Advanced Modes of Mechanical Ventilation

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Peds Intensivist
Why New Modes?

• Safety
  – Barotrauma
  – Volutrauma
  – Biotrauma
  – Atelectrauma

• Patient comfort
  – Less WOB
  – Less sedation and/or paralysis
  – Faster weaning (better outcome?)

• User friendly??!!
Shear Injury (Electron Microscopy)

West et al, JAP, 1992
Old Fashion Ventilation vs New

Lung Biopsy at 24 Hours

Conventional Ventilation

High Frequency Oscillation

Premature baboon model

Coalson J.  Univ Texas San Antonio
Recruitment

SensorMedics 3100A

- Electrically powered, electronically controlled piston-diaphragm oscillator
- Paw of 3 - 45 cmH2O
- Pressure Amplitude from 8 - 110 cmH2O
- Frequency of 3 - 15 Hz (180-900 BPM)
- % Inspiratory Time  30% - 50%
- Flow rates from 0 - 40 LPM
• Paw is created by a continuous bias flow of gas past the resistance (inflation) of the balloon on the mean airway pressure control valve.
Oxygenation

• The Paw is used to inflate the lung and optimize the alveolar surface area for gas exchange.
• Paw = Lung Volume
Despite the fact that tidal volumes approach the anatomic dead space, adequate gas exchange is still maintained.
Primary control of CO₂ is by the stroke volume produced by the Power Setting.
CO2 control

• Alveolar ventilation during CMV is defined as:
  \[ F \times Vt \]

• Alveolar Ventilation during HFV is defined as:
  \[ F \times Vt^2 \]

• Therefore, changes in volume delivery (as a function of Delta-P, Freq, or % Insp. Time) have the most significant affect on CO2 elimination
Frequency controls the time allowed (distance) for the piston to move. Therefore, the lower the frequency, the greater the volume displaced, and the higher the frequency, the smaller the volume displaced.
Points of Discussion

• Triggered Modes of Ventilation
  – Volume Support (VS)
  – Proportional Assist Ventilation (PAV or PPS)

• Hybrid Modes of Ventilation
  – Volume Assured Pressure Support
  – Pressure Regulated Volume Control (PRVC)
  – Auto mode: VS and PRVC
  – Adaptive Support Ventilation: ASV
  – Bi-level Ventilation (APRV and Bi-vent)
  – Mandatory Minute Ventilation (MMV)
Conventional Mode

- CPAP
- CPAP with PS
- CMV (IPPV)
  - PC or VC
- AC
  - PC or VC
- SIMV with CPAP/PS
  - PC or VC
Continuous Positive Airway Pressure (CPAP)

Pressure (cm H₂O)

Flow (L/m)

Volume (mL)

Time (sec)
CPAP+PSV

Patient Triggered, Flow Cycled, Pressure limited Mode
Control Mode (Pressure-Targeted Ventilation)

- Set PC Level
- Time Cycling

**Graphs:***
- **Pressure (cm H₂O):**
- **Flow (L/m):**
- **Volume (mL):**

**Text:**
Time Triggered, Pressure Limited, Time Cycled Ventilation
Control Mode (Volume-Targeted Ventilation)

- **Pressure** (cm H₂O)
  - Dependent on $C_L$ & $R_\text{aw}$
  - Time Cycling

- **Flow** (L/m)
  - Preset $V_T$
  - Volume Cycling

- **Volume** (mL)

**Time Triggered, Flow Limited, Volume Cycled Ventilation**

Time (sec)
Assisted Mode
(Volume-Targeted Ventilation)

Patient Triggered, Flow limited, Volume Cycled Ventilation
Assisted Mode  
(Pressure-Targeted Ventilation)

- Set PC Level
- Time Cycling

Patient Triggered, Pressure Limited, Time Cycled Ventilation
Hybrid Mode Ventilation: Synchronization (SIMV+PSV)

Pressure (cm H₂O)

Flow (L/m)

Cycles

Time (sec)

M Mandatory Cycle Time

T_{supp} Triggered window for supported breaths

T_{synch} Triggered window for synchronized breaths
## Dual Control Breath-to-Breath

Pressure-limited flow-cycled ventilation

**Volume Support**

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**Pressure Limited Flow Cycled Ventilation**
Volume Support

• Volume-support ventilation is a volume-targeted mode of ventilation that is essentially pressure support with VT as a feedback.
• The level of inspiratory pressure is adjusted with each breath to reach a targeted clinician-selected volume.
• All breaths are patient triggered, pressure limited, and flow cycled.
VS (Volume Support)

1. VS test breath (5 cm H2O);
2. Pressure is increased slowly until target volume is achieved;
3. Maximum available pressure is 5 cm H2O below upper pressure limit;
4. VT higher than set VT delivered results in lower pressure;
5. Patient can trigger breath;
6. If apnea alarm is detected, ventilator switches to PRVC;
Dual control breath to breath:
Proportional Assist Ventilation (PAS)
Proportional Pressure Support (PPS)

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Pressure Limited Flow Cycled Ventilation
PAS/PPS

• Proportional-assist ventilation (PAV) is designed so that, theoretically, the level of ventilatory support is proportional to patient effort.

• This mode was designed to increase or decrease airway pressure by amplifying airway pressure proportional to inspiratory flow and volume.

• Unlike other modes in which a preset volume or pressure determines the level of support, in PAV, the level of support is determined in an interaction between the patient and the ventilator.
Proportional Assist Ventilation (PAV)

Changing pressure support based on patient’s efforts

Regulates the pressure output of the ventilator moment by moment in accord with the patient’s demands for flow and volume. Thus, when the patient wants more, (s)he gets more help; when less, (s)he gets less. The timing and power synchrony are therefore nearly optimal—at least in concept.
Muscular effort \( (P_{\text{mus}}) \) and airway pressure assistance \( (P_{\text{aw}}) \) are better matched for Proportional Assist (PAV) than for Pressure Support (PSV).
Dual Control within a Breath

volume-assured pressure support

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<tbody>
<tr>
<td>Dual Pressure/Volume</td>
<td>Patient</td>
<td>Pressure</td>
<td>Volume</td>
<td>Flow or volume</td>
</tr>
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</table>

Volume Assured Pressure Support Ventilation
Volume-assured pressure support

• A dual control within a breath mode, where the ventilator switches from PC to VC within the breath.
• In this mode, the clinician chooses a volume target and the breath begins as a pressure-limited, flow-cycled breath, either spontaneously (pressure support) or mechanically.
• When inspiratory flow has decelerated to the minimum set level, delivered volume is measured. If the target volume has been met or exceeded, the breath ends. If the delivered volume has not met the target, the breath is transitioned to a volume-targeted breath by prolonging inspiration at the minimum flow and increasing the inspiratory pressure until the delivered volume has been obtained.
**Set pressure limit**

- **$P_{aw}$ cmH$_2$O**

**Set tidal volume cycle threshold**

- **Volume L**

**Flow L/min**

**Set flow**

- **Flow cycle**

**Switch from Pressure control to Volume/flow control**

- Inspiratory flow greater than set flow
- Tidal volume not met
- Tidal volume met
- Inspiratory flow equals set flow
- Pressure limit overridden
Dual Control Breath-to-Breath
Pressure Regulated Volume Control

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<tbody>
<tr>
<td>Volume</td>
<td>Patient or Time</td>
<td>Pressure</td>
<td>Lowest pressure for set volume</td>
<td>Time</td>
</tr>
</tbody>
</table>

Pressure-limited Time-cycled Ventilation
PRVC
(Adaptive pressure ventilation, variable PC, Autoflow, VC+)

- PRVC has a variable decelerating flow pattern, with breaths time cycled.
- During PRVC, the pressure and volume are regulated. Thus, all breaths are volume targeted, with pressure adjusted to reach that volume target.
- PRVC often incorporates a “compliance curve” that is developed within the ventilator computer, as it gives several initial breaths at varying VTs that increase incrementally up to the set value. From this information, the ventilator computes the pressure target required to deliver the desired VT. Depending on the respiratory system compliance, the pressure associated with the tidal breath can vary over time.
- If the patient's compliance improves, the pressure required to deliver the volume breath will be reduced. Thus, a specific VT and minute ventilation is assured, while pressure-induced lung damage is minimized.
PRVC  
(Pressure Regulated Volume Control)

(1), Test breath (5 cm H₂O)  
(2), pressure is increased to deliver set volume  
(3), maximum available pressure  
(4), breath delivered at preset \( f \), at preset \( f \), and \( T_I \)  
(5), when \( V_T \) corresponds to set value, pressure remains constant  
(6), if preset volume increases, pressure decreases  

the ventilator continually monitors and adapts to the patient’s needs
PRVC Automatically Adjusts To Compliance Changes
PRVC
(Pressure Regulated Volume Control)

Disadvantages and Risks

• Varying mean airway pressure
• May cause or worsen auto-PEEP
• When patient demand is increased, pressure level may diminish when support is needed
• May be tolerated poorly in awake non-sedated patients
• A sudden increase in respiratory rate and demand may result in a decrease in ventilator support

Advantages

• Maintains a minimum PIP
• Guaranteed VT
• Patient has very little WOB requirement
• Allows patient control of respiratory rate
• Decelerating flow waveform for improved gas distribution
• Breath by breath analysis
PRVC
(Pressure Regulated Volume Control)

• Indications
  • Patient who require the lowest possible pressure and a guaranteed consistent VT
  • ALI/ARDS
  • Patient with the possibility of CL or Raw changes
Automode

<table>
<thead>
<tr>
<th>Mandatory</th>
<th>Spontaneous</th>
</tr>
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<tbody>
<tr>
<td>PRVC</td>
<td>VS</td>
</tr>
<tr>
<td>Ventilator triggered, pressure controlled and time cycled; the pressure is adjusted to maintain the set tidal volume</td>
<td>Patient triggered, pressure limited, and flow cycled.</td>
</tr>
<tr>
<td>Apnea for 12 seconds</td>
<td>Two consecutive breaths</td>
</tr>
</tbody>
</table>
Dual Control Breath-to-Breath adaptive support ventilation
ASV (Adaptive Support Ventilation)

- A dual control mode that uses pressure ventilation (both PC and PSV) to maintain a set minimum minute volume (volume target) using the least required settings for minimal WOB depending on the patient’s condition and effort
  - It automatically adapts to patient demand by increasing or decreasing support, depending on the patient’s elastic and resistive loads
MMV (Mandatory Minute Ventilation)

- Operator sets a minimum “Minute Ventilation” which usually is 70% - 90% of patient’s current Minute Ventilation.
- The ventilator provides whatever part of the Minute Ventilation that the patient is unable to accomplish.
- This accomplished by increasing the breath rate or the preset pressure.
- It is a form of PSV where the PS level is not set, but rather variable according to the patient’s need.
BiLevel Ventilation

$P_{aw}$ (cmH₂O)

-60 to 60

$P_{EEP_H}$

$P_{EEP_L}$

$P_{aw}$ (cmH₂O)

5, 6, 7

assure Support

BiLevel Ventilation: PEEP and Pressure Support
Airway Pressure Release Ventilation

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Time Triggered Time-cycled Ventilation
APRV
(Airway Pressure Release Ventilation)
Phigh = CPAP

T High duration

CPAP Phase

Spontaneous Breaths

Release Phase (T Low)

Time (s)

L/min

Spontaneous Breaths

Time (s)
APRV (Airway Pressure Release Ventilation)

• Indications
  – Partial to full ventilatory support
  – Patients with ALI/ARDS
  – Patients with refractory hypoxemia due to collapsed alveoli
  – Patients with massive atelectasis
  – May use with mild or no lung disease??
APRV advantages

• Clinical studies have shown that oxygenation and ventilation can be maintained at lower pressures with APRV when compared with conventional ventilatory management.

• Additionally, improvements in hemodynamic parameters and splanchnic perfusion have been reported.

• As the patient is able to breathe spontaneously throughout the entire respiratory cycle with this mode of ventilation, the need for heavy sedation and neuromuscular blockade is much less than with other modes of ventilation.
APRV disadvantages

• APRV is a form of PC ventilation; therefore, mechanical VT varies according to lung mechanics.
• The spontaneous breaths during the long inflation period can further increase end-inspiratory lung volume beyond that set by the inflation pressure; therefore, APRV may be less effective as a strategy to limit alveolar overdistension.
• APRV has not been well compared to other forms of conventional ventilation in a controlled fashion (data in children?!!!).
THANK YOU