Mechanical Ventilation

Understanding Modes

Rob Chatburn, RRT-NPS, FAARC

Research Manager – Respiratory Therapy

Cleveland Clinic

Associate Professor

Case Western Reserve University

Overview

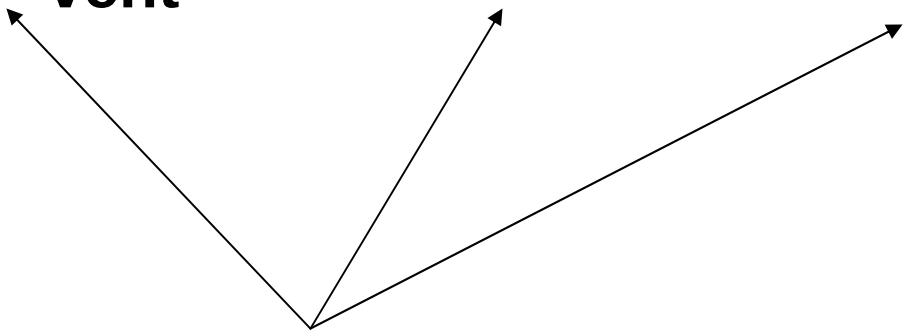
- **Characteristics of modes**
  - Pressure control vs volume control
  - Graphical representations of modes
- **Breath types**
  - Mandatory vs spontanous
  - Assisted vs unassisted
- **Breathing patterns**
  - Definitions, indications, examples
  - Graphical representations
- **Computer control of 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

$$P_{vent} = E \times V + R \times \dot{V}$$



Ventilator can control only one variable at a time

Independent variable is control variable

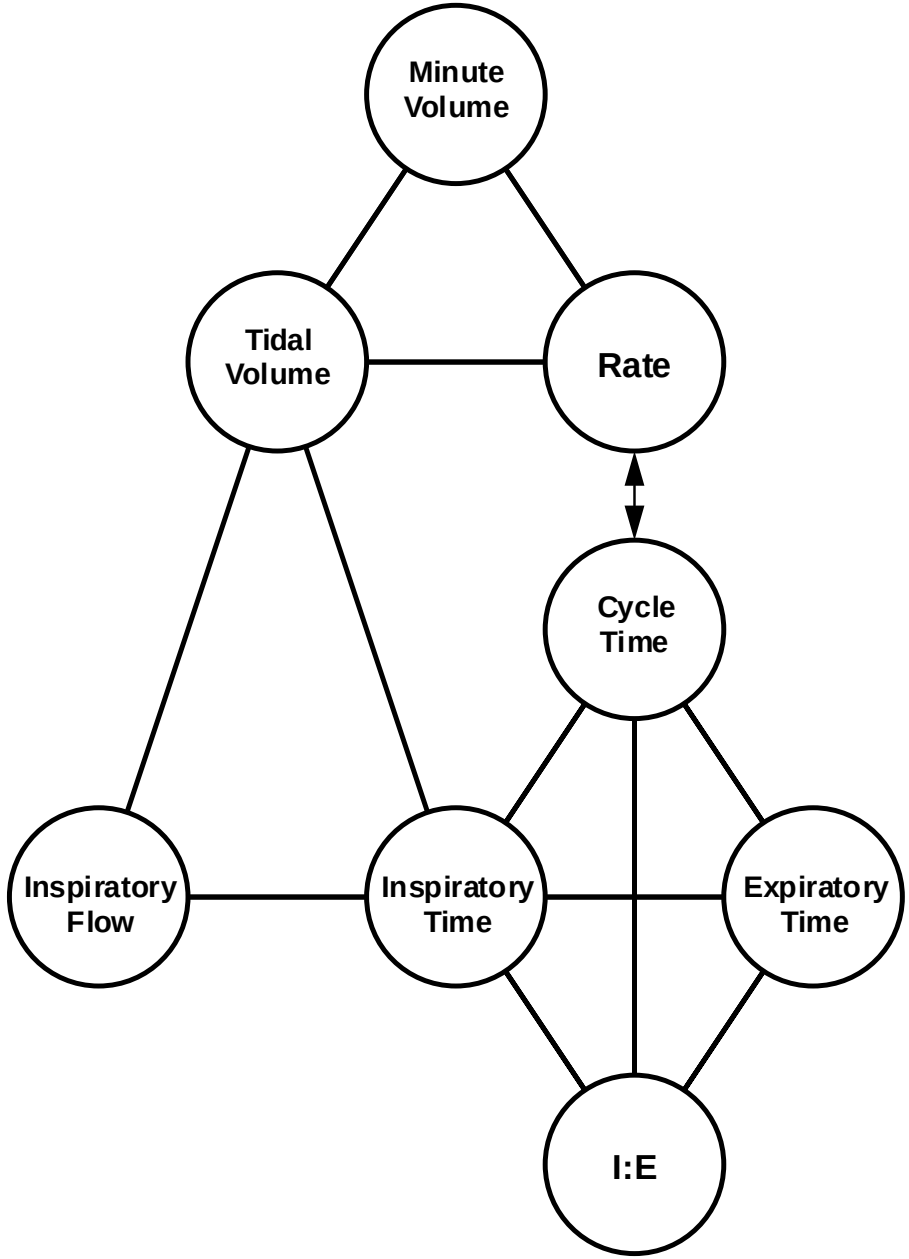
Volume Control

- **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

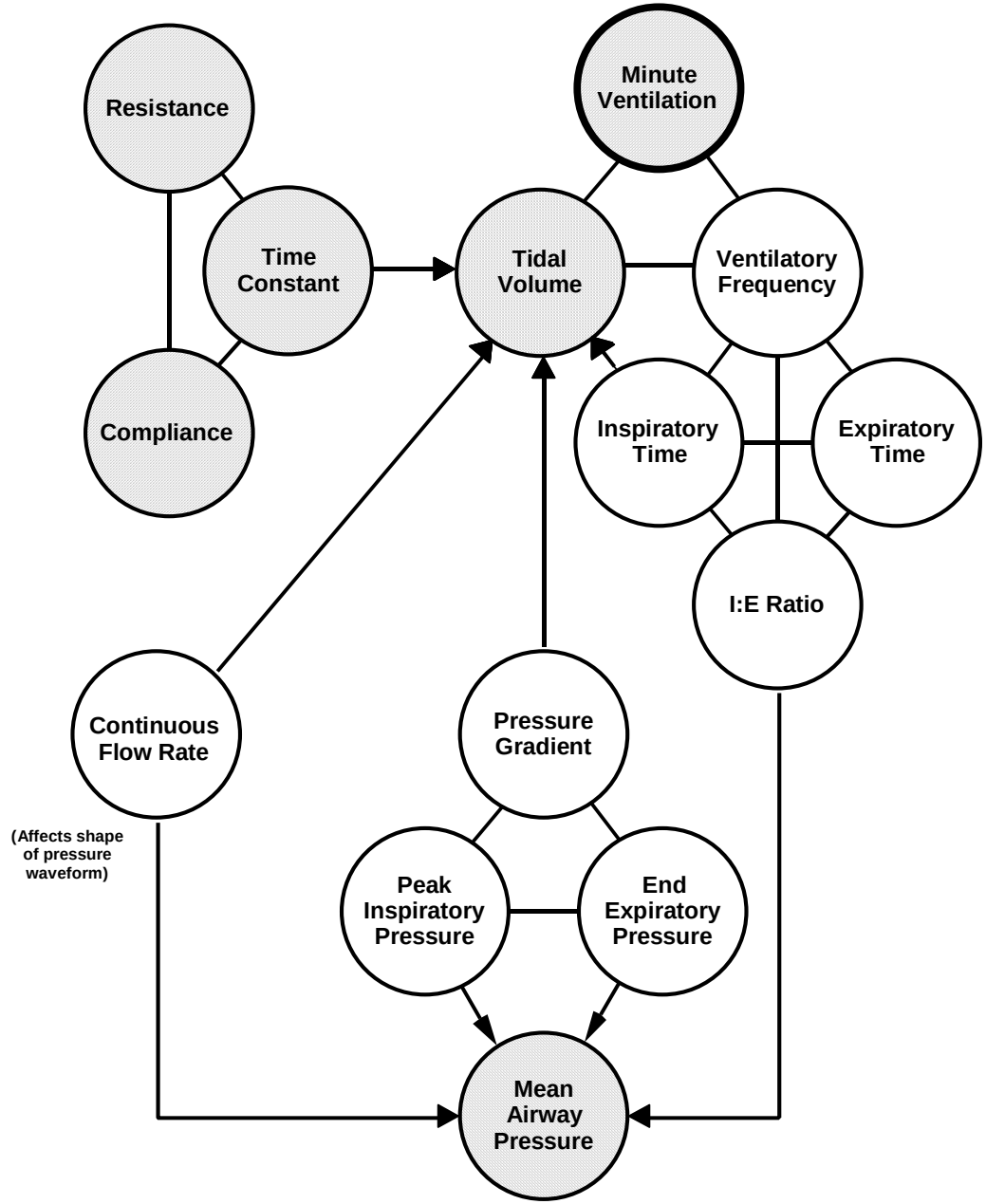
Pressure Control

- **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

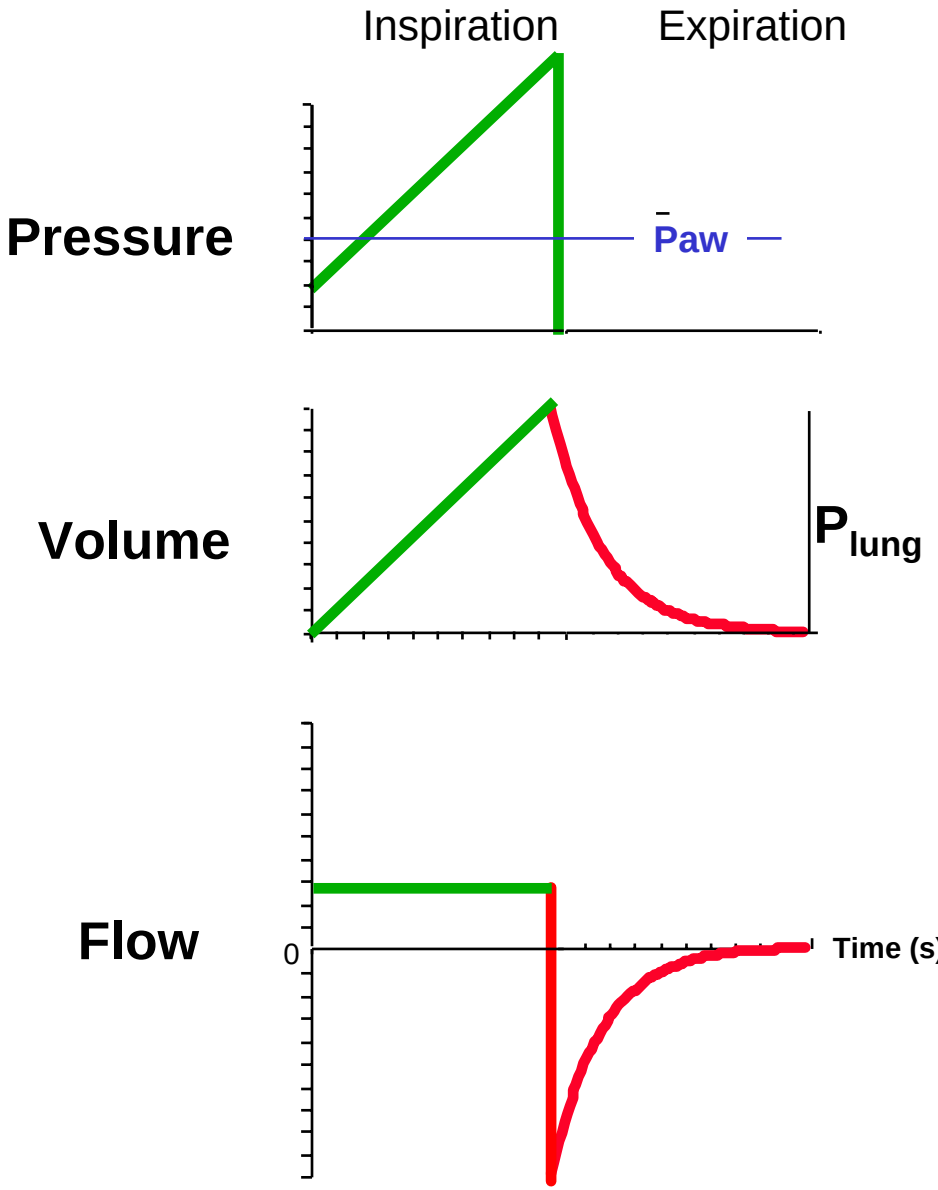
Volume Control Influence Diagram



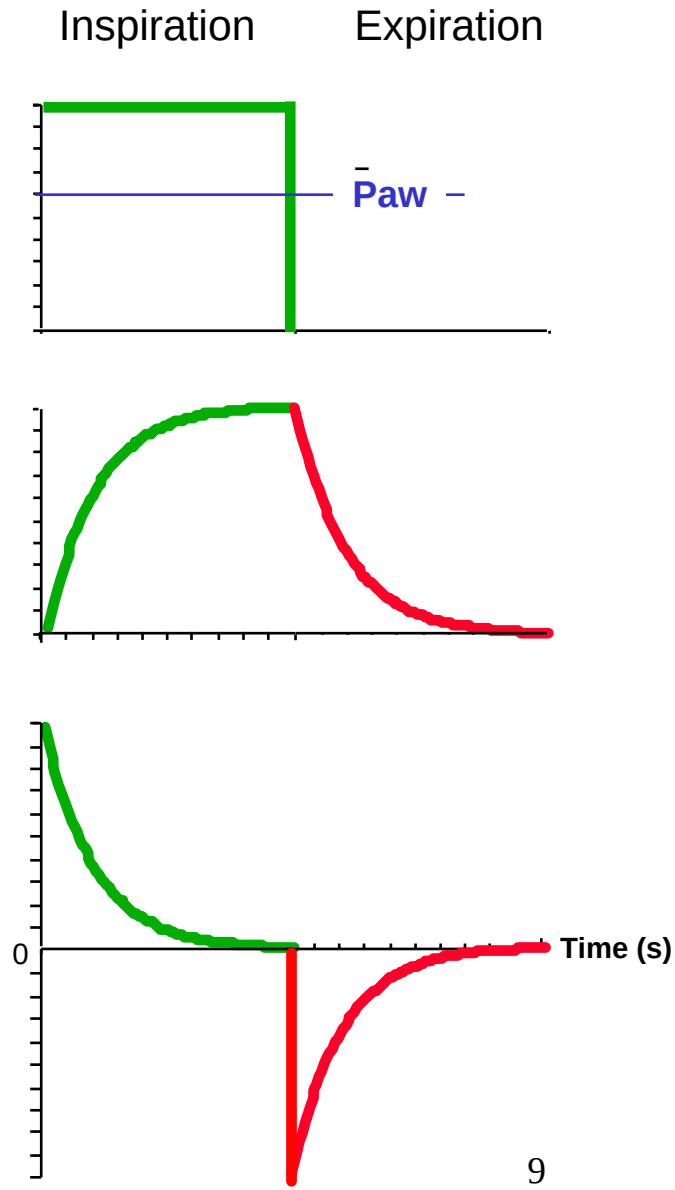
Pressure Control Influence Diagram



Volume/Flow Control



Pressure Control



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

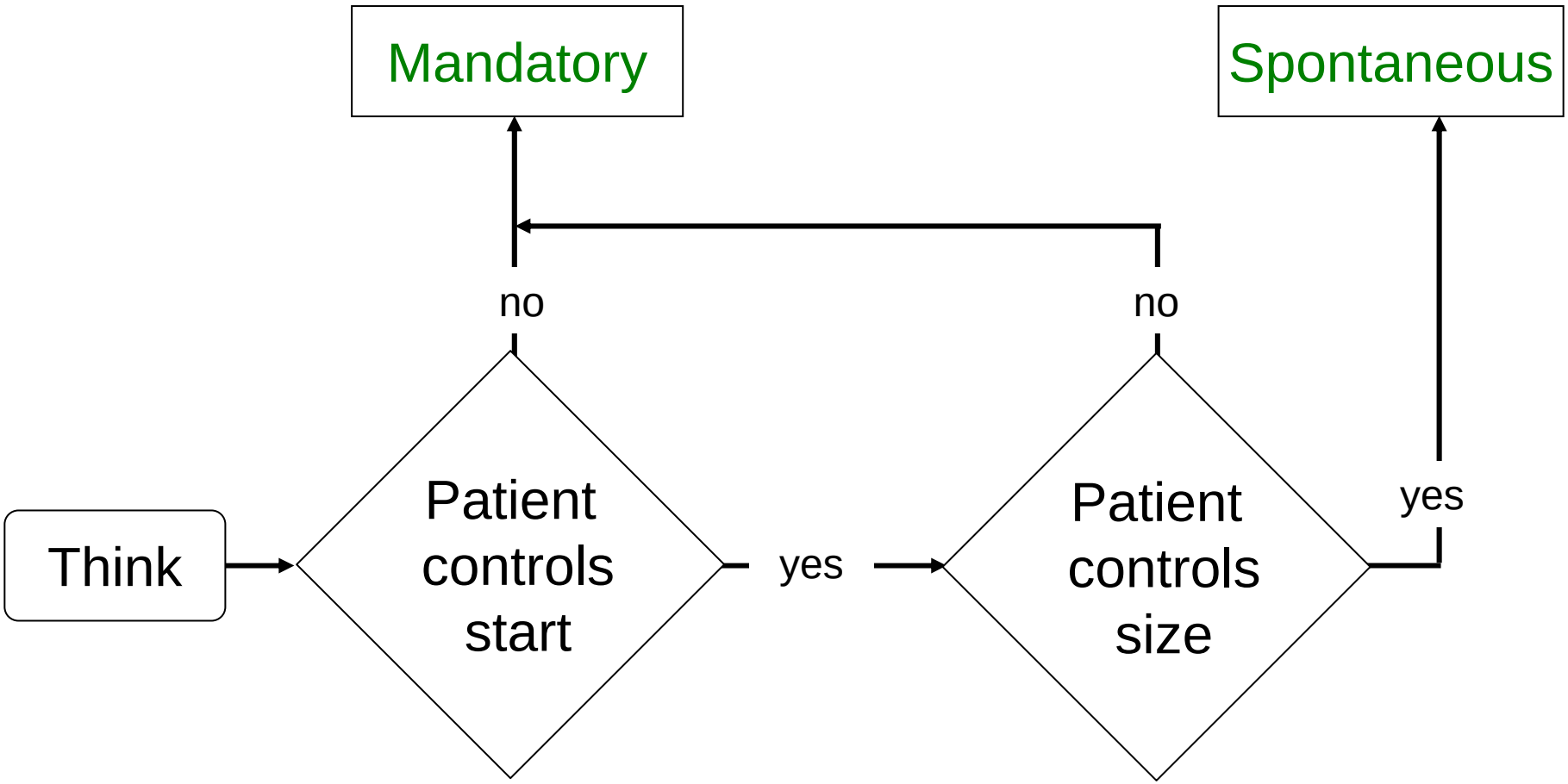
Characteristics of a Mode

1. **Breathing Pattern**
   - Control variable
   - Breath sequence
2. **Control Type**
   - Setpoint, auto-setpoint, servo, adaptive, optimal
3. **Control Strategy**
   - Phase variables
   - Operational logic

Breath Types

What is the difference between mandatory and spontaneous breaths?

Breath Types



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
   - Breath sequence
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   - Setpoint, auto-setpoint, servo, adaptive, optimal
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   - Phase variables
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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

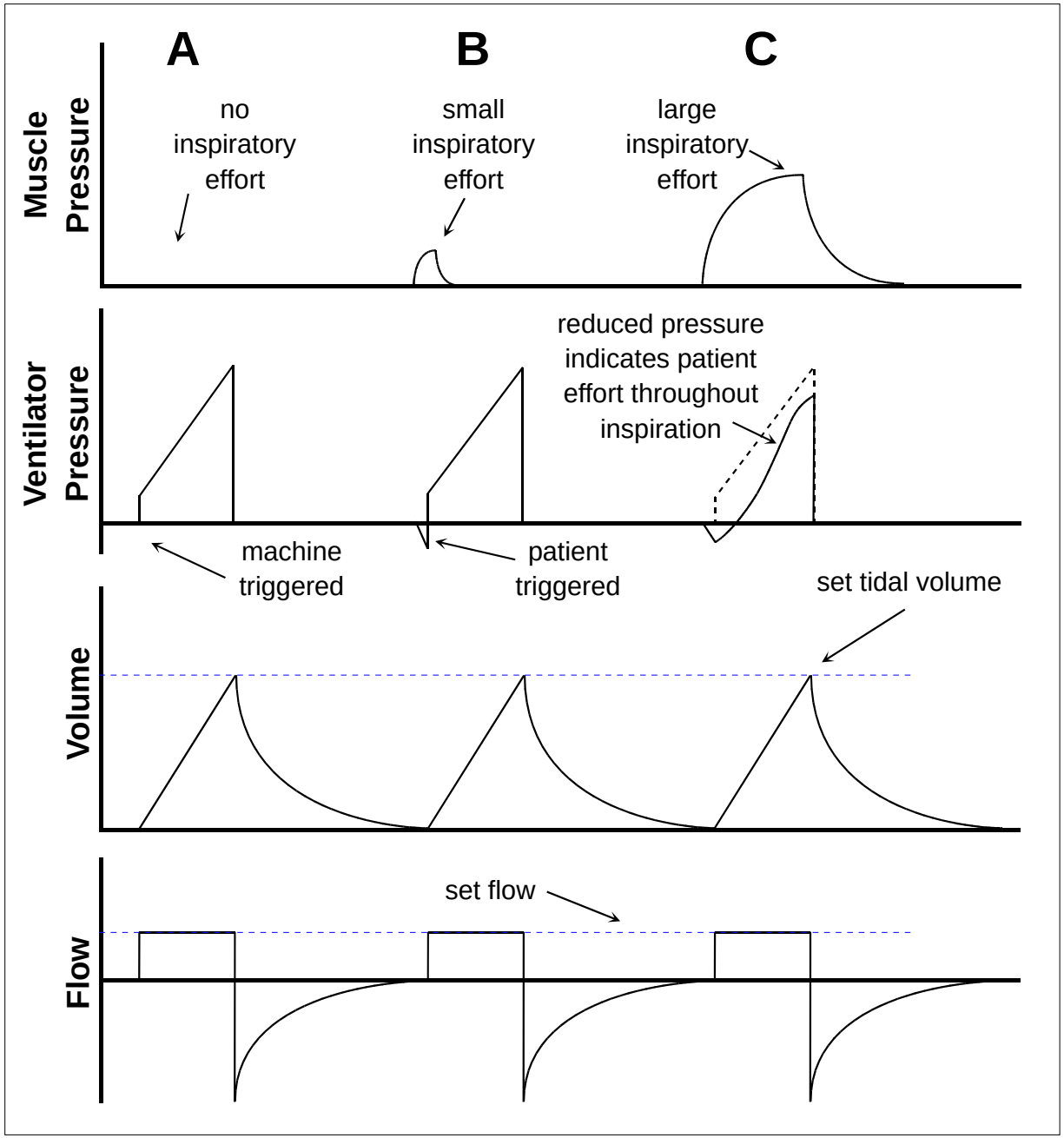
1. **Breathing Pattern**
   - Control variable
   - Breath sequence
2. **Control Type**
   - Setpoint, auto-setpoint, servo, adaptive, optimal
3. **Control Strategy**
   - Phase variables
   - Operational logic

8 Basic Breathing Patterns

Control Variable	Breath Sequence	Symbol
Volume	Continuous Mandatory Ventilation	VC-CMV
	Intermittent Mandatory Ventilation	VC-IMV
Pressure	Continuous Mandatory Ventilation	PC-CMV
	Intermittent Mandatory Ventilation	PC-IMV
	Continuous Spontaneous Ventilation	PC-CSV
Dual	Continuous Mandatory Ventilation	DC-CMV
	Intermittent Mandatory Ventilation	DC-IMV
	Continuous Spontaneous Ventilation	DC-CSV

VC-CMV

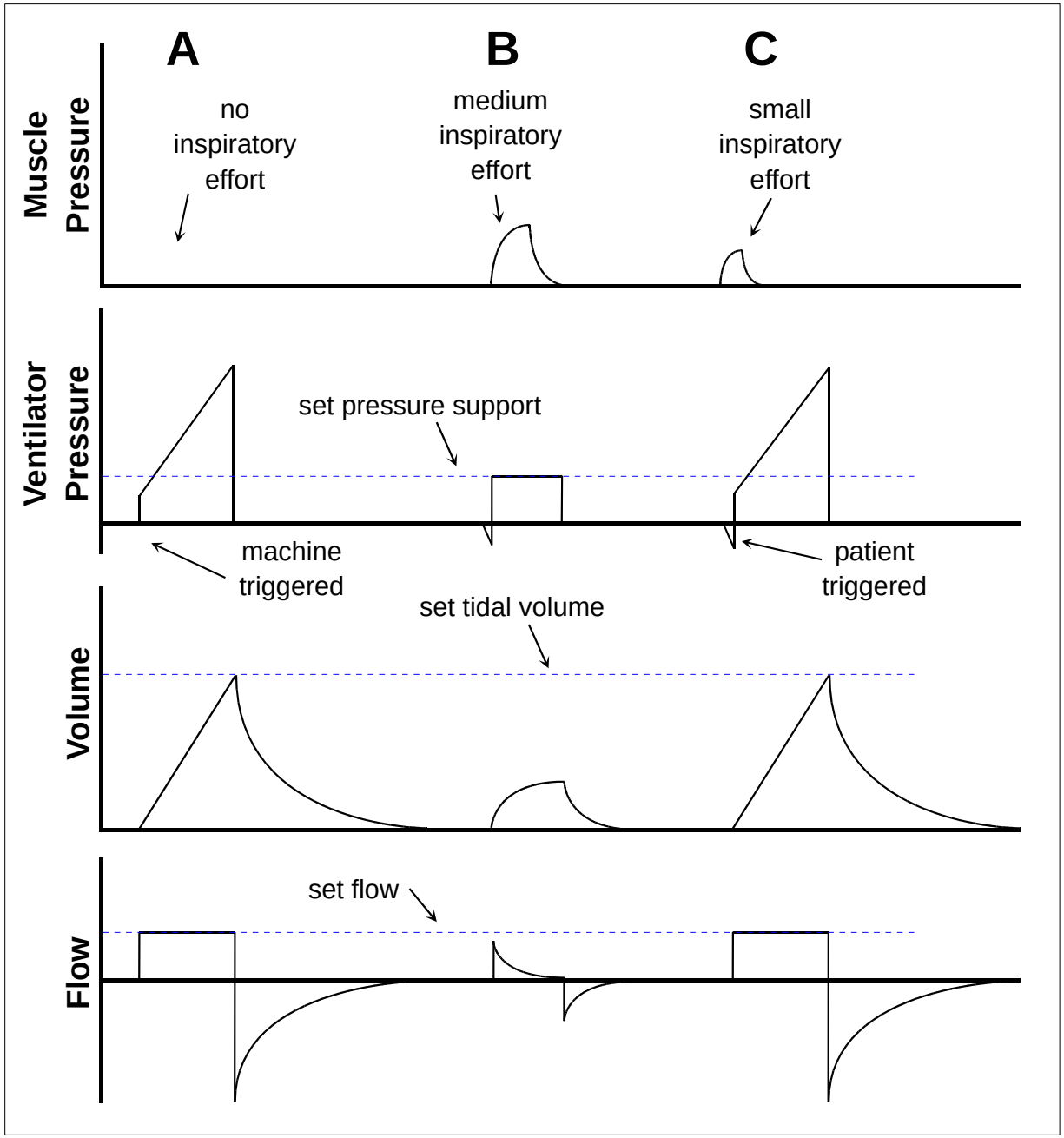
- **Often referred to as "Assist/Control"**
- **Characteristics**
  - VC results in more even distribution of ventilation among lung units with equal resistance and unequal compliance than PC
  - Selection of flow and sensitivity is critical
- **Indications**
  - Need for total ventilatory support
  - Need for precise regulation of blood gases
- **Example**
  - Precise regulation of $PaCO_2$ in patients with traumatic brain injury



VC-CMV waveforms

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

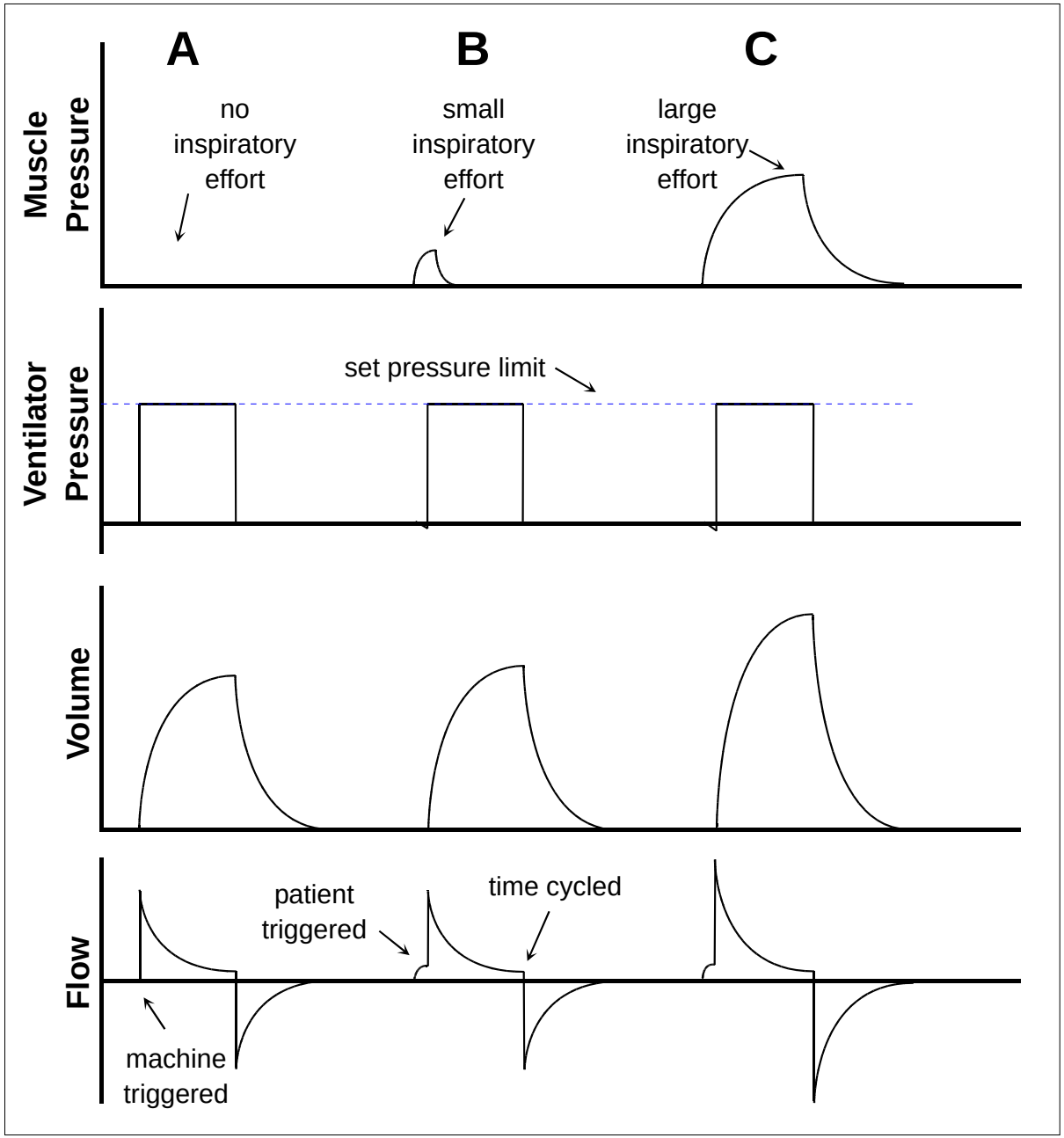


VC-IMV waveforms

Are spontaneous breaths assisted?

PC-CMV

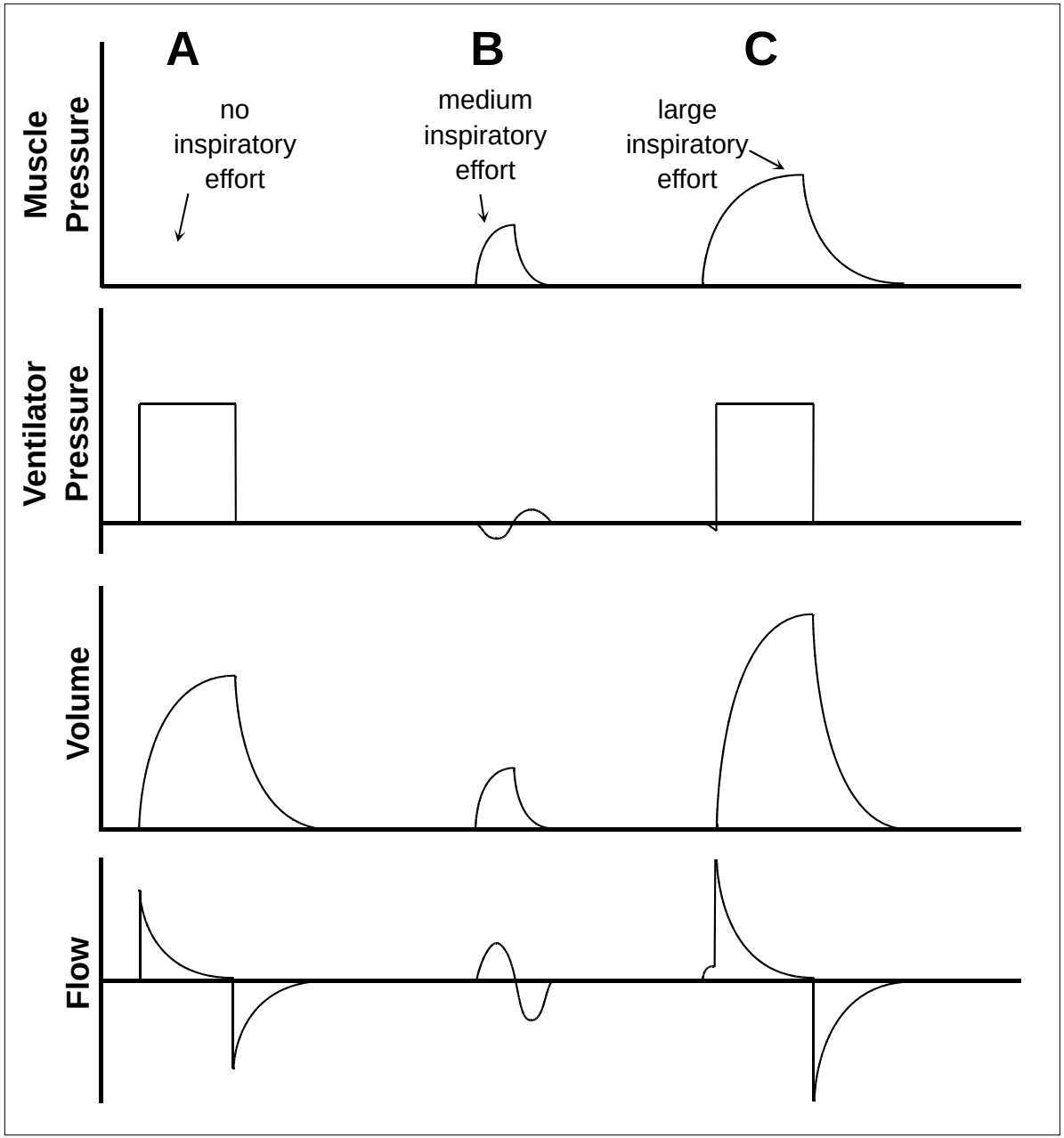
- **Characteristics**
  - PC results in more even distribution of ventilation among lung units with equal compliance and unequal resistance than VC
  - Pressure control results in higher mean airway pressure and earlier lung opening than VC
- **Indications**
  - Problems with oxygenation or synchrony
- **Example**
  - Treatment of ARDS patients with oxygenation problems



PC-CMV waveforms

PC-IMV

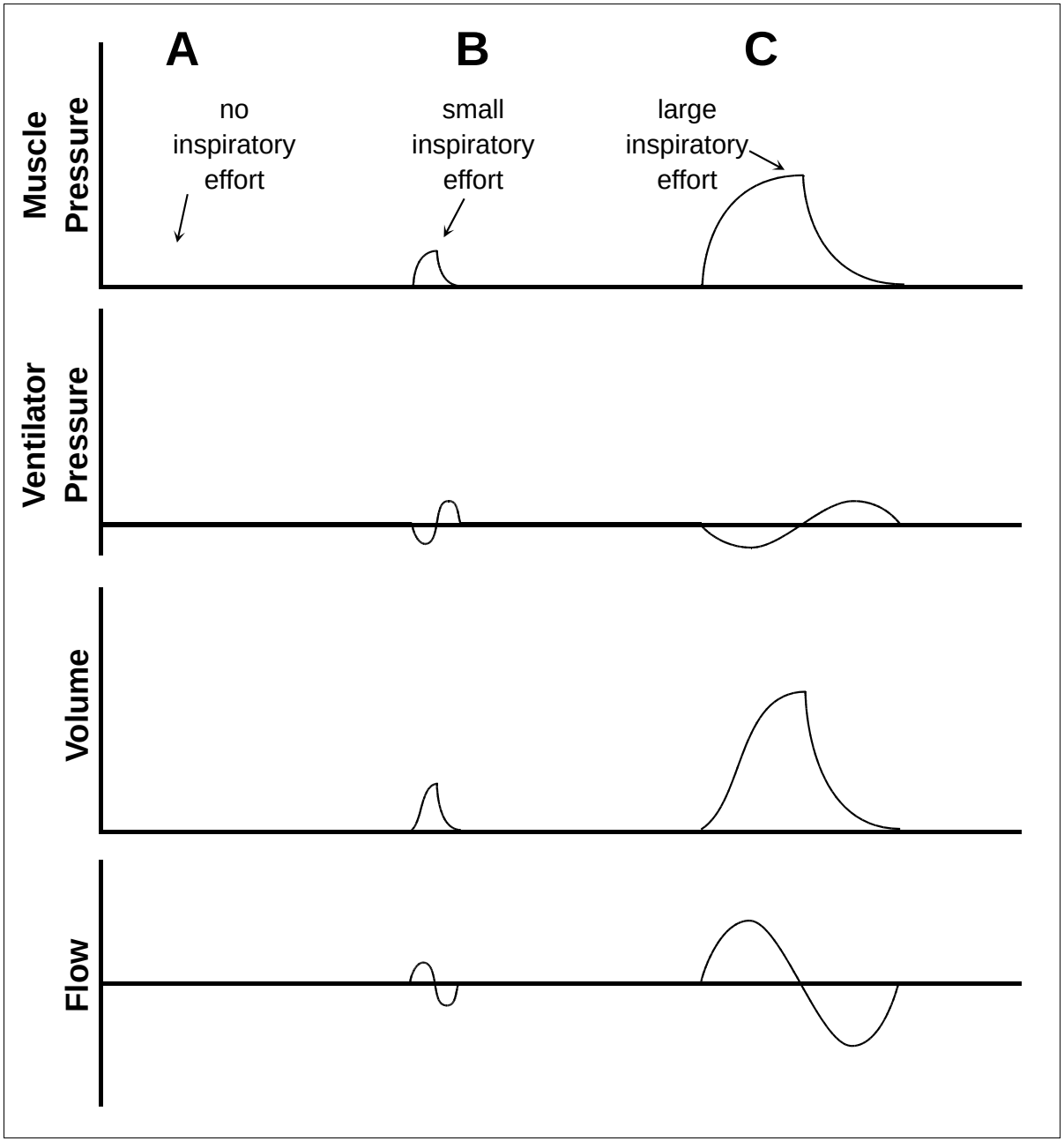
- **Characteristics**
  - Relatively simple mode
  - Used historically for infants
  - Spontaneous breaths may be assisted
- **Indications**
  - Problems with oxygenation or synchrony
  - Adequate ventilatory drive
- **Example**
  - Treatment of premature infants with RDS



PC-IMV waveforms

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

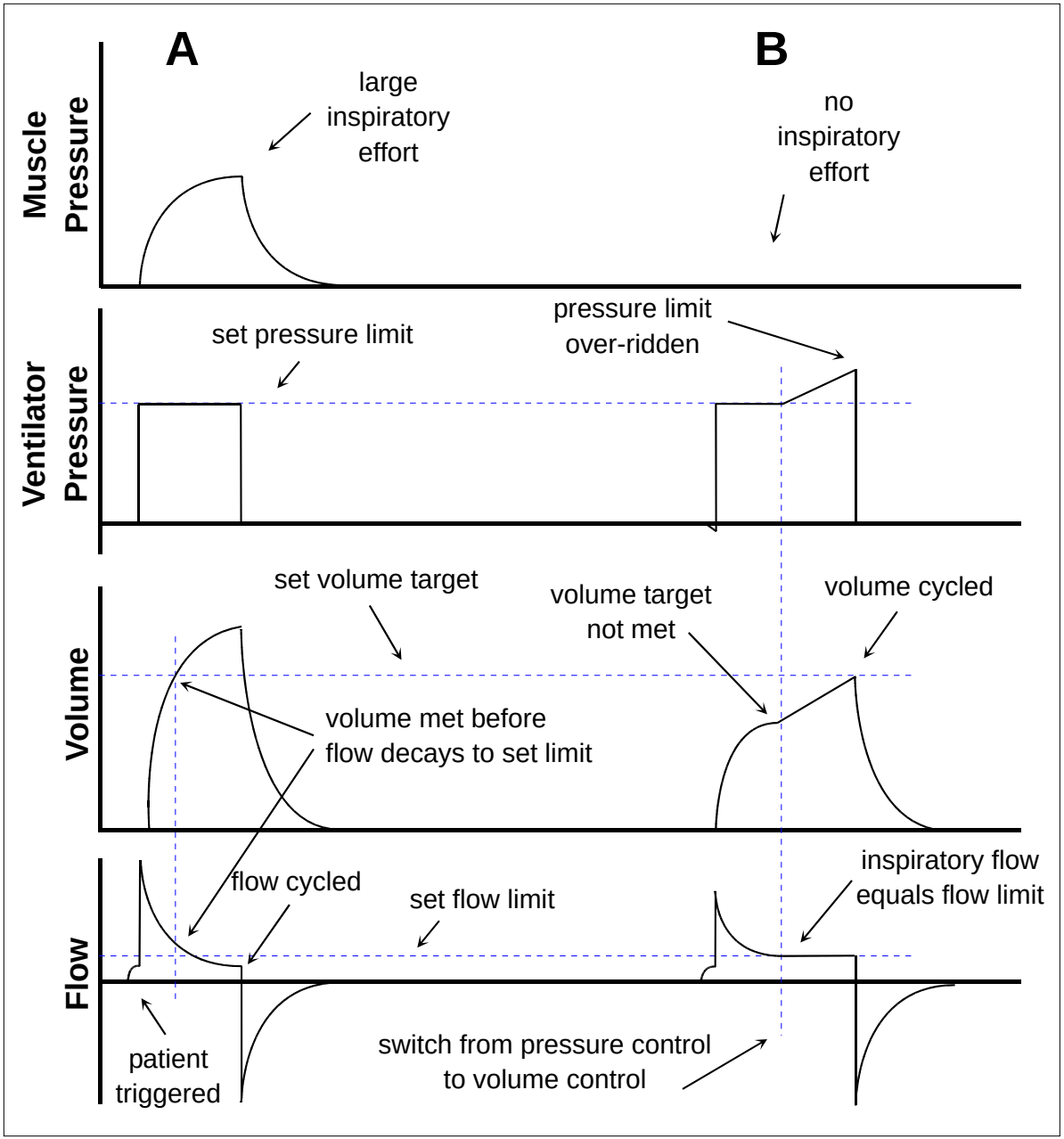


PC-CSV waveforms

Spontaneous breaths are not assisted (CPAP)

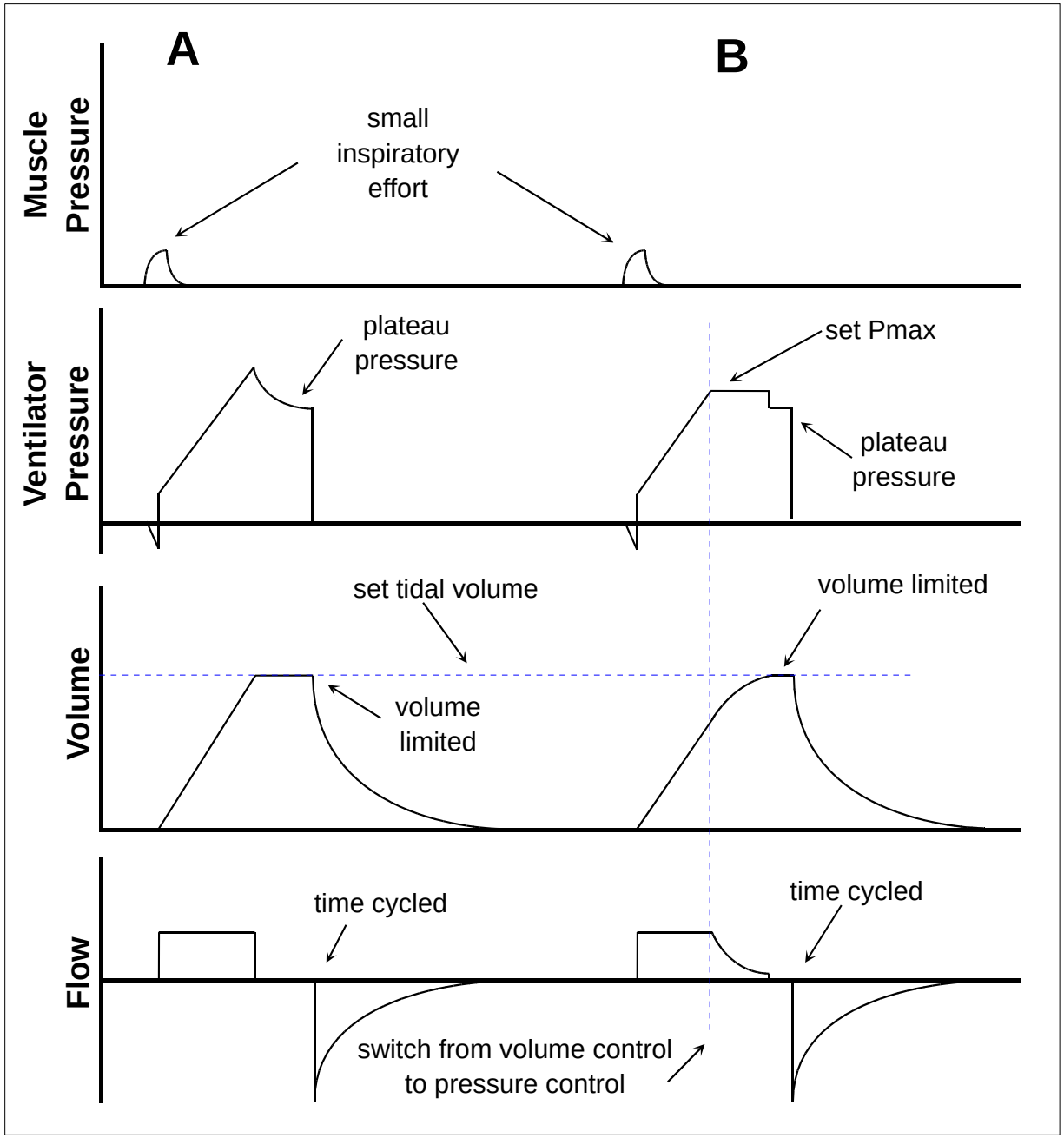
DC-CMV

- **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



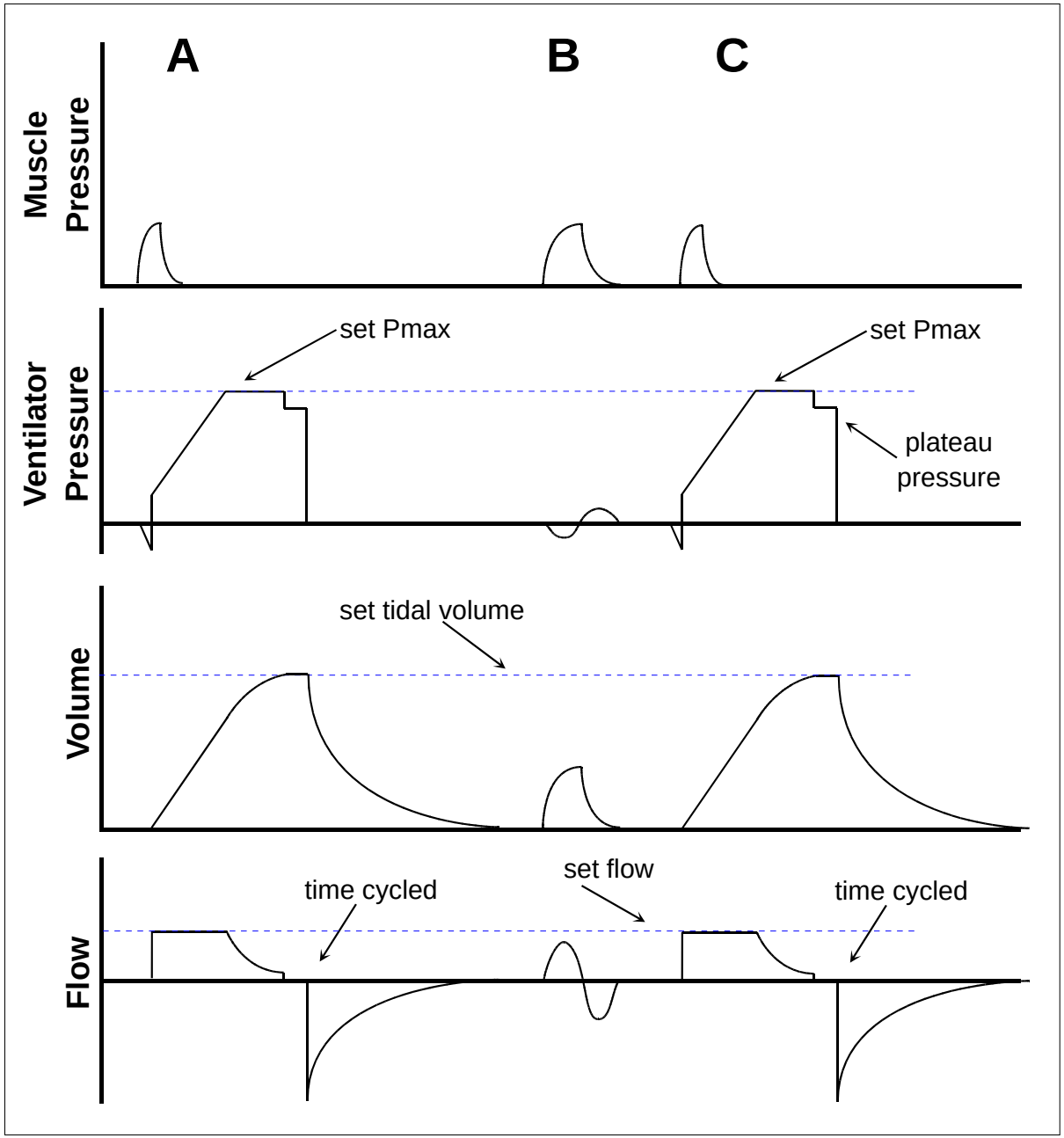
DC-CMV waveforms

pressure-to-volume
Bird VAPS



DC-CMV waveforms

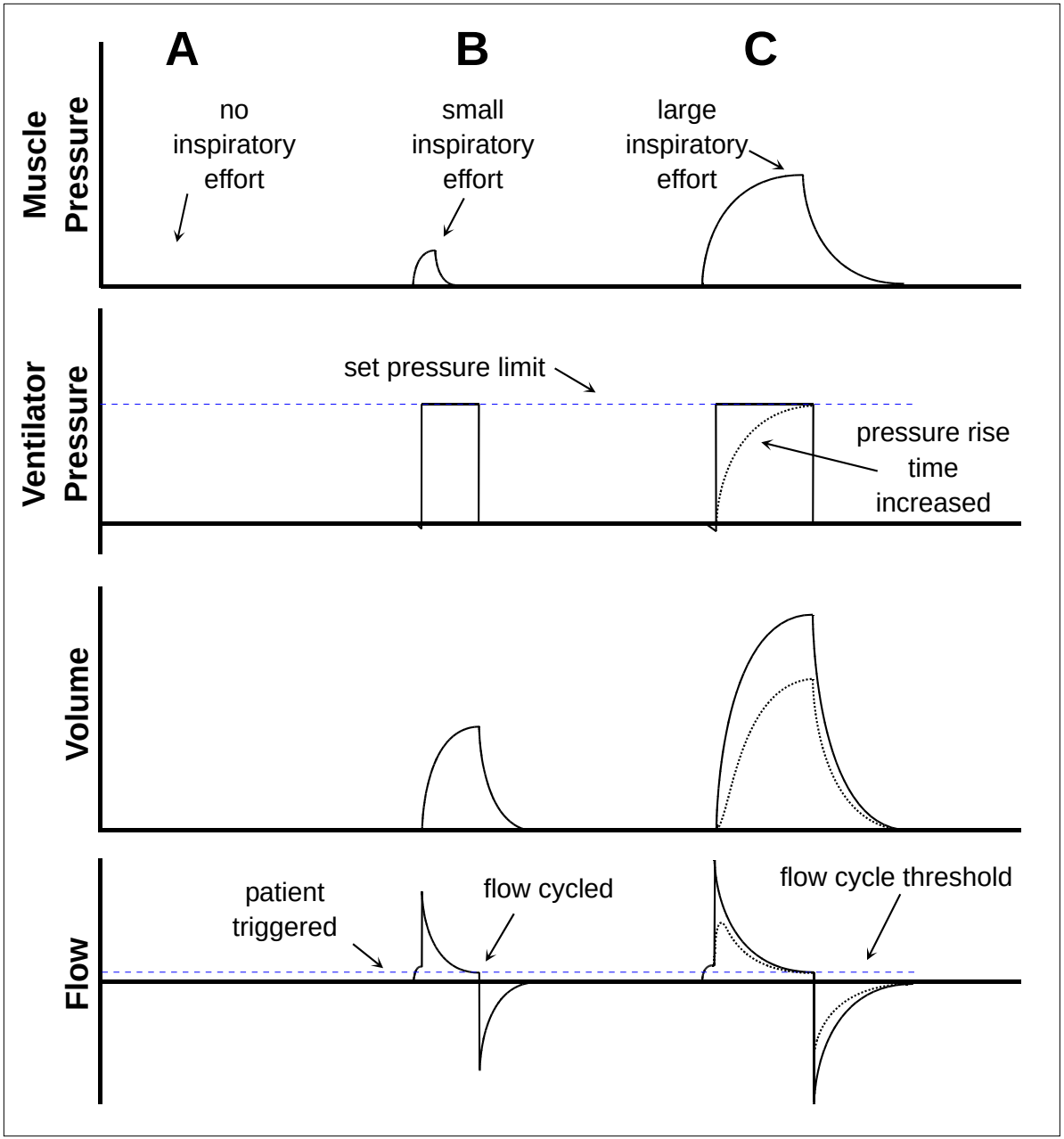
volume-to-pressure
Dräger
Pressure Limited Ventilation



DC-IMV waveforms

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

$$P_{mus} = E_{normal} \times volume + R_{normal} \times flow$$

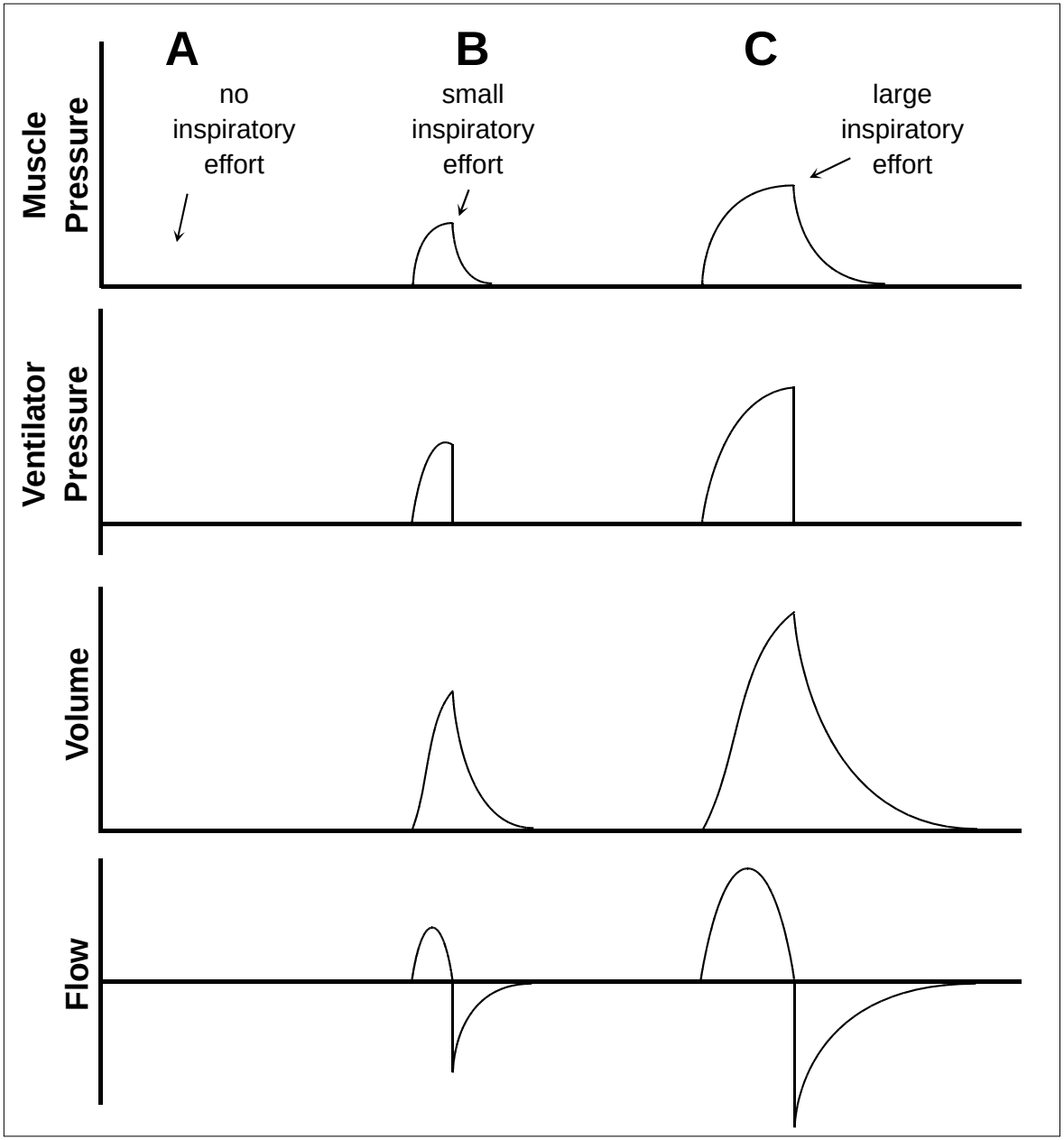
$$P_{mus} = (E_{normal} + E_{abnormal}) \times volume + (R_{normal} + R_{abnormal}) \times flow$$

$$P_{mus} = (normal\ load) + (abnormal\ load)$$

$$P_{mus} + P_{vent} = (normal\ load) + (abnormal\ load)$$

$$P_{vent} = abnormal\ load = E_{abnormal} \times volume + R_{abnormal} \times flow$$

operator settings (volume and flow amplification factors)



PC-CSV waveforms

Spontaneous breaths are assisted (Proportional Assist)

Automatic Tube Compensation

$$P_{vent} = abnormal\ \ resistive\ load = R_{tube} \times flow^2$$

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)*

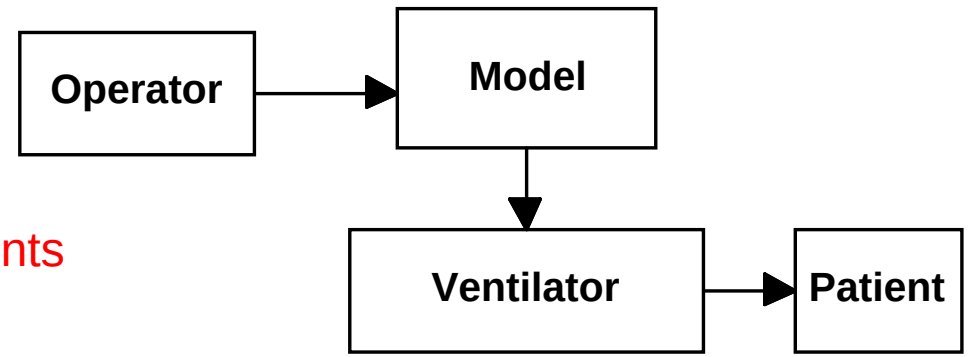
operator-selected, static setpoints

Strategic Control (between breaths)

- *adaptive (CMV+AutoFlow)*
- *optimal (ASV)*

ventilator-selected, dynamic setpoints

static model



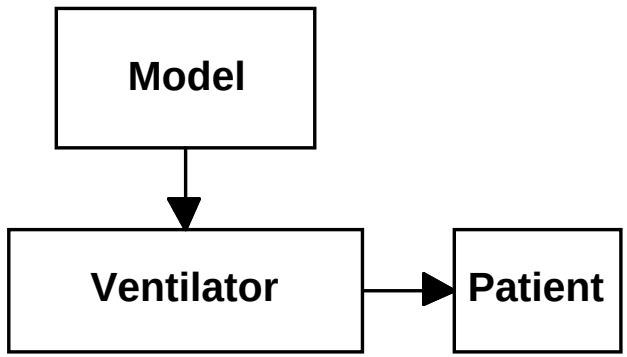
Intelligent Control (between patients)

- *knowledge based*
- *artificial neural network*

ventilator-selected, dynamic setpoints

dynamic model

ability to learn from experience

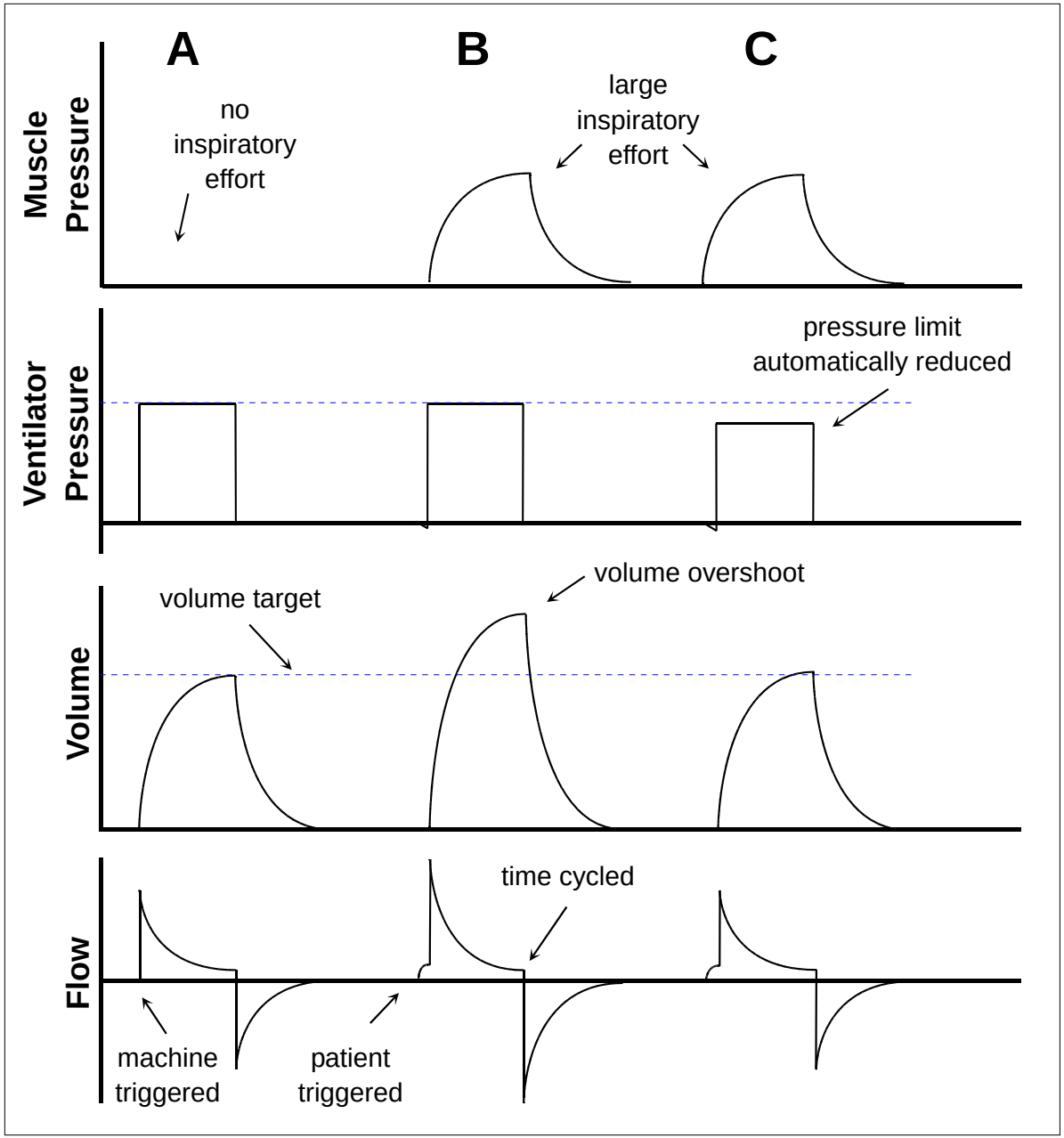


Tactical Control

- **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

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

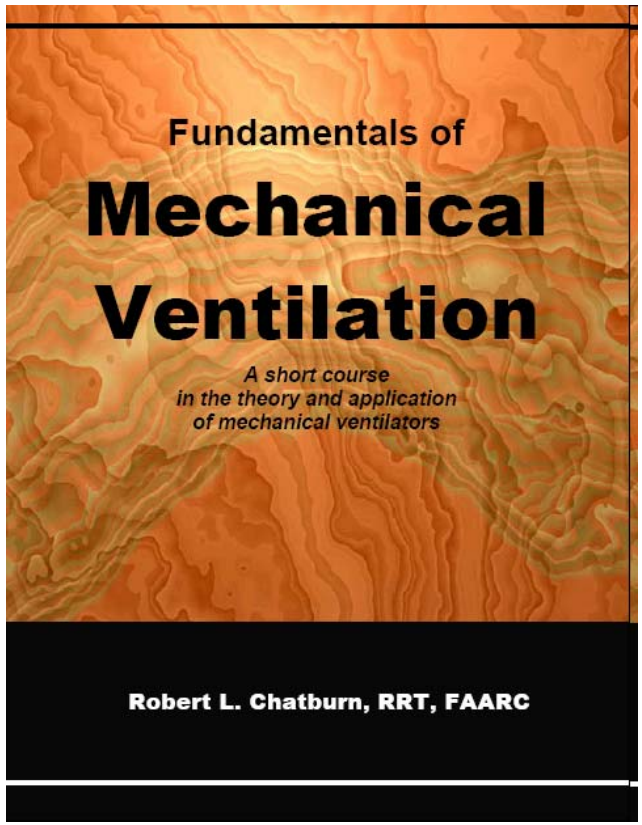
- **Pressure Regulated Volume Control**
- **AutoFlow**
- **VC+**
- **PC-SIMV + Volume Guarantee**

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.VentWorld.com
  - 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