Respiratory Physiology
Part I

BIO 219
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Respiratory System

• Primary functions:
  • Supply oxygen and eliminate carbon dioxide
  • Regulate pH of blood
Structure of Respiratory System

- Respiratory tract is made up of two zones
  - Conducting zone
    - No gas exchange
  - Terminal zone
    - Where gas exchange occurs

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Alveoli

• Primary sites of gas exchange, have huge surface area
  • Type I cells- simple squamous epithelia
  • Type II cells- secrete surfactant, helps keep alveoli open
  • Alveolar macrophages- “dust cells” help keep lungs clean
• Alveoli are surrounded by pulmonary capillaries, exchange gas with blood
Anatomy of Thoracic Cavity

- Nasal cavity
- Nostril
- Oral cavity
- Pharynx
- Trachea
- Larynx
- Right main (primary) bronchus
- Right lung
- Left main (primary) bronchus
- Base of left lung
- Diaphragm
Thoracic Cavity

• Chest Wall
  • Surrounds thoracic cavity (ribs, intercostal muscles, etc)

• Diaphragm
  • Separates thoracic and abdominal cavities

• Pleurae
  • Serous membranes that surround each lung, form fluid filled pleural sacs
  • Parietal pleura lines chest wall and diaphragm
  • Visceral pleura covers lungs

• Intrapleural space
  • Thin fluid filled space between parietal and visceral pleurae
    • Fluid in intrapleural space connects lung to chest wall
Respiratory Muscles

• Inspiration:
  • Active process - requires contraction of diaphragm (skeletal muscle)
  • Also requires external intercostal muscles

• Expiration
  • Passive process at rest - diaphragm only relaxes and air flows out
  • Active during exercise - diaphragm can push, and intercostals can as well.
Ventilatory Mechanics

- Gas flows in and out of lungs due to pressure gradients between lungs and environment
  - If $P_{\text{ATM}} > P_{\text{Alv}}$, then gas will flow in to lungs from environment
  - If $P_{\text{ATM}} < P_{\text{Alv}}$, then gas will flow out of lungs into environment
Pressure – Volume Relationship

- Pressure of any gas is inversely proportional to its volume
  - Boyle’s Law $P_1V_1 = P_2V_2$
  - During inspiration, respiratory muscles contract, and thoracic cavity expands (more volume), lowering the pressure in the thoracic cavity
  - Pressure in lungs is now greater than the pressure in thoracic cavity so they expand (increase in volume, decrease in pressure)
  - $P_{ATM} > P_{alv}$ Air flows in to lungs.
  - Negative pressure in intrapleural space allows lungs to stay inflated
    - Pneumothorax- air enters IP space and lung collapses
Atmospheric pressure

Transpulmonary pressure:
760 mm Hg - 756 mm Hg
= 4 mm Hg

Intrapleural pressure:
756 mm Hg (4 mm Hg)

Intra-alveolar pressure:
760 mm Hg (0 mm Hg)

Parietal pleura
Visceral pleura
Pleural cavity
Thoracic wall
Lung
Diaphragm
Pressures involved in breathing

- Atmospheric ($P_{\text{ATM}}$) = 760mmHg at sea level we use 0 as reference
- Alveolar (intrapulmonary) ($P_{\text{ALV}}$) = air pressure in alveoli
  - $P_{\text{alv}} = P_{\text{atm}} = 0$ at end of exhalation.
- Intrapleural pressure ($P_{\text{IP}}$) = Pressure inside IP space (negative)
  - Keeps lungs inflated

  - **Inspiration**: resp. muscles contract $\rightarrow$ Pip ↓ (< -4 mm Hg) $\rightarrow$ V ↑ $\rightarrow$ Palv ↓ $\rightarrow$ air flows in

  - **Expiration**: resp. muscles relax $\rightarrow$ Pip ↑ (back to -4 mm Hg) $\rightarrow$ V ↓ $\rightarrow$ Palv ↑ $\rightarrow$ air flows out
**Intrapulmonary pressure.** Pressure inside the lung decreases as lung volume increases during inspiration; pressure increases during expiration.

**Intrpleural pressure.** Pleural cavity pressure becomes more negative as the chest wall expands during inspiration. Returns to initial value as the chest wall recoils.

**Volume of breath.** During each breath, the pressure gradients move 0.5 liter of air into and out of the lungs.
Physical Properties of Lungs

• Compliance
  • Increased compliance means increased breath size and vice versa

• Elasticity
  • Stretching force, ability to return to normal length or volume
  • Helps with expiration

• Airway resistance
  • Diameter of small airways
    • Asthma attack can reduce airway diameter
Surface Tension and Surfactant

• **Surface Tension**
  • - results from forces between water molecules at air-water interface
  • - contributes to inward recoil force in lungs, tends to collapse alveoli inward
  • - greater effect on small alveoli than large alveoli  \((\text{Law of Laplace}: P = 2T/r)\)

• **pulmonary surfactant** - secreted by type II alveolar cells → reduces surface tension
  • - ↑ compliance, decreases work of breathing
  • - stabilizes alveoli by reducing surface tension more in small alveoli
  • *respiratory distress syndrome* (RDS) in premature infants is due to insufficient surfactant
Lung Volumes and Capacities

- **Total lung capacity**
  - Total air in lungs at max capacity
- **Tidal volume**
  - Volume of 1 normal breath
- **Vital capacity**
  - Maximum breathing volume
- **Inspiratory reserve volume**
  - Inhalation volume after normal tidal inhalation
- **Expiratory reserve volume**
  - Exhalation volume after normal tidal exhalation
- **Residual volume**
  - Air in lungs after maximal exhalation
Pulmonary Ventilation

- Minute Ventilation ($V_E$) = Respiration Rate $\times$ Tidal Volume
  - $12$ breaths/ min $\times$ $500$ mL/breath $= 6L/min$

- Alveolar Ventilation is a better measure of actual respiration because this is where gas exchange occurs
  - $V_A = RR \times (V_T - V_{DS}) =$
  - $12$ b/min $\times (500 - 150$ mL/ breath $) = 4.2L/min$
Pulmonary Disorders

- **restrictive disorders** – e.g., pulmonary fibrosis
- reduced lung compliance → difficult inspiration, reduced vital capacity
- **obstructive disorders** – e.g., asthma
- increased airway resistance → difficult expiration, lower rate of expiration
- *chronic obstructive pulmonary disease* (COPD): emphysema, asthma, chronic bronchitis
- emphysema involves destruction of alveolar tissue
- - fewer, larger alveoli → decreased surface area for gas exchange
- - reduced elastic recoil of lungs → difficult expiration, small airways collapse → air trapping