Anatomy and Physiology: The Respiratory System

AI-Generated Study Guide

(Based on lectures delivered by Dr. Ty C.M. Hoffman)

I. Major Functions of the Respiratory System

- **Gas Exchange:** The primary function, involving the exchange of oxygen (O2) and carbon dioxide (CO2) between the atmosphere and the blood.
- **External Respiration:** The exchange of O2 and CO2 that occurs at the lungs (alveoli).
- **Internal Respiration:** The exchange of O2 and CO2 that occurs at the systemic capillaries (body tissues).
- **Ventilation (Breathing):** The mechanical process of moving air in and out of the lungs, encompassing inhalation and exhalation.
- **Other Functions:**Maintaining blood pressure (complex mechanism not fully detailed).
- Speaking/Vocalization.
- Blowing (e.g., blowing out candles).

II. Anatomy of the Respiratory System

- **Major Organs:** Lungs (most important).
- **Airway (Plumbing):Nose/Nasal Cavity:** Entry point for air, involved in humidification and filtration. Contains nasal conchae.
- **Mouth/Oral Cavity:** Overlaps with the digestive system, also an entry point for air.
- **Pharynx (Throat):** Shared pathway for air and food. Divided into three regions:
- **Nasopharynx:** Superior, opens to the nasal cavity.
- **Oropharynx:** Middle, opens to the oral cavity.
- **Laryngopharynx:** Inferior, opens to the larynx.
- **Larynx:** Superior part of the trachea. Contains vocal cords (involved in speaking).
- **Trachea (Windpipe):** Rigid tube reinforced with C-shaped cartilage rings to keep it open. Lined with mucus-producing, ciliated epithelium (mucociliary escalator). Bifurcates into two primary bronchi.
- **Bronchial Tree (Respiratory Tree):** A series of branching tubes within the lungs.
- **Primary Bronchi:** Two main branches, one for each lung, splitting from the trachea.

- **Secondary Bronchi:** Branches from primary bronchi.
- **Tertiary Bronchi:** Branches from secondary bronchi.
- **Bronchioles:** Smaller and smaller tubes resulting from further subdivisions.
- **Terminal Bronchioles:** End of the conducting zone.
- **Respiratory Bronchioles:** Begin the respiratory zone, capable of gas exchange due to vascularization and alveoli.
- **Lungs:Lobes:** Right lung has three lobes (superior, middle, inferior). Left lung has two lobes (superior, inferior) due to the heart's position.
- **Fissures:** Grooves separating the lobes (horizontal and oblique on the right, oblique on the left).
- **Pleura:** Serous membrane enclosing each lung.
- **Parietal Pleura:** Outer layer, attached to the thoracic cavity wall.
- **Visceral Pleura:** Inner layer, directly covers the lung surface.
- **Pleural Cavity:** Space between the two pleural layers, containing pleural fluid.
- **Pleural Fluid:** Serous fluid that lubricates the lungs and ensures the layers remain close, allowing lung expansion during ventilation. Its incompressibility is crucial for lung inflation.
- **Alveoli (Alveolus singular):** Tiny air sacs at the ends of the respiratory bronchioles.
- Drastically increase surface area for gas exchange.
- Lined by epithelium with two main cell types:
- **Type I Alveolar Cells (Squamous Epithelial Cells):** Flat, thin cells facilitating gas diffusion.
- **Type II Alveolar Cells (Septal Cells):** Produce surfactant to reduce surface tension and prevent alveolar collapse.
- Associated with **macrophages:** Phagocytic cells that engulf debris and pathogens.
- Surrounded by **blood capillaries** for gas exchange.
- **Diaphragm:** Powerful muscle inferior to the lungs, crucial for inspiration. Contracts (flattens) to increase thoracic volume.
- **Intercostal Muscles:** Muscles between the ribs.
- **External Intercostal Muscles:** Superficial, contract during inspiration to pull ribs upward and outward, increasing thoracic volume.
- **Internal Intercostal Muscles:** Deep, contract during forced exhalation to pull ribs downward and inward, decreasing thoracic volume.

III. Mechanics of Ventilation (Breathing)

- **Inspiration (Inhalation):** Active process.
- Diaphragm contracts and moves downward (decreases archedness).
- External intercostal muscles contract, pulling ribs upward and outward.
- Thoracic cavity volume increases (wider, deeper, taller).
- Lung volume increases (pulled by parietal pleura and incompressible pleural fluid).
- Intrapulmonary pressure decreases (becomes lower than atmospheric pressure).
- Air flows from higher atmospheric pressure into the lungs (down its pressure gradient).

- **Expiration (Exhalation):Normal Exhalation:** Passive process.
- Diaphragm relaxes and returns to arched position.
- External intercostal muscles relax, ribs fall downward and inward.
- Thoracic cavity volume decreases due to elastic recoil.
- Lung volume decreases.
- Intrapulmonary pressure increases (becomes higher than atmospheric pressure).
- Air flows from higher intrapulmonary pressure out of the lungs.
- **Forced Exhalation:** Active process.
- Internal intercostal muscles contract, actively pulling ribs down and in.
- Abdominal muscles contract, pushing abdominal organs upward against the diaphragm, forcing it higher.
- Rapid and significant decrease in thoracic and lung volume.
- Rapid and significant increase in intrapulmonary pressure, expelling air forcefully.
- **Pressure-Volume Relationship (Boyle's Law):** Inverse relationship between volume and pressure in a closed container of gas. When lung volume increases, pressure decreases; when lung volume decreases, pressure increases.

IV. Lung Volumes and Capacities

- **Volumes:** Single, defined amounts of air.
- **Tidal Volume (TV):** Volume of air moved in and out during normal, quiet breathing.
- **Inspiratory Reserve Volume (IRV):** Additional volume of air that can be inhaled after a normal inspiration.
- **Expiratory Reserve Volume (ERV):** Additional volume of air that can be exhaled after a normal expiration.
- **Residual Volume (RV):** Volume of air remaining in the lungs even after maximal exhalation (cannot be expelled).
- **Capacities:** Combinations of two or more volumes.
- **Vital Capacity (VC):** Maximum amount of air that can be moved in and out of the lungs (TV + IRV + ERV).
- **Total Lung Capacity (TLC):** Total volume of air the lungs can hold after maximal inspiration (VC + RV).

V. Non-Respiratory Air Movements

- Coughing, sneezing, crying, laughing, hiccups, yawning, speaking, singing, blowing (e.g., candles).

VI. Gas Exchange and Transport

- **Diffusion:** Gases move down their partial pressure gradients. What one gas does does not affect another.
- **External Respiration (at lungs):**Oxygen (O2): Higher partial pressure in alveoli than in blood, so O2 diffuses from alveoli into pulmonary capillaries.
- Carbon Dioxide (CO2): Higher partial pressure in pulmonary capillaries (from tissues) than in alveoli, so CO2 diffuses from blood into alveoli.
- **Respiratory Membrane:** The barrier gases must cross, composed of:

1. Alveolar epithelium (Type I cells)
2. Fused basement membrane (shared by alveolar and capillary epithelia)
3. Capillary endothelium (epithelium of the blood capillary wall)

- **Internal Respiration (at systemic tissues):**Oxygen (O2): Higher partial pressure in systemic capillaries (from lungs) than in tissue cells, so O2 diffuses from blood into cells. Used for cellular respiration.
- Carbon Dioxide (CO2): Higher partial pressure in tissue cells (product of cellular respiration) than in systemic capillaries, so CO2 diffuses from cells into blood.
- **Oxygen Transport:** Primarily by hemoglobin in red blood cells. Each hemoglobin molecule can carry up to four O2 molecules.
- **Carbon Dioxide Transport:**Small amount dissolved in plasma.
- Some binds to hemoglobin.
- Majority transported as **bicarbonate ion (HCO3-)** in plasma.
- **CO2 + H2O ↔ H2CO3 ↔ H+ + HCO3-**
- **At systemic capillaries (internal respiration):** CO2 enters blood from tissues. This drives the reaction to the right, producing more H+ and HCO3-. Increased H+ makes blood more acidic, causing hemoglobin to *release* O2 (Bohr effect).
- **At pulmonary capillaries (external respiration):** CO2 leaves blood and enters alveoli. This drives the reaction to the left, consuming H+ and HCO3-. Decreased H+ makes blood less acidic, causing hemoglobin to *bind* O2 more readily.

VII. Neural Control of Breathing

- **Breathing Center:** Located in the brainstem (base of the brain).
- **Chemoreceptors:** Sensitive to changes in blood chemistry.
- Primary stimulus for breathing is **increased CO2 levels** in the blood.
- Increased CO2 leads to increased H+ (acidity) in the blood.
- The brainstem detects this increase in acidity and forces inhalation.
- There are also sensors in the aorta that contribute to rhythmic breathing.
- **Motor Neurons:** Stimulate the diaphragm and external intercostal muscles to contract, initiating inspiration.
- Breathing is typically unconscious and rhythmic (tidal breathing), but can be consciously controlled to some extent.

Quiz: Short-Answer Questions

1. Differentiate between "cellular respiration" and "respiration" as it applies to the respiratory organ system.
2. Explain the primary function of the nasal conchae in the nasal cavity.
3. Describe the structural difference between the trachea and the esophagus, and explain why this difference is important for their respective functions.
4. What is the mucociliary escalator, and what is its role in the respiratory system?
5. Why does the left lung have fewer lobes than the right lung?
6. Explain the role of pleural fluid in lung function during ventilation.
7. Distinguish between the "conducting zone" and the "respiratory zone" of the bronchial tree. Provide an example of a structure found in each.
8. Identify the two main types of cells lining the alveoli and state their respective functions.
9. Describe how changes in intrapulmonary pressure drive airflow during normal inspiration.
10. Explain how the chemical reaction involving carbon dioxide, water, and bicarbonate ion affects hemoglobin's affinity for oxygen at the systemic capillaries.

Quiz Answer Key

1. **Cellular respiration** is a metabolic process occurring inside cells that uses oxygen to produce ATP, releasing carbon dioxide as a byproduct. **Respiration**, in the context of the respiratory organ system, specifically refers to the exchange of oxygen and carbon dioxide between the body and the external environment, encompassing both external and internal respiration.
2. The nasal conchae are folds in the nasal cavity that create turbulence in inhaled air. This turbulence increases the likelihood that the air will come into contact with the moist epithelium, allowing for humidification of the air and trapping of particles, protecting the lungs from dry air and debris.
3. The trachea contains C-shaped cartilage rings that keep its lumen (airway) open at all times, preventing collapse and ensuring continuous airflow. The esophagus, conversely, is typically collapsed and only opens during swallowing, as it does not need to remain patent constantly for its function of transporting food.
4. The mucociliary escalator is a protective mechanism in the trachea and other airways. It consists of mucus-producing cells that trap dust particles and bacteria, and cilia that beat rhythmically to sweep the mucus and trapped debris superiorly towards the pharynx, where it can be swallowed and neutralized in the stomach.
5. The left lung has only two lobes (superior and inferior) compared to the right lung's three lobes (superior, middle, inferior). This asymmetry is due to the slightly asymmetrical placement of the heart, whose apex juts leftward and occupies more space in the left side of the thoracic cavity, making the left lung slightly smaller.
6. Pleural fluid fills the pleural cavity between the parietal and visceral pleura. It acts as a lubricant, preventing friction as the lungs inflate and deflate. Crucially, as an incompressible liquid, it ensures that when the parietal pleura is pulled by the expanding

rib cage, the visceral pleura (and thus the lung) is pulled along with it, allowing the lung to expand.
7. The **conducting zone** consists of the structures that simply move air in and out, without gas exchange. Examples include the trachea, primary bronchi, and terminal bronchioles. The **respiratory zone** is where actual gas exchange occurs. Examples include the respiratory bronchioles and alveoli.
8. The two main types of cells lining the alveoli are **Type I alveolar cells** (or squamous epithelial cells), which are very thin and flat to facilitate efficient gas diffusion, and **Type II alveolar cells** (or septal cells), which produce surfactant, a substance that reduces surface tension in the alveoli and prevents them from collapsing.
9. During normal inspiration, the diaphragm contracts and moves downward, and the external intercostal muscles contract, pulling the ribs upward and outward. This increases the overall volume of the thoracic cavity, which in turn increases the volume of the lungs. According to Boyle's Law, as lung volume increases, the intrapulmonary pressure inside the lungs decreases, becoming lower than the atmospheric pressure outside. This pressure gradient forces air from the higher atmospheric pressure into the lower pressure lungs.
10. At the systemic capillaries, carbon dioxide (CO_2), a waste product from cellular metabolism, enters the blood. This influx of CO_2 drives the chemical reaction $CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3^-$ to the right, leading to an increase in hydrogen ions (H^+) in the blood plasma. The increased acidity (lower pH) in turn causes hemoglobin to release its bound oxygen more readily, allowing oxygen to diffuse into the tissue cells where it is needed for cellular respiration.

Essay Format Questions

1. Discuss the pathway of an oxygen molecule from the atmosphere to a hemoglobin molecule, detailing each structure it passes through and the barriers it crosses within the respiratory membrane and blood components.
2. Compare and contrast the processes of normal and forced exhalation, identifying the muscles involved (or lack thereof), the changes in thoracic volume, and the resulting pressure dynamics.
3. Explain how the unique anatomical features of the nasal cavity and the trachea contribute to the conditioning and protection of inhaled air before it reaches the respiratory zone of the lungs.
4. Describe the concept of "partial pressure gradient" in the context of gas exchange, and explain how it drives both external respiration at the lungs and internal respiration at the systemic tissues.
5. Analyze the critical role of the bicarbonate buffer system (the chemical reaction involving CO_2, H_2O, H_2CO_3, H^+, and HCO_3^-) in both carbon dioxide transport and the regulation of hemoglobin's oxygen affinity, illustrating how it adapts to the specific needs of the lungs versus the body tissues.

Glossary of Key Terms

- **Alveoli (Alveolus):** Tiny air sacs in the lungs where gas exchange occurs.
- **Atmospheric Pressure:** The pressure exerted by the air surrounding the body; also known as barometric pressure.
- **Bicarbonate Ion (HCO_3^-):** The primary form in which carbon dioxide is transported in the blood.
- **Bifurcate:** To divide into two branches or forks.
- **Boyle's Law:** States that for a fixed amount of gas at constant temperature, the pressure and volume are inversely proportional.
- **Bronchi (Bronchus):** The two main airways that branch off the trachea, leading to the lungs.
- **Bronchioles:** Smallest branches of the bronchi, leading to the alveoli.
- **Carbonic Acid (H_2CO_3):** An unstable acid formed when carbon dioxide reacts with water in the blood.
- **Cellular Respiration:** The metabolic process within cells that converts nutrients into ATP, requiring oxygen and producing carbon dioxide.
- **Cilia:** Hair-like projections on the surface of epithelial cells that sweep mucus and debris.
- **Conducting Zone:** The parts of the respiratory system that transport air but do not participate in gas exchange (e.g., trachea, bronchi, terminal bronchioles).
- **Diaphragm:** The dome-shaped skeletal muscle that separates the thoracic and abdominal cavities, essential for breathing.
- **Diffusion:** The net movement of particles from an area of higher concentration to an area of lower concentration.
- **Elastic Recoil:** The tendency of an elastic structure to return to its original shape after being stretched or deformed.
- **Endothelium:** The specialized epithelial tissue that lines the inside of blood vessels.
- **Exhalation (Expiration):** The process of expelling air from the lungs.
- **Expiratory Reserve Volume (ERV):** The additional amount of air that can be forcibly exhaled after a normal exhalation.
- **External Intercostal Muscles:** Muscles located between the ribs that contract during inspiration to expand the rib cage.
- **External Respiration:** The exchange of gases (oxygen and carbon dioxide) between the alveoli of the lungs and the blood in pulmonary capillaries.
- **Fissures:** Deep grooves or cracks that divide the lobes of the lungs.
- **Hemoglobin:** An iron-containing protein in red blood cells that reversibly binds oxygen.
- **Humidification:** The process of adding moisture to the air.
- **Inhalation (Inspiration):** The process of drawing air into the lungs.
- **Inspiratory Reserve Volume (IRV):** The additional amount of air that can be forcibly inhaled after a normal inspiration.
- **Intercostal Muscles:** Muscles located between the ribs that play a role in breathing.
- **Internal Intercostal Muscles:** Muscles located between the ribs that contract during forced exhalation to depress the rib cage.

- **Internal Respiration:** The exchange of gases (oxygen and carbon dioxide) between the blood in systemic capillaries and the tissue cells of the body.
- **Intrapulmonary Pressure:** The pressure inside the alveoli of the lungs.
- **Larynx:** The voice box; a cartilaginous structure that contains the vocal cords and connects the pharynx to the trachea.
- **Lobes:** Major divisions of the lungs, separated by fissures.
- **Macrophages:** Phagocytic cells that engulf foreign particles and pathogens.
- **Mucociliary Escalator:** A protective mechanism involving mucus and cilia that traps and sweeps foreign particles out of the respiratory tract.
- **Nasal Conchae:** Bony projections in the nasal cavity that create turbulence in inhaled air to aid in humidification and filtration.
- **Nasopharynx:** The upper part of the pharynx, connected to the nasal cavity.
- **Oropharynx:** The middle part of the pharynx, connected to the oral cavity.
- **Pharynx:** The throat; a muscular tube that serves as a passageway for both air and food.
- **Pleura:** The serous membrane that encloses the lungs. It consists of two layers: the parietal pleura and the visceral pleura.
- **Pleural Cavity:** The space between the parietal and visceral layers of the pleura, containing pleural fluid.
- **Pleural Fluid:** The serous fluid within the pleural cavity that lubricates the lungs and facilitates their movement during breathing.
- **Primary Bronchi:** The two main airways branching from the trachea, entering the lungs.
- **Residual Volume (RV):** The volume of air remaining in the lungs after a maximal exhalation.
- **Respiration:** In the context of the respiratory system, the exchange of oxygen and carbon dioxide.
- **Respiratory Membrane:** The thin barrier across which gases are exchanged in the alveoli, composed of the alveolar epithelium, fused basement membrane, and capillary endothelium.
- **Respiratory Zone:** The parts of the respiratory system where gas exchange occurs (e.g., respiratory bronchioles, alveoli).
- **Sagittal Section:** A vertical cut that divides the body or an organ into right and left parts. A midsagittal (median) section divides it exactly in the middle.
- **Surfactant:** A fluid secreted by Type II alveolar cells that reduces surface tension in the alveoli, preventing their collapse.
- **Systemic Capillaries:** Capillary beds found throughout the body's tissues (excluding the lungs) where internal respiration occurs.
- **Terminal Bronchioles:** The smallest bronchioles in the conducting zone, leading to the respiratory bronchioles.
- **Thorax:** The part of the body between the neck and the abdomen, enclosed by the ribs, containing the heart and lungs.
- **Tidal Volume (TV):** The volume of air inhaled or exhaled during normal, quiet breathing.
- **Total Lung Capacity (TLC):** The total volume of air that the lungs can hold after a maximal inspiration.

- **Trachea:** The windpipe; a cartilaginous tube that extends from the larynx to the bronchi.
- **Transverse Cut:** A horizontal cut that divides the body or an organ into superior and inferior parts; also called a cross-section.
- **Turbulence:** Irregular, swirling air movement.
- **Ventilation:** The mechanical process of moving air into and out of the lungs; also known as breathing.
- **Visceral Pleura:** The inner layer of the pleura that directly covers the surface of the lungs.
- **Vital Capacity (VC):** The maximum amount of air that can be exhaled after a maximal inspiration.