Guidelines for Initiation of Mechanical Ventilation in Acute Respiratory Failure

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Topics for Consideration

• Classification of Respiratory Failure and Distinctions Between Acute and Chronic
• Underlying Pathophysiologic Principles in Respiratory Failure
• When to Intubate and When to Initiate Mechanical Ventilation
• Contemporary Basic Ventilator Strategies
Classification of Respiratory Failure

- Respiratory failure
  - Hypercapnic
    - Acute
    - Chronic
  - Hypoxemic
    - Acute
    - Chronic

Source: Michael A. Griggs, Jack A. Ellies, Jay A. Fishman, Robert M. Kozloff, Allan I. Pack, Robert M. Senicic, Mark D. Siegel; Fishman's Pulmonary Diseases and Disorders; www.accessmedicine.com
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# Distinctions Between Acute and Chronic Hypoxemic and Hypercapnic Respiratory Failure

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<th>Hypoxemic</th>
<th>Hypercapnic</th>
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<tr>
<td></td>
<td>PaO2 &lt; 60 mmHg</td>
<td>PaCO2 &gt; 45 mmHg</td>
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<tr>
<td>Acute</td>
<td>Develops in minutes to hours</td>
<td>Develops in minutes to hours; no pH compensation</td>
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<tr>
<td>Chronic</td>
<td>Present for days to years</td>
<td>Present for days to years; partial pH compensation</td>
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Concept of Ventilatory Supply Versus Demand

A Ventilatory supply exceeds ventilatory demand.

B Ventilatory supply equals ventilatory demand.

C Ventilatory demand exceeds ventilatory supply.
Afferent and Efferent Limbs of Respiratory Control
Mechanical Ventilation for Acute Hypoxemic Respiratory Failure: Usual Indications

• The usual trigger is inability to initially achieve or sustain “adequate” oxygenation (>88% saturation) using high FiO₂ via face mask.
• Considerations may include use of noninvasive ventilation.
• Other concurrent clinical issues may drive timing of the decision to intubate.
• Note: Decision to intubate may be independent of decision to mechanically ventilate.
Mechanical Ventilation for Hypercapnic Respiratory Failure: Common Considerations

- Magnitude of hypercapnia, trend, and rate of change in \( \text{PaCO}_2 \)
- Arterial pH
- Presence or absence of antecedent history of hypercapnia
- Co-existing issues (e.g., cerebral edema)
Objectives of Mechanical Ventilation

• Improve gas exchange (hypoxemia, hypercapnia)
• Alleviate respiratory distress
• Provide support during treatment of underlying disease process
• Improve respiratory mechanics
• Minimize additional lung injury

Implementation of Mechanical Ventilation: Topics for Consideration

• Underlying physiologic principles
• Basic modes
• Initiation and maintenance
• Complications
Physiologic Principles Related to Mechanical Ventilation

- Alveolar, pleural, and elastic recoil pressures
- Lung and chest wall compliances
- Airway resistance
- Work of breathing
Concepts of Elastic Recoil ($P_{el}$) and Pleural ($P_{pl}$) Pressures
$P_{aw}$ and $P_{pl}$ During a Breath

![Graph showing $P_{aw}$ and $P_{pl}$ during spontaneous breathing and mechanical ventilation.](image)
Resistances Overcome During Mechanical Ventilation

• Lung and chest wall *elasticity*
• Airway and tissue *resistance* to airflow
• *Inertial resistance* of the stationary column of air in the tracheobronchial tree
Static P-V Curve of the Lung
Static Lung Compliance

• Static lung compliance \((C_{st})\) = change in lung volume divided by change in distending pressure

• Elastance \((E) = 1/C_{st}\)
Resistances Overcome During Mechanical Ventilation

- Lung and chest wall elasticity
- *Airway and tissue resistance to airflow*
Relationship Between Airway Radius and Flow

• In a laminar flow system, flow is described by Poiseuille’s law:
  \[ \dot{V} = \frac{(P\pi r^4)}{(8\eta l)} \]

• Flow varies directly with the fourth power of the airway radius; halving the radius reduces flow 16-fold.
Additional Determinants of Airway Resistance

- Airway length
- Airway smooth muscle tone
- Physical properties of gas flowing through the airways
Selected Modes of Mechanical Ventilation

• Assist-Control (A/C)
• Synchronized Intermittent Mandatory Ventilation (SIMV)
• Pressure Support (PS)
• Noninvasive Ventilation (NIV)
Standard Ventilator Circuit
Pressure Waveform in Controlled Ventilation
Controlled Mechanical Ventilation

- Rate, tidal volume, and, therefore, minute ventilation are fixed.
- Usually not well tolerated in awake patients.
- Is an outdated mode of mechanical ventilation.
Pressure Waveform in Assist-Controlled Ventilation
Assist-Controlled Ventilation

• “Back-up” respiratory rate is guaranteed.
• Tidal volume is pre-set, but not fixed.
• Patient can initiate a breath.
• Minute ventilation may vary.
• Every breath is machine-delivered (i.e., patient can’t breathe “around” the machine).
Ventilator Circuit in SIMV
Pressure Waveform in SIMV

Synchronized

Machine-initiated

Spontaneous

assist window

A

B

time

pressure
Synchronized Intermittent Mandatory Ventilation (SIMV)

• A guaranteed minimal number of breaths of specified tidal volume is delivered.
• Patient may interpose a variable number of spontaneous breaths of variable tidal volume.
• Minute ventilation can be extremely variable.
• Originally developed as a weaning modality; now rarely used as maintenance mode.
Pressure Support Ventilation

- Pressure-targeted (pressure-limited) mode.
- Breaths are patient-triggered.
- Breath duration is patient-determined.
- Breath termination is triggered by fall in inspiratory flow.
- $V_T$ depends on respiratory mechanics; it varies with changes in compliance or resistance.
- Can not be used in an apneic patient.
Pressure, Flow, and Volume in Pressure Support Ventilation
Noninvasive Mechanical Ventilation: CPAP and BiPAP

• **CPAP: Continuous Positive Airway Pressure**
  – A given pressure is applied to airway throughout both phases of the respiratory cycle.
  – The patient must be capable of breathing spontaneously.
  – Airway pressure fluctuates minimally around the set level of CPAP.

• **BiPAP (or BPAP): Bilevel Positive Airway Pressure**
  – An inspiratory pressure (like pressure support) is superimposed on a baseline expiratory pressure pressure (like CPAP or PEEP).
  – Inspiratory flow is boosted.
  – A back-up respiratory rate can be set as well.
  – Used to augment ventilation and CO₂ elimination.
Considerations in Initiation of Mechanical Ventilation

• Mode: usually A/C or PS
• $F_{I\text{O}_2} = 1.0$
• $V_T$: It depends!
• Rate: It also depends!
• Inspiratory flow rate: 40 – 60 L/min
• Alarm settings
• PEEP?
Mode, Volume, and Rate: Important Considerations

- Obstructive or restrictive lung disease
- Acute lung injury
- Neurologic status
- Acid-base status
- Initial and target PaCO$_2$
- Presence of auto-PEEP
Abbreviated List of Immediate Complications of Intubation

• Esophageal intubation
• Glottic injury
• Perforated pharynx or esophagus
• Aspiration
• Hypoxemia
• Arrhythmias
Complications of Mechanical Ventilation: an Incomplete List

- Endotracheal tube-related complications
- “Ventilator-Associated Events” (VAE), including infection (e.g., Ventilator-Associated Pneumonia, VAP)
- Barotrauma
- Hemodynamic instability
Contemporary Ventilator Strategies: The Concept of Ventilator-Induced Lung Injury

• **Volutrauma**
  • Excessive alveolar distention (trans-alveolar pressure >30 – 40 cm H2O) in acute lung injury (ALI) is deleterious.
  • High inflation pressure may over-distend normal lung units in heterogeneous acute lung injury, potentiating alveolar damage.

• **Cyclic opening-closing of alveoli and role of PEEP**
  • Repeated opening/closing of alveoli in ALI may potentiate injury.
  • A level of PEEP which prevents alveolar closure may be protective.
Historical Versus New Ventilator Strategies

• Objectives
  • Historical: normalize ABG’s
  • New: achieve “adequate” ABG’s, prevent alveolar injury, facilitate lung healing

• Ventilator modes and settings
  • Historical: volume-cycled, $V_T$ of 8-10 ml/kg, PEEP as needed, accept whatever peak $P_{alv}$ results
  • New: pressure-targeted, $V_T$ of 4 – 8 ml/kg, sufficient PEEP to prevent tidal recruiting cycle, peak $P_{alv}$ of ≤ 30 cm H$_2$O
Special Consideration: Permissive Hypercapnia

• Within limits, and in absence of clinical disorders aggravated by hypercapnia, an increase in PaCO$_2$ is usually well tolerated.

• Lung injury-related costs of maintenance of normal PaCO$_2$ may exceed costs of moderate hypercapnia.

• pH effects of hypercapnia can be off-set by use of intravenous bicarbonate.
Summary

• Respiratory failure can be classified as hypoxemic or hypercapnic or mixed.
• Mechanical properties of lungs, chest wall, and airways are important determinants of $V_T$ during mechanical ventilation.
• Basic modes of MV include AC, SIMV, PS, and NIV.
• Contemporary ventilator strategies employ low-stretch protocols.