New Modes of Mechanical Ventilation

Trend Towards Pressure-Limited Ventilation

Volume Control : What Was So Good About It ?
- Guaranteed tidal volume
  \( V_T \) is constant even with variable compliance and resistance.
- Less atelectasis compared to pressure control.
- \( V_T \) increase is associated with a linear increase in minute ventilation.

What's Wrong With Volume Control Ventilation ?
- The limited flow available may not meet the patient's desired inspiratory flow rate.
- If the patient continues to inspire vigorously, added, unnecessary work is done. This can lead to fatigue.
- Can cause excessive airway pressure leading to barotrauma, volutrauma, and adverse hemodynamic effects.
How Volume Control Causes Excess WOB

Pressure Control:
The Alternative

- Increases mean airway pressure by constant inspiratory pressure.
- Limits excessive airway pressure
- Improves gas distribution
- Lowers WOB

The Cons of Pressure Control

- Variable \( V_T \) as pulmonary mechanics change
- Potentially excessive \( V_T \) as compliance improves
- Inconsistent changes in \( V_T \) with changes in PIP and PEEP.

Comparing Volume Control With Pressure Control

<table>
<thead>
<tr>
<th>Variable</th>
<th>Volume-Control</th>
<th>Pressure Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trigger</td>
<td>Pt or machine</td>
<td>Pt or machine</td>
</tr>
<tr>
<td>Limit</td>
<td>Flow</td>
<td>Pressure</td>
</tr>
<tr>
<td>Cycle</td>
<td>Volume</td>
<td>Time or flow</td>
</tr>
<tr>
<td>( V_T )</td>
<td>Constant</td>
<td>Variable</td>
</tr>
<tr>
<td>Peak Pressure</td>
<td>Variable</td>
<td>Constant</td>
</tr>
<tr>
<td>Modes</td>
<td>VC,AC,SIMV</td>
<td>PC,AC,SIMV,PS</td>
</tr>
</tbody>
</table>

Pressure Support

- Pressure Support
  - Pressure-limited, flow-cycled ventilation
  - High, variable inspiratory flow
  - Less WOB for pt
- Problems?
  - Respiratory drive
  - Impedance (compliance, resistance)
  - Minimum minute ventilation not guaranteed!

Pressure Support Ventilation

- Pressure support is intended to overcome the WOB imposed by breathing apparatus (ETT) and by abnormal lung/chest impedance.
- The actual level of pressure needed to achieve this, however, varies within a single breath with variable flow rates, and over short periods of time as impedance changes.
Pressure Support Ventilation

- PSV can increase PEEPi and prevent triggering of a breath by the patient.
- If the patient’s lung/chest compliance decreases or airways resistance increases, a given level of pressure support will subsequently produce a lower tidal volume.

Pressure-Limited Ventilation

- Can we overcome some of these limitations of pressure-limited ventilation?
- Perhaps some kind of volume sensor to trend tidal volume, so that we get *volume control*, but *pressure limited* ventilation.

Dual Control Modes

Dual Control Breaths

- Dual: switch between PC and VC breaths
- Switch either within a single breath
  - VAPS
  - PA
- Switch between breaths
  - Volume Support
  - Pressure-Regulated Volume Control (PRVC)

Dual Control Within Breath

Within a single breath we can switch from pressure to volume control.
Dual Control Within a Breath

• Volume-Assured Pressure Support
• Pressure Augmentation

Volume-Assured Pressure Support

• This mode allows a feedback loop based on tidal volume
• Switches even within a single breath from pressure control to volume control if minimum tidal volume has not been achieved

Volume-Assured Pressure Support

• The Respiratory Therapist sets:
  – pressure limit = plateau seen during VC
  – respiratory rate
  – peak flow rate (the flow if TV < target)
  – PEEP
  – FiO2
  – trigger sensitivity
  – minimum tidal volume

Volume-Assured Pressure Support

• Once a breath is triggered, rapid, variable flow pushes pressure to reach set pressure support level.
• Tidal volume delivered from the machine is monitored.
Volume-Assured Pressure Support

If tidal volume equals minimum set TV, you get a typical pressure support breath.

If patient-effort is weak, convert from pressure-support to volume control.

If impedance changes, switch from pressure-support to volume control with prolonged inspiration.

Limitations:
- If pressure too high, all breaths are pressure-limited.
- If peak flow set too low, the switch from pressure to volume is late in the breath, inspiratory time is too long.

Dual Control Breath to Breath

- Breath to breath.
- Switch between pressure support and pressure control.

Volume-Assured Pressure Support

- Amato et al Chest 1992;102: 1225-1234
- Compared VAPS to simple AC volume
- Lower WOB
- Lower $R_{aw}$
- Less PEEPi
Dual Control Breath to Breath

- Volume Support (flow cycled)
- PRVC (time cycled)

Dual Control Breath to Breath

- Maintains minimum peak pressure required to keep set TV (a more subtle volume control mode)
- Maintains more consistent TV with varying compliance or resistance.
- Automated reduction of pressure and flow while maintaining constant minute volume.

Breath To Breath Dual Control

- Siemens 300
  - Volume Support
  - Pressure-Regulated Volume Control
- Galileo
  - Adaptive Pressure Ventilation
- Drager Evita 4
  - Autoflow
- Venturi Cardiopulmonary Corp.
  - Variable Pressure Support

Volume Support

- Pressure-limited
- Flow cycled
- Automatic weaning of pressure support as long as tidal volume matches minimum required TV (TV set in a feedback loop to adjust pressure).

VS vs VAPS

- How does volume support differ from VAPS?
  - In volume support, we are trying to adjust pressure so that, within a few breaths, desired TV is reached.
  - In VAPS, we are aiming for desired TV tacked on to the end of a breath if a pressure-limited breath is going to fail to achieve TV

Volume Support

- What happens in VS if impedance changes (higher resistance or less compliance)?
  - TV will decrease, subsequent pressure will be increased to bring TV back toward the goal.

• What happens in VS if impedance changes (higher resistance or less compliance)?
  - TV will decrease, subsequent pressure will be increased to bring TV back toward the goal.
Volume Support

- Little data to show it actually works.
- If pressure support level increases to maintain TV in pt with increased airways resistance, PEEPi may increase.
- If minimum TV set too high, weaning may be delayed.

Pressure-Regulated Volume Control

- Pressure-limited
- Time cycled
  - Adaptive Pressure Ventilation (Galileo)
  - Autoflow (Evita 4)
- Automatically adjusts pressure support level to minimum needed to maintain constant set TV.

Response of Dual Control Breath to Breath To Rapid Decrease in Lung Compliance

Limitations of PRVC

- As patient demand increases producing higher TV because of more pt effort, pressure level drops, giving less ventilator support at a time when the patient may be needing more.
- As pressure support level drops, mean airway pressure drops, possibly causing hypoxemia.

Automode

- Siemens 300A
- Combines Volume Support and PRVC into a single mode
- Switches between pressure support and pressure control, with pt effort determining whether the breath will be VS or PRVC.

Automode

- If patient makes no effort, you get PRVC.
- As pt begins to breathe spontaneously, switch to Volume Support.
- Mean airway pressure could become too low.
- No evidence to advocate its use.
Adaptive Support Ventilation

- Galileo
- Dual control, breath to breath mode. Pressure limit of spontaneous and mandatory breaths is constantly adjusted.
- Based on idea that a patient will breathe at a tidal volume and rate that minimizes elastic and resistive loads.

Adaptive Support Ventilation

- Respiratory Therapist enters pt's ideal body weight, sets high pressure alarm, PEEP, FiO2, flow cycle variable (10-40%) of initial peak flow, and % volume control (20% - 200%).
- Ventilator delivers 100 ml/kg/min for adults, 200 ml/kg/min for children as 100% volume control.

Minimum and Maximum Ventilator Variable for ASV

<table>
<thead>
<tr>
<th>Variable</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
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<tbody>
<tr>
<td>Peak pressure limit</td>
<td>PEEP + 5 cm H2O</td>
<td>Clinician set high pressure limit</td>
</tr>
<tr>
<td>Tidal volume</td>
<td>4.4 ml/kg</td>
<td>13.4 ml/kg</td>
</tr>
<tr>
<td>Respiratory frequency</td>
<td>5 breaths/min</td>
<td>60 breaths/min</td>
</tr>
<tr>
<td>Inspiratory time</td>
<td>0.5 x or 1 time constant</td>
<td>Two time constants</td>
</tr>
<tr>
<td>Expiratory time</td>
<td>None</td>
<td>None</td>
</tr>
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</table>

PEEP = positive end-expiratory pressure.

Adaptive Support Ventilation

- If patient makes no effort to breathe, vent delivers required minute ventilation as pressure control.
- If patient starts to breathe spontaneously, vent gradually reduces number of mandatory breaths and lowers pressure support level as necessary to keep minute ventilation above the minimum setting.

Adaptive Support Ventilation

- If patient spontaneous tidal volume is more than the target and rate is less, the pressure limit is reduced and rate of mandatory breaths is increased.
- If TV > target and rate > target, pressure limit is lowered and number of mandatory breaths is reduced.
Adaptive Support Ventilation

- If TV < target and rate > target, pressure limit is increased and mandatory rate is lowered. This is analogous to pressure support ventilation with relatively high level of pressure.

Adaptive Support Ventilation

- If both TV and rate are less than target, vent increases mandatory rate and pressure limit. This is similar to SIMV with pressure control.

Adaptive Support Ventilation

- Several studies have shown that ASV can adjust ventilation to stay within desired ranges in spite of patient paralysis and changes in position.
- Usually ASV provides lower TV, lower peak pressure and faster respiratory rates.
- No studies on weaning.

Adaptive Support Ventilation

- ASV is a very versatile mode of ventilation.
- It is NOT just a method of weaning.

Automatic Tube Compensation

- Drager Evita 4
- Overcome WOB added by artificial airways.
- Improve patient/ventilator synchrony by providing variable fast inspiratory flow.

Resistance Due To Endotracheal Tube

- Varies with
  - radius
  - length
  - flow

![Graph showing pressure vs flow for different ETT sizes](image-url)
Automatic Tube Compensation
- Due to varying inspiratory flow rates, no single level of pressure support can actually fully compensate for WOB caused by the ETT.
- Autotube uses known static resistance for each size and type of ETT/trach tube, and measures flow rates.

Automatic Tube Compensation
- Pressure is applied and continuously adjusted proportional to resistance.
- Tracheal pressure (cm H₂O) = proximal airway pressure (cm H₂O) - tube coefficient (cm H₂O /L/sec) * flow² (L/min)

Automatic Tube Compensation
- Pressure support can cause increased PEEPi so that the patient cannot trigger a breath.
- Increasing the level of pressure support causes VT and TI to get longer so PEEPi gets even worse.
- It can look like patient effort is less, but actually the ventilator just isn’t recognizing the attempts to breathe.

ATC and Electronic Weaning
- Stocker et al have suggested that a patient’s breathing during ATC looks like it would if the patient was extubated.
- They called this “electronic extubation”
- Cannot predict airway patency, however, after extubation.

Automatic Tube Compensation
- This mode seems to achieve what we were trying to get with pressure support.
- What about impedance changes and the effect on VT?
- Is this a dual control mode?

Automatic tube compensation answers the question …
If the patient’s ETT suddenly disappeared and his airway remained patent, what would his breathing look like?

ATC is a test of weanability.
Proportional Assist Ventilation

- Available on Drager Evita 4, Proportional Pressure Support
- Delivered flow and volume is proportional to patient demand and impedance.
- Respiratory Therapist sets PEEP, FiO2, volume assist and flow assist.

The Goldilocks Principle

- A recent editorial (Critical Care Medicine 4/00 by MacIntyre N) suggested that we need to select a level of pressure support that is "not too low, not too high, but just right".
- There is some evidence that once respiratory muscles are fatigued, giving too much support from the ventilator (higher pressure support) may retard recovery.

The Goldilocks Principle

- Similarly, giving too little pressure support so that the patient has to do too much work may retard recovery from ventilatory muscle fatigue.
- The right level of pressure support appears to be whatever level produces a work of breathing that is normal.

Theoretical Background For Proportional Assist Ventilation

- Muscle pressure = (normal elastance x volume) + (normal resistance x flow) + abnormal load.
- We want the ventilator to do the work to cover the abnormal load.

Proportional Assist Ventilation

- The goal is to maintain a constant fraction of work per breath done by the ventilator.
- If vent is set to give 80% volume and flow assist, if the patient’s tidal volume increases, the pressure increases to keep the amount of patient work constant.
**Proportional Assist Ventilation**

- If tidal volume stays the same but the patient tries to increase inspiratory flow rate, pressure provided by the ventilator increases to keep the fraction of pt WOB per breath constant.
- PAV requires accurate, instantaneous measurement of compliance and resistance.

**Proportional Assist Ventilation**

- PAV is a form of pressure control, but the pressure waveform can be highly variable depending on elastance, resistance, flow and volume.
- Several studies have shown that PAV, compared to pressure support, produces lower WOB.

**Conclusion**

- Modern ventilators offer several potentially very useful new modes designed for a variety of purposes.
- Most of the newer modes offer the benefits of pressure-limited breaths with the security of an assured minimum tidal volume.
- More patient comfort with less patient work.