Mechanical Ventilation

Understanding Modes

Rob Chatburn, RRT-NPS, FAARC
Research Manager – Respiratory Therapy
Cleveland Clinic
Associate Professor
Case Western Reserve University
Overview

• Characteristics of modes
  – Pressure control vs volume control
  – Graphical representations of modes

• Breath types
  – Mandatory vs spontaneous
  – Assisted vs unassisted

• Breathing patterns
  – Definitions, indications, examples
  – Graphical representations

• Computer control of mechanical ventilation
Characteristics of a Mode

1. Breathing Pattern
   – Control variable
   – Breath sequence

2. Control Type
   – Setpoint, auto-setpoint, servo, adaptive, optimal

3. Control Strategy
   – Phase variables
   – Operational logic
Control Variables

\[ P_{\text{vent}} = E \times V + R \times \dot{V} \]

Ventilator can control only one variable at a time

*Independent variable is control variable*
Volume Control

• Tidal volume and flow preset
• Airway pressure changes with lung mechanics
• Advantage:
  – Minute ventilation and gas exchange stable
• Disadvantage:
  – Volume and flow may not be optimal
Pressure Control

- Airway pressure preset
- Volume and flow change with lung mechanics

**Advantage:**
- Better patient flow synchrony
- Possibly better oxygenation
- Potentially reduced risk of volutrauma

**Disadvantage:**
- Gas exchange may not be stable
Volume Control Influence Diagram
Pressure Control Influence Diagram
**Volume/Flow Control**

- **Pressure**
  - Inspiration: Steep rise
  - Expiration: Constant level
  - **Paw**

- **Volume**
  - Inspiration: Steep rise
  - Expiration: Steep decline
  - **Plung**

- **Flow**
  - Inspiration: Steep rise
  - Expiration: Steep decline
  - **Time (s)**

**Pressure Control**

- **Inspiration**
- **Expiration**
  - Steep rise
  - Steep decline
  - Constant level
  - **Paw**

- **Time (s)**
Dual Control

• **Volume control to Pressure Control:**
  – Attempts to deliver a constant tidal volume while limiting peak pressure

• **Pressure control to Volume Control:**
  – Attempts to limit peak pressure but assures tidal volume delivery

• **Disadvantage:**
  – Requires high degree of understanding
  – Difficult to adjust and maintain
Characteristics of a Mode

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   – Phase variables
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Breath Types

What is the difference between mandatory and spontaneous breaths?
Breath Types

Mandatory

Think

Patient controls start 

yes

no

Spontaneous

Patient controls size

yes

no

Think controls start
Definition of Assisted Breath

• Assisted
  – Ventilator does work on patient.

• Un-Assisted
  – Ventilator does no work on patient.

• Loaded (work imposed on patient)
  – Patient does work on ventilator.
Identification of Assisted Breaths

• **Assisted**
  – Airway pressure rises above baseline during inspiration (or falls below baseline during expiration).

• **Un-Assisted**
  – Airway pressure stays constant during inspiration or expiration.

• **Loaded (work imposed on patient)**
  – Airway pressure falls below baseline during inspiration and rises above baseline during expiration.
Assisted Spontaneous Breaths

- Pressure Support
- Volume Support
- Automatic Tube Compensation
- Proportional Assist Ventilation
- SmartCare
Potential Confusion

• An assisted breath may be spontaneous or mandatory
• A spontaneous breath may be assisted or unassisted
• A mandatory breath is assisted by definition
Characteristics of a Mode

1. Breathing Pattern
   – Control variable
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3. Control Strategy
   – Phase variables
   – Operational logic
Continuous Mandatory Ventilation (CMV)

• Mandatory breaths
  – Machine triggered and/or machine cycled

• Spontaneous breaths
  – *During* mandatory breaths only, not *between*

• Key clinical concept
  – Level of support independent of frequency (if patient is breathing)
Intermittent Mandatory Ventilation (IMV)

- **Mandatory breaths**
  - Machine triggered and/or machine cycled

- **Spontaneous breaths**
  - *Between* and *during* mandatory breaths

- **Key clinical concept**
  - Level of support is proportional to set frequency (if spontaneous breaths unassisted)
  - Historically used as a mode of weaning
Continuous Spontaneous Ventilation (CSV)

• All breaths spontaneous
  – Patient triggered and cycled
  – No backup rate in case of apnea

• Breaths may or may not be assisted
  – Full support may be achieved (if no apnea)
Characteristics of a Mode

1. Breathing Pattern
   - Control variable
   - Breath sequence

2. Control Type
   - Setpoint, auto-setpoint, servo, adaptive, optimal

3. Control Strategy
   - Phase variables
   - Operational logic
## 8 Basic Breathing Patterns

<table>
<thead>
<tr>
<th>Control Variable</th>
<th>Breath Sequence</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Volume</strong></td>
<td>Continuous Mandatory Ventilation</td>
<td>VC-CMV</td>
</tr>
<tr>
<td></td>
<td>Intermittent Mandatory Ventilation</td>
<td>VC-IMV</td>
</tr>
<tr>
<td><strong>Pressure</strong></td>
<td>Continuous Mandatory Ventilation</td>
<td>PC-CMV</td>
</tr>
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<tr>
<td></td>
<td>Continuous Spontaneous Ventilation</td>
<td>PC-CSV</td>
</tr>
<tr>
<td><strong>Dual</strong></td>
<td>Continuous Mandatory Ventilation</td>
<td>DC-CMV</td>
</tr>
<tr>
<td></td>
<td>Intermittent Mandatory Ventilation</td>
<td>DC-IMV</td>
</tr>
<tr>
<td></td>
<td>Continuous Spontaneous Ventilation</td>
<td>DC-CSV</td>
</tr>
</tbody>
</table>
VC-CMV

• Often referred to as “Assist/Control”

• Characteristics
  – VC results in more even distribution of ventilation among lung units with equal resistance and unequal compliance than PC
  – Selection of flow and sensitivity is critical

• Indications
  – Need for total ventilatory support
  – Need for precise regulation of blood gases

• Example
  – Precise regulation of PaCO₂ in patients with traumatic brain injury
VC-CMV waveforms

- **A**: no inspiratory effort
- **B**: small inspiratory effort
- **C**: large inspiratory effort

- Muscle Pressure
- Ventilator Pressure
  - machine triggered
  - patient triggered
  - reduced pressure indicates patient effort throughout inspiration
  - set tidal volume

- Volume
- Flow
  - set flow
  - set tidal volume
VC-IMV

- **Characteristics**
  - Spontaneous breaths may be assisted
  - Selection of mandatory flow and spontaneous pressure support critical

- **Indications**
  - Relatively normal lung function
  - Rapid recovery from sedation or respiratory failure
  - Recent data suggest it is worst choice for weaning

- **Example**
  - Treatment of neuromuscular disease like Gullian-Barre syndrome
VC-IMV waveforms

Are spontaneous breaths assisted?
PC-CMV

• Characteristics
  – PC results in more even distribution of ventilation among lung units with equal compliance and unequal resistance than VC
  – Pressure control results in higher mean airway pressure and earlier lung opening than VC

• Indications
  – Problems with oxygenation or synchrony

• Example
  – Treatment of ARDS patients with oxygenation problems
PC-CMV waveforms

A
no inspiratory effort

B
small inspiratory effort

C
large inspiratory effort

set pressure limit

patient triggered
time cycled

machine triggered
PC-IMV

- **Characteristics**
  - Relatively simple mode
  - Used historically for infants
  - Spontaneous breaths may be assisted

- **Indications**
  - Problems with oxygenation or synchrony
  - Adequate ventilatory drive

- **Example**
  - Treatment of premature infants with RDS
PC-IMV waveforms

A
no inspiratory effort

B
medium inspiratory effort

C
large inspiratory effort
PC-CSV

• **Characteristics**
  – No assist = CPAP
  – Assist
    ▫ Pressure Support
    ▫ Proportional Assist
    ▫ Automatic Tube Compensation

• **Indications**
  – Weaning
  – Reduce work of breathing or stabilize oxygenation

• **Examples**
  – Nasal CPAP for neonates recovering from RDS
  – Noninvasive ventilation of adults
Spontaneous breaths are not assisted (CPAP)
DC-CMV

• **Characteristics**
  – Mandatory breaths adapt to changing lung mechanics

• **Indications**
  – Unstable lung mechanics or ventilatory drive

• **Example**
  – Treatment of patient with pneumonia and intermittent secretion problems
DC-CMV waveforms

**Pressure-to-volume**

*Bird VAPS*
DC-CMV waveforms

volume-to-pressure
Dräger
Pressure Limited Ventilation
DC-IMV waveforms

- Muscle Pressure
- Ventilator Pressure
- Volume
- Flow

Graphs showing waveforms with annotations:
- Set Pmax
- Plateau pressure
- Set tidal volume
- Time cycled
- Set flow
Pressure Support

- Pressure or flow triggered, pressure limited, inspiratory flow cycled
- Level of ventilatory support determined by pressure limit
- Sometimes set to approximately support resistive work of breathing (through endotracheal tube)
PC-CSV waveforms

Spontaneous breaths are assisted
Proportional Assist

\[ P_{\text{mus}} = E_{\text{normal}} \times \text{volume} + R_{\text{normal}} \times \text{flow} \]

\[ P_{\text{mus}} = (E_{\text{normal}} + E_{\text{abnormal}}) \times \text{volume} + (R_{\text{normal}} + R_{\text{abnormal}}) \times \text{flow} \]

\[ P_{\text{mus}} = (\text{normal load}) + (\text{abnormal load}) \]

\[ P_{\text{mus}} + P_{\text{vent}} = (\text{normal load}) + (\text{abnormal load}) \]

\[ P_{\text{vent}} = \text{abnormal load} = E_{\text{abnormal}} \times \text{volume} + R_{\text{abnormal}} \times \text{flow} \]

operator settings (volume and flow amplification factors)
PC-CSW waveforms

Spontaneous breaths are assisted (Proportional Assist)
Automatic Tube Compensation

\[ P_{vent} = \text{abnormal resistive load} = R_{tube} \times \text{flow}^2 \]

operator sets tube diameter
ventilator calculates resistance factor
Characteristics of a Mode

1. **Breathing Pattern**
   - Control variable
   - Breath sequence

2. **Control Type**
   - Within breaths
   - Between breaths

3. **Specific Control Strategy**
   - Phase variables
   - Operational logic
Evolution of Ventilator Control Types

Tactical Control (within-breaths)
- setpoint (PC-IMV)
- auto-setpoint (Pmax)
- servo (Automatic Tube Compensation)
  operator-selected, static setpoints

Strategic Control (between breaths)
- adaptive (CMV+AutoFlow)
- optimal (ASV)
  ventilator-selected, dynamic setpoints
  static model

Intelligent Control (between patients)
- knowledge based
- artificial neural network
  ventilator-selected, dynamic setpoints
  dynamic model
  ability to learn from experience
Tactical Control

• All the modes discussed so far
• All require the operator to set
  – Pressure (PIP, PEEP)
  – Volume (tidal volume, minute ventilation)
  – Flow (peak inspiratory flow)
  – Time (inspiratory time, frequency, I:E)
Strategic Control

• **Characteristics**
  – Breathing pattern may be PC-CMV, PC-IMV, PC-CSV
  – Pressure limit automatically adjusted to compensate for changes in compliance to meet target tidal volume

• **Indications**
  – (Self) Weaning
  – Reduce work of breathing or stabilize oxygenation
  – Reduce clinician workload

• **Examples**
  – Post-operative patients with normal lungs
  – Mixed ICU patients
  – COPD exacerbation
Adaptive Control

- **A**: No inspiratory effort
- **B**: Large inspiratory effort
- **C**: Pressure limit automatically reduced

- **Volume**: Volume target
- **volume overshoot**

- **Flow**: Machine triggered, patient triggered
- **time cycled**
Hamilton Galileo Adaptive Support Mode

- **Optimum control**
- **Clinician enters**
  - Patient ideal body weight
  - Percent of predicted minute ventilation to support
- **Ventilator monitors**
  - minute ventilation
  - lung mechanics (expiratory time constant)
- **Automatically adjusts minute ventilation**
  - mandatory breath frequency
  - pressure limit
  - inspiratory time
- **Sets frequency to minimize WOB as if patient was breathing spontaneously**
“Any medical instrumentation that requires constant input from a human operator is obsolete”

Hamilton Medical
Intelligent Control

• **Characteristics**
  – Classification of patient condition
    ▫ Manual (eg, by diagnosis)
    ▫ Fuzzy logic
  – Rule based expert system or artificial neural network

• **Indications**
  – Weaning
  – Respiratory failure of various types
  – Trauma

• **Examples**
  – Post-operative patients with normal lungs
  – Mixed ICU patients
  – Emergency department
**Commercial Example**

- **SmartCare (Dräger Evita XL)**
  - Knowledge Based Control
    1. Automatically adjust pressure support: breathing rate, tidal volume and end tidal CO$_2$.
    2. Automatically test patient tolerance of a lower pressure support level without leaving the comfort zone.
    3. Attempts “extubation” with PS at resistive WOB.

- **Artificial intelligence**
  - Fuzzy logic interprets patient condition
  - Rule based expert system treats condition

- **Operator sets**
  - patient weight
  - history (neuro or COPD)
  - type of airway
Characteristics of a Mode

1. Breathing Pattern
   – Control variable
   – Breath sequence

2. Control Type
   – Setpoint, auto-setpoint, servo, adaptive, optimal knowledge based

3. Specific Control Strategy
   – Phase variables
   – Operational logic
Mode Description Utility

• Describe the difference in modes
  – Pressure Support
  – Volume Support

• Describe the difference in ventilators
  – Pressure support (PB7200)
  – Pressure support (Servo-i)
Mode Description Summary (without the brand jargon)

• **Pressure Support**
  – Only Level 1 needed
    ▪ PC-CSV

• **Volume Support**
  – Requires Level 2
    ▪ PC-CSV with adaptive control
Adaptive Pressure Control

- Pressure Regulated Volume Control
- AutoFlow
- VC+
- PC-SIMV + Volume Guarantee
Mode Description Summary
(without the brand jargon)

- **Level 3 Pressure Support**
- **PB 7200**
  - Cannot adjust rise time (limit variable)
  - Cannot adjust cycle threshold (cycle variable)
- **Servo-i**
  - Adjustable rise time (limit variable)
  - Adjustable cycle threshold (cycle variable)
Resources

• Get the book
  – college level textbook
  – 300 pages
  – www.aarc.org/store
    □ Training Software
  – www.Amazon.com
Too Complicated?
Final Thought

“If you explain something so simply that even a fool can understand it, then only a fool will understand it.”

FP Primiano Jr