Mechanical Ventilation: Is there anything new?

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Introduction

“But so that life may in some measure be restored to the animal, you must attempt an opening in the trunk of the trachea and pass into it a tube of rush or reed, and you must blow into this so that the lung may expand and the animal draw breath after a fashion; for at a light breath the lung in this living animal will swell to the size of the cavity of the thorax, and the heart take strength afresh and exhibit a great variety of motions”.

Andreas Vesalius, *De humani coporis fabrica*, 1543.
Objectives

- Provide definitions
- Review accepted modes of ventilation
- Discuss alternative modes of ventilation
- Discuss adjunctive ventilation therapies
- Introduce other therapies

* Presentation is limited to Adult patients
Background

Reasons for mechanical ventilation

• Pulmonary causes = pneumonia, aspiration, inhalation injury, near drowning and pulmonary contusion

• Extra-pulmonary causes = sepsis, shock, transfusion and trauma
Definitions

• Hypoxemic Respiratory Failure

• ALI - Acute lung injury

• ARDS - Acute Respiratory Distress Syndrome
Definitions

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• ARDS - Acute Respiratory Distress Syndrome
  \( \text{PaO}_2: \text{FiO}_2 \) ratio < 200
Definitions

- **Barotrauma** = pneumothorax, etc
- **Volutrauma** = overdistention of alveoli due to large tidal volume ventilation
- **Atelectrauma** = ventilation without PEEP
- **Biotrauma** = infection resulting in alveolar permeability
- **VILI** = ventilator-induced lung injury
- **Open Lung Ventilation** = Lung-protective ventilation strategy
Current Standard of Care

The NHLBI ARDS Clinical Trials Network

http://www.ardsnet.org
Standard Modes of Ventilation

- Lung protective ventilation strategy (Low tidal volume settings)
- Protocol driven reduction in ventilatory support
- Volume control or Pressure control ventilation
Pressure-Volume Relationships

Problems Encountered

- Inadequate oxygenation
- Inability to clear CO$_2$
- Patient-ventilator asynchrony
Tactics to Improve Gas Exchange

• Positive End Expiratory Pressure (PEEP)
  – Alveolar recruitment
  – Increased functional residual capacity (FRC)
  – Redistribution of lung water
  – Improved ventilation-perfusion (V-Q) matching

• Recruitment Maneuvers
Recruitment Maneuvers

• 2 recruitment maneuvers compared in a 2008 study by Constantin et. al. in Critical Care
  – CPAP of 40 cm H₂O for 40 seconds or
  – eSigh with PEEP set at 10 cm H₂O above LIP
• Recruited volumes, PaO₂ and P:F ratios measured on each patient
• eSigh recruitment maneuvers showed increased recruited volumes compared to traditional CPAP
Recruitment Maneuvers

Both recruitment maneuvers increased oxygenation. Extended sigh (eSigh) induced a significantly higher increase in arterial partial pressure of oxygen (PaO₂) than continuous positive airway pressure (CPAP) at 5 and 60 minutes after the recruitment maneuver. * significant versus baseline, † significant versus CPAP.

Constantin et al. Critical Care 2008; 12:R5C0
Other Ventilator Strategies and Modes
Prone Position Ventilation

Benefits

• Improved gas exchange in human and animal studies
• Suggested improvements in V-Q matching
• More uniform airway pressures
• Improved secretion drainage, lower VAP
Figure 2: Effect of ventilation in the prone position on mortality. We used a random-effects model in our analysis. The duration of prone positioning was up to 24 hours for 1–2 days in the short-term trials and up to 24 hours daily for more than 2 days in the prolonged-duration trials.

Sud et al., CMAJ 2008, Apr 22;178(9):1153-61.
Problems

• Labor intensive, loss of access and airway
• Contraindicated in pts with tracheotomy
• Pressure ulcers
• No significant mortality benefit
Prone Position Ventilation

The bottom line

• Overall, no proven benefit in mortality
• No consensus on therapy implementation
• Difficult therapy to initiate
• Beneficial effects are not lasting
• Pts likely to develop more pressure ulcers
• May be beneficial as rescue therapy in patients with very low PaO$_2$
High Frequency Oscillatory Ventilation (HFOV)

- More than 20 yrs use in neonatal ICU
- Limited use in adult populations
- Basic mechanics: very rapid inspiratory rate 
  \( \sim \) 3-10 cycles/sec, active exhalation phase
- Consistent elevation in mean airway pressure improves \( O_2 \) delivery
- Low peak airway pressures minimizes VILI
Mechanisms of Gas Exchange During HFOV

High Frequency Oscillatory Ventilation (HFOV)

- Provides best ‘open-lung’ model of ventilation
- No benefits, or dangers, when compared to conventional ventilator modes - Bollen 2005
- Requires highly trained personnel and specialized equipment
- Effective as rescue therapy
- More studies are needed for adult patients
Adjunctive Therapies
Inhaled Nitric Oxide (iNO)

• Potent pulmonary vasodilator, used in neonatal hypoxic pulmonary failure and treatment of pulmonary hypertension in adults
• iNO activates guanylate cyclase in ventilated portions of the lung
• cGMP causes smooth muscle relaxation
• Increased perfusion improves V-Q matching
• Result is improved PaO$_2$ with lower PIP
Inhaled Nitric Oxide (iNO)

• ~50% of ARDS pts with hypoxic respiratory failure respond to iNO
• Typical dose requirements 10 - 40 ppm
• No correlation between improved oxygenation and survival
• Often effective as rescue therapy
• Typical costs $2000 - $4000/day
Can Aerosolized Beta-2 Agonist Therapy Help in ARDS/ALI?

Possible Mechanisms of Potential Benefit:

- Accelerate the resolution of alveolar edema by upregulating the transport of Na and Cl across distal lung epithelium.
- Reduce lung vascular injury by a direct effect on endothelial junctions and by modest anti-inflammatory properties.
- Increase surfactant secretion
- Reduce peak & plateau airway pressures
Beta-2 Agonist Therapy for the Treatment of Clinical Acute Lung Injury

- Advantages: Multiple mechanisms for beneficial effects in ALI/ARDS, excellent preclinical and encouraging clinical phase II data, inexpensive, and likely to be safe in critically ill patients with ALI.

- Potential downside: mechanism of actions may not be effective because of the severity of lung epithelial or lung endothelial injury.
Clinical Trial Design: ALTA
(Albuterol Treatment in Acute Lung Injury)

• Aerosolized delivery of 5 mg albuterol or placebo q 4 hours (double blind randomized)
• Primary end point: Ventilator Free Days (> 2 days)
• Secondary end point: mortality
• Exclusions as in prior trials: chronic liver disease, chronic lung disease, < 6 month expected survival
• Anticipated enrollment of 1000 patients
• Futility and efficacy end boundaries to be reviewed by the DSMB every 300 patients
Clinical Trial Design: ALTA

- Biological markers to be measured in plasma, mini-BAL and urine.
- Patients to be analyzed in secondary outcomes for presence or absence of shock.
- Low tidal volume and plateau pressure for mechanical ventilation.
- Simplified fluid conservative protocol from ARDS network - begins when patient is out of shock for 12 hours, requires CVP (NEJM, June 2006)
Bundled Interventions
Combination Therapy

Lung protective ventilation strategies

+ Prone position ventilation

+ HFOV
Combination Therapy

Evolution of PaO₂/FIO₂ ratio. Positions were prone position followed by high-frequency oscillatory ventilation (filled circles); conventional lung-protective mechanical ventilation in the supine position followed by high-frequency oscillatory ventilation (open circles); and conventional lung-protective mechanical ventilation in the prone position followed by supine (triangles). *p < .001 vs. end-optimization and p < 0.001 vs. high-frequency oscillatory ventilation in the supine position; ‡p < .02 vs. CVsupine-HFOVsupine and CVprone-CVsupine; †p < .001 vs. end-optimization and 24 hrs

Combination Therapy

Lung protective ventilation strategies
  +
Prone position ventilation
  +
  +
HFOV
  +
iNO
Newer Modes of Ventilation

Modes designed to preserve spontaneous ventilation and promote ventilator synchrony by unloading respiratory muscles
P.A.V.

- Proportional Assist Ventilation
- Ventilator augments assistance in response to changes in lung compliance and resistance
- Goal is unloading of respiratory mechanics
- Typically set for 80% reduction in work of breathing
- Interactive mode that varies ventilatory output to maintain its proportion of the workload
Proportional Assist Ventilation (PAV)
Limitations of P.A.V.

- Over/under estimation of support ("Runaway Phenomenon")
- Unstable respiratory mechanics
- Dynamic hyperinflation
N.A.V.A.

- Neurally Adjusted Ventilatory Assistance
- Software varies applied pressure in direct proportion to the diaphragmatic EMG signal
- The goal is simultaneous ventilator and diaphragmatic breath initiation to reduce ventilator asynchrony
Summary

- Prone position ventilation
- HFOV
- iNO
- ALTA
- Combination therapies
- PAV and NAVA
Is there anything new?