Just-In-Time Tools for Training Non-Critical Care Providers: Troubleshooting Problems in the Ventilated Patient

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Abstract

Due to the limited number of critical care providers in the United States, even well-staffed hospitals are at risk of exhausting both physical and human resources during the outbreak of SARS-CoV-2, One potential response to this problem is redeployment of non-critical care providers to increase the supply of available clinicians. To support efforts to increase capacity as part of surge preparation for the COVID-19 outbreak, we created an online educational resource for non-intensivist providers to learn basic critical care content. Among those materials, we created a series of one-page learning guides for the management of common problems encountered in the intensive care unit (ICU). These guides were meant to be used as just-in-time tools to guide problem-solving during the provision of ICU care. This document presents 5 guides related to managing complications that can arise in patients receiving invasive mechanical ventilation.

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There is a limited number of critical care providers in the United States with nearly half of US hospitals operating without one dedicated intensivist.[1] During a pandemic, such as the outbreak of SARS-CoV-2, even well-staffed hospitals can be exhausted of both physical and human resources.[2] One potential response to this problem is redeployment of non-critical care providers to increase the supply of available clinicians. To support efforts to increase capacity as part of surge preparation for the COVID-19 outbreak in Seattle, Washington, the University of Washington School of Medicine's Division of Pulmonary, Critical Care and Sleep Medicine created an online educational resource for non-intensivist providers to learn basic critical care content. Among those materials, we created a series of one-page learning guides for the management of common problems encountered in the intensive care unit (ICU). These guides were meant to be used as just-in-time tools to guide problem-solving during the provision of ICU care.

The documents are intended for the use of individuals who do not have subspecialty training in critical care medicine. The recommendations in each one-page document were designed with several assumptions that may not be universally true at all institutions. Many of the frameworks presented here assume availability of the technology and resources present in a modern ICU and rely heavily on the presence of a multidisciplinary team including a critical care nurse, respiratory therapist and pharmacist. The guides also assume that a critical care "consultant" is available (in person or virtually) whenever care must deviate from the included schema or the complexity of a problem is beyond the scope of these basic algorithms. Because many providers who may be called to help in the ICU will lack training in specific procedures, interpretation of hemodynamic data, or point-of-care ultrasonography (POCUS), these aids intentionally deemphasize these skills. Despite these assumptions, these guides were drafted to be appropriately broad, such that a non-critical care trained provider can perform core critical care tasks.

This set of documents addresses advanced troubleshooting scenarios in patients already receiving mechanical ventilation as well as the initial management of ARDS given its prevalence among critically ill patients with COVID-19.[3,4] Other examples include evaluation of patient agitation, high ventilator peak pressures, and abnormal ventilator waveforms. Volume control ventilation is assumed in these guides as this is the primary mode of ventilation at our institution. Additionally, local sedation practices lean heavily towards a guideline concordant analgesia-first regimen[5] with as-needed fentanyl and reserving propofol as the first-line agent when continuous sedative infusion is required.

The approaches in this section are meant to provide a general framework for troubleshooting common problems that occur in patients on mechanical ventilation and require swift action to stabilize the patient and gain control of the situation. These recommendations are based upon guidelines[6,7] and on the usual practice of the contributing authors. We acknowledge that different critical care providers may have their own practices which vary from those presented below. Each patient is unique and more nuanced management may be necessary than can be provided in a one-page document. We designed the content to be simple, streamlined, and easy to use at the bedside by providers with varying levels of experience. Throughout these documents we use the phrase "**Call for Help!**" to designate times when management has progressed beyond the basics and the reader should consult with a critical care provider. These materials are not meant to replace or supersede local policies or practices and should not be used in place of critical care specialists when available.

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Glossary of Terms

CST: Static compliance of the respiratory system
F_IO_2: Fractional concentration of oxygen
P_aO_2: arterial partial pressure of oxygen
P_aCO_2: arterial partial pressure of carbon dioxide
PEEP: positive end-expiratory pressure
PIP: peak inspiratory pressure
RASS: Richmond agitation and sedation scale
S_aO_2: arterial oxygen saturation

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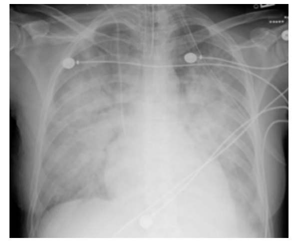
My Patient is Developing ARDS… Now What Do I Do?

1) **Confirm the Presence of ARDS and Classify Severity**
Patients are deemed to have ARDS if they meet all 4 of the Berlin criteria: (https://jamanetwork.com/journals/jama/fullarticle/1160659)



- Acute onset (<7 days) from known cause (e.g., COVID-19 infection)
- Bilateral opacities on chest radiograph
- P_aO_2 / F_IO_2 (P/F ratio) < 300
- Not *entirely* due to pleural effusions, volume overload or cardiogenic edema

Classification of Severity: (P_aO_2 obtained from ABG; F_IO_2 expressed as a decimal)

- Mild: $200 \leq P_aO_2 / F_IO_2 < 300$
- Moderate: $100 \leq P_aO_2 / F_IO_2 < 200$
- Severe: $P_aO_2 / F_IO_2 < 100$

2) **Initiate low tidal volume ventilation (often referred to as lung protective ventilation)**
Change tidal volume (V_T) to 6 ml/kg *predicted* body weight (male: 50 kg + 2.3 kg per inch over 60 inches in height; female: 45.5 kg + 2.3 kg per inch over 60 inches in height).

Goals:

- Plateau Pressure < 30 cm H_2O :
  - If $P_{plateau}$ > 30 cm H_2O: consider decreasing V_T further, to as low as 4 ml/kg PBW
  - If $P_{plateau}$ < 30 cm H_2O: maintain 6 ml/kg

- S_aO_2 88 – 95% (or P_aO_2 55 – 80 mmHg):
  - Use the PEEP/ F_IO_2 ladder: (http://www.ardsnet.org/files/ventilator_protocol_2008-07.pdf)
  - Monitor for hypotension due to increased PEEP
  - **Call for Help! with persistent or worsening hypoxemia**

- pH >7.20 (Tolerate increases in P_aCO_2, "permissive hypercapnia")

3) **If P_aO_2 / F_IO_2 < 150 consider prone positioning and call for help!**
Note this requires substantial personnel to safely perform, so consider available resources

Protocol: Prone for 16 hours, then return to supine position
Repeat daily
Stop when P/F >150 on PEEP < 10 cmH_2O and F_IO_2 < 0.6 or if ineffective

4) **If P_aO_2 / F_IO_2 < 150 and patient is not synchronous with the ventilator, start neuromuscular blockade and call for help!**
48-hour infusion of cis-atracurium
Ensure deep sedation (RASS -4 to -5)

5) **Call for help** if hypoxemia persists despite prone positioning and neuromuscular blockade

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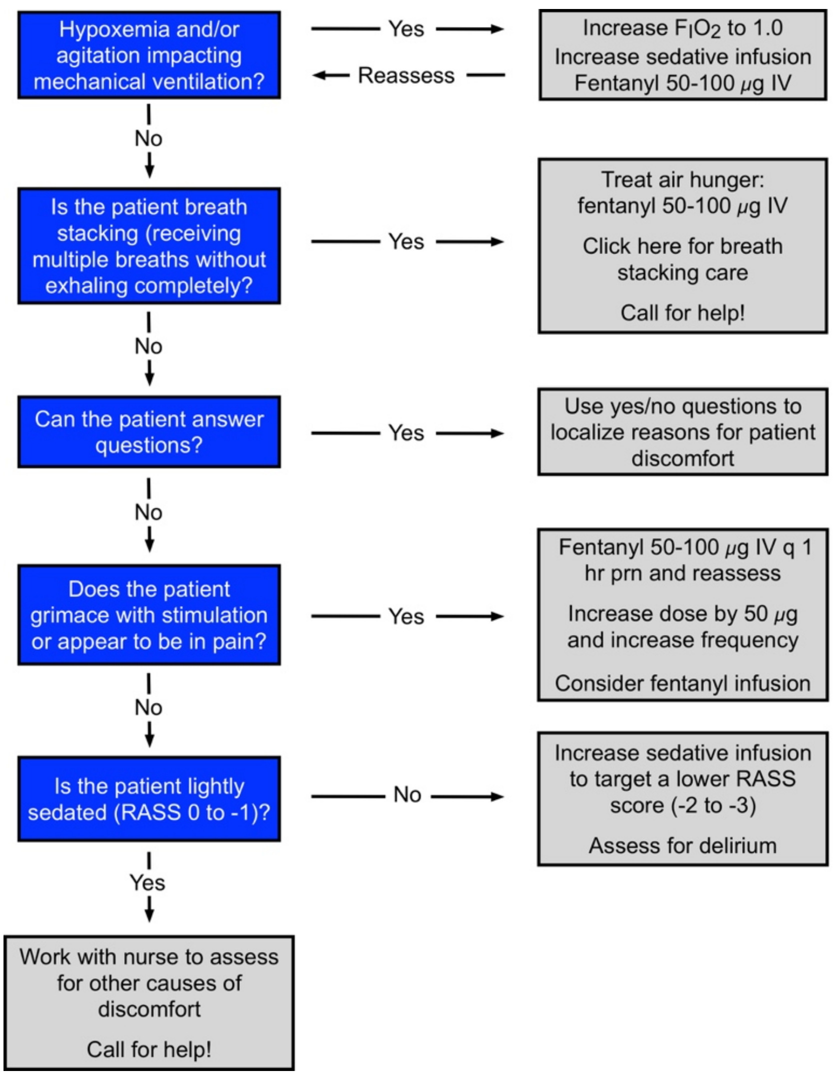
My Patient is Agitated While Receiving Mechanical Ventilation… Now What Do I Do?

The Patient Who Is Not Meeting Sedation Targets

Usually, patients who are not severely hypoxemic will be maintained in an alert or lightly sedated state. The degree of sedation is measured by the Richmond Agitation Sedation Score (RASS). Further information on the RAAS can be found using the following link: https://doi.org/10.1164/rccm.2107138. The goal RASS is usually 0 (alert) to -1 (sedated but easily arousable). When the patient is out of this range (RASS > 0), the following step-by-step process can be used to resolve the issue.



Sudden Unexpected Agitation with Ventilator Alarms

Sudden, unexpected agitation in a previously calm patient can be due to a problem with the ventilator and/or ventilator circuit or a problem with the patient. The first step in this situation is to **call for help!** The patient should then be disconnected the patient from the ventilator and manually ventilated with an anesthesia bag.

- If the agitation resolves, the problem is with the ventilator or the circuit. Consult the respiratory therapist.
- If the problem does not resolve, the problem is with the patient and can be anyone of a number of problems. Perform a focused physical exam and assessment of the patient and discuss with your critical care consultant.

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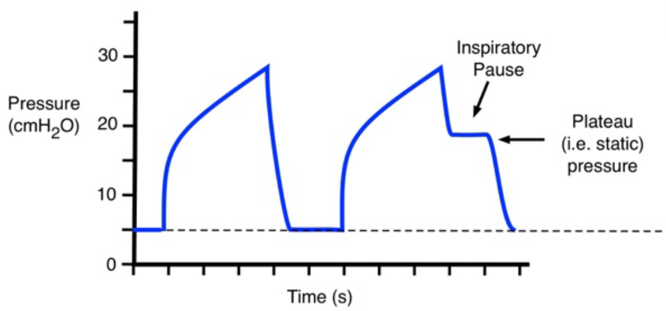
The Peak Inspiratory Pressure Has Increased… Now What Do I Do?

1) **What Determines Peak Inspiratory Pressure?**
In volume assist control, the peak inspiratory pressure (PIP) reflects how hard the ventilator must "work" to deliver a breath and is a function of three variables: (1) the inspiratory flow rate and flow pattern; (2) airway resistance (including the endotracheal tube and circuit); (3) the compliance of the respiratory system; and (4) the total positive end-expiratory pressure (PEEP). If the flow rate, flow pattern, PEEP have not changed and there is no autoPEEP, any change in PIP is due to either a change in resistance or a change in compliance.

2) **How Do I Distinguish Between Resistance and Compliance Issues on the Ventilator?**
Perform an inspiratory pause maneuver. During the pause, there is no airflow and, therefore, resistance is no longer a factor. The pressure measured during the pause (referred to as the "plateau" or "static" pressure) is the pressure needed to keep the system open at that volume and reflects the compliance of the respiratory system. Static compliance (C_{ST}) is then calculated using the formula in the figure below. In healthy, non-intubated individuals C_{ST} is about 100 ml/cm H_2O. Values < 20 ml/cm H_2O are indicative of very low compliance.

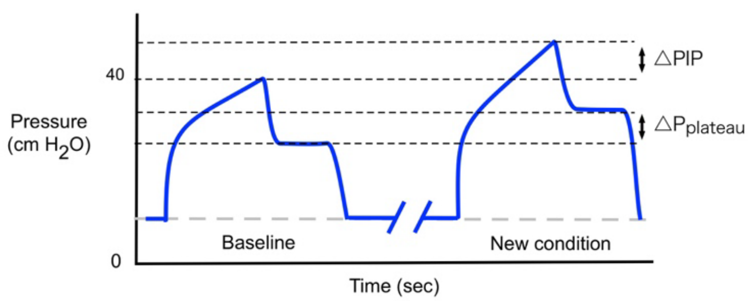


$$C_{ST} = \frac{\text{Tidal Volume}}{P_{plateau} - PEEP}$$

Note: This figure depicts volume assist control

4) **Management**

• Recognizing and evaluating a compliance problem



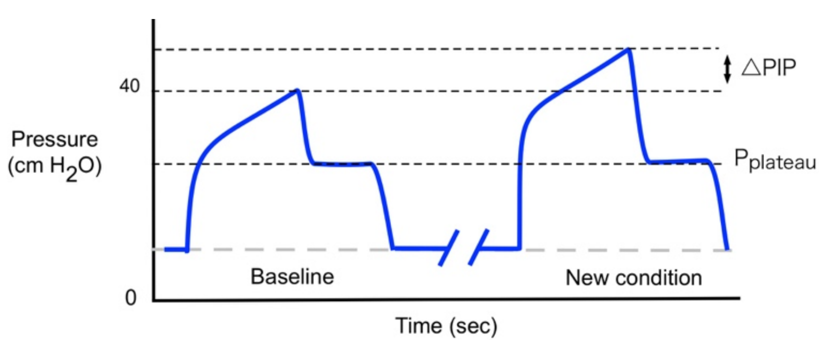
Compliance Problem (PIP and plateau pressure both increase)

Evaluate for and manage:

Abdominal distention (ascites, air-filled bowel)
ARDS
AutoPEEP
Lobar or whole-lung collapse
Pleural effusions
Pneumothorax
Pulmonary edema

Call for help if unable to determine the cause or the plateau pressure > 30 ml/cm H_2O.

• Recognizing and evaluating a resistance problem



Resistance Problem (PIP is increased but plateau pressure is unchanged)

Evaluate for and manage:

Airway secretions
Bronchospasm
COPD or asthma exacerbation
Kinked endotracheal tube or ventilator tubing

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The Respiratory Therapist Said My Patient Has AutoPEEP…Now What Do I Do?

1) What Is AutoPEEP and Why Is It a Problem?

Under normal circumstances, the entire delivered tidal volume is expired during exhalation. If expiratory time is insufficient (see below), some portion of the previously delivered breath may remain in the lungs at the time the next breath is delivered. If this happens on a repeated basis, the lungs become hyperinflated. This can lead to increased intrathoracic pressure which decreases venous return and impairs cardiac output. In severe cases, people become hypotensive and can even go into pulseless electrical activity.

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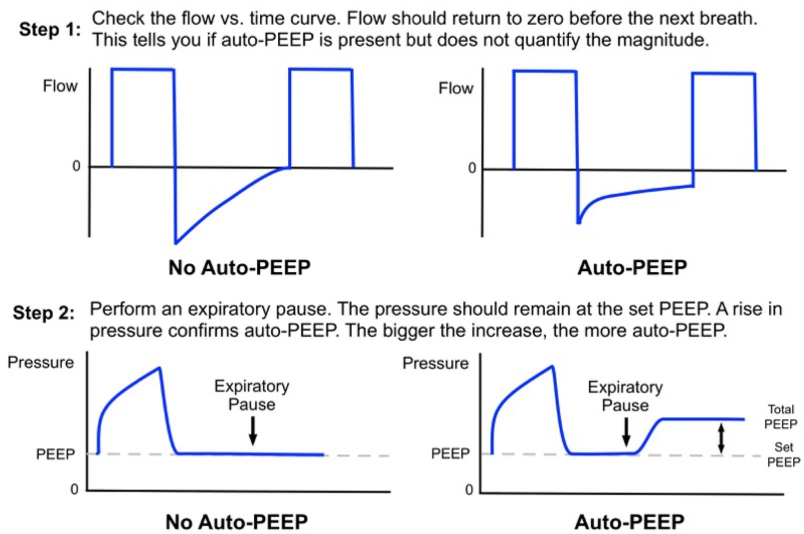
2) When to Look For This?

- Patients with obstructive lung disease (e.g., COPD, asthma)
- Patients requiring a very high respiratory rate to compensate for severe metabolic acidosis
- Patients who are spontaneously breathing at a very high rate
- Unexplained hypotension or cardiac arrest while on mechanical ventilation

3) How to Recognize AutoPEEP on The Ventilator?



Note: This figure depicts the situation for volume assist control

4) Management

Initial Steps:

- Decrease minute ventilation by lowering rate and/or tidal volume.
- Increase sedation if patient is overbreathing the set rate on the ventilator
- Initiate bronchodilators and consider steroids for patients with asthma and COPD
- Increase the inspiratory flow rate; change to a square wave flow pattern (if in a decelerating flow pattern)

Severe Cases:

Call for help!

Initiate neuromuscular blockade

Hypotension and//or bradycardia progressing toward PEA arrest: disconnect from ventilator (the loss of cardiac output is a greater risk than the transient cessation of ventilation). Readjust ventilator settings using the above-noted steps with reconnection.

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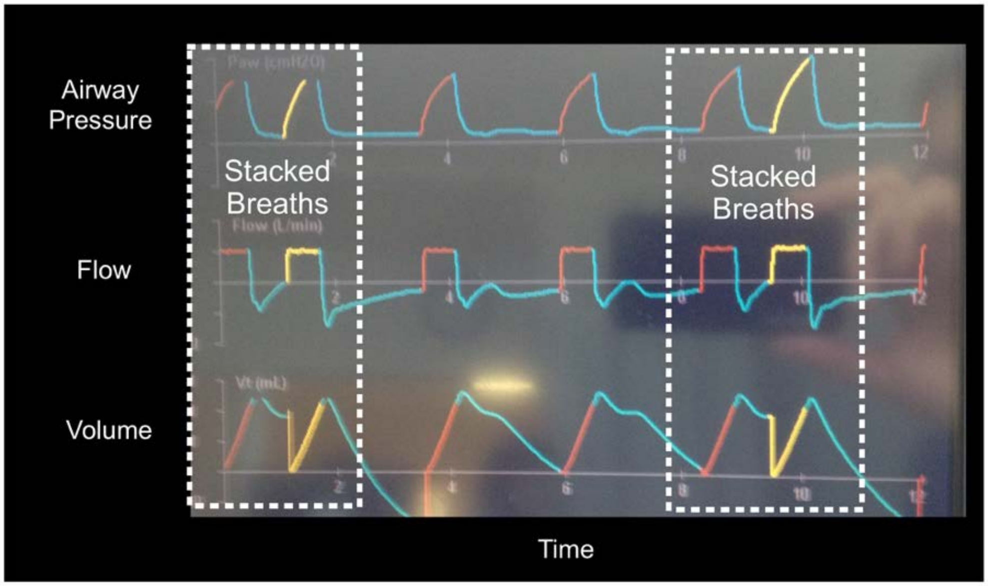
The Respiratory Therapist Said My Patient is Breath Stacking… Now What Do I Do?

1) **What Is Breath Stacking and When Does It Occur?**
In volume assist control, the ventilator delivers a full tidal volume every time the patient inhales. If the ventilator inspiratory time has finished but the patient continues to inhale after the set tidal volume has been delivered, the machine may sense the ongoing inhalation effort and deliver another tidal volume. This results in a larger than the set tidal volume and higher peak and plateau pressures. If a second breath is delivered before any exhalation has occurred, the resulting tidal volume could be as much as twice the set tidal volume. You will most commonly see this in patients receiving low tidal volumes as part of lung protective ventilation.

2) **What Does It Look Like on the Ventilator?**



3) **Is This a Problem That Needs to Be Addressed?**
Breath stacking leads to delivery of higher than intended tidal volumes, which can be injurious to the lungs. Whether to address it depends on several factors:

- Okay to simply monitor if: Breath stacking is very infrequent.
- Address the problem if: Breath stacking occurs on a frequent basis and/or the patient has severe oxygenation problems

4) **A Step-wise Approach to Management**

- Step 1: Increase sedation with propofol and fentanyl to decrease respiratory drive
- Step 2: Decrease the inspiratory flow rate
- Step 3: Consider increasing tidal volume as long as the plateau pressure < 30 cm H_2O
- Step 4: Add an end-inspiratory pause (0.25-0.3 second, may require increased sedation)

Call for help if Steps 1-4 Do Not Fix the Problem

- Step 5: Initiate neuromuscular blockade

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