Module 1.1: Cardiovascular System

**Reading Assignment:** KIN173_1_1_Sykes_1987_ADWallerAndTheElectrocardiogram.pdf

**Anatomical Position**
- A standardized method of observing or imaging the body that allows precise and consistent anatomical references.
  - Body erect
  - Feet slightly apart
  - Arms ___________________________________________
  - Palms ___________________________________________

**Directional Terms**
- _____________________________: Toward the head end or upper part of the body. Above.
- _____________________________: Away from the head end or upper part of the body. Below.
- _____________________________: Toward or at the front of the body. In front of.
- _____________________________: Toward or at the back of the body. Behind.
- _____________________________: Toward the middle of the body.
- _____________________________: Away from the middle of the body.
- _____________________________: Closer to the point of origin (attachment) of the body part.
- _____________________________: Farther from the origin of the body part.

**What does the Cardiovascular System Do?**
- 
-
The Circulation of the Blood through the Body:

- Transports ________________________________ for carbon dioxide.

- Removes ________________________________ and other metabolic wastes from tissues.

- Distributes hormone secretions from the endocrine glands.

- Transports immune system components (cells and antibodies).

- Helps regulate ____________________________________________.

- Maintains pH and fluid balance of bodily tissues.

**WHAT IS BLOOD?**

- Blood is the body’s only fluid ________________________________.

- The average adult human has about 5 liters of blood inside of their body, which makes up 7-8% of their body weight.

- Blood is about 5 times as thick as water.

- Blood on average is 38°C, slightly higher than “normal” body temperature

**Terminology**

- Heme, Hemato = Blood

- Emia = Blood Condition

- Hypovolemia - low blood volume

- Hypervolemia - high blood volume

**Blood is primarily comprised of 2 major components**

- 55% _____________________________________________

- 45% _____________________________________________

**Blood Plasma**

- Pale yellow liquid part of the blood.

- Made up of 91% ___________________________________________.
- 2% are **Solute**s – Nutrients, Electrolytes, Hormones, Blood Gases.

- 7% are Proteins:
  - **Albumin**: Important for maintaining
    - Accounts for 60 to 80% of blood proteins.
  - **Globulins**: Important for transporting immune cells and enzymes.
  - **Fibrinogen**: Responsible for the formation of blood clots.

**Formed Elements**

- Leukocytes (______________________________________________)
- Platelets
- Erythrocytes (______________________________________________
- For every 1 White Blood Cells, there are 45 Platelets, and 700 Red Blood Cells.
- So in 1 drop of blood, there are approximately:
  - 7 thousand WBCs, 300 thousand Platelets, and 5 million RBCs.

**What Makes Red Blood Cells Red?**

- Red blood cells contain ____________________________________________, which gives them their characteristic red color and helps them carry the oxygen.

- When oxygen binds to hemoglobin, the ________________________________ in the hemoglobin molecule reacts resulting in the bright red color.

- Without oxygen, the hemoglobin has a darker brownish-red hue.

- Each RBC contains 250 million molecules of hemoglobin taking up 97% of the cell contents.

- Erythrocytes are dedicated to respiratory gas transport.

- The flexible biconcave disc shape increases the surface area of the RBC by 30% allowing more

  ____________________________________________
to bind to each RBC.

- During a RBCs 100 to 120 day lifespan, it travels approximately 750 miles through the bloodstream.
**Anemia**

- Anemia occurs when the blood has abnormally low oxygen-carrying capacity.
  - Low blood oxygen levels cannot support normal metabolism.
- Can result from a number of issues including:
  - ____________________________ – blood loss, bone marrow disease, etc..
  - Decreased Hemoglobin Content – iron deficiencies, B₁₂ deficiency
  - ____________________________ – Sickle-cell anemia

**CARDIAC ANATOMY**

- An average adult heart is approximately the size of one to two fists.
- It takes about as much force as squeezing a tennis ball to contract the heart.
  - Even at rest, the muscles of the heart work twice as hard as the leg muscles of a person sprinting.
- The heart beats about:
  - 100 thousand times per day, 35 million times per year, 2.5 billion times over the course of 70 years.
- The heart is located near the center of the thoracic cavity between the lungs and is contained in the pericardial sac.
- The broad end, or ____________________________, of the heart is also partially supported by large arteries and veins.
- The pointed end, or ____________________________, of the heart is directed toward the abdomen.
- The ____________________________ is a loose fitting, double layered sac designed to:
  - Supports the weight of the heart and roots of the great (large) blood vessels.
  - Prevents friction from damaging the heart or lungs as the heart beats.
  - Comprised of 3 layers:
    - The outside connective tissue.
• The inner layer filled with pericardial fluid – one layer attaches to the outside connective tissue, the other is a part of the heart wall.

The Heart Wall

1. The ________________________________ pericardium is the most superficial layer, made up of dense connective tissue.

2. The ________________________________ pericardium is the inner layer of the pericardium, which secretes pericardial fluid to prevent friction.

3. The ________________________________ pericardium - also known as the Epicardium - is a smooth membrane on the surface of the heart.

4. The ________________________________ cardium is the actual cardiac muscle tissue layer.

5. The ________________________________ cardium is the inner most layer of the heart, consisting of endothelial cells which cover the heart valves and lines the blood vessels.

The Chambers of the Heart

• In mammals and birds, the heart is divided into a right and left side and each side is divided into an atrium and ventricle.

• Therefore, the heart is said to have four chambers.

• When viewed Anteriorly you mostly see the ____________________________ Ventricle.
• When viewed posteriorly you mostly see the ____________________________ Ventricle.

• The 2 atria act as collecting reservoirs.

• The 2 ventricles act as pumps.

• The thickness of the chamber walls varying as a function of the stress placed upon them.

• Because the left ventricle is responsible for sending the blood to ____________________________________________________________________________, the left ventricle has a massive muscular wall.

• The right ventricle wall is relatively thin because it only sends blood to the lungs.

**Blood Vessels**

• The blood vessels are long, skinny tubular structures running throughout the body.
  
  • The average human has roughly the equivalent of 62,000 miles of blood vessels.
  
  • The heart completely circulates the blood 1,000 times each day.

• Blood vessels are classified into 5 types according to their form and function.
  
  • _______________________________ - Blood vessels that carry blood away from the heart.
    
    • Have elastic tissue in walls to absorb high pressure surges of blood.
  
  • _______________________________ - As the arteries extend away from the heart they branch out into smaller arteries called Arterioles.
    
    • Have thick layers of smooth muscle tissue in walls to control blood flow.
  
  • _______________________________ - Arterioles branch into smaller vessels called Capillaries.
    
    • Allow diffusion of gases, nutrients, and wastes.
  
  • _______________________________ - Capillaries unite to form small vessels called Venules. Have valves in the vessel.
  
  • _______________________________ - Venules join together to form larger Veins which carry blood to the heart. Have valves in the vessel.
Why do Veins and Venules have Valves?

- Arteries have the advantage of being High Pressure vessels.
- This pressure can exceed the forces of gravity and cause blood to circulate into tissues above the heart.
- Veins are Low Pressure vessels and therefore must rely on other mechanisms in order for blood to return to the heart.
- Valves make the system a One-Way loop and prevent the

• Valves also allow for the skeletal muscle to help push blood back up into the heart – a process called the ___________________________.

Blood Vessels

• Aorta - The Aorta is the largest artery in the body, originating from the

________________________________________________________ of the heart and extending down to the abdomen.

• Because the blood pressure is greatest in the Aorta, it has the most elastic fibers and is responsible for partially diffusing the pulsating blood into a smooth laminar stream.

• Vena Cava - Actually Two Different Blood Vessels which drain into the

________________________________________________________ of the Heart.

• The ___________________________Vena Cava is a large diameter, yet short, vein which carries blood from the upper portion of the body.
• The _____________________________ Vena Cava is a long large diameter vein which carries blood from the lower portion of the body.

• The Vena Cava and Aorta are the primary blood vessels involved in the Systemic Circuit which delivers blood to the rest of the body.

• In the Systemic Circuit:
  
  • Arteries carry ________________________________ Blood
  
  • Veins carry ________________________________ Blood

• Pulmonary Artery - The pulmonary artery is a large artery that originates from the ________________________________ and divides into the left and right pulmonary arteries.
  
  • These arteries take blood away from the heart and bring it to the lungs where it can be enriched with oxygen,

• Pulmonary Vein - The pulmonary veins carry oxygen rich blood from the lungs to the ________________________________ of the Heart.

  • The Pulmonary Artery and Pulmonary Vein make up the Pulmonary Circuit which is responsible for oxygenating the blood.

• In the Pulmonary Circuit:
  
  • Arteries carry ________________________________ Blood
  
  • Veins carry ________________________________ Blood

**CARDIAC CYCLE**

• The _______________________ side of the heart deals with deoxygenated blood (in blue).
  
  • The Atrium receives deoxygenated blood from the body.
  
  • The Ventricle sends deoxygenated blood to the lungs.

• The _______________________ side of the heart deals with oxygenated blood (in red).
  
  • The Atrium receives oxygenated blood from the lungs.
  
  • The Ventricle sends oxygenated blood to the body.
Tracing Blood Flow

1. The ____________________________ returns blood that is low in oxygen to the Right Atrium of the Heart.

2. The ____________________________ contract slightly and the ____________________________ opens allowing blood to flow into the Right Ventricle.

3. The Right Ventricle contracts causing the ____________________________ to shut and blood to flow through the ____________________________ into the Pulmonary Artery.

4. The blood then moves into the lung to be oxygenated.

5. The oxygenated blood returns to the heart through the ____________________________

6. As the heart relaxes, blood drains from the Pulmonary Vein into the Left Atrium.

7. The Atria contract slightly and the ____________________________ opens allowing blood to flow into the ____________________________.

8. The thick-walled Left Ventricle contracts ejecting blood through the ____________________________ into the Aorta.

9. The heart then returns to its resting, non-contracted state.
One Cardiac Cycle = 1 contraction phase and 1 relaxation phase:

- The cardiac cycle is defined as the mechanical and electrical events that occur during one heart beat.
  
  - _______________________________ is the relaxation phase during which the chambers fill with blood.
  
  - _______________________________ is the contraction phase during which the chambers expel blood.

- While the heart is in its resting, non-contracted state, the Atria are filling with blood.
  
  - Referred to as **Diastole**.

- The Atria contract slightly and both the _______________________________ Valves open allowing blood to flow into the Ventricles.
  
  - 80% of the blood enters the Ventricles passively, with **Atrial Systole** pushing the remainder out.

- The Ventricles contract ejecting blood through the Pulmonary Valve towards the lungs and Aortic Valve towards the body.
  
  - Referred to as _______________________________, the blood cannot be ejected until the pressure in the ventricle exceeds that of the arteries.

- The heart then returns to its resting, non-contracted state, and Atrial filling begins again.

**WHAT MECHANICAL ACTION CAUSES THE HEART SOUNDS?**

- During the cardiac cycle, the heart makes a Lub-Dub sound:

  - The 1st heart sound ‘Lub’ occurs during **Ventricular Systole**, when the rising **ventricular pressure** pushes the

    _______________________________________________________________ Valves closed.

  - The 2nd heart sound ‘Dub’ occurs during **Ventricular Diastole**, when the **backflow** of blood in the blood vessels push the

    _______________________________________________________________ Valves closed.

**WHAT CAUSES THE HEART TO BEAT?**

- The Heart contracts spontaneously and can contract without any stimulation from the nervous system.
• Motor nerves that innervate the heart serve to modulate heart rate.
  
  • Parasympathetic Nervous System (‘Rest and Digest’) innervation occurs through the _______ and acts to slow heart rate.
    • Heavy PNS activity can cause Bradycardia – resting HR below 60 bpm.
  
  • Sympathetic Nervous System (‘Fight or Flight’) innervation occurs through the _______ and acts to increase heart rate.
    • Heavy SNS activity can cause Tachycardia – resting HR above 100 bpm.
  
• The Heart can work without any nervous system innervation because cardiac cells can depolarize spontaneously.
  
  • These cells are termed __________________________ Cells and are:
    • Non-contractile cells
    • Self-excitible
    • Can generate spontaneous action potentials triggering the contraction of the heart.

Sequence of Excitation

1. ____________________________ (SA) Node
   • Electrical excitation begins in the SA Node.
   • The action potentials spread along the Atrial walls causing muscle contractions.

2. ____________________________ (AV) Node
   • The depolarization of cardiac tissue reaches the AV Node which delays the action potential by approximately 100 ms.
• Action potentials are conducted more slowly here than in any other part of the cardiac system.

3. **Bundle of ________________________________**

• The depolarization of cardiac tissues passes from the Atria into the Ventricles through the Bundle of His.

4. **_______________________________ Fibers**

• Action potentials descend to the apex of each ventricle and are carried by the Purkinje Fibers up along the ventricular walls causing contraction of the ventricles.

**Electrical Activity in the Heart**

• Scientists in the late 1800’s and early 1900’s discovered that they could reliably record the electrical activity of the heart using the ‘String Galvanometer’ which was invented by Willem Einthoven (for which he was awarded the Nobel Prize).

• Einthoven’s description and nomenclature of the electrical activity of the heart as an ‘Electrocardiogram’ have become the standard.

• Electrocardiography (ECG or EKG from the *German Elektrokardiogramm*) detects and amplifies the electrical activity which occurs when the heart muscles depolarize during each cardiac cycle.

• Changes in the electrical voltage (the difference in charge between two points) are associated with specific aspects of the cardiac excitation sequence.

• An ECG trace has different characteristics depending on the ________________________of the electrodes recording it.

• Einthoven created a now standard electrode arrangement using 3 standard leads plus 7 additional electrodes which allows 12 different views of the electrical activity in the heart – referred to as a 12-lead ECG.

• Most ECG uses can be accomplished using only the 3 standard leads – referred to as a ____________________________________________________________________.

**Einthoven’s Triangle**

• The Standard Lead configuration places:

  • One electrode on each side of the ______________________________.

  • One electrode on the ________________________________.

**Lead I:**
• Comparison of ____________________________________________.

• Looks at the electrical activity in the heart running medially to laterally through the body.

• Commonly used in Heart Rate Monitoring devices such as Polar HR monitors.

Lead II:

• Comparison of ____________________________________________.

• Looks at the electrical activity in the heart running medial-superior to lateral-inferior through the body.

• This most closely follows the conduction pathway of the heart.

Lead III:

• Comparison of ____________________________________________.

• Looks at the electrical activity in the heart running superior to inferior through the body.

Normal Sinus Rhythm

• The prototypical ECG pattern is referred to as

________________________________________________________
is and is typically characterized from Lead II.

• Each peak has a specific naming convention associated with it.

• **Note:** the size of the peak does not indicate the ___________________________ of the contraction, just the net electrical activity oriented towards the electrode at any given time.

• The __________________ wave is associated with Atrial Depolarization signaling the onset of atrial contraction.
  
  • Since the atrial muscle action potential is slow, the wave presents with a rounded deflection.

• The delay immediately after the P wave, with no electrical activity, occurs due to the
• The ______________________________ complex occurs during Ventricular Depolarization.
  • During this time Atrial Repolarization occurs, but is hidden by the greater electrical activity of Ventricular Depolarization.
  • The septum depolarizes from the inside out (therefore not heading towards the Left Lower lead) creating the __________________________ wave.
  • The depolarization of cardiac tissue descending to the apex of each ventricle creates the __________________________ wave.
  • The depolarization up along the ventricular walls creates the ___________ wave.
  • The __________-wave is a reflection of the slow process of ventricular repolarization of cardiac tissue beginning from the lateral wall back to the septum.

**FAILURES IN THE EXCITATION PATHWAYS**

![ECG waveform]

• The lack of a P wave indicates that the ______________________________ is not firing.

• Referred to as a ‘Junctional Rhythm’.

• If the SA node is not firing then how do we get Ventricular Depolarization?

• There are three potential areas in the heart which are capable of beginning the cardiac cycle.
  • **Sinoatrial (SA) Node** - Referred to as the ‘pacemaker’ of the heart.
    • Generates impulses with an intrinsic rate of ____________ beats per minute.
  • **Atrioventricular (AV) Node** - Back-up pacemaker.
    • Generates impulses with an intrinsic rate of ____________ beats per minute.
  • **Ventricular Cells** - Secondary back-up pacemaker
    • Generates impulses with an intrinsic rate of ____________ beats per minute.
• The P wave indicates that Atrial depolarization is occurring.
• The depolarization stops before the Q-R-S complex.
• So the failure must be in the ________________________________ from the Atria to the Ventricles – This is referred to as ‘Atrioventricular Block’.

• Premature Ventricular Contractions (PVC’s) - the Q-R-S complex occurs prematurely without being preceded by the P-wave, and is wide and bizarre.
• The ________________________________ fired before the SA node could initiate the cycle.

• Ventricular ________________________________ – Runs of three or more consecutive PVC’s.
• Individuals in Ventricular Tachycardia feel palpitations in their chest and feel faint.
• If they are sustained for longer periods of time, unconsciousness can occur.
MODULE 1.1: CARDIOVASCULAR SYSTEM

• **Ventricular** — Completely abnormal depolarization!

• There are no true Q-R-S Complexes, contraction is insufficient to push blood around the body.

• Seen in dying hearts. CPR and Defibrillation are needed!

• — A state of no cardiac electrical activity (no contractions – no circulation of blood).

• Asystole is one of the conditions necessary for medical personnel to certify death.

• Unlike in TV, a defibrillator will not restart electrical activity from Asystole.

**CARDIAC OUTPUT**

• **Cardiac Output** \( (Q) \) — the amount of blood pumped by __________________________.

• Cardiac output is the product of ______________ and ______________:
  \[ Q = \text{HR} \times \text{SV} \]

  • Stroke Volume is the amount of blood pumped out by the left ventricle with each beat.

**In order to calculate Stroke Volume we have to know:**

• How much blood filled the left ventricle at rest (diastole).

  • End __________________________ Volume (EDV) – ‘Preload’

• How much blood is left in the left ventricle after contraction (systole).

  • End __________________________ Volume (ESV)

• **Stroke Volume = End Diastolic Volume – End Systolic Volume**

**Change in Stroke Volume With Exercise**

• During exercise, End Diastolic Volume increases as a result of:
• Increased __________________________ of blood.

• ________________________________ Volume of blood.

Frank-Starling Mechanism

• The Frank-Starling Mechanism states that ventricular contraction becomes more forceful as the cardiac muscle cells are __________________________.

• This does not occur in Skeletal Muscles!

• By increasing the volume of blood in the ventricle at rest, the cardiac muscle is stretched, causing an increase in the force of the contraction which ejects more blood and increases Stoke Volume.

  • The more blood going ________________________________,

  the more blood ________________________________.

The Heart never ejects 100% of the blood from the ventricle.

• The proportion that is ejected is called the ‘Ejection Fraction’ (EF)

  • Ejection Fraction = __________________________ / __________________________

  • At rest, EF averages approximately 60%

  • During maximal exercise, EF averages approximately 80%

  • Ejection Fraction offers one of the best indicators of heart performance and heart disease prognosis – ‘the functional measure of the heart’.

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<thead>
<tr>
<th></th>
<th>At Rest</th>
<th>Moderate Exercise</th>
<th>Maximal Exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart Rate</td>
<td>70 bpm</td>
<td>130 bpm</td>
<td>200 bpm</td>
</tr>
<tr>
<td>End Diastolic Volume</td>
<td>120 ml</td>
<td>160 ml</td>
<td>163 ml</td>
</tr>
<tr>
<td>End Systolic Volume</td>
<td>50 ml</td>
<td>48 ml</td>
<td>35 ml</td>
</tr>
<tr>
<td>Stroke Volume</td>
<td>70 ml</td>
<td>112 ml</td>
<td>128 ml</td>
</tr>
<tr>
<td>Ejection Fraction</td>
<td>58.3%</td>
<td></td>
<td></td>
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<tr>
<td>Cardiac Output</td>
<td></td>
<td></td>
<td>4.9 L/min</td>
</tr>
</tbody>
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**Blood Pressure**

• Pressure During the Cardiac Cycle
During Ventricular Diastole:
- The pressure in the ventricles is ____________________ - Blood is filling from the Atria.

During Ventricular Systole:
- The pressure in the ventricles ___________________________.
- Blood is ejected into pulmonary and systemic circulation.

The Pressure generated in the arteries during ventricular contraction (systole) is referred to as ‘Systolic Blood Pressure’.

The Pressure generated in the arteries during ventricular relaxation (diastole) is referred to as ‘Diastolic Blood Pressure’.

Blood Pressure is expressed as Systolic / Diastolic.
- The hypothetical ‘Normal’ blood pressure is 120/80 mmHg.
- Hypertension is blood pressure exceeding _______________ mmHg.

Because arterial pressure pulsates with the contraction and relaxation of the heart, Mean Arterial Pressure (MAP) is used to represent the overall driving pressure in the system.

\[
\text{MAP} = \text{Diastolic BP} + \frac{1}{3}(\text{Systolic BP} - \text{Diastolic BP})
\]

BP = 120 / 80 mmHg
\[
\text{MAP} = 80 + \frac{1}{3}(120 - 80)
\]

Mean Arterial Pressure = 80 + 13 = _________________ mmHg

Blood Pressure in any given tissue is State dependent
- The body has the ability to regulate blood pressure in specific tissues to meet the demands of the body.
  - The blood flow to appendages can be ___________________________ to keep more heat near the core of the body.
  - Metabolic demands (both requirements and by-products) can require additional blood flow.
  - Circulating inflammatory chemicals can modulate local blood pressure.

Blood flow is redistributed during exercise:
- ___________________________ Muscles, _____________________________ Organs

This redistribution depends on the intensity of the exercise.
- Arterial Blood Pressure increases with increased exercise intensity.
• Systolic pressure rises progressively.
• Diastolic pressure changes very little.

• Thus, MAP ________________________________ with intensity.

Changing Blood Flow

• Blood flow can change by either changing pressure (cardiac output) or resistance or a combination of the two.
  • Changing resistance has a ________________________________ on blood flow.
• The smaller the vessel the less fluid can flow through it.
  • The majority of changes in resistance occur in the ____________________________.
• The smooth muscle tissue in the Arterioles offers the ability to change the resistance in the blood vessel.
  • Vasoconstriction - Contraction of the smooth muscle, ____________________________ blood flow.
  • Vasodilation - Relaxation of the smooth muscle, ____________________________ blood flow.
WHAT DOES THE RESPIRATORY SYSTEM DO?

The primary purpose of the respiratory system is to:

- Provide a means of oxygen and carbon dioxide exchange between

-----------------------------------------------------------------------------------------------------------------------

- This process works together with the circulatory system!

- If respiratory system and/or circulatory system fails, death will occur within minutes.
  - After 4 minutes without oxygen brain damage begins to occur.
  - After 10 minutes this brain damage becomes irreversible.

The respiratory system is also involved in:

- **Regulation of _____________________________** – Modulates the circulating levels of carbon dioxide.

- __________________________________________________________________ - Movement of air past vocal folds makes sound and speech.

- **Olfaction** - Smell occurs when airborne molecules drawn into nasal cavity.

- **Thermoregulation** - Heating and cooling of body.

- **Protection** - Filtering inspired air to protect against microorganisms.

STAGES OF THE RESPIRATORY CYCLE

The Respiratory Cycle has 3 stages:

1. **Pulmonary _____________________________** – The exchange of gases between the lungs and external environment.

2. **External _____________________________** – The exchange of gases between the lungs and the blood stream.

3. **Internal _____________________________** – The exchange of gases between the blood stream and bodily tissues.
ANATOMY OF THE RESPIRATORY SYSTEM

- The respiratory system consists of all the structures that make up the airway and allow us to breathe.

- The organs of the respiratory system can be subdivided according to functions into two separate zones.
  - The Conduction Zone consisting of all the respiratory passageways
  - The Respiratory Zone where gases are exchanged.

Nasal Cavity

- Provides an airway for respiration.
- Warms and moistens air.
- Filters and cleans inspired air.
- Houses olfactory receptors.
- Resonating chamber for speech.

- Common passageway for both air and food.
- Commonly referred to as the Throat.

- Complex structure formed by many independent cartilage structures.
  - Nine c-rings of cartilage form the framework of the larynx.
- Cricoid cartilage forms the lowest portion of the larynx.
- Routes air and food into proper passageways.

- Routes air and food into proper passageways.
- Rotates inferior-posteriorly during swallowing.
• Flexible tube also referred to as the ‘windpipe’.
• Formed by C-shaped tracheal cartilages which reinforce and provide rigidity to ensure the trachea remains open.
• Conduit for air entry into the lungs.
• **Carina** – marks where the trachea divides.

**Lungs**

• Paired, cone-shaped organs divided into lobes.

• Left Lung is divided by the ______________________________ into 2 lobes.
  • Cardiac notch accommodates the heart.

• Right Lung is divided by ______________________________ and ______________________________ into 3 lobes.
  • Located more superiorly in the body due to the liver.

**Pleura**

• Lungs are enclosed by membranes called pleura.

• The outer surface of each lung is tightly covered by the ______________________________ **pleura**.

• The thoracic wall and diaphragm are covered by the ______________________________ **pleura**.

• The pleural membranes produce **pleural fluid** that circulates in the pleural cavity and acts as a lubricant, ensuring minimal friction between the lungs and the rib cage.

**Alveoli**

• Alveoli are small, thin walled, inflatable sacs at end of bronchioles.
  • There are millions of alveoli in each lung.
  • Surrounded by jacket of pulmonary capillaries.
• Provide thin barrier and enormous surface area for gas exchange by diffusion.

• Type ________________ alveolar cells form the structure.

• Type ________________ secrete surfactant.

**Respiratory Zones**

• The **Conduction Zone** consists of the passageways down to and including the bronchi.

• The **Respiratory Zone** consists of the lower bronchioles and __________________________.

**Muscles Involved in Respiration**

• At rest, in a healthy adult, the ____________________________ is the dominant muscle of respiration.

• A parachute shaped musculotendinous sheet attached to the thoracic cage under the lower ribs.

• Muscle contraction causes the diaphragm to flatten.

• During ________________________________, the intercostal muscles and pectoralis minor become involved.

**SO HOW DO WE GET AIR INTO THE LUNGS?**

• **Pulmonary Ventilation**, commonly referred to as ‘breathing’, is the process of ____________________________ in and out of the lungs.

• This process is divided into Inhalation and Exhalation, both of which are the result of changes in the volume of the thorax which causes air to move from High Pressure to Low Pressure.

  • **Inspiration** is an ____________________________ Process, requiring muscular contraction.

  • **Expiration** is a ____________________________ Process, involving relaxation of the muscles.

**Mechanics of Inspiration**

• Air is a compressible gas which obeys ____________________________ Law.

  • When temperature is constant, the pressure of a gas varies inversely with it’s volume.
• \( P_1V_1 = P_2V_2 \) \( \rightarrow \) If Volume increases, pressure must ________________________________.

• During inspiration, the diaphragm contracts and flattens and the intercostals maintain the rigidity of the chest wall.
  • Otherwise, reduced intra-thoracic pressure would cause the chest wall to collapse inwards.

• Expansion of the lungs causes the pressure inside to ________________________________ atmospheric pressure.

• Air enters the lungs to ________________________________ the pressure difference between the external atmosphere and the internal compartments of the lungs.

• During exertion, the **accessory muscles** (intercostal muscles and pectoralis minor) become involved to help increase interthoracic volume. These muscles cause the ribcage to

  ________________________________________________.

**Mechanics of Expiration**

• The thorax and lungs tend to resist distension and thus recoil when the distending force subsides.

• When the diaphragm and intercostal muscles relax, the

  ________________________________________________ causes the thorax and lungs to recoil.

  • The volume of the chest decreases, causing the pressure inside the lungs to _________________ the atmospheric pressure.

  • Air leaves the lungs to stabilize the pressure difference between the external atmosphere and the internal compartments of the lungs.

  • During exertion or ________________________________, the intercostals and abdominal muscles assist in decreasing the volume of the thorax and lungs.

**MECHANICAL FAILURES IN PULMONARY VENTILATION**

Factors Affecting Pulmonary Ventilation

Intrinsic factors:

• Infections

• Allergic reactions

• Breathing disorders
Extrinsic factors:

- Trauma
- Foreign body airway obstruction

Pneumothorax

- Occurs when ____________________ leaks from the lung into the chest cavity.
- Often occurs following blunt trauma.
- Can result in a collapsed lung. Causes difficulty breathing.

Open Pneumothorax

- Occurs when an ____________________________ to the chest allows air to enter the pleural space instead of into the lung.
- Often referred to as a ‘sucking chest wound’.
- Can result in a collapsed lung. Causes difficulty breathing.

Hemothorax

- Occurs when ____________________________ leaks into the pleural cavity.
- Often occurs following blunt trauma.
- Can result in a collapsed lung. Causes difficulty breathing.

**PULMONARY VOLUMES**

- **Pulmonary Ventilation (V)** - The amount of air moved in or out of the lungs per minute (‘respiratory minute ventilation’). A factor in determining oxygen levels in blood.

\[
V = \text{Tidal Volume} \times \text{Breathing Frequency}
\]
• **Volume (TV)** - the volume of gas inspired or expired during each normal (unforced) ventilation cycle
  - Volume of air moved into the lungs in a single breath.

• **Reserve Volume (IRV)** - The maximum amount of gas that can be forcefully inhaled after a normal inhalation (typically about 3100 ml).

• **Reserve Volume (ERV)** - The maximum volume of gas that can be forcefully exhaled after a normal exhalation (typically about 1200 ml).

• **Residual Volume (RV)** - The amount of gas left in the lungs after a maximum (forced) exhalation. Necessary otherwise the lungs would collapse (typically about 1200 ml).

Combinations of two or more pulmonary volumes are called capacities

• **Capacity (IC)** - Tidal volume plus inspiratory reserve volume.
  \[ IC = TV + IRV \]

• **Capacity (FRC)** - Expiratory reserve volume plus the residual volume.
  \[ FRC = ERV + RV \]

• **Capacity (VC)** - Sum of inspiratory reserve volume, tidal volume, and expiratory reserve volume.
  \[ VC = IRV + TV + ERV \]

• **Total lung capacity (TLC)** - Sum of inspiratory and expiratory reserve volumes plus the tidal volume and residual volume.
  \[ TLC = IRV + ERV + TV + RV \]

**EXTERNAL AND INTERNAL RESPIRATION**

_______________________________________________ is the key process by which respiration occurs.

• When there is a difference in the concentration of a substance between two areas.

• The substance will spread from areas of high concentration to areas of low concentration.
The movement of gasses between the Alveoli and the Blood (External Respiration) or the Blood and the Cells (Internal Respiration) depends on the difference in ____________________________ of the two areas.

______________________________ Law states that the total pressure (force) exerted by a mixture of gases is the sum of the pressures exerted independently by each gas in the mixture.

- Each gas thus has a **Partial Pressure**.
- The partial pressure of a gas is directly proportional to the ____________________________ in a mixture.
- To calculate the partial pressure of a gas, multiply the total pressure of the mixture by the percent concentration of the gas.
  
  \[ P_{\text{total}} = P(\text{Nitrogen}) + P(\text{Oxygen}) + P(\text{Carbon Dioxide}) + P(\text{Other Gasses}) \]
  
  \[ P_{\text{total}} = P(78\%) + P(21\%) + P(0.04\%) + P(0.9\%) \]
  
  Atmospheric Pressure at Sea Level (760 mmHg) = 760(78\%) + 760(21\%) + 760(0.04\%) + 760(0.9\%)
  
  \[ P_N = 593 \text{ mmHg} \quad P_{O_2} = 160 \text{ mmHg} \quad P_{CO_2} = 0.3 \text{ mmHg} \quad P_{\text{other gases}} = 7 \text{ mmHg} \]

______________________________ Law states that the rate at which gases diffuse is

- Proportional to the differences in ____________________________
- Proportional to the surface area available.
  - In humans there are about 600 million total alveoli, with a total surface area between 60 to 80 square meters -> 42 times the surface area of the body or about half the size of a tennis court.
- Inversely proportional to the ____________________________ of the membrane.
  - Each alveolus has an epithelium only one cell thick which is surrounded by pulmonary capillaries with walls that are only one cell thick.
EXTERNAL RESPIRATION

- Alveolar oxygen partial pressure is lower than the atmospheric oxygen partial pressure for two reasons:
  - As the air enters the lungs, it is ____________________________ by the upper airway and thus the partial pressure of water vapor reduces the oxygen partial pressure.
  - The continual uptake of oxygen by the pulmonary capillaries and the continual diffusion of carbon dioxide into the alveoli causes the overall partial pressure to be lower.

- The Partial Pressure of Oxygen is ____________________________ in Alveoli than in the Pulmonary Capillaries, so Oxygen diffuses into the blood.
  - Oxygen molecules take approximately 4ms to diffuse from the Alveoli into the Capillaries.

- The Partial Pressure of Carbon Dioxide is ____________________________ in the Pulmonary Capillaries than in Alveoli, so Carbon Dioxide diffuses into the Alveoli.

- The Carbon Dioxide is then exhaled through ventilation.
  - At rest, the entire process only nets a change in pressure of 40 mmHg of Oxygen and 27 mmHg of Carbon Dioxide.

INTERNAL RESPIRATION

The supply of blood and oxygen to cellular tissues is called ________________________________.

- The Partial Pressure of Oxygen is ____________________________ in the Arterial Capillaries than in the Cellular Tissues, so Oxygen diffuses into the Tissues.
• The Partial Pressure of Carbon Dioxide is ________________________________ in the Cellular Tissues than in the Arterial Capillaries, so Oxygen diffuses into the Blood Stream.

**Fick Principle**

• The Fick Principle describes the relationship between cardiac output, oxygen consumption, and pulmonary circulation.

\[
(Q) = \frac{\text{Volume of Oxygen Consumed} \ (V_{O_2})}{\text{Arterial - Veinous Oxygen Difference} \ (A-V \ O_2)}
\]

• A-V O₂ Difference reveals the amount of oxygen ________________________________.

• At Rest, 5 ml of Oxygen are consumed per 100 ml of blood.

• During Exercise, 15 ml of Oxygen are consumed per 100 ml of blood.

**Gas Transport**

• Oxygen is transported through the blood stream through two mechanisms:

• _______% of Oxygen in the blood stream is dissolved in the blood plasma.

• _______% of Oxygen in the blood stream is bound to the hemoglobin in red blood cells.
  
  • The Oxygen-Hemoglobin Dissociation Curve describes how readily hemoglobin acquires and releases oxygen molecules into the fluid that surrounds it.

• At Rest, arterial blood is at approximately 98% Oxygen Saturation.

• In the cellular tissue, the partial pressure of oxygen falls to around 40 mmHg resulting in hemoglobin rapidly unbinding oxygen.

• A decrease in the partial pressure of carbon dioxide, a decrease in temperature, or an increase in pH ________________________________ the ability of hemoglobin to hold oxygen shifting the curve to the left.
• **The Bohr Effect** - an increase in the carbon dioxide content in the blood (due to high tissue levels) decreases the ability of hemoglobin to hold oxygen causing more oxygen to be released shifting the curve to ____________________________.
  - The Bohr Effect allows the body to regulate oxygen distribution to tissues that need it most. The Bohr Effect relates to ____________________________.
  - The ____________________________ states that as blood deoxygenates it increases its ability to carry carbon dioxide.
  - Conversely, oxygenated blood has a reduced capacity for carbon dioxide.

• Carbon Dioxide is transported through the blood stream through three mechanisms:
  - ______% of Carbon Dioxide in the blood stream is dissolved in the blood plasma.
  - ______% of Carbon Dioxide in the blood stream combines with water molecules to form **Bicarbonate**.
  - 24% of Carbon Dioxide in the blood stream combines with amino groups in the Hemoglobin.

**NORMAL BREATHING**

• The prototypical healthy adult averages between ________________________ breaths per minute (respiratory rate – RR) at rest.
  - If a person experiences difficulty or labored breathing resulting in shortness of breath they are said to have ________________________.
  - As carbon dioxide levels build up in the blood it can lead to a condition known as **Hypercapnia**.
    - High levels of ________________________ in the blood are the main driving factor for changing rate and depth of breathing!
  - If the rate of breathing is excessive for a particular workload, it is referred to as **hyperventilation**.
    - Hyperventilating results in an abnormally low partial pressure of ________________________.
  - If breathing is insufficient for a particular workload, it is referred to as **hypoventilation**.
    - Hypoventilating results in an abnormally high partial pressure of ________________________.
Module 1.3: Skeletal System

**WHAT DOES THE SKELETON DO?**

- Support against _________.
  - Bones provide a hard framework that supports the body.
  - Bones provide support for internal organs.
- Protection of soft tissues.
  - Fused bones provide a case that protects the brain.
  - Spinal cord is surrounded by vertebrae.
  - Rib cage protects vital organs.
- Movement.
  - Skeletal muscles use the bones as ________ to move the body.
  - Arrangement of bones and joints determine the movements possible.
- Mineral Storage.
  - Bone serves as a mineral reservoir.
  - 99% of the body’s calcium is stored in bone.
  - 85% of the body’s phosphorous is stored in bone.
- Formation of new blood cells.
  - Red and White blood cells and platelets are produced in ________.

**BONE CLASSIFICATION**

There are 206 named bones in the human body.

- Each belongs to one of 2 large groups:
  - _________________ skeleton
    - Forms long axis of the body.
    - Includes the bones of the skull, vertebral column, and rib cage.
    - These bones are involved in protection, support, and carrying other body parts.
There are 4 main types of bones in the human body.

- ________________ Bones
  - Much longer than they are wide.
  - Consists of a shaft plus 2 expanded ends.
  - Classification is based on shape, not size.
    - All bones of the limbs except for the patella (kneecap), and the bones of the wrist and ankle.
    - Your finger bones are long bones even though they’re very short.

- ________________ Bones
  - Roughly cube shaped.
  - Thin compact bone layer surrounding spongy bone mass.
  - Bones of the wrist and ankle.

- ________________ Bones
  - Thin, flattened, and usually a bit curved.
  - Scapulae, sternum, ribs and most bones of the skull.

- ________________ Bones
  - Complicated shapes that do not fit into the other categories.
  - Consist of a spongy bone with a layer of compact bone.
  - Hip bones & vertebrae.
  - Vertebral Column:
    - ________________ Cervical Vertebrae
    - ________________ Thoracic Vertebrae
    - ________________ Lumbar Vertebrae
**Bone Structure**

- Regardless of the type of bone, all bones have some arrangement of compact and spongy bone.

- **compact bone** - dense, solid outer layer consisting of repeating patterns of solid bone tissue organized into concentric layers.

- **spongy bone** - honeycomb configuration of flat, needle-like projections called trabeculae packed with red marrow.

**Law**

- The arrangement of compact and spongy bone balances strength and flexibility to meet the demands placed on the bone.

- The mass density of bone loosely correlates with the strength of the bone.
  - Solid bone would be too brittle to absorb the forces of the muscles and too heavy for the muscles to move.

- **Trajectory Architecture** theory posits that maximum strength can be achieved with a minimum of constructional materials by placing material only in the paths of

**Bone Alterations**

- Bone cells may be divided into two broad classifications depending on whether they make bone or resorb it

  - **form bone tissue.**

  - **resorb or take away bone.**

  - Osteocytes are osteoblasts trapped in bone matrix during bone tissue production.

- There are 3 major ways bone tissue can be altered depending on the tissue on which the bone is placed and the way in which osteoblasts and osteoclasts work together.

  - Osteogenesis, Modeling, and Remodeling

**Osteogenesis**

- Osteogenesis is the production of bone on **

- This is the way in which bones are formed during embryonic development and how fractures heal.
Osteogenesis may be divided into two sub classifications depending on the mechanism and soft tissue base for bone formation.

- Intramembranous ossification
- Endochondral ossification

Intramembranous Ossification

- This is the process that forms flat bones like the skull, mandible, and clavicle.
- Also called dermal ossification because it normally occurs in the deeper layers of connective tissue of the dermis of the skin.
  - Unlike Endochondral ossification, cartilage is __________________________ during Intramembranous ossification.
  - Stage 1: Mesenchymal stem cells (MSC) condense in well-vascularized connective tissue forming a center of ossification
  - Stage 2: ____________________________ deposit mineral salts causing calcification
  - Stage 3: Production of trabeculae with random collagen organization.
  - Stage 4: Compaction of trabeculae to form ____________________________ bone.

Endochondral Ossification

- This is the process that forms much of the ____________________________ skeleton.
- Developing bones are deposited as a hyaline cartilage model
- This cartilage is progressively replaced by bone tissue.
  - Step 1: Cartilage model grows in length (interstitial growth) & in width (appositional growth). Chondrocytes at the center of the growing cartilage model enlarge and then die as the matrix calcifies.
  - Step 2: Newly derived ____________________________ cover the shaft of the cartilage in a thin layer of bone called the periosteum.
  - Step 3: Blood vessels penetrate the cartilage. New osteoblasts form a primary ossification center.
  - Step 4: The medullary cavity begins to hollow out. Bone tissue continues to replace ____________________________ of the diaphysis, and & continues toward each epiphysis.
• Step 5: Blood vessels invade the epiphyses and osteoblasts form secondary centers of ossification. Cartilage remains only at the ends (articular cartilage) & at metaphysis (epiphyseal plate)

Bone Modeling

• Reshaping of the bone – can cause large changes in bone structure.
• Results in optimizing bone for the forces that are placed on it.
  • Trajectory Architecture!
• Characteristics of bone modeling:
  • Changes in bone structure occur on __________________________ bone structures.
  • Bone structure alterations occur by __________________________ action of osteoblasts and osteoclasts.
    • This means that bone resorption and formation may occur on different surfaces.

Bone Remodeling

• Differs from other means of bone structure alterations in that osteoblasts and osteoclasts do not act independently but are coupled.
  • Bone resorption and formation occur at the __________________________ on the bone surface.
• Like modeling, bone remodeling occurs on existing bone surfaces.
• However, remodeling cannot cause large changes in bone structure at a given site.
  • At best, remodeling maintains the current amount of bone structure.
• Stage 1: Quiescence - Resting state of bone.
• Stage 2: Activation - Recruitment of osteoclasts to bone surface and signal coupling of osteoblasts.
• Stage 3: Resorption - Removal of bone by __________________________.
• Stage 4: Reversal - Osteoclasts stop removing bone and osteoblasts begin to fill the defect.
• Stage 5: Formation - __________________________ lay down bone.
  • Stage 6: Quiescence - Resting state of bone surface with reformed area.
• The previous illustration was most relevant to spongy (trabecular) bone surface remodeling.
• In compact bone, the same steps occur, but the remodeling occurs in a different shape, known as a ________________________________.

• Stage 3: **Resorption** – Forming resorption cavity. Removal of bone by osteoclasts.

• Stage 4: **Reversal** - Osteoclasts stop removing bone and osteoblasts begin to fill the defect.

• Stage 5: **Formation** - Osteoblasts lay down bone forming the distinct ________________________________ system found in compact bone.

• During the course of normal skeletal development, bone formation gradually slows, while bone resorption becomes accelerated later in life.

**BONE FAILURES**

**Osteoporosis**

• Bone (osteo) that is porous (porosis)

• Disease in which loss of ________________________________ (BMD) accelerates beyond loss expected with normal aging.

• Characterized by low bone mass and deterioration of bone tissue.
  • As bones become more fragile they are more likely to fracture.

• ________________________________: bone mineral density is lower than normal but not low enough to be considered osteoporosis.
  • “pre-osteoporosis”

• Represents a MAJOR public health threat.

• Over 34 million Americans have low bone mass (osteopenia).

• 10 million Americans suffer from osteoporosis.

  • ________________% are women

• 1.5 million people suffer an osteoporosis-related fracture.
  • 1 in 2 women and 1 in 4 men over 50 will have an osteoporosis-related fracture in their lifetime.

• Osteoporosis makes bones more brittle and susceptible to fractures.
• Also slows the healing process.
• Accordingly the these fractures result in negative health outcomes in the elderly.

  • ____________% will never be able to walk unassisted again
  • 25% confined to nursing homes
  • ____________% die within 6 months of fracture

Osteoporosis Risk Factors

• **Sex**: Females are more likely to develop osteoporosis than males.
• **Age**: Risk increases with age.
• **Ethnicity**: Caucasians and Asians have the greatest likelihood for developing osteoporosis.
• **Family History**: Having a parent or sibling with osteoporosis puts you at greater risk, especially if you also have a family history of fractures.
• **Body Type**: small body frames tend to have a higher risk because they may have less bone mass to draw from as they age.
• **Low calcium intake**: Low calcium intake contributes to diminished bone density, early bone loss and an increased risk of fractures.
• **Tobacco**: Tobacco use contributes to weak bones.
• **Eating disorders**: Higher risk of lower bone density.
• **Alcohol**: Excessive alcohol consumption can interfere with the body's ability to absorb calcium.
• **Sedentary lifestyle**: Individuals who spend a lot of time sitting have a higher risk of osteoporosis than their more-active counterparts.

Osteoporosis and Physical Activity

• PA can promote both primary and secondary prevention.
• Exercise promotes increases in bone mineral density.
  • Bones respond to exercise by becoming stronger
  • Bones must be “__________________________________________________________”
    (pressed or pushed on) to promote optimal bone mass
    • Weight-bearing exercise- forces you to work against gravity
    • Weight training- muscle contraction compresses bone
• High impact activities are more effective than low impact activities.
  • However, risk of injury is greater
  • These changes don’t happen overnight! Requires regular physical activity for a minimum

  of __________________ months for changes in bone mineral density to occur.

**Spinal Curvatures**

• The Vertebral column curves give the back its normal posture and help absorb shock.
  • Excessive or decreased curvature can cause problems.

  • __________________________ curves
    • Concave (curve inward)
    • Cervical and lumbar regions

  • __________________________ curves
    • Convex (curve outward)
    • Thoracic and sacral regions

• Abnormal curves
  • Combinations of Lordosis and Kyphosis

  • __________________________ (more than 10 degrees of lateral curvature)
Module 1.3: Skeletal System