ADVANCED MODES OF MECHANICAL VENTILATION

Mazen Kherallah, MD, FCCP
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)
**NEW MODES OF VENTILATION**

**DUAL-CONTROLLED MODES**

<table>
<thead>
<tr>
<th>Type</th>
<th>Manufacturer; ventilator</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dual control within a breath</td>
<td>VIASYS Healthcare; Bird 8400Sti and Tbird, VIASYS Healthcare; Bear 1000</td>
<td>Volume-assured pressure support</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pressure augmentation</td>
</tr>
<tr>
<td>Dual control breath to breath:</td>
<td>Siemens; servo 300, Cardiopulmonary corporation; Venturi</td>
<td>Volume support</td>
</tr>
<tr>
<td>Pressure-limited flow-cycled ventilation</td>
<td></td>
<td>Variable pressure support</td>
</tr>
<tr>
<td>Dual control breath to breath:</td>
<td>Siemens; servo 300, Hamilton; Galileo, Drager; Evita 4, Cardiopulmonary corporation; Venturi</td>
<td>Pressure-regulated volume control</td>
</tr>
<tr>
<td>Pressure-limited time-cycled ventilation</td>
<td></td>
<td>Adaptive pressure ventilation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Autoflow</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Variable pressure control</td>
</tr>
<tr>
<td>Dual control breath to breath: SIMV</td>
<td>Hamilton; Galileo</td>
<td>Adaptive support ventilation</td>
</tr>
</tbody>
</table>
### Dual Control Breath-to-Breath

Pressure-limited Flow-cycled Ventilation
Volume Support

<table>
<thead>
<tr>
<th>Control</th>
<th>Trigger</th>
<th>Limit</th>
<th>Target</th>
<th>Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>Patient</td>
<td>Pressure</td>
<td>Volume</td>
<td>Flow</td>
</tr>
</tbody>
</table>

Pressure Limited Flow Cycled Ventilation
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
Control logic for volume support mode of the servo 300

1. Trigger
2. Pressure limit Based on VT/C
3. Calculate new Pressure limit
4. Volume from Ventilator= Set tidal volume
5. Calculate compliance
6. Flow = 5% of Peak flow
7. Cycle off
Dual control breath to breath:
Proportional Assist Ventilation (PAS)/Proportional Pressure Support (PPS)

<table>
<thead>
<tr>
<th>Control</th>
<th>Trigger</th>
<th>Limit</th>
<th>Target</th>
<th>Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>Patient</td>
<td>Pressure</td>
<td>Volume</td>
<td>Flow</td>
</tr>
</tbody>
</table>

Pressure Limited Flow Cycled Ventilation
PROPORTIONAL ASSIST VENTILATION (PAV)

Changing pressure support based on patient’s efforts

Rregulates 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 \( (PSV) \).
Self-Adjusting Modes of Partial Ventilatory Support

Volume Support

Volume Assured Pressure Support

Proportional Assist

Pressure

\( p_{aw} \)

\( p_{es} \)
PAV (Proportional Assist Ventilation)

- **Indications**
  - Patients who have WOB problems associated with worsening lung characteristics
  - Asynchronous patients who are stable and have an inspiratory effort
  - Ventilator-dependent patients with COPD
PAV (Proportional Assist Ventilation)

Disadvantages

- Patient must have an adequate spontaneous respiratory drive
- Variable VT and/or PIP
- Correct determination of CL and Raw is essential (difficult). Both under and over estimates of CL and Raw during ventilator setup may significantly impair proper patient-ventilator interaction, which may cause excessive assist (“Runaway”) – the pressure output from the ventilator can exceed the pressure needed to overcome the system impedance (CL and Raw)
- Air leak could cause excessive assist or automatic cycling
- Trigger effort may increase with auto-PEEP

Advantages

- The patient controls the ventilatory variables (I, PIP, TI, TE, VT)
- Trends the changes of ventilatory effort over time
- When used with CPAP, inspiratory muscle work is near that of a normal subject and may decrease or prevent muscle atrophy
- Lowers airway pressure
## Dual Control within a Breath

**Volume-Assured Pressure Support**

<table>
<thead>
<tr>
<th>Control</th>
<th>Trigger</th>
<th>Limit</th>
<th>Target</th>
<th>Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dual Pressure/Volume</td>
<td>Patient</td>
<td>Pressure</td>
<td>Volume</td>
<td>Flow or volume</td>
</tr>
</tbody>
</table>

**Volume Assured Pressure Support Ventilation**
Set pressure limit

Pressure limit overridden

Set tidal volume cycle threshold

Tidal volume met

Tidal volume not met

Inspiratory flow greater than set flow

Flow cycle

Set flow

Switch from Pressure control to Volume/flow control

Set tidal volume cycle threshold

Flow

Volume

Flow

P_{aw} cmH_2O

Inspiratory flow equals set flow

Inspiratory flow greater than set flow

Inspiratory flow

Flow cycle

Set flow

Switch from Pressure control to Volume/flow control

Set tidal volume cycle threshold

Flow

Volume

Flow

P_{aw} cmH_2O

Inspiratory flow equals set flow

Inspiratory flow greater than set flow

Inspiratory flow

Flow cycle

Set flow

Switch from Pressure control to Volume/flow control

Set tidal volume cycle threshold

Flow

Volume

Flow

P_{aw} cmH_2O

Inspiratory flow equals set flow

Inspiratory flow greater than set flow

Inspiratory flow

Flow cycle

Set flow

Switch from Pressure control to Volume/flow control
Control logic for volume-assured pressure-support mode

- Trigger
  - Pressure at Pressure support
    - no
    - flow=25% peak
      - yes
      - no
        - Cycle off inspiration
      - no
        - delivered VT ≥ set VT
          - yes
          - no
          - no
            - Switch to flow control at peak flow setting
              - no
              - no
                - yes
                - no
                  - delivered VT = set VT
                    - yes
                    - no
                      - PAW < PSV setting
                      - yes
                      - no

**DUAL CONTROL BREATH-TO-BREATH PRESSURE REGULATED VOLUME CONTROL**

<table>
<thead>
<tr>
<th>Control</th>
<th>Trigger</th>
<th>Limit</th>
<th>Target</th>
<th>Cycle</th>
</tr>
</thead>
<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 (Pressure Regulated Volume Control)

PRVC. (1), Test breath (5 cm H2O); (2) pressure is increased to deliver set volume; (3), maximum available pressure; (4), breath delivered at preset $\dot{V}_E$, at preset $f$, and during preset $T_I$; (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
Control logic for pressure-regulated volume control and autoflow
**PRVC (Pressure Regulated Volume Control)**

<table>
<thead>
<tr>
<th>Disadvantages and Risks</th>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Varying mean airway pressure</td>
<td>Maintains a minimum PIP</td>
</tr>
<tr>
<td>May cause or worsen auto-PEEP</td>
<td>Guaranteed VT</td>
</tr>
<tr>
<td>When patient demand is increased, pressure level may diminish when support is needed</td>
<td>Patient has very little WOB requirement</td>
</tr>
<tr>
<td>May be tolerated poorly in awake non-sedated patients</td>
<td>Allows patient control of respiratory rate Decelerating flow waveform for improved gas distribution</td>
</tr>
<tr>
<td>A sudden increase in respiratory rate and demand may result in a decrease in ventilator support</td>
<td>Breath by breath analysis</td>
</tr>
</tbody>
</table>
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>
</thead>
<tbody>
<tr>
<td><strong>PRVC</strong></td>
<td><strong>VS</strong></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 $\dot{V}_E$ (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
ASV (Adaptive Support Ventilation)

- The clinician enters the patient’s IBW, which allows the ventilator’s algorithm to choose a required $\dot{V}E$. The ventilator then delivers 100 mL/min/kg.
- A series of test breaths measures the system $C$, resistance and auto-PEEP.
- If no spontaneous effort occurs, the ventilator determines the appropriate respiratory rate, VT, and pressure limit delivered for the mandatory breaths.
- I:E ratio and TI of the mandatory breaths are continually being “optimized” by the ventilator to prevent auto-PEEP.
- If the patient begins having spontaneous breaths, the number of mandatory breaths decrease and the ventilator switches to PS at the same pressure level.
- Pressure limits for both mandatory and spontaneous breaths are always being automatically adjusted to meet the $\dot{V}E$ target.
ASV (Adaptive Support Ventilation)

Indications

- Full or partial ventilatory support
- Patients requiring a lowest possible PIP and a guaranteed VT
- ALI/ARDS
- Patients not breathing spontaneously and not triggering the ventilator
- Patient with the possibility of work land changes (CL and Raw)
- Facilitates weaning
ASV (Adaptive Support Ventilation)

<table>
<thead>
<tr>
<th>Disadvantages and Risks</th>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inability to recognize and adjust to changes in alveolar VD</td>
<td>Guaranteed VT and VR</td>
</tr>
<tr>
<td>Possible respiratory muscle atrophy</td>
<td>Minimal patient WOB</td>
</tr>
<tr>
<td>Varying mean airway pressure</td>
<td>Ventilator adapts to the patient</td>
</tr>
<tr>
<td>In patients with COPD, a longer TE may be required</td>
<td>Weaning is done automatically and continuously</td>
</tr>
<tr>
<td>A sudden increase in respiratory rate and demand may result in a decrease in ventilator support</td>
<td>Variable Vm to meet patient demand</td>
</tr>
<tr>
<td></td>
<td>Decelerating flow waveform for improved gas distribution</td>
</tr>
<tr>
<td></td>
<td>Breath by breath analysis</td>
</tr>
</tbody>
</table>
MMV (Mandatory Minute Ventilation)

- AKA: Minimum Minute Ventilation or Augmented minute ventilation
- Operator sets a minimum $\dot{V}_E$ which usually is 70% - 90% of patient’s current $\dot{V}_E$. The ventilator provides whatever part of the $\dot{V}_E$ 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.
MMV (Mandatory Minute Ventilation)

- Indications
  - Any patient who is spontaneously and is deemed ready to wean
  - Patients with unstable ventilatory drive
**MMV (Mandatory Minute Ventilation)**

<table>
<thead>
<tr>
<th>Disadvantages</th>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>An adequate $\dot{V}E$ may not equal sufficient $A$ (e.g., rapid shallow breathing)</td>
<td>Full to partial ventilatory support</td>
</tr>
<tr>
<td>The high rate alarm must be set low enough to alert clinician of rapid shallow breathing</td>
<td>Allows spontaneous ventilation with safety net</td>
</tr>
<tr>
<td>Variable mean airway pressure</td>
<td>Patient’s $\dot{V}E$ remains stable</td>
</tr>
<tr>
<td>An inadequate set $\dot{V}E$ ($&gt;\text{spontaneous } \dot{V}E$) can lead to inadequate support and patient fatigue</td>
<td>Prevents hypoventilation</td>
</tr>
<tr>
<td>An excessive $sc^+ \dot{V}E$ ($&gt;\text{spontaneous } \dot{V}E$) with no spontaneous breathing can lead to total support</td>
<td></td>
</tr>
</tbody>
</table>
Bilevel Ventilation

$P_{aw}$ (cmH$_2$O)

$PEEP_H$ $PEEP_L$

$P_{aw}$ (cmH$_2$O)

1 2

5 6 7

assure Support
Thigh

Tlow

Plow

Phigh

Time

Pressure

P_{high}

T_{high}

T_{low}

P_{low}

P_{supp}

Time

Pressure
## Airway Pressure Release Ventilation

<table>
<thead>
<tr>
<th>Control</th>
<th>Trigger</th>
<th>Limit</th>
<th>Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>Time</td>
<td>Pressure</td>
<td>Time</td>
</tr>
</tbody>
</table>

Time Triggered Time-cycled Ventilation
AIRWAY PRESSURE RELEASE VENTILATION
APRV (Airway Pressure Release Ventilation)
MV high !!!

### APRV

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pmean</td>
<td>15</td>
</tr>
<tr>
<td>PEEP</td>
<td>3</td>
</tr>
<tr>
<td>Vol. %</td>
<td>36</td>
</tr>
<tr>
<td>FiO2</td>
<td>8.84</td>
</tr>
<tr>
<td>L/min</td>
<td>1.79</td>
</tr>
<tr>
<td>MV</td>
<td>12</td>
</tr>
<tr>
<td>MV expn</td>
<td></td>
</tr>
<tr>
<td>bpm</td>
<td>12</td>
</tr>
<tr>
<td>ftot</td>
<td>0.719</td>
</tr>
<tr>
<td>VT</td>
<td></td>
</tr>
<tr>
<td>O2</td>
<td>36</td>
</tr>
<tr>
<td>Phigh</td>
<td>30</td>
</tr>
<tr>
<td>Thigh</td>
<td>5.00</td>
</tr>
<tr>
<td>Tlow</td>
<td>1.00</td>
</tr>
<tr>
<td>Plow</td>
<td>0.00</td>
</tr>
<tr>
<td>Ramp</td>
<td>0.20</td>
</tr>
</tbody>
</table>

**Alarm Reset**
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 (Airway Pressure Release Ventilation)

Disadvantages and Risks
- Variable VT
- Could be harmful to patients with high expiratory resistance (i.e., COPD or asthma)
- Auto-PEEP is usually present
- Caution should be used with hemodynamically unstable patients
- Asynchrony can occur if spontaneous breaths are out of sync with release time
- Requires the presence of an “active exhalation valve”

Advantages
- Allows inverse ratio ventilation (IRV) with or without spontaneous breathing (less need for sedation or paralysis)
- Improves patient-ventilator synchrony if spontaneous breathing is present
- Improves mean airway pressure
- Improves oxygenation by stabilizing collapsed alveoli
- Allows patients to breathe spontaneously while continuing lung recruitment
- Lowers PIP
- May decrease physiologic deadspace
QUESTIONS