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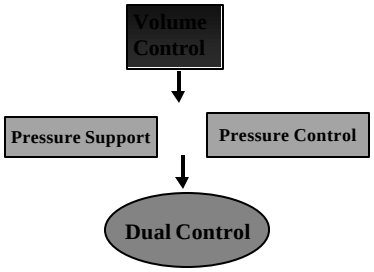
New Modes of Mechanical Ventilation

Trend Towards Pressure-Limited Ventilation

Evolution of Modes



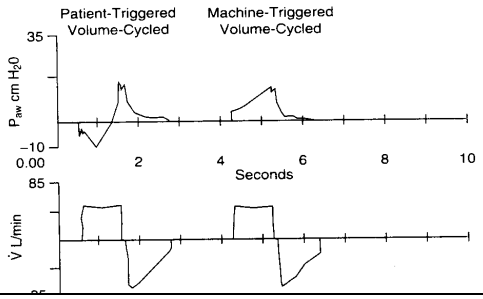
Volume Control : What Was So Good About It ?

- 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

Variable	Volume-Control	Pressure Control
Trigger	Pt or machine	Pt or machine
Limit	Flow	Pressure
Cycle	Volume	Time or flow
V_T	Constant	Variable
Peak Pressure	Variable	Constant
Modes	VC,AC,SIMV	PC,AC,SIMV,PS

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.

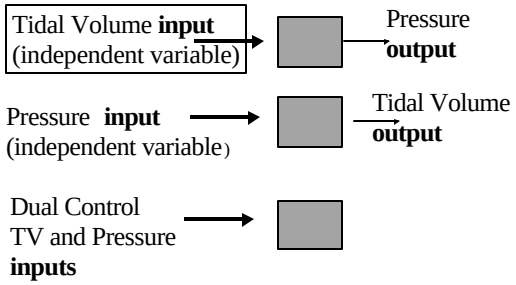
Pressure Support Ventilation

- 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

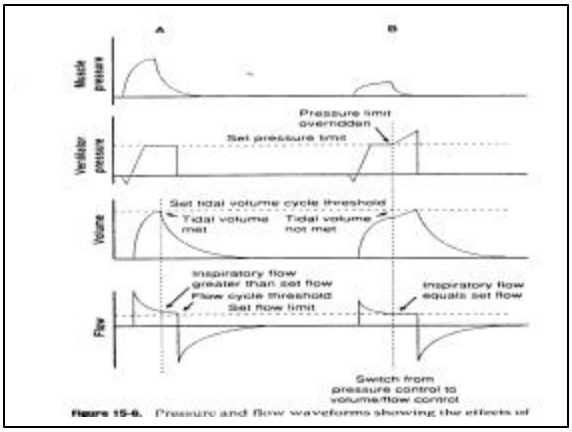
- Bird 8400STi (VAPS)
  - SIMV
  - Assist/Control
  - Pressure Support
- Bear 1000 (Pressure Augmentation)
  - SIMV
  - A/C
  - PS

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

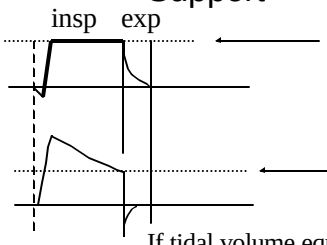
- The Respiratory Therapist sets :
  - **pressure limit** = plateau seen during VC
  - respiratory rate
  - peak flow rate (the flow if TV < target)
  - PEEP
  - FiO2
  - trigger sensitivity
  - **minimum tidal volume**



Volume-Assured Pressure Support

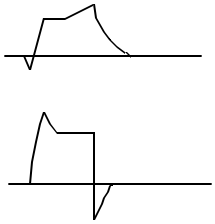
- Once a breath is triggered, rapid,variable flow pushes pressure to reach set pressure support level.
- Tidal volume delivered from the machine is monitored.

Volume-Assured Pressure Support



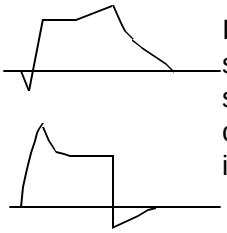
If tidal volume equals minimum set TV,you get a typical pressure support breath.

Volume-Assured Pressure Support



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

Volume-Assured Pressure Support



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

Volume-Assured Pressure Support : 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.

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

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

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

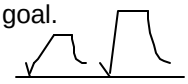
- Pressure-limited
- Flow cycled
- Automatic weaning of pressure support as long as tidal volume matches minimum required TV (TV set in a feedback loop to adjust pressure).

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.



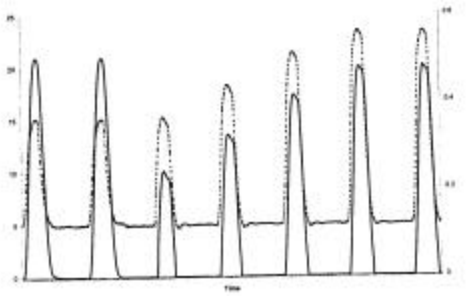
Volume Support

- 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

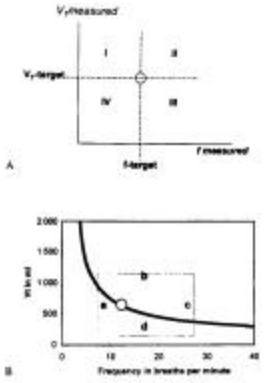
- Respiratory Therapist enters pt's ideal body weight, sets high pressure alarm,PEEP,FiO2,flow cycle variable (10-40%) of initial peak flow,and % volume control (20% - 200%).
- Ventilator delivers 100 ml/kg/min for adults, 200 ml/kg/min for children as 100% volume control.

Minimum and Maximum Ventilator Variable for ASV

Minimum and Maximum Ventilator Variables for Adaptive Support Ventilation

Variable	Minimum	Maximum
Peak pressure limit	PEEP + 5 cm H_2O	Clinician set high pressure limit
Tidal volume	4.4 ml/kg	15.4 ml/kg
Respiratory frequency	5 breaths/min	60 breaths/min
Inspiratory time	0.5 s or 1 time constant	Two time constants
Expiratory time	Two time constants	None

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

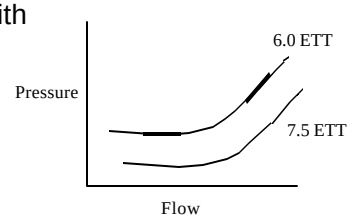
- ASV is a very versatile mode of ventilation.
- It is NOT just a method of weaning.

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



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 H_2O) = proximal airway pressure (cm H_2O) - tube coefficient (cm H_2O /L/sec) * flow^2 (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 V_T and T_I 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 V_T ?
- 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.

The Goldilocks Principle

- By constantly adjusting the level of pressure support to cover abnormally increased loads caused by increased resistance or reduced compliance, we can allow the ventilator to do the “excess” work and let the patient do a normal amount of work.

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