Lecture Outline: The Respiratory System

I. **Major Functions of the Respiratory System**
   A. **Exchange of Oxygen (O2) and Carbon Dioxide (CO2)**
      1. Breathing (Ventilation): Refers to the collective processes of air moving in and out of the lungs.
      2. External Respiration: Specifically refers to the exchange of carbon dioxide and oxygen that occurs at the lungs.
   B. Other Functions
      1. Maintaining blood pressure (a complex process)
      2. Speaking and Singing (the respiratory system is essential for vocalization)
      3. Blowing (e.g., blowing a fly off your arm, blowing out candles)

II. **Anatomy of the Respiratory System**
   A. Major Organs
      1. **Lungs**: Considered the most important organs of the respiratory system.
   B. Airway Plumbing (Respiratory Tree)
      1. Nose and Mouth: The entry points for air
         a. Nasal cavity
         b. Oral cavity: While primarily associated with the digestive system, it also serves as part of the respiratory system.
      2. **Pharynx** (throat): A shared passageway for both the digestive and respiratory systems.

    a. Nasopharynx: The part of the pharynx that opens to the nasal cavity.
    b. Oropharynx: The part of the pharynx that opens to the oral cavity.
    c. Laryngopharynx: The final section of the pharynx for inhaled air, leading into the larynx.
3. **Larynx**: The superior part of the trachea.
4. **Trachea** (windpipe): A single tube that serves as the main airway.
    a. Structural Integrity: The trachea is constructed with C-shaped cartilages (partial rings) that give it a rigid appearance and ensure it remains open constantly, like a dryer hose, to allow for continuous air flow.
    b. In contrast, the esophagus (the food pipe, located just posterior to the trachea) normally collapses when not in use and is only forced open during swallowing by a food bolus.
5. Bronchial Tree: A system of branching tubes within the lungs.
    a. Primary bronchi: The trachea splits into two primary bronchi, one for each lung.
    b. Secondary bronchi: Primary bronchi further divide into secondary bronchi.
    c. Tertiary bronchi: Secondary bronchi divide into tertiary bronchi.
    d. Bronchioles: These are even smaller tubes that result from further subdivisions of tertiary bronchi, continuing to branch within the lungs.
6. **Pleura**: A serous membrane that encloses each lung individually.

        a. Layers: Composed of two distinct layers:
            (1) Parietal pleura: The outer layer.
            (2) Visceral pleura: The inner layer, directly covering the lung surface.
        d. Pleural cavity: The thin space between the parietal and visceral pleura, filled with pleural fluid.
        e. Function: The pleural fluid lubricates the highly mobile lungs, preventing friction and rubbing as they inflate and deflate during breathing.

III. **Nasal Cavity and Air Conditioning**

A. Lining: The nasal cavity is lined by moist epithelium.

B. **Nasal Conchae**: Three major folds (superior, middle, and inferior) are present on each side of the nasal cavity.

1. Function: These conchae create turbulence in the air as it is inhaled through the nose.

C. Humidification and Water Conservation:

1. Humidification: The turbulence ensures that the incoming, often dry, air has ample opportunity to contact the moist nasal epithelium, leading to the **humidification of the air** before it enters the lungs. This prevents the lungs from drying out.
2. Water Conservation: During exhalation, the reverse process occurs; water vapor in the exhaled air condenses back onto the moist epithelium of the nasal conchae. This mechanism significantly reduces the amount of water lost with each breath, conserving body water.

IV. **Trachea Structure and Epithelium**

A. Epithelium Lining: The cells lining the trachea have specialized features for protection.

1. Mucus Production: These cells produce **mucus**, a sticky

substance that effectively traps dust particles, bacteria, and other foreign substances that could be harmful to the lungs.

2. Cilia: The epithelial cells also possess **cilia**, hair-like projections that continuously beat back and forth.
3. Mucociliary Escalator: The coordinated beating of cilia sweeps the mucus, along with any trapped debris, superiorly (upward) from the lungs towards the mouth and pharynx. This debris is then continuously swallowed, entering the stomach where its high acidity typically disposes of harmful bacteria.

V. **Lung Lobes and Fissures**

A. Lungs are structurally divided into distinct sections called lobes, which are separated by deep grooves known as fissures.

B. **Right Lung**: Anatomically larger and is comprised of three lobes.

1. Fissures: These lobes are separated by two fissures:
   a. Horizontal fissure: Divides the superior lobe from the middle lobe.
   b. Oblique fissure: Separates the middle lobe from the inferior lobe.

C. **Left Lung**: Slightly smaller than the right lung due to the asymmetrical placement of the heart (its apex projects leftward), and it consists of two lobes.

1. Fissure: The two lobes are separated by a single oblique fissure, dividing the superior lobe from the inferior lobe.

VI. **Mechanics of Ventilation (Breathing Process)**

A. **Diaphragm**: A powerful, arch-shaped muscle located inferior to the lungs.

1. Contraction: During **inspiration** (inhalation), the diaphragm actively contracts, pulling downward and decreasing its arched shape. This action effectively "drops the floor" of the

thoracic cavity.

2. Relaxation: During normal expiration, the diaphragm simply relaxes. It is a passive process where the diaphragm resumes its arched shape due to the elastic recoil of connected tissues, without active upward pushing.

B. **Intercostal Muscles**: Muscles situated between the ribs.

1. **External Intercostal Muscles**:
   a. Location: These muscles are superficial.
   b. Function in Inspiration: They **contract during inspiration**, actively pulling the ribs upward and slightly laterally. This action increases the overall width and depth of the rib cage, similar to lifting the handles of two buckets.
2. **Internal Intercostal Muscles**:
   a. Location: These muscles are located immediately deep to the external intercostals.
   b. Function in Forced Expiration: They **contract during forced expiration**, actively pulling the ribs downward and inward, which speeds up the exhalation process.

C. Role of the Pleura in Lung Expansion:

1. The pleura consists of a parietal layer (attached to the rib cage) and a visceral layer (attached directly to the lung surface), with a thin pleural cavity containing pleural fluid between them.
2. Pleural Fluid Properties: Pleural fluid is a liquid, meaning it is uncompressible and unexpandable, unlike gas.
3. Mechanism of Lung Expansion: During inspiration, as the rib cage moves upward and laterally, it pulls on the parietal pleura. Because the pleural fluid is incompressible, it gets pulled along, which in turn pulls on the visceral pleura. Since

the visceral pleura is attached to the lung surface, this action **pulls the lung itself into a larger volume**, facilitating air entry.

4. Clinical Significance: If the pleura is punctured and air enters the pleural cavity, it disallows the lung from being pulled, making it impossible to inflate that lung.

D. Pressure Changes and Airflow during Ventilation:

1. **Inspiration (Active Process)**:
    a. Muscle Contraction: The diaphragm contracts (moving downward) and external intercostal muscles contract (pulling ribs up and out).
    b. Volume Change: These actions collectively **increase the volume of the thoracic cavity** and, consequently, the lungs.
    c. Pressure Change: According to gas laws, increasing the volume of a chamber filled with gas causes its internal pressure to **decrease**. The intrapulmonary pressure (pressure inside the lungs) drops below the atmospheric (barometric) pressure outside.
    d. Airflow: Due to this pressure gradient, air is **forced into the lungs** from the higher atmospheric pressure to the lower intrapulmonary pressure.
2. **Normal Expiration (Passive Process)**:
    a. Muscle Relaxation: The diaphragm and external intercostal muscles simply relax.
    b. Volume Change: The elastic recoil of the lungs and thoracic cage causes the rib cage to become narrower, shallower, and shorter, leading to a **decrease in the volume of the lungs**.

c. Pressure Change: Decreasing the volume of gas in the lungs causes the intrapulmonary pressure to **increase**, becoming higher than the atmospheric pressure.
d. Airflow: Air is then **forced out of the lungs** from the higher internal pressure to the lower external pressure.

3. **Forced Expiration (Active Process)**:
    a. Muscle Contraction: This process involves the active contraction of internal intercostal muscles (pulling ribs down faster) and abdominal muscles.
    b. Abdominal Muscle Action: Contracting abdominal muscles squeeze the abdominal organs (mostly liquid-filled) upward against the diaphragm, forcing it rapidly upward.
    c. Result: This combined action causes a rapid and significant reduction in lung volume, leading to a much greater increase in intrapulmonary pressure and a forceful expulsion of air.

VII. **Bronchial Tree Zones**

A. **Conducting Zone**:

1. Components: Includes the trachea, all bronchi, and bronchioles up to and including the terminal bronchioles.
2. Function: Its primary role is simply to **move air** in and out of the lungs; **no gas exchange** takes place within this zone.

B. **Respiratory Zone**:

1. Components: Begins where terminal bronchioles divide into respiratory bronchioles, and includes the alveoli.
2. Function: This is the critical area where **gas exchange occurs**, facilitated by the richly vascularized epithelium lining these structures, which are surrounded by blood vessels.

VIII. **Alveoli (Air Sacs)**

A. Structure: Tiny, sack-like structures located at the very ends of the respiratory tree.
B. Surface Area: The alveoli collectively **drastically increase the surface area** available for gas exchange. The lungs are not empty sacks but are more like sponges composed of thousands of these tiny sacs. The total surface area of all alveoli in both lungs is roughly equivalent to a tennis court, which is crucial for efficient gas exchange.
C. Alveolar Pores: Adjacent alveoli are connected by small alveolar pores.
D. Alveolar Cell Types: The lining of each alveolus is an epithelium composed of a couple of major cell types:
    1. **Type One Alveolar Cells** (Squamous Epithelial Cells):
        a. Most numerous cells, characterized by being very flat and scale-like.
        b. They form a simple squamous epithelium (a single, very thin layer of cells) to **minimize the distance** gases must diffuse, enabling efficient passive transport of oxygen and carbon dioxide.
    2. **Type Two Alveolar Cells**:
        a. Function: Primarily responsible for secreting **surfactant**.
        b. Surfactant: A wetting agent that significantly **minimizes the surface tension** within the tiny alveoli. Without surfactant, the alveoli would be prone to collapsing due to water droplets and would be much harder to inflate.
    3. **Macrophages**:
        a. Mobile immune cells that continuously crawl around the alveolar surface.

b. Function: They perform **phagocytosis**, engulfing and disposing of dust particles, bacteria, and any other foreign substances that should not be in the lungs, thus providing protection.

IX. **Respiratory Membrane**

A. Definition: This is the extremely thin barrier that oxygen and carbon dioxide must cross to be exchanged between the air in the alveoli and the blood in the capillaries.

B. Components: For an oxygen molecule moving from the lung air into the blood, it must sequentially cross three major parts:

1. The **alveolar epithelium** (composed of Type One squamous epithelial cells).
2. A **fused basement membrane**: This single basement membrane is shared by and underlies both the alveolar epithelium and the capillary epithelium.
3. The **capillary epithelium** (also known as the endothelium), which forms the wall of the blood capillary.

C. Gas Exchange Mechanism: Both oxygen and carbon dioxide move across the respiratory membrane by **diffusion**, driven by their respective **partial pressure gradients**.

1. **Oxygen (O2) Movement**: Moves from an area of higher partial pressure in the lung air (alveoli) to an area of lower partial pressure in the blood.
2. **Carbon Dioxide (CO2) Movement**: Moves from an area of higher partial pressure in the blood to an area of lower partial pressure in the lung air (alveoli).
3. Independence: Crucially, the movement of oxygen and carbon dioxide is independent; one gas's movement does not affect the other's.

X. **Oxygen Transport Pathway (from air to red blood cell)**

A. An oxygen molecule begins as part of the air mixture within a lung alveolus.

B. It then traverses the plasma membrane on one side of an alveolar epithelial cell.

C. Next, it diffuses through the cytoplasm (liquid interior) of that alveolar epithelial cell.

D. It passes through the plasma membrane on the other side of the same alveolar epithelial cell.

E. The molecule then diffuses through the fused basement membrane.

F. It crosses the plasma membrane on one side of a capillary epithelial cell (endothelium), which forms the wall of the blood capillary.

G. Once inside, it diffuses through the cytoplasm of that capillary epithelial cell.

H. It then passes through the plasma membrane on the other side of the capillary epithelial cell.

I. At this point, the oxygen molecule is inside the blood, specifically in the **plasma** (the liquid component of blood).

J. It diffuses through the plasma until it encounters a **red blood cell** (erythrocyte).

K. The oxygen molecule enters the red blood cell by crossing its surrounding plasma membrane.

L. Inside the red blood cell, it diffuses through the cytoplasm.

M. Finally, it encounters and attaches to a **hemoglobin molecule** (each red blood cell contains millions of hemoglobin molecules, and each hemoglobin molecule can carry up to four oxygen molecules). Once attached, it is ready to be transported throughout the body.

XI. **Lung Volumes and Capacities**

A. Distinction between Volumes and Capacities:

1. **Volume**: Refers to a single, distinct measurement of air.
2. **Capacity**: Represents a combination or sum of multiple different volumes.

B. Key Volumes:

1. **Tidal Volume (TV)**: The volume of air that is moved in and out of the lungs during normal, relaxed breathing (e.g., when at rest). It represents the minimum amount of air inhaled and exhaled.
2. **Inspiratory Reserve Volume (IRV)**: The additional volume of air that can be forcibly inhaled beyond a normal inspiration. It is the "reserve" amount of air one could still take in.
3. **Expiratory Reserve Volume (ERV)**: The additional volume of air that can be forcibly exhaled after a normal expiration.
4. **Residual Volume (RV)**: The volume of air that perpetually remains in the lungs even after a maximal exhalation. This air cannot be expelled from the lungs.

C. Key Capacities:

1. **Vital Capacity (VC)**: The total amount of air that can be moved in and out of the lungs. It is the sum of the Inspiratory Reserve Volume, Tidal Volume, and Expiratory Reserve Volume (VC = IRV + TV + ERV). This represents the maximum volitional breath.
2. **Total Lung Capacity (TLC)**: The sum of all four volumes (TLC = VC + RV). This represents the maximum volume of air that the lungs can possibly hold after a maximal inhalation, varying by individual factors such as size and sex.

XII. **Gas Exchange at Capillary Beds Throughout the Body**

A. **Pulmonary Capillaries (External Respiration â€“ at the Lungs)**:

1. Air inhaled into the lungs (inspired air) has a high concentration of oxygen and a relatively low concentration of carbon dioxide.
2. Blood arriving at the pulmonary capillaries (from the body's tissues) is oxygen-poor (because oxygen has been used by tissues) and carbon dioxide-rich (as CO2 is a waste product from tissues).
3. **Oxygen Movement**: Due to its partial pressure gradient, oxygen diffuses from the alveoli (where its partial pressure is higher) into the blood (where it is lower).
4. **Carbon Dioxide Movement**: Similarly, carbon dioxide diffuses from the blood (where its partial pressure is higher) into the alveoli (where it is lower) to be exhaled.
5. Result: Blood leaving the pulmonary capillaries is **oxygen-rich** and **carbon dioxide-poor**, and it returns to the left side of the heart via the pulmonary veins.

B. **Systemic Capillaries (Internal Respiration â€“ at Body Tissues)**:

1. Oxygen-rich blood (pumped from the left side of the heart) arrives at the systemic capillaries located throughout the body's tissues.
2. Tissue cells, which are constantly undergoing metabolic processes like cellular respiration, have a low oxygen concentration (as they consume it) and a high carbon dioxide concentration (as they produce it as waste).
3. **Oxygen Movement**: Oxygen diffuses from the blood (where its partial pressure is higher) into the tissue cells (where it is

lower), where it is used for cellular processes.

4. **Carbon Dioxide Movement**: Carbon dioxide diffuses from the tissue cells (where its partial pressure is higher) into the blood (where it is lower).
5. Result: Blood leaving the systemic capillaries is now **oxygen-poor** and **carbon dioxide-rich**, returning to the right side of the heart via the superior and inferior vena cavae to be pumped back to the lungs for re-oxygenation.

XIII. **Chemical Regulation of Respiration and Hemoglobin's Role**

A. Key Reversible Chemical Reaction: The concentration of carbon dioxide in the blood is linked to blood pH through a reversible chemical reaction: **CO2 + H2O â†” H2CO3 â†” H+ + HCO3-**

1. CO2: Carbon Dioxide
2. H2O: Water
3. H2CO3: Carbonic Acid
4. H+: Hydrogen Ion (directly influences blood acidity/pH)
5. HCO3-: Bicarbonate Ion

B. At the **Lungs (External Respiration)**:

1. When CO2 leaves the blood and enters the lungs for exhalation, the reaction shifts to the right (as CO2 is consumed) to replenish the CO2.
2. This shift **reduces the concentration of hydrogen ions (H+)** in the plasma.
3. Result: The blood plasma becomes **less acidic** (its pH increases), which makes **hemoglobin much more able to bind to oxygen**. This is crucial for efficiently loading oxygen into the blood at the lungs.

C. At the **Systemic Tissues (Internal Respiration)**:

1. When CO2 enters the blood from the tissue cells (as a waste

    product), the reaction shifts to the right (as CO_2 is added), leading to the production of more H^+ and HCO_3^-.

    2. Result: This **increases the concentration of hydrogen ions (H^+)** in the plasma, making the blood **more acidic** (its pH decreases). In this more acidic environment, **hemoglobin becomes much less able to hold onto oxygen**, causing oxygen to be released from hemoglobin and diffuse into the cells that require it for metabolism.

D. Implication for Breath Holding:

    1. The strong urge to breathe when holding one's breath is **not primarily due to a lack of oxygen** (there is still plenty of oxygen in the blood).
    2. Instead, it is caused by the **build-up of carbon dioxide (CO_2)** in the blood because exhalation is stopped.
    3. This CO_2 accumulation leads to an increase in hydrogen ions (H^+), making the blood progressively more acidic.
    4. The brain stem, which is highly sensitive to changes in blood acidity, detects this increase in H^+ and forcibly triggers the respiratory muscles to initiate breathing.

XIV. **Neural Control of Breathing**

A. Breathing Center: Normal breathing is primarily controlled by a **breathing center** located in the **brain stem** (at the base of the brain).

B. Primary Stimulus for Inspiration:

    1. The brain stem is particularly sensitive to an **increase in hydrogen ions (H^+)** in the blood, which typically occurs due to rising CO_2 levels.
    2. Upon sensing this increase, the brain stem stimulates the **diaphragm** and **external intercostal muscles** via motor

neurons.

3. This stimulation causes these muscles to contract, leading to an increase in the volume of the rib cage and thus initiating **inspiration**.

C. Rhythmic Breathing: Breathing usually occurs rhythmically and **unconsciously** (e.g., tidal breathing when at rest). Sensors located in the aorta also send information to the brain, contributing to this rhythmic control of respiration.

XV. **Non-Respiratory Gas Movements**

A. These are movements of air through the respiratory system that serve purposes other than gas exchange, often involving forced expiration:

1. Coughing
2. Sneezing
3. Crying
4. Laughing
5. Hiccups
6. Yawning
7. Speaking
8. Singing

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