Basic Pulmonary Mechanics during Mechanical Ventilation

Mazen Kherallah, MD, FCCP
Points of Discussion

<table>
<thead>
<tr>
<th>Basics and Scalars</th>
<th>Abnormalities</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Equation of motion</td>
<td>1. Air Leak</td>
</tr>
<tr>
<td>2. Airway pressures</td>
<td>2. Auto PEEP</td>
</tr>
<tr>
<td>3. Mean airway pressure</td>
<td>3. Active Exhalation</td>
</tr>
<tr>
<td>4. End-inspiratory plateau</td>
<td>4. Inadequate insp flow</td>
</tr>
<tr>
<td>5. Compliance</td>
<td>5. Obstruction</td>
</tr>
<tr>
<td>7. Pressure-Time</td>
<td></td>
</tr>
<tr>
<td>8. Flow-Time</td>
<td></td>
</tr>
</tbody>
</table>
Lung Mechanics

**Elastance** = \( \frac{\Delta \text{pressure}}{\Delta \text{volume}} \)

**Resistance** = \( \frac{\Delta \text{pressure}}{\Delta \text{flow}} \)

**Diagram**:
- **Flow** indicates the direction of airflow.
- **Volume** is represented by a yellow circle.
- **Transairway pressure** is indicated by a vertical line.
- **Transthoracic pressure** is indicated by a vertical line.
- **Transrespiratory pressure** is indicated by a vertical line.

---

Lung Mechanics

**Elastance** = \( \frac{\Delta \text{pressure}}{\Delta \text{volume}} \)

**Resistance** = \( \frac{\Delta \text{pressure}}{\Delta \text{flow}} \)
Equation of Motion

\[ \text{ventilation pressure} = \text{resistive pressure} + \text{elastic pressure} \]

\[ P = P_{\text{resistive}} + P_{\text{elastance}} \]

\[ P = R \times V + E \times V \]
Pressure vs Time
Spontaneous Breath

$P_{aw}$ (cm H$_2$O)

Expiration

Inspiration

Time (sec)
Pressure vs Time
Mechanical Breath

Peak Inspiratory Pressure (PIP)

Inspiration

Expiration

\( P_{aw} \) (cm H\(_2\)O)

Time (sec)

\( T_i \)

\( T_e \)

PEEP
Spontaneous vs. Mechanical

Inspiration
Expiration

$P_{aw}$ (cm H$_2$O)

Mechanical
Expiration
Inspiration

Time (sec)
Assisted vs Controlled

- Assisted
- Controlled

Pressure (cmH$_2$O) vs Time (sec)
Components of Inflation Pressure

- P_{aw} (cm H_2O)
- Begin Inspiration
- P_{plateau} (Palveolar)
- Inspiratory Pause
- Begin Expiration
- Expiration
- Time (sec)
PIP vs Pplat

Normal

High Raw

High Flow

Low Compliance

Time (sec)

Paw (cm H₂O)
Mean Airway Pressure

- Increase Flow
- Increase peak pressure
- Lengthen Inspiratory Time
- Increase Rate
- Increase PEEP
Increasing Mean Airway Pressure

1. Increase flow
2. Increase peak pressure
3. Lengthen inspiratory time
4. Increase PEEP
5. Increase Rate
Volume vs. Time

Inspiration

Expiration

Inspiratory Tidal Volume

Time (sec)

Volume (ml)
Active Exhalation

Volume (ml) vs Time (sec)
Air Leak

Volume (ml)

Time (sec)

Air Leak
Pressure/Flow/Volume vs Time

- Pressure (cm H₂O)
- Flow (L/m)
- Volume (mL)
- Time (sec)
Flow Patterns

- SQUARE
- DECELERATING
- ACCELERATING
- SINE
Flow Patterns and Effects of Volume

- SQUARE
- DECELERATING
- ACCELERATING
- SINE
Inspiratory Flow Pattern

- Peak inspiratory flow rate (PIFR)
- Beginning of inspiration: exhalation valve closes
- Inspiration
- Time (sec)
- Flow (L/min)
- Expiratory Time ($T_E$)
- Total cycle time (TCT)
- Beginning of expiration: exhalation valve opens
- Expiration
Expiratory Flow Pattern

- **Inspiration**
- **Expiration**
- **Expiration time**
- **Peak Expiratory Flow Rate (PEFR)**
- **Beginning of expiration**: exhalation valve opens
- **Duration of expiratory flow**
Spontaneous Breath

Flow (L/min)

Inspiration

Expiration

Time (sec)
Mechanical vs Spontaneous

Mechanical

Spontaneous

Inspiration

Expiration
Increased Expiratory Resistance

Flow

Normal Resistance

Increased Resistance

Time
Response to Bronchodilator

Before

Flow (L/min)

PEFR

After

Long $T_E$

Higher PEFR

Shorter $T_E$

Time (sec)
Insufficient Expiratory Time

End-Expiratory Flow
Excessive Secretions

Inspiration

Expiration

Flow (L/min)

Time (sec)

Normal

Patient
Air Leak

Expiratory flow area less than inspiratory flow area

Inspired volume
Expired volume

Leak
Air Leak (Flow Trigger, autotriggering)

- Inspiration
- Expired
- Leak in LPM

Flow (L/min)

Time (sec)
Active Inspiration or Asynchrony

Patient’s effort

Normal
Abnormal

Flow (L/min)

Time (sec)
Excessive Inspiratory Time

- Inspiration
  - Increase WOB and “Fighting” of the ventilator

- Expiration
  - Air Trapping
  - Auto-PEEP

Time (sec)
Obstruction vs Active Expiration

Time (sec)

Flow (L/min)

Obstruction

Active Expiration

Normal

Abnormal
Trigger Sensitivity

Pressure

Flow

Sensitivity level
Thank You