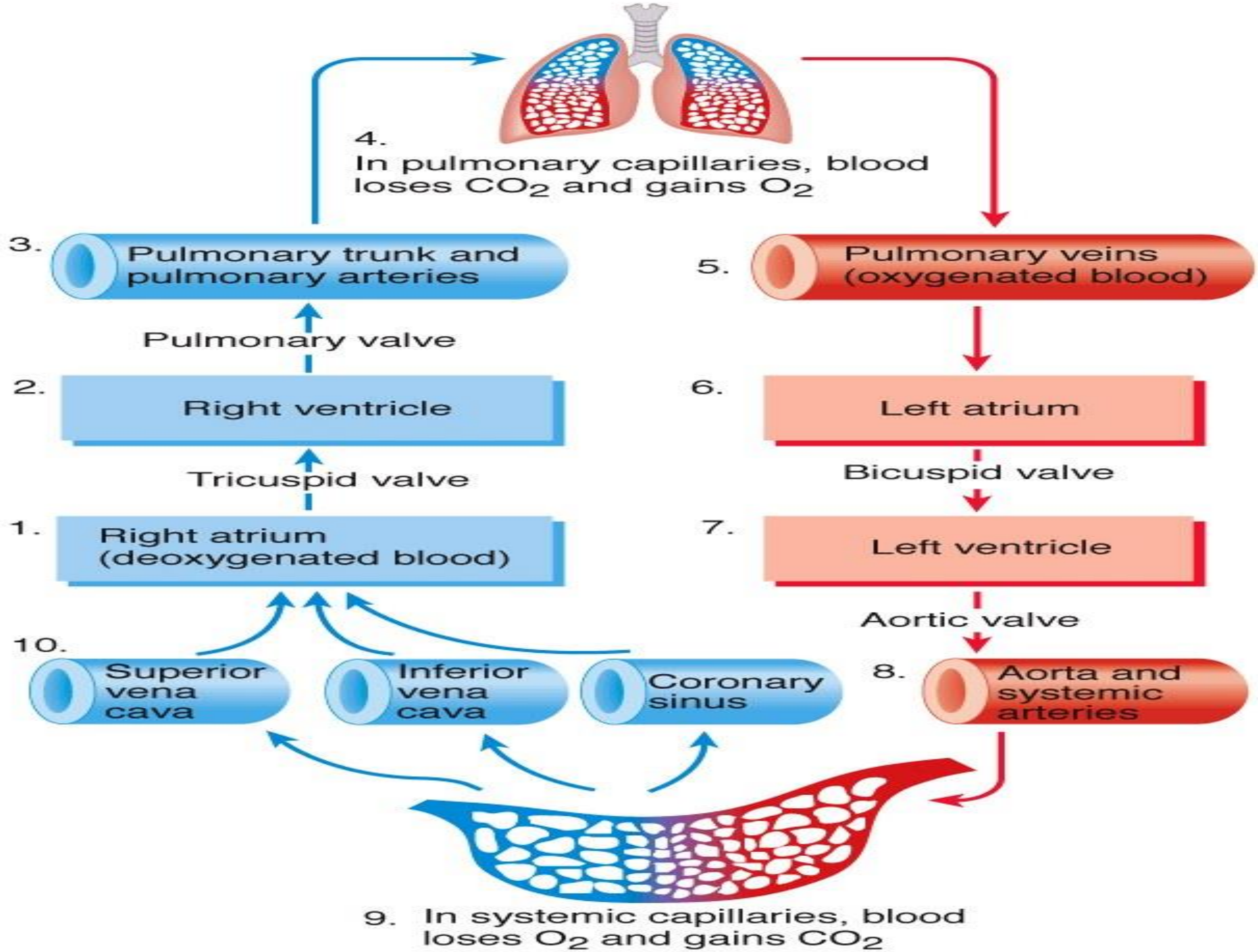
- Pulmonary (right) and aortic (left) valves
- Three moon-shaped cusps prevent backflow
- Open when pressure in ventricles exceeds pressure in arteries, as ventricles contract
- Close when ventricle relaxes and back-flowing blood fills the valve cusps



(f) Superior view of atrioventricular and semilunar valves

Dissection Shawn Miller, Photograph Mark Nielsen

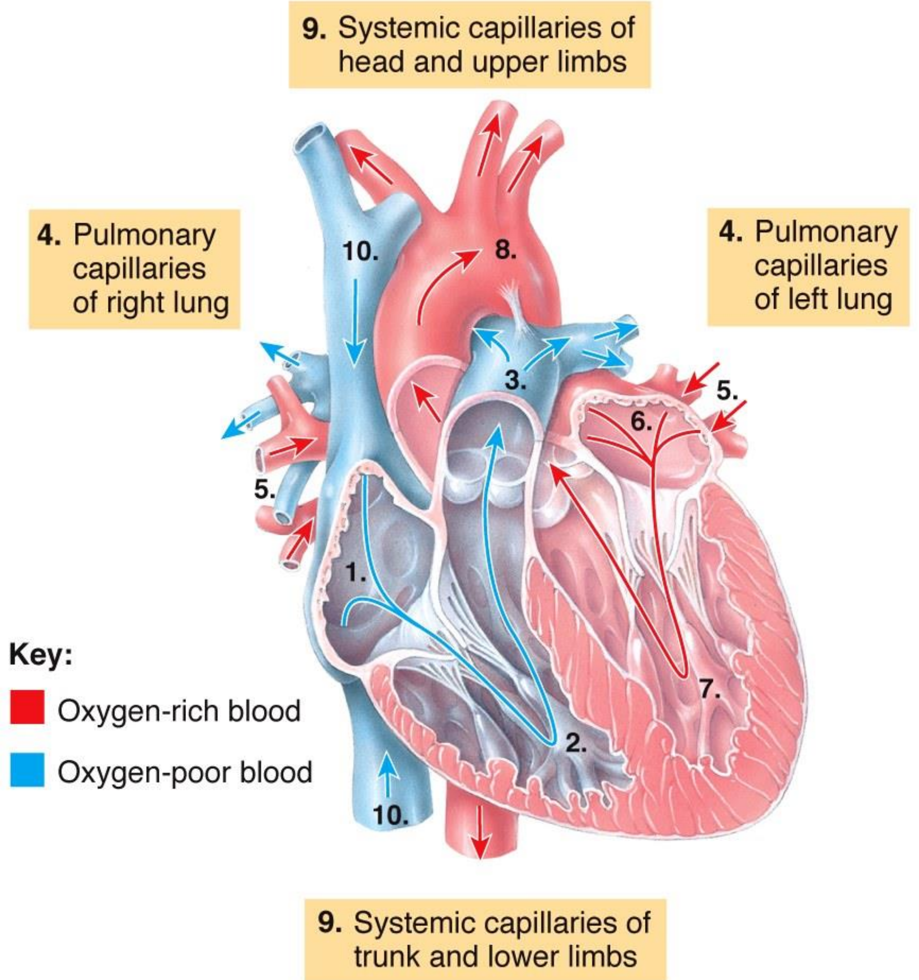
Circulations



Pulmonary Circulation

- Right side of heart is pump
- Circulation of oxygen-poor blood through the lungs
  - Unloads CO_2
  - Picks up O_2
- Right ventricle ejects blood into the pulmonary trunk, then pulmonary arteries, and capillaries where gas exchange occurs
- Pulmonary veins carry blood back to left atrium

Pulmonary Circulation



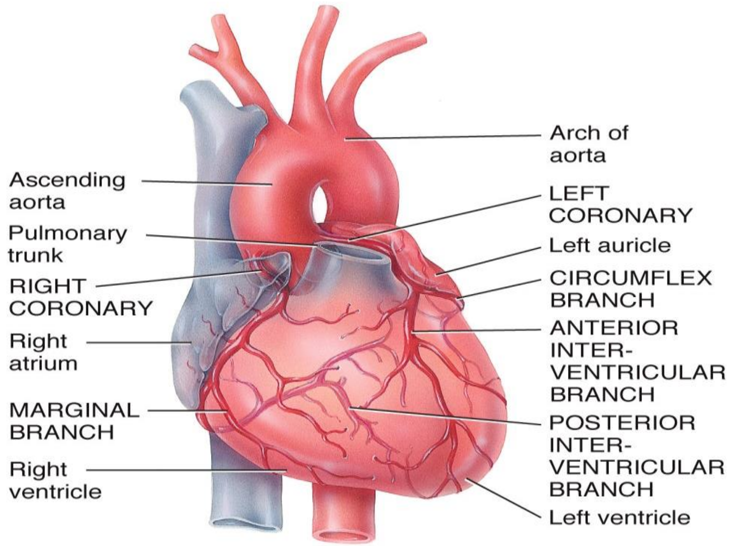
(a) Blood flow through heart

Systemic Circulation

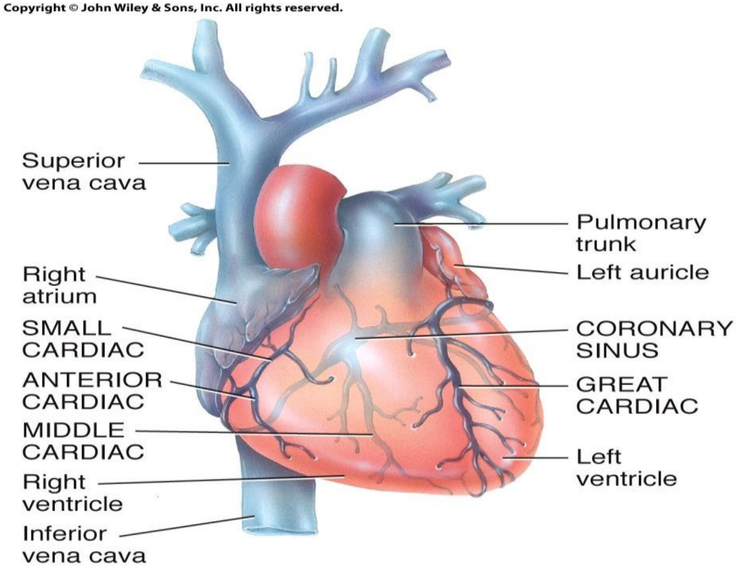
- Left side of heart is pump
- Circulation of oxygen-rich blood through the body
  - Delivers O_2 to all body cells (except for the air sacs in lung)
  - Picks up CO_2
- Left ventricle ejects blood into the aorta, then through systemic arteries, and capillaries where gas exchange occurs
- Systemic veins carry blood back to right atrium

Coronary Circulation

- Right and left coronary arteries branch from ascending aorta to supply oxygen-rich blood to myocardium of heart
- Coronary capillaries – exchange gases and nutrients/wastes
- Coronary veins
  - Collect oxygen-poor blood into coronary sinus on posterior of heart, emptying into right atrium



(a) Anterior view of coronary arteries

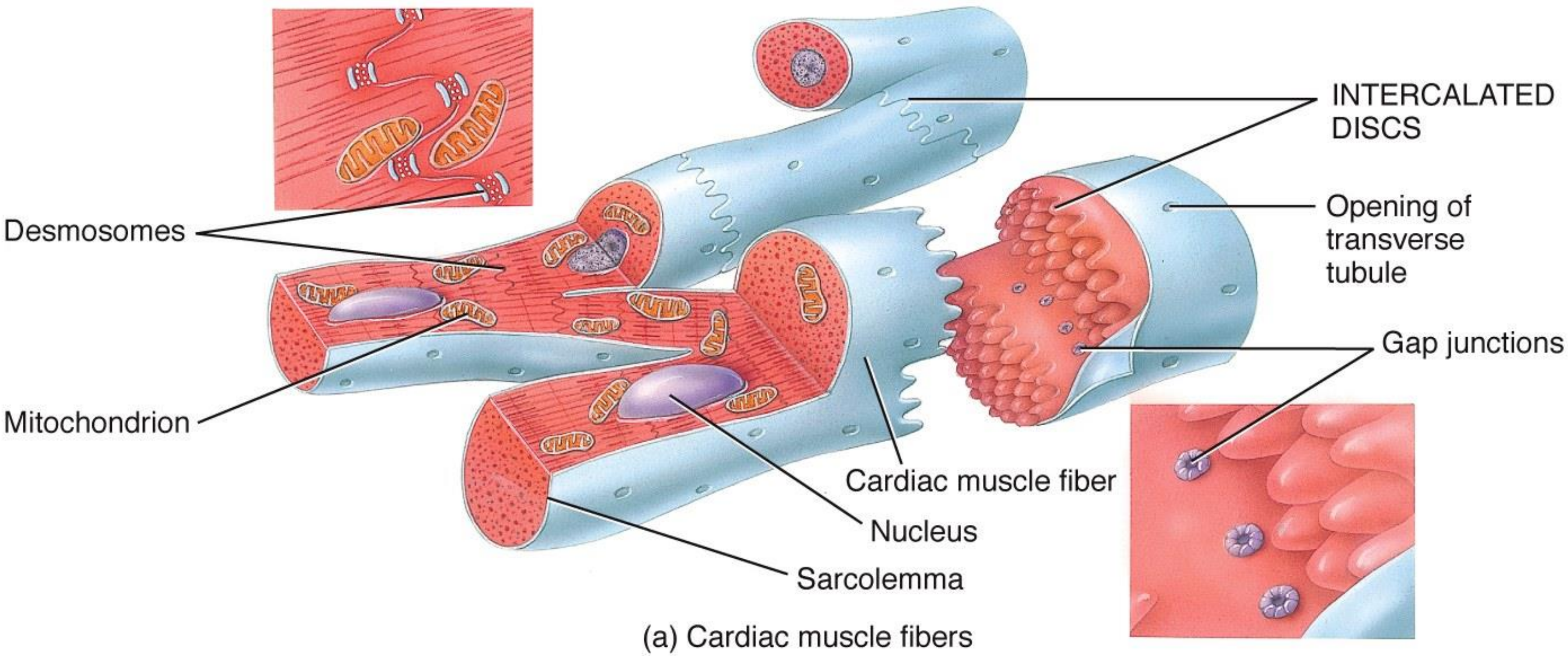


(b) Anterior view of coronary veins

Cardiac Muscle Tissue

- Cardiac muscle fibers connected end-to-end via intercalated discs
  - Desmosomes in discs provide strength
  - Gap junctions allow muscle action potentials to conduct from one muscle fiber to its neighbor
- Autorhythmic fibers
  - Form the cardiac conduction system
  - Spontaneously depolarize and generate action potentials
- Contractile fibers
  - Powerful contractions propel blood

Cardiac Muscle Tissue



(a) Cardiac muscle fibers

Lesson 4: Blood pressure and the cardiac cycle

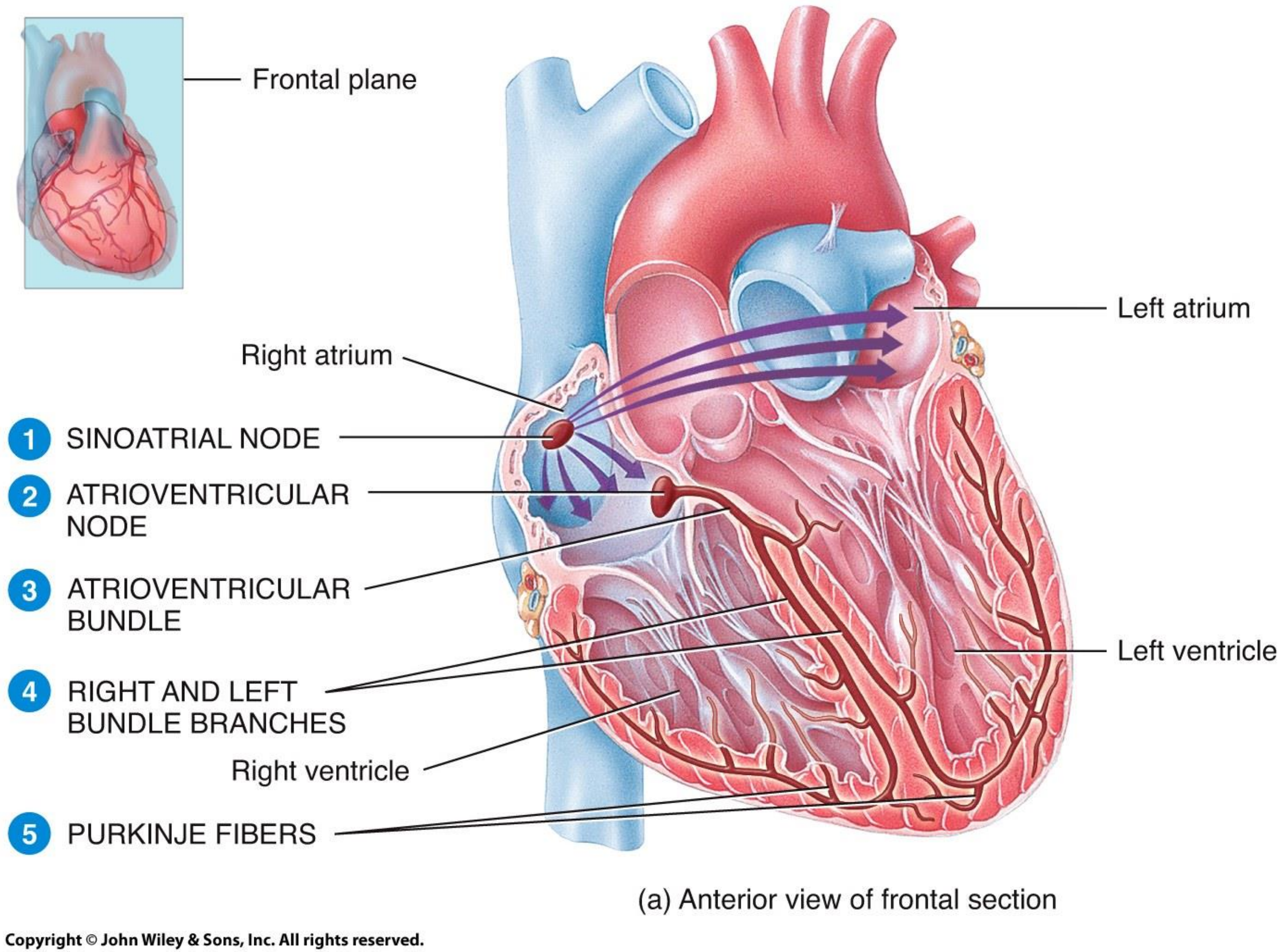
Objective:

- Describe the relationship between blood pressure and blood flow
- Summarize the events of the cardiac cycle
- Compare atrial and ventricular systole and diastole
- Relate heart sounds detected by auscultation to action of heart's valves

Cardiac Conduction System

- Sinoatrial (SA) node pacemaker sets the rhythm of electrical excitation
- Conduction system provides path for each cycle of cardiac excitation
  - Progresses through the heart
    - Sinoatrial (SA) node – right atrial wall
    - Atrioventricular (AV) node – interventricular septum
    - Atrioventricular (AV) bundle – interventricular septum
    - Right and left bundle branches – toward apex
    - Purkinje fibers – from apex upward in myocardium
  - Ensures chambers stimulated to contract in coordinated manner

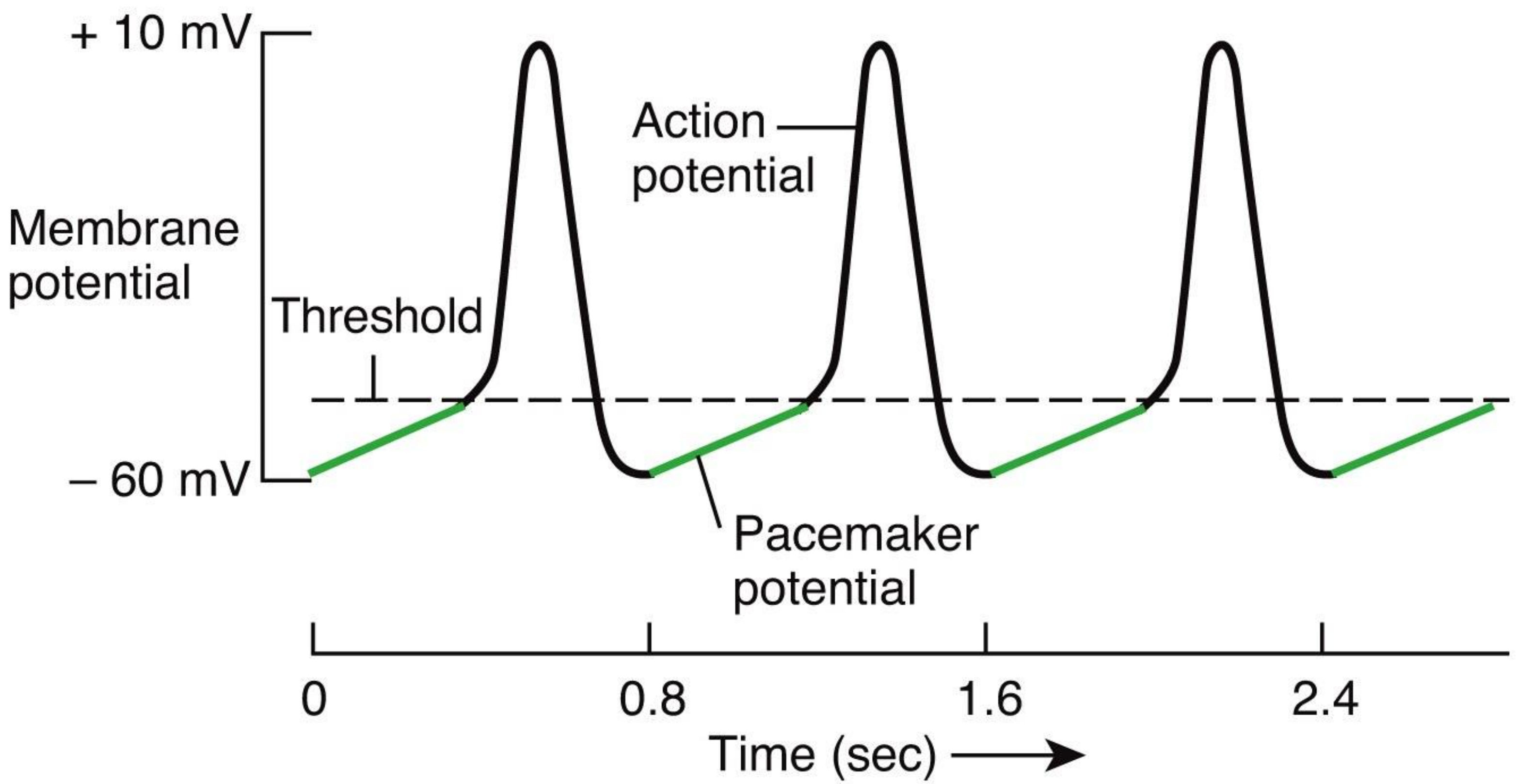
Cardiac Conduction System



Contraction of Contractile Fibers

- Mechanism of cardiac contraction similar to skeletal muscle
- Phases of action potential
  - Depolarization – Na^+ channels open and ions inflow
  - Plateau – Ca^{2+} channels open, inflow triggers contraction
  - Repolarization – K^+ channels open and ions outflow
- Electrical activity leads to mechanical response
  - Anything affecting Ca^{2+} movement influences strength of cardiac muscle contraction
- Long refractory period allows chambers to refill with blood
- ATP mainly from aerobic cellular respiration, but also creatine phosphate with creatine kinase (CK)

Contraction of Contractile Fibers

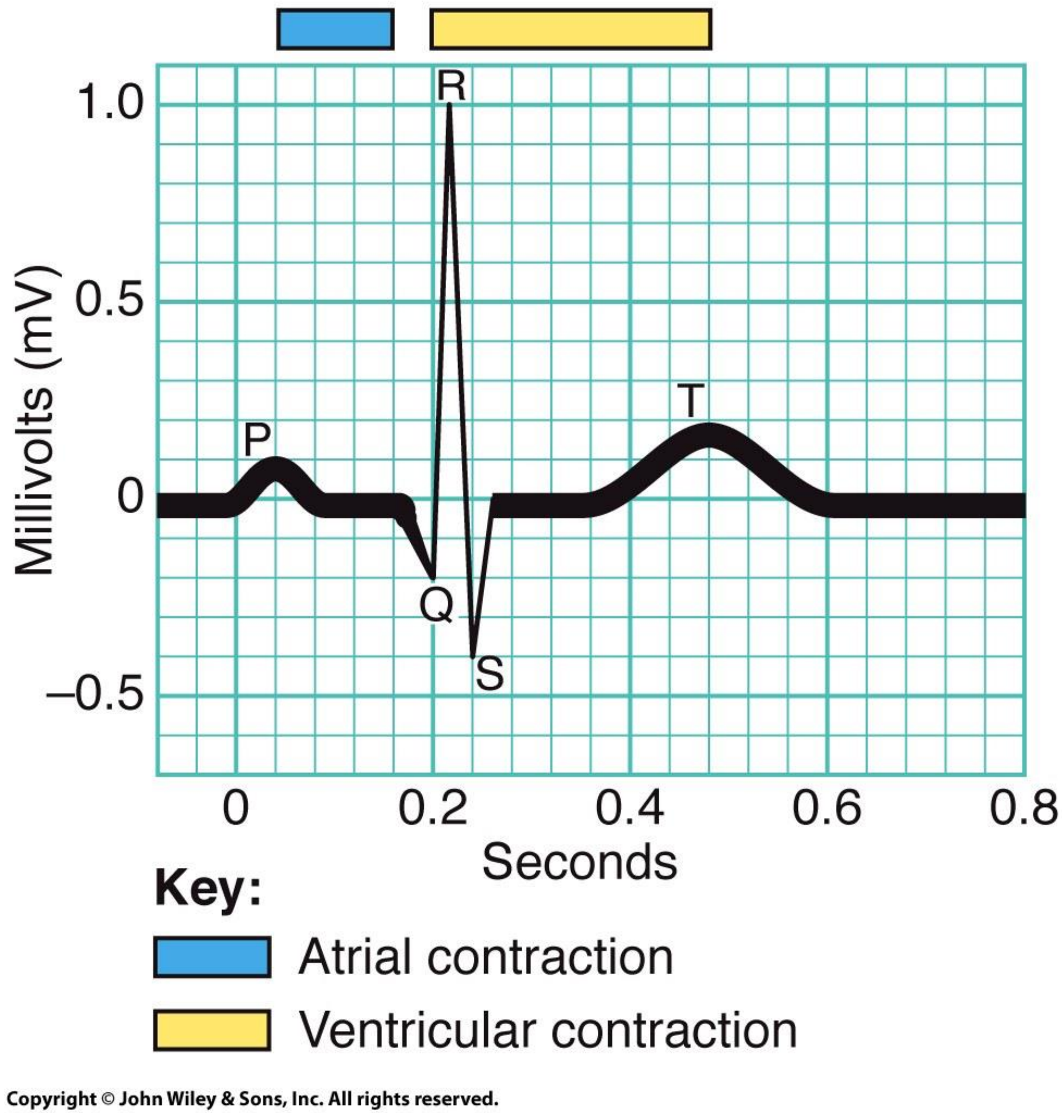


(b) Pacemaker potentials (green) and action potentials (black) in autorhythmic fibers of SA node

Electrocardiogram (ECG or EKG)

- Recording of the electrical charges that accompany each heartbeat
  - Composite of all the action potentials produced by conduction system and cardiac muscle cells during each heartbeat
- Normal ECG waves
  - P wave – atrial depolarization
  - QRS complex – onset of ventricular depolarization
  - T wave – ventricular repolarization

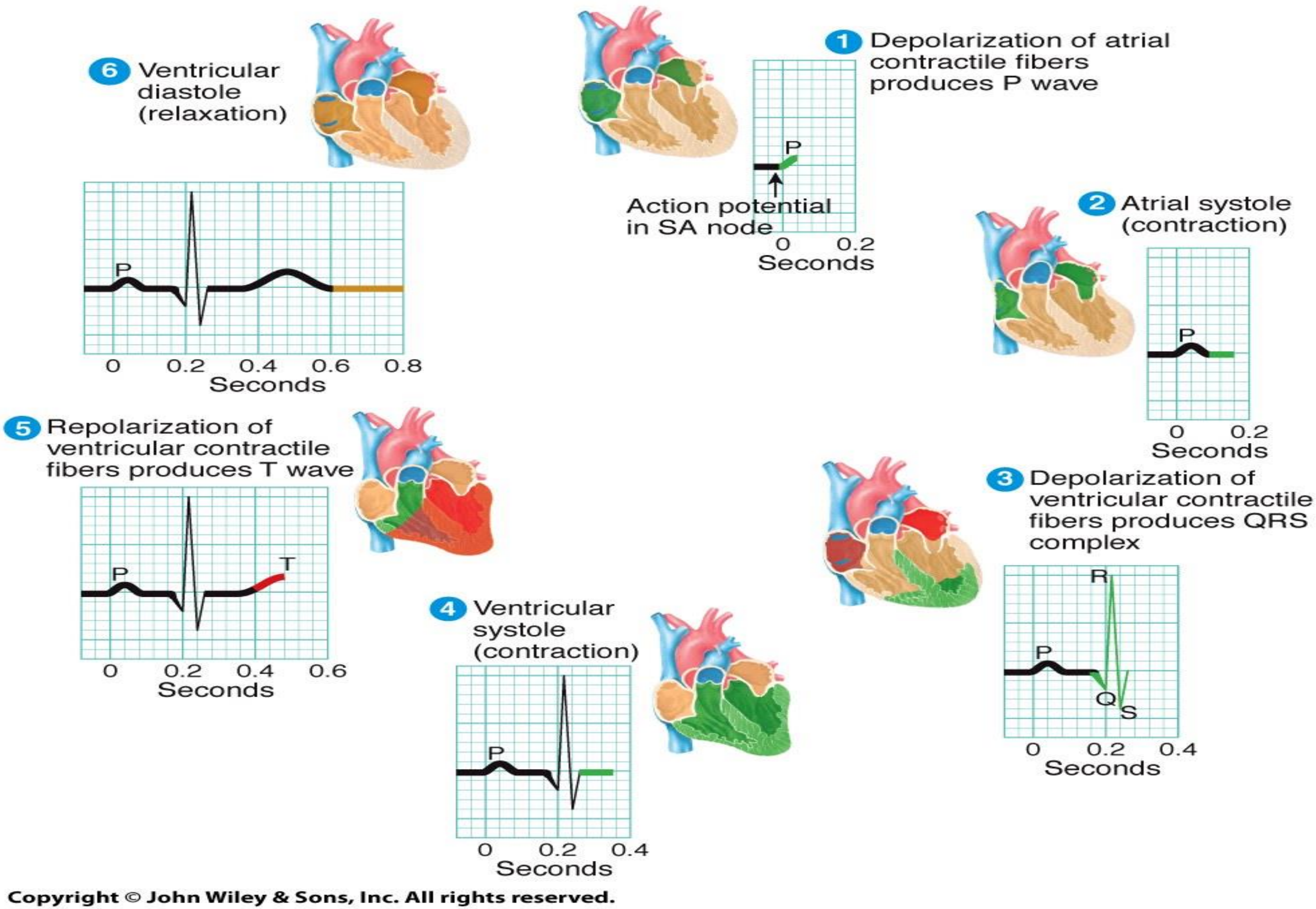
Electrocardiogram (ECG or EKG)



Correlation of ECG Waves with Heart Activity

- Diastole – atrial and ventricular relaxation
- Systole – atrial and ventricular contraction
- Sequence of systole and diastole
  - Depolarization of atria – P wave
  - Atrial systole occurs
  - Ventricular depolarization – QRS complex
    - Masks atrial repolarization occurring at same time
  - Ventricular systole begins; atrial diastole begins
  - Repolarization of ventricles – T wave
  - Ventricular diastole occurs

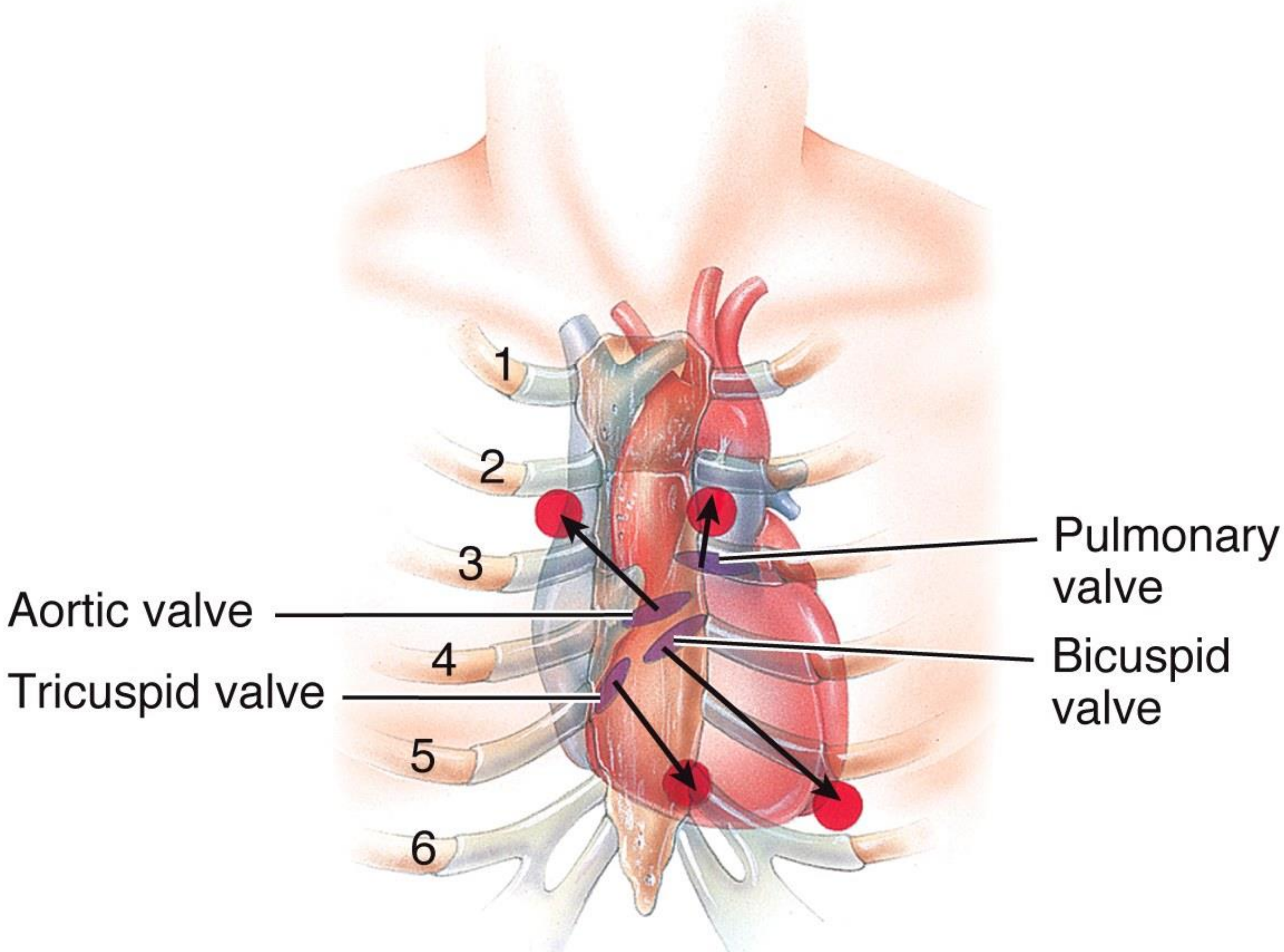
Correlation of ECG Waves with Heart Activity



Cardiac Cycle

- All events associated with single heartbeat
  - Two atria contract (systole) and relax (diastole)
  - Two ventricles contract (systole) and relax (diastole)
- Heart sounds – caused by blood turbulence due to closing of valves
  - Lubb sound (S1) – closure of both AV valves as ventricles contract (ventricular systole)
  - Dupp sound (S2) – closure of both SL valves as ventricles relax (ventricular diastole)

Cardiac Cycle



Anterior view of heart valve locations and auscultation sites

Regulation of Heart Rate (HR)

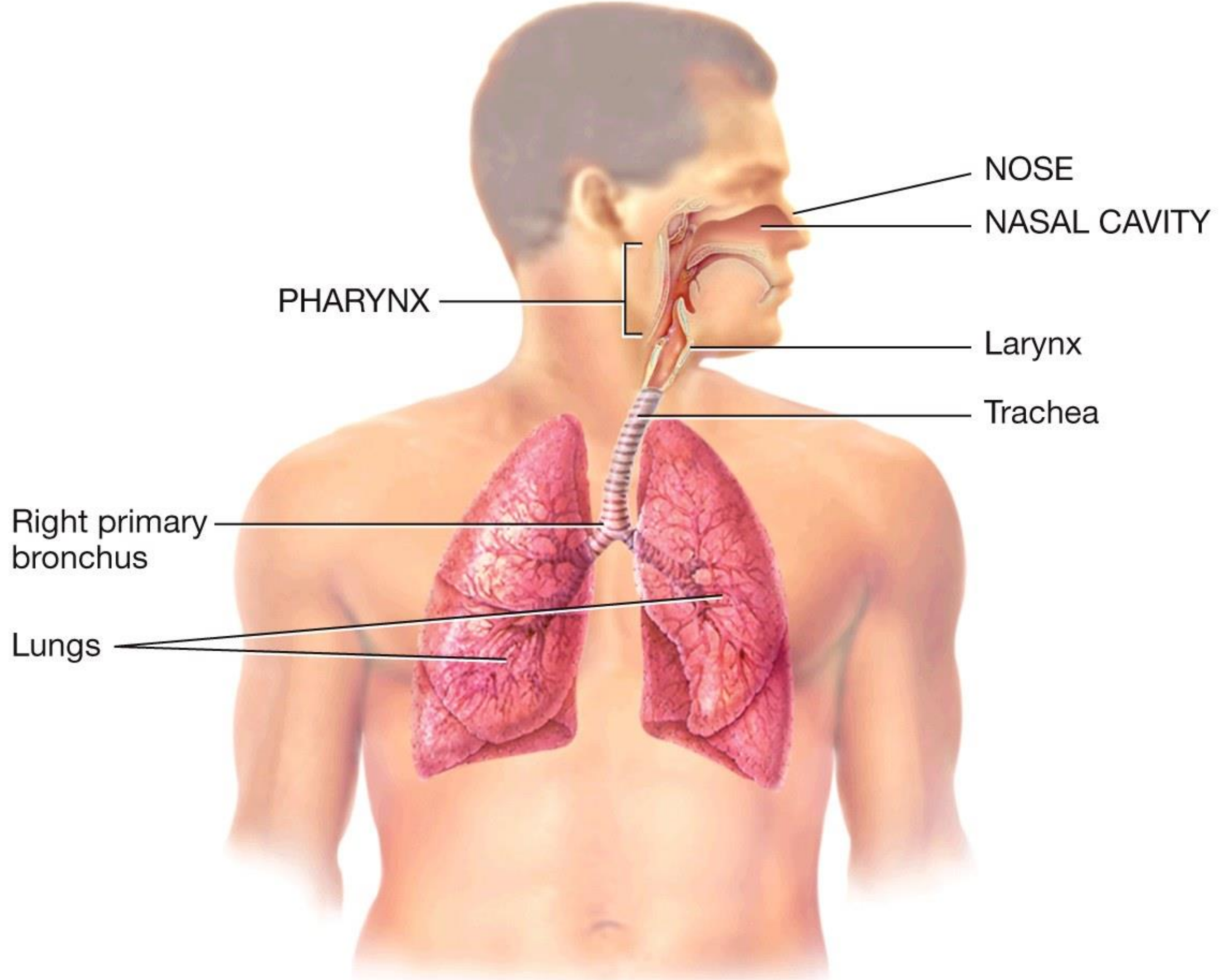
- Cardiovascular center in medulla oblongata is origin of nervous system regulation of HR
  - Receives input from proprioceptors, chemoreceptors, and baroreceptors
  - Also input from limbic system and cerebral cortex
  - Autonomic regulation
- Chemical regulation of HR
  - Hormones – epinephrine and norepinephrine from adrenal gland, thyroid hormones
  - Cations – ionic imbalances of Na^+, K^+, and Ca^{2+}
- Other factors
  - Age, gender, physical fitness, and body temperature

Lesson 5: Respiratory Anatomy

Objective:

- List the structures that make up the respiratory system
- Describe how the respiratory system processes oxygen and CO_2
- Compare the functions of upper respiratory tract with the lower respiratory tract

Respiratory System



(a) Anterior view showing organs of respiration

Functions of Respiratory System

- Provides for gas exchange
- Helps regulate blood pH
- Others
  - Filters inspired air
  - Produces vocal sounds
  - Excretes small amounts of water and heat
  - Contains receptors for sense of smell

Respiratory System

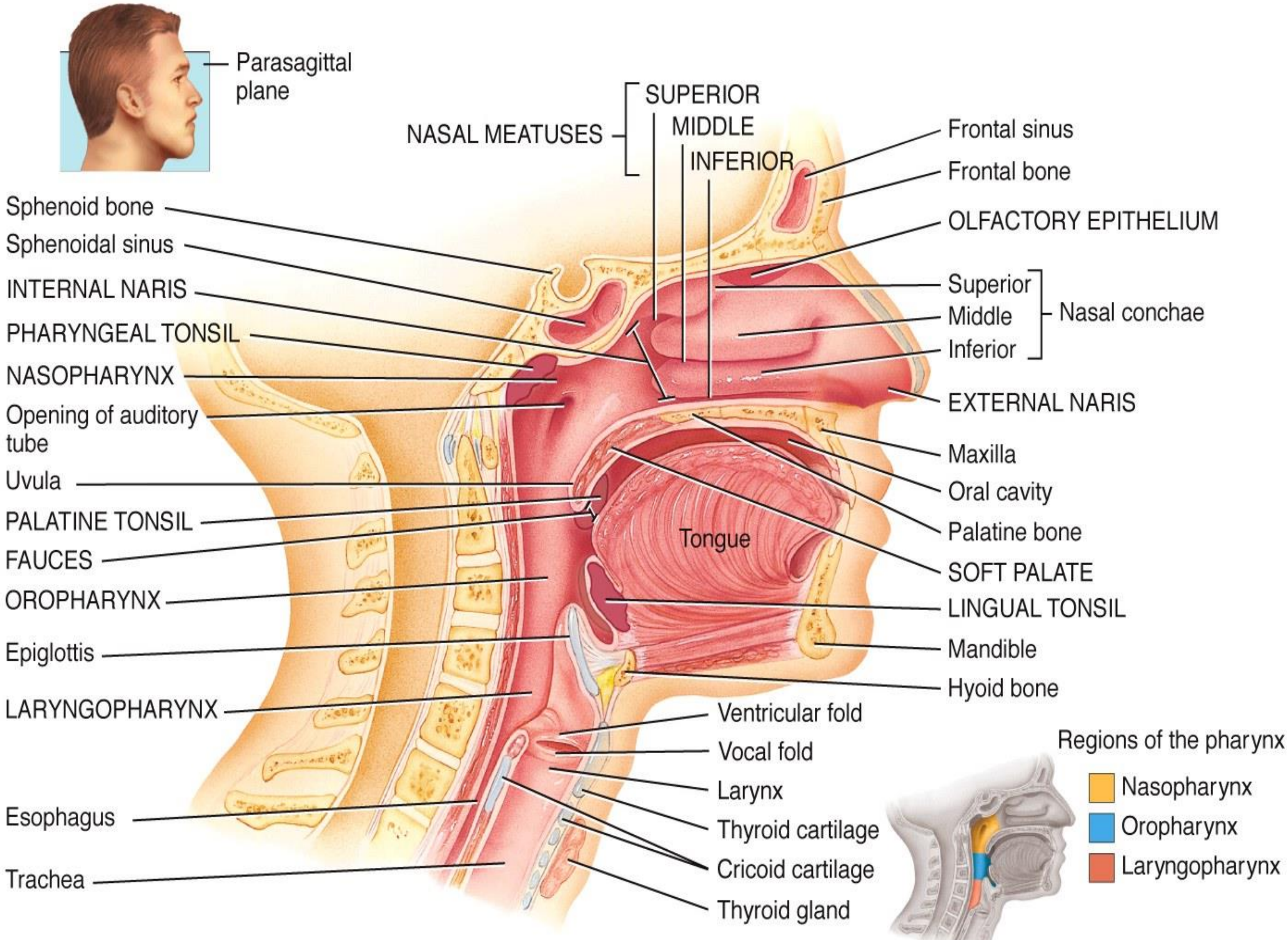
- Structurally consists of two parts
  - Upper respiratory system includes the nose, pharynx, and associated structures
  - Lower respiratory system includes the larynx, trachea, bronchi, and lungs
- Functionally also consists of two parts
  - Conducting zone – all upper and lower passageways that filter, warm, moisten, and conduct air (nose to terminal bronchioles)
  - Respiratory zone – portion of lower respiratory system within lungs with gas exchange between air and blood (respiratory bronchioles, alveolar ducts, alveolar sacs, and alveoli)

Nose and Paranasal Sinuses

- Nose
  - Visible external portion supported by cartilage and bone, with external nares
  - Nasal cavity is lined by mucous membrane, divided by nasal septum, with conchae extending into cavity from lateral walls
  - Functions
    - Warms, moistens, and filters incoming air
    - Detects olfactory stimuli
    - Contributes to voice resonance
- Paranasal sinuses
  - Cavities in skull bones that open into nasal cavity
  - Produce mucus and contribute to voice resonance

Pharynx

- Muscular tube lined with mucous membrane
- Three regions
  - Nasopharynx – passageway for air from internal nares of nasal cavity with openings to auditory tube
  - Oropharynx – intermediate portion with opening to mouth
  - Laryngopharynx – inferior portion with opening to both esophagus (posterior) and larynx (anteriorly)
- Functions
  - Passageway for air and food
  - Resonating chamber for speech sounds
  - Houses tonsils for immune response to inhaled or ingested pathogens

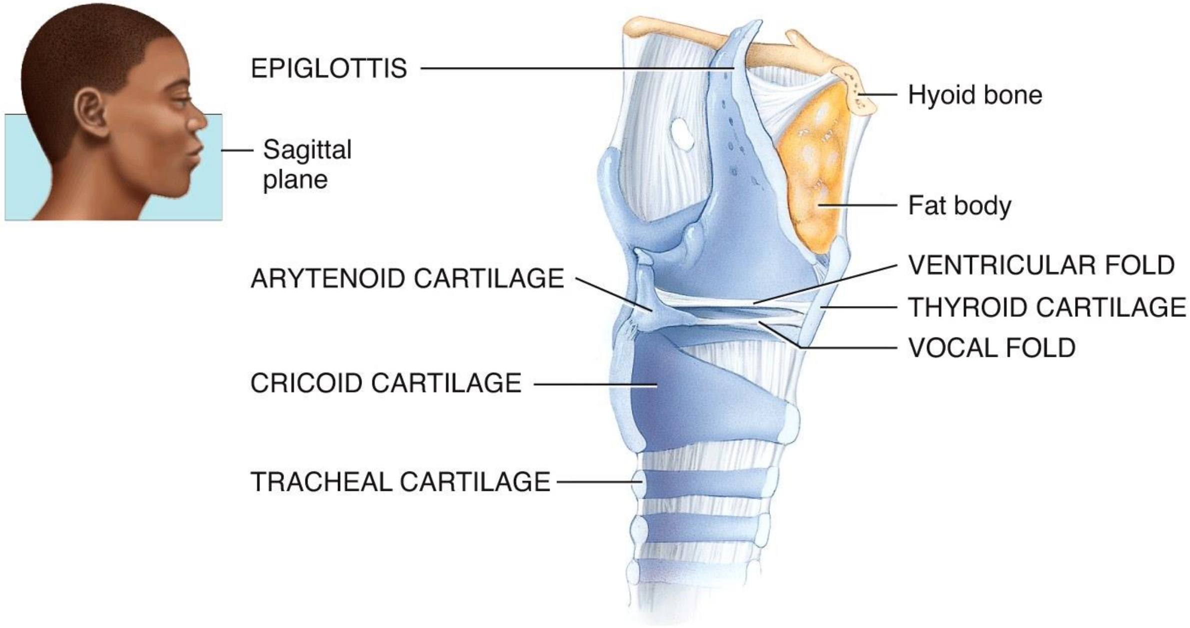


(b) Parasagittal section of left side of head and neck showing location of respiratory structures

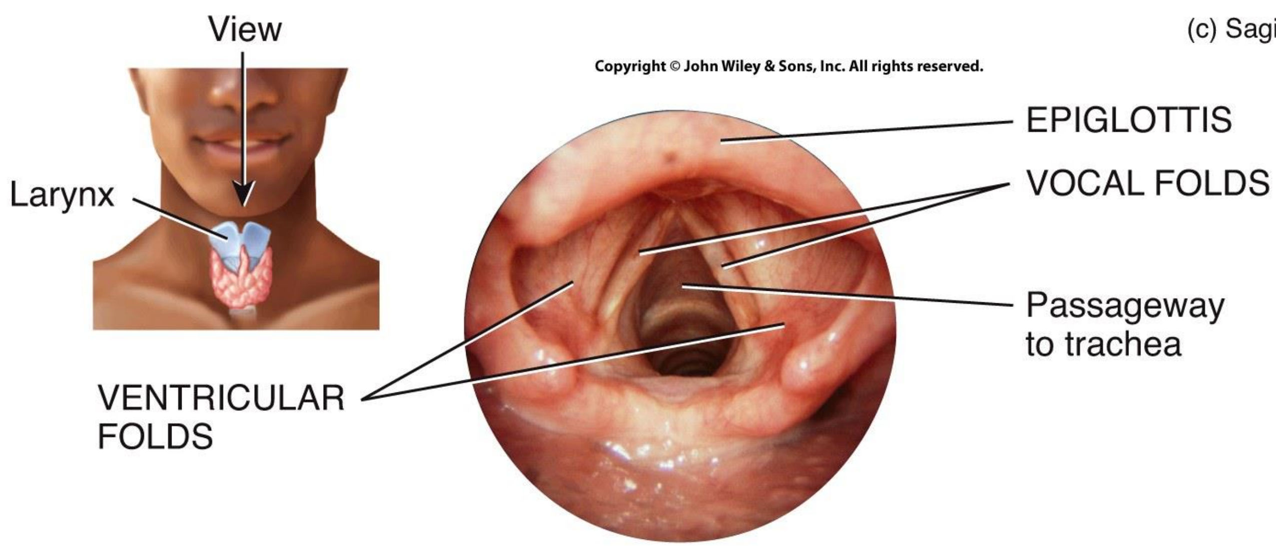
Larynx

- Passageway connecting laryngopharynx with trachea
- Support cartilages
  - Thyroid cartilage, cricoid cartilage, arytenoid cartilages
- Epiglottis
  - Moves to cover larynx airway during swallowing, routing food and liquids into the esophagus
- Glottis
  - Opening with two mucous membrane folds
    - Ventricular folds – hold breath, do not produce sound
    - Vocal folds – vibrate to produce sound, pitch changes with change in tension

Larynx



(c) Sagittal section

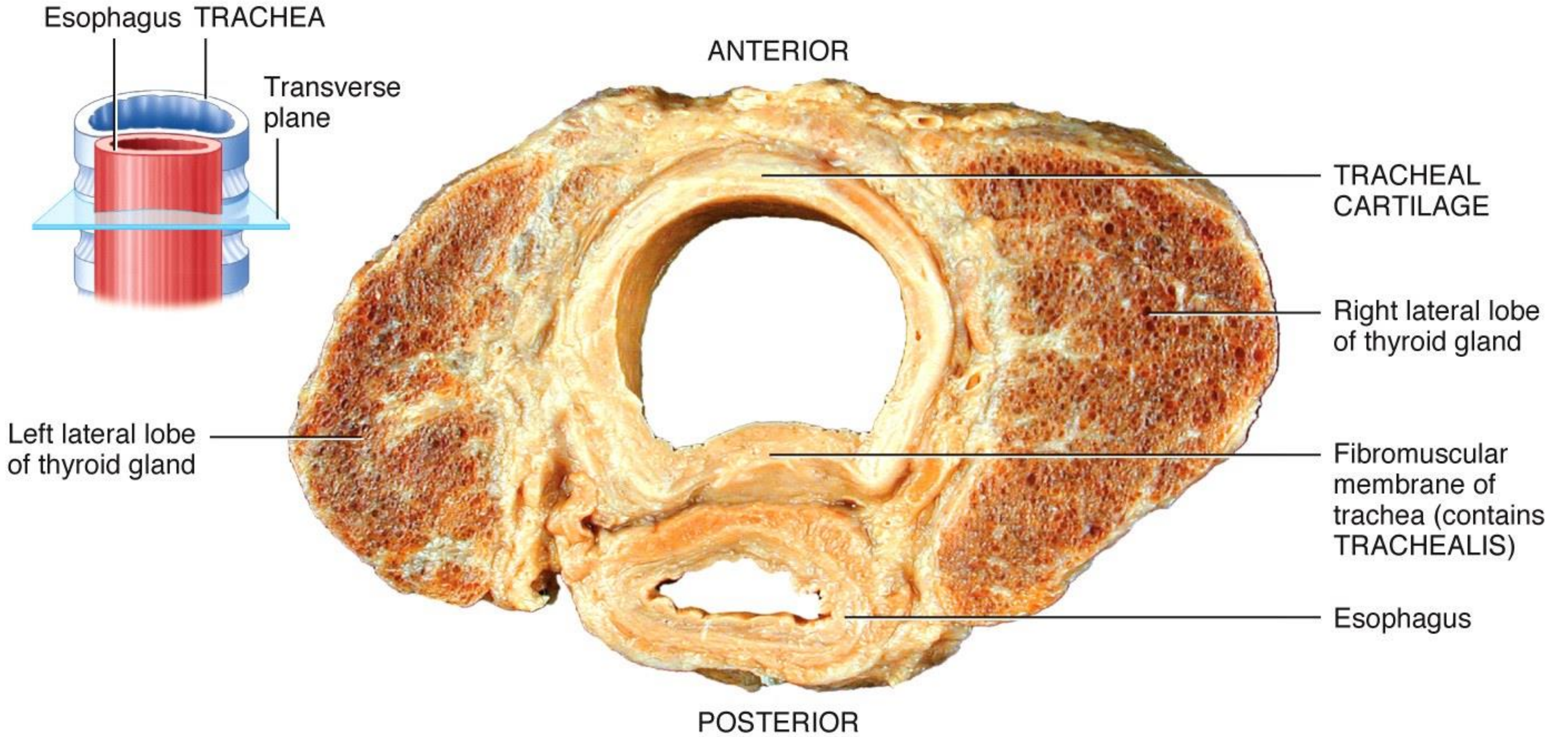


(c) Superior view

Trachea

- Passageway extending from larynx to primary bronchi (windpipe; anterior to esophagus)
- C-shaped cartilage rings give support to prevent wall from collapsing and obstructing airway
- Trachealis smooth muscle and elastic connective tissue connect ends of C-cartilage posteriorly
- Carina is a projection of inferior-most tracheal cartilage at point where trachea divides into the right and left primary bronchi, with sensitive receptors for triggering a cough reflex

Trachea

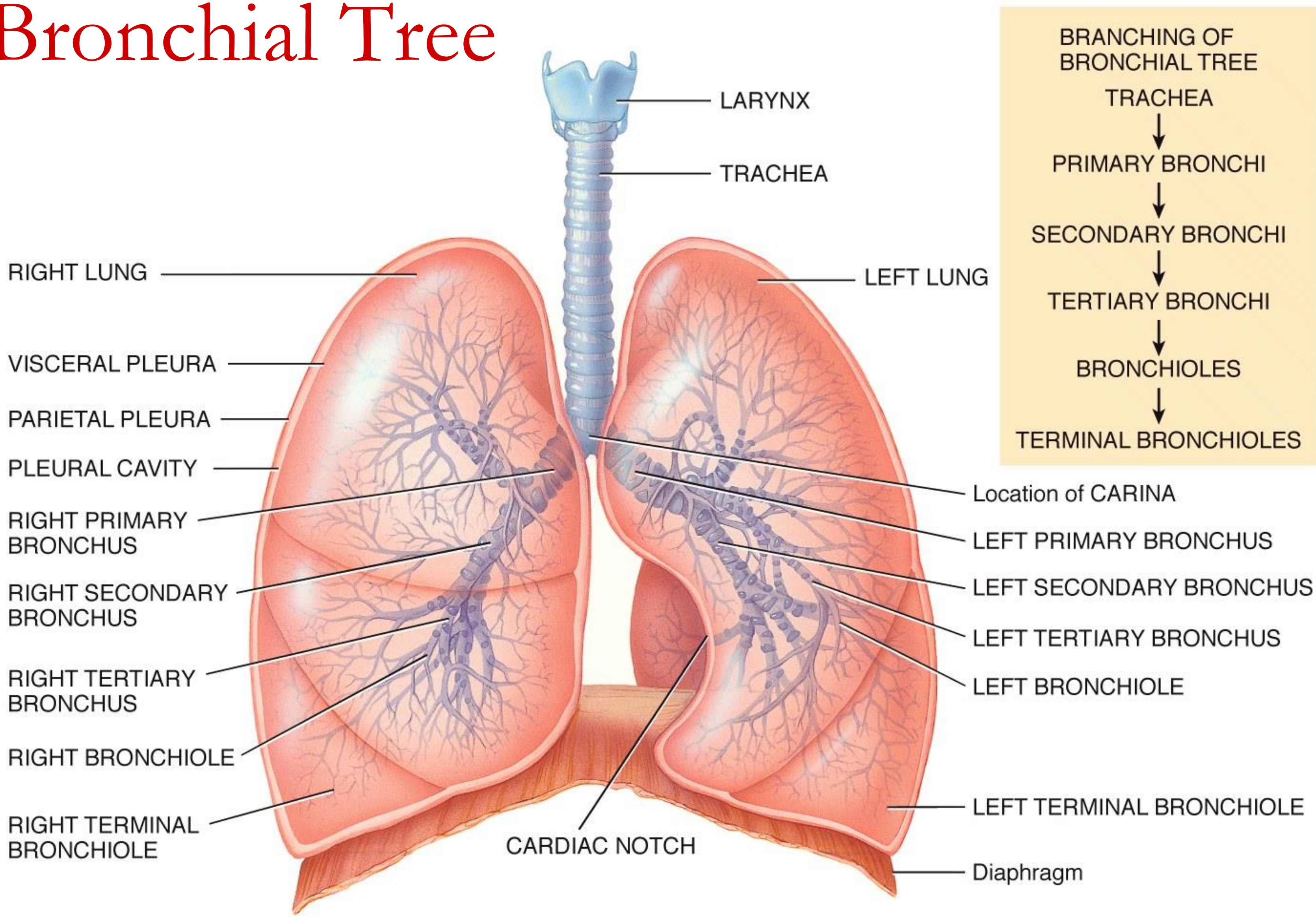


Superior view of transverse section of thyroid gland, trachea, and esophagus

Bronchial Tree

- Branching sequence of airways, including trachea, primary bronchi, secondary bronchi, tertiary bronchi, bronchioles, and terminal bronchioles
- Structural changes associated with successive branching into lung
  - Mucous membrane changes from pseudostratified, to ciliated simple columnar, to simple cuboidal epithelium
  - Cartilage incomplete rings, replaced by plates, and finally disappear in distal bronchioles
  - Amount of smooth muscle increases as amount of cartilage decreases

Bronchial Tree

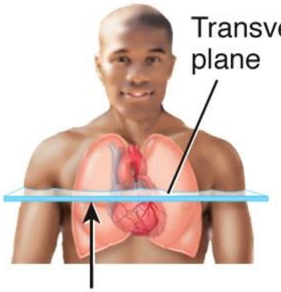


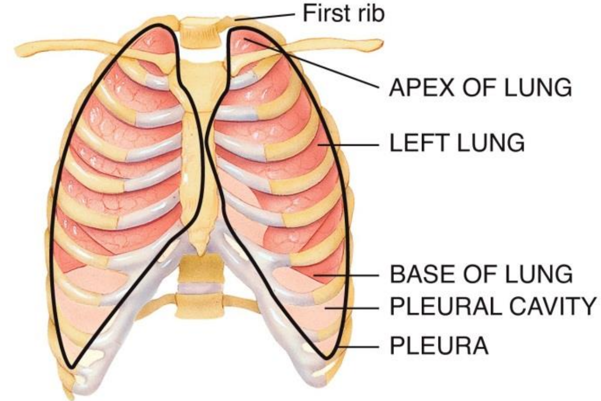
Anterior view

Lungs

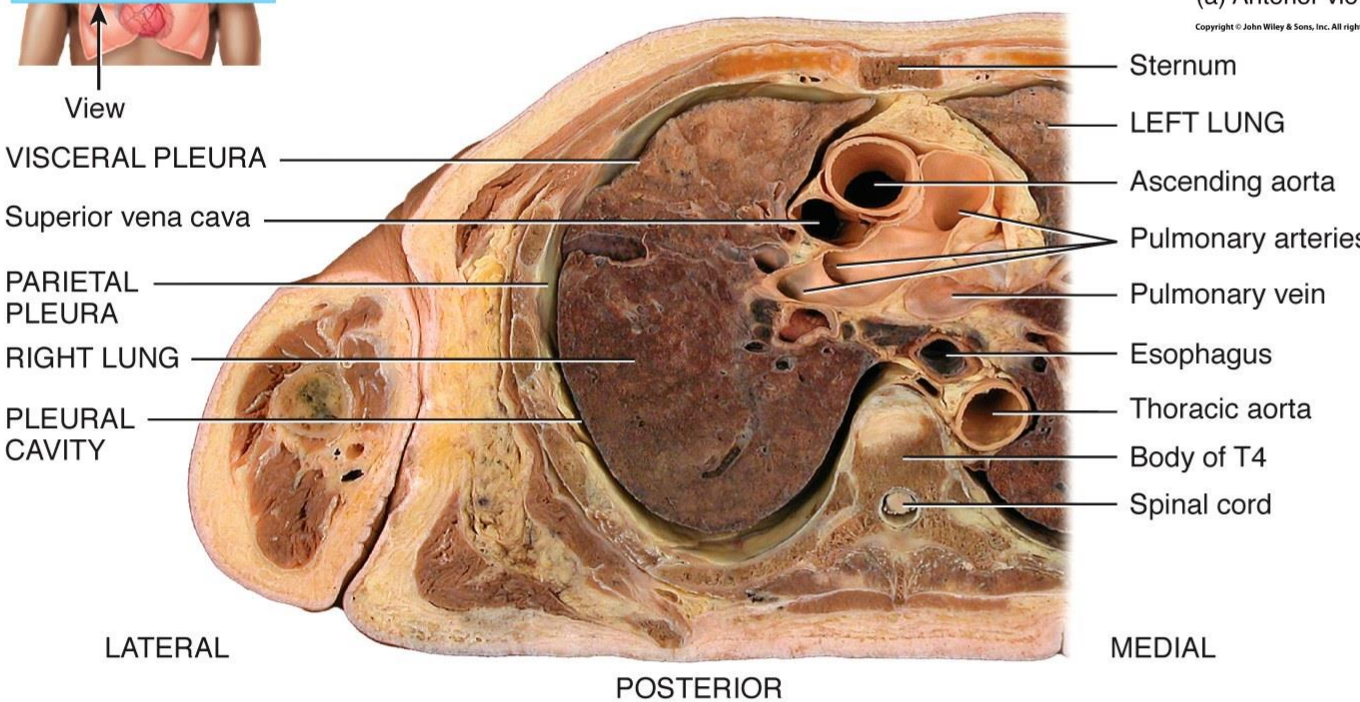
- Paired thoracic cavity organs
  - Visceral pleura covers each lung
  - Parietal pleura lines wall and forms distinct chamber for each lung
  - Pleural cavity filled with serous fluid
- Lobes divided by fissures
  - Right lung three lobes; left lung two lobes and cardiac notch
  - Each lobe supplied by secondary (lobar) bronchus
  - Bronchopulmonary segments, within lobe, are supplied by tertiary bronchi
  - Many smaller lobules are supplied by terminal bronchiole and respiratory bronchioles with alveoli

Lungs



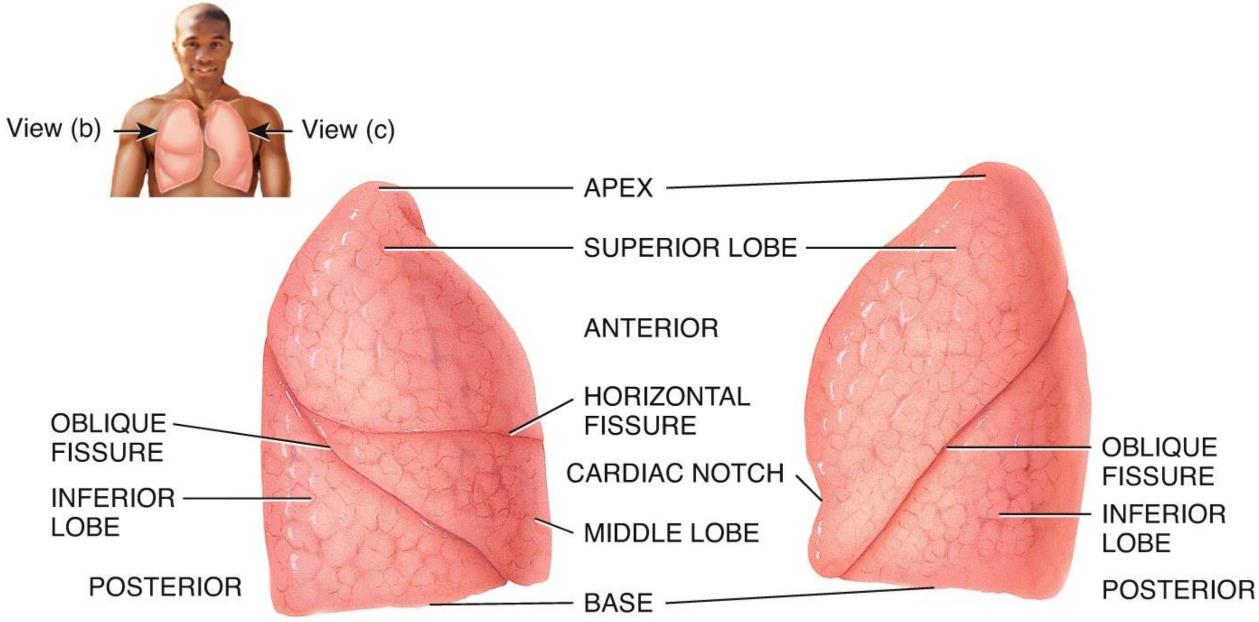


(a) Anterior view of lungs and pleurae in thorax

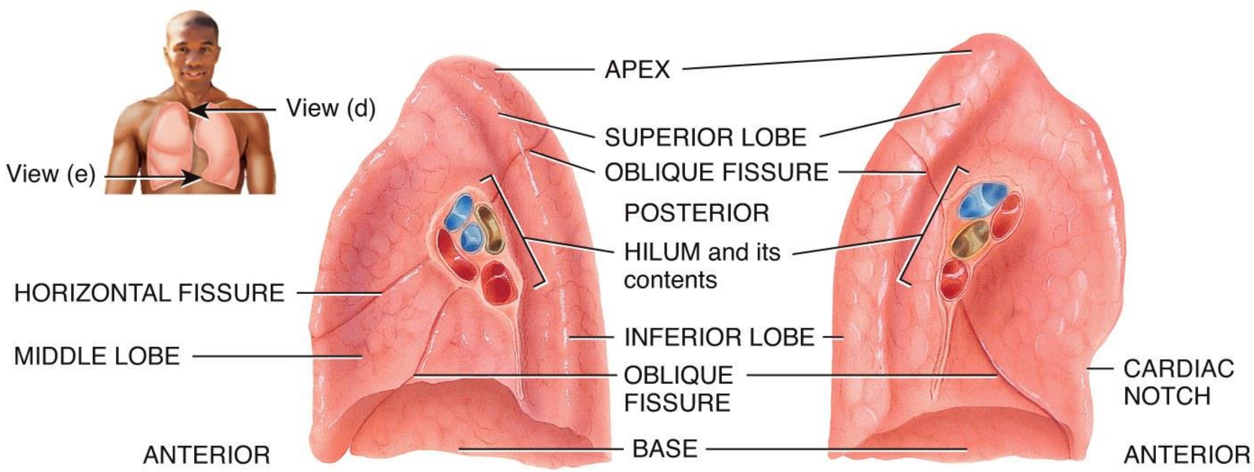


Inferior view of transverse section through thoracic cavity showing pleural cavity and pleural membranes

Lungs



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

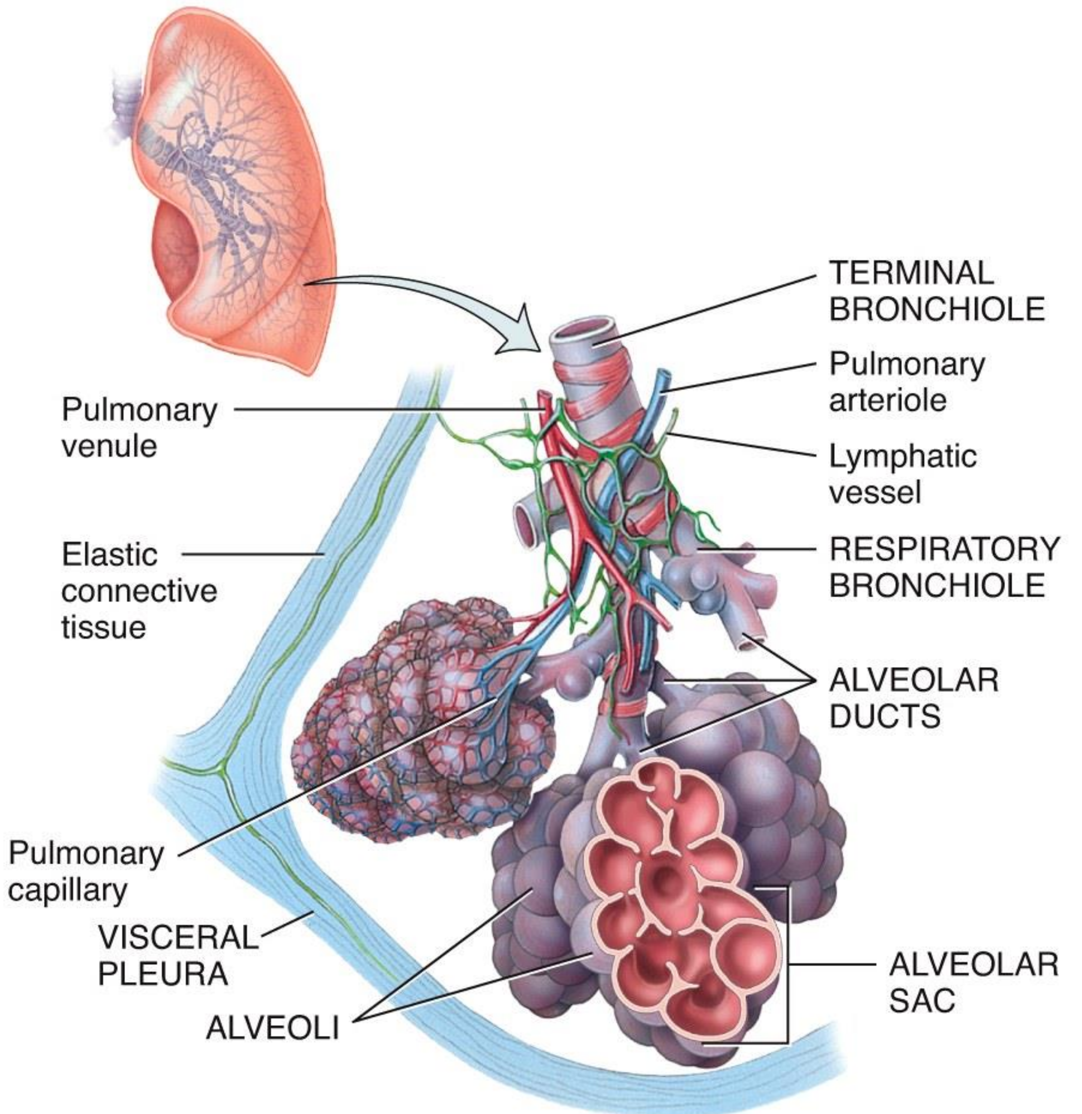


(d) Medial view of right lung (e) Medial view of left lung

Alveoli

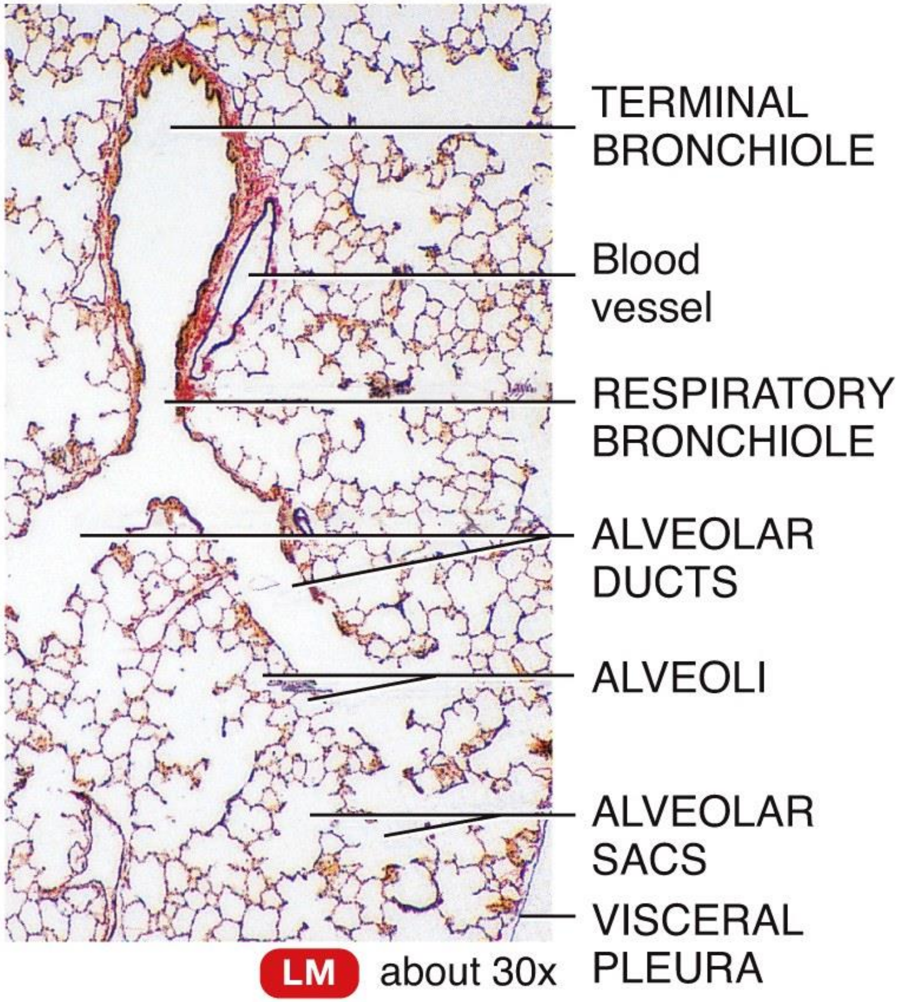
- Alveolar sac consists of two or more cup-shaped alveoli sharing a common opening to an alveolar duct within lobule
  - Each lobule is wrapped in elastic connective tissue and contains lymphatic vessel, an arteriole, and a venule
  - Each alveolar sac is surrounded by pulmonary capillary
- Alveoli wall around air space in lung has different kinds of cells
  - Type I alveolar cells – simple squamous epithelium
  - Type II alveolar cells (septal cells) – rounded epithelial cells that secrete alveolar fluid with surfactant to inhibit alveolar collapse
  - Alveolar macrophages – remove dust and debris

Alveoli



(a) Diagram of portion of lobule of lung

Alveoli

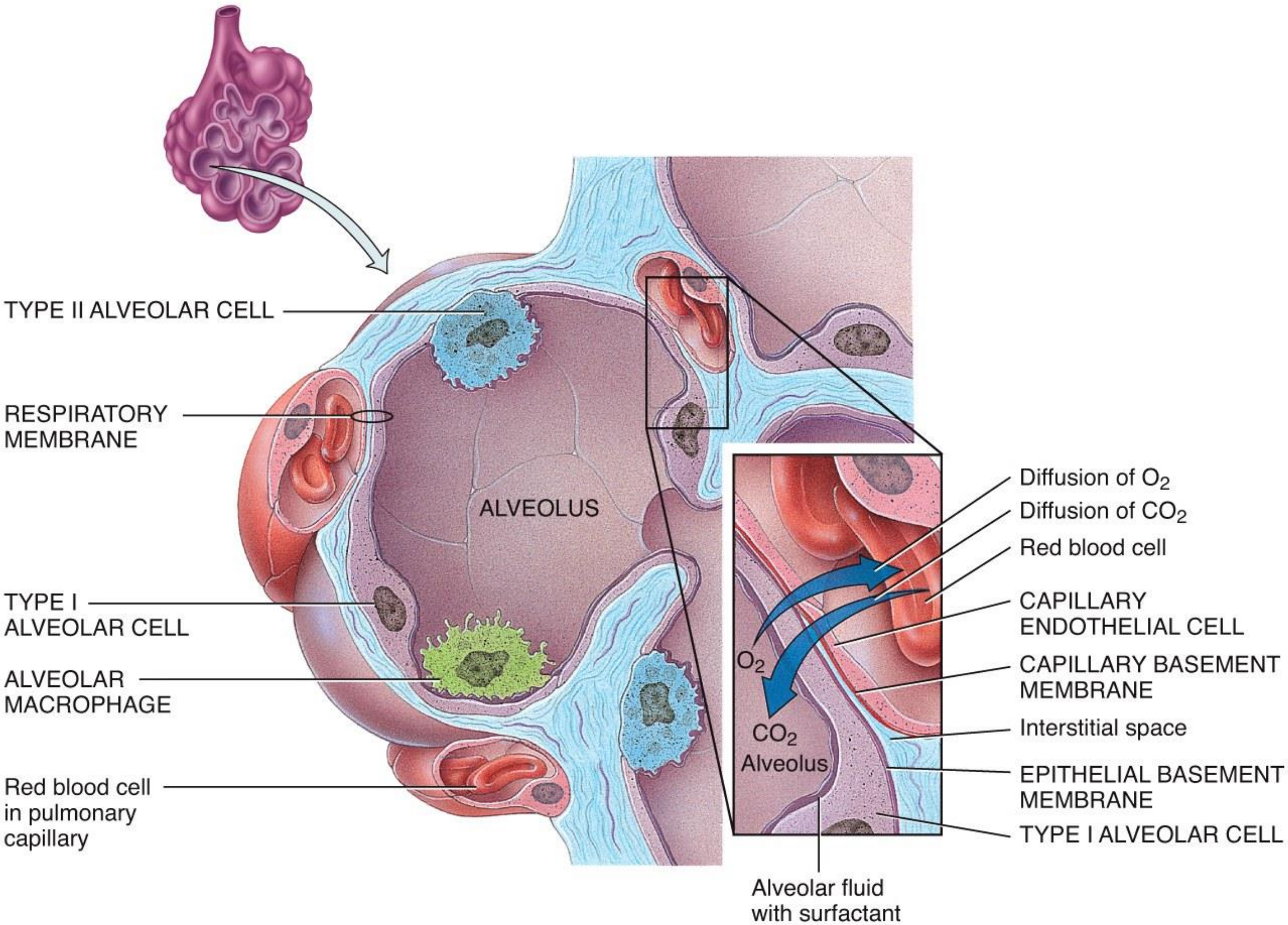


(b) Lung lobule

MICROSCOPIC AIRWAYS

TERMINAL BRONCHIOLES
↓
RESPIRATORY BRONCHIOLES
↓
ALVEOLAR DUCTS
↓
ALVEOLAR SAC
↓
ALVEOLI

Respiratory Membrane



(a) Section through an alveolus showing cellular components

(b) Details of respiratory membrane

Lesson 6: Gas exchange and Breathing mechanics

Objective:

- Compare the composition of atmospheric air and alveolar air
- Describe the mechanisms that drive gas exchange

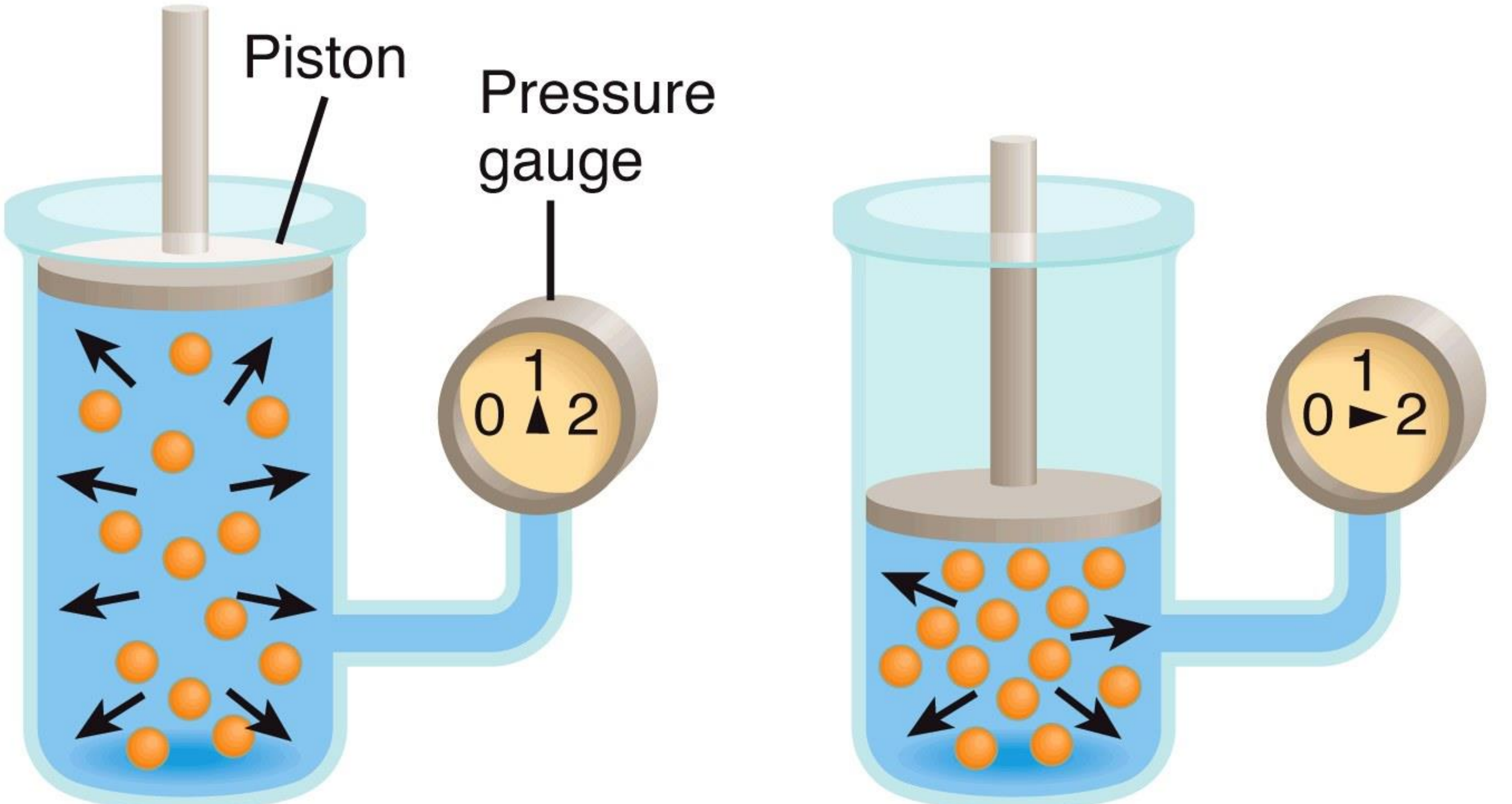
Respiration

- Three basic steps to the process of gas exchange in the body
- Pulmonary ventilation (breathing)
  - Air flow between atmosphere and alveoli due to alternating pressure differences created by contraction and relaxation of respiratory muscles
  - Inhalation and exhalation
- External respiration (pulmonary exchange)
  - Passive diffusion of gases based on gradient
- Internal respiration (tissue exchange)
  - Passive diffusion of gases based on gradient

Pressure Changes During Pulmonary Ventilation

- Inhalation occurs when alveolar pressure falls below atmospheric pressure
- Exhalation occurs when alveolar pressure is higher than atmospheric pressure
- Boyle's law
  - Volume of gas varies inversely with its pressure
- Differences in pressure caused by changes in lung volume force air into lungs during inhalation and out during exhalation

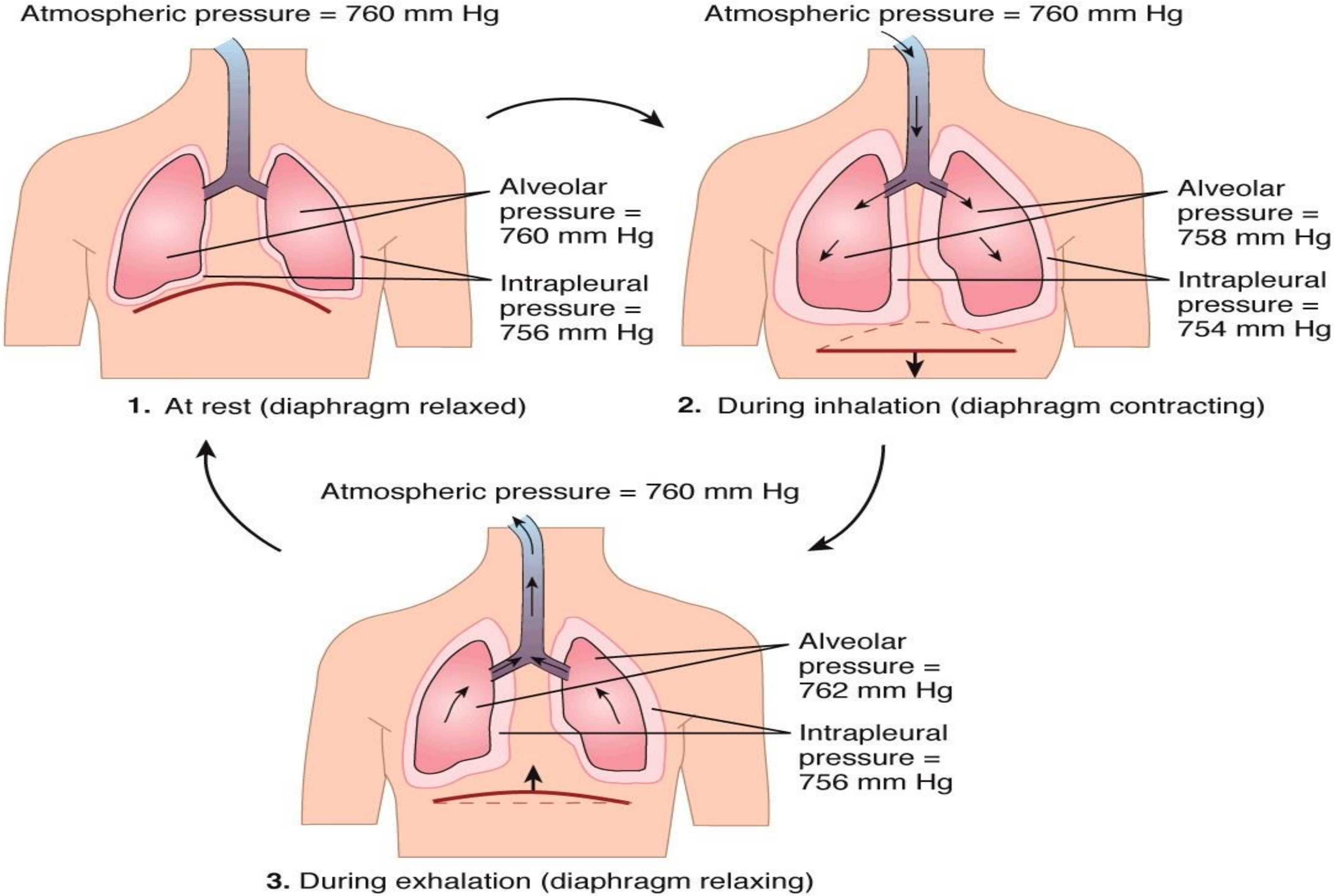
Boyle's Law



Volume = 1 liter
Pressure = 1 atm

Volume = 1/2 liter
Pressure = 2 atm

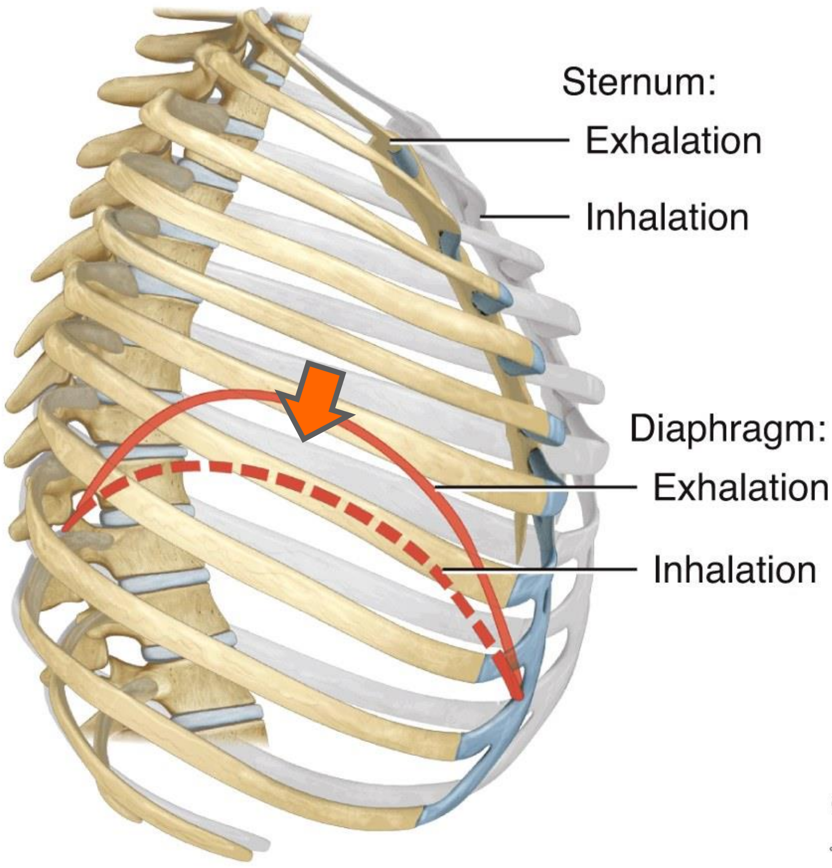
Pressure Changes During Pulmonary Ventilation



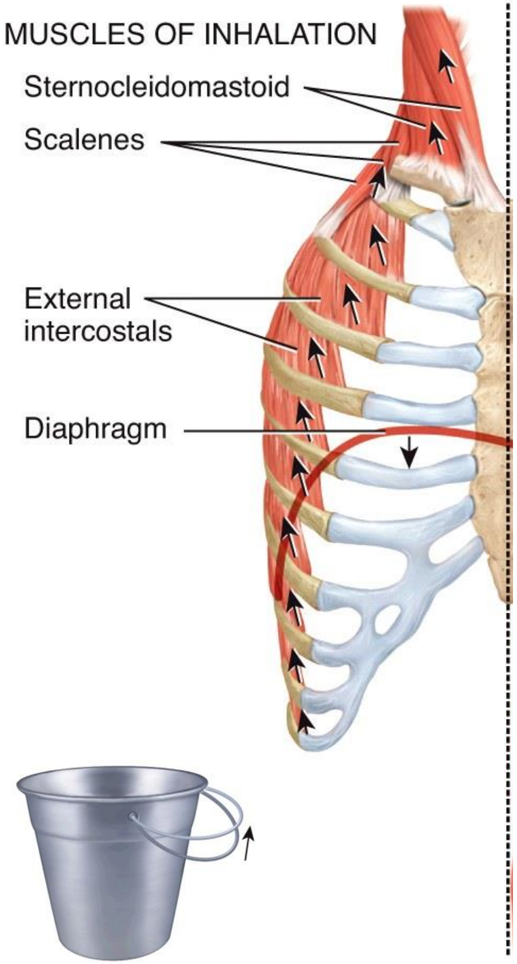
Inhalation

- Contraction of diaphragm and external intercostal muscles increase size of the lungs
- Expansion of lungs decreases alveolar pressure
- Air moves down a pressure gradient from the atmosphere into the lungs
- Deep, forceful inhalation involves accessory muscles that increase size of thoracic cavity further
- Intrapleural pressure (pleural cavity) maintained as sub atmospheric pressure helps keep alveoli slightly inflated

Inhalation



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

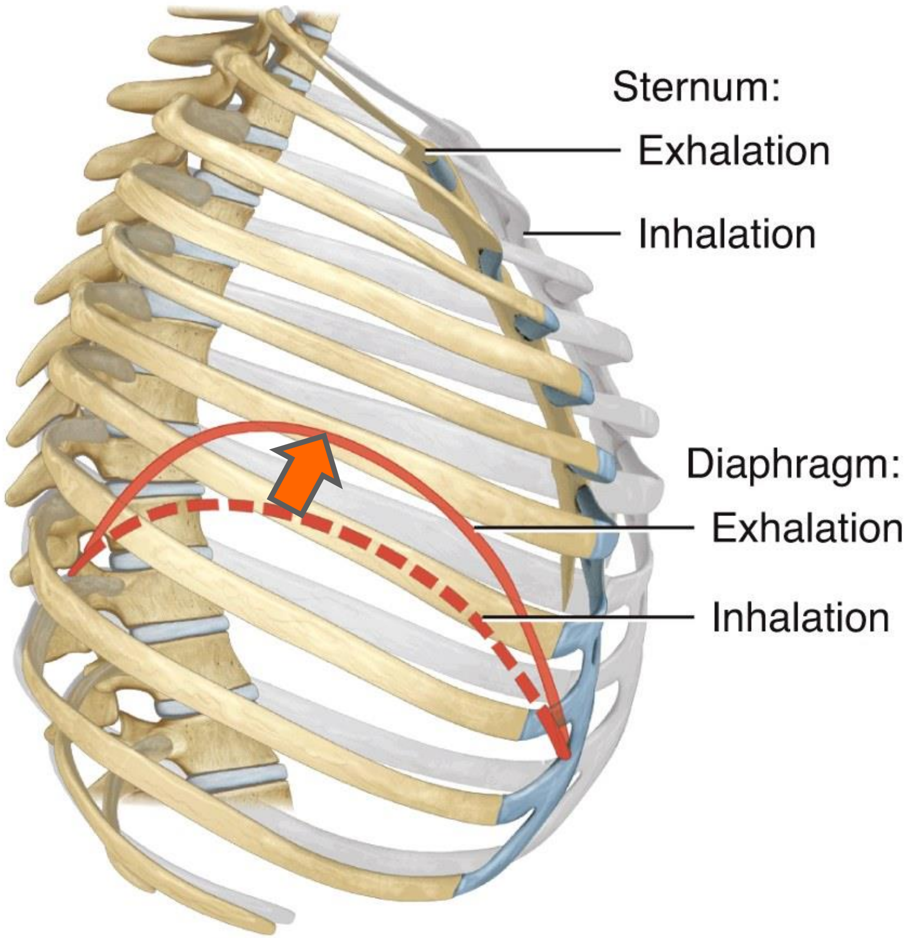


(c) During inhalation, the ribs move upward and outward like the handle on a bucket

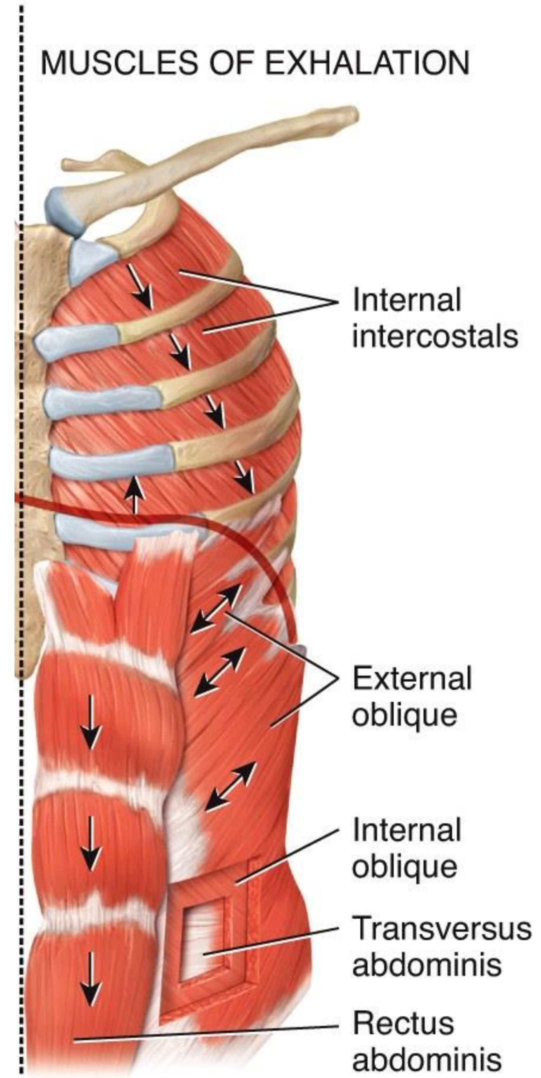
Exhalation (Expiration)

- Passive process during normal exhalation; active only with forced exhale
- Relaxation of diaphragm and external intercostals results in elastic recoil of chest wall and lungs
- Decreased size increases alveolar pressure
- Air moves down a pressure gradient from the lungs to the atmosphere
- Deep, forceful exhalation involves accessory muscles that decrease size of thoracic cavity further to force additional air out of lungs

Exhalation (Expiration)



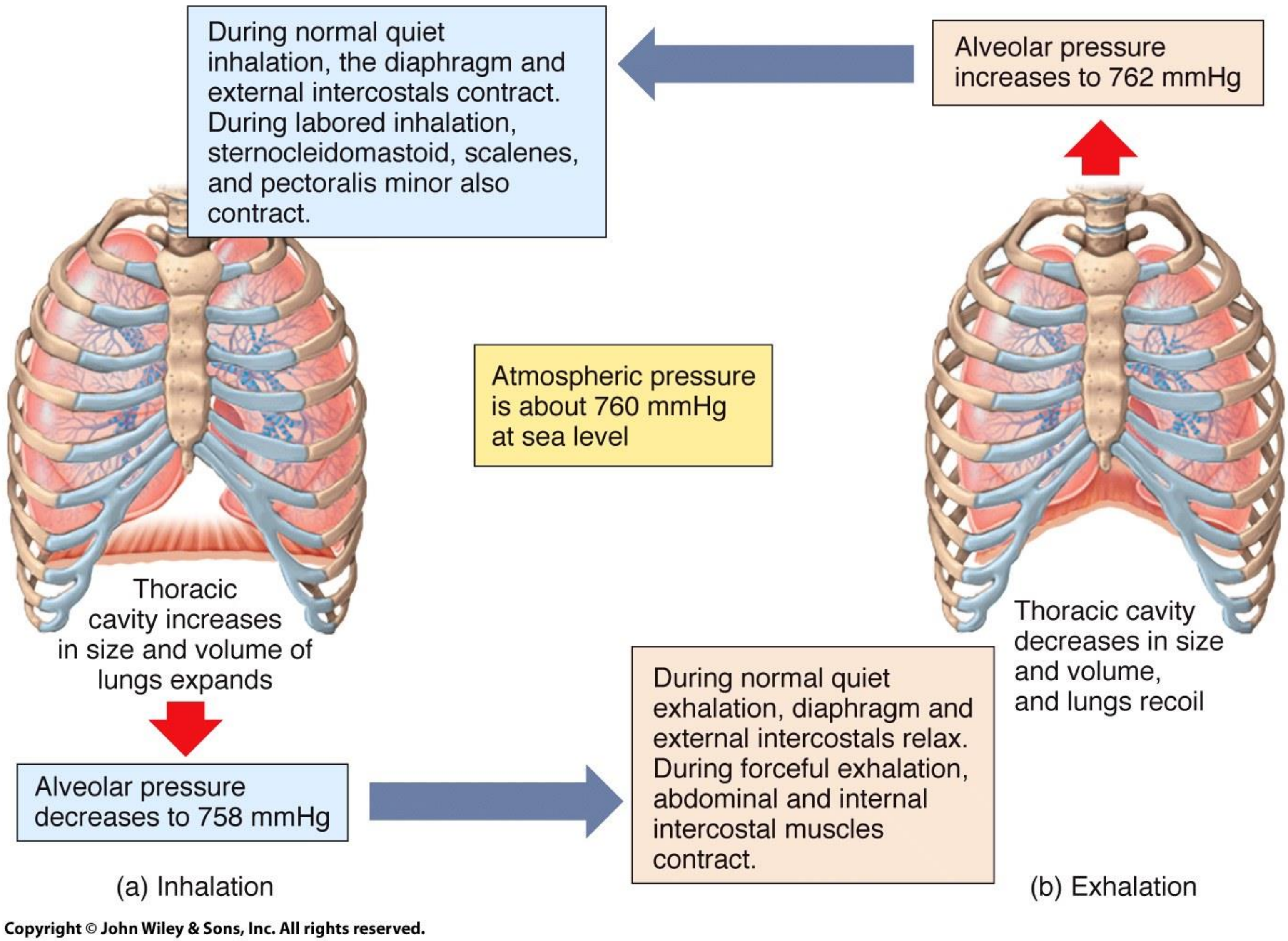
(b) Changes in size of thoracic cavity during inhalation and exhalation



Factors Affecting Pulmonary Ventilation

- Surface tension of alveolar fluid
  - Alveolar fluid produces an inward force on alveoli, accounting for much of the elastic recoil of exhalation
  - Surfactant in alveolar fluid reduces surface tension
- Compliance of lung tissue
  - Amount of effort required to stretch the lungs
  - Typically high compliance (expand easily) due to elastic fibers
- Airway resistance
  - Walls of airway offer resistance to flow of air in lumen
  - Anything that narrows or obstructs airways increases resistance

Pulmonary Ventilation Summary



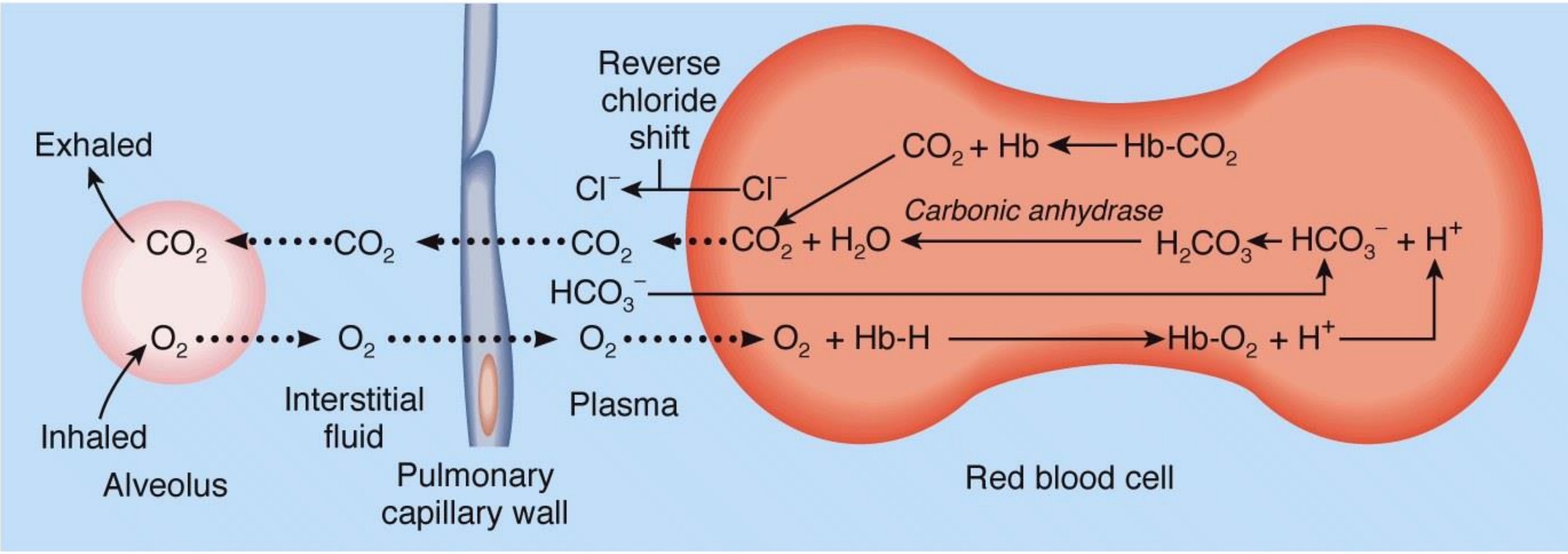
Diffusion of Gases

- Partial pressure of a gas is the pressure exerted by the gas in a mixture of gases
- Passive diffusion of gases is based on partial pressure gradients and solubility
- Dalton's law
  - Each gas in a mixture exerts its own pressure as if the other gases were not present
  - Each gas diffuses across a membrane by moving down its partial pressure gradient
- Henry's law
  - The quantity of a gas that will diffuse into a liquid is proportional to its partial pressure and solubility

External and Internal Respiration

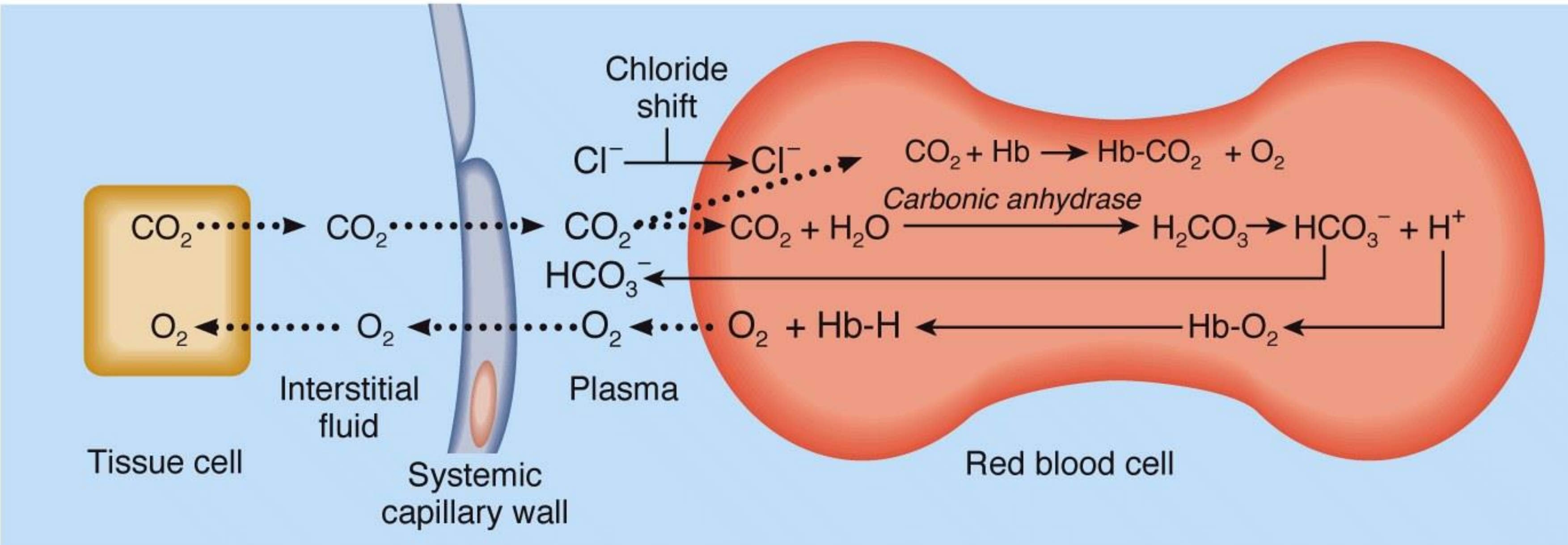
- External = net pulmonary gas exchange
  - Diffusion of O_2 from alveoli to blood in pulmonary capillary
  - Diffusion of CO_2 from pulmonary capillary blood to air
  - Converts oxygen-poor blood from right ventricle into oxygen-rich blood that returns to left atrium
- Internal = net tissue gas exchange
  - Diffusion of O_2 from systemic capillary blood to cell
  - Diffusion of CO_2 from cell to systemic capillary blood
  - Converts oxygen-rich blood from left ventricle into oxygen-poor blood that returns to right atrium
- Direction of exchange depends on partial pressure gradient across membranes

Summary of Chemical Reactions During Gas Transport and Exchange: External Respiration



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

Summary of Chemical Reactions During Gas Transport and Exchange: Internal Respiration



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

External and Internal Respiration Rate

- Rate of exchange varies depending on several factors
- Partial pressure differences of the gases
  - Larger differences accelerate rates of diffusion
- Surface area available for gas exchange
  - Any decrease in functional surface area slows diffusion
- Diffusion distance
  - Buildup of interstitial fluid increases distance and slows diffusion
- Molecular weight and solubility of the gases
  - CO_2 net diffusion greater than O_2 net diffusion

Oxygen Transport

- Small amount of O_2 is dissolved in blood plasma
- Most oxygen transported in blood bound temporarily to iron of hemoglobin in RBCs
  - Reversible reaction: oxyhemoglobin/deoxyhemoglobin
- Amount bound depends on partial pressure of oxygen (PO_2)
  - Higher PO_2 – hemoglobin saturated with 4 oxygen molecules
  - As PO_2 decreases - bond is weaker, O_2 dissociates (separates), and hemoglobin is partially saturated
  - Percent saturation depends on average number of O_2 molecules bound to hemoglobin (e.g., 2 O_2 = 50%)

Other Factors Affecting Affinity of Hemoglobin for Oxygen (Unloading)

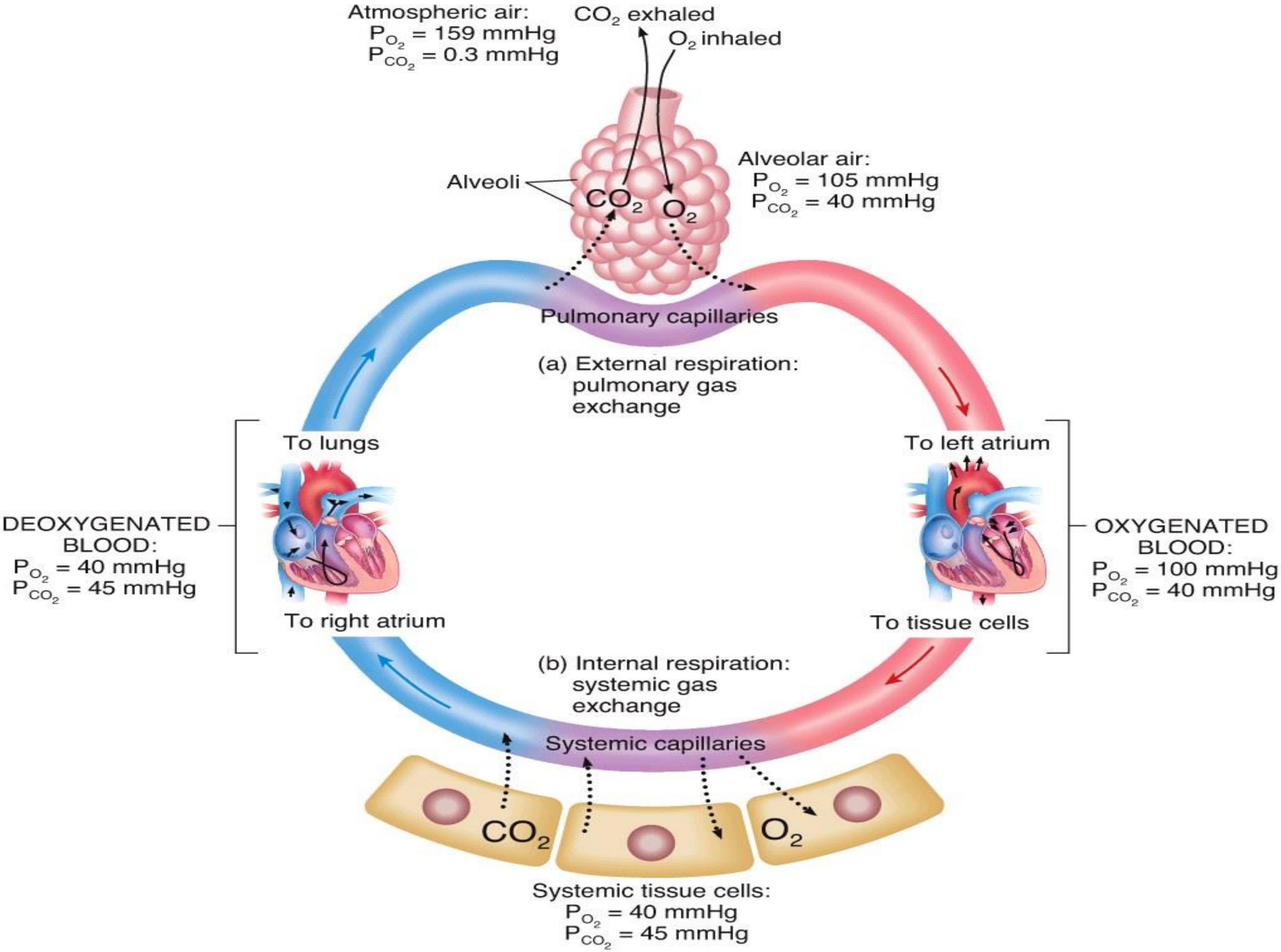
- As affinity (tightness of hemoglobin-oxygen bond) changes, O_2 is released from hemoglobin (unloaded), providing more O_2 to metabolically active cells
- Acidity
  - As acidity increases (pH decrease) O_2 dissociates more readily from hemoglobin – Bohr effect
  - Lactic acid and carbonic acid produced by active cells
- Temperature
  - As temperature increases, O_2 dissociates more readily from hemoglobin
  - Heat is a by-product of metabolic reactions

Other Factors Affecting Affinity of Hemoglobin for Oxygen

- P_{CO_2}
  - CO_2 can also bind to hemoglobin, affecting the bond
  - CO_2 also affects the bond through pH and Bohr effect
    - As CO_2 enters blood, it temporarily reacts with water (H_2O) to form carbonic acid in RBCs catalyzed by the enzyme carbonic anhydrase
    - Carbonic acid dissociates into bicarbonate ions (HCO_3^-) and hydrogen ions (H^+)
    - As concentration increases, blood pH decreases, and O_2 dissociates more readily from hemoglobin
- BPG (2,3-bisphosphoglycerate)
  - Byproduct of RBC metabolism, increases O_2 unloading

Carbon Dioxide Transport

- CO_2 is transported from cells back to lungs in three main forms
- Dissolved in blood plasma CO_2 ~ 7%
- Bound to hemoglobin ~ 23%
  - Carbaminohemoglobin – bound to globin portion of hemoglobin molecule
- Bicarbonate ions (HCO_3^-) ~ 70%
  - Carbonic anhydrase catalyzes formation of bicarbonate ions in RBCs as CO_2 reacts with H_2O
  - Bicarbonate ions move out of RBC into plasma, down concentration gradient
  - Chloride shift (Cl^- into RBC) maintains electrical balance



Atmospheric air:
P_{O_2} = 159 mmHg
P_{CO_2} = 0.3 mmHg
CO_2 exhaled
O_2 inhaled
Alveoli
CO_2
O_2
Alveolar air:
P_{O_2} = 105 mmHg
P_{CO_2} = 40 mmHg
Pulmonary capillaries
(a) External respiration: pulmonary gas exchange
To lungs
To left atrium
DEOXYGENATED BLOOD:
P_{O_2} = 40 mmHg
P_{CO_2} = 45 mmHg
OXYGENATED BLOOD:
P_{O_2} = 100 mmHg
P_{CO_2} = 40 mmHg
To right atrium
To tissue cells
(b) Internal respiration: systemic gas exchange
Systemic capillaries
CO_2
O_2
Systemic tissue cells:
P_{O_2} = 40 mmHg
P_{CO_2} = 45 mmHg

Control of Respiration

- Respiratory center, in the brain stem, sends impulses to respiratory muscles that alter size of the thorax for ventilation
- Medullary rhythmicity area – medulla oblongata
  - Inspiratory area establishes basic rhythm of breathing with impulses on phrenic and intercostal nerves
  - Expiratory area stimulates accessory muscles during forceful breathing
- Pneumotaxic area – upper pons
  - Inhibits inspiratory area before the lungs become too full
- Apneustic area – lower pons
  - Stimulates inspiratory area to prolong inhalation

Acid-Base Imbalances

- Acidosis
  - Systemic arterial blood pH below 7.35
  - Physiological effect – depression of CNS
- Alkalosis
  - Systemic arterial blood pH above 7.45
  - Physiological effect – overexcitability of CNS
- Respiratory compensation within minutes if source of pH change is metabolic
  - Acidosis – increased rate and depth of breathing expels more CO_2 (hyperventilation)
  - Alkalosis – decreased rate and depth of breathing accumulates CO_2 in blood

Acid-Base Imbalances

- Respiratory acidosis
  - Abnormally high systemic blood P_{CO_2} due to inadequate exhalation of CO_2 causes drop in blood pH
  - Causes include emphysema, pulmonary edema, injury to respiratory center, airway obstruction, and disorders of the respiratory muscles
- Respiratory alkalosis
  - Abnormally low systemic blood P_{CO_2} due to hyperventilation causes rise in blood pH
  - Causes include oxygen deficiency due to high altitude or pulmonary disease, stroke, and severe anxiety