Chapter 37: Pulmonary Ventilation

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Respiratory Structures
Basic Structures of Respiration

- Nasal/Oral Cavities
- Larynx
- Trachea
- Bronchi
- Secondary Bronchi
- Bronchioles
- Alveoli
Mechanics of Ventilation
Boyle’s Law

\[ P_1 V_1 = P_2 V_2 \]

Pressure of gas varies inversely with its volume

Increase in volume leads to a decrease in pressure = inhalation

Decrease in volume leads to an increase in pressure = exhalation

Air moves from an area of high concentration to low
Muscular Events During Inspiration

- **Diaphragm contraction**
  - Normal respiration
  - Assists during heavy breathing

- **Rib cage elevation**
  - Normal respiration
  - Assists during heavy breathing
Muscular Events During Expiration

Diaphragm relaxes

Abdominal muscles contract

Normal respiration

Assists during heavy breathing
True or False:
Expansion of the thoracic cage decreases the pressure inside the lungs.

A. True
B. False
Thoracic Pressures

Intrapulmonary (alveolar) Pressure
Pressure of the air inside the lung alveoli
No exchange = atmospheric pressure
Negative pressure = inspiration
Positive pressure = exhalation
Thoracic Pressures

Intrapleural (pleural) Pressure
Pressure of the fluid in the space between the lung pleura and the chest wall
Slightly negative - decreases during inhalation
Thoracic Pressures

Intrapleural (pleural) Pressure
Negative pressure is created by fluid draining into the lymphatic system
This negative pressure is required to keep the lungs from collapsing
Thoracic Pressures

Transpulmonary Pressure

The difference between the alveolar pressure and the pleural pressure

It is a measure of the elastic forces in the lungs
Lung Compliance

The extent to which the lungs expand for each unit increase in transpulmonary pressure

Every 1 cm H$_2$O increase results in a 200mL expansion in lung volume

Two factors

1. Elastic forces in lungs: Elastin and collagen in the lungs

2. Alveolar surface tension: Surface tension caused by the fluid inside the alveoli and the air inside the alveoli
   a. Creates a contractile effect within the alveoli
Lung Compliance

Factors reducing lung compliance:

- Reduced tissue elasticity
- Increased surface tension
- Increased airway resistance
  - Mucus buildup
- Bronchial constriction
Respiratory Volumes and Capacities
Pulmonary Volumes

1. **Tidal Volume** ($V_T$): Volume of air inspired and expired within a normal breath.

2. **Inspiratory Reserve Volume** (IRV): Extra volume of air that can be inspired after a normal, tidal breath.

3. **Expiratory Reserve Volume** (ERV): Extra volume of air that can be expired after a normal, tidal breath.

Pulmonary Capacities

1. **Inspiratory Capacity (IC):** \( IC = V_T + IRV \)
   
   Amount of air a person can breathe in beginning at the normal expiratory level and distending the lungs to max amount. aka. forceful inspiration.

2. **Functional Residual Capacity (FRC):** \( FRV = ERV + RV \)
   
   Amount of air that remains in lungs at the end of normal expiration.

3. **Vital Capacity (VC):** \( VC = IRV + V_T + ERV \) or \( VC = IC + ERV \)
   
   Max amount of air a person can expel from their lungs after first filling lungs with max inspiration.

4. **Total Lung Capacity (TLC):** \( TLC = VC + RV \) or \( TLC = IC + FRC \)
   
   Max volume the lungs can be expanded with greatest possible effort.
Which of the following is defined by the amount of air that remains in the lungs at the end of normal expiration?

A. Residual Volume
B. Functional Residual Capacity
C. Expiratory Reserve Volume
D. Vital Capacity
Other Pulmonary Measurements

1. **Minute Respiratory Volume (MRV):** \( \text{MRV} = (V_T)(\text{Respiratory Rate/min}) \)
   Total amount of new air moved into the respiratory passages each minute.
   
   a. This can become as great as the vital capacity giving a minute respiratory volume greater than 30x normal. However, most people cannot sustain \( \frac{1}{2} \) of this value for longer than a minute.

2. **Dead Space:** Areas of the respiratory system that contain some volume of air but do not perform gas exchange. (Anywhere other than closely related alveolar areas) This air, called *dead space air*, is not useful for gas exchange because it cannot reach the areas of gas exchange. Air in the dead space is expired first from pulmonary system.
   
   a. **Anatomic Dead Space:** Measurement of volume of all the space of the respiratory system other than the alveoli and their other closely related gas exchange areas.

   b. **Physiological Dead Space:** When there is alveolar dead space present in total measurement of dead space.
Methods of Pulmonary Measurement
Spirometry

Measures pulmonary ventilation by recording volume movement of air in and out of the lungs.

How it works: Person breathes into a drum filled with breathing gas (usually $O_2$) suspended in water, counterbalanced by a weight. This moves drum up and down in the water and this is recorded by a moving sheet of paper.
Helium Dilution Method

Measurement of FRC, RV, and TLC.

How it works: Indirect use of spirometer. A spirometer with known volume is filled with air mixed with helium at known concentration. Before breathing into the spirometer a person exhales normally and immediately begins to breath from spirometer. Gases mix (of lungs and spirometer). Helium is diluted by FRC gases. The following is then calculated.

Calculations:

$$\text{FRC} = \left( \frac{C_{i_{He}}}{C_{f_{He}}} - 1 \right) V_{i_{Spir}}$$

$C_{i_{He}}$ is the initial [He] in the spirometer and $C_{f_{He}}$ is the final [He] in the spirometer, and $V_{i_{Spir}}$ is initial volume in the spirometer.

$$\text{RV} = \text{FRC} - \text{ERV}$$

$$\text{TLC} = \text{FRC} + \text{IC}$$
Dead Space Measurement

How it works:

1. Person takes deep breath of O₂ filling entire dead space with pure O₂. (Some O₂ does mix with alveolar air but does not completely replace it)

2. Then, the person expires through a nitrogen recording meter. First portion expired (pure O₂) comes from the dead space. When alveolar air reaches the nitrogen meter the [N] increases rapidly.

3. Eventually nitrogen reaches a plateau level equal to the concentration in the alveoli

Calculations: \( V_D = \frac{\text{Gray area} \times \text{expired volume of ventilation per minute}}{\text{Pink area} + \text{Gray area}} \)
Alveolar Ventilation
Alveolar Ventilation

The rate at which new air reaches the gas exchange zones

In these regions, air is in close proximity with pulmonary blood

Including...
Alveolar Ventilation

Alveolar ventilation rate: Total volume of new air entering the alveoli per minute

Measures effective ventilation, meaning determining the amount of oxygen and carbon dioxide in the alveoli.

\[ V_A = \text{frequency} \times (V_T - V_D) \]

- \( V_A \) = volume of alveolar ventilation per minute
- Frequency = breaths per minute
- \( V_T \) = tidal volume
- \( V_D \) = dead space volume
Which gas diffuses across the alveolar surface the fastest?

A. Carbon Monoxide
B. Carbon Dioxide
C. Oxygen
D. Nitrogen