An Overview of Ventilator Pressures and Waveforms

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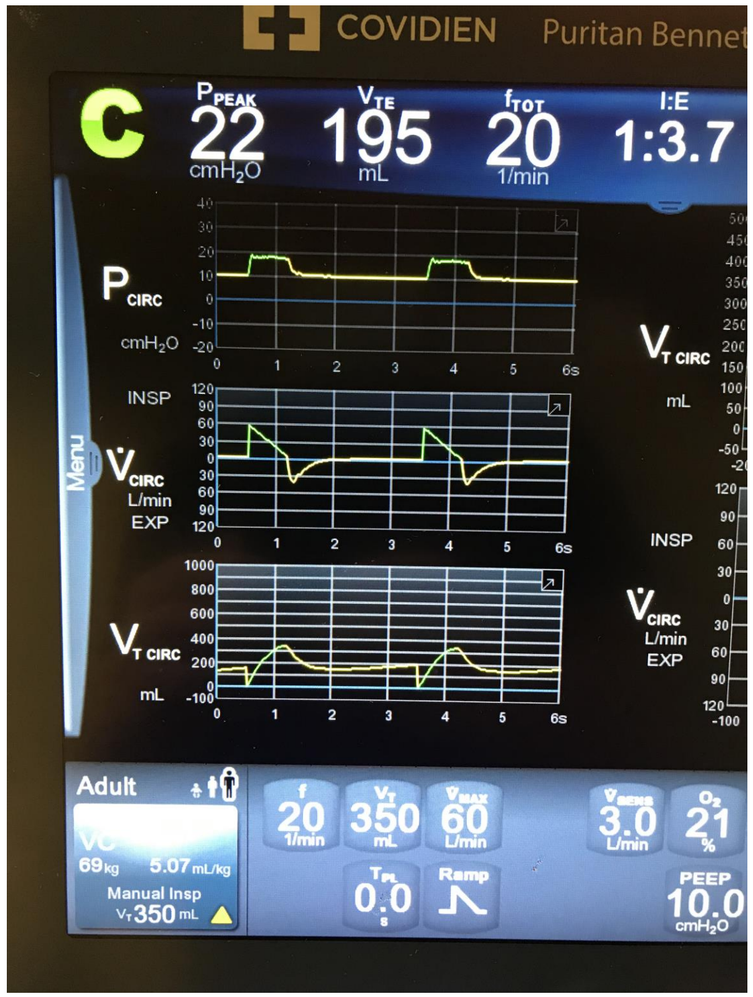
Learning Objectives

- Review Various Ventilatory Pressures
- Examine Strategies to Manage Pressures
- Describe Pulmonary Mechanics and Techniques to Manage Them
- Review the Basics of Ventilator Waveforms
- Examine Strategies to Manage Common Waveform Abnormalities
- Review Some Examples
- Furnish Additional Resources

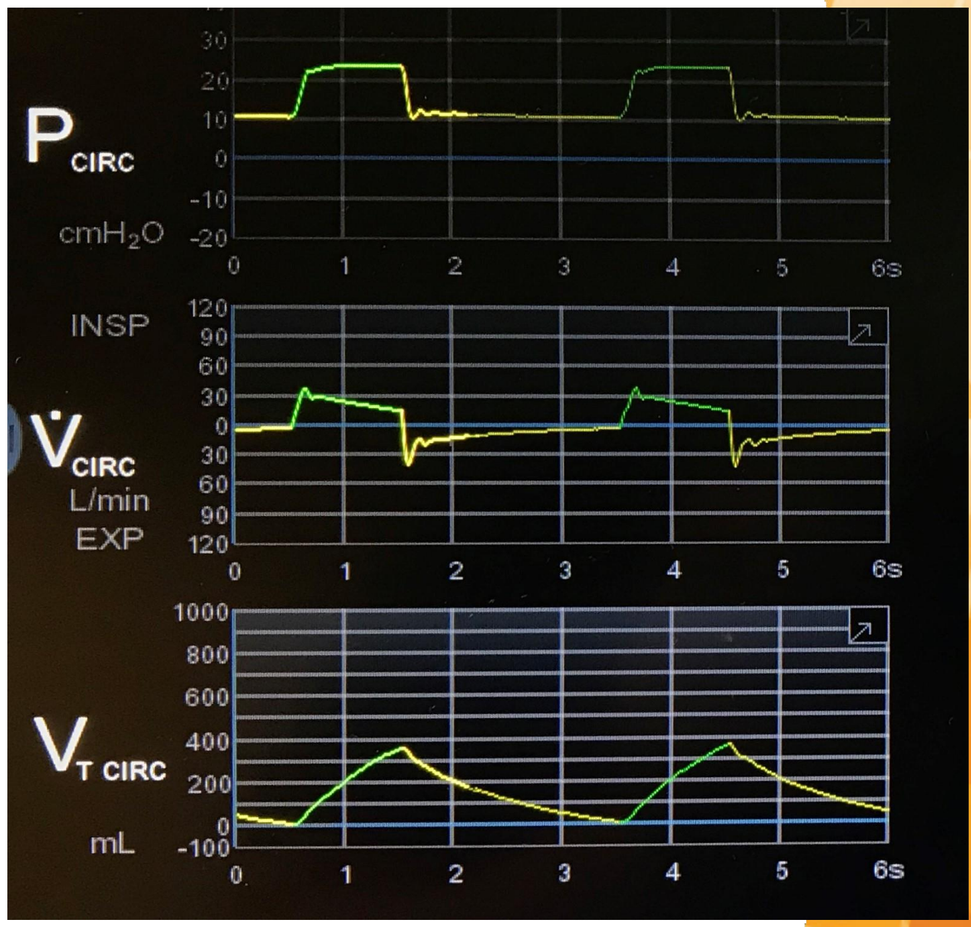


Atlantic Health System

Key Ventilating Pressures

Pressures:

- ✓ Peak Inspiratory Pressure (PIP) - The highest level of pressure applied to the lungs during Inhalation.
- ✓ Positive End Expiratory Pressure (PEEP) - The application of pressure above atmospheric during exhalation.
- ✓ ***Mean Airway Pressure (P_{MEAN})***
- ✓ ***Plateau Pressure (P_{PLAT})***
- ✓ ***Driving Pressure ($\triangle P$)***



Positive End Expiratory Pressure (PEEP)

NIH NHLBI ARDS Clinical Network
Mechanical Ventilation Protocol Summary

OXYGENATION GOAL: PaO_2 55-80 mmHg or SpO_2 88-95%
Use a minimum PEEP of 5 cm H_2O. Consider use of incremental FiO_2/PEEP combinations such as shown below (not required) to achieve goal.

Lower PEEP/higher FiO2

FiO_2	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.7
PEEP	5	5	8	8	10	10	10	12

FiO_2	0.7	0.8	0.9	0.9	0.9	1.0
PEEP	14	14	14	16	18	18-24

Higher PEEP/lower FiO2

FiO_2	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.5
PEEP	5	8	10	12	14	14	16	16

FiO_2	0.5	0.5-0.8	0.8	0.9	1.0	1.0
PEEP	18	20	22	22	22	24

Mean Airway Pressure (P_{MEAN} or MAP)

- Refers to the *average* pressure applied during positive-pressure mechanical ventilation.

- Used to Calculate Oxygen Index:

  - ✓ (OI) = **MAP X FIO2 X 100 / PO2**

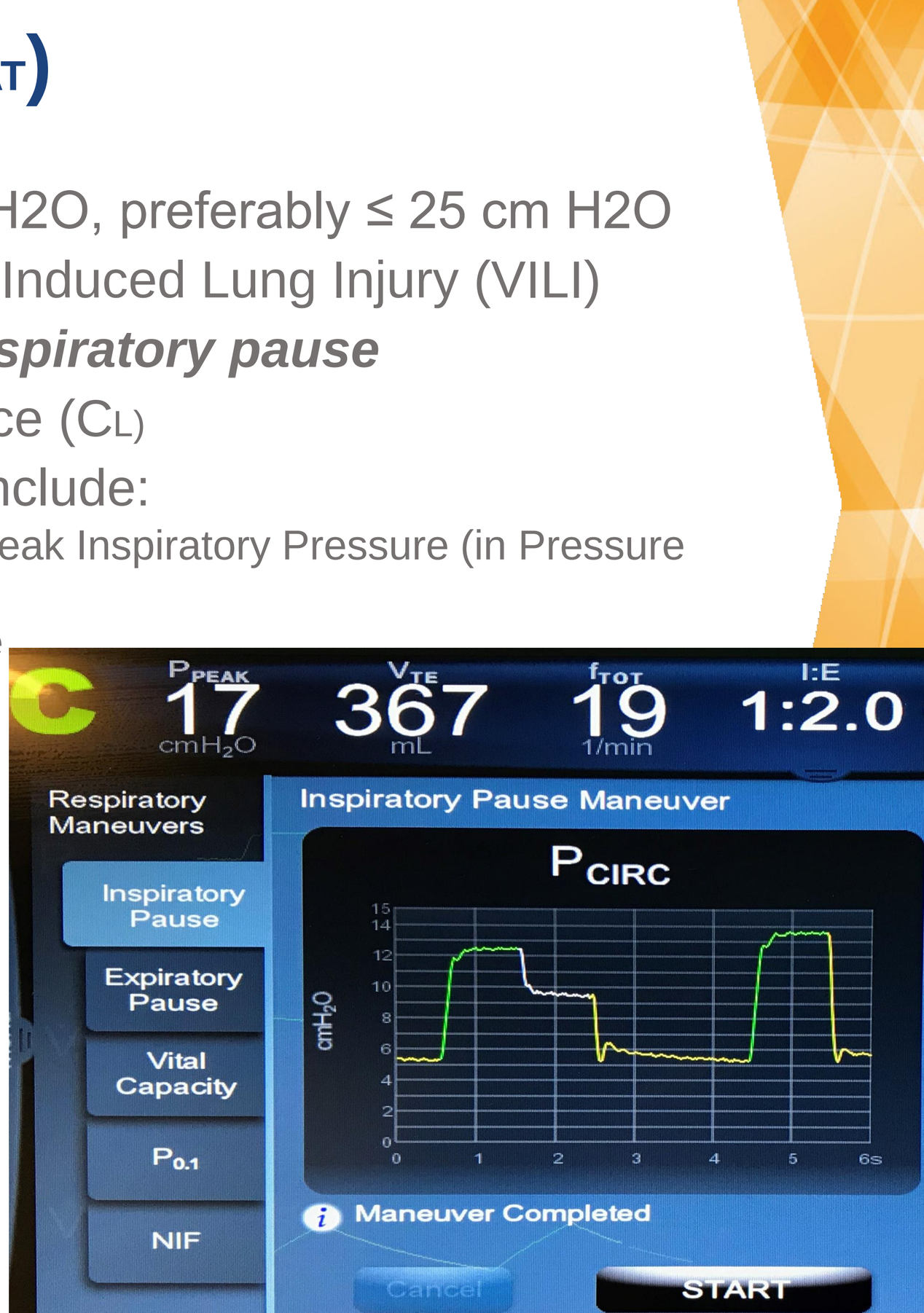
  - ✓Lower OI is better -- Targeted OI < 20-25

  - ✓Unlike P:F Ratio, OI considers patient ***response to both PEEP*** & FIO2

- **PEEP is a major contributor to MAP**

Plateau Pressure (P_{PLAT})

- Goal is to maintain a P_{PLAT} ≤ 30cmH2O, preferably ≤ 25 cm H2O
- Implicated as a contributor to Vent Induced Lung Injury (VILI)
- It is measured by performing an ***inspiratory pause***
- Used to Calculate Static Compliance (C_L)
- Basic strategies to manage P_{PLAT} Include:
  - ✓Tidal Volume (in volume ventilation) or Peak Inspiratory Pressure (in Pressure Control Ventilation)
  - ✓Inspiratory Time or Inspiratory Flow Rate
  - ✓Inspiratory Flow Waveform
  - ✓Address any Air Trapping or Auto-Peep



Driving Pressure

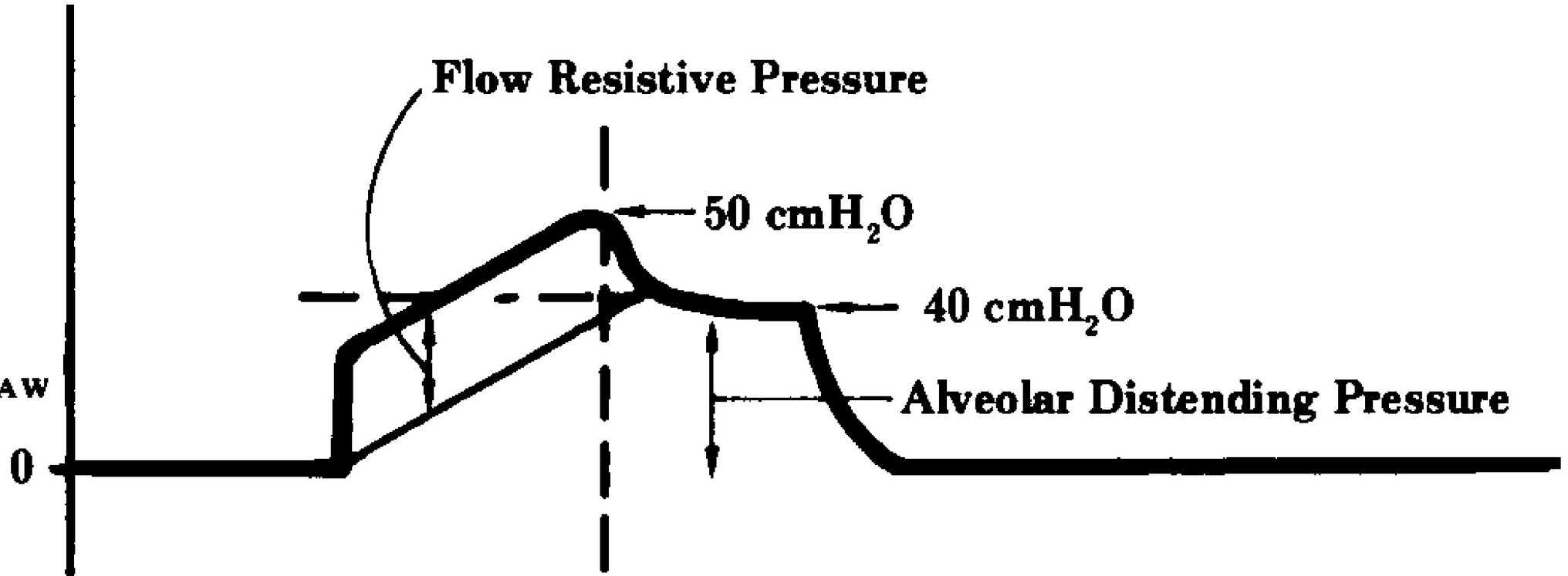
- The difference between the plateau pressure and PEEP **(Plateau minus PEEP).**

- Comprised of two pressures applicable to the lung itself, the transpulmonary pressure **(△PL)**, and that applied to the chest wall **(△PCW)**.

- Current suggestions are to maintain driving pressures ***< 15cmH2O.***

- Management Strategies are similar to those for Plateau Pressures
  - ✓***Except***, where increases in PEEP result in lung recruitment without increasing driving pressure.

Pulmonary Mechanics—
Compliance and Resistance



Sample Calculations:

$$C_L = \frac{V_T}{\text{Plateau } P_{AW} - \text{Baseline } P_{AW}} = \frac{1000}{40 - 0} = 25 \text{ ml./cmH}_2\text{O}$$

$$R_{AW} = \frac{\text{Peak } P_{AW} - \text{Plateau } P_{AW}}{\dot{V}} = \frac{50 - 40}{1} = 10 \text{ cmH}_2\text{O/LPS}$$

Basic Strategies for Managing Pulmonary Mechanics

Static Compliance

- ↓ VT to 6 ml/Kg (if ABG permits)
- Body position-Reverse Trendelenburg

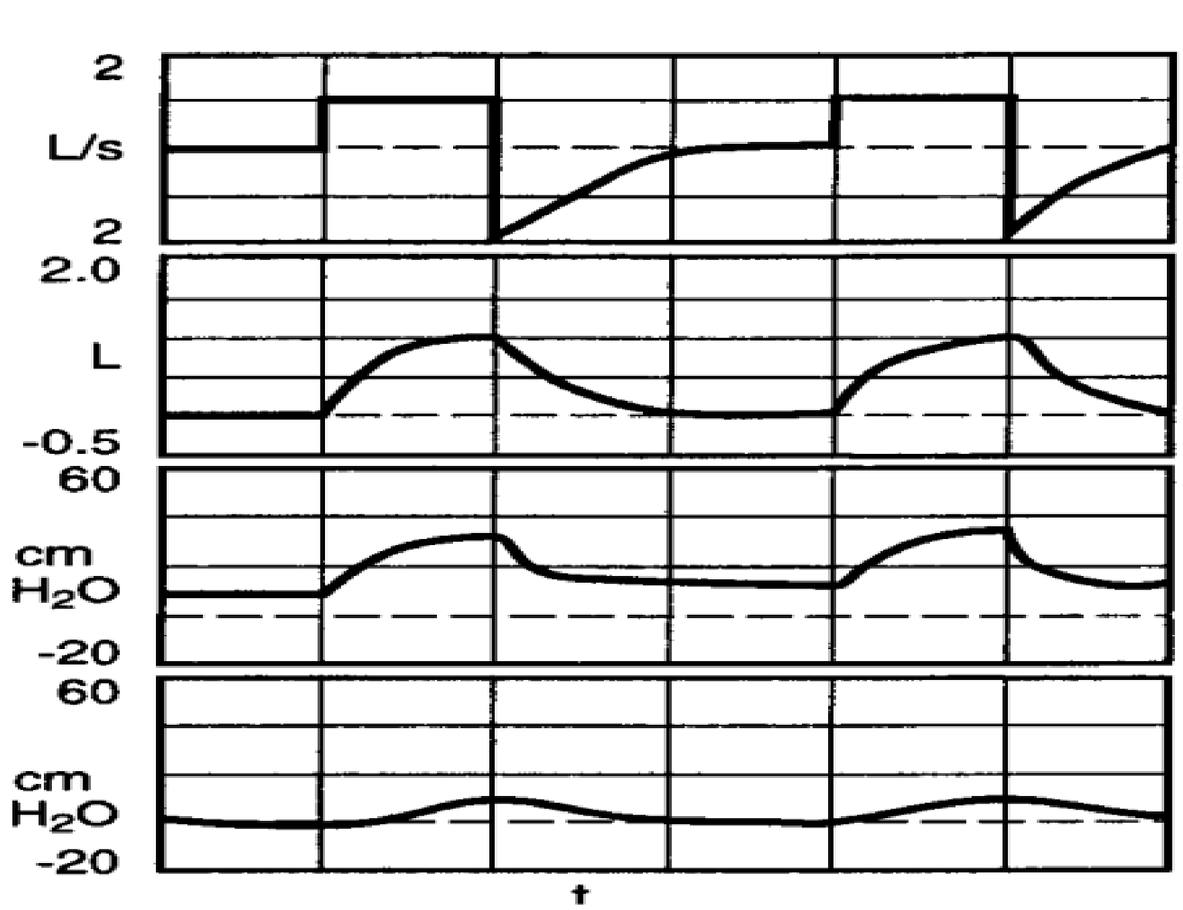
Resistance

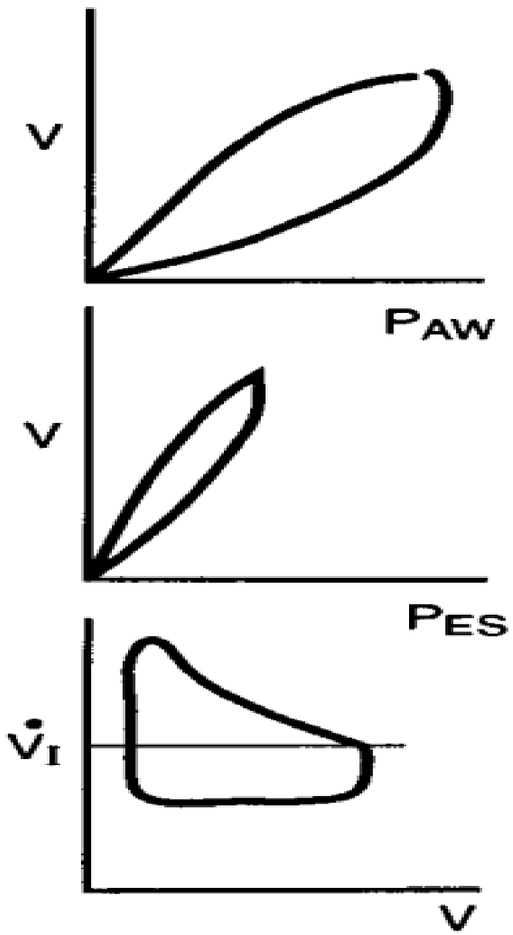
- Airway diameter
  - ✓Anatomic Airway-
    - ➢Bronchodilatators
    - ➢Suction
  - ✓Artificial airway-
    - ➢Increase airway size
    - ➢Wiper catheter
    - ➢Tube exchange

Types of Graphics Displays

Scalars are waveform representations of pressure, flow or volume on the y axis vs time on the x axis

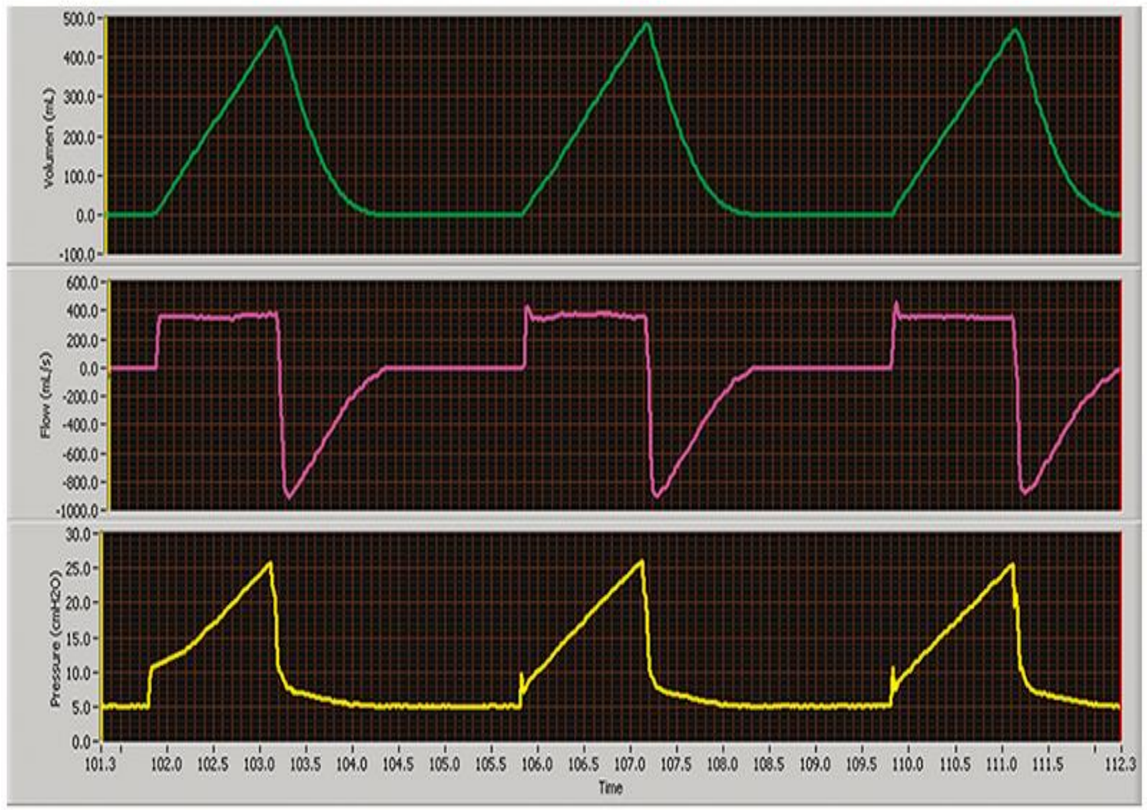
Loops are representations of pressure vs volume or flow vs volume



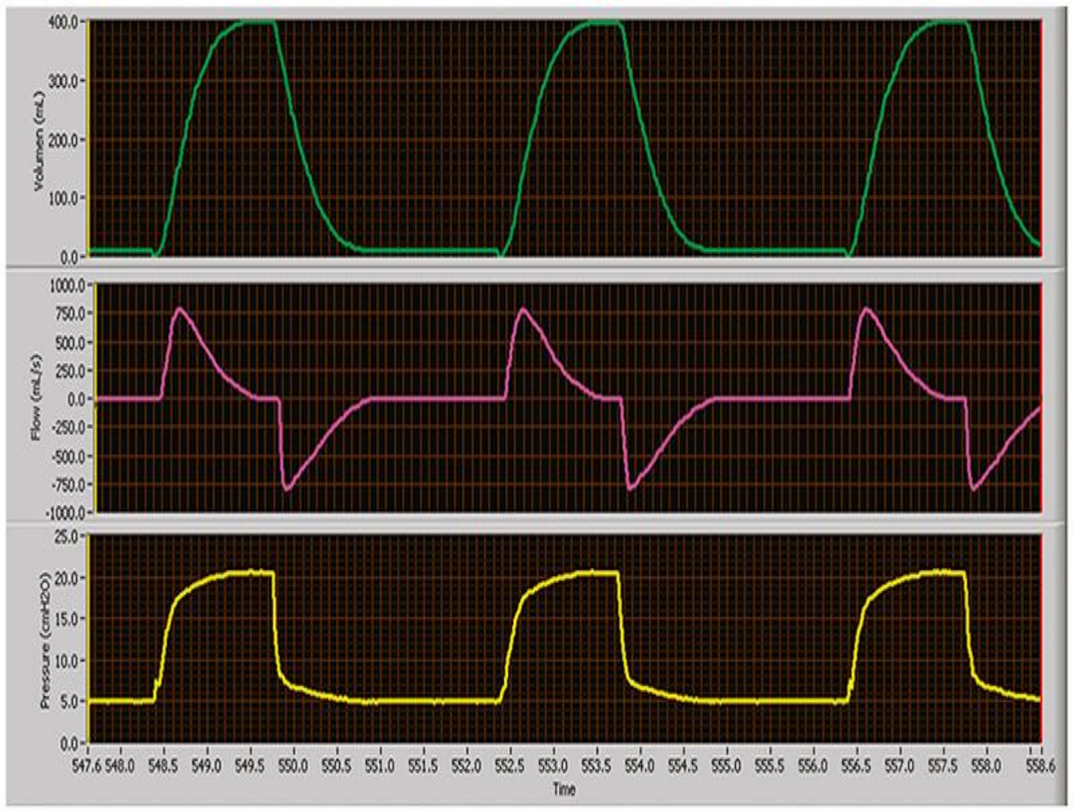


Volume Control vs Pressure Control

Assist Control -- Volume Controlled Ventilation



Pressure Controlled Ventilation



Uses of Vent Waveforms

Abnormal Ventilator Parameters & Lung Mechanics (e.g., Overdistension and Auto-PEEP)

Patient Ventilator Interaction (e.g., Flow starvation, triggering problems)

Vent Circuit & Artificial Airways Problems (e.g., secretion build-up in circuit/Airway), Leaks

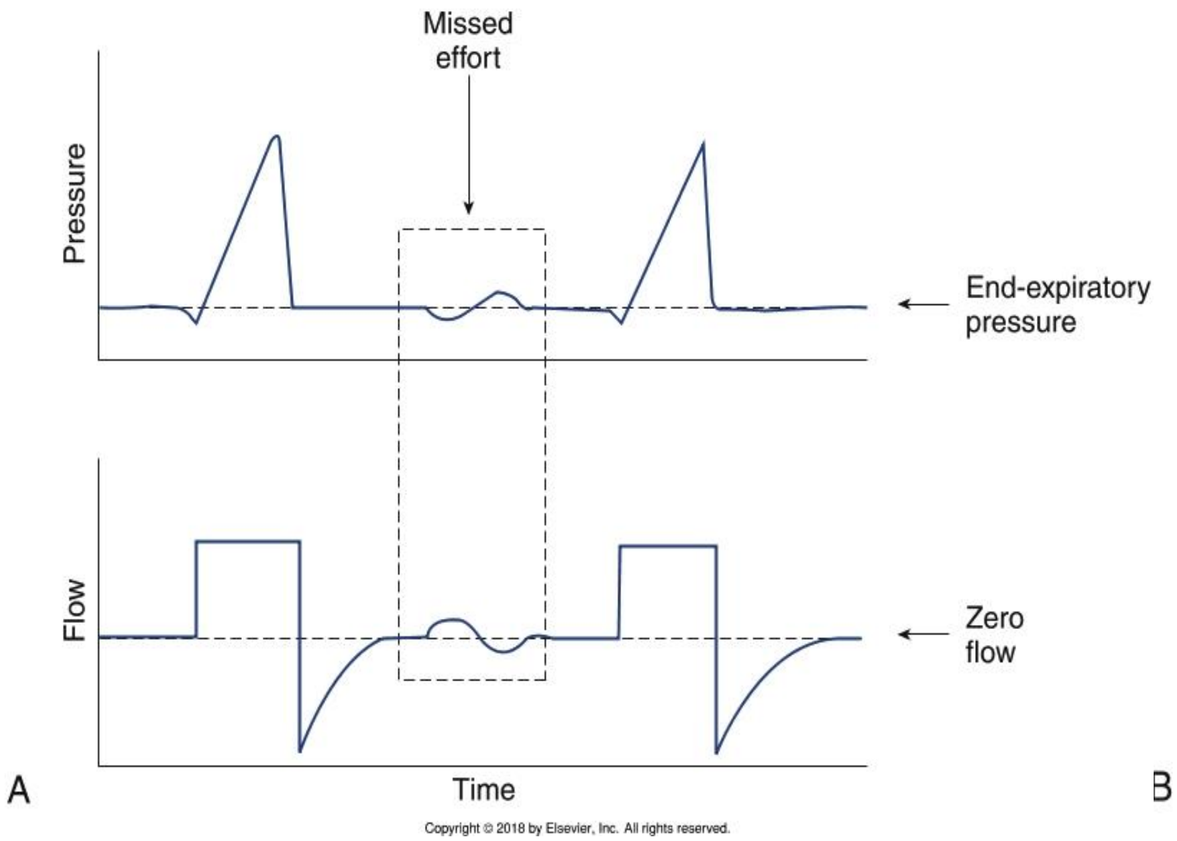
Detecting Common Abnormal Events

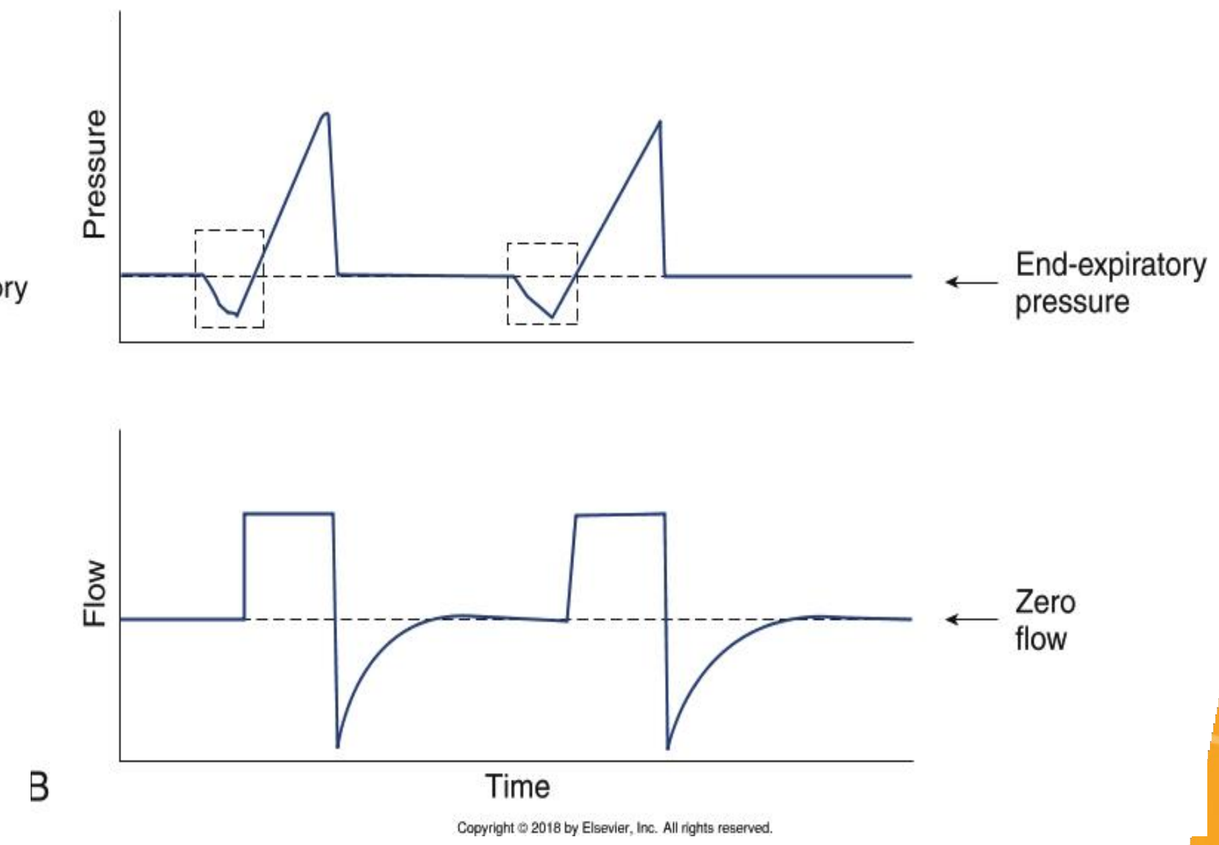
- **Examples:**
  - ✓**Scalers**
    - ➢Trigger/Sensitivity Problems
    - ➢Auto-PEEP (air trapping)
    - ➢Patient-Ventilator Desynchrony
  - ✓**Loops**
    - ➢Over distension
    - ➢Setting PEEP

Trigger Sensitive Problems—

A = Patient could not trigger a breath (Not sensitive enough)

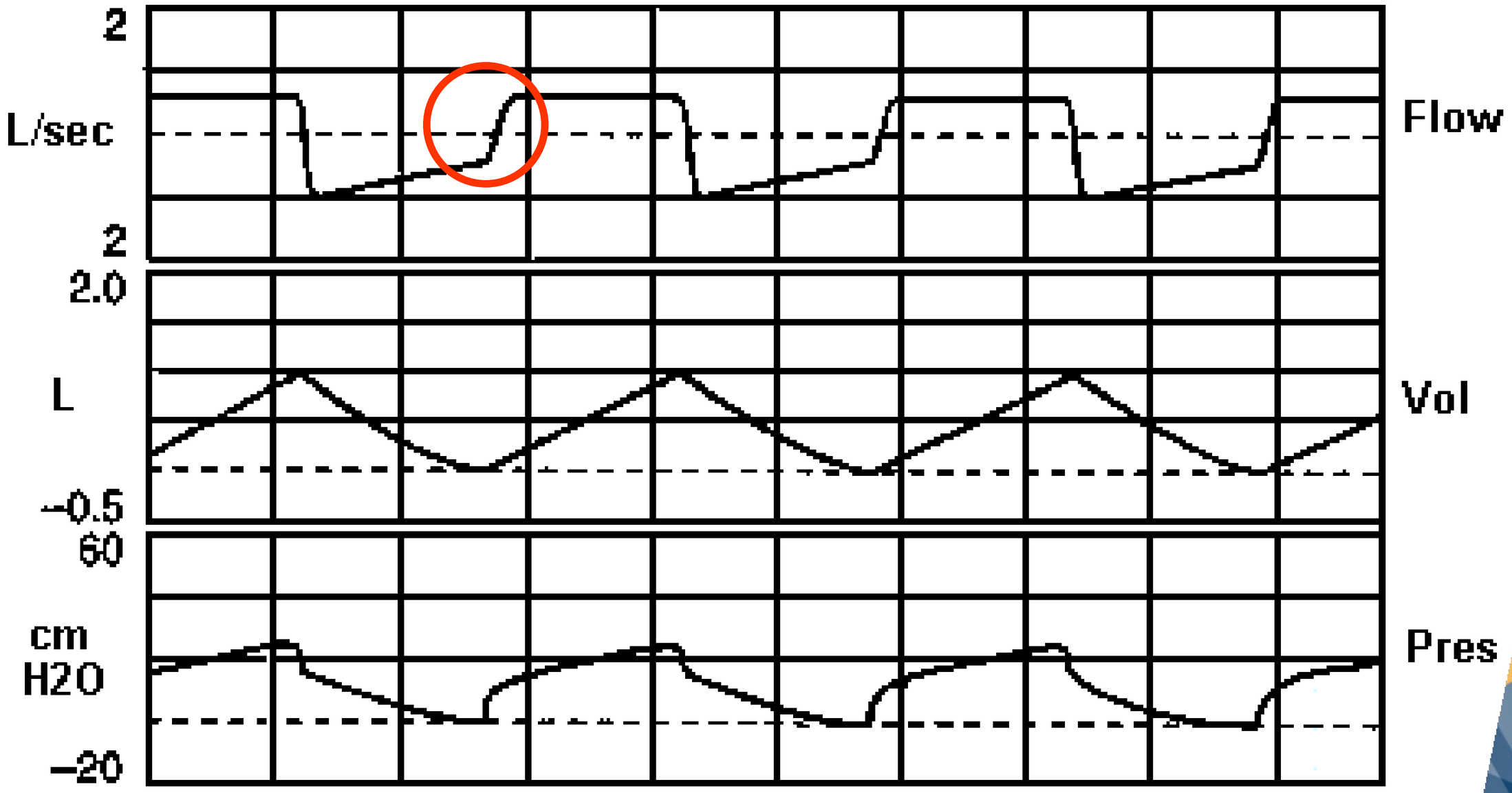
B = Excessive effort to trigger a breath





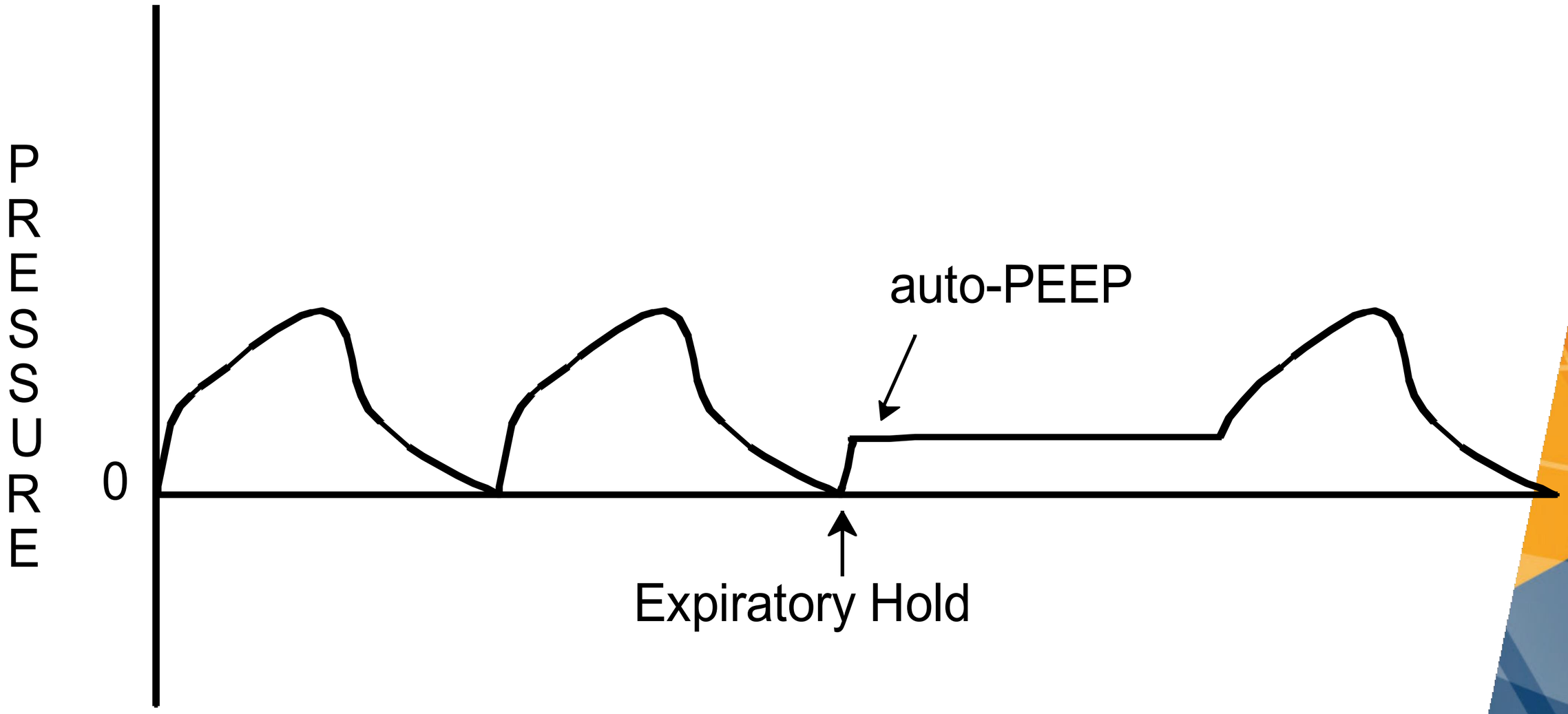
- **Management:**
  - ✓Switch to a Flow Trigger
  - ✓Properly set trigger level

Auto-PEEP *Detection*



Auto-PEEP ***Measurement***

- Perform expiratory pause maneuver
- Quantifies how much auto-Peep

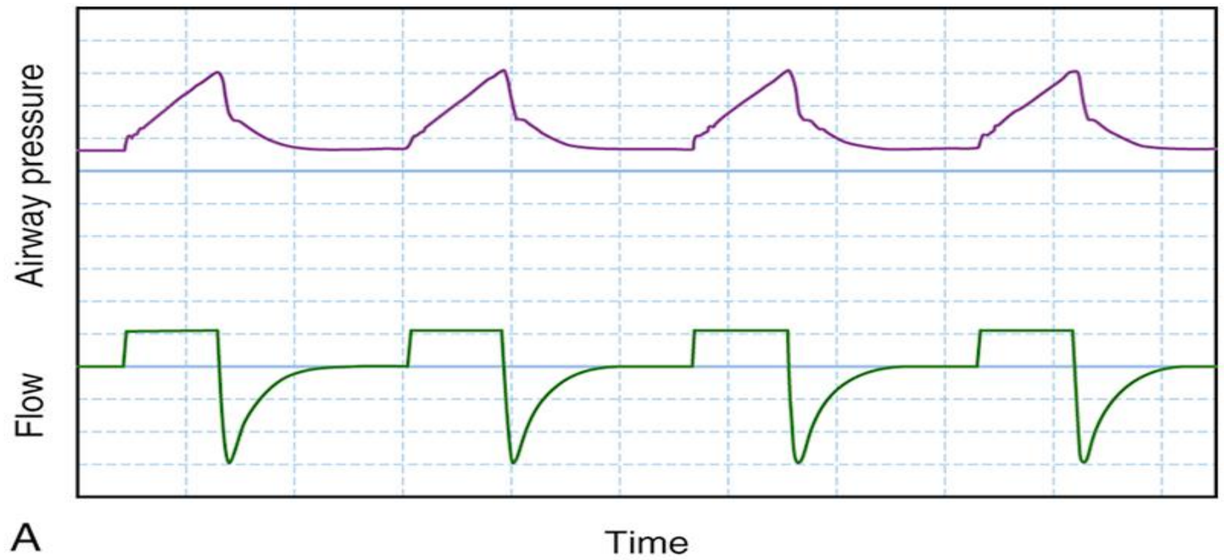


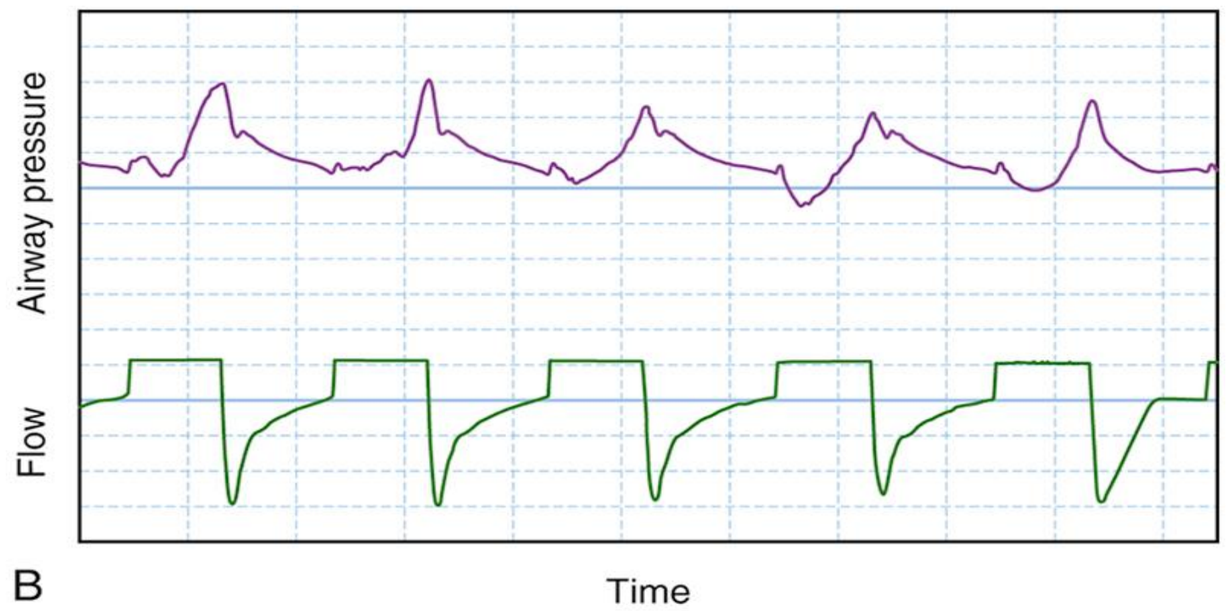
Basic Strategies for Managing Auto-PEEP

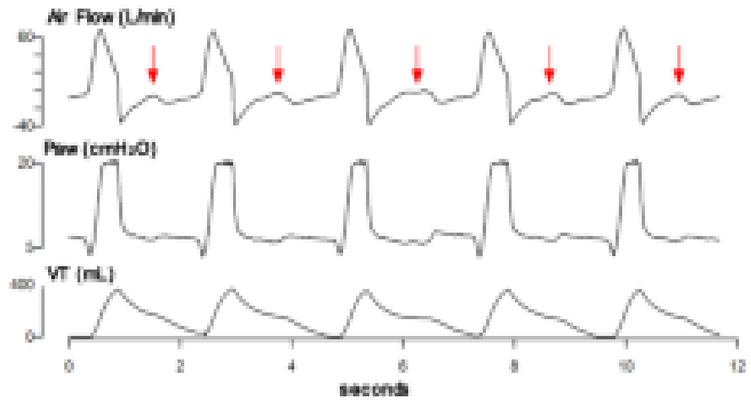
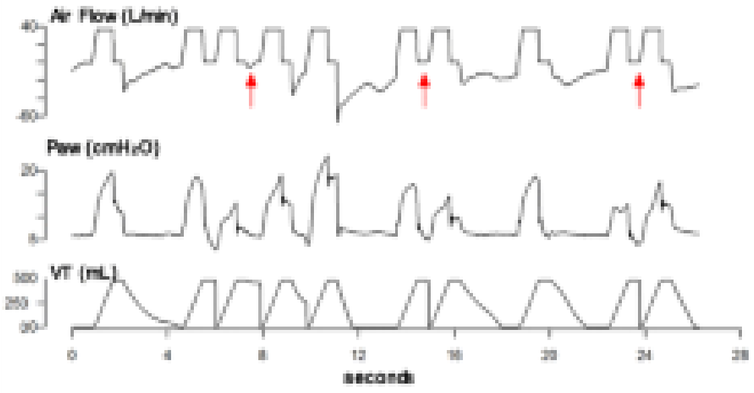
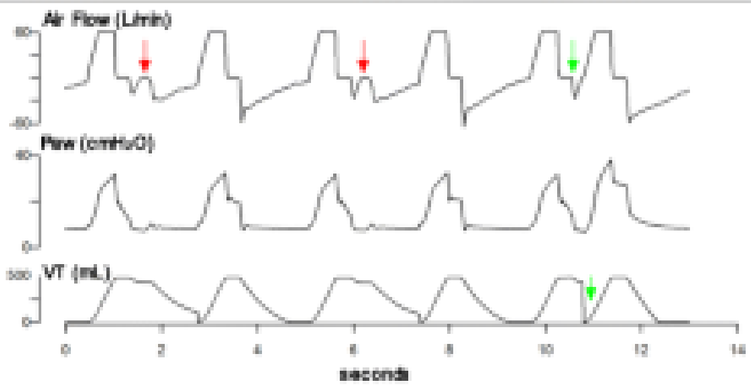
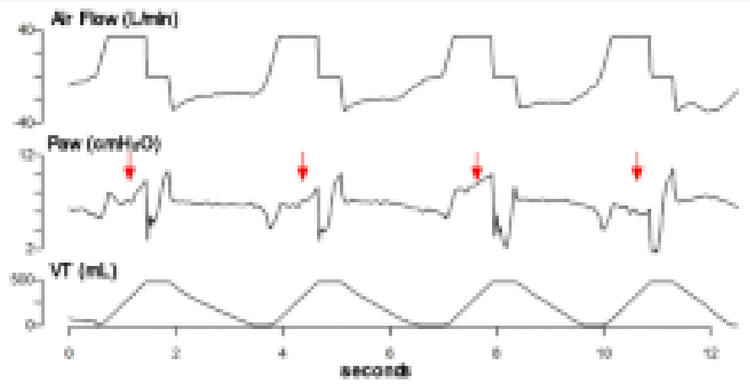
- Adjustment of Inspiratory Time or Flow Rate
  - ✓↓ I-Time (If Dual Mode/VC+)
  - ✓↑ Airway size
  - ✓↑ Inspiratory Flow (if VC/AC)
- ↓ Respiratory Rate (If ABG permits)
- Treatment of Bronchospasm
- Secretion Management/Suctioning
- Address asynchrony/desynchrony

Flow Desynchrony

- A = Adequate flow shown by linear increase in pressure
- B = Severe flow desynchrony



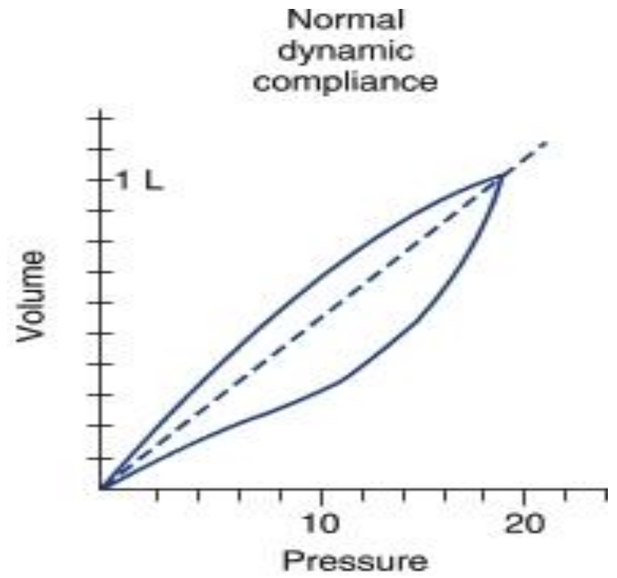


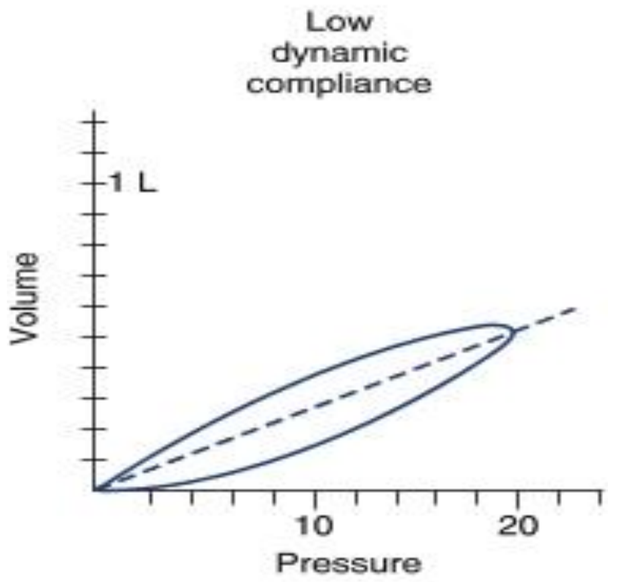
Asynchrony	Graphic representation	Description	Causes
Ineffective Efforts		Inspiratory muscle efforts not followed by a ventilator breath (red arrows)	Inadequate trigger sensitivity Excessive assistance Overdistension/Air trapping Low respiratory drive Low level of pCO2 Oversedation
Double Cycling		Inspiratory effort that continues beyond the ventilator inspiratory time producing a second or a third ventilator breath (red arrows) without expiration. Consequently, the volume of the first breath is added to the second or third breath.	Inadequate setting of ventilator inspiratory time Inadequate trigger sensitivity (too sensible) Inadequate circuit pressurization Patient effort too strong Reverse triggering
Reverse Triggering		Ventilator insufflations that trigger diaphragmatic muscle contractions (red arrows) in response to passive insufflation of the lungs. When the diaphragmatic muscle contraction occurs at the end of inspiration a double cycled breath can occur (green arrow) .	Oversedation Overdistension/Air trapping
Inspiratory Airflow Dyssynchrony		Strong patient inspiratory effort (concavity in pressure tracing) due to insufficient inspiratory airflow in a patient ventilated in assist-volume controlled mode.	Inadequate gas flow Dyspnea Delirium/Pain

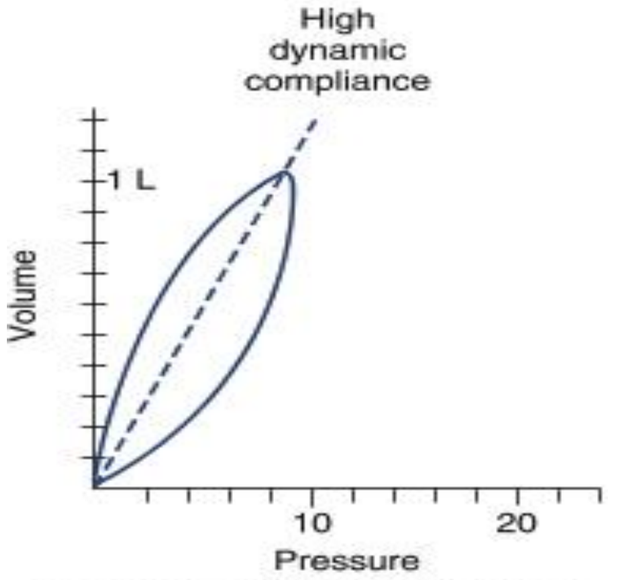
Basic Strategies for Managing Desynchrony

- ***Agitation and/or Delirium***
  - ✓Medication
- ***If stable, switch to PSV => Extubate if possible***
  - ✓Decouple SAT and SBT
- ***Trigger Sensitivity***
  - ✓Switch to Flow Trigger (if pressure trigger)
- ***Adjust Inspiratory Time or Inspiratory Flow***
- ***Auto-PEEP***
  - ✓Address Auto-Peep
- ***Bronchospasm***
  - ✓Bronchodilators

Pressure Volume Loops
with
Different Lung Mechanics







Adjusting PEEP Levels

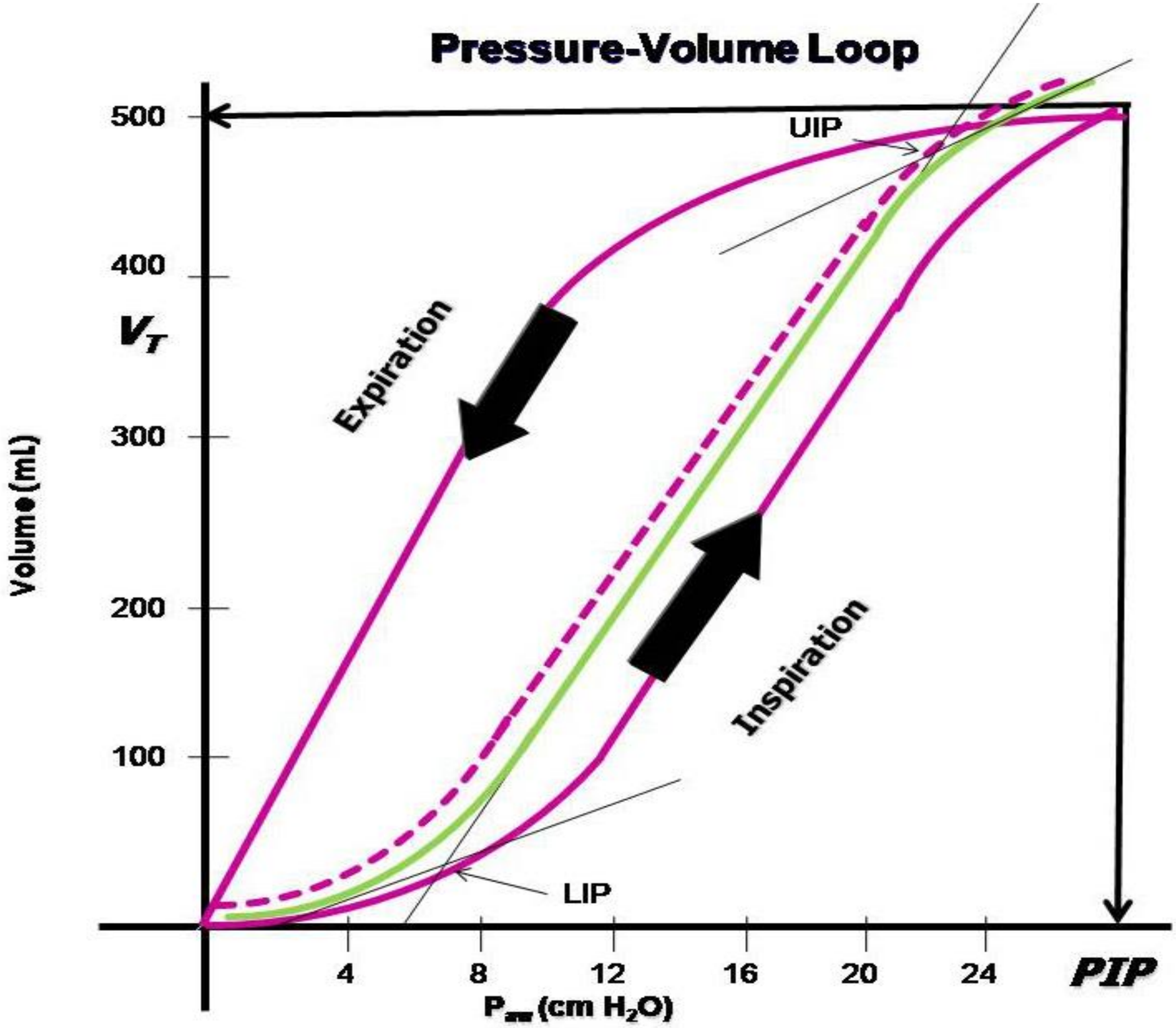
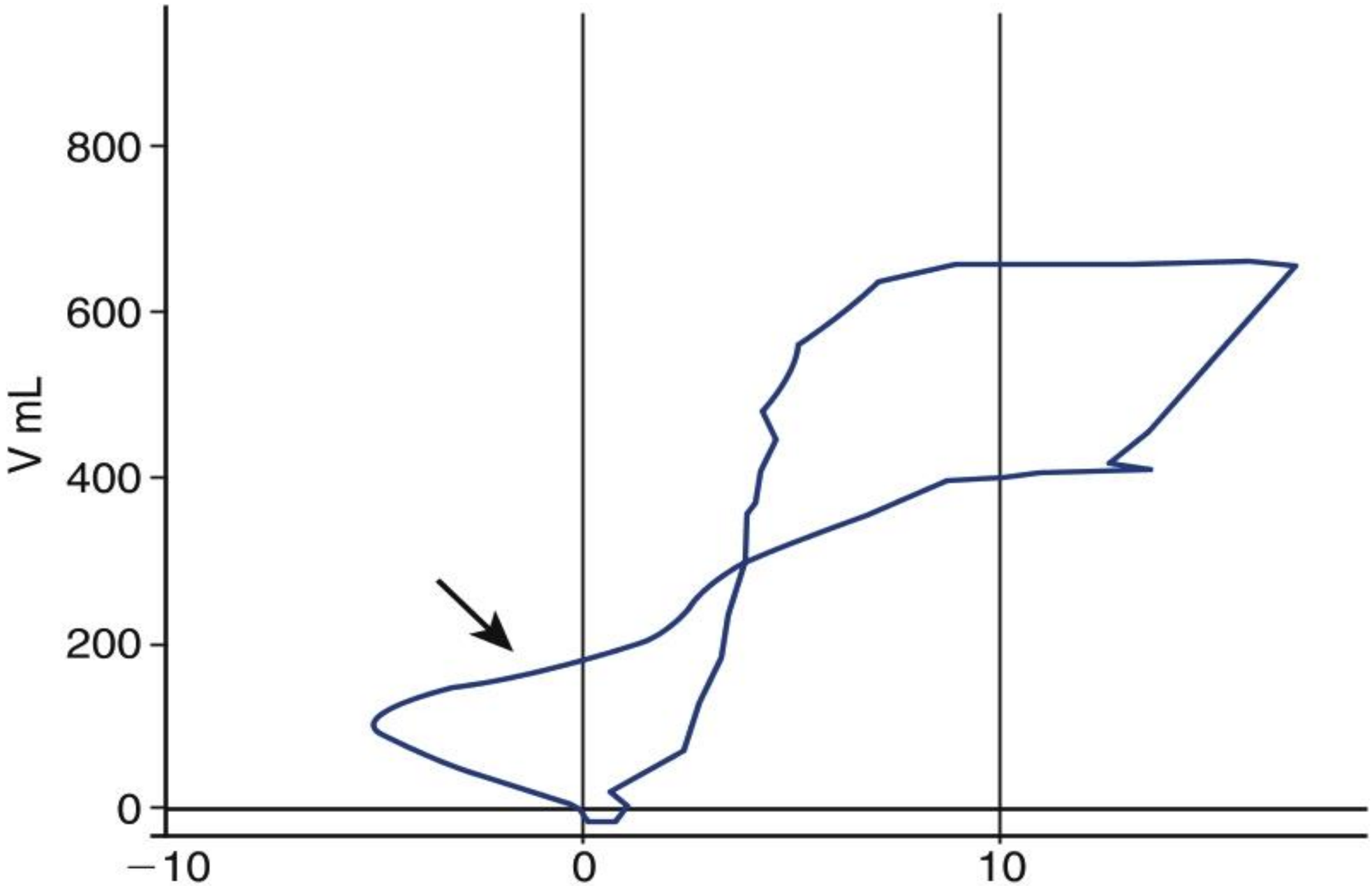


Figure Eight Pressure Volume Curve -- Suggesting Patient's Inspiratory Flow Exceeds that Which is Set.



Basics of Utilizing Pressure Volume Loops

- ***If Over distension Suspected via An Upper Deflection Beak***
  - ✓Reduce VT, as tolerated per ARDS Net
  - ✓Reduce Insp Flow or increase I-Time

- ***If Figure Eight, Increase Flow***

- ***If insufficient PEEP is suspected, consider increasing PEEP to 1-2 CM above lower inflection point, as tolerated.***
  - ✓Monitor patient for adverse response
    - ➢Hemodynamic compromise (BP, CO)
    - ➢Driving Pressure

Case 1- Managing Plateau Pressures

- 54 YO, 5’10”, 250lb (114 Kg’s) male post - chest trauma patient day 7 of mechanical ventilation with settings of AC-560-20-60%-8 PEEP. ABG is 7.44-35-61-26- +1 - 91%. PAP = 37 cm H2O, plateau 31 cm H2O.
- What recommendation would you make regarding vent settings to enhance oxygenation and manage airway pressures and why?
- **Suggested Recommendations:**
  - ✓Reduce VT from approx. 8 ml/Kg to 6 ml/Kg = 450ml
  - ✓Increase PEEP to 10 cmH2O, repeat insp. pause
  - ✓Possibly reduce inspiratory. flow or increase I-time to 1:2 I:E

Case 2- Addressing Auto PEEP

- 21 YO 5’5” 120lb female with status asthmaticus recently intubated for impending respiratory failure. Vent settings are AC – 350 – 24 – 40% - 5 PEEP. ABG 7.39-42-76-24-0-95%. PAP = 39 cm H2O and Plateau pressures approx. 26 cm H2O. An expiratory pause indicates her (intrinsic) auto-PEEP is 10 . What recommendation could be made to the attending physician to reduce the auto-PEEP and improve ventilation?
- ***Suggested Recommendations:***
  - ✓Recommend bronchodilator (continuous albuterol?)
  - ✓Decrease insp. time (target I:E of 1:3 – 1:4)
  - ✓Increase insp. Flow
  - ✓Suction A/W
  - ✓Heliox (70/30)
  - ✓Manually Decompress (Intermittently take off the vent)

Case 3- Addressing Desynchrony

- 45 YO 5’8” 190lb (86 Kg) male s/p exploratory lap, resulting in an uncomplicated bowel resection. Vent settings are VC 450 – 20 – 40% - 8 PEEP. ABG 7.37-38-112-20--2-99%. PAP = 32 cm H2O and Plateau pressures approx. 24 cm H2O. Actual RR is 32 breaths per minute. HR is sinus tach 120. RASS is +2. What recommendation could be made to the attending physician to improve patient ventilator synchrony?
- ***Suggested Recommendations:***
  - ✓Decouple SAT and SBT
  - ✓Consider extubation

Selected References

- Kacmarek, RM, Stoller, J & Heuer AJ, ***Egan's Fundamentals of Respiratory Care***, ed 12th ed, 2021.
- The National Heart, Lung, and Blood Institute (NHLBI), National Institutes of Health (NIH), ARDSNet, NHLBI ARDS Network
- **Ventilator Graphics**: Scalars, Loops, & Secondary Measures. Dexter AM, Clark K, Dexter AM, et al. Respir Care. 2020 Jun;65(6):739-759. doi: 10.4187/respcare.07805.
- Mechanically **Ventilating** the Severe Asthmatic. Laher AE, Buchanan SK.Laher AE, et al. J Intensive Care Med. 2018 Sep;33(9):491-501. doi: 10.1177/0885066617740079. Epub 2017 Nov 5.J Intensive Care Med. 2018. PMID: 29105540

Questions?