Mechanical Ventilation Strategies

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Objectives

- Describe the differences in volume targeted and pressure targeted ventilation modes, as well as the benefits of modern spontaneous breathing modes

- Describe the pathophysiologic pulmonary changes in ARDS that limit the effectiveness of conventional mechanical ventilation and necessitate alternative ventilation strategy

- Describe the differences between lung protection and lung recruitment strategies
Volume Targeted (Control) Ventilation (VCV)

- Guaranteed tidal volume with each breath
- Set flowrate
- *Pressure varies* based on resistance and compliance of the lung and chest wall
Volume Targeted (Control) Ventilation (VCV)
Pressure Targeted (Control) Ventilation (PCV)

Fixed inspiratory pressure but

*Volume is variable*

- Inspiratory pressure & inspiratory time*
- Airway resistance
- Lung compliance

* Practitioner controlled
Pressure Control Ventilation (PCV)
Case

40 y.o. male, URD involved in an MVC

– One hour extrication time & hypovolemic shock

– Injuries
  » Multiple mesenteric bleeders
  » Ruptured spleen
  » Multiple liver lacerations

– Damage control laparotomy

– ICU for resuscitation
Case continued…

48 hours later…….

- Febrile
- HR 142
- Increasing oxygen requirement
  - P/F ratio: 80  (PaO₂ 80 on 1.0 FIO₂)
- Rising peak inspiratory pressures
Pathophysiology

- Alveolar injury/ permeability
- Changes in airway diameter/resistance
- Pulmonary vasoconstriction/ vascular injury
- Alterations in oxygen delivery, consumption and extraction
ARDS Continuum

Mild ARDS  Moderate ARDS  Severe ARDS

<table>
<thead>
<tr>
<th>PaO₂/FiO₂ Ratio</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
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<tbody>
<tr>
<td>Mild</td>
<td>200 – 300</td>
<td>100 - 200</td>
<td>&lt; 100</td>
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ARDS Definition

- Acute onset (within 7 days)
- Bilateral opacities (CXR or CT)
- Alveolar edema is not fully explained by cardiac failure or fluid overload
  - *Does not* require normal PCWP
  - *Does not* require absence of LA hypertension
Ventilator Induced Lung Injury (VILI)
“Volutrauma”

Caused by the over-expansion (over-distention) of alveoli from ventilation with volumes in excess of relative lung capacity

- Correlated with transalveolar pressure > 30 cmH2O
  (Static “plateau” pressures of > 30 cm H2O)
Zone of ↑ Risk
Spectrum of Regional Opening Pressures (Supine Position)

Superimposed Pressure

- **Inflated**
  - Opening Pressure: 0

- **Small Airway Collapse**
  - Opening Pressure: 10-20 cmH\(_2\)O

- **Alveolar Collapse (Reabsorption)**
  - Opening Pressure: 20-60 cmH\(_2\)O

- **Consolidation**
  - Opening Pressure: ∞

(from Gattinoni)

Lung Units at Risk for Tidal Opening & Closure
Ventilator Induced Lung Injury
**Collapsed Alveoli**

- End-tidal collapse/shearing force
- “Milking” of surfactant from alveoli with repeat closure
Inspiratory Hold: PIP and Plateau pressures (VC)
**PIP Elevated and Plateau Normal**

Proximal airway pressure

Peak Pressure

40 cm H_{2}O

Plateau

20 cm H_{2}O

Inspiratory Hold
Airway Pressures

- Peak Inspiratory Pressure High and Plat unchanged:
  (Greater than 10 cmH2O difference between)

  - Tracheal tube obstruction
  - Airway obstruction from secretions
  - Acute bronchospasm

- Rx: Suctioning and Bronchodilators
**PIP Elevated and Plateau Elevated**

Peak Pressure: 40 cmH₂O

Plateau: 36 cmH₂O

Proximal airway pressure

Inspiratory Hold
Airway Pressures

- Pip and Plat are both increased (less than 10 cm H₂O difference)
  - Pneumothorax
  - Lobar atelectasis
  - Acute pulmonary edema
  - Worsening pneumonia
  - ARDS
  - COPD with tachypnea and Auto-PEEP
  - Increased abdominal pressure (ACS)
  - Asynchronous breathing
Lung Protective Principles

- Maintain safe transalveolar pressures
  - Plateau pressure $< 30 \text{ cm H}_2\text{O}$

- Prevent end-tidal alveolar collapse
  - PEEP
**Tidal Volume**

**Conventional Volumes**
- 10 – 12 ml / kg predicted body weight (PBW)

**Low Tidal Volume (LTV)**
- 5 - 8 ml / kg predicted body weight (PBW)

**Ideal Body Weight Calculation**
- Male PBW in lb: 106 + [6 x (height in inches – 60)]
- Female PBW in lb: 105 + [5 x (height in inches – 60)]
Comparison of “traditional” tidal volume (12 ml/kg) versus “low” tidal volume (6 ml/kg)

861 patients at 30 centers

Low Tidal Volumes (432)
- 25-30 cmH2O plateau

Traditional Tidal Volumes (429)
- 45-50 cmH2O plateau

ARDSNET (2000). Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome. NEJM, 342(8), 1301-1308.
Acute Respiratory Distress Syndrome Network ARDSNET

Low tidal Volume Ventilation

- Lower mortality
- Lower levels of IL-6 (lung inflammation)
- Higher number of days without organ or system failure

ARDSNET (2000). Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome. NEJM, 342(8), 1301-1308.
Improving Oxygenation

- Manipulation of FiO$_2$
- Manipulation of Mean Airway Pressure (Paw)
Mean Airway Pressure (Paw)

Definition: the MAP is the area under the curve during inspiration and expiration divided by the duration of the cycle.

\[
\text{MAP} = \frac{\text{area under the pressure curve}}{\text{duration of the cycle}}
\]

Adapted from Pilbeam, 2006
Increase Mean Airway Pressure

- PEEP
- I:E Ratio Manipulation
  - Inverse Ratio Ventilation (IRV)
  - Respiratory Rate
- Inspiratory Pause
- Square Waveform
Positive End Expiratory Pressure (PEEP)

- Maintains the alveoli open at the end of the breath
- Reduces shear force injury to alveoli
- Displacement of lung H₂O
Pulmonary Pitfalls of PEEP

- Overdistension of normal alveoli
- Shunt
- Alveolar Injury
- Deadspace
Cardiovascular Pitfalls of PEEP

1. Increased Intra-thoracic Pressure
   - Venous Return (RV filling)
   - False Elevations of CVP-PAP-PCOP
2. RV Afterload
   - Cardiac Output
Lung Protection is Not Enough
Alveolar Recruitment Strategies

- Recruitment Maneuvers (episodic)
- Pressure Control Ventilation
- Manipulation of I: E ratio
- Airway Pressure Release Ventilation (APRV)
- High Frequency Oscillation Ventilation (HFOV)
Recruitment

- **OPEN**
  - Overcome the Trans-alveolar Opening Pressure

- **MAINTAIN**
  - Positive End Expiratory Pressure
High pressures may be needed to open some lung units, but once open, many units stay open at lower pressure.
Recruitment Maneuver
Patient Selection

- Early ALI/ARDS (<72 hrs) vs. Late ARDs
- Intra-pulmonary vs. Extra-pulmonary lung injury
- Hemodynamic stability
- Absence of Contraindications
Recruitment Strategies

- Intermittent Recruitment Maneuver
- Pressure Control Ventilation/PEEP
Intermittent Recruitment Maneuver

Brief application of high inspiratory pressures to recruit collapsed alveoli

- Inspiratory pressure application
  - CPAP 40- 50 cm H$_2$O for 30 - 40 seconds

- Optimal PEEP application to prevent collapse

- Repeat maneuver after a ventilator disconnect
Recruitment
**Decremental PEEP Trial**

- PEEP set at 20-25 cm H$_2$O
- PEEP decreased 2 cmH$_2$O every 5-20 min
  - Monitoring oxygenation
  - Compliance

- Until Optimal PEEP is achieved
  - the lowest PEEP associated with the best compliance/oxygenation

- Recruitment maneuver repeated
- PEEP set 2 cm H$_2$O above the Optimal PEEP
Decremental PEEP Trial with PCV
Recruitment Maneuver Contraindications

- Pulmonary blebs, bullae, existing barotrauma
- Hemodynamic instability
  - Hypovolemia
  - Impaired RV function
- Increased intracranial pressure (relative)
Pressure Control Ventilation (PCV)

An inspiratory pressure limit, rather than a tidal volume is set by the practitioner.

- Inspiratory pressure & inspiratory time*
- Airway resistance
- Lung compliance

* Practitioner controlled
Pressure Control Ventilation (PCV)
PCV Waveform Advantages

- Controlled, constant inspiratory pressure
- Better distribution of tidal volume to collapsed alveoli
- Optimal increase in $P_{aw}$

![Diagram showing pressure over time with controlled, constant inspiratory pressure and optimal increase in $P_{aw}$]
Volume Control vs. Pressure Control Waveform

PIP

Paw

Paw

50
25
5
0
Collateral Ventilation Channels

Channels of Martin (Inter Bronchial)

Lambert’s Canals (Bronchiole Alveolar)

Pores of Kohn (Intra Alveolar)
Pressure Control Inverse Ratio (PCIRV)
Auto-PEEP

Pressure

Time

I-Time

E-Time

I-Time

Auto-PEEP

Set PEEP
PCV

PC-IRV

Actual PEEP

Auto PEEP Measurement

Exp. Flow 50 - 80% of Peak
Volume Assured Pressure Modes

Pressure Limited + Minimum Volume Guarantee

- aka...
  - Adaptive Pressure Control Modes
  - “Dual Control” Modes

Machine adjusts to changing lung mechanics to provide tidal volume within pressure limit
Volume Assured Pressure Modes

Also known as……

- Adaptive Pressure Control Modes
- “Dual Control” Modes
Pressure Regulated Volume Control

[Diagram showing pressure and flow with labeled sections]

Pressure

Flow
Volume Support

VS adjusts pressure level to maintain selected volume

This is a spontaneous mode
Pressure Augmentation

Pressure Augmentation starts as a pressure breath but ends as a volume breath if volume not reached

Spontaneous and control options available

- Tidal volume (Vt)
- Sensitivity
- FiO₂
- PEEP

Control mode
- Rate (fₙ)
- Inspiratory time (Tᵢ)
Volume Assured Pressure Modes

- Pressure Regulated Volume Control (PRVC)
  - Volume Support
- Volume Control Plus (VC+)
  - Volume Support
- Pressure Control Volume Guarantee (PCVG)
- Volume Targeted Pressure Control (VTPC)
- Adaptive Pressure Ventilation
  - Adaptive Support Ventilation
- Pressure Augmentation
Control Mode Settings

- Rate (fx)
- Inspiratory time (Ti)
- FiO₂
- PEEP

Support Mode Settings

- Target tidal volume
- FiO₂
- PEEP
Points to Remember

- Guaranteed minimum tidal volume but not a constant tidal volume!!

- Tidal volume may not be achieved if lung compliance becomes low or pressure limit is set too low

- Excessive tidal volume if the patient generates excessive inspiratory efforts
Pressure Control
Spontaneous Breathing Modes

Provides ventilatory support while allowing the patient to perform some work of breathing
Benefits of Spontaneous Breathing

- Improved ventilation/perfusion matching
- Lower airway pressures
- Reduced hemodynamic side effects
- Improved organ perfusion
- Less need for sedation/neuromuscular blockade
- New pressure modes have exhalation valves and other technology that allow for patient interaction throughout the respiratory cycle.
Diaphragm Excursion

Awake
spontaneous

Anesthetized
spontaneous

Paralyzed

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Diaphragm Excursion

Awake
spontaneous

Anesthetized
spontaneous

Paralyzed
Active Exhalation Valve

PCV W/O Active Valve

PCV with Active Valve

Spontaneous Efforts

- $P_{CIRC}$ (cmH$_2$O)
- INSP
- $V$ (L/min)
- EXP

Spontaneous Efforts
Pressure Support (PSV)

- A mode of ventilation that augments or supports a \textit{spontaneous} inspiration with a clinician-selected pressure level

- Patient selection
  - stable?
  - reliable ventilatory drive
  - ready to wean
Bi-Level/Bi-Phasic Ventilation

- **Bi-level**: is similar to pressure controlled ventilation, during which unrestricted spontaneous breathing is possible in each phase of the respiratory cycle.

- **APRV**: allows spontaneous breathing on a preset CPAP level and which is interrupted by a short (<1s) release for expiration.
**Biphasic Ventilation**

- Inspiratory Pressure Limit ($\text{PEEP}_{\text{HI}}$)
- PEEP ($\text{PEEP}_{\text{LOW}}$)
- Inspiratory time ($T_i$)
- Rate ($f_x$)
- Pressure Support

- Biphasic
- Bi-level
- Bi-Vent
- BIPAP
- Duo PAP
APRV Characteristics

- High CPAP level with a short expiratory releases at set intervals (rate).
- APRV always implies an inverse I:E ratio
- All spontaneous breathing is done at upper pressure level
Spontaneous Breaths

**APRV**

- * Spontaneous Breaths
- † Synchronized Transition

**BiPhasic**

- Spontaneous Breaths
Airway Pressure Release Ventilation Waveform

(P$_{hi}$): 25 cm H$_2$O

(T$_{hi}$): 6 seconds

(P$_{lo}$): 0 cm H$_2$O

(T$_{lo}$): 0.8 seconds
Initiating APRV

- **Pressure High** (*PEEP*$_{hi}$): set at the level of the measured plateau pressure
  - 20-30 cmH$_2$O

- **Time High**: 4 seconds increasing to 15 seconds

- **Pressure Low** (*PEEP*$_{low}$)
  - 0 cmH$_2$O

- **Time Low**: 0.5 - 1.0 seconds (0.8 average)
Alveolar Volumetric Changes

Conventional

APRV

Insp.

Exp.

Insp. ≈ Exp.
Managing Oxygenation
APRV - Principle of Operation

PCV

APRV

Actual PEEP

AutoPEEP Measurement

P

F

Exp. Flow
50 - 80% of Peak
APRV Pressure and CO$_2$ Adjustments

Increase the number of releases

0.8 sec
Weaning APRV

“Drop and Stretch”
Bi-level/APRV Considerations

- Tidal volume changes with lung compliance
- Over-sedation/NMB may reduce minute ventilation
- Caution in patients requiring longer expiratory time (COPD, Asthma)
- Elevated ICP in TBI
  - Hypercapnea/ Cerebral venous congestion
General Considerations

- Avoid disconnection of the circuit
- Closed system suctioning
- Transport on the ventilator
High Frequency Ventilation

- Jet Ventilation
  - Up to 600 bpm

- Oscillation
  - 300 to 3000 bpm

- Small tidal volumes

- Combined applied and intrinsic (Auto-PEEP) to recruit alveoli
3100B Oscillator
Oscillator
Alveolar Volumetric Changes During HFO

Conventional

HFOV

Insp.  Exp.

Insp. ∼Exp.
Volumetric Diffusive Respiration (VDR)
VDR Waveform

Images courtesy of Percussionaire Corporation
Summary Points

- Protect the lung and support oxygenation/ventilation
- Recruit the lung
- Know the mode you select!
Bibliography


Thank You

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