New Modes of Ventilation

Dr. Zia Hashim

Mode

- Describes the specific combination of:
  - control
  - phase
  - conditional variables
- Defined for
  - spontaneous
  - mandatory breaths

Variable

- **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

<u>Control</u>

- Flow
- Pressure

<u>Target</u>

- Time
- Pressure
- Volume

Volume control

Targeting

Control

- Flow
- Pressure

Target

- Time
- Pressure
- Volume

Time-cycled pressure control

Targeting

Control

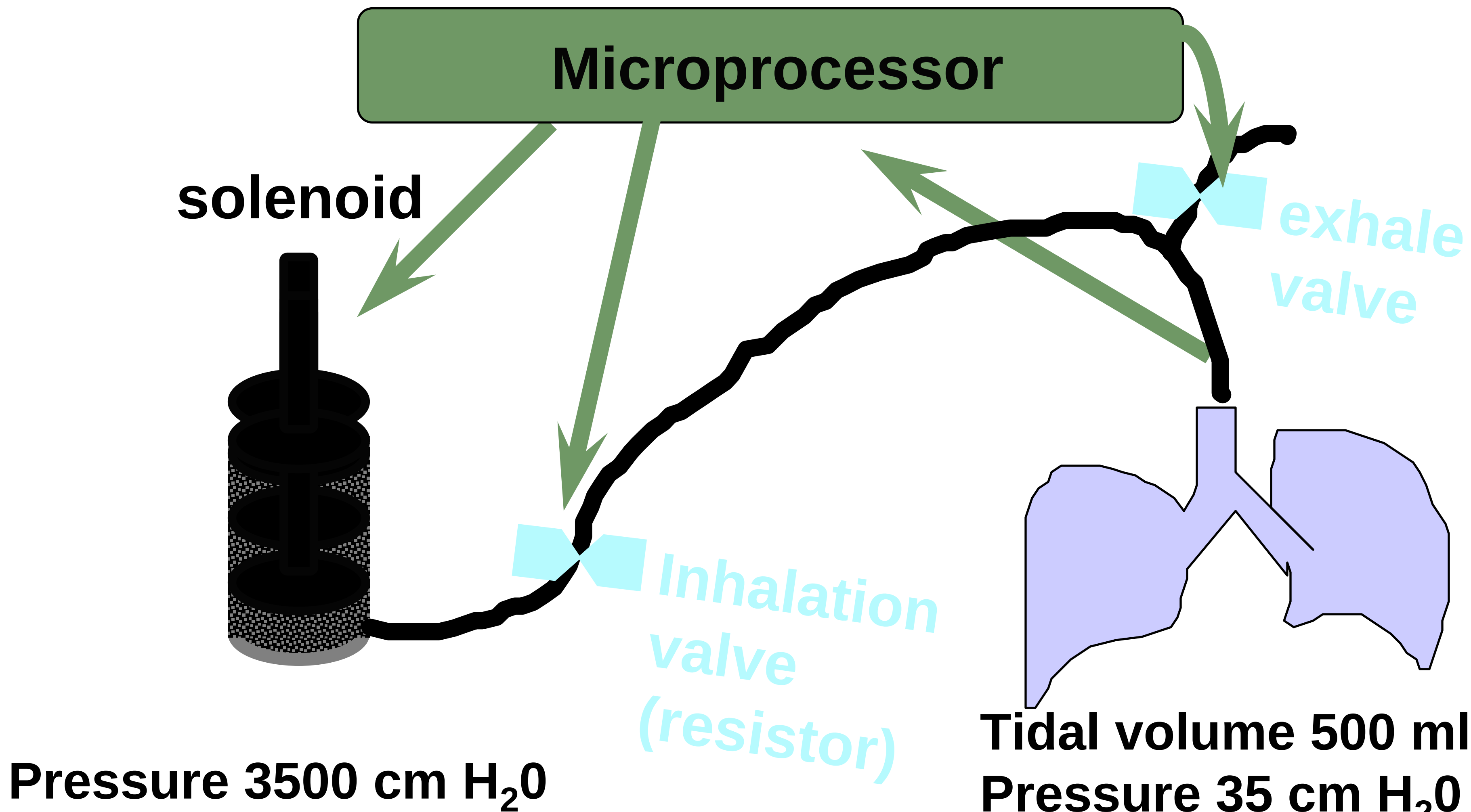
- Flow
- Pressure

Target

- Time
- Pressure
- Volume

Volume targeted pressure control

Microprocessor Control



Goals of Mechanical Ventilation

- Avoiding extension of lung injury,
- ↓O_2 toxicity
- Recruiting alveoli by ↑ mean Paw by ↑ PEEP and/or prolonging inspiration,
- ↓ 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 at. 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

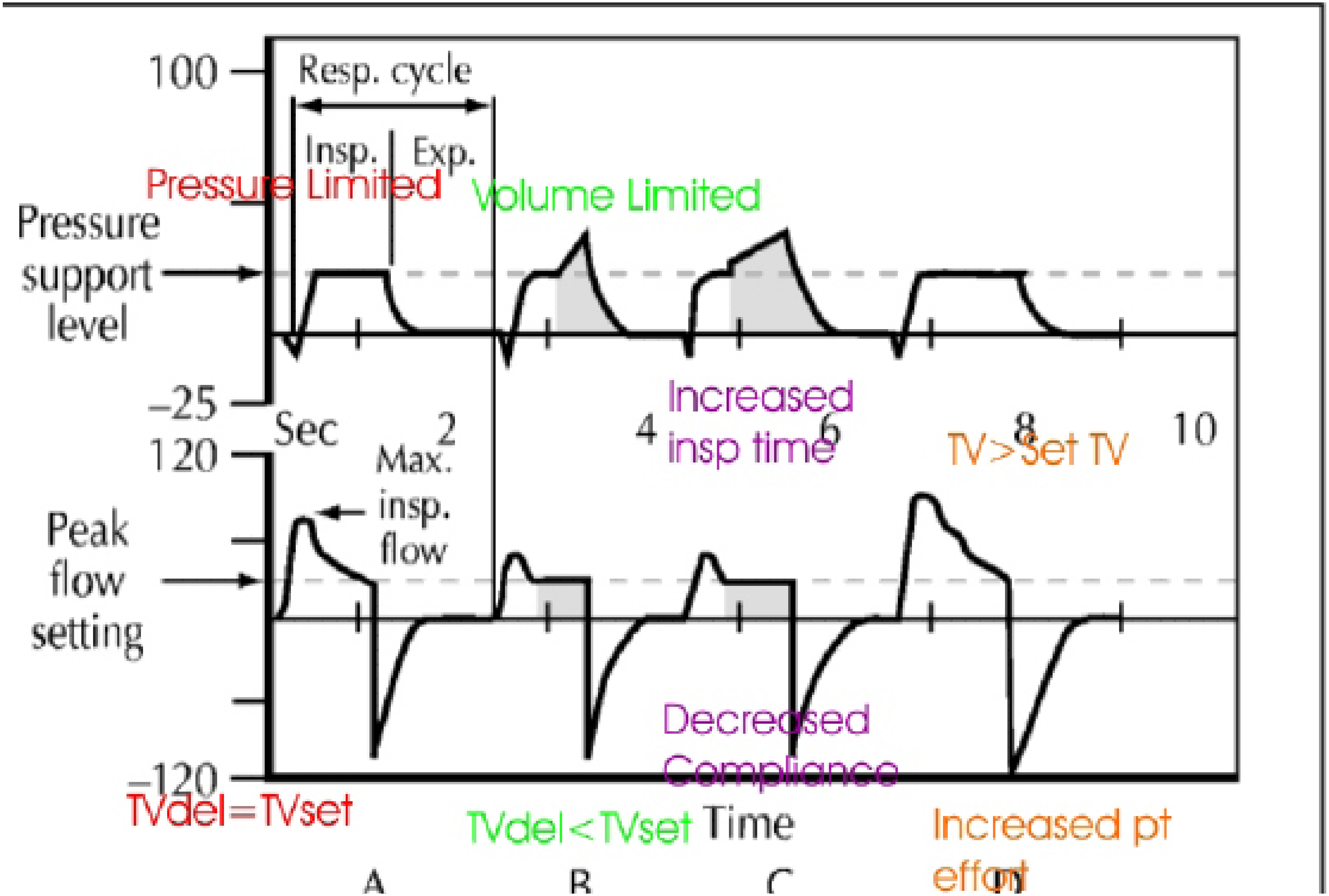
- Mandatory breaths or PS breaths
- Meant to combine the high variable flow of a pressure-limited breath with the constant volume delivery of a volume-limited breath
- During pressure support: VAPS is a safety net that always supplies a minimum TV

VAPS

- 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
- FiO_2
- Trigger sensitivity
- Minimum desired Vt
- **Pressure support setting** = plateau pressure obtained during a volume-controlled breath at the desired Vt



100
Resp. cycle
Insp.
Exp.
Pressure Limited
Volume Limited
Pressure support level
–25
Sec
2
4
6
8
10
Increased insp time
TV>Set TV
120
Max. insp. flow
Peak flow setting
Decreased Compliance
–120
TVdel=TVset
TVdel<TVset
Time
Increased pt effort
A
B
C
D

VAPS

If the delivered TV = set TV

↓

pressure-support breath

breath is **pressure-limited** at the pressure-support setting and is flow-cycled at 25% of the initial peak flow

VAPS

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 H_2O below pressure alarm limit
- FIO_2
- Inspiratory time or I:E ratio
- Rise time
- PEEP

PRVC

- The pressure limit will fluctuate between 0 cm H_2O above the PEEP level to 5 cm H_2O 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 → 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

PRVC

- 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

Piotrowski et al. Intensive Care Medicine 1997

PRVC Evidence

- 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

Alvarez et al. J Crit Care 1998

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

↓

↑Force to overcome the elastic recoil

↓

↑TV required

↓

↑WOB

Adaptive Support Ventilation: Principle

@ very high RR

↓

overcome the flow-resistance

↓

↑WOB

↓

Maintaining MV

Adaptive Support Ventilation (ASV)

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

$$RR = \frac{\sqrt{1 + 4\pi^2 RC \bullet (VA/VD) - 1}}{2\pi^2 RC}$$

ASV Input

- **Ideal body weight**: determines dead space
- **High-pressure alarm**: 5 cm H_2O above PEEP to 10 cm H_2O 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

↓

- 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

Anaethesia Analgesia. 2003 Dec

ASV Evidence

- 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×Elastance + Flow×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

PAV

- ARDS: Further studies are required
- Response to hypocapnia: In ACV ability to reduce VT is impaired, preserved during PAV

PAV Disadvantage

- 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

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_{high} level set at the MAP level from the previous mode (pressure control, volume control
- Starting off with APRV→start high (28cmH2O 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)

APRV Settings

- 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

Varpula et al. Acta Anasthesiol Scand 2003

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

APRV

- 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 it's output based on measured based on a measured input variable
- Spontaneous breaths: pressure control is used
- If anticipated V_E < set (based on MV of past 30 sec): Mandatory breaths which are VC, time triggered

MMV

- 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

ATC

- 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

ATC

- 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

Haberthur et al. Acta Anaesthiol Scand 2002

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 H_2O 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

Mode	Mand	Assist	Support	Spont	Condn Variable
VC-CMV	Tr: T, L:f Cy: V/T	✗	✗	✗	✗
VC-A/C	Tr: T, L:f Cy: V/T	Tr: Pt, L:f Cy: V/T	✗	✗	Pt effort/T
VC-IMV	Tr: T, L:f Cy: V/T	✗	✗	Tr: Pt, L:Pr, Cy:P/f	✗
VC-SIMV	Tr: T, L:f Cy: V/T	✗	✗	Tr: Pt, L:Pr, Cy:P/f	Pt effort/T

Mode	Mand	Assist	Support	Spont	Condn Variable
PC-CMV	Tr: T, L:Pr Cy: T	✗	✗	✗	✗
PC-A/C	Tr: T, L:Pr Cy: T	Tr: Pt, L:f Cy: V/T	✗	✗	Pt effort/T
PC-IMV	Tr: T, L:Pr Cy: T	✗	✗	Tr: Pt, L:Pr, Cy:P/f	✗
PC-SIMV	Tr: T, L:Pr Cy: T	✗	✗	Tr: Pt, L:Pr, Cy:P/f	Pt effort/T

Mode	Mand	Assist	Support	Spont	Condn Variable
PSV	✗	✗	Tr: Pt, L:Pr Cy: F	✗	✗
CPAP	✗	✗	✗	Tr: Pt, L:P Cy: P/F	Pt effort/T
APRV	Tr: T, L:Pr Cy: T	✗	✗	Tr: Pt, L:Pr, Cy:P/f	✗
VAPS	Tr: T, L:Pr/F Cy: F/V	Tr: P, L:Pr/F Cy: F/V	Tr: Pt, L:Pr Cy: F/V	✗	VTdel vs VTset

Mode	Mand	Assist	Support	Spont	Condn Variable
Volume Support	✗	✗	Tr: Pt, L:P Cy: P/F	✗	TV
PRVC	Tr: T, L:Pr Cy: T	Tr: Pt, L:P Cy: P/F	✗	Tr: Pt, L:P Cy: P/F	TV
ATC	✗	✗	✗	Tr: Pt, L:Pr, Cy:F	✗
ASV	Tr: T, L:Pr Cy: T	✗	Tr: Pt, L:Pr, Cy:F	✗	Pt effort impedenc changes

Synonyms Causing Confusion: Drager

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

Thanks！