New Modes of Ventilation

Dr. Zia Hashim
Mode

- Describes the specific combination of:
  - control
  - phase
  - conditional variables

- Defined for:
  - spontaneous
  - mandatory breaths
Control variable: Constant throughout inspiration, regardless of changes in respiratory impedance

Trigger variable: For initiating a breath.

Limit variable: Constant throughout inspiration but does not result in the termination of inspiratory time

Cycle variable: Causes inspiration to end

Conditional variable: results in a change in output
What controls the adjustments?

Volume?
(flow control)

Pressure?
Targeting

Control

- Flow
- Pressure

Target

- Time
- Pressure
- Volume

Volume control
Targeting

Control
- Flow
- Pressure

Target
- Time
- Pressure
- Volume

Time-cycled pressure control
Targeting

Control
- Flow
- Pressure

Target
- Time
- Pressure
- Volume

Volume targeted pressure control
Goals of Mechanical Ventilation

- Avoiding extension of lung injury,
- $\downarrow$ O$_2$ toxicity
- Recruiting alveoli by $\uparrow$ mean Paw by $\uparrow$ PEEP and/or prolonging inspiration,
- $\downarrow$ Peak Paw
- Preventing atelectasis
- Using sedation and paralysis judiciously
- Better Patient-Ventilator synchrony
VILI & Lung Protection

- Volutrauma
- Atelectrauma: Even the best possible lung protective strategy may cause injury to some of lung units (due to heterogenous involvement)
- Barotrauma
- Biotrauma: majority of deaths in ARDS are not because of oxygenation failure but because of MODS
Lung Protective Strategy

- Prevention of overdistension related lung injury by avoiding high transpulmonary pressure
- The “open lung” concept: recruitment & maintenance of lung volume
- Reduction of FiO$_2$
**Volume Control: Advantages**

- Guaranteed tidal volume
  VT is constant even with variable compliance and resistance.
- Less atelectasis compared to PC
- VT increase is associated with a linear increase in minute ventilation
Volume Control: Disadvantages

- The limited flow available may not meet the patient’s desired inspiratory flow rate
- If the patient continues to inspire vigorously → Patient Vent Asynchrony: ↑WOB → fatigue
- In LPV → Acute hypercapnia → ↑WOB
- Can cause ↑ airway pressure leading to barotrauma, volutrauma, & adverse hemodynamic effects
Pressure Control: Advantage

- Increases mean airway pressure by constant inspiratory pressure.
- Limits excessive airway pressure
- Improves gas distribution
- ↓ WOB
Disadvantage of Pressure Control

- Variable VT as pulmonary mechanics change
- Potentially excessive VT as compliance improves
- Inconsistent changes in VT with changes in PIP and PEEP
Is Pressure Control Really Better?

Previous studies that used a conventional VT to compare WOB between pressure regulated modes and VCV may have been biased because measurements were made at a constant VT and inspiratory time that resulted in an abnormally low peak flow (55 L/min).
Is Pressure Control Really Better

- No significant benefit in treating ventilator-patient asynchrony with a pressure-regulated mode compared to VCV with the peak insp flow of approximately 75 L/min

*MacIntyre et al. Critical Care Med 1997*
Does Pressure Control Really ↓ WOB

- ALI/ARDS (N=14) crossover, repeated-measures design
- VT of 6.4± 0.5 mL/kg set during VCV and PRVC. During PCV the inspiratory pressure set to achieve the same VT
- Nonsignificant trend toward ↑ WOB during PCV & PRVC vs VC with ↑ flow
- Mean VT not statistically different: in 40% of patients VT markedly exceeded the lung-protective ventilation
- In some patients VT not precise

Richard et al. Resp Care 2005 Dec
Various Modes Available
Why new modes?

- Conventional modes are uncomfortable
- Need for heavily sedation & paralysis
- Patients should be awake and interacting with the ventilator
- To enable patients to allow spontaneous breath on inverse ratio ventilation
Dual modes

- Combining advantages of both volume & pressure control
- Recently developed modes allow the ventilator to control V or P based on a volume feedback
- Allow the ventilator to control V or P based on a volume feedback
Dual Control

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

- Switches from pressure-controlled to volume-controlled in the middle of the breath
Dual control breath-to-breath

- Dual control breath-to-breath simpler: ventilator operates in either the PS or PC modes
- The difference: pressure limit ↑ or ↓ in an attempt to maintain a selected TV (based on the TV of the previous breath)
- Analogous to having a therapist at the bedside who ↑ or ↓ the pressure limit of each breath based on the TV of the previous breath
VAPS

- Mandatory breaths or PS breaths
- Meant to combine the high variable flow of a pressure-limited breath with the constant volume delivery of a volume-limited breath
- During pressure support: VAPS is a safety net that always supplies a minimum TV
Breath: initiated by the patient or may be time-triggered

Once the breath is triggered, ventilator will attempt to reach the PS setting as quickly as possible

This portion of the breath is the pressure-control portion and is associated with a rapid variable flow: may ↓ WOB
VAPS: Settings

- RR
- Peak flow (flow if TV<Target)
- PEEP
- FiO₂
- Trigger sensitivity
- Minimum desired Vt

**Pressure support setting** = plateau pressure obtained during a volume-controlled breath at the desired Vt
If the delivered TV = set TV

\[ \downarrow \]

pressure-support breath

breath is pressure-limited at the pressure-support setting and is flow-cycled at 25% of the initial peak flow
If the patient's inspiratory effort ↓

↓

ventilator will deliver a smaller volume
microprocessor decides minimum set Vt will not be delivered

- flow decelerates and = set peak flow
- breath changes from a pressure-limited to a volume-limited breath
VAPS Evidence

VAPS compared to A/C (N=30)
- ↓WOB: higher inspiratory flow which provided larger Vt
- ↓Raw
- ↓PEEPi
- Better patient-ventilator synchrony

Amato et al. Chest 1992
Pressure Regulated Volume Control (PRVC) Dual Control Breath to Breath
PRVC

- Assist-control ventilation
- Pressure control titrated to a set TV
- Time cycled
Synonyms of PRVC

- Pressure-regulated volume control (PRVC; Siemens 300; Siemens Medical Systems)
- Adaptive pressure ventilation (APV; Hamilton Galileo; Hamilton Medical, Reno, NV)
- Autoflow (Evita 4; Drager Inc., Telford, PA)
Settings for PRVC

- Minimum respiratory rate
- Target tidal volume
- Upper pressure limit: 5 cm H2O below pressure alarm limit
- FIO2
- Inspiratory time or I:E ratio
- Rise time
- PEEP
The pressure limit will fluctuate between 0 cm H$_2$O above the PEEP level to 5 cm H$_2$O below the high-pressure alarm setting.

The ventilator will signal if the tidal volume and maximum pressure limit settings are incompatible.
Advantage of PRVC

Decelerating inspiratory flow pattern

- Pressure automatically adjusted for changes in compliance and resistance within a set range
- Tidal volume guaranteed
- Limits volutrauma
- Prevents hypoventilation
Advantage of PRVC

- Maintaining the minimum Ppk that provides a constant set VT
- Automatic weaning of the pressure as the patient improves
- Limited staffing → maintain a more consistent TV as compliance ↑ or ↓
Disadvantage of PRVC

- Pressure delivered is dependent on tidal volume achieved on last breath
  - Intermittent patient effort $\rightarrow$ variable tidal volumes

- Asynchrony with variable patient effort

  Richard et al. Resp Care 2005 Dec

- Less suitable for patients with asthma or COPD
Disadvantage of PRVC

If in assisted breaths the Pt's demand ↑

Pressure level ↓ at a time when support is most necessary

Mean airway pressure will ↓

Hypoxemia
VC-IMV (N=30) vs PRVC(N=27) until extubation

Parameters did not shown any differences in outcome variables or complications

Duration of ventilation was reduced in the PRVC

VCV, pressure-limited time-cycled ventilation, and PRVC in acute respiratory failure (N=10)

No advantage of PRVC over PCV in this small group of patients during a very short period of investigation

Automode (Siemens Servo)

- Designed to allow the ventilator to be interactive with the patient's needs by making breath-by-breath adjustments in both control and support modes.
- Automatically shifts between controlled ventilation, supported ventilation & spontaneous ventilation.
  - VC to VS
  - PRVC to VS
  - PC to PS

Holt et al. Respir Care 2001
Pitfalls of Automode

During the switch from time-cycled to flow-cycled ventilation

↓

Mean airway pressure ↓

↓

hypoxemia in the patient with acute lung injury
Adaptive Support Ventilation ASV
Adaptive Support Ventilation

- Very versatile mode
- Based on minimal WOB concept
- "Electronic" ventilator management protocol that may improve the safety and efficacy of mechanical ventilation
- Automatic adaptation of the ventilator settings to patient's passive and active respiratory mechanics
Adaptive Support Ventilation: Principle

For a given level of alveolar ventilation

@ Particular RR

least costly in terms of respiratory work
Adaptive Support Ventilation: Principle

To maintain a given MV, at very low RR

\[ \uparrow \text{Force to overcome the elastic recoil} \]

\[ \downarrow \]

\[ \uparrow \text{TV required} \]

\[ \downarrow \]

\[ \uparrow \text{WOB} \]
Adaptive Support Ventilation: Principle

@ very high RR

\[ \downarrow \]

overcome the flow-resistance

\[ \downarrow \]

↑WOB

\[ \downarrow \]

Maintaining MV
Adaptive Support Ventilation (ASV)

- RR: Respiratory rate
- RC: Respiratory time constant
- VA: Alveolar ventilation
- VD: Dead space volume

\[ RR = \sqrt{1 + \frac{4\pi^2 RC \cdot (VA/VD)}{2\pi^2 RC}} - 1 \]
ASV Input

- **Ideal body weight**: determines dead space
- **High-pressure alarm**: 5 cm H$_2$ O above PEEP to 10 cm H$_2$ O below set Pmax
- **Mandatory RR**
- **PEEP**
- **FiO$_2$**
- **Insp time** (0.5–2 secs), **exp time** (3 × RCe to 12 secs)
ASV

Adjusts

- inspiratory pressure
- I:E ratio,
- mandatory respiratory rate

\[ \downarrow \]

- maintain the target MV (according to IBW) and RR, to avoid both rapid shallow breathing and excessive inflation volumes
ASV

- Delivers 100 mL/min/kg of MV for adult and 200 mL/min/kg for children: setting known as the % minute volume control.
- Can be set from 20% to 200%.
- Allows the clinician to provide full ventilatory support or to encourage spontaneous breathing and facilitate weaning.
ASV

- Variables are measured on a breath-to-breath basis and altered by the ventilators algorithm to meet the desired targets.
- If patient breathes spontaneously, ventilator will pressure-support breaths.
- Spontaneous and mandatory breaths can be combined to meet the MV target.
Uses of ASV

- Initially designed to reduce episodes of central apnea in CHF: improvement in sleep quality, decreased daytime sleepiness
- Can be used for pts who are at risk for central apnea like those with brain damage
ASV Evidence

- ASV(N=18) vs SIMV + PS (N=16)
- Standard management for rapid extubation after cardiac surgery
  - ↓Ventilatory settings manipulations
  - ↓High-inspiratory pressure alarms

⚠️ Outcome: same

Anaesthesia Analgesia. 2003 Dec
Partial ventilatory support: ASV provided MV comparable to SIMV-PS.

ASV: central respiratory drive & inspiratory load ↓

Improved patient-ventilator interactions

Decreased sedation use

Helpful mode in weaning

*Critical Care Medicine 2002*
Proportional Assist Ventilation

- $P_{aw} + P_{mus} = V \times \text{Elastance} + \text{Flow} \times \text{Resistance}$
- Regardless of change in patient effort, ventilator continues to do same % of work
- PAV requires only PEEP & FiO$_2$ % volume assist, % flow assist (or to control % work which will include both)
PAV

- Pressure control
- Patient triggered
- Pressure limited
- Flow cycled
PAV

- Similar to cruise control
- Position of accelerator changes to keep speed constant
- Major impediment is accurate measurement of elastance & resistance breath to breath
- PAV is always patient triggered: backup reqd
Benefits of PAV

- Improves synchrony b/w neural & machine inflation time: **Neuroventilatory coupling**
- Hypercapnic respiratory failure in COPD
- Adaptability of ventilator to changing patients ventilatory demands
- Increases sleep efficiency
- Non invasive use of PAV in COPD & Kyphoscoliotic patients: delivered through nasal mask; improves dyspnea score
ARDS: Further studies are required.

Response to hypocapnia: In ACV ability to reduce VT is impaired, preserved during PAV.
All clinical situations characterized by high ventilatory output uncoupled with ventilatory requirements (i.e. respiratory alkalosis) may be potentially worsened by PAV
Airway Pressure Release Ventilation APRV
Ventilator cycles between two different levels of CPAP – an upper pressure level and a lower level.

The two levels are required to allow gas move in and out of the lung.

Baseline airway pressure is the upper CPAP level, and the pressure is intermittently “released” to a lower level, thus eliminating waste gas.
APRV

- Mandatory breaths occur when the pressure changes from high to low
- If pt paralyzed: pressure control, time triggered, pressure limited time cycled ventilation
- Spontaneous breathing: transition of pressure from ↑ to ↓: results in tidal movement of gas
- Time spent at low pressure (short expiratory time): prevents complete exhalation; maintains alveolar distension
APRV SET UP
APRV Settings

- Expiratory time variable: ↓ enough to prevent derecruitment & ↑ enough to obtain a suitable TV (0.4 to 0.6 s) – Target TV (4-6ml/kg)
- If the TV is inadequate → expiratory time is lengthened
- If TV too high (>6ml/kg) → expiratory time is shortened
APRV Settings

- $P_{\text{high}}$ level set at the MAP level from the previous mode (pressure control, volume control)
- Starting off with APRV $\rightarrow$ start high (28 cmH2O of less) and work way down. Higher transalveolar pressures recruit the lungs. Low PEEP is set at 0-5 cmH2O.
APRV Settings

- The inspiratory time is set at 4-6 seconds (the respiratory rate should be 8 to 12 breaths per minute - never more)
- I:E ratio: at least 8:1 and
- Time at low pressure level should be brief (0.8 sec)
Neuromuscular blockade should be avoided: the patient allowed to breath spontaneously (beneficial)

The breaths can be supported with pressure support - but the plateau pressure should not exceed 30cmH2O
APRV Weaning

Two different ways to wean

- If lung mechanics rapidly return to normal, patient should be weaned to pressure support.
- If ARDS is prolonged → the high CPAP level is gradually weaned down to 10cmH2O → standard vent wean
APRV Benefits

- Preservation of spontaneous breathing and comfort with most spontaneous breathing occurring at high CPAP
- ↓ WOB
- ↓ Barotrauma
- ↓ Circulatory compromise
- Better V/Q matching
APRV Evidence

- APRV vs pressure controlled conventional ventilation patients with ALI after trauma ($n = 30$)
- Randomized controlled, prospective trial
- ↓ ICU days, ventilator days, better gas exchange, hemodynamic, lung comp,
- ↓ Need for sedation and vasopressors

APRV Evidence

- Prospective, randomized intervention study (N=45)
- Combined effects of proning and SIMV PC/PS vs. APRV; patients with ALI
- Oxygenation was significantly better in APRV group before and after proning; sedation use and hemodynamics were similar

Puntsen et al. Am J Respir Crit Care Med 2001
APRV Evidence

- Stock (1987) APRV vs. IPPV; dogs with ALI (n = 10): **Better**
- Rasanen (1988) APRV vs. conventional ventilation vs. CPAP; anesthetized dogs (n = 10): **Similar**
- Martin (1991) APRV vs. CPAP vs. conventional ventilation: **Better**
- Davis (1993) APRV vs. SIMV; surgery patients with ALI (n = 15) **Similar**
Rathgeber (1997): APRV vs conventional ventilation vs. SIMV; patients after cardiac surgery \( (n = 596) \)

- Shorter duration of intubation: (10 hrs) than SIMV (15 hrs) or conventional ventilation (13 hrs)
- ↓ Sedation & analgesia requirement
- Prospective, randomized, controlled, open trial over 18 months, uneven randomization
Disadvantage of APRV

- Volumes change with alteration in lung compliance and resistance
- Limited access to technology capable of delivering APRV
- An adequately designed and powered study to demonstrate reduction in mortality or ventilator days compared with optimal lung protective conventional ventilation
Mandatory Minute Ventilation

- Closed loop ventilation: ventilator changes its output based on measured input variable
- Spontaneous breaths: pressure control is used
- If anticipated $V_E < \text{set (based on MV of past 30 sec)}$: Mandatory breaths which are VC, time triggered
In contrast to SIMV: MMV gives mandatory breaths only if spontaneous breathing has fallen below a pre-selected minimum ventilation
MMV Evidence

MMV vs SIMV (N=30 neonates)

- No statistically significant differences for EtCO$_2$, minute volumes, PIP & PEEP
- ↓ Mechanical breaths
- MAP generated with MMV
- May reduce the risk of some of the long-term complications associated with MV

*J Perinatol. 2005 Oct*
Automatic Tube Compensation

Compensates for the resistance of the endotracheal tube
Automatic Tube Compensation

- Single greatest cause of imposed WOB is the endotracheal tube
- ↑ing PS levels as endotracheal tube diameter decreases and inspiratory flow increases
- Under static conditions PS can effectively eliminate endotracheal-tube resistance
Variable inspiratory flow and changing demands: cannot be met by a single level of PS

ATC attempts to compensate for ET resistance via closed-loop control of calculated tracheal pressure

Measurement of instantaneous flow to apply pressure proportional to resistance throughout the total respiratory cycle
Inputs type of tube: ET or tracheostomy, and the percentage of compensation desired (10%-100%)

During expiration, there is also a flow-dependent pressure ↓ across the tube

ATC also compensates for this

↓ Expiratory resistance

↓ Unintentional hyperinflation
Automatic Tube Compensation

- Alternative weaning approach
- Half of patients who failed in a spontaneous trial on PS or T-p were successfully extubated after a trial with ATC
- Improved patient comfort as compared with that for pressure-support ventilation

Volume Support

Dual Control: Breath to Breath
Concept of Volume Support

- Closed-loop control of pressure-support ventilation
- Pressure-support ventilation that uses TV as a feedback control for continuously adjusting the pressure-support level
  - Patient-triggered
  - Pressure-limited
  - Flow-cycled
Operation

Test breath with Ppk 5 cm H2O to calculate system compliance

↓

Following 3 breaths delivered at a PIP of 75% of the pressure calculated to deliver the min TV

↓

Further breaths use the previous calculation of system compliance to manipulate peak pressure to achieve the desired TV
Operation

- Max pressure change is <3 cm H2O and can range from 0 cm H2O above PEEP to 5 cm H2O below the high-pressure alarm setting
- All breaths are pressure-support breaths
- VS will wean the patient from pressure support as patient effort increases and lung mechanics improve
Disadvantage of Volume Support

- No literature available
- If the pressure level increases in an attempt to maintain TV in the patient with airflow obstruction, PEEPi may result
- In cases of hyperpnea, as patient demand increases, ventilator support will decrease
Other New Modes
High Frequency Ventilation

- High-Frequency Percussive Ventilation
- High-Frequency Jet Ventilation
- **High-Frequency Oscillatory Ventilation**
  - Only as *salvage*: not enough evidence to conclude whether reduces mortality or long-term morbidity in patients with ALI or ARD

  *Wunch et al. Cochrane Systematic Review 2005*

- Pediatric
- Broncho-pleural fistula
Partial Liquid Ventilation

- There is no evidence from randomized controlled trials to support or refute the use of partial liquid ventilation in adults with ALI or ARDS

*Davies et al. Cochrane Systematic Review 2005*
Neurally Adjusted Ventilatory Assist

- Electrical activity of respiratory muscles used as input EAdi
- Cycling on, cycling off: determined by EAdi
- Amount of assistance for a given EAdi: user controlled gain factor
- Synchrony between neural & mechanical inspiratory time is guaranteed
- Patient comfort
Biologically Variable Ventilation

- Volume-targeted
- Controlled ventilation
- Aimed at improving oxygenation
- Incorporates the breath-to-breath variability that characterizes a natural breathing pattern
Summary

Conventional & New Modes
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Synonyms Causing Confusion: Dräger

- IPPV = VC (w AutoFlow OFF)
- IPPV=PRVC (w AutoFlow ON)
- BiPAP=SIMV-PC
- BiPAP/Assist: CMV-PC with an active exhalation valve
Thanks !