Introduction to MECHANICAL VENTILATION

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Disclosures
• No disclosures

House Rules:
1. Please take your cell phones out, and text IDCCM to 37607 or go to PollEv.com/idccm
2. Open dialogue, feel free to interrupt and ask questions

Objectives
At the end of today’s session you will:
• Develop an approach to managing respiratory failure
• Review concepts in initiation and management of patients on mechanical ventilation
• Review evidence behind mechanical ventilation of elective OR patients
Case 1

- 35F pedestrian was found in a back alley following a hit and run. The paramedics arrive to the scene. She is unconscious, and appears to have a lower extremity crush injury. Her initial vitals show:
  - GCS 3, HR 130bpm, BP 70/40, O₂Sats 80% on room air

Which of the following is the most common cause of hypoxemia?
1. V/Q mismatch
2. Shunt
3. Hypoventilation
4. Diffusion abnormality
5. Low inspired FiO₂
Physiologic Causes of Hypoxemia
1. V/Q mismatch
2. Shunt
3. Hypoventilation
4. Diffusion abnormality
5. Low inspired FiO2

How does hypoventilation cause hypoxemia
- Alveolar space is made of both partial pressure of O2 and CO2
- If one goes up, the other goes down
- If PaCO2 ↑, there is “less” space inside the alveolus for O2
- The lower the amount of PAO2, the less is available for gas exchange

PAO2 = FiO2(Pb - PH2O) – PaCO2/0.8
PAO2 – PaO2 = A-a gradient

Case 1 revisited...
- 35F pedestrian was found in a back alley following a hit and run. Her initial vitals show:
  - GCS 3, HR 130bpm, BP 70/40, O2 Sats 80% on room air
- Why is she hypoxic?
Common causes Respiratory Failure?

- Pneumonia
- ARDS
- Aspiration
- Heart failure/pulmonary edema
- Multi-trauma
- Pulmonary embolism
- Drug/toxic metabolites

Most common physiological cause of hypoxemia?

<table>
<thead>
<tr>
<th>V/Q mismatch</th>
<th>Shunt</th>
<th>Dead Space</th>
<th>Hypoventilation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pneumonia</td>
<td>+++</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aspiration</td>
<td>+++</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ARDS</td>
<td>+++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>CHF</td>
<td>+++</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PE</td>
<td>++</td>
<td>++</td>
<td></td>
</tr>
<tr>
<td>Drugs/Toxic</td>
<td>+++</td>
<td></td>
<td>+++</td>
</tr>
</tbody>
</table>

Hypercapneic Respiratory Failure

- CO₂ is a common form of respiratory waste by the tissue
- CO₂ – tightly controlled in the body
- PaCO₂ = k x CO₂ production

\[ \text{CO}_2 \text{ removal} = k \times \text{VCO}_2 \]

Vₐ - alveolar ventilation = V (1-V/D/V);
VCO₂ – CO₂ production
Vₐ goes down with more dead space; Vₐ = minute ventilation = RR x Vₐ

Causes of hypercapnea

1. Hypoventilation
   - Central CNS
   - Low RR
   - Shallow breathing
   - Drugs/opioids abnormality

2. V/Q mismatch and Vₐ
   - COPD
   - Asthma
   - PE

3. Muscle and chest wall
   - Nerve
   - Muscle
   - Kyphoscoliosis

4. Increased CO₂ production
   - Metabolism
   - Sepsis, fever
   - Hyperthyroid
   - Drug overdose
   - Refeeding
   - Extreme tachypnea

Case 1 revisited...

- 35F pedestrian was found in a back alley following a hit and run. Her initial vitals show:
  - GCS 3, HR 130 bpm, BP 70/40, O₂Sats 80% on room air
- Hypoxic likely secondary to:
  - Chest trauma, lung contusions, ARDS, shock......
What will you do next?

Oxygen Therapy

• What's available?

Oxygen therapy

Low-flow systems

• Provide supplemental O₂ without a guaranteed FiO₂
• Flows >2LPM – nasal irritations
  – Add humidity and heat → go up to 5-6LPM
  – Switch to a simple mask
• How much FiO₂ do you get with low flow systems?

High-Flow Systems – Venturi Masks

• Provides a fixed FiO₂
• 100% from the wall
• The smaller the O₂ orifice, the higher the flow going through
• Entrain room air as it passes by

Venturi Masks

<table>
<thead>
<tr>
<th>Color</th>
<th>FiO₂</th>
<th>Wall Flow (LPM)</th>
<th>Total Flow (LPM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>24%</td>
<td>2-4</td>
<td>51-108</td>
</tr>
<tr>
<td>yellow</td>
<td>28%</td>
<td>6</td>
<td>66</td>
</tr>
<tr>
<td>white</td>
<td>30%</td>
<td>8</td>
<td>72</td>
</tr>
<tr>
<td>green</td>
<td>35%</td>
<td>12</td>
<td>72</td>
</tr>
<tr>
<td>pink</td>
<td>40%</td>
<td>15</td>
<td>60</td>
</tr>
<tr>
<td>orange</td>
<td>50%</td>
<td>15</td>
<td>40</td>
</tr>
</tbody>
</table>
High-Flow Nasal Cannula

- Flows between 10-60 liters
- heated, humidified
- can deliver up to 100%
- maximum flow of 60 LPM via nasal prongs or cannula.
- FiO2 may be guaranteed if patient does not breathe through the mouth

Reservoir Systems

- Mechanisms that gather and store oxygen
- Additional source of O₂, in case patient’s minute ventilation exceed that of the device

Case 1 revisited...

- 35F pedestrian was found in a back alley following a hit and run. Her initial vitals show:
  - GCS 3, HR 130bpm, BP 70/40, O₂Sats 85% on 100% non-re-breather
- What next?

Indications for Intubation and Mechanical Ventilation

- Airway Protection
  - Altered LOC
  - Absent reflexes
  - Pulm. Toilet
- Respiratory Failure
  - Oxygenation (Type I)
  - Ventilation (Type II)
- Work of Breathing
  - High drive and VO₂ by resp. muscles

Case continues:

She is intubated in the field and given a 2L bolus of NS en route to the hospital. On arrival she is being bagged by EMS on 100%. Her vitals: O₂Sats 92%, BP 80/60, HR 130bpm, T 35°C. Her breaths seem rapid and shallow.

The TTL is barking orders and getting ready for a scan and assessment. As you get dressed the RT looks at you and says “Do you want me to put them on VC or PC?”
You tell the RT...

1. Try Non-invasive Ventilation
2. Start on Volume Control with PEEP at 10, and set a tidal volume of 6mL/kg,
3. Start on Pressure Control with a PEEP at 10, and aim for Ppeak <40cm H₂O
4. Put them on Pressure Support
5. I don’t know....

What is Mechanical Ventilation?
- Positive pressure ventilation
- Partially or completely replace SPONTANEOUS breathing
- Recognizes the patient is trying to take a breath, then pushes air into the central airways, downstream into the alveoli

What are the TWO BROAD Categories of Mechanical Ventilation?

Non-invasive vs. Invasive
- Non-Invasive Ventilation
  - aka Bi-Level Ventilation
  - Spontaneous (patient triggered) mode
  - Delivered through a mask or helmet
- Invasive Ventilation
  - Delivered through an endotracheal tube
  - Can be spontaneous (patient driven) or controlled (machine driven)

How do you start someone on mechanical ventilation?
Phase Variables

A. Trigger – What initiates the breath (negative flow or pressure, time)
B. Limit or Target – what stops the gas from flowing (flow, or pressure)
C. Cycling – when to go from inspiration to expiration (time, flow, volume, pressure)

Fraction of Inspired Oxygen (FiO₂)

- Concentration of oxygen in inspired gas (Set between 0.21 and 1.0)
- Goals:
  - Use the lowest possible FiO₂ necessary to meet your oxygenation goals (PaO₂)
  - Reduces the risk of any potential adverse reactions from supplemental oxygen
    - Absorption atelectasis, worsening hypercapnea, airway and parenchymal lung injury

Tidal Volume (Vₜ)

- Volume of gas that is inhaled and exhaled, measured in mL
- Vₜ is made up of:
  - Dead Space Ventilation ~ Vₐ
  - Alveolar Ventilation ~ Vₐ
  - Almost always 6mL/kg or less
  - Depends on several patient and lung factors (disease state, lung compliance)

Respiratory Rate (RR or f_tot)

- Number of breaths per minute that the ventilator delivers
  - No ideal number is established
  - Most patients start on RR 10-20/minute
  - Patients in respiratory distress may breathe more and the RR will be higher

PEEP

- Positive end-expiratory pressure
- Amount of pressure maintained at the end of a breath (cmH₂O)
  - Applied to maintains open alveoli
  - Generally >5cmH₂O
  - In normal people - this is represented by your RV

PEEP - How does it work?

- Physiological Benefits
  - Improvement in Gas Exchange
  - Improvement in V/Q mismatch
  - Increased Minute Ventilation
- Decreased the W.O.B
  - Reduced auto-peep
  - EPAP balances the auto-peep
  - PSV/IPAP augments your tidal volume
Minute Ventilation ($V_E$)
- The average volume of gas entering or leaving the lungs in 1 minute (in L/min)
  - $V_E = V_T \times$ RR
  - Normal $V_E = 5$-10L/min
  - This is closely related to CO$_2$ clearance by the lungs
    - In normal lungs – increasing the $V_E$ will decrease PaCO$_2$
    - In diseased states, an increase in VE is usually due to increased RR, without effective change in $V_A$

Flow Rate (V)
- The highest flow or speed by which a tidal breath is delivered during inspiration
  - Peak flow rates of 60L/min are usually sufficient
  - When flow is insufficient, patients are dyspneic, and the vent waveforms change shape
  - The faster the flow, the faster the gas is delivered, and the shorter the inspiratory time

Inspiratory:Expiratory Time (I:E ratio)
- The ratio or amount of time spent in each phase of breathing
- Normal is 1:2, or 1s for inspiration
  - If the ratio is increased, meaning more I-time, there may not be enough time for expiration
    - Residual gas is trapped within the alveoli
    - breath stacking, gas trapping, or auto-PEEP
    - CO$_2$ clearance or ventilation requires enough E-time

Areas of Potential NIV Use
- Adjunct to early liberation in hypercapnic COPD patients
- After planned extubation in patients at high risk of respiratory failure
- Hypoxic respiratory failure in patients with immunocompromise
  - Stem cell transplants
  - Chemotherapy
  - Solid Organ Transplant

Starting NIPPV
- Ensure patient is upright with HOB >30
- Appropriate interface and head gear
- Start with low-level pressure → EPAP 5-7, IPAP 10-12
- Gradual increase in pressure based on tachypnea, comfort, tidal volume, and synchrony
- Provide FiO2 to maintain sats >90%
- Check for leaks
- Reassurance, mild sedation prn

NON-INVASIVE VENTILATION

Clinical Practice Guidelines for the use of noninvasive positive pressure ventilation and noninvasive continuous positive airway pressure in the acute care setting. CMAJ 2011; 183: E185
**Monitoring**

- Re-assess cough and secretion clearance
- Monitor for complications
- Watch for gastric distension and risk of vomiting
- Check Blood Gases within 1-2h of initiation
- **Watch for signs requiring intubation**
  - Increased secretions, tachypnea, or hemodynamic instability
  - Deteriorating level of consciousness
  - Worsening gas exchange \( \rightarrow \) low sats, low pH, increased CO₂

**Recipes for Success**

- Lower acuity of illness (APACHE score)
- Intact dentition
- Moderate hypercarbia (PaCO₂ 45-92 mmHg)
- Moderate acidemia (pH 7.10-7.35)
- Improvements in gas exchange and RR~2 hr
- Younger age
- Alert, cooperative, compliant
- Breathe spontaneously
- Appropriate disease
- No contraindications to NIPPV

**Contraindications**

- Cardiac or respiratory arrest
- Non-respiratory organ failure
- Severe encephalopathy (e.g., GCS <10)
- Severe upper gastrointestinal bleeding
- Hemodynamic instability or unstable cardiac arrhythmia
- Facial or neurological surgery, trauma, or deformity
- Upper airway obstruction
- Inability to cooperate/protect airway
- Inability to clear secretions
- High risk for aspiration

**Summary**

- NIPPV can be used as an alternative to intubation
- Patient selection is the most important determinant of success
- Evidence best supports its use in the setting of COPD and cardiogenic pulmonary edema
  - Select cases of hypoxic respiratory failure
  - Weaning in chronic CO₂-retainers
- Frequent monitoring is necessary to identify early failures and prevent poor outcomes

**INVASIVE VENTILATION**
Pressure vs. Volume based

Depends on the lung compliance

Gattinoni L et al., Am J Respir Crit Care Med 2001;164:1701-1711.

Pressure Support (PSV)
- Partial assistance from the ventilator
- Preset level of inspiratory support (Pressure)
- Variable RR, flow, and \( V_T \)
- Cycles from inspiration to expiration based on a preset level (<25% peak flow)

Pressure Control (PC)
- Set RR and Insp. Pressure
- \( V_T \) is variable, aim for <6mL/kg
- If the patient takes a breath, they get the set pressure level
- Guarantees a pressure limit
- Ppeak <35cmH2O

Volume/Assist Control (VC/AC)
- Set RR and \( V_T \)
- Insp. Pressure is variable, aim for \( P_{plat} <30cmH2O \)
- If patient triggers a breath, they get the set \( V_T \)
- Guarantees \( V_E \) because there is a guaranteed \( V_T \)

Advantages and Disadvantages

<table>
<thead>
<tr>
<th>Mode</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controlled Ventilation vs. Spontaneous</td>
<td>Reduced work of breathing</td>
<td>Hypotension, hyperventilation</td>
</tr>
<tr>
<td>Volume Control Ventilation</td>
<td>Guarantees a set tidal volume</td>
<td>May cause increases in pressure and barotrauma, hyperventilation</td>
</tr>
<tr>
<td>Pressure Control Ventilation</td>
<td>Limits to pressure reduces risk of barotrauma</td>
<td>Hyperventilation or hypoventilation if lung compliance/resistance changes</td>
</tr>
<tr>
<td>Pressure Support Ventilation</td>
<td>Patient comfort, improved ventilator interaction</td>
<td>Not tolerated by all patients, back up rate only if apneic</td>
</tr>
<tr>
<td>SIMV</td>
<td>Guarantees set number of breaths, less alkalosis</td>
<td>Increased work of breathing when trying to initiate spontaneous breaths</td>
</tr>
</tbody>
</table>

Case repeated:

She is intubated at the scene and given a 2L bolus of NS en route to the hospital. On arrival she is being bagged by EMS on 100%. Her vitals: \( O_2 \) Sat 92%, BP 80/60, HR 135bpm, T 35°C. Her breaths seem rapid and shallow

The TTL is barking orders and getting ready for the Pan-Scan. As you get dressed the RT looks at you and says "Do you want me to put them on VC or PC, I’m setting the FiO2 at 1.0 and the PEEP at 5 for now. Is that OK?"

With **complete and total** confidence you tell the RT...
You tell the RT...

1. Start on Volume Control with PEEP at 10, and set a tidal volume of 6mL/kg,
2. Start on Pressure Control with a PEEP at 10, and aim for $P_{\text{peak}} < 40\, \text{cm H}_2\text{O}$
3. Use SIMV with a back up rate of 15
4. Put them on Pressure Support

Case continues....

- The patient had bilateral chest tubes inserted in ER for pneumothoraces. Subsequently, compartment syndrome is identified and she is taken to the OR for urgent fasciotomy and ongoing resuscitation. She is now being transported back to the ICU for management. She is sedated and paralyzed prior to transport and bagged en route.
- On arrival to ICU, the RT’s are busy initiating MV. You ask “How do you know what to set the vent at?”

When starting a patient on the vent you...

A. Pressure-targeted mode of ventilation with ZEEP (PEEP = 0)
B. SIMV with a back up rate of 18
C. Controlled mode of ventilation (either pressure or volume)
D. Don’t know, I just do what the RT tells me to do

Initiating Mechanical Ventilation

- **Goal is to maintain adequate gas exchange**
- Start on a controlled mode of ventilation, either pressure or volume targeted
- In PCV
  - Set PEEP between 5-10
  - Aim for a $V_t$ of 6-8mL/kg
  - Start at FiO$_2$ 1.0 and adjust down later
  - Get a gas and titrate
Improving Oxygenation

- Increase FiO2
- Recruit Lung
  - Increase P-inflation
  - Increase I-time
  - Increase PEEP
- Decrease VO2
  - Sedate, NMBA
- Rescue therapy
  - Drugs, position, ECLS

Improving Ventilation

- Increase $V_E$
  - Increase $V_t$ and/or RR
- Reduce $CO_2$ production/asynchrony – sedation/analgesia ± NMBA
  - Treat fever, seizures, etc.
- Rescue therapies
  - HFIV, ECMO

Lower your expectations!

- Target Reasonable Goals, balance iatrogenic harm (VILI)
  - $SpO_2 > 88\%$ or $PaO_2 > 50-55$ mmHg
  - $pH > 7.25$
- Depends on what else is going on:
  - Brain Injury
  - Pregnancy...

When starting a patient on the vent you...

A. Pressure-targeted mode of ventilation with ZEEP ($PEEP = 0$)
B. SIMV with a back up rate of 18
C. Controlled mode of ventilation (either pressure or volume)
D. Don’t know, I just do what the RT tells me to do

Case 2

A 60M is coming for elective reversal of a Hartman’s procedure. He presented previously with bowel ischemia 9 months ago. He is a 20py smoker, but no other relevant past medical history. He is very active, and currently training for his 3rd marathon. He will be undergoing the procedure under general anesthesia.
Regarding this case, which of the following is false?

A. In elective surgical patients, intraoperative ventilation with lung protective strategy improves mortality

B. In patients without ARDS, ventilation with a lung protective strategy reduces development of ARDS

C. Ventilation with low tidal volumes intraop for elective abdominal surgery reduces rates of infection and atelectasis in the early post-op period

D. Ventilating with smaller tidal volumes in the OR is associated with decreased hospital length of stay
Case recap...

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D. Ventilating with smaller tidal volumes in the OR is associated with decreased hospital length of stay

Summary

- There are several ways to approach respiratory failure, clinical, anatomical, and physiological
- The most common physiological cause of hypercapneic and hypoxemic failure is V/Q mismatch
- Mechanical Ventilation can help support a patient in respiratory failure

Summary

- Acutely ill patients often require a controlled mode of ventilation that is either volume or pressure targeted
- Lung-protective ventilation improves outcomes in mechanically ventilated patients with or without ARDS

QUESTIONS?
Christie.Lee@sinahealthsystem.ca