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Author: Thomas Sisson, MD, 2009

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Introduction to Mechanical Ventilation

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Winter 2009

University of Michigan
Medical School

What is Mechanical Ventilation?

Delivery of Ventilation and Supplemental Oxygen with a Mechanical Ventilator to Support a Patient Experiencing Respiratory Failure.

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Indications for Mechanical Ventilation:

Respiratory Failure:

Hypoxemic Failure:

V/Q Mismatch vs. Shunt vs. Hypoventilation

PaO2<60mmHg on 100% NRB

Pneumonia
ARDS
Congestive Heart Failure
Pulmonary Embolism

Ventilatory Failure:

Altered Respiratory Mechanics

Acute ↑ pCO2 with Resp. Acidosis

COPD/Asthma
Acute Intoxication
Neuromuscular Disease
Sepsis
Obesity Hypoventilation

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Recognizing Respiratory Failure:

1) Arterial Blood Gas Abnormalities:

- Hypoxemia: $PaO_2 < 60$mmHg or O_2 sat < 90% on 100% NRB
- Hypercapnea:
  - -Acute: pHΔ0.08 for pCO_2Δ10mmHg
  - -Chronic: pHΔ0.03 for pCO_2Δ10mmHg

2) Clinical Impression:

- Use of Accessory Muscles
- Inability to Speak in Full Sentences
- Paradoxical Respirations
- Altered Mentation
- Cardiopulmonary Arrest: When Respirations and Pulse Cease

How to Begin Mechanical Ventilation:

Need a Conduit:

- Endotracheal Tube: Invasive Mechanical Ventilation
- Face Mask: Noninvasive Mechanical Ventilation (NPPV)

2. Deliver Cyclical Positive-Pressure ‘Breaths’.

3. Provide Supplemental Oxygen.

4. Minimize Complications.

Placement of an Endotracheal Tube:

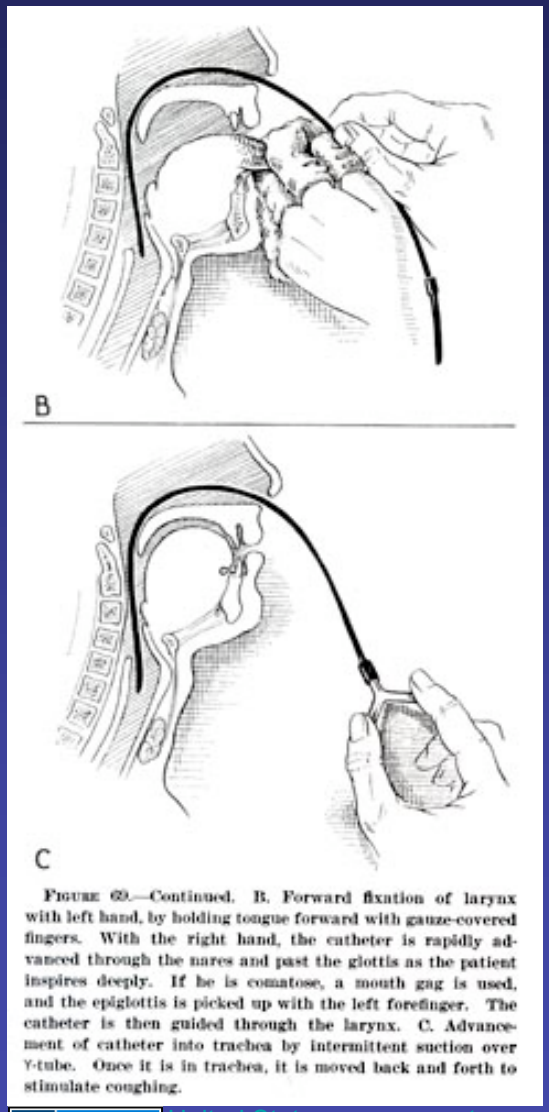

FIGURE 69.—Continued. B. Forward fixation of larynx with left hand, by holding tongue forward with gauze-covered fingers. With the right hand, the catheter is rapidly advanced through the nares and past the glottis as the patient inspires deeply. If he is comatose, a mouth gag is used, and the epiglottis is picked up with the left forefinger. The catheter is then guided through the larynx. C. Advancement of catheter into trachea by intermittent suction over Y-tube. Once it is in trachea, it is moved back and forth to stimulate coughing.

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Non-invasive Ventilation Mask:

PD-INEL ResMed

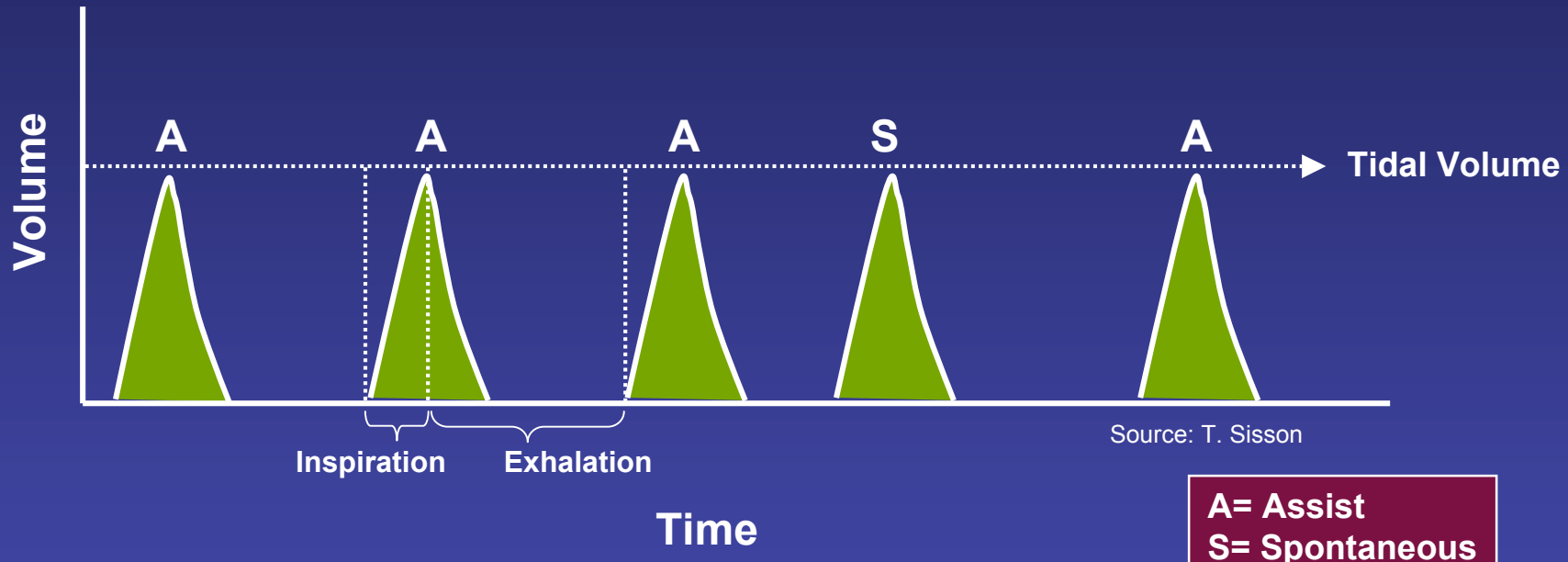
How to Begin Invasive Mechanical Ventilation: Settings

Options (for invasive ventilation):

- Mode: Assist-Control (A/C), Intermittent Mandatory Ventilation (IMV), Pressure Support Ventilation (PS), Others.
- FiO2: 21%-100%
- Rate: 0-35
- Tidal Volume: 4cc/kg to 10cc/kg
- Inspiratory Flow Rate: 60L/mim to 120L/min

Modes of Invasive Mechanical Ventilation:

Assist/Control



- I:E- Ratio of Time Spent in Each Phase
- Tidal Volume for Each Breath is Constant at Set TV
- Minute Ventilation: Rate (breaths/min) x Tidal Volume
- Additional Breaths Above Set Rate Are at Set TV.

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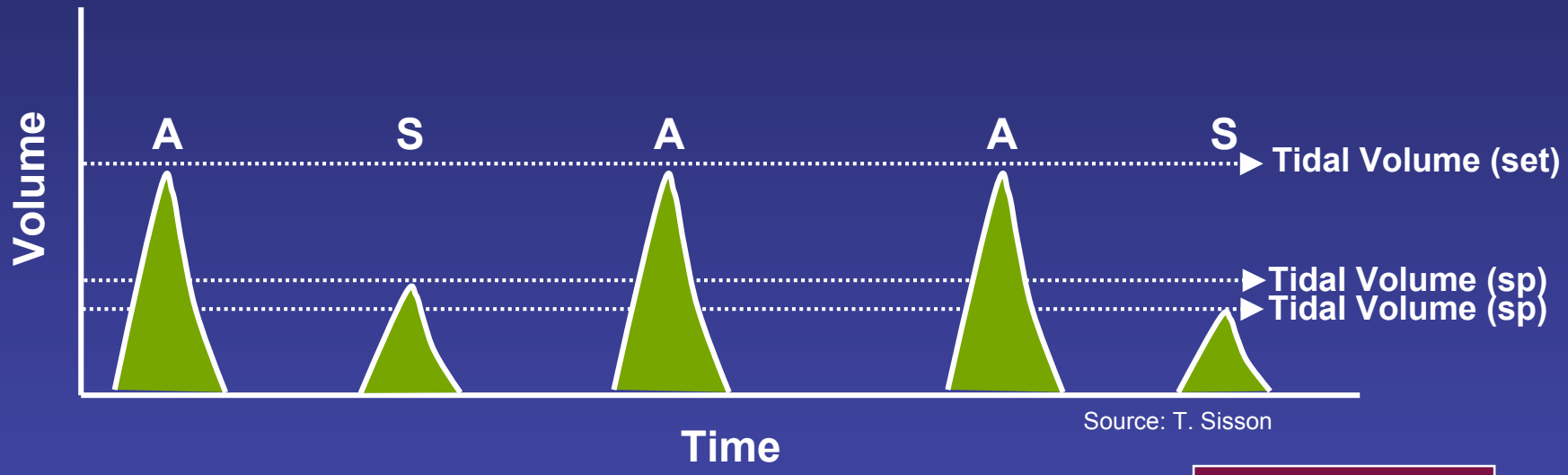
Modes of Invasive Mechanical Ventilation:

Intermittent Mandatory Ventilation



Source: T. Sisson

A= Assist
S= Spontaneous

- **Tidal Volume: Varies between Set Volume and Spontaneous**
- **Minute Ventilation: Rate (breaths/min) x Tidal Volume**
- **Additional Breaths Above Set Rate Are What Patient Generates.**

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Modes of Invasive Mechanical Ventilation:

Pressure Support Ventilation

S= Spontaneous

- **Tidal Volume: Varies with Each Breath. No Set Volume.**
- **Minute Ventilation: Rate (breaths/min) x Tidal Volume.**
- **No Set Rate with Pressure Support.**

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Choosing the Mode of Invasive Mechanical Ventilation:

	Rate	TV	Pressure	Flexibility	Comfort
A/C	Yes	Yes	No	++++	+
IMV	Yes	Yes	No	++	++
PS	No	No	Yes	+	++++

What is Meant By Flexibility?

Minute Ventilation = TV x RR ⟶ Determined by Metabolic State = CO_2 Production

Example: 55 year old woman admitted with toxic shock from lower extremity cellulitis. Intubated for respiratory distress. Initial minute ventilation is 10 L/min. Ventilator rate is set at 20 breaths/min with a TV of .500 L.

Mode	$Rate_{set}$	TV_{set}	TV_{sp}	$Rate_{sp}$	MV
A/C	20	.500 L	-	0	10L/min
IMV	20	.500 L	-	0	10L/min

Example: Over the next several hours the patient becomes increasingly unstable with a low blood pressure (70/50) and fevers (temp-102.5F). The minute ventilation also increases to 15 L/min.

Mode	$Rate_{set}$	TV_{set}	TV_{sp}	$Rate_{sp}$	MV	$Rate_{total}$
A/C	20	.500 L	.500 L	10	15 L/min	30
IMV	20	.500 L	.250 L	20	15 L/min	40

10 L/min

10 L/min

RRset + RRsp

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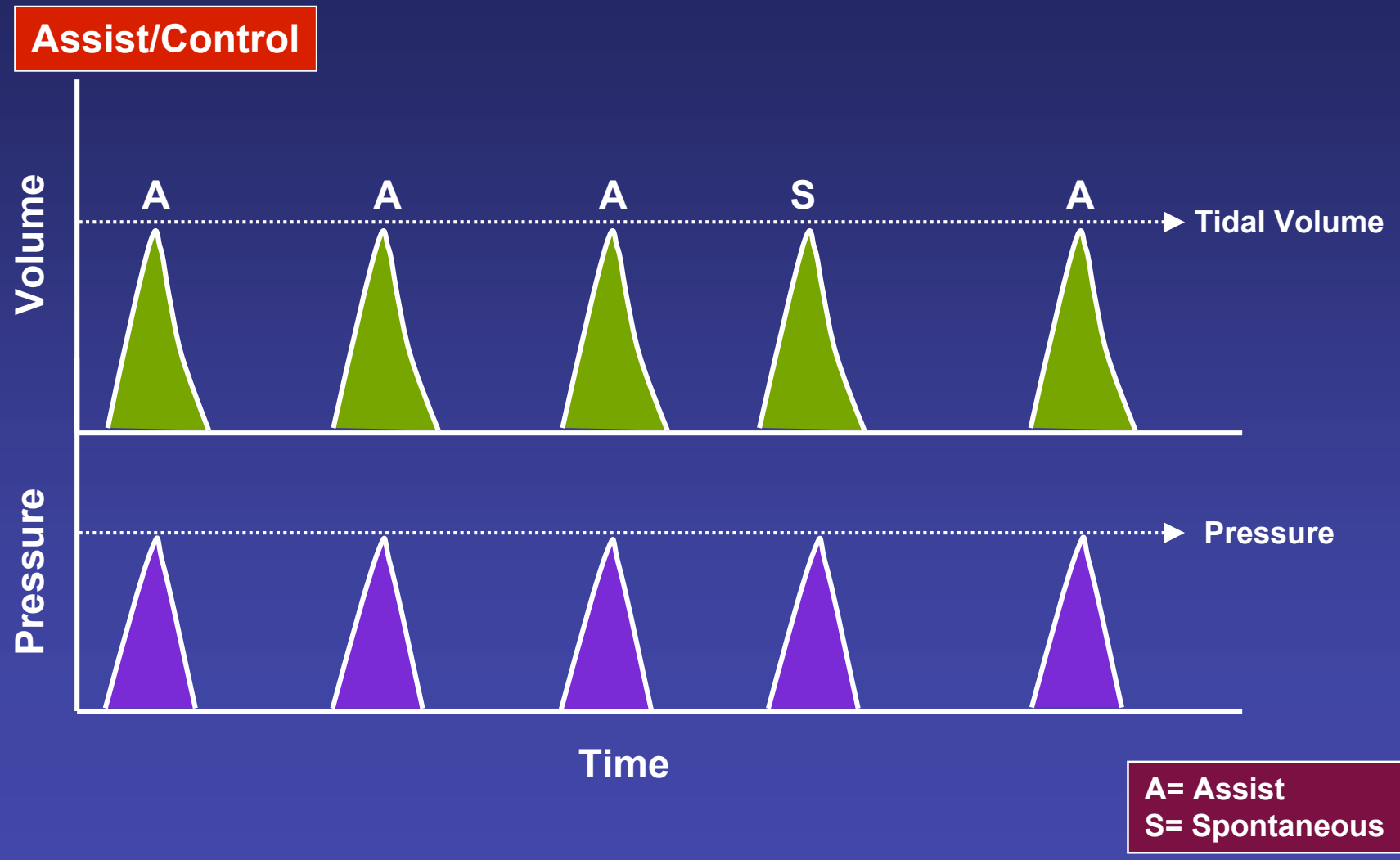
Getting Started on Invasive Mechanical Ventilation

- Pick a Mode: A/C in Medical Intensive Care Unit Secondary to Flexibility.
- Pick a Volume
  - 8-10 ml/kg body mass as starting point
- Pick a Rate
  - 10-12 is Reasonable in an Adult
  - Rates are Higher in Children and Infants
- Pick an FiO_2
  - Start at 100%.

10:10:10 Rule: 10 breaths/min: 10 cc/kg: 100% FiO2

The Relationship Between Volume and Pressure



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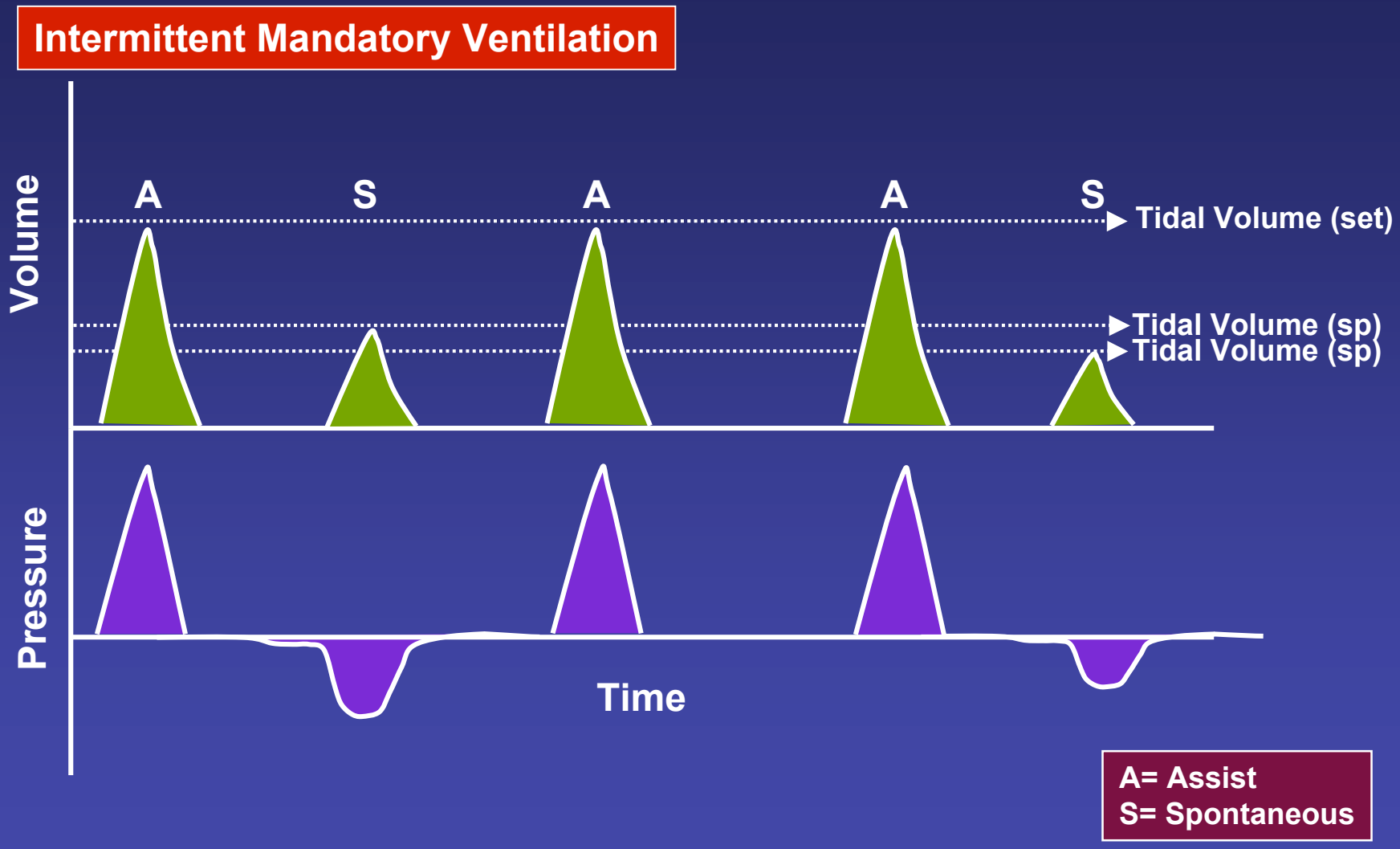
The Relationship Between Volume and Pressure



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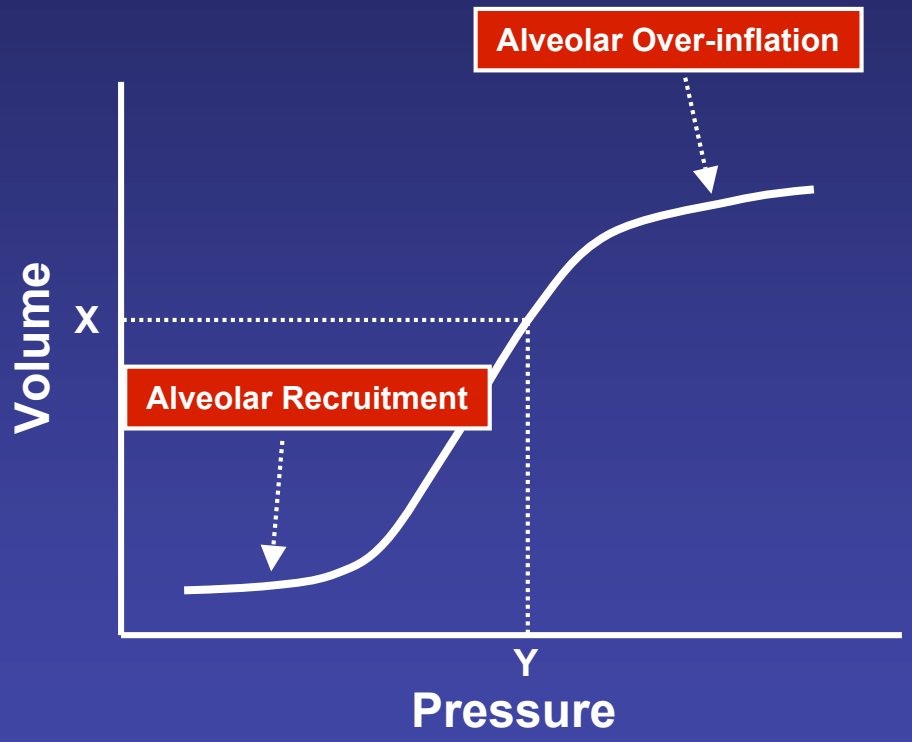
Compliance: Volume and Pressure Relationship

Compliance = $\Delta V/\Delta P$



X = 500 ml
Y = 20 cmH2O
Compliance = 25

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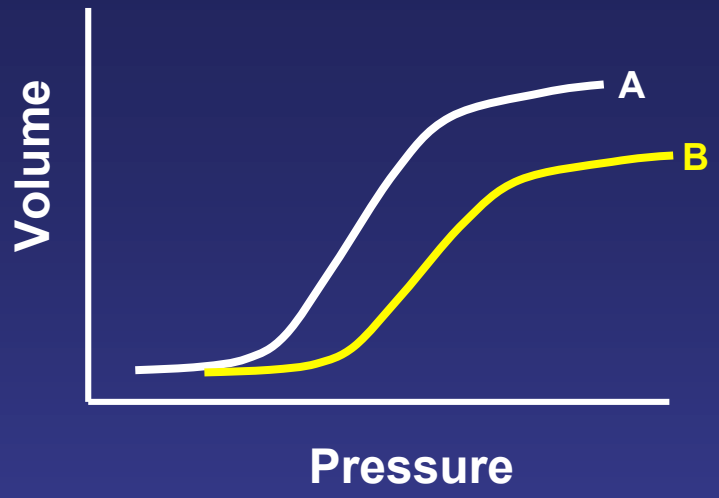
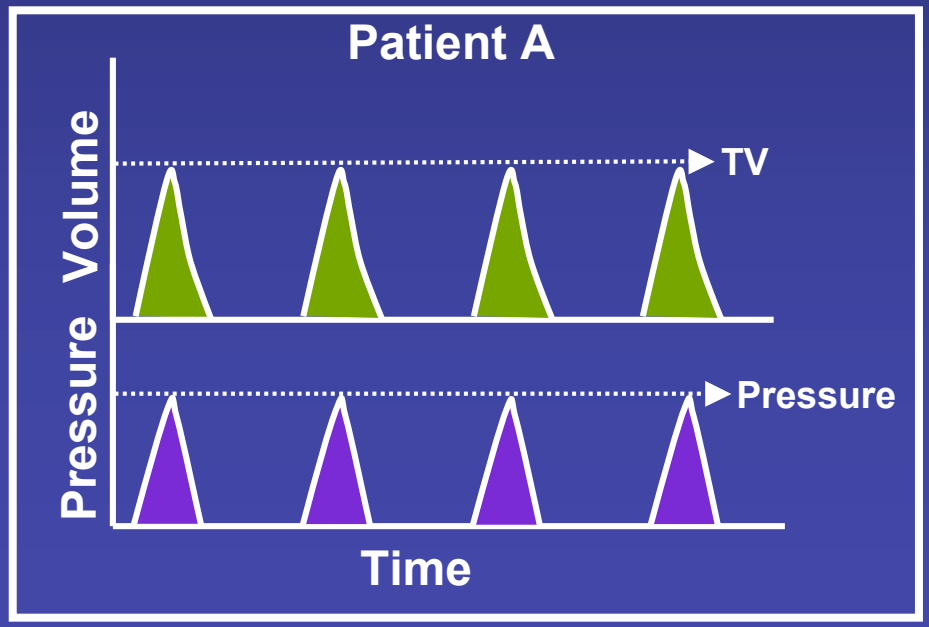
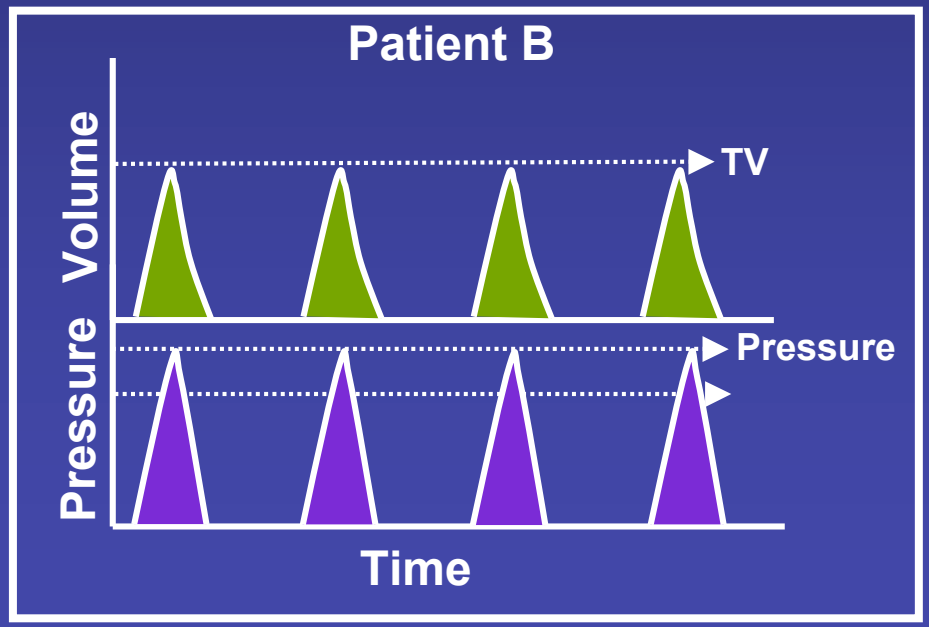
Compliance: Volume and Pressure Relationship







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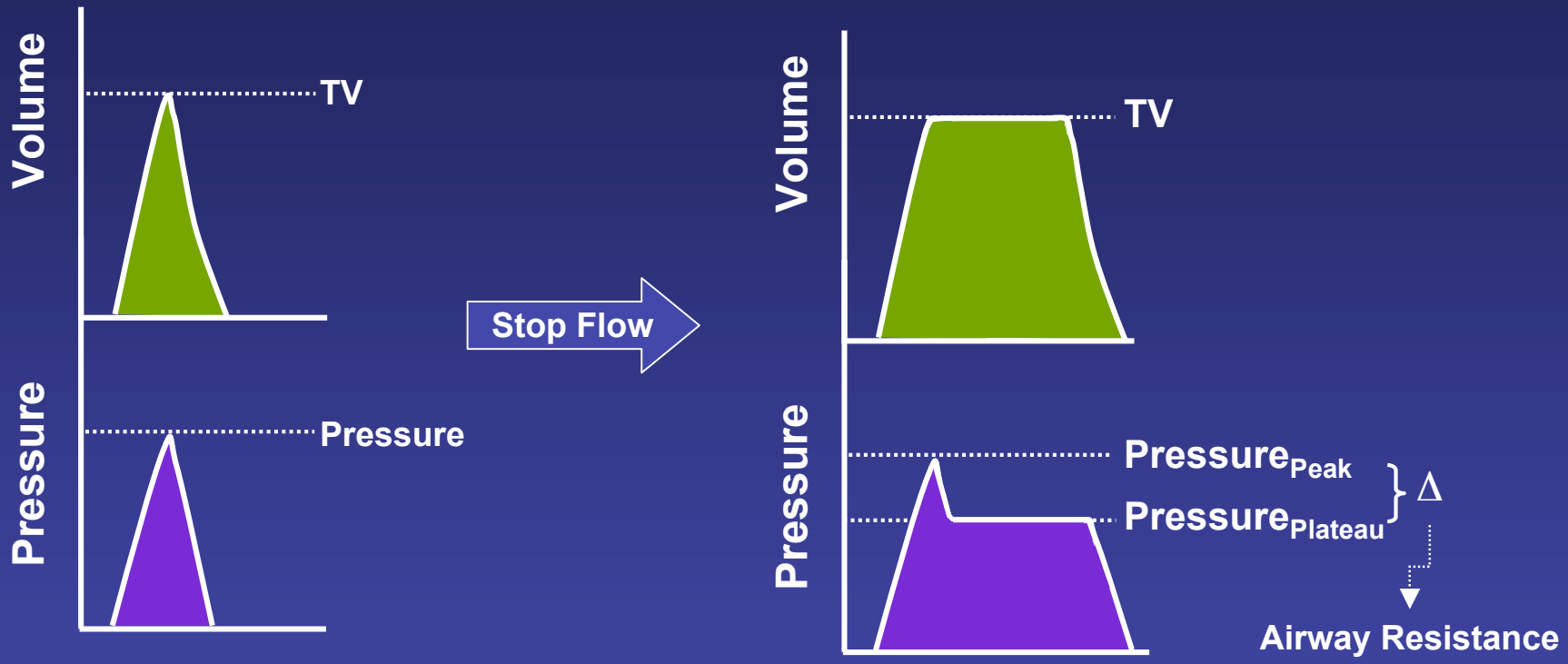
Pressure Also Influenced by Airway Resistance



- Pressure$_{Peak}$: Determined by Airway Resistance and Lung Compliance.
- Pressure$_{Plateau}$: Determined only by Lung Compliance.
- Why Do We Care About Lung Pressures?

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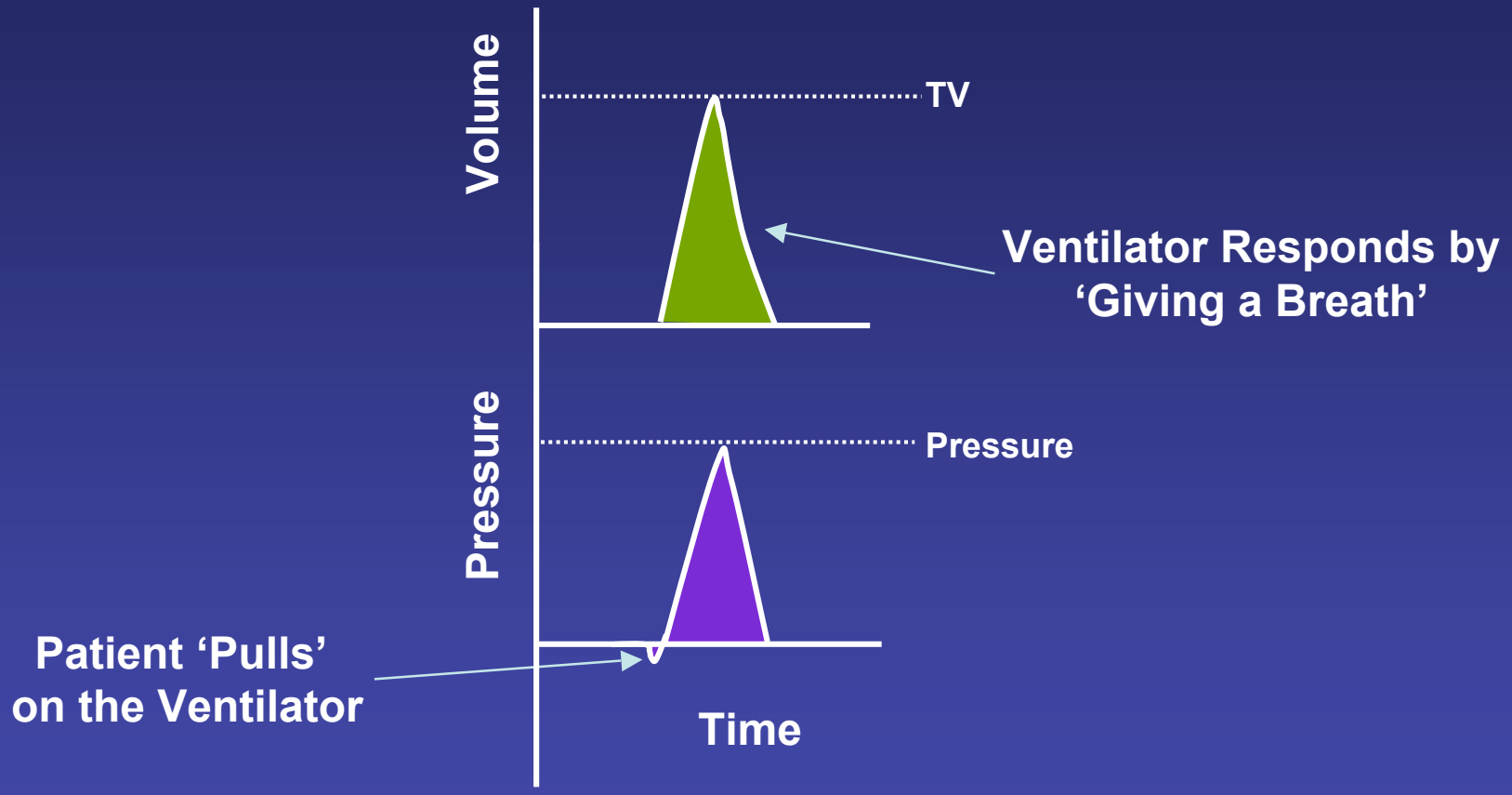
Other Ventilator Functions:

- Syncronizing with Patient's Respirations (Both A/C and IMV).



- Trigger Requires only -2-3 cmH2O Pressure
- Allows Fatigued Muscles to Rest While Providing Some Work

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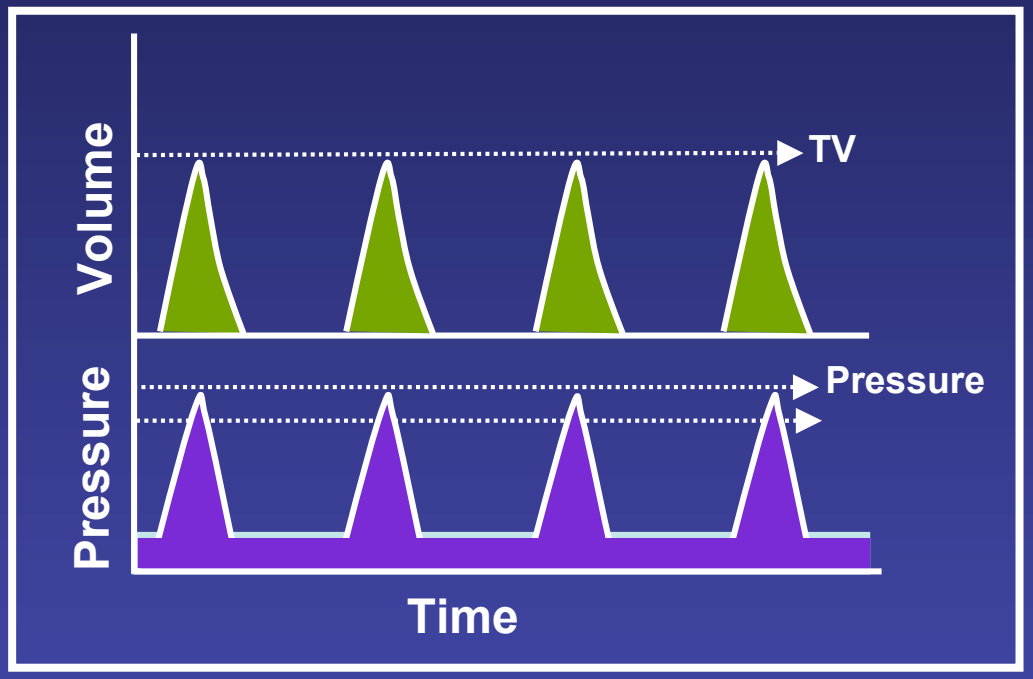
Other Ventilator Functions:

- Positive End Expiratory Pressure (PEEP)

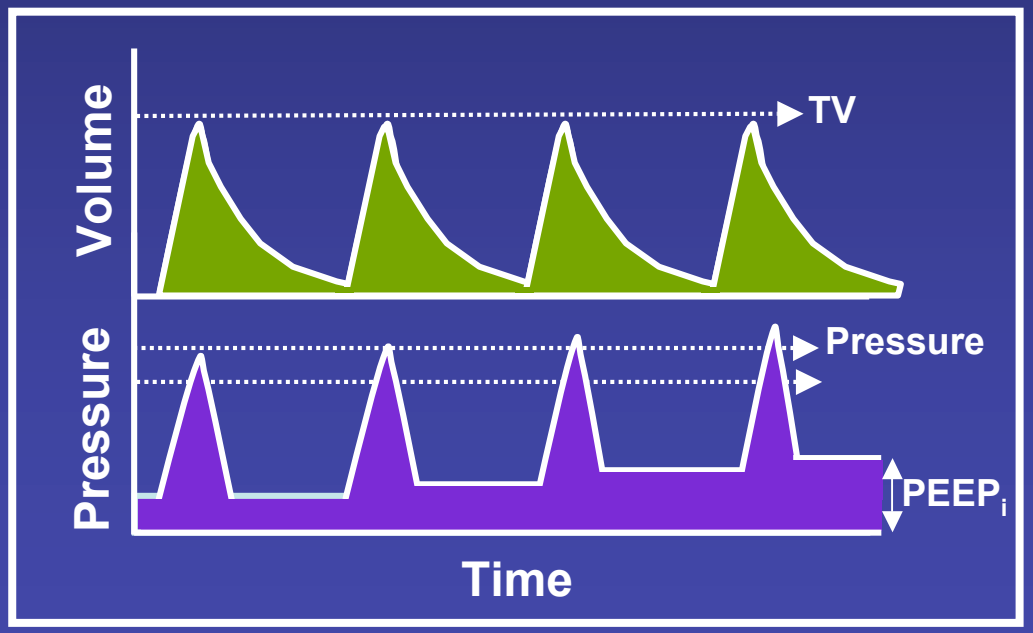


- Ventilator Never Lets Circuit Pressures Fall Below Chosen Pressure:
  - Prevents At-Risk Alveoli From Collapsing During Exhalation.
  - 5 cm H_2O a Common Starting Point.
  - Can Significantly Improve Oxygenation by Recruiting Alveoli for Gas Exchange and Thereby Correcting V/Q Mismatch.

Complications of Mechanical Ventilation

Complications of Invasive Mechanical Ventilation:

- Auto-PEEP (Intrinsic PEEP)
  - End Expiratory Pressure Does Not Return to Zero (or Set PEEP):
    - Typically a Complication of Obstructive Lung Disease.
    - Results From an Inadequate Expiratory Time.
    - Patients with Asthma and COPD Need Prolonged Expiratory Phase to Empty Previous Breath.



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Complications of Invasive Mechanical Ventilation:

- Auto-PEEP (Intrinsic PEEP)
  - Problem: If Thoracic Pressure > Central Venous Pressure then Impairment in Venous Return Resulting in Hypotension.
  - Management: Prolong Exhalation (Change I:E Ratio)
    -Fewer Breaths/Minute (Increase Tidal Volume)
    -Shorter Inspiratory Time (Increase Inspiratory Flow Rate)

Example: Back to Our Patient with a Tidal Volume of .500 L with Respiratory Rate of 30/minute to Meet a Minute Ventilation of 15 L/minute. Over Time, She Develops a PEEPi of 15 cmH2O with a Decrease in Blood Pressure.

If TV is Increased to .750 L, the Respiratory Rate Will Fall Giving More Time for Exhalation.

.500 L x 30 breaths/minute = 15 L.

.750 L x ? breaths/minute x = 15 L. ? = 20 breaths/minute

.750 L Comes with a Cost of Increasing Pressure in Lung.

Complications of Invasive Mechanical Ventilation:

- **High Pressures:**
  - **Problem: Barotrauma vs. Volutrauma (see ARDS lecture)**
    - Large Tidal Volumes ± High Lung Pressures Lead to Lung Injury.
    - Improved Outcome in Acute Respiratory Distress Syndrome by Limiting Tidal Volumes.
    - Barotrauma Can also Manifest as Pneumothorax.
  - **Causes:**

High Peak/Normal Plateau

↓

Increase in Airways Resistance

↓

Worsening Airway Obstruction (Asthma/COPD)
Endotracheal Tube Obstruction

Biting Tube Mucus Plugging

High Peak/High Plateau

↓

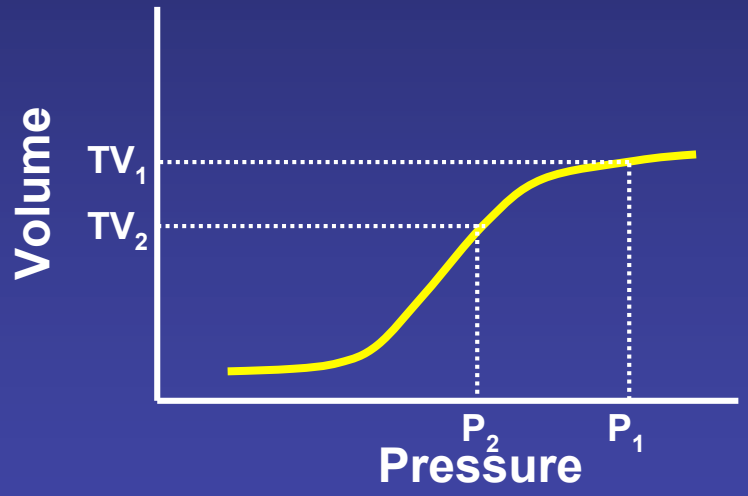
Decrease in Lung Compliance

↓

Worsening Disease (ARDS/CHF)
Pneumothorax
Right Mainstem Intubation

Complications of Invasive Mechanical Ventilation:

- High Pressures:
  - Management:
    - Dependent on Cause, So Try to Determine Etiology.
    - If Due to Low Lung Compliance, Decrease Tidal Volume (see ARDS).
    - Can Consider Pressure Cycled Ventilation.



    - If Due to Increased Airway Resistance, Less of a Problem: Suctioning Bronchodilators, etc.

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Complications of Invasive Mechanical Ventilation:

- Over-Ventilation:
  - When Minute Ventilation Is Greater Than Patient Needs:
    - Patient Will Make No Spontaneous Efforts.
    - Suspect Over-ventilation When Patient Sits on Back-up Rate.
    - Also Can Be Detected with an Arterial Blood Gas.

Example: 70 year old man is initiated on mechanical ventilation for a COPD exacerbation. Blood Gas just prior to starting mechanical ventilation reveals: pH- 7.24, pCO_2-60. After starting mechanical ventilation with A/C, rate of 20, TV of 600, the patient is noted to be breathing at rate of 20 (no efforts above back-up rate). Blood Gas reveals pH-7.48 and pCO_2 of 30.

  - Management:
    - Decrease Minute Ventilation (↓ TV or ↓ Respiratory Rate).
    - For A/C, Set Back-up Rate ~4 Breaths Below Total Respiratory Rate.

Complications of Invasive Mechanical Ventilation:

- High FiO2:
  - Problem: High Levels of Oxygen Are Toxic to Patient's Lungs.
    - Exact Level that Is Safe Has Not Been Determined.
    - ≤ 50% FIO2 Is Goal.
    - However, FIO2 Is not Decreased if it Results in Inadequate Oxygenation (Sat > 90% or pO2 > 60 mmHg).
  - Management: (see ARDS Lecture)
    - PEEP.
    - Prone Positioning.
    - Inhaled Nitric Oxide.

Complications of Invasive Mechanical Ventilation:

- **Patient-Ventilator Dysynchrony:**
  - **Problem: Patient Discomfort and Anxiety, Impaired Oxygenation/Ventilation.**
  - **Management:**
    - **Sedation: Benzodiazepines and Narcotic Analgesics**
    - **Change Ventilator Mode.**
    - **Paralysis: Increases Risk for ICU Myopathy.**
- **Ventilator Associated Pneumonia:**
  - **Problem: Interruption of Upper Airway Defenses.**
    - **Cough, Gag, Mucus Clearance.**
    - **Colonization of the Airway/Upper GI Track with Pathogenic Bacteria.**
  - **Management:**
    - **No Fool Proof Method to Prevent Vent-associated Pneumonia.**
    - **Elevate Head of Bed to 30-45 degrees.**

Monitoring Patients on Mechanical Ventilation

Daily Assessments of Invasive Mechanical Ventilation:

- Pressures: (Peak and Plateau).
- Arterial Blood Gas: (Ventilation, Oxygenation)
- Chest X-ray: Position of Endotracheal Tube
- Auto-PEEP: Especially in Patient with Obstruction.
- Patient Comfort and Position of Head.
- Weaning Candidacy.

Weaning From Invasive Mechanical Ventilation

- When?
  - Underlying Condition Has Improved:
    - $FIO_2 \leq 40\%$
    - Minute Ventilation ≤ 10 L
    - Mental Status Allows Patient to Follow Commands.

- Pre-Weaning Assessment: Parameters
  - Patient is Taken Off Support Briefly
  - Several Parameters are Assessed: MV, TV, RR, Negative Inspiratory Force, Vital Capacity
  - No Perfect Predictor for Success in Coming Off Ventilator.
  - Rapid Shallow Breathing Index Commonly Used: RR/TV (Liters). < 105 Suggests Likely Success.

Weaning From Invasive Mechanical Ventilation

- How?
  - If Parameters Suggest that Patient is Ready, Begin Weaning Trial:
    - Spontaneous Trial: Patient Breaths on Own.
    - IMV Wean: Back-up Rate is Slowly Decreased So that Patient Progressively Takes Over Load.
    - Pressure Support Wean: Level of Pressure is Slowly Decreased So that Patient Takes Over Load.

- Duration of Spontaneous Trial: Depends on Circumstance
  - ~ 2 Hours.

- If Spontaneous Trial is Successful, Endotracheal Tube is Removed.

Non-Invasive Mechanical Ventilation

- CPAP: Continuous positive airway pressure

- BiPAP: Similar to Pressure Support Where Each Inspiration Is Supported by a Set Pressure. An Expiratory Pressure Is Also Set (Typical Settings 12/5 cmH2O).

- Why Non-Invasive Ventilation?
  - Avoids Complications of Invasive Ventilation
  - Particularly Beneficial (Decreased Mortality) For Management of COPD and CHF if Invasive Mechanical Ventilation Can Be Avoided.

Key Points to Understand:

- **Indications for Invasive Mechanical Ventilation.**
- **Settings for Invasive Ventilation and How to Adjust:**
  - **FiO_2**
  - **Modes**
  - **Rate**
  - **Tidal volume**
  - **Airway pressures**
  - **PEEP**
- **Complications of Invasive Mechanical Ventilation.**
- **Weaning From Invasive Mechanical Ventilation.**

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