Respiratory System and Disorders

Lesson 1

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Respiration

Respiration has two meanings:

1. Utilization of oxygen in the metabolism of organic molecules by cells, termed ***internal*** or ***cellular respiration.***
2. The exchange of O_2 and CO_2 between an organism and the external environment, called ***pulmonary physiology.***

Functions of Respiratory System

1. Provides oxygen to the blood
2. Eliminates carbon dioxide from the blood
3. Regulates the blood's pH in coordination with the kidneys
4. Forms speech sounds (**phonation**)
5. Defends against inhaled microbes
6. Influences arterial concentrations of chemical messengers by removing some from pulmonary capillary blood and producing and adding others to this blood
7. Traps and dissolves blood clots arising from systemic veins such as those in the legs

Introduction

- Humans have two lungs **(Right & Left).**
- The lungs consist mainly of tiny air-containing sacs called **alveoli** (singular, **alveolus**).
- The **airways** are the tubes through which air flows from the external environment to the alveoli and back.

Introduction

- **Inspiration** (inhalation) is the movement of air from the external environment into the lungs.
- **Expiration** (exhalation) is air movement in the opposite direction.
- **Respiratory cycle =** Inspiration + Expiration

Upper Air Ways

- During inspiration, air passes through the nose or the mouth (or both) into the **pharynx,** a passage common to both air and food.
- The pharynx branches into two tubes: the esophagus, and the **larynx.**
- The larynx houses the **vocal cords.**
- The nose, mouth, pharynx, and larynx are collectively termed the **upper airways.**

Airways and Airflow

- The larynx opens into a long tube, the **trachea,** which in turn branches into two **bronchi** (singular, **bronchus**), one of which enters each lung.
- The larger proximal airways have a lot of cartilage in their walls.
- The first airway branches that no longer contain cartilage are termed **bronchioles.**

Airways and Airflow

- *Trachea divides into:*

  → right and left main bronchi

  → lobar bronchi

  → segmental bronchi.

- The airways beyond the larynx can be divided into two zones:

  1. **The conducting zone**
  2. **The respiratory zone**

Airways and Airflow

- Conducting zone contains **no alveoli** and take no part in gas exchange (*anatomic dead space ≈150 ml).*
- The terminal bronchioles divide into ***respiratory bronchioles***, which have occasional alveoli budding from their walls.
- Airways end with ***alveolar ducts***, which are completely lined with **alveoli.**
- This alveolated region of the lung where the gas exchange occurs is known as the ***respiratory zone***

Defense Mechanisms

- The oral and nasal cavities trap airborne particles in nasal hairs and mucus.
- The epithelial surfaces of the airways, contain cilia that constantly beat upward toward the pharynx.
  - They also contain glands that secrete mucus
  - And **macrophages**, which can phagocytize inhaled pathogens.
- Ciliary activity and number can be decreased by many noxious agents, including tobacco smoke.

The Alevoli

- The alveoli are tiny, hollow sacs with open ends that are continuous with the lumens of the airways.
- Air-facing surfaces of the wall are lined by flat epithelial cells called **type I alveolar cells.**
- Interspersed between these cells are thicker ,specialized cells termed **type II alveolar cells.**

Stability of The Alevoli

- **Type II alveolar cells** produce a detergent-like substance called **surfactant** that, is important for preventing the collapse of the alveoli.

- Surfactant reduces «**surface tension**».

Blood-Gas Interface

- Oxygen and carbon dioxide move between air and blood by **simple diffusion**.
- The blood-gas barrier is exceedingly **thin** and extremely large (≈ 50-100 m^2)
- 500 million alveoli in the human lung. The total surface area of alveoli in contact with capillaries is roughly the size of a tennis court.

Blood Vessels and Flow

- The pulmonary blood vessels also form a series of branching tubes from the ***pulmonary artery*** to the ***capillaries*** and back to the ***pulmonary veins*****.**
- The capillaries form a dense network in the walls of the alveoli.
- The lung has an additional blood system, the **bronchial circulation.**

Respiratory Muscles

- The thorax is a closed compartment and completely separated from the abdomen by a large, dome-shaped sheet of skeletal muscle called the **diaphragm.**

- The wall of the thorax is formed by the spinal column, the ribs, the breastbone (sternum), and several groups of muscles that run between the ribs that are collectively called the **intercostal muscles.**

Pleura

- Each lung is surrounded by a completely closed sac, the **pleural sac,** consisting of a thin sheet of cells called **pleura** *(visceral pleura + parietal pleura)***.**
- Two layers are separated by an extremely thin layer of **intrapleural fluid,** the total volume of which is only a few milliliters.
- The intrapleural fluid totally surrounds the lungs and lubricates the pleural surfaces.
- Changes in the hydrostatic pressure of the intrapleural fluid—the **intrapleural pressure** (***P*ip**)—cause the lungs and thoracic wall to move in and out together during normal breathing.

Principles of Ventilation

- **Ventilation** is defined as the exchange of air between the atmosphere and the lungs.

- F (Flow) = ΔP (ΔPressure) / R (Resistance)

Alveolar pressure (P_{alv}) - atmospheric pressure (P_{atm})

- All pressures in the respiratory system will be given r*elative to atmospheric pressure.*

Principles of Ventilation

- $P_{alv} = P_{atm}$ (no airflow)
- $P_{alv} < P_{atm}$ (inspiration)
- $P_{alv} > P_{atm}$ (expiration)

Boyle's Law

$$P_1V_1 = P_2V_2$$

Transmural Pressure

- There are **no muscles** attached to the lung surface to pull the lungs open or push them shut.

- Lungs are passive elastic structures—like balloons—and their volume, therefore, depends on other factors.
  1. The difference in pressure between the inside and outside of the lung , **transpulmonary pressure** ($\mathbf{P_{tp}}$).
  2. How stretchable the lungs are, which determines how much they expand for a given change in P_{tp}.

Transmural Pressure

- **P_{alv}** = Air pressure inside the alveoli (pressure inside the lungs)
- **P_{ip}** = the pressure of the intrapleural fluid surrounding the lungs (Pressure outside the lungs)
- Transpulmonary pressure **(P_{tp}) = P_{alv} - P_{ip}**
- Transpulmonary pressure is the **transmural pressure** that governs the static properties of the lungs. *Transmural* means «across a wall».

Collapse of the Lungs

- The **elastic recoil**, is defined as the tendency of an elastic structure to oppose stretching or distortion.
- Even at rest, the lungs contain air, and their natural tendency is to collapse because of elastic recoil.
- The lungs are held open by the positive P_{tp}, which, at rest, exactly opposes elastic recoil.
- Chest wall also has elastic recoil, and, at rest, its natural tendency is to expand. At rest, these opposing transmural pressures balance each other out.

Visceral Pleura

Intrapleural Fluid

Parietal Pleura

P_{ip}

Elastic Recoil of the Lungs

Elastic Recoil of the Chest Wall

Collapse of the Lungs

- If the chest wall is pierced without damaging the lung atmospheric air enters the intrapleural space through the wound.
  - $\mathbf{P_{ip}}$ increases from −4 mmHg to 0 mmHg.
- The transpulmonary pressure acting to hold the lung open is eliminated and the lung collapses ***(Pneumothorax).***

Inspiration

1. Diaphragm and inspiratory intercostals contract.
   – Diaphragm is innervated by **phrenic nerve**
2. Thorax expands.
3. P_{ip} becomes **more** subatmospheric
4. Transpulmonary pressure increases
5. Lungs expand
6. P_{alv} becomes subatmospheric
7. Air flows into alveoli

(a) normal inspiration **(b)** maximal inspiration

Expiration

1. Diaphragm and inspiratory intercostals stop contracting.
2. Chest wall recoils inward
3. P_{ip} moves back toward preinspiration value
4. Transpulmonary pressure moves back toward preinspiration value
5. Lungs recoil toward preinspiration size
6. P_{alv} becomes greater than P_{atm}
7. Air flows out of lungs

(a) normal expiration; **(b)** maximal expiration;

Lung Mechanics

Lung Compliance

- How much any given change in transpulmonary pressure expands the lungs depends upon the stretchability, or **compliance**, of the lungs.

- **Lung compliance** ($\mathbf{C_L}$) is defined as the magnitude of the changein lung volume (ΔVL) produced by a given change in the transpulmonary pressure:

$$C_{\mathrm{L}} = \Delta V_{\mathrm{L}} / \Delta P_{\mathrm{tp}}$$

Lung Mechanics

Determinants of Lung Compliance

- There are two major determinants of lung compliance:
  1. Stretchability of the lung tissues, particularly their elastic connective tissues.
  2. **Surface tension** at the air–water interfaces within the alveoli.

- At an air–water interface, the attractive forces between the water molecules, known as **surface tension.**

Surfactant

- The **type-II alveolar cells** secrete surfactant**,** which markedly reducesthe cohesive forces between water molecules on the alveolar surface.

Surfactant

- Its effect is greater in smaller alveoli, thereby reducing the surface tension of small alveoli below that of larger alveoli.
- A deep breath increases its secretion by stretching the type II cells. Its concentration decreases when breaths are small.
- Production in the fetal lung occurs in late gestation and is stimulated by the increase in cortisol (glucocorticoid) secretion that occurs then.

Law of Laplace

- The **Law of Laplace** describes the relationship between pressure (*P*), surface tension (*T*), and the radius (*r*) of an alveolus.

$$P = 2T/r$$

As the radius of an alveolus decreases, the pressure inside it increases.

Respiratory Distress Syndrome of the Newborn

- Leading cause of death in premature infants.
- Surfactant-synthesizing cells may be too immature to function adequately.
- Because of low lung compliance, the affected newborn infant can inspire only by the most strenuous efforts, which may ultimately cause complete exhaustion, inability to breathe, lung collapse, and death.
- Current therapy includes assisted breathing with a mechanical ventilator and the administration of natural or synthetic surfactant given through the infant's trachea.

Airway Resistance

- Remember:
  - F (Flow) = ΔP (ΔPressure) / **R (Resistance)**
- Airway resistance is inversely proportional to the fourth power of the **airway radii.**
- Airway resistance to airflow is normally so small that very small pressure differences produce large volumes of airflow.

Airway Resistance

- Physical, neural, and chemical factors affect airway radii and therefore resistance.

- Physical factors (in inspiration):
  1. Transpulmonary pressure, which exerts a distending force on the airways, just as on the alveoli.
  2. **Lateral traction:** elastic connective-tissue fibers that link the outside of the airways to the surrounding alveolar tissue. These fibers are pulled upon as the lungs expand during inspiration.

Airway Resistance

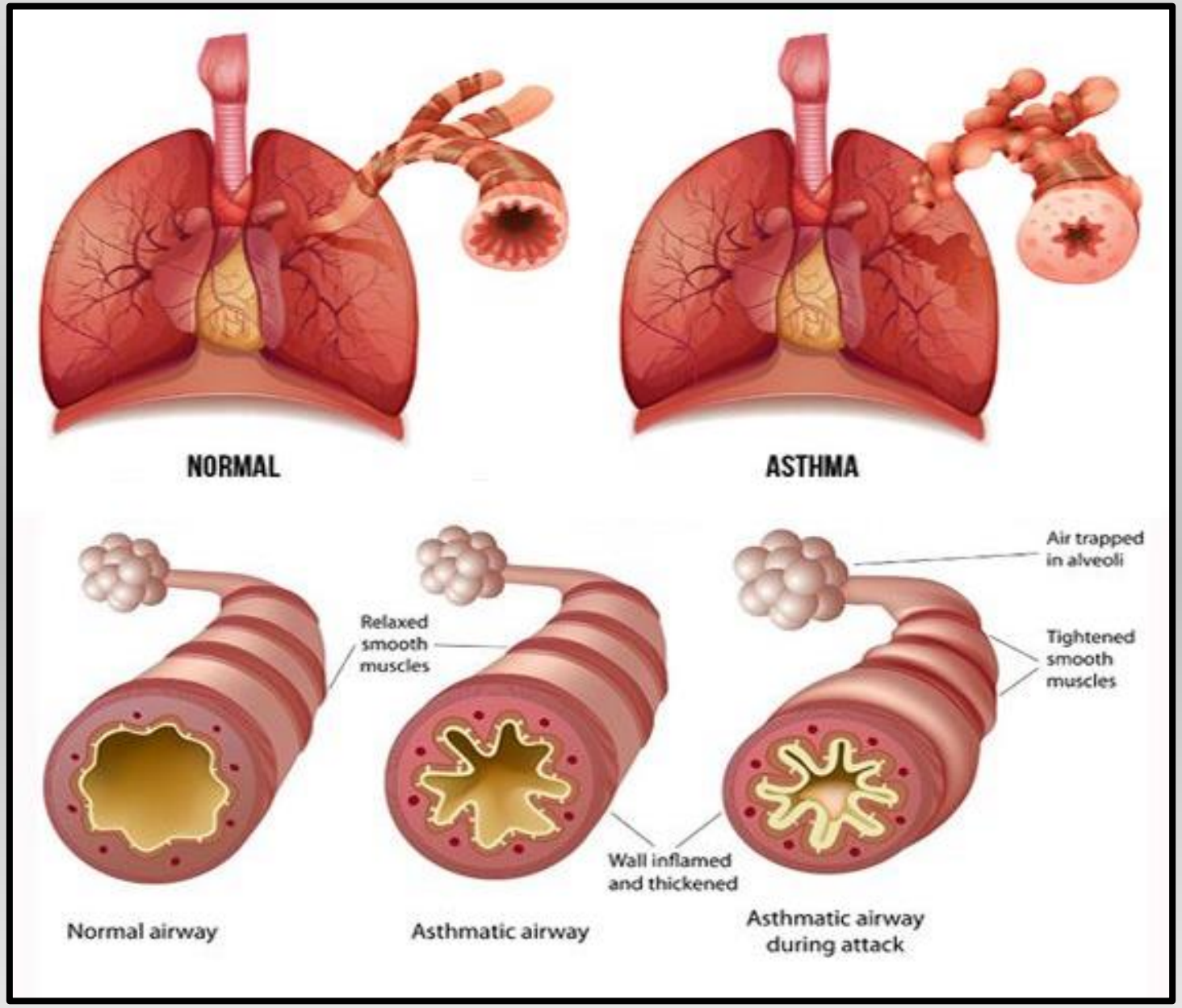
- Physical factors (in expiration)
  - Airways become narrower and airway resistance increases during a forced expiration.
  - Because of increased airway resistance, there is a limit to how much one can increase the airflow rate during a forced expiration no matter how intense the effort.
- Neuroendocrine and paracrine factors can influence airway smooth muscle and thereby airway resistance.
  - **Bronchodilation:** Increasing the radius of the lungs
  - **Bronchoconstriction:** Decreasing the radius of the lungs
- Diseases in which airway resistance is increased classified as **obstructive diseases** (asthma, COPD).

Asthma

- ***Asthma*** is a disease characterized by intermittent episodes in which airway smooth muscle contracts strongly, markedly increasing airway resistance.

- The basic defect in asthma is chronic inflammation of the airways.

- The underlying inflammation makes the airway smooth muscles hyperresponsive and causes them to contract strongly in response to such things as exercise (especially in cold, dry air), tobacco smoke, environmental pollutants, viruses, allergens, normally released bronchoconstrictor chemicals, and a variety of other potential triggers.



(1) Anti-inflammatory drugs **(2)** Bronchodilator drugs

Chronic Obstructive Pulmonary Disease (COPD)

- Chronic obstructive pulmonary disease (COPD) is a chronic inflammatory lung disease that causes obstructed airflow from the lungs.
- Symptoms include breathing difficulty, cough, mucus (sputum) production and wheezing.
- It's typically caused by long-term exposure to irritating gases or particulate matter, most often from cigarette smoke.
- In contrast to asthma, increased smooth muscle contraction is *not* the cause of the airway obstruction in these diseases.
- **Emphysema** and **chronic bronchitis** are the two most common conditions that contribute to COPD.

Chronic Obstructive Pulmonary Disease (COPD)

Lung Volumes and Capacities

Lung Volumes

Lung Volumes & Capacities

Lung Volumes (4):

1. Normal breathing = **tidal volume (V_T or TV)** (≈500 ml).

2. **Inspiration reserve volume (IRV)** (≈3100 ml) is the additional air that can be forcibly inhaled after the **inspiration** of a normal tidal **volume.**

3. **Expiratory reserve volume (ERV)** (≈1100 ml) is the amount of extra air — above anormal breath — exhaled during a forceful breath out.

4. Some gas remained in the lung after a maximal expiration; this is the **residual volume (RV)** (≈1200 ml).

Lung Volumes & Capacities

Lung Capacities (4):

1. Maximal inspiration followed by maximal expiration=**vital capacity (VC)** (3-5 L). VC = IRV+TV+ERV

2. **Inspiratory capacity (IC)** is the amount of air taken in during a deep breath. IC = TV + IRV

3. The volume of gas in the lung after a normal expiration is the **functional residual capacity (FRC)** (1,8 - 2,4 L). *FRC= RV+ERV*

4. **Total lung capacity (TLC)** is the maximum volume of air the lungs can accommodate (4-6 L). VC = IRV+TV+ERV+RV

Measurement of Lung Volumes

- Some of these volumes can be measured with a **classic water-bell spirometer**.
- Electronic devices have now replaced the water spirometer.

Measurement of Lung Volumes

- **Residual volume** cannot be measured with a simple spirometer (Because you cannot be exhaled).
  - So **TLC** and **FRC** also cannot be measured.

- These volumes can be measured by **«helium dilution method»**.

- Another way of measuring the FRC is with a «**body plethysmograph»**. This is a large airtight box, like an old telephone booth, in which the subject sits.

Measurement of Lung Volumes

Ventilation

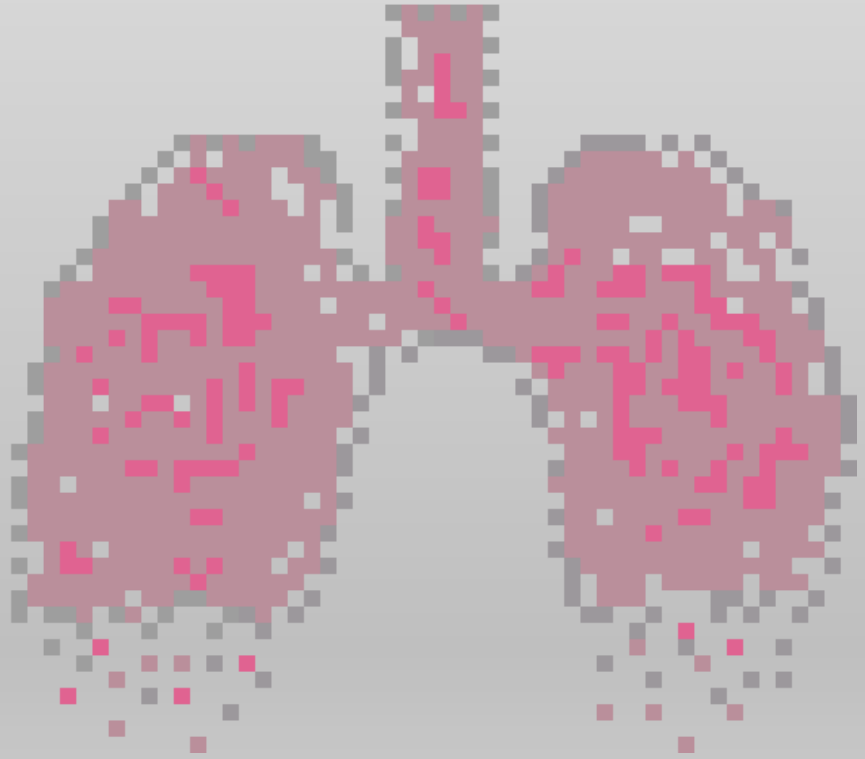
- The total volume leaving the lung each minute:
  - The volume exhaled with each breath is ≈500 ml
  - 15 breaths/min
  - 500 × 15 = 7500 ml/min
- This is known as the ***total ventilation*** or the ***minute ventilation*** or ***pulmonary ventilation***.
- However of each 500 ml inhaled in, 150 ml remains behind in the **anatomic dead space**.
  - Thus, the volume of fresh gas entering the respiratory zone each minute is (500 − 150) × 15 = 5250 ml/min.
  - This value is called ***alveolar ventilation*** **($\dot{V}_A$).**

Alveolar Ventilation

- Alveolar ventilation, rather than minute ventilation, is the important factor in the effectiveness of gas exchange.
- Increased *depth* of breathing is far more effective in increasing alveolar ventilation than an equivalent increase in breathing *rate.*
- Conversely, a decrease in depth can lead to a critical reduction in alveolar ventilation.

Alveolar Ventilation

- This is because some alveoli may, for various reasons, have little or no blood supply. This volume of air is known as **alveolar dead space.**
- It is quite small in healthy persons but may be very large in persons with lung disease.
- The sum of the anatomical and alveolar dead spaces is known as the **physiological dead space.**



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Thank you for your patience!