CURRENT TRENDS IN LUNG-PROTECTIVE VENTILATION

Part III – Alternative Lung Protective Modes & Therapies

QUESTIONS TO BE ANSWERED

- PART I:
  - What’s so bad about mechanical ventilation?
  - What is Ventilator-Induced Lung Injury?

- PART II:
  - How do we safely manage the “handful” of ventilator parameters that are currently available to us?

- PART III:
  - What are some newer alternative lung-protective ventilatory modes
  - What are some newer lung-protective strategies?
SOME ALTERNATIVE MODES OF VENTILATION

AIRWAY PRESSURE RELEASE VENTILATION (APRV)
**APRV**

- **1987** – Downs – *Update; Springer Berlin Heidelberg: 228-233*
  - First description of Airway Pressure Release Ventilation

- **DEFINITION:**
  - **2001** – Frawley – *AACN Clinical Issues; 12 (2): 234-246*
    - Relatively high CPAP with regular, brief, intermittent releases in airway pressure
    - Facilitates both oxygenation and CO2 clearance
    - Release phase permits alveolar ventilation & removal of CO2
    - Allows unrestricted spontaneous breathing

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**Airway pressure release ventilation with spontaneous breathing**

- **P high**
- **P low**
- **Mean airway pressure**
- **T high**
- **T low**

<table>
<thead>
<tr>
<th>Time (seconds)</th>
<th>Airway pressure (cm H2O)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>35</td>
</tr>
<tr>
<td>2</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>35</td>
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<td>4</td>
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<td>6</td>
<td>10</td>
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<td>7</td>
<td>5</td>
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<td>8</td>
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<td>9</td>
<td>5</td>
</tr>
<tr>
<td>10</td>
<td>30</td>
</tr>
</tbody>
</table>

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**2011** – Mondrykamien – *Cleveland Clinic J of Medicine; 78(2): 101-110*
A Caveat Regarding APRV Research

  - Care must be exercised when reviewing APRV research
  - Two “eras” in the application of APRV:
    - **Early Methodology (Downs/Stock) - Fixed APRV (F-APRV):**
      - Relatively short Thigh (<90% total cycle time)
      - Fixed Tlow not adjusted based on changing lung mechanics
    - **Recent Methodology (Habashi) – Personalized (P-APRV):**
      - Phigh set at previous $P_{PLAT}$
      - Thigh > 90% of total cycle time
      - Tlow adjusted based on changes in lung mechanics
        - Analysis of expiratory flow curve
    - Plow set at 0 cmH2O

**Fixed vs Personalized APRV**

  - **Fixed (F-APRV)**
  - **Personalized (P-APRV)**
# APRV Advantages & Disadvantages

- 2011 – Mondrykamien—*Cleveland Clinic J of Medicine; 78(2): 101-110*

## High Mean Airway Pressure

<table>
<thead>
<tr>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lung recruitment</td>
<td>Worsening of air-leaks</td>
</tr>
<tr>
<td>Reduction of left ventricular transmurual pressure <em>reduction of LV afterload</em></td>
<td>Increase in R ventricular afterload <em>worsening of pulmonary hypertension</em></td>
</tr>
</tbody>
</table>
|  | Reduction of R ventricular venous return  
  *may worsen intracranial hypertension*  
  *may worsen cardiac output in hypovolemia*  |

## Spontaneous Breathing

- 2011 – Mondrykamien—*Cleveland Clinic J of Medicine; 78(2): 101-110*

<table>
<thead>
<tr>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
</thead>
</table>
| Ventilation of dependent areas | Increase in transpulmonary pressure  
  *May lead to VILI*  |
| Better venous return *Increase in cardiac output* | Increased venous return may worsen right ventricular dysfunction |
| Better small-bowel perfusion | Maintains WOB |
| Lower sedation requirements |  |
**APRV Pro & Con**


<table>
<thead>
<tr>
<th>PRO</th>
<th>CON</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serves the goals of safety and comfort.</td>
<td>No human studies have demonstrated a reduction in WOB</td>
</tr>
<tr>
<td>Promotes alveolar stability and recruitment (animal studies)</td>
<td>No human studies have demonstrated a reduction in the need for sedation and narcotics</td>
</tr>
<tr>
<td>Minimizes airway pressure (animal studies)</td>
<td>No human studies have demonstrated a minimized likelihood of VILI</td>
</tr>
<tr>
<td>Seems to decrease or prevent lung injury</td>
<td>No human studies have demonstrated a reduction in VLOS or ICU stay</td>
</tr>
<tr>
<td>Allows unrestricted spontaneous breathing</td>
<td>No human studies have demonstrated an effect on mortality.</td>
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**HIGH-FREQUENCY VENTILATION**
High-Frequency Ventilation Types

- High Frequency ventilators:
  - Described by their delivery method
  - Classified by their exhalation mechanism (active or passive).

- High-Frequency Oscillatory Ventilation (HFOV)
  - Active Exhalation

- High-Frequency Percussive Ventilation (HFPV)
  - Passive Exhalation

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High-Frequency Ventilation
HFOV Definition

- **DEFINITION:**
    - Constant mean airway pressure
    - Pressure waves in the ventilatory circuit (generated by a diaphragm) at frequencies between 3 and 15 Hz (180–900 bpm)
    - Active exhalation as diaphragm creates both inspiratory and expiratory pressure waves

    - First published findings of adequate CO2 clearance with HFOV

  - 2000 – FDA approval of Adult HFOV
HFOV RESEARCH

- **2002 – Derdak – AJRCCM; 166: 801-808 (MOAT Trial)**
  - First RCT comparing HFOV with conventional ventilation
  - HFOV group:
    - Significant *early* ↑ in P/F ratio
    - Did not persist past 24 hrs
    - No significant difference in hemodynamic variables
    - Trend towards ↓ mortality
    - Similar complication rates

- **2003 – Sedeek – Anesthesiology**
  - ↓ histological damage & lung inflammation with HFOV vs CMV

HFOV RESEARCH

- **2013 – Mashael – Semin Respir Crit Care Med; 34 (04).**
  - Mean airway pressures during HFOV often exceed the 30-35 cm H2O lung-protective threshold employed during CMV.
  - Could tolerance of higher mean’s during HFOV be 2° to better maintained alveolar structure with a *slowly* applied constant pressure as opposed to cyclical brief tidal pressures?
THE SUD ADULT HFOV META-ANALYSIS

  - 8 RCT’s with a total of 419 patients were included
    - Almost all patients had ARDS
    - HFOV may ↓ mortality in ARDS patients
    - HFOV ↑ P/F ratio
    - No significant difference in
      - VLOS
      - Ventilator-free days
    - No significant differences in the risk of:
      - Barotrauma
      - Hypotension
      - Endotracheal tube obstruction

THE OSCILLATE & OSCAR STUDIES

- 2013 – Ferguson – *NEJM; 368:795–805*. (The OSCILLATE Study)
  - ↑ mortality with HFOV compared to CMV with high PEEP’s
  - ↑ need for pressor medications
    - High mean-airway pressures led to hemodynamic compromise

  - No major difference in outcome between HFOV and CMV

  - OSCILLATE & OSCAR underscore the notion that HFOV should be:
    - Reserved for patients failing conventional lung protective strategies
    - Provided by clinicians with expertise in the technology.
**High-Frequency Ventilation**

**HFJV Definition**

- **Definition:**
  - 2010 – Allan – *J Burn Care & Research; 31.4: 510-520*
    - Small high-frequency pulses of gas
    - Pulses accumulate/stack to form a “low”-frequency Vt
    - Emulates a typical pressure-limited, time-cycled waveform

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**HFPV Research**

  - HFPV provides favorable gas exchange in several well-defined patient populations
  - ↑ oxygenation and ↓ PIP’s vs conventional ventilation

  - HFPV may ↑ oxygenation in patients with ARDS without a concomitant increase in mPaw

- 2010 – Allan *& Research; 31.4: 510-520*
  - Lack of literature regarding the practical application of HFPV towards improving gas exchange.
  - No discussion yet regarding the possible risk of HFPV-associated VILI.
**Closed-Loop Control of Ventilation**

  - First published report of closed-loop ventilation
  - Automatic adjustment of negative pressure of an iron lung in response to EtCO2.

- **DEFINITION:**
  - **2002** – Branson – *Respiratory Care; 49(7):742–760.*
    - **Simple** - control of one output based on the measurement of one input.
      - The modification of inspiratory flow (output) to maintain the preset PSV pressure (input).
    - **Complex** – control of multiple outputs (eg, ventilator frequency, airway pressure, tidal volume) based on the measurement of multiple inputs (eg, compliance, oxygen saturation, respiratory rate).
**CLOSED-LOOP VENTILATION**

- **2002** – Branson – *Respiratory Care; 49(7):742–760.*
  - **Simple** - control of one output based on the measurement of one input.
    - The constant modification of inspiratory flow (output) to maintain the pre-set PSV pressure (input).
  - **Complex** – control of multiple outputs (eg, ventilator frequency, airway pressure, tidal volume) based on the measurement of multiple inputs (eg, compliance, oxygen saturation, respiratory rate).

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**CLOSED LOOP VENTILATION: ADAPTIVE SUPPORT VENTILATION (ASV)**

  - First description of Mandatory Minute Ventilation (MMV)
  - ASV is based upon MMV with adaptive pressure control

  - First description of clinical application of ASV
  - Measured respiratory mechanics applied to algorithms of pressure control to maintain a target Ve

- **2007** – ASV commercially available in the US
**ASV DEFINITION**

- **DEFINITION:**
    - Assist-control, pressure-targeted, time-cycled mode
  - RR/Vt pattern automatically adjusted to minimize ventilator work.
    - Selects the appropriate RR and Vt for mandatory breaths
    - Selects the appropriate Vt for spontaneous breaths
  - This minimal ventilator work *may* translate into minimal stretching forces on the lungs

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**ASV RESEARCH**

- **2002 - Tassaux – *Critical Care Medicine; 30:801–7***
  - In patients undergoing partial ventilatory support, with clinical and electromyographic signs of increased respiratory muscle loading, ASV provided levels of minute ventilation comparable to those of SIMV-PS.
  - With ASV, central respiratory drive and sternocleidomastoid activity were markedly reduced, suggesting decreased inspiratory load and improved patient-ventilator interactions.

- **2001 – Linton - *Respir Care Clin N Am; 7[3]:409-424.***
  - Demonstrated the economy of ASV for weaning without the need for a Respiratory Therapist or Intensivists
ASV RESEARCH

- 2008 – Chen - *J Intern Med Taiwan; 19: 465-471*
  - Small studies have demonstrated that ASV can be used as a safe weaning mode for **specific postoperative** and **chronically ventilated** patient groups
    - May save manpower and management,
    - May reduce VILI
  - There is concern regarding patient/ventilator asynchrony if there is no awareness of the underlying mechanism for respiratory distress in the patients
    - Could worsen the patient's condition or prolong weaning process

ASV vs PC CMV – THE KRAKLI STUDY

  - RCT comparing ASV vs PC A/C in Medical ICU patients
    - Previous RCT’s focused on post-op cardiac patients
  - ASV arm outcomes:
    - ↓VLOS
    - ↓ number of manual ventilator setting changes
    - ↑ patients extubated successfully on the first attempt
  - Weaning success and mortality at day 28 were comparable between the two arms
**Response to Kirakli Study**

- **2016 – Greico – Chest; 149.1: 280-281**
  - Aspects of the Kirakli RCT require further discussion
    - Reasons of weaning failure were not presented.
    - PSV was *contemplated* in the PC-CMV arm only *after* failure of the third SBT
      - Delay in applying PSV hampers the understanding of to what extent the benefit described in patients receiving ASV
    - No mention of sedation in either arms
      - Patients in the PC-CMV arm may have required more sedation to achieve adequate patient/ventilator interaction.
    - No data on fluid balance and cardiac function even though cardiac decompensation and fluid overload are recognized as the most common causes of SBT failure

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**Closed Loop Ventilation: Proportional Assist Ventilation (PAV)**

- **1992 – Younes – ARRD; 145.1: 121-129.**
  - First description of Proportional Assist Ventilation (PAV)

- **DEFINITION:**
  - **2007 – Wysocki – Critical Care Clinics; 23: 223–240**
    - Pressure-regulated mode of ventilation in which inspiratory pressure is titrated within each breath in proportion to the patients inspiratory airflow
      - Proportionality set by the clinician determining the proportions of the total WOB to be performed by ventilator and patient.
    - PAV+ measures dynamic resistance ($R_{ds}$) and compliance ($C_{rs}$) of the respiratory system and the percentage of assistance is adjusted accordingly.
**Defining PAV**

  - All PAV breaths are spontaneous.
    - Patient controls the timing and size of the breath.
  - No present pressures, flow, or volume goals
    - Safety limits on the volume and pressure delivered can be set.
  - Patient effort is boosted according to a pre-set proportion of the measured WOB.
    - ↑ patient effort = ↑delivered flow

- PAV is contraindicated in:
  - Respiratory depression (bradypnea)
  - Large air leaks (e.g. bronchopleural fistulas)

**Defining PAV+**

- PAV+ measures dynamic resistance ($R_{ds}$) and compliance ($C_{rs}$) of the respiratory system and the percentage of assistance is adjusted accordingly.
**PAV & PAV+ Research**

  - Hemodynamic profile similar to that of PSV
  - Vt’s are variable but are usually within the lung-protective range

- **2008 – Xirouchaki – *Intensive Care Medicine; 34.11: 2026-2034*
  - ↓ patient/ventilator dys-synchrony vs PSV
  - ↑ probability of spontaneous breathing without assistance vs PSV

- No trial has reported effect of PAV on mortality

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**PAV+ Research**

- **2015 – Teixiera – *Respiratory Care; 60(11):1527–1535*
  - RCT compared weaning with PAV+, PSV, or T-tube

  - When subjects were ready to perform the SBT:
    - **PAV+ group** - ventilated in PAV mode up to 40% support
    - **PSV group** - ventilated with 7 cmH2O
    - **T-tube group** - connected to T-piece with supplemental oxygen.

  - No significant differences in the groups was observed regarding:
    - Rate of extubation failure
    - VLOS
    - Duration of ICU and hospital stay
PAV+ Research

  - Crossover study comparing PAV+ to PSV
  - Ventilator Ti was significantly longer than patient Ti in PSV vs PAV+
  - ↑ patient/ventilator dys-synchronies in PAV+ vs PSV while patients were awake
  - Variable end inspiratory hold observed in PAV+.
  - Non-significant ↑ in compliance and P/F ratio in PAV+
  - PSV and PAV+ modes perform similarly for patient-ventilator interactions in awake and sedated states.
  - Changeover between modes resulted in swings in hemodynamics and respiratory mechanics
  - Patient “tunes” to ventilator deliveries over time.

Closed Loop Ventilation: Neurally-Adjusted Ventilatory Assist (NAVA)

  - First published report of NAVA technology

  - Diaphragmatic EMG signal (EAdi) triggers and cycles ventilator breath.
    - EMG sensor positioned in esophagus at crural level of the diaphragm.
  - Triggering - virtually simultaneous with phrenic nerve excitation of inspiratory muscles.
  - Termination - linked to the cessation of inspiratory muscle contraction.
NAVA RESEARCH

  - Small clinical studies have demonstrated improved trigger and cycle synchrony with NAVA
  - Data lacking showing improved outcomes (e.g. VLOS, sedation needs).
  - Concern with NAVA is the expense associated with the EMG sensor.

  - ↑ variability of Vt and Paw with NAVA vs PSV

- 2016 – Carteaux – *Critical Care Medicine; 44.3: 503-511*
  - Small clinical studies have demonstrated improved trigger and cycle synchrony with NAVA
  - Data lacking showing improved outcomes (e.g. VLOS, sedation needs).
  - Concern with NAVA is the expense associated with the EMG sensor.

  - Associated with less frequent application of post-extubation noninvasive mechanical ventilation.
SOME VENTILATORY ADJUNCT THERAPIES

PERMISSIVE HYPERCAPNIA
PERMISSIVE HYPERCAPNIA

  - First description of Permissive Hypercapnia
  - 50 ARDS patients with 16% mortality (predicted to be 40%)
    - PaCO2 averaged 60 mmHg

- Volutrauma & atelectrauma are more detrimental to patient outcomes than respiratory acidosis.

- Effects of Respiratory Acidosis:
  - Cellular: In the absence of hypoxemia, intracellular acidemia appears to be well tolerated.
  - Cardiovascular: Increased HR, BP & stroke volume.
  - CNS: Variable, some agitation may occur.
**Variable Ventilation & Noise**

  - Breathing patterns are highly variable
  - Vт’s can vary up to 33% in healthy individuals at rest and up to 25% in patients with COPD and restrictive lung disease

- **2015** – Naik – *Respiratory Care; 60(8):1203–1210.*
  - Biological systems are characterized by a continuously variable response to changing intrinsic or extrinsic inputs (noise)
    - **Bad Noise** = irregular, random input
    - **Good Noise** = frequency and amplitude of input controlled
      - Signal output can be improved with the addition of good noise
      - **Stochastic resonance.**

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**Variable Ventilation Research**

- **2004** – Boker – *Anesthesiology; 100(3):608-16*
  - First application of variable ventilation in a clinical setting
  - Variable ventilation arm:
    - Significant ↓ in Ve to maintain PaCO2
    - Significant ↑ in static compliance
    - Significant ↓ in dead-space

- **2013** – Kowalski – *Can J Anesth; 60.5: 502-503.*
  - Cross-over study of 8 pts post-sx pts ventilated >72h
  - Variable ventilation arm:
    - Significant ↑ in Oxygenation Index
    - Significant ↑ in static compliance
    - Significant ↓ in dead-space
**Variable Ventilation Research**

- 2016 – Huhle – *Critical Care; 20:62*
  - Rationale for variable controlled mechanical ventilation:
    - Physiologic variability in the respiratory system may be beneficial to improve function and reduce damage in the diseased lung
  - Current research is inconclusive on the relationship between variable ventilation and its effect on lung inflammation and damage

- 2007 – Terragni – *AJRCCM; 20:62*
  - Low-Vt ventilation does not *definitively* protect the lung from over-distention during a tidal breath.
  - End-inspiratory over-distention occurs in 30% of ARDS patients receiving lung-protective ventilation
  - *Maneuvers to recruit alveoli* might counteract those adverse effects of low VT and improve oxygenation

- 2003 – Pelosi – *AJRCCM; 167.4: 521-527.*
  - The application of intermittent *sigh breaths* offers the opportunity to introduce some limited variability.

**How We Can Apply Noise**

- No commercially available ventilators are capable of variable ventilation.

- 2007 - Terragni – *AJRCCM; 20:62*
  - Low-Vt ventilation does not *definitively* protect the lung from over-distention during a tidal breath.
  - End-inspiratory over-distention occurs in 30% of ARDS patients receiving lung-protective ventilation
  - *Maneuvers to recruit alveoli* might counteract those adverse effects of low VT and improve oxygenation
APPLYING NOISE WITH SIGHS

• 1919 – Haldane – *J Physiol; 52.6: 433*.
  • First description of a Sigh Breath

  • ↑ lung compliance in patients undergoing general anesthesia with
    the application of intermittent deep inflation breaths

• 1990 – Wirtz – *Science; 250.4985 : 1266-1270*.
  • Stretch of alveolar Type II cells through intermittent ↑ Vt’s
    • Increased surfactant production

• 2010 – Vlemicnx – *Biological Psychology 84.1: 82-87*
  When breathing becomes either excessively random or lacks significant
  variability, sigh breaths can restore the deterministic non-random
  variability

DOES ANYBODY REMEMBER SIGH’S?

• 2016 – Naik - *Respiratory Care ; 60(8):1203–1210*
  • Intermittent deep-inflation breaths are a normal mechanism for
    creating respiratory variability
    • Characterized by breaths 2-3 X Vt
    • Occur 1-25 breaths/hr
  • Effects of physiologic sighs:
    • Reaeration of collapsed alveoli
    • Improved FRC
    • Reduction of pulmonary shunt
**Applying Noise With Sighs**

  - Sigh-augmented ventilation in patient-triggered (PSV) modes
  - ↑ arterial oxygenation
  - ↑ end-expiratory lung volume
  - ↑ pulmonary compliance

- **2009 – Badet – *Respiratory Care; 54(7):847–854* 
  - Sighs superimposed on lung-protective ventilation significantly improve oxygenation and Cstat in patients with ALI/ARDS

  - Sigh breath frequency should be limited to 2–3 breaths/min 
    - Facilitates maximum recruitment without inducing volume-related lung injury.

**Recruitment Maneuvers (RM)**
**RM**

- **2007** – Kacmarek – *Respiratory Care; 52.5: 622-635.*
  - Intentional, transient increase in transpulmonary pressure to reopen non-aerated/poorly aerated alveoli.
  - Immediate expected benefits are improvements in oxygenation and respiratory system compliance

  - Clear role as rescue therapy for patients with severe hypoxemia, refractory to protective ventilation strategies and prone position.

  - RCT comparing RM vs traditional PEEP in p/o cardiac pts
  - RM arm: ↓ ICU LOS, Hospital LOS, Pulmonary Complications

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**RM’s Using Sustained Inflation**


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RM’S WITH DECREMENTAL PEEP


Atelectatic lung is relatively inert with scant cytokine production. Cytokine production may be markedly increased by inadequate recruitment or repeated derecruitment.


Progressive RM significantly reduced lung inflammation, alveolar epithelial cell apoptosis, and alveolar-capillary membrane injury. Epithelial damage more pronounced if high distending pressures are applied abruptly as compared to progressive approaches.
RM Concerns

- **2015** - Koutsoukou – *Archivos de Medicina: 9.3: 2.*
  - High distending pressure may impair hemodynamics
  - Correcting patients volume status prior to RM may attenuate potent circulatory depression

- **2010** - Silva – *Critical Care: 38.11: 2207-2214.*
  - Fluid management, used to minimize hemodynamic instability associated with RM’s, may have an impact on lung and distal organ injury
    - In *hypovolemic* animals RM’s:
      - Improved oxygenation
      - Increased lung injury
      - Increased inflammatory and fibrogenic responses.

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**PRONE POSITIONING**
**PRONE POSITIONING**

- May promote recruitment of dependent, atelectatic lung regions by relieving external compressive forces
  - Abdominal contents push upward on the diaphragm and collapse lower lobes of the lung.
  - Over 40% of left lung and 15% of right lung are located under the heart and may be compressed

**PRONE POSITIONING RESEARCH**

- **2006** – Mancebo – *AJRCCM; 173.11: 1233-1239.*
  - Trend towards ↑ survival when prone positioning:
    - Administered early
    - For a much as 20h /day

  - No significant survival benefit in ARDS patients or in patients with moderate and severe hypoxemia.

- **2008** – Sud – *Canadian Medical Association Journal; 186.10: E381-E390.*
  - No significant ↓ in mortality or VLOS despite improved oxygenation and a decreased risk of pneumonia
PRONE POSITIONING RESEARCH

- 2013 – Guerin – *NEJM; 68.23: 2159-2168* (The PROSEVA Trial)
  - RCT involving 566 patients
  - Test arm patients were prone at least 16 h/day
  - Early application of prolonged prone-positioning sessions significantly ↓ 28- & 90-day mortality.

PRONE POSITIONING COMPLICATIONS

- 2009 – Taccone – *JAMA; : 02.18: 1977-1984*
  - ↑ need for increased sedation/muscle relaxants
  - Airway obstruction
  - Transient desaturation
  - Vomiting
  - Hypotension, arrhythmias, increased vasopressors
  - Loss of venous access
  - Displacement of endotracheal tube
  - Displacement of thoracotomy tube
**Endotracheal Tube Resistance Compensation (ETRC)**

ETRC DEFINITION

  - Endotracheal tubes provide a significant resistance to flow during both inspiration and expiration.
  - May result in significant initial flow dys-synchrony in patients with vigorous inspiratory efforts.

  - Designed to overcome the imposed WOB due to artificial airways by providing dynamic ventilatory support of each spontaneous breath.
  - Delivers the exact amount of pressure necessary to overcome the resistive load of the endotracheal tube for the flow measured at that time.
ETRC Research

  - A 2-hour trial of spontaneous breathing through an ETT mimicked the WOB performed after extubation.
    - The WOB dissipated against the ETT represented around 10% of the overall work performed by the patient.
    - This increased work load was not different from what was related to upper airways obstruction immediately following extubation.
  - The use of such a compensatory mode may falsify spontaneous breathing trial relevance.

- 2009 – Aggarwal – *Respiratory Care; 54.12: 1697-1702.*
  - 41 patients requiring mechanical ventilation due to acute respiratory failure secondary to poisoning from snakebites.
  - Compared weaning time of PS with ETRC vs PSV alone
    - PSV with ETRC – median weaning time was 8h
    - PSV alone – median weaning time was 12h

- 2012 – Oto – *Respiratory Care; 57.5: 697-703*
  - ETRC does not necessarily compensate for an ETT-imposed respiratory work load.
    - ETT configuration changes and tracheal secretions can increase ETT resistance and decrease the ability of ETRC to compensate for the increased respiratory work load.
ETRC Research

  - Mode evaluated as a method for the first trial of withdrawal from mechanical ventilation in a few studies
  - Favorable results in the rate of successful first weanings
  - Rate of extubation failure was similar to that reported using other weaning modes

SURFACTANT REPLACEMENT
Almost all of the currently used exogenous surfactants have a high efficacy in treating neonatal respiratory distress syndrome, yet almost none of them are as successful in treating surfactant dysfunction in adults.

Administration of calfactant was not associated with improved oxygenation or longer-term benefits relative to placebo in this randomized, controlled, and masked trial. At present, exogenous surfactant cannot be recommended for routine clinical use in ARDS.

Meta-analysis of nine trials involving 2,575 patients
Surfactant replacement therapy:
- No significant ↓ mortality.
- Significant ↑ P/F ratio in the first 24 hours
  - Lost by 120 hours.
- Causes a non-significant trend towards ↓ VLOS
- Slightly ↑ risk of adverse effects.
INHALED NITRIC OXIDE (INO)
IN THE ADULT PATIENT

ADULT iNO DEFINITION

  - iNO induces pulmonary capillary vasodilatation in ventilated lung areas

  - iNO diffuses across the alveolar membrane and binds with Hb
    - Works in the areas of the lung that are participating in ventilation
  - Lung units that are participating in ventilation:
    - Vasculature will dilate and preferentially receive more of the systemic blood flow.
    - Improves V/Q
  - Lung units with impaired ventilation:
    - Lower ratio of perfusion
    - Provide a lower amount of the body's total arterial oxygenation
**Adult iNO Research**

  - When dissolved in alveolar fluid iNO may react with Reactive Oxygen Species to form reactive Nitrogen species which may be cytotoxic to epithelial calls

  - Trend towards ↑ rates in groups using iNO
  - Significantly increased risk for renal dysfunction

- **2014** – Adhikari – *Critical Care Medicine; 42.2: 404-412*.
  - Nitric oxide does not reduce mortality in adults or children with ARDS, regardless of the degree of hypoxemia.

- **2016** – Gebistorf – *Cochrane Reviews*
  - Evidence is insufficient to support iNO in any category of critically ill patients with acute hypoxemic respiratory failure
  - Inhaled NO results in a transient improvement in oxygenation
  - Inhaled NO does not reduce mortality
  - Inhaled NO seems to increase renal impairment.
ECMO
- High cost and limited access
- Two recent studies indicated an improvement in mortality with ECMO but the results are controversial
  - 2009 – Davies – *JAMA* 302.17 : 1888-1895 (The ANZ ECMO Study)

Intravenous Beta 2 Agonists
- Early experiments have shown:
  - Increased fluid clearance from alveolar space
  - Decreased inflammation
  - Bronchodilation
**ON THE HORIZON**

- **Inhibition of platelet activation & platelet-neutrophil aggregates**
  - Associated with impressive reductions in ALI caused by acid aspiration and sepsis

- **Aerosolized heparin & N-Acetylcysteine**
  - Attenuates lung injury in patients with smoke inhalation

- **Activated protein C**
  - Antithrombotic & Anti-inflammatory

- **Granulocyte-Macrophage Colony-Stimulating Factor (GM-CSF)**
  - Limits damage & enhances repair of lung cells

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**VENTILATORY ANALYTICS**
THE COST OF MECHANICAL VENTILATION

Mechanically ventilated patients in US acute care hospitals
- 3% of patients
- 7% of days
- 12% of cost

Mechanically ventilated patients in US intensive care units
- 36% of patients
- 58% of days
- 72% of cost

Medicare DRG 207 patients
- Per patient average revenue: $31,405
- Average cost of care: $37,585
- Loss per patient: ($6,180)

($6,180) x 200 patients = ($1.2 million)


“IT IS REMARKABLE HOW LITTLE IS KNOWN ABOUT ALVEOLAR DEFORMATION DURING BREATHING.”
Rolf Hubmayr
Am J Respir Crit Care Med, 2002

The most meaningful cost reduction strategies will involve standardization of clinical care and elimination of variation in patient procedures.

Moody’s Analytics

May 9, 2012
**Respiratory Care Quality Formula**

\[ Q = A \times \left( \frac{O + S}{W} \right) \]

- **Q** = Quality
- **A** = Appropriateness
- **O** = Outcomes
- **S** = Service
- **W** = Waste

**Respiratory Care Survival Goals**

**Clinical Goals**

1. Provide Life Support
2. Prevent Patient Harm
3. Minimize Time on Vent

**Financial Goals**
Examples of data to be analyzed to optimize care:
- Ventilator Length-of-Stay (VLOS)
- Adherence to Alarm protocols
- Spontaneous Breathing Trial optimization (SAT)
- Adherence to Lung Protective Ventilation guidelines
- VAE early warning & response

One Hospital's Experience with Analytics: Optimizing SBT's
**Steps to Successful Change**

Eight Steps To Successful Change  
- John Kotter

1. Institutionalise the change
2. Consolidate & build on the gains
3. Create short term wins
4. Empower people to act on the vision
5. Communicate the vision
6. Develop a clear shared vision
7. Create a guiding coalition
8. Establish a sense of urgency


**Questions?**
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