VENTILATORS

Teaching Module

Manoj Dalmia, MD
BIDMC Anesthesia Resident

Module Objective

- The objective of this module is to develop a solid understanding of the different modes of ventilation utilized in the care of surgical patients and other ventilator-related considerations.

Lesson 1

- By the end of this lesson, the learner should be able to demonstrate and explain the difference between the two most common modes of controlled ventilation: volume control and pressure control.

Case Scenario

- You have a 28 yo female patient who is scheduled to undergo an inguinal hernia repair under general anesthesia. She has a past medical history significant for asthma, snoring (no definitive dx of OSA), GERD, and a recent URI which she said resolved over a week ago. She is 64 inches tall and weighs 110 kg. Her vital signs in the preoperative holding area are as follows: BP 135/87, HR 90, RR 16, and SpO2 99%.

Case Scenario (cont)

- Given her body habitus and reflux history, you decide intubating this patient would be the safest way to manage her airway. Would you choose a volume control or pressure control ventilation strategy with this patient? Why?

Our Ventilator…

Two Main Ventilation Strategies

VOLUME CONTROL

- Tidal volume ***constant***
- Peak airway pressure ***variable***
- Pressure will increase (to set limit) to maintain tidal volume

PRESSURE CONTROL

- Tidal volume ***variable***
- Peak airway pressure ***constant***
- Tidal volume will increase/decrease if peak pressures decrease/increase

Effect of ΔCompliance & ΔResistance during Volume & Pressure Ventilation

	VOLUME-TARGETED	PRESSURE – TARGETED
Decreased compliance	↑ Pressure	↓ Volume
Increased compliance	↓ Pressure	↑ Volume
Pneumothorax	↑ Pressure	↓ Volume
Bronchospasm	↑ Pressure	↓ Volume
Pleural effusion	↑ Pressure	↓ Volume
Increased patient effort	↓ Pressure	↑ Volume
Decreased patient effort	↑ Pressure	↓ Volume

Try it yourself!

- Adjust the volume under a volume control setting and make note of the change in airway pressures during each mechanical breath
- Adjust the pressure under a pressure control setting and make note of the change in tidal volumes during each mechanical breath
- *Observe the differences noted with surgical pressure on the abdomen during the case

Back to our scenario…

- Which mode of ventilation would be most suitable in our patient?

- Volume control
  - Obesity → decreased compliance
  - Abdominal surgery → further decreased compliance/↑ airway pressures with manipulation of the abdomen
    - Able to maintain constant minute ventilation
    - With pressure control, minute ventilation could be extremely variable
  - *By far, most common mode used in adults

Major Teaching Points

- Volume control is most common mode of ventilation used in adults
  - Tidal volume constant, pressure variable

- Pressure control
  - Pressure constant, tidal volume variable
  - Specific instances where it may be preferable over volume control
    - Eg. small children → concern for barotrauma (limits peak inflating pressure) plus setting anesthesia ventilators to deliver accurate small tidal volumes is difficult because of the proportionately large compression volume loss in the ventilator and circuit

Questions?

You're now ready for the next lesson, nice job ☺

Lesson 2

- By the end of this lesson, the learner should be able to demonstrate and explain the difference between the two modes of controlled ventilation most commonly utilized in ICU settings: assist-control (A/C) ventilation and synchronized intermittent mandatory ventilation (SIMV).

Case Scenario

- At the end of the inguinal hernia repair, you notice that the peak airway pressures for your patient begin to rise significantly. In addition, the slope of Phase 2 on the $EtCO_2$ curve begins to increase. You listen to the patient and notice diffuse expiratory wheezes bilaterally. In addition, you notice a diffuse rash and swelling of the patient's face. Her BP drops to 90/40, her HR increases to 110, and her SpO_2 drops to 92% with an FiO_2 of 1.0.

Case Scenario (cont)

- You become concerned about an anaphylactic reaction but are unsure of the source. Regardless, you correctly make the decision to immediately treat the patient with epinephrine, steroids, and beta-2 agonists. She is transferred to the ICU intubated till her reaction resolves. As her condition improves, she is switched over to assist-control ventilation but you are curious why this is chosen over SIMV.

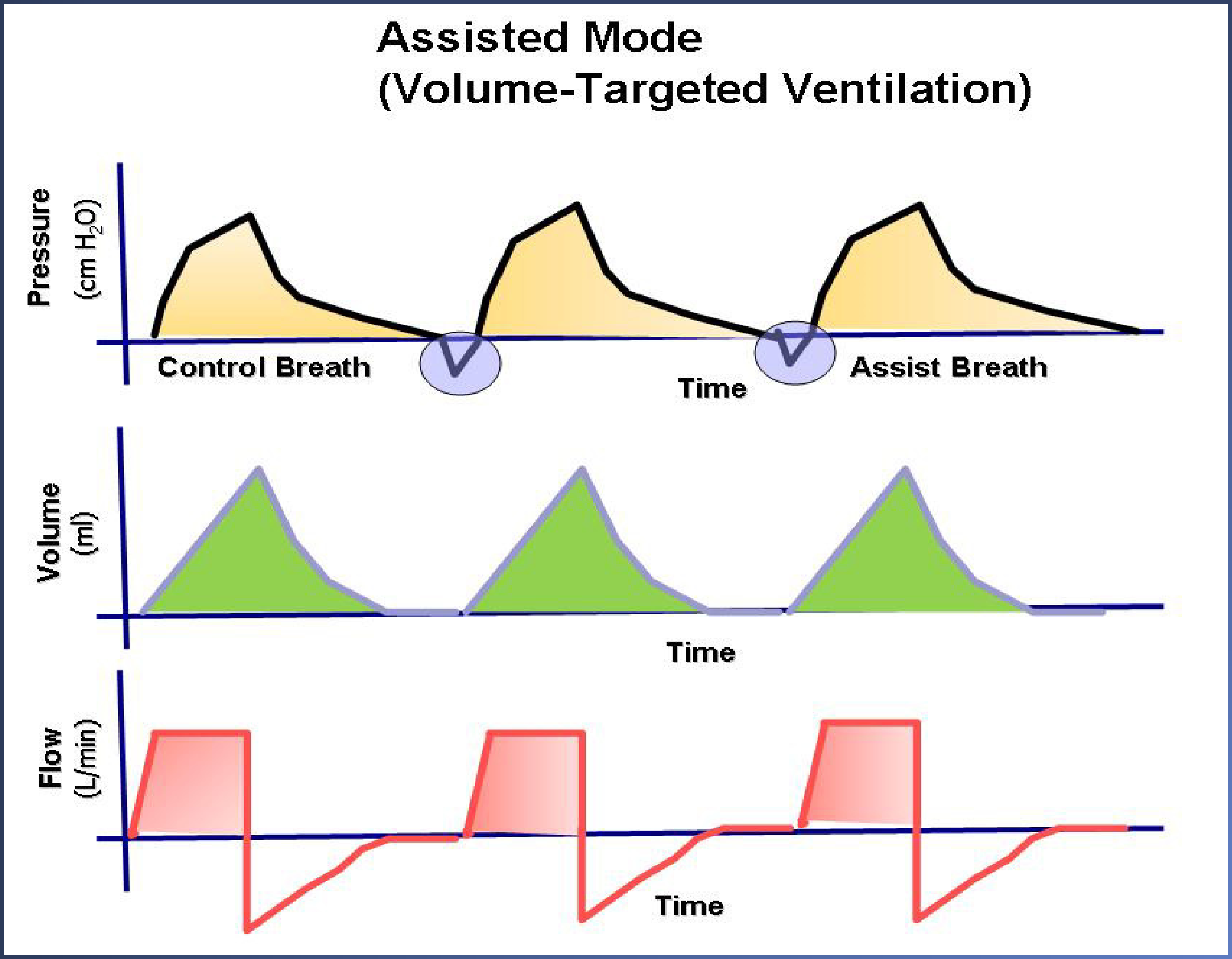
Assist-Control and SIMV - Similarities

- Both control modes of ventilation (either volume or pressure-controlled)
- Both allow for patient-triggered breaths between minimum programmed mandatory rate
  - Ensures minimum minute ventilation achieved
- Both modes have their advocates and detractors

Assist-Control Ventilation

- If the ventilator senses a spontaneous breath (negative airway pressure), the ventilator triggers and delivers a full tidal volume to the patient
  - May adjust sensitivity of trigger
- Patient determines ventilatory rate though minimum back-up rate set to ensure a minimum minute ventilation
- *Most commonly used mode of ventilation utilized in ICUs worldwide

Assist-Control Ventilation



http://emedicine.medscape.com/article/304068-overview

Assist-Control Ventilation

ADVOCATES

- Patients with normal respiratory centers able to auto-regulate respiratory rate
- May prevent atrophy of ventilatory muscles compared to pure controlled modes of ventilation
- Decreased work of breathing compared to SIMV

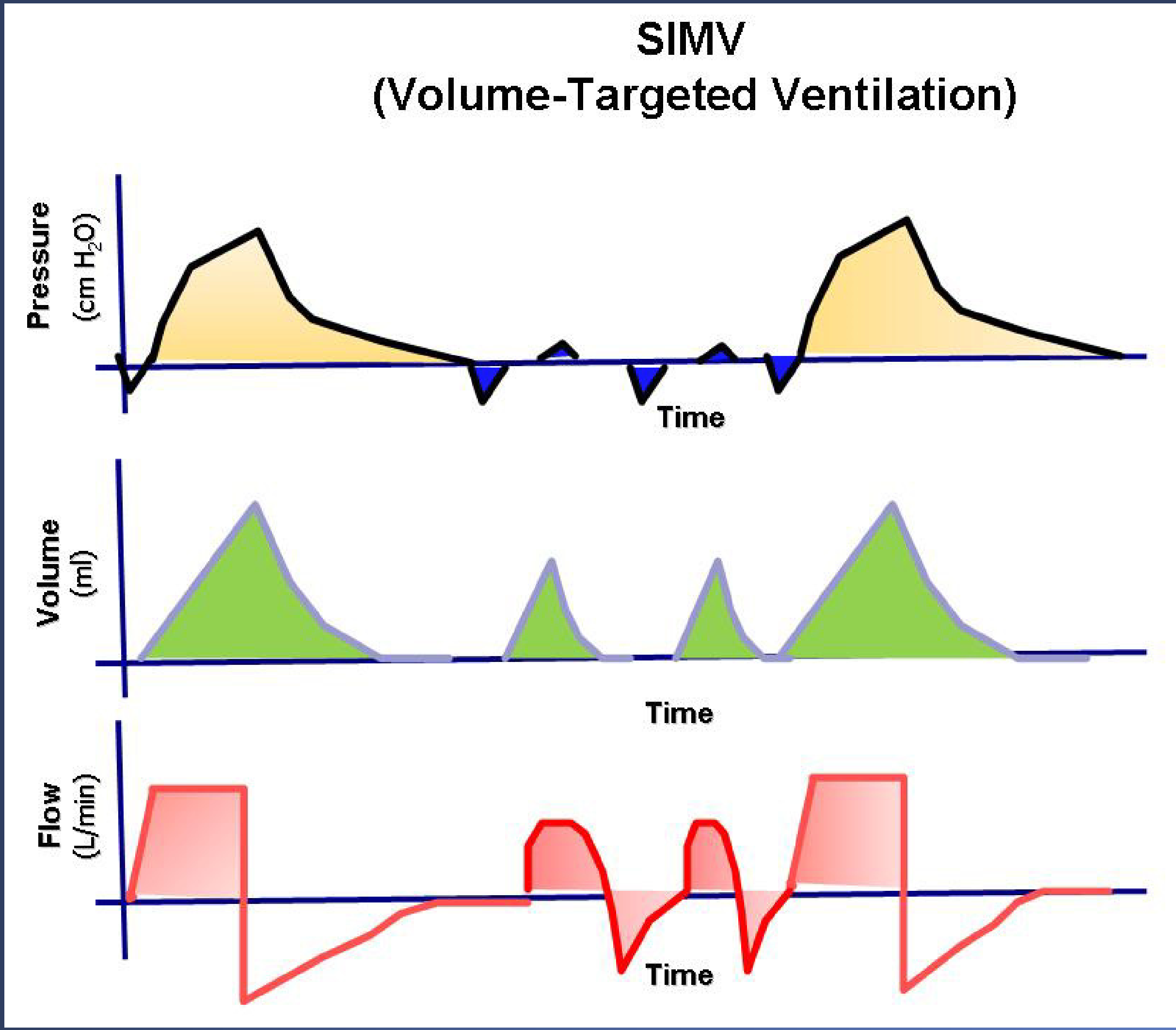
DETRACTORS

- "Trigger" issues
  - If trigger too sensitive, may hyperventilate
  - If trigger not sensitive enough, breathing may become dysynchronous
  - If respiratory center not normal, may be inappropriate to use
- Each positive-pressure breath ↑ intrathoracic pressure and subsequently ↓ venous return/CO
- In those with obstructive airway disease, it may worsen air-trapping and breath-stacking

SIMV

- Allows combination of spontaneous, unsupported breathing with a minimum mandatory back-up rate
- "Window" of breathing opportunity
  - Time in which a patient may breathe spontaneously
  - If ventilator does not sense effort during this "window", then a positive pressure controlled breath is delivered
- *Original intent: allow respiratory muscles to rest during controlled breaths and work during spontanous respirations
  - (***does not hold true – see continued discussion)***

SIMV



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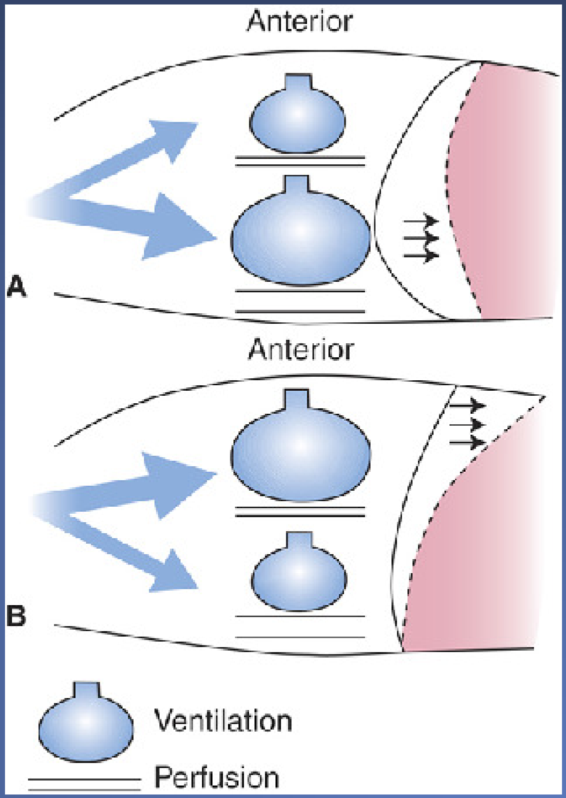
SIMV

ADVOCATES

- Spontaneous breathing may improve V/Q matching (Figure 83-8)
- Negative intrathoracic pressure during spontaneous breaths improves venous return/CO

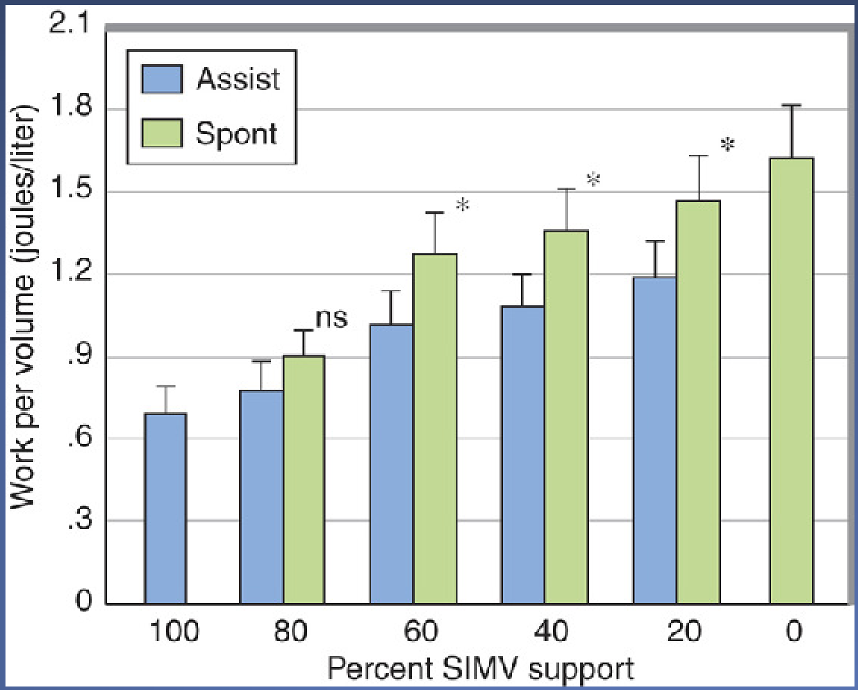


Effect of spontaneous ventilation and positive-pressure ventilation on gas distribution in a supine subject. During spontaneous ventilation (A) diaphragmatic action distributes most ventilation to the dependent zones of the lungs, where perfusion is greatest. The result is good matching of ventilation to perfusion. During positive-pressure ventilation (B) because the diaphragm is doing little to no contraction, ventilation is primarily distributed to nondependent lung, increasing the level of ventilation to perfusion mismatch. (Reprinted from Wilkens RL, Stoller JK, Scamlon CC. Egan's Fundamentals of Respiratory Care. 8th ed. St. Louis, MO: Mosby, 2003:972, with permission from Elsevier.)

SIMV

DETRACTORS

- Work of breathing *excessive* (see figure)
  - Has been shown that work of breathing not decreased during mandatory breaths as originally thought
  - Delays extubation compared w/ PS and SBT (see Lesson 3)
- Greater likelihood of dysynchrony versus A/C



Inspiratory work per unit volume (work per liter [Wp/L]) done by the patient during assisted cycles (open bars) and spontaneous cycles (reverse cross-hatched bars). Wp/L increased with decreasing synchronized intermittent mandatory ventilation percentage for both types of breath. Wp/L for spontaneous breaths tended to exceed Wp/L for machine-assisted breaths. (Marini JJ, Smith TC, Lamb VJ. External work output and force generation during synchronized intermittent mechanical ventilation. Am Rev Respir Dis 1988;138:1169. © American Thoracic Society)

Major Teaching Points

- Both A/C and SIMV are control modes of ventilation that allow for patient triggered breaths
- Assist control – greatest benefit is decreased work of breathing compared to SIMV
- SIMV – greatest benefit is possible improvement in V/Q matching and improved CO compared to A/C

Questions?

You're now ready for the next lesson, nice job ☺

Lesson 3

- By the end of this lesson, the learner should be able to understand the pressure-support ventilator mode and its utility in weaning patients from a ventilator.

Case Scenario

- After a 24-hr period in the ICU, your patient's anaphylactic reaction has resolved. The ICU team would like to wean the patient from the ventilator and she has done well on assist-control ventilation. As a result, they have placed the patient on pressure-support ventilation with starting settings of FiO_2 0.50, PS 10, PEEP 5.

Pressure Support Ventilation

- Closest mode to *true* assist ventilation
  - Lowers work of breathing
  - Requires stable ventilatory drive

- No *true* back-up rate

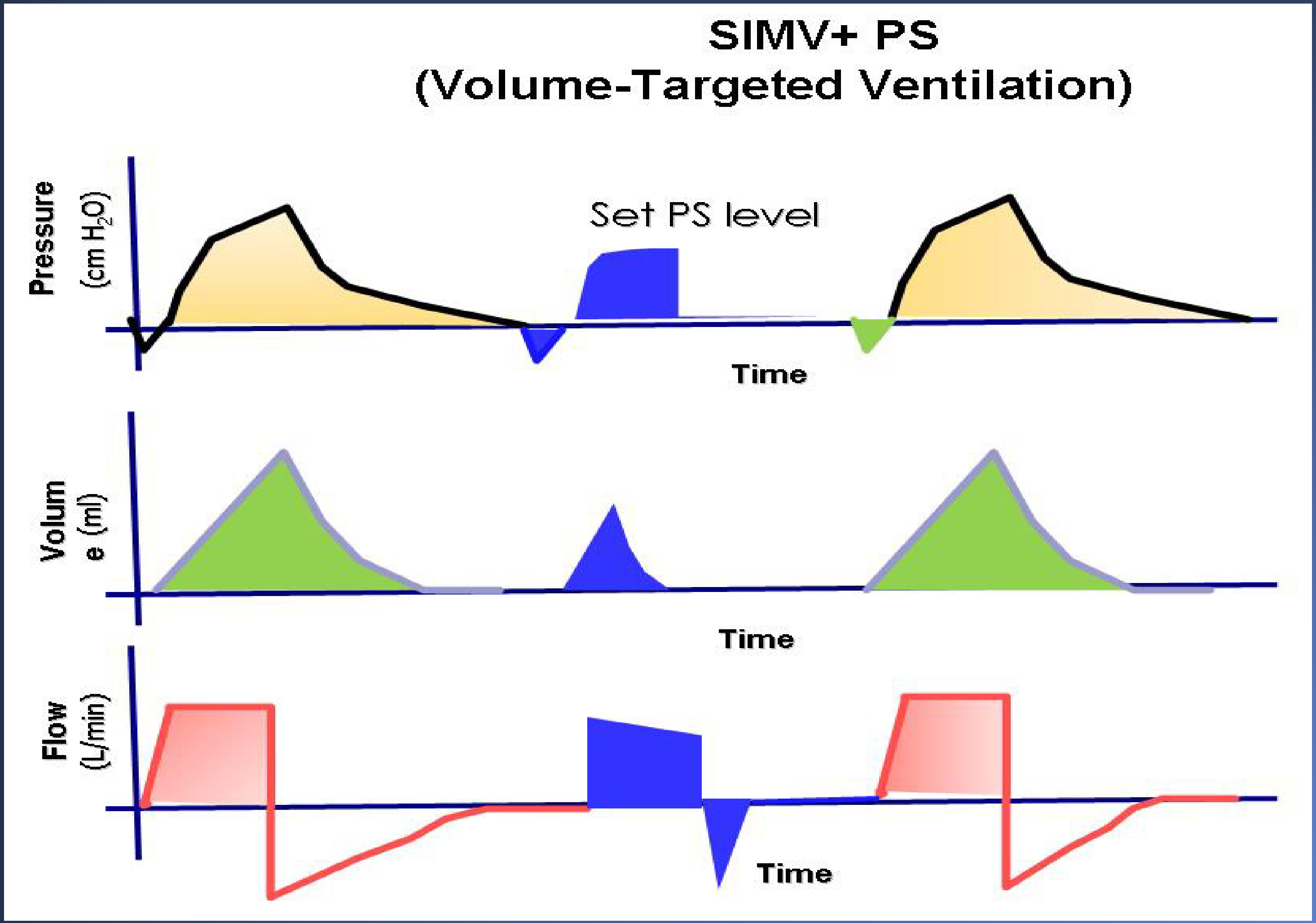
- Similar to Pressure A/C **but** major difference is mechanism that terminates inspiration
  - A/C → inspiration terminated by time
  - PS → inspiration terminated by **decreasing** gas flow
    - Tracheal flow decreases to ~25% → breath terminated

Pressure Support Ventilation

- Allows patient greatest control over ventilation
  - Patient triggers each breath
  - End of breath based on demand of patient

- TV varies with each breath, may adjust PS level
  - Weaning is accomplished by decreasing PS level and gradually transferring increased work to patient till PS ~5
    - Extubation typically successful at this level

SIMV w/ PS



http://emedicine.medscape.com/article/304068-overview

Major Teaching Points

- Pressure support ventilation is ideal mode for ventilator wean
  - Lowers work of breathing
  - Allows patient to gradually increase work of breathing as tolerated with eventual goal for extubation
  - Patient triggers each breath

Questions?

You're now ready for the next lesson, nice job ☺

Lesson 4

- By the end of this lesson, the learner should be able to state the criteria to conduct a spontaneous breathing trial (SBT), what defines failure of a SBT, and which factors may contribute to ventilator dependence in difficult-to-wean patients.

Case Scenario

- The patient has done extremely well on pressure support ventilation and does not look to be in much respiratory distress. Her current settings are FiO_2 of 40%, PS of 5, and PEEP of 0. Her RR is 18. Her ABG results are as follows: 7.41/158/38/26/0. Her VS are similar to her preoperative state. The ICU team has decided to initiate a SBT with goal of extubation.

How did the ICU team determine the patient was ready for a SBT?

- Criteria
  - Improvement in factors that led to ventilator dependence in the first place
  - Assessment of oxygenation
    - $PaO_2/FiO_2 \geq 150$ mmHg
    - PEEP ≤ 8 cm H_2O
    - $FiO_2 \leq 0.5$
    - pH ≥ 7.25
  - Hemodynamic stability (low-dose vasopressors OK)
  - Spontaneous (duh!) respirations

What's considered a failure of a SBT?

- Patient typically performs SBT for 30-120 minutes and ***does not*** meet any of the following criteria to be considered for extubation:
  - RR > 35 breaths/minute
  - HR > 140 or a sustained ↑ of 20% from baseline
  - SBP > 180 mmHg or DBP > 90 mmHg
  - ↑ anxiety
  - ↑ diaphoresis

What about other measurements of lung mechanics?

- Other parameters used include:
  - RR < 25 breaths per minute
  - TV > 5 cc/kg
  - VC > 10 cc/kg
  - Negative inspiratory force (NIF) < -25 cmH2O
  - ***Rapid shallow breathing index (RSBI)**
    - **= RR/Vt < 105**
    - Though used in many institutions, has **not** proven universally successful in identifying those ready to wean

Difficult-to-Wean Patients: Contributing Factors

**WHEANS NOT*

- **W**heezing
- **H**eart disease
- **E**lectrolyte imbalance
- **A**nxiety, aspiration, alkalosis
- **N**euromuscular weakness
- **S**epsis, sustained sedation
- **N**utritional deficits
- **O**besity, opioid overdose
- **T**hyroid disease

*Anesthesiology by Longnecker, et al

Major Teaching Points

- There are specific criteria that have been created to determine whether a patient is a candidate for a SBT (though the clinical picture must still be taken into account)
  - NIF and RSBI, though still commonly used, have not been consistently shown to be great predictors of ability to wean
- Remember the mnemonic "WHEANS NOT" when considering which patients may be a difficult ventilator wean!
  - What characteristics does this patient have that may make her a difficult wean?
- *Think about possible scenarios which would make a patient an appropriate candidate for a SBT.

Questions?

You're now ready for the next lesson, nice job ☺

Lesson 5

- By the end of this lesson, the learner should be able to understand the use of non-invasive positive pressure ventilation (NIPPV) in facilitating the transition to unsupported spontaneous respirations.

Case Scenario

- The patient successfully passes her SBT and the decision is made to extubate her. Over the next 2 hours, the patients becomes progressively tachypneic. The ICU team draws a blood gas with the patient on RA (prior to putting on a nonrebreather) which demonstrates the following: pH 7.51, PaO2 80, and PaCO2 30. The team wants to avoid reintubating this patient and decides to see how the patient responds to NIPPV.

What could be the primary cause of this patient's hypoxemia?

- Primary mechanism after surgery…
  - V/Q mismatch secondary to development of atelectasis!
    - Positioning
    - Absorption atelectasis
    - Diaphragm weakness/dysfunction
    - Incisional pain leading to impaired secretion clearance

- Goal: increase FRC!
  - How can this be accomplished?

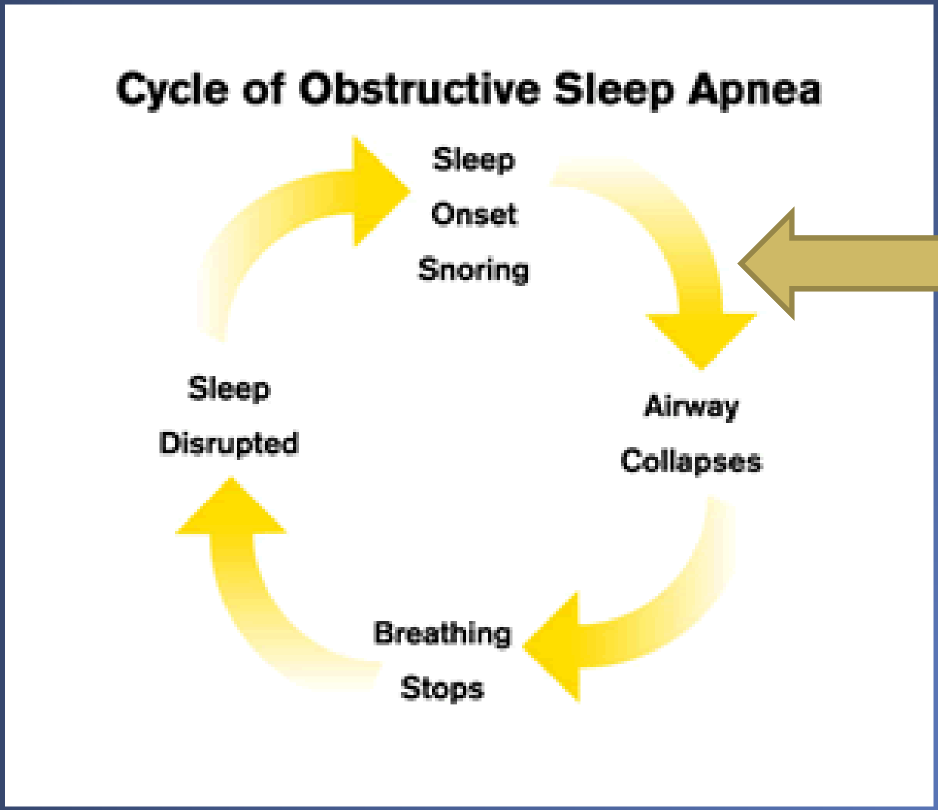
2 Major Forms of NIPPV

- Continuous Positive Airway Pressure (CPAP)
- Bi-Level Positive Airway Pressure (BiPAP)

CPAP

- Delivers a predetermined and constant stream of pressure through a tight-fitting mask that essentially “stents” the airway open
  - Effective for reducing atelectatic areas
  - Effective for patients with obstructive sleep apnea

CPAP



CPAP breaks this cycle at this point!

CPAP

PROS

- Safe and effective
- Compact and portable

CONS

- Headaches
- Skin irritation
- Stomach bloating
- Nasal congestion
- **Many do not tolerate continuous positive pressure, esp. awake!**

BiPAP

- Two levels of pressure
  - Inspiratory Positive Airway Pressure
    - High amount of pressure on inhalation
  - Expiratory Positive Airway Pressure
    - Low positive pressure on exhalation
- Usually prescribed when a patient does not tolerate CPAP or has additional respiratory issues

BiPAP

PROS

- Safe and effective
- Better tolerated due to variation in inspiratory and expiratory pressures

CONS

- Headaches
- Skin irritation
- Stomach bloating
- Nasal congestion
- Not compact/portable
- **Requires constant supervision of pressure settings**

Major Teaching Points

- In many instances, NIPPV can effectively improve V/Q mismatch
- CPAP → continuous stream of pressure throughout respiratory cycle, stents the airway open, portable
- BiPAP → increased pressure on inspiration, less on expiration, better tolerated than CPAP but requires constant supervision of pressures

Questions?

You're now ready for the next lesson, nice job ☺

Lesson 6

- By the end of this lesson, the learner should be able to understand ventilator-induced lung injury (VILI).

Case Scenario

- Your 28 yo patient did fantastic and was able to be discharged to the floor 2 days after her initial admission to the ICU. Luckily, she did not incur any injury from her time on the ventilator (unlike one of the other unfortunate patients in the ICU).

- What *is* ventilator-induced lung injury?

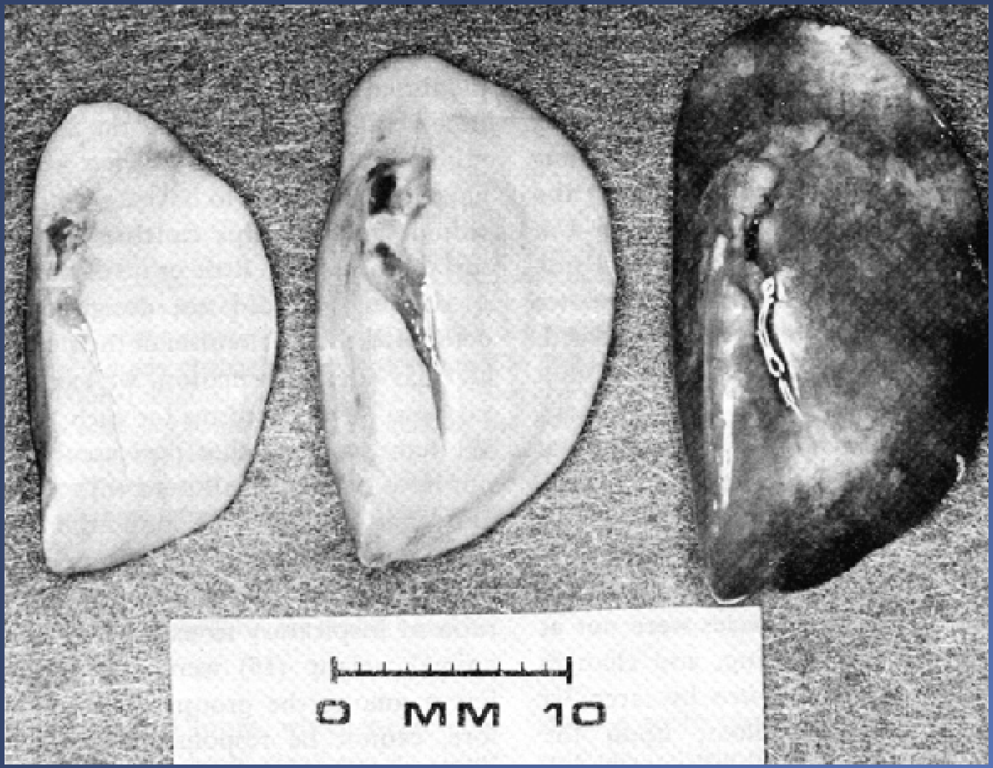
VILI

- Definition
  - An increase in the permeability of the alveolar capillary membrane, the development of pulmonary edema, the accumulation of neutrophils and protein within the lung parenchyma and airway, the disruption of surfactant production, and a decrease in lung compliance.

VILI - Terminology

- "Volutrauma" – injury due to excessive volume
- Barotrauma – injury due to excessive pressure
- "Atelectrauma" – recruitment/derecruitment injury

VILI



Comparison of lungs excised from rats ventilated with peak pressure of 14 cm H_2O, zero positive end-expiratory pressure (PEEP); peak pressure 45 cm H_2O, 10 cm H_2O PEEP; and peak pressure 45 cm H_2O, zero PEEP (left to right). The perivascular groove is distended with edema in the lungs from rats ventilated with peak pressures of 45 cm H_2O, 10 cm H_2O PEEP. The lung ventilated at 45 cm H_2O peak pressure zero PEEP is grossly hemorrhaged. (Webb HH, Tierney D. Experimental pulmonary edema due to intermittent positive pressure ventilation, with high inflation pressure protection by positive end expiratory pressure. Am Rev Respir Dis 1974;110:556–565. © American Thoracic Society.)

Questions?

Congratulations! You're done! Nice job ☺