

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

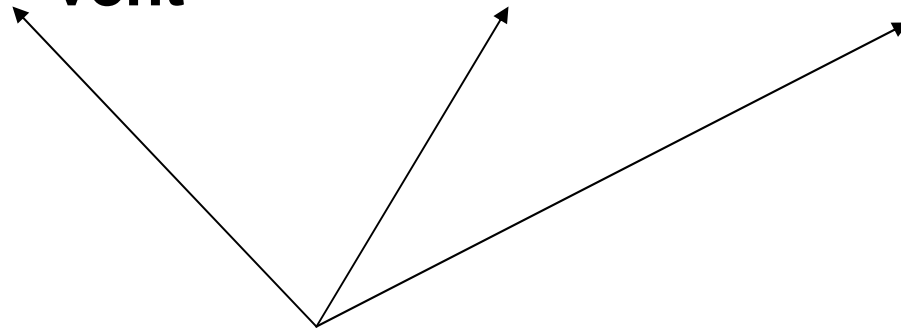
- Setpoint, auto-setpoint, servo, adaptive, optimal

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

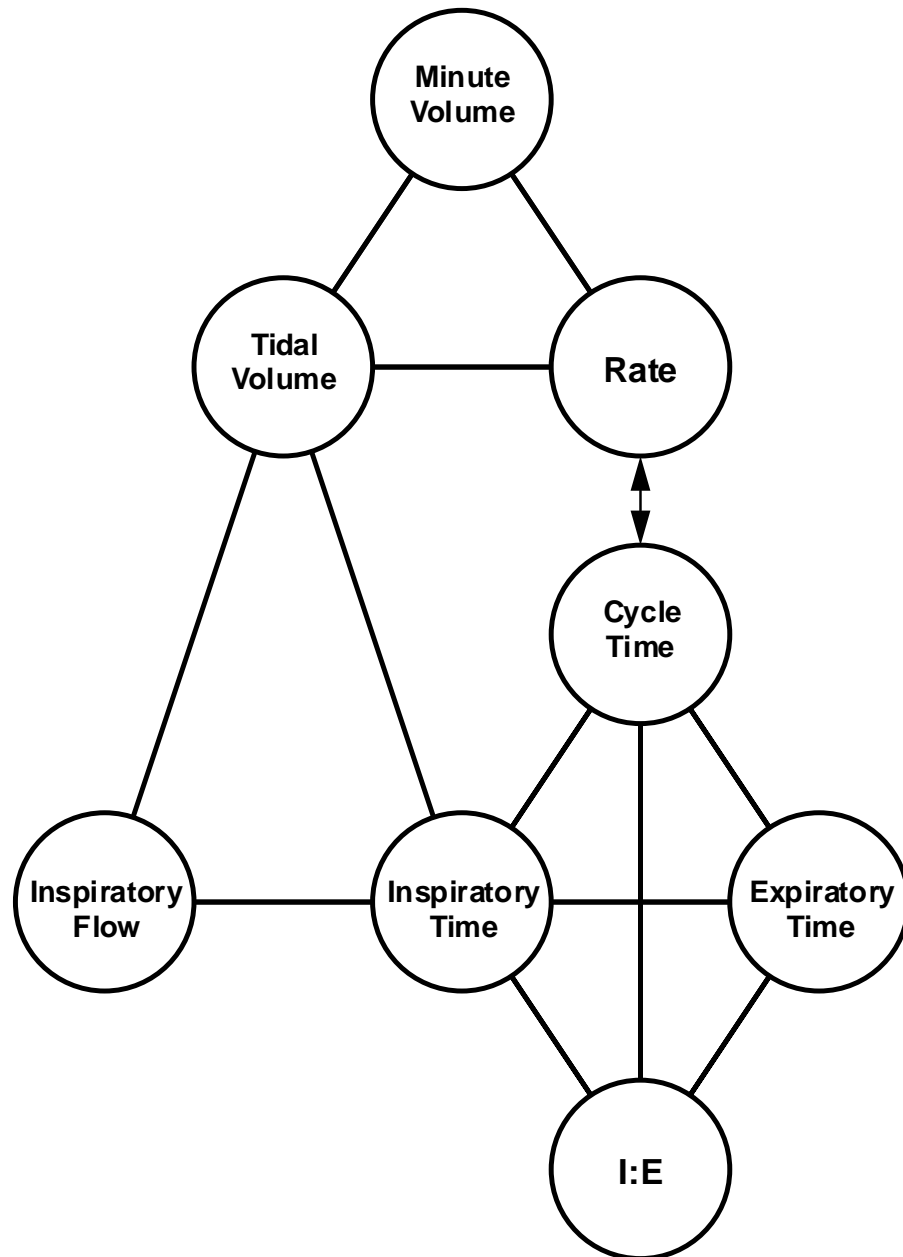
Volume Control

- **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

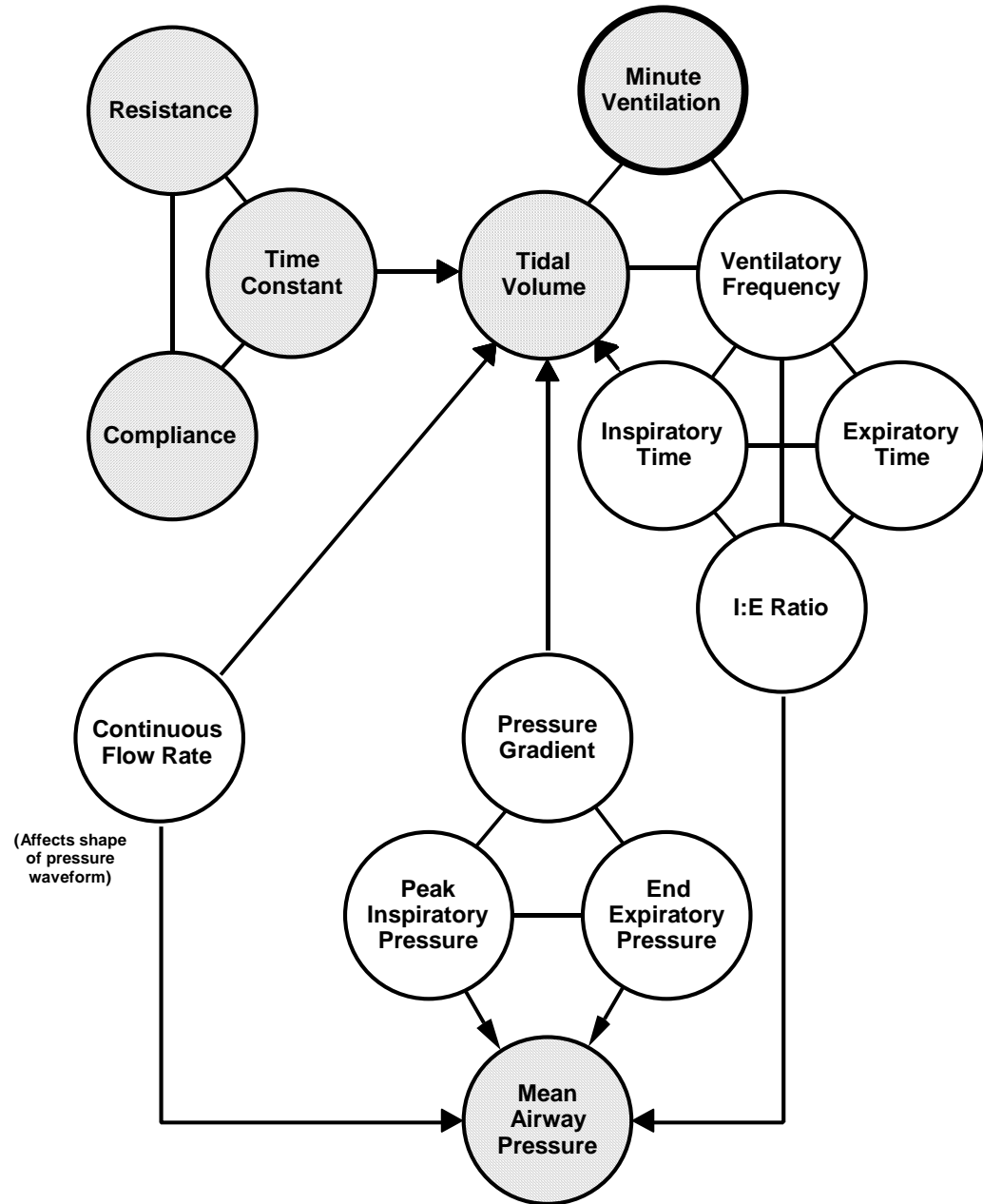
Pressure Control

- **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

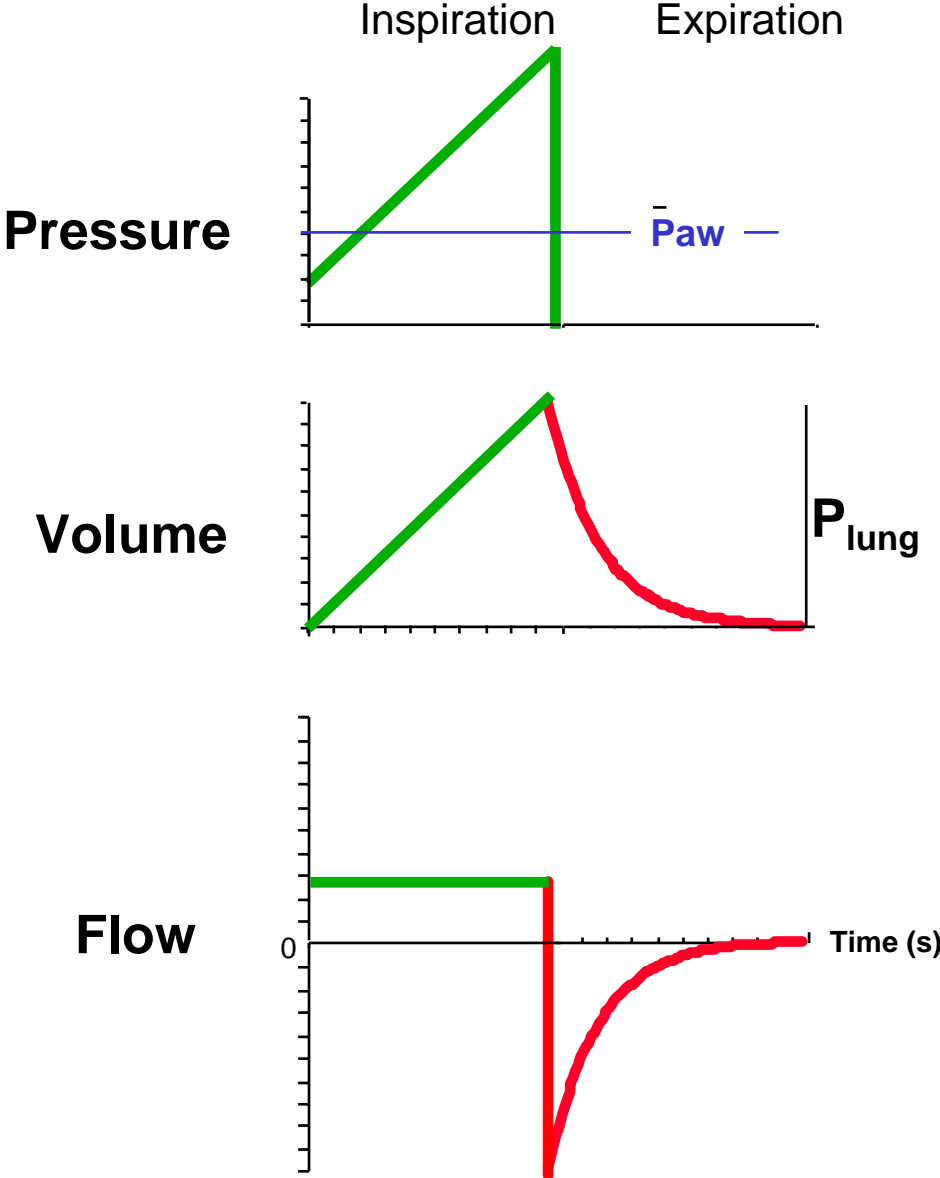
Volume Control Influence Diagram



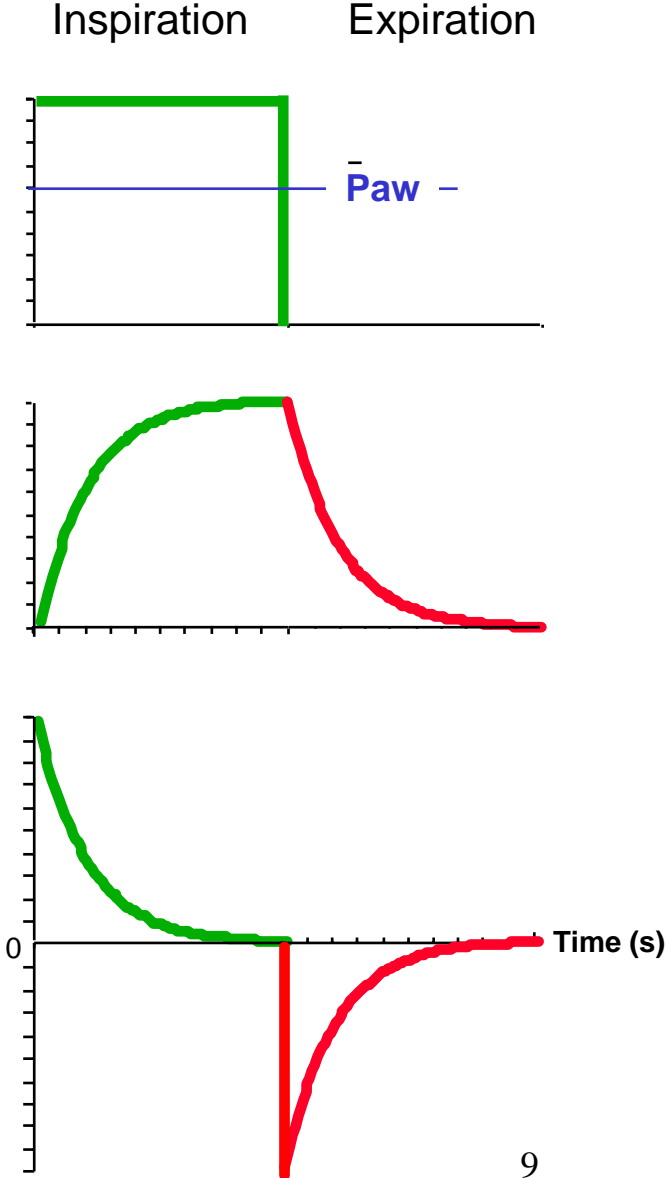
Pressure Control Influence Diagram



Volume/Flow Control



Pressure 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

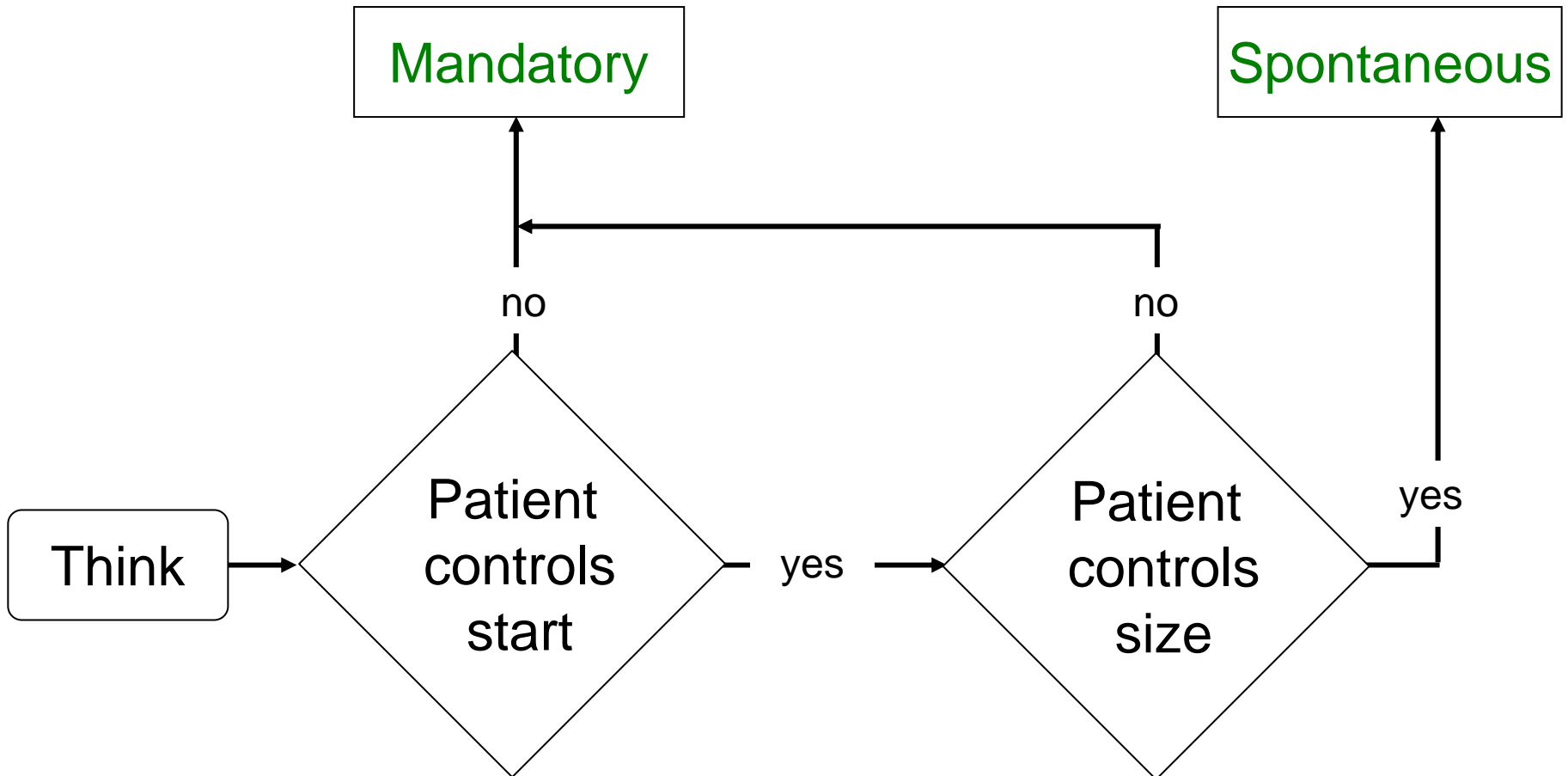
3. Control Strategy

- 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

2. Control Type

- Setpoint, auto-setpoint, servo, adaptive, optimal

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

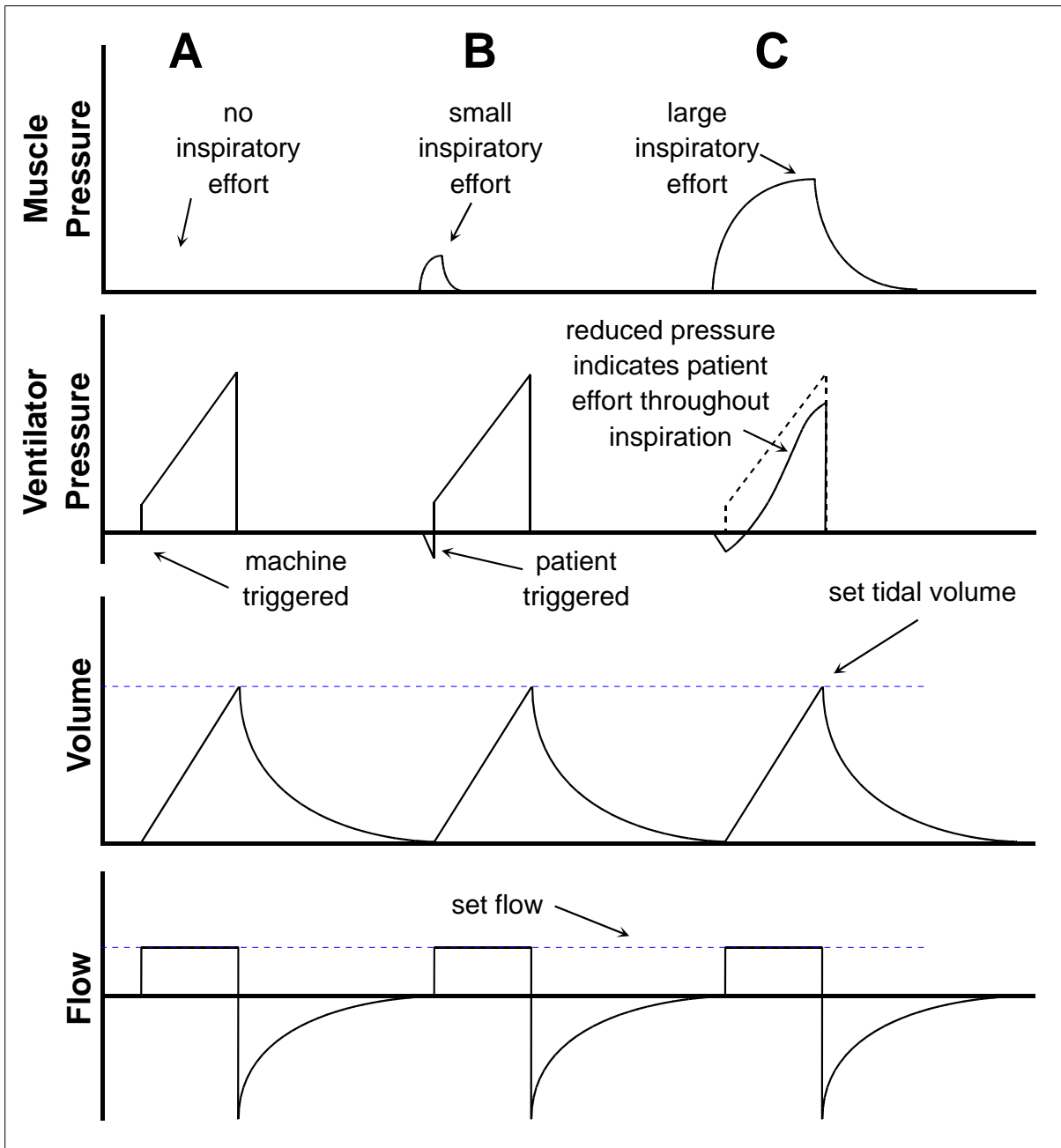
8 Basic Breathing Patterns

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 PaCO₂ 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**

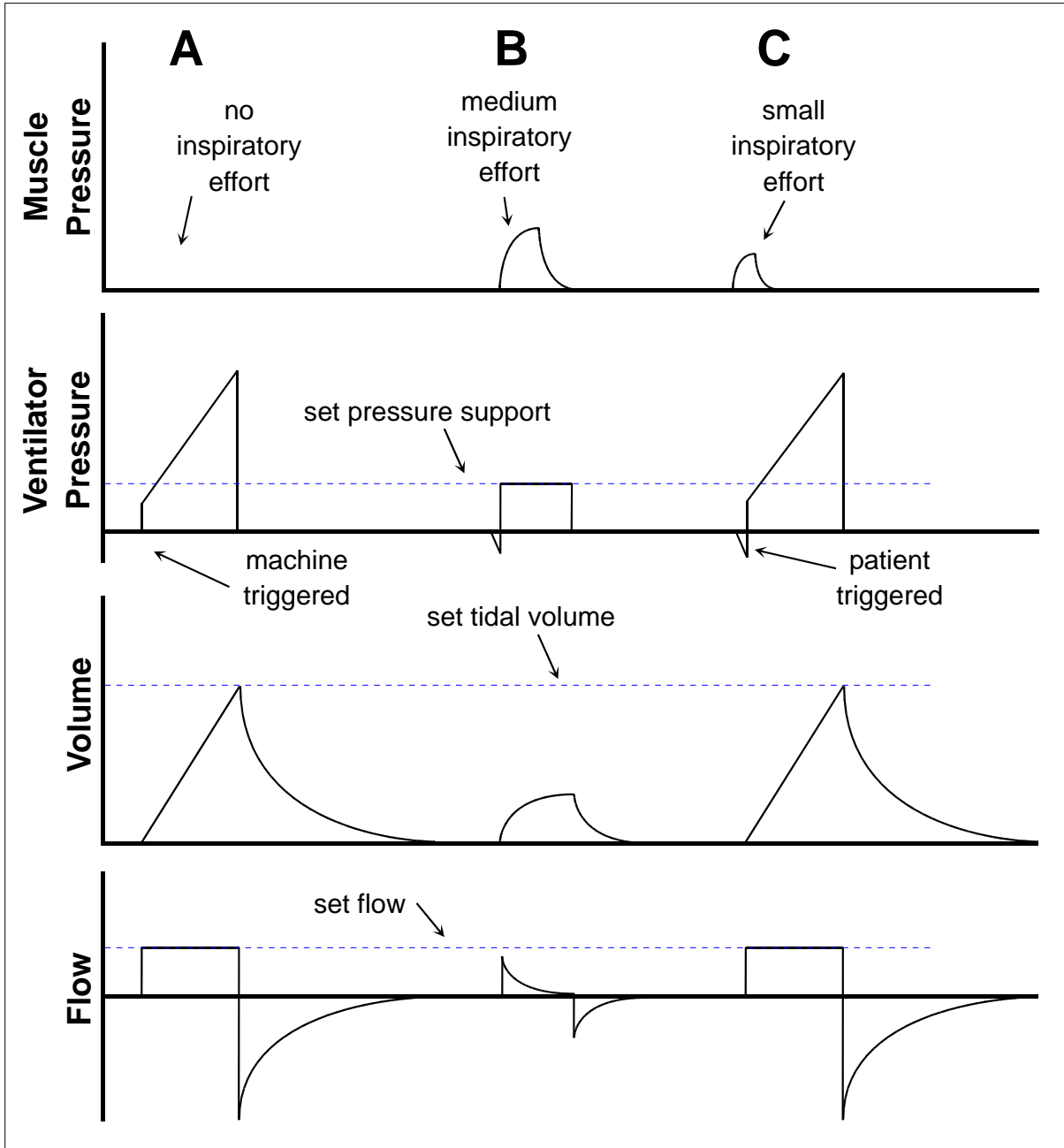
- Relatively normal lung function
- Rapid recovery from sedation or respiratory failure
- Recent data suggest it is worst choice for weaning

- **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

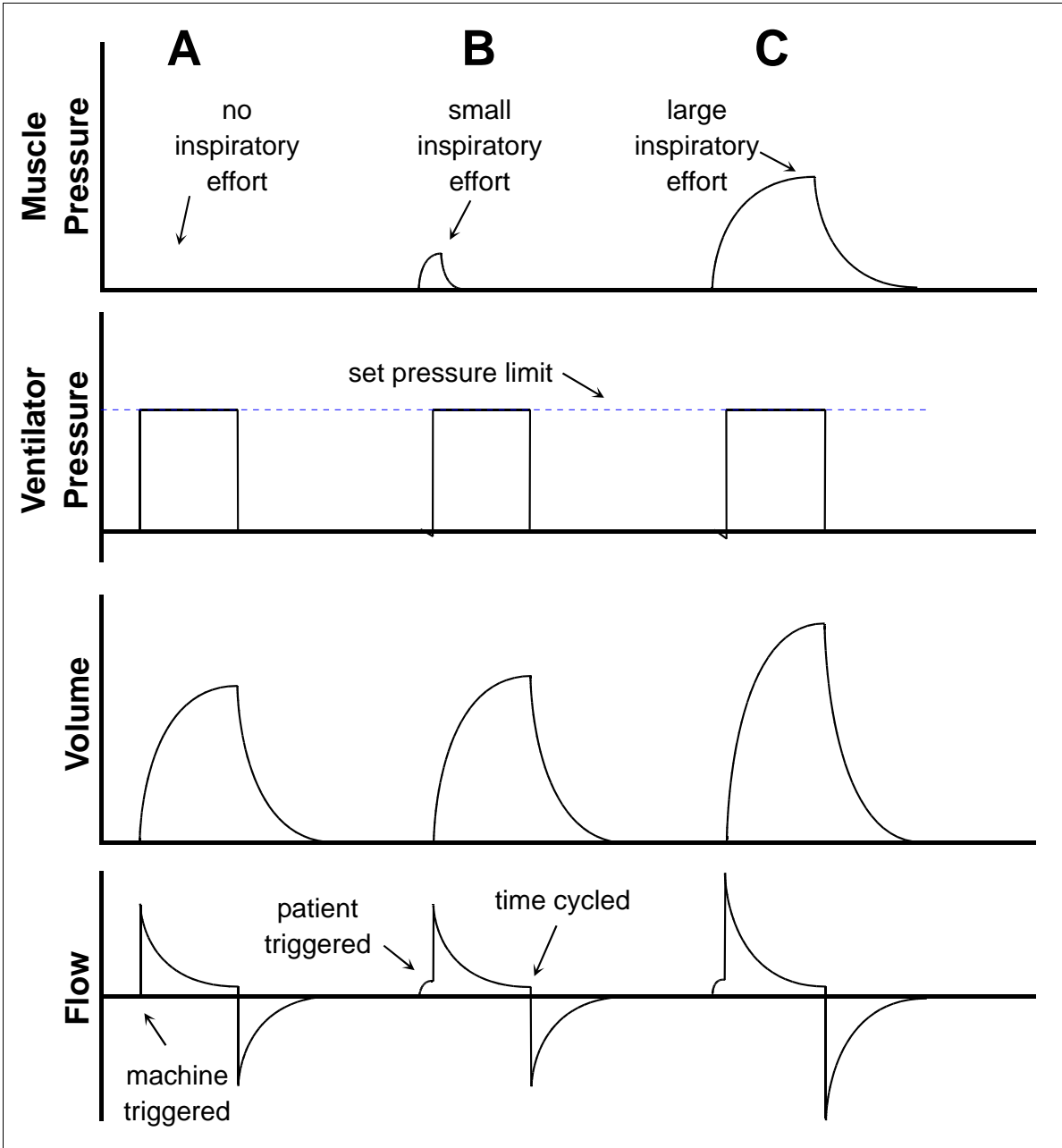
- **Indications**

- Problems with oxygenation or synchrony

- **Example**

- Treatment of ARDS patients with oxygenation problems

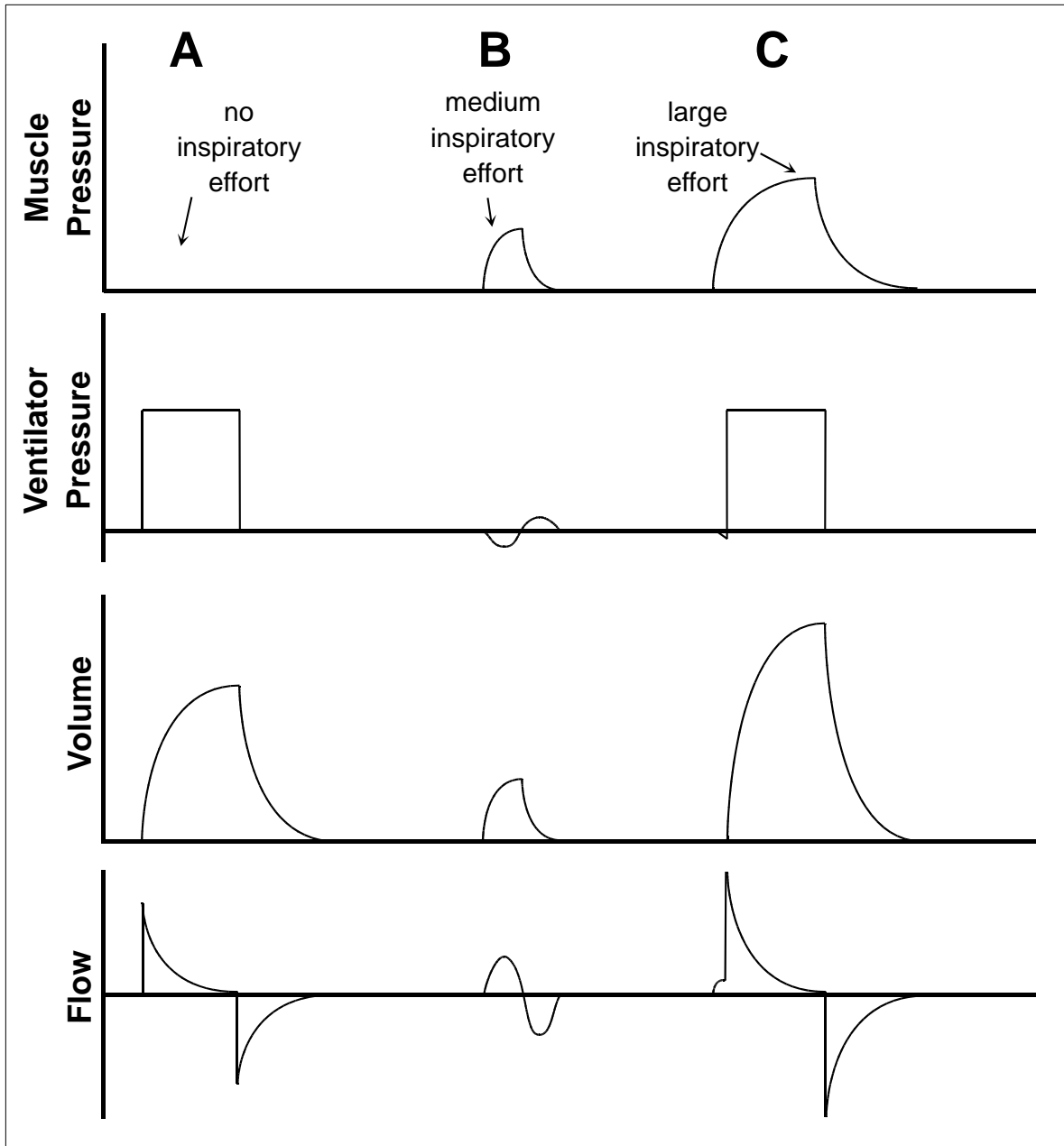
PC-CMV waveforms



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**

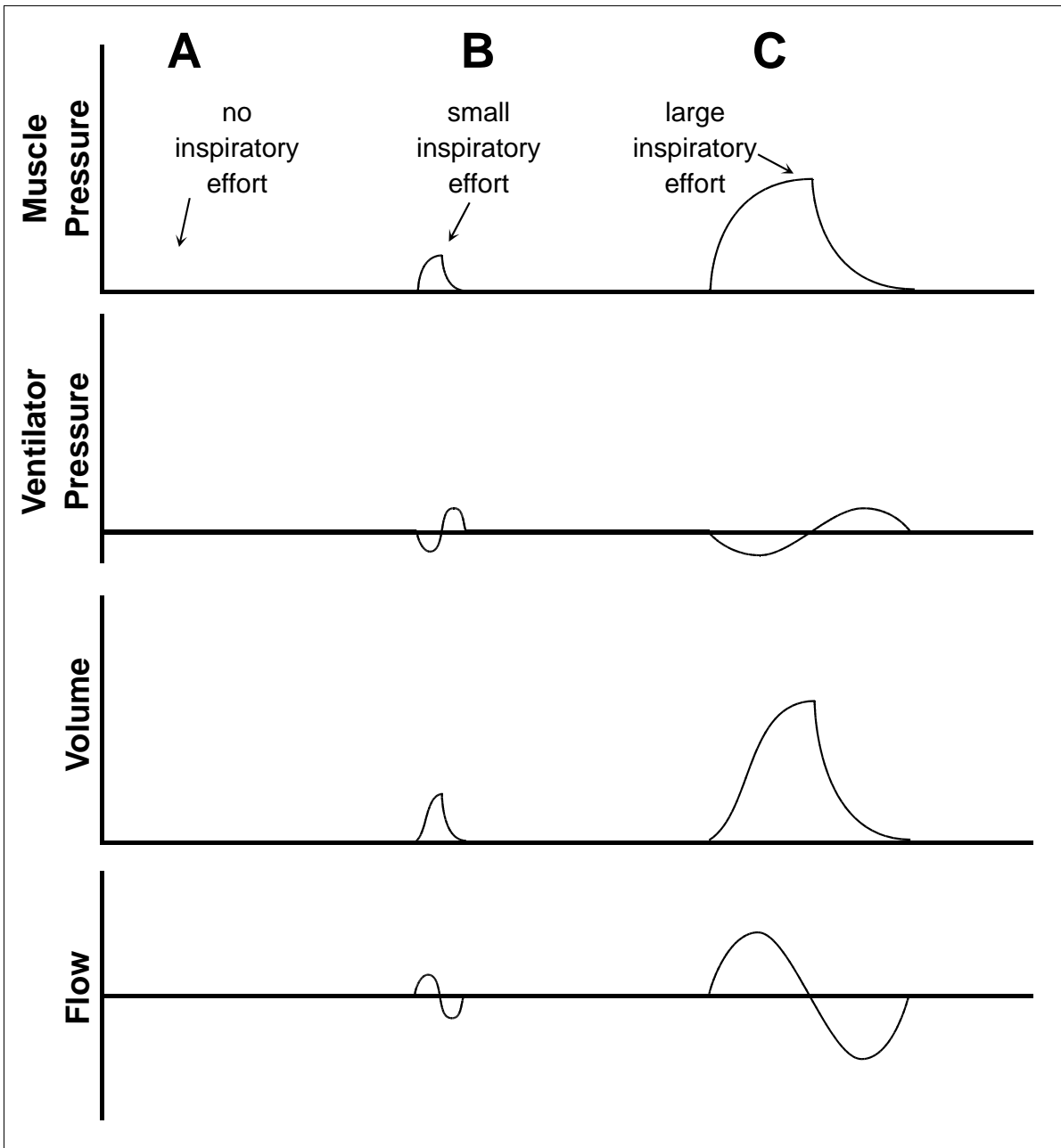
- Weaning
- Reduce work of breathing or stabilize oxygenation

- **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**

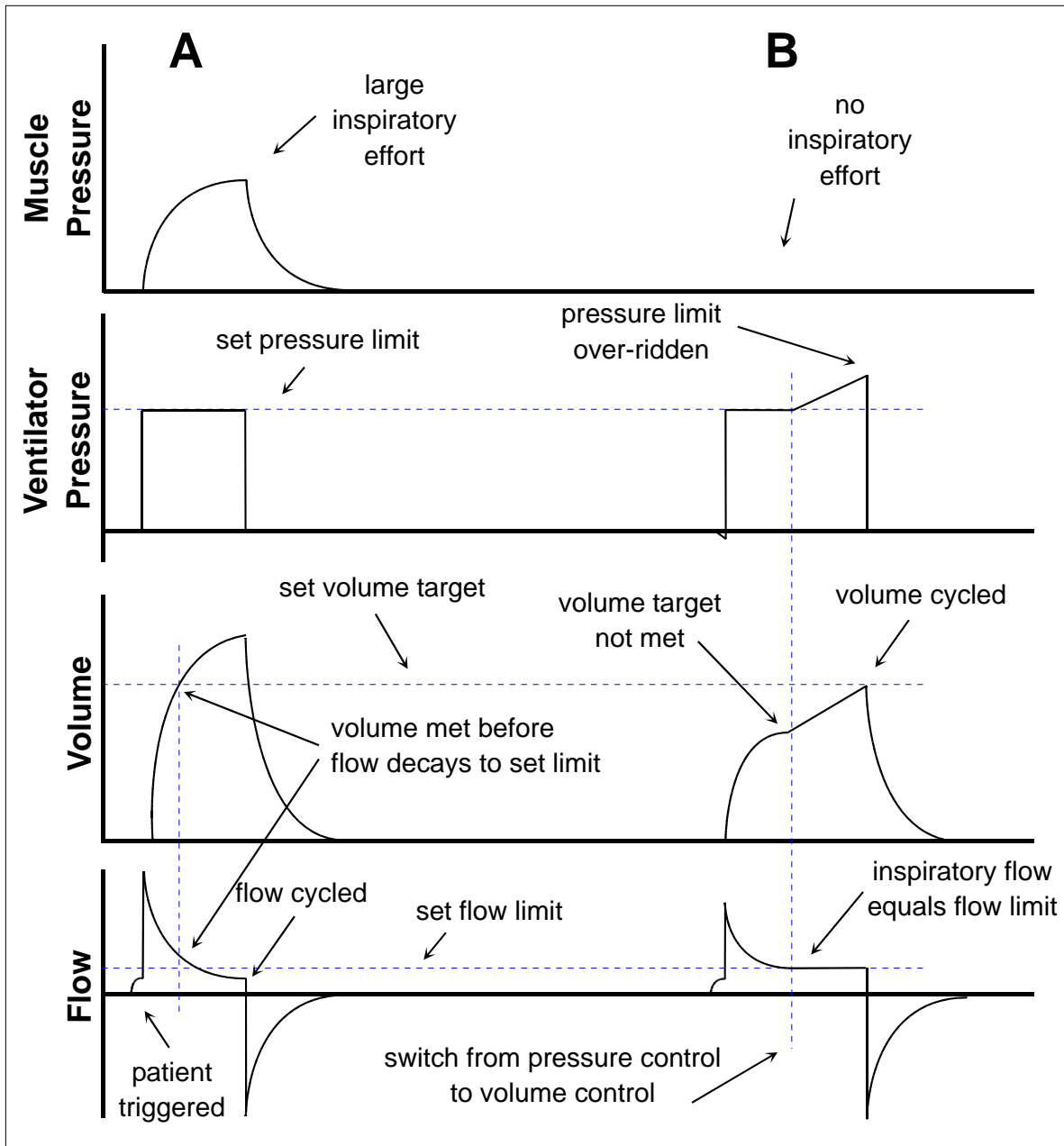
- Unstable lung mechanics or ventilatory drive

- **Example**

- Treatment of patient with pneumonia and intermittent secretion problems

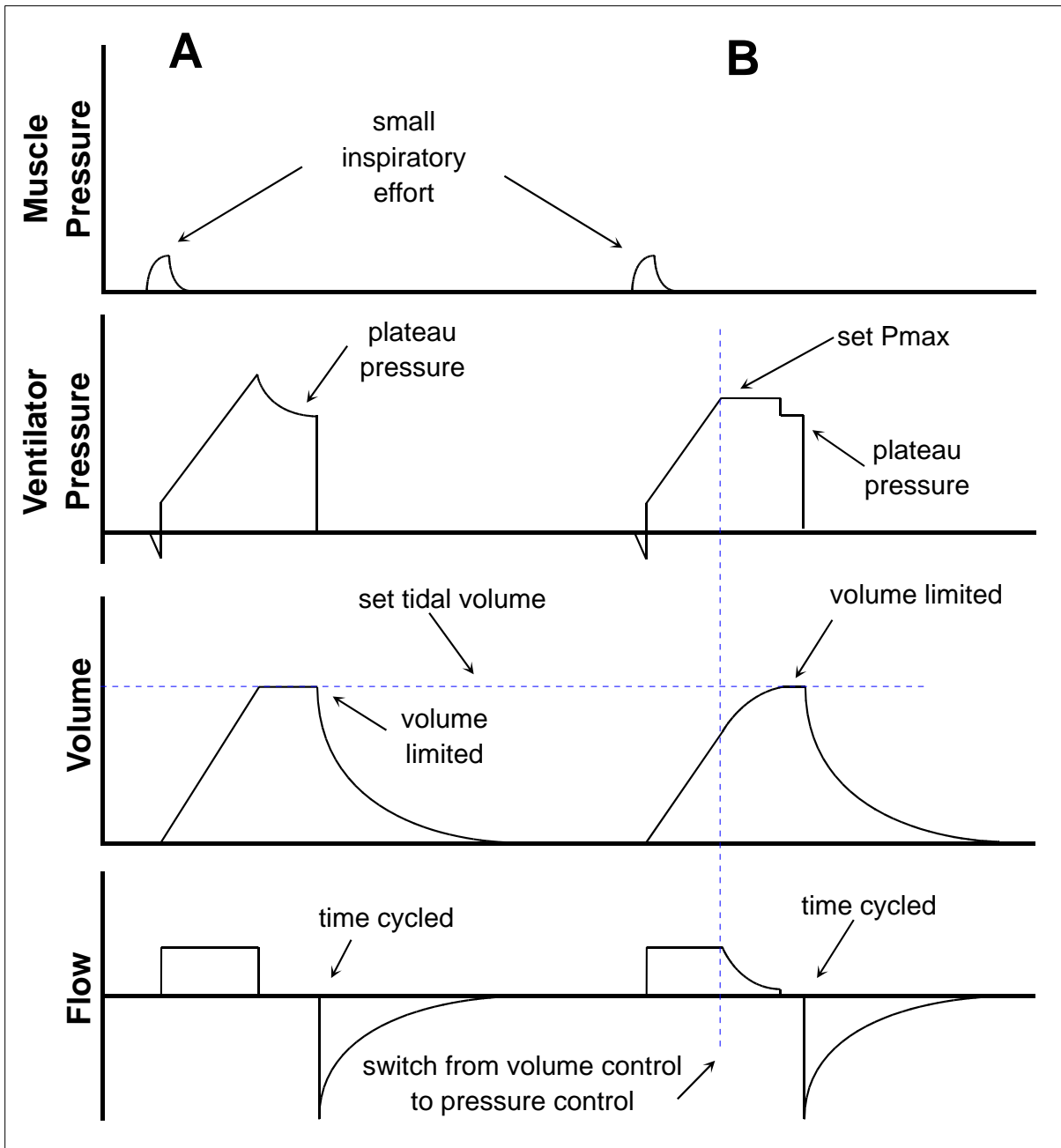
DC-CMV waveforms

*pressure-to-volume
Bird VAPS*

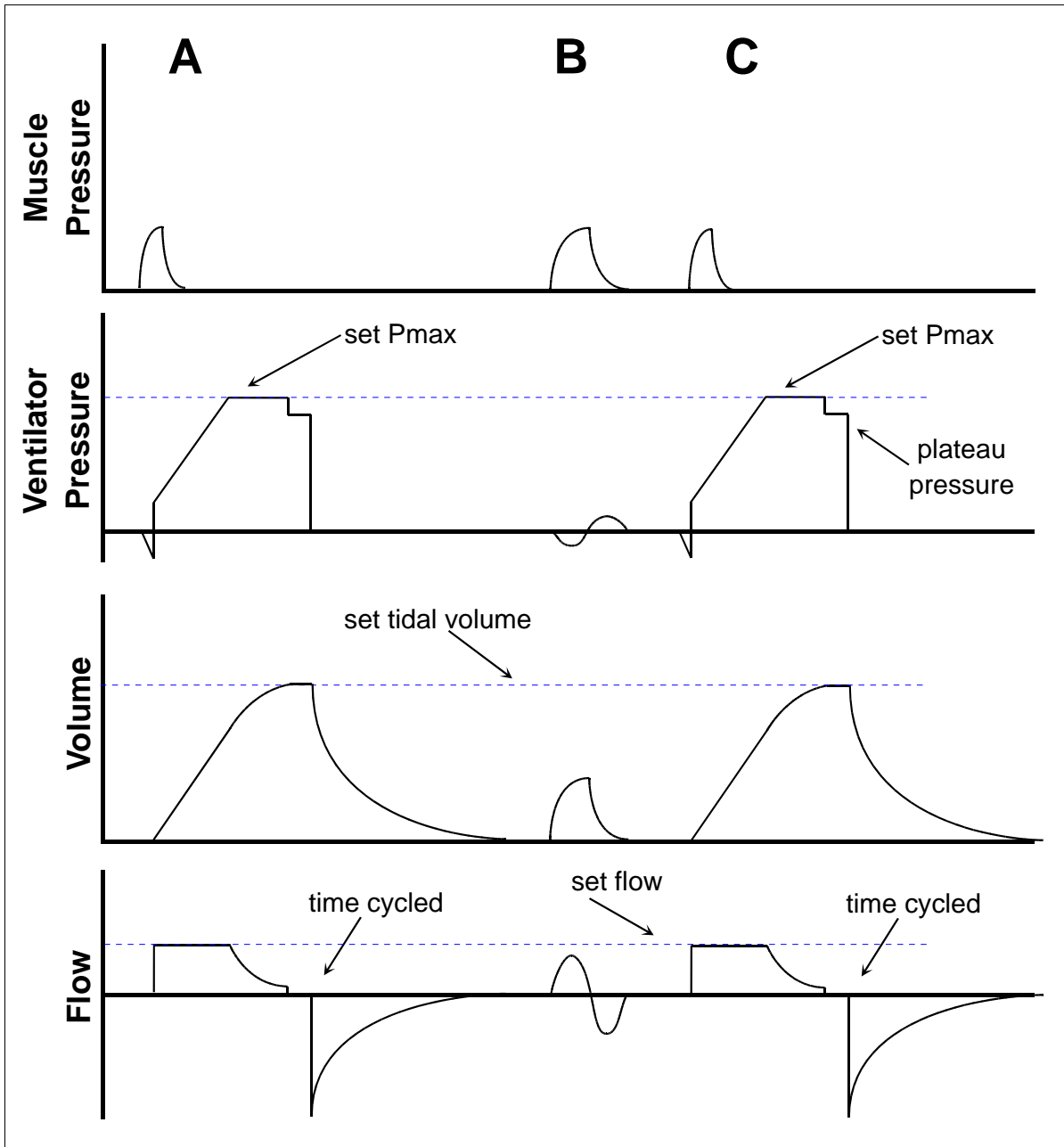


DC-CMV waveforms

*volume-to-pressure
Dräger
Pressure Limited
Ventilation*



DC-IMV waveforms

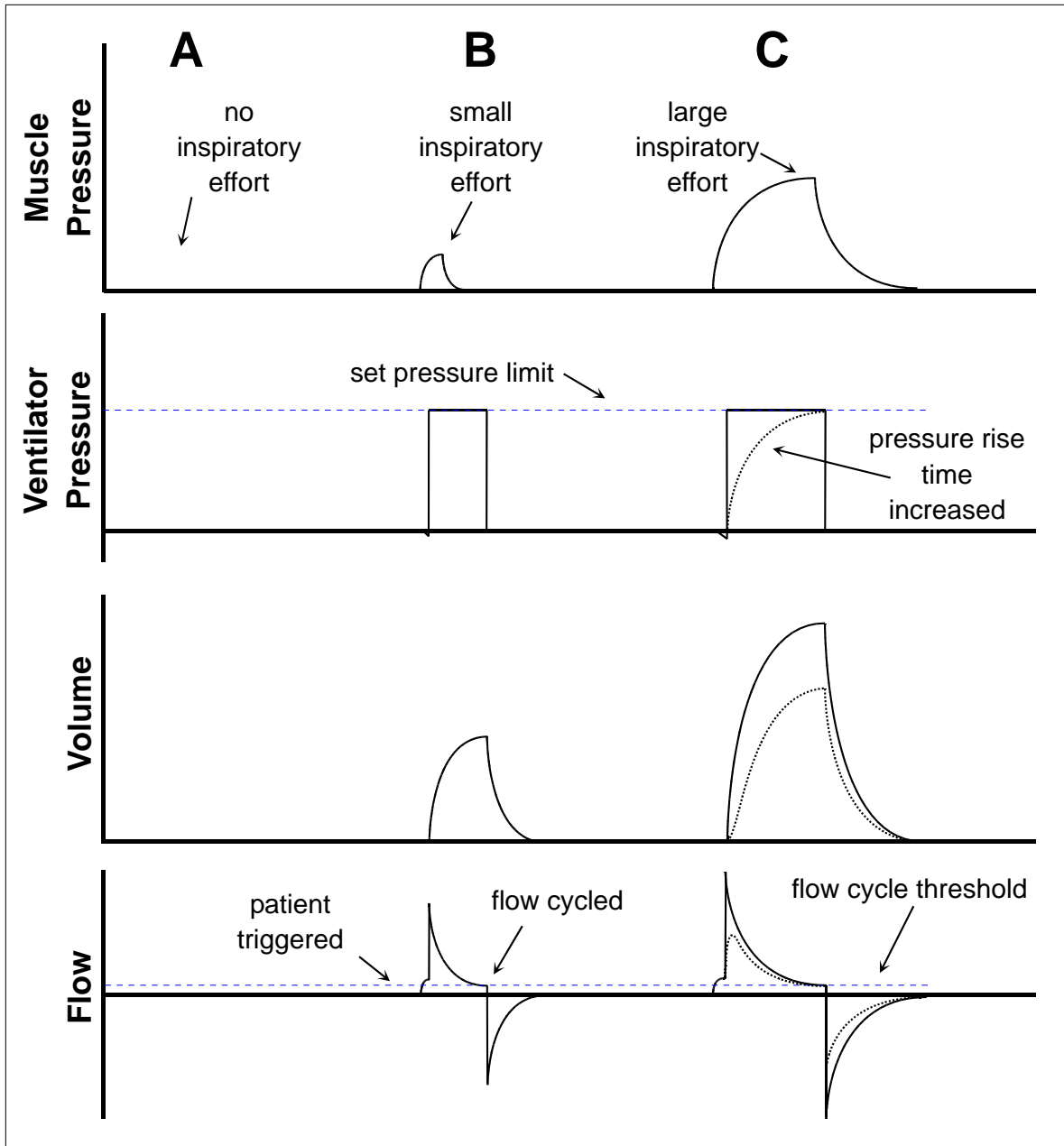


Pressure Support

- **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

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

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

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

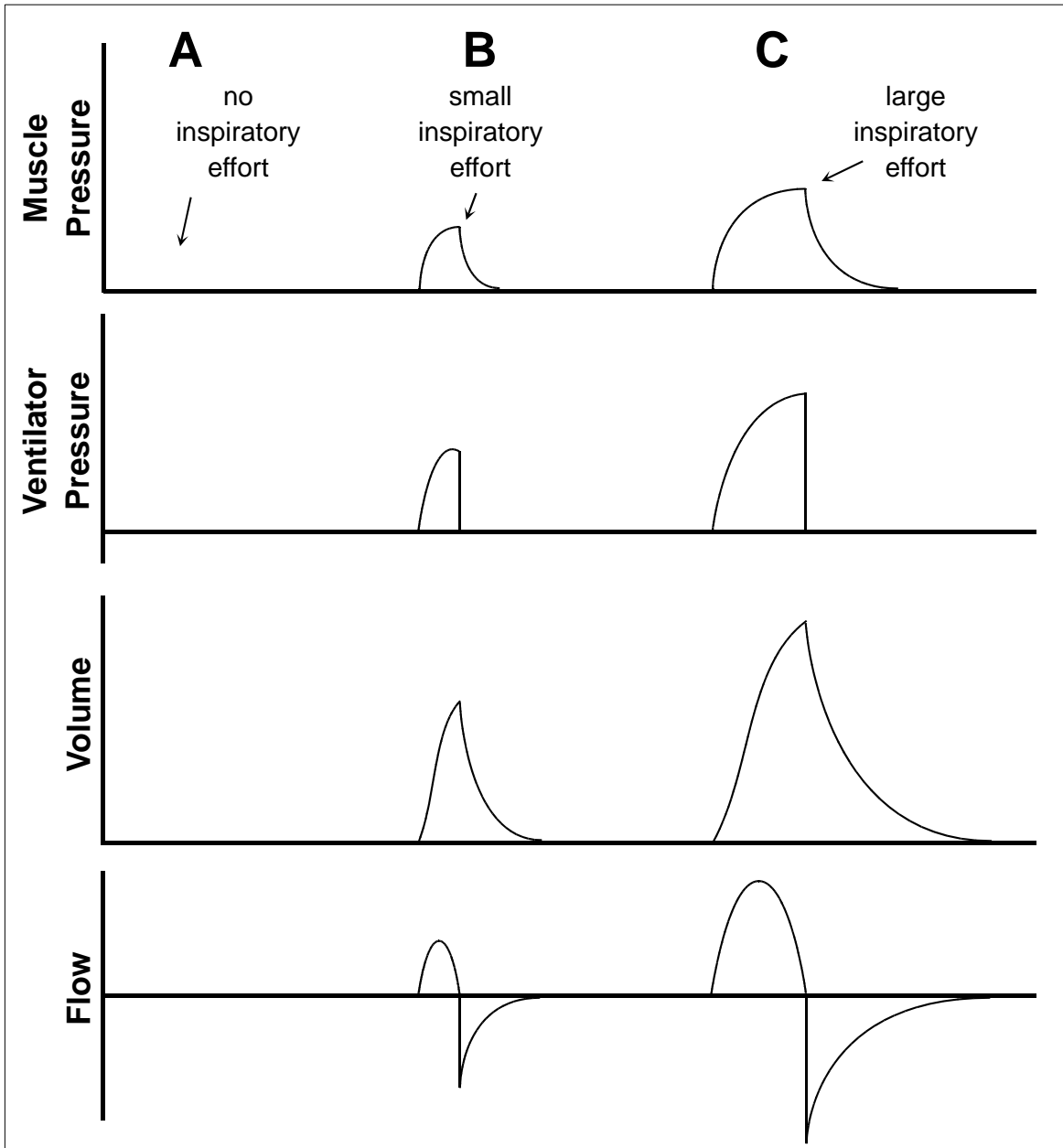
$$P_{mus} + P_{vent} = (normal\ load) + (abnormal\ load)$$

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

operator settings (volume and flow amplification factors)

PC-CSV waveforms

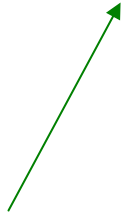
Spontaneous breaths
are assisted
(Proportional Assist)



Automatic Tube Compensation

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

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

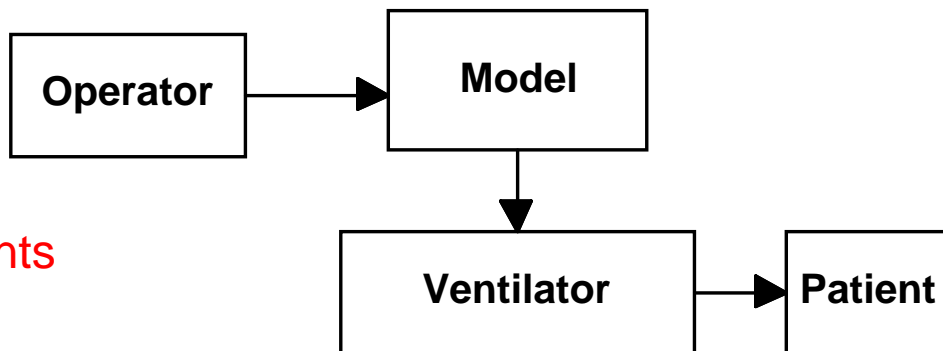
Tactical Control (within-breaths)

- *setpoint (PC-IMV)*
 - *auto-setpoint (Pmax)*
 - *servo (Automatic Tube Compensation)*
- operator-selected, static setpoints



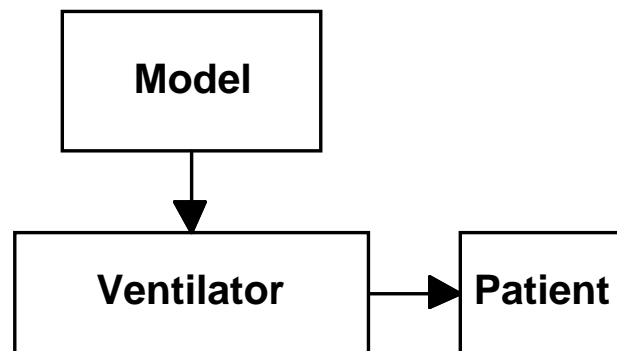
Strategic Control (between breaths)

- *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

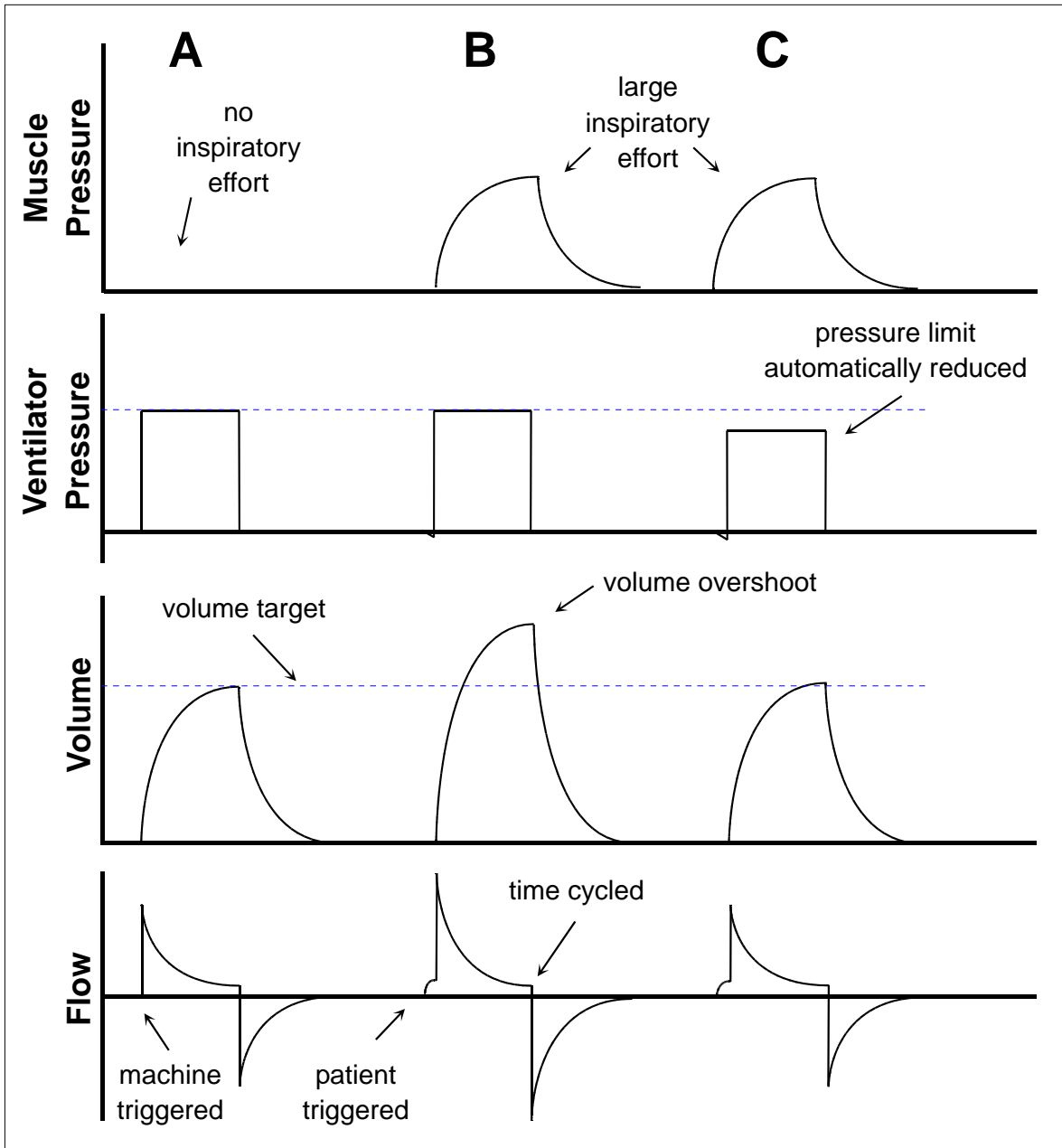
- **Indications**

- (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 CO₂.
 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

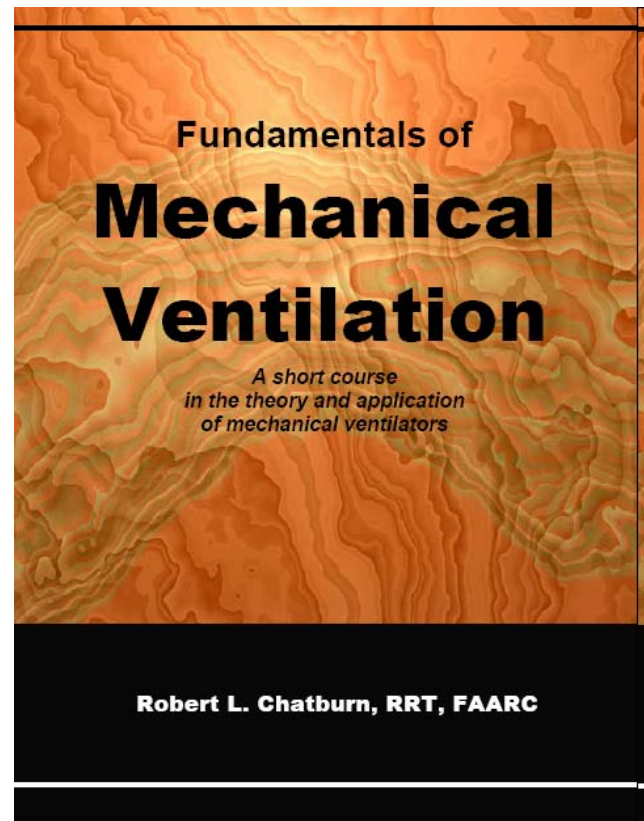
- **Pressure Regulated Volume Control**
- **AutoFlow**
- **VC+**
- **PC-SIMV + Volume Guarantee**

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