

Just-In-Time Tools for Training Non-Critical Care Providers

Troubleshooting Problems in the Ventilated Patient

Trevor C. Steinbach¹, Tyler J. Albert^{2,3}, Hugo D. Carmona¹, Nicholas J. Johnson^{1,4}, Patricia A. Kritek^{1*}, Joshua D. Lee¹, and Andrew M. Luks¹

¹Division of Pulmonary, Critical Care & Sleep Medicine, Department of Medicine, ²Division of General Internal Medicine, and ⁴Department of Emergency Medicine, University of Washington, Seattle, Washington; and ³Hospital & Specialty Medicine, Veterans Affairs Puget Sound Healthcare System, Seattle, Washington

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 severe acute respiratory syndrome coronavirus 2 (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 coronavirus disease (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 article presents five guides related to managing complications that can arise in patients receiving invasive mechanical ventilation.

Keywords:

mechanical ventilation; acute respiratory distress syndrome; auto-PEEP; sedation

There is a limited number of critical care providers in the United States, with nearly half of U.S. hospitals operating without one dedicated intensivist (1). During a pandemic, such as the outbreak of severe acute respiratory syndrome coronavirus 2

(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

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Correspondence and requests for reprints should be addressed to Andrew M. Luks, M.D., Professor of Medicine, Division of Pulmonary, Critical Care & Sleep Medicine, Harborview Medical Center and the University of Washington, 325 Ninth Avenue Box 359762, Seattle, WA 98104. E-mail: aluks@uw.edu.

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efforts to increase capacity as part of surge preparation for the coronavirus disease (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 nonintensivist 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 acute respiratory distress syndrome (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. In addition, local sedation practices lean heavily toward 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 that require swift action to stabilize the patient and gain control of the situation. These recommendations are based upon existing guidelines (6, 7) and on the usual practice of the contributing authors. We acknowledge that different critical care providers may have their own practices that 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.

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 four of the Berlin criteria: (<https://jamanetwork.com/journals/jama/fullarticle/1160659>)



- Acute onset (<7 d) from known cause (e.g., COVID-19 infection)
- Bilateral opacities on chest radiograph
- Pa_{O_2}/Fi_{O_2} (P/F ratio) < 300
- Not *entirely* due to pleural effusions, volume overload, or cardiogenic edema

Classification of Severity (Pa_{O_2} obtained from arterial blood gas; Fi_{O_2} expressed as a decimal):

- Mild: $200 \leq Pa_{O_2}/Fi_{O_2} < 300$
- Moderate: $100 \leq Pa_{O_2}/Fi_{O_2} < 200$
- Severe: $Pa_{O_2}/Fi_{O_2} < 100$

2. Initiate Low Tidal Volume Ventilation (Often Referred to as Lung Protective Ventilation)

Change tidal volume to 6 ml/kg *predicted* body weight (PBW) (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 ($P_{plateau}$) < 30 cm H₂O:
 - If $P_{plateau} > 30$ cm H₂O: consider decreasing tidal volume further, to as low as 4 ml/kg PBW
 - If $P_{plateau} < 30$ cm H₂O: maintain 6 ml/kg
- Sa_{O_2} 88–95% (or Pa_{O_2} 55–80 mm Hg):
 - Use the positive end-expiratory pressure (PEEP)/ Fi_{O_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 Pa_{CO_2} , “permissive hypercapnia”)

3. If $Pa_{O_2}/Fi_{O_2} < 150$ 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 cm H₂O and $Fi_{O_2} < 0.6$ or if ineffective

4. If $Pa_{O_2}/Fi_{O_2} < 150$ and Patient Is Not Synchronous with the Ventilator, Start Neuromuscular Blockade and Call for Help!

48-hours infusion of cis-atracurium

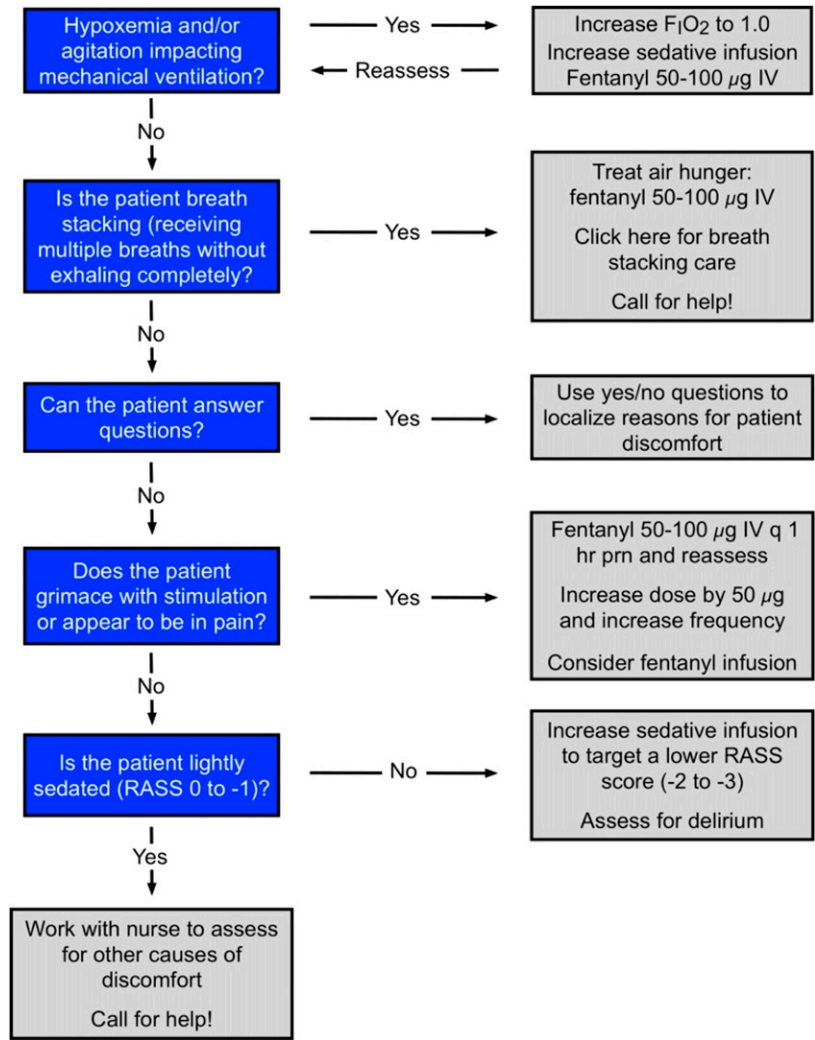
Ensure deep sedation (RASS -4 to -5)

5. Call for Help if Hypoxemia Persists despite Prone Positioning and Neuromuscular Blockade

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 RASS 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 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.

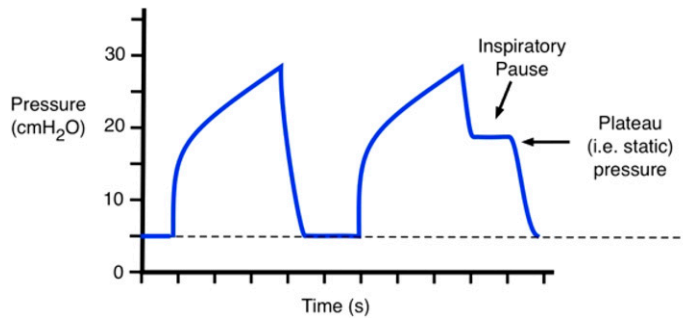
THE PEAK INSPIRATORY PRESSURE HAS INCREASED... NOW WHAT DO I DO?

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 four 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 PEEP. If the flow rate, flow pattern, and 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, nonintubated individuals C_{ST} is about 100 ml/cm H₂O. Values <20 ml/cm H₂O are indicative of very low compliance.

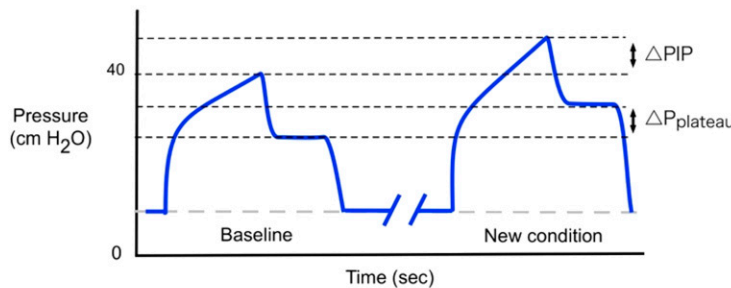


$$C_{ST} = \frac{\text{Tidal Volume}}{P_{\text{plateau}} - \text{PEEP}}$$

Note: This figure depicts volume assist control

3. Management

- Recognizing and evaluating a compliance problem



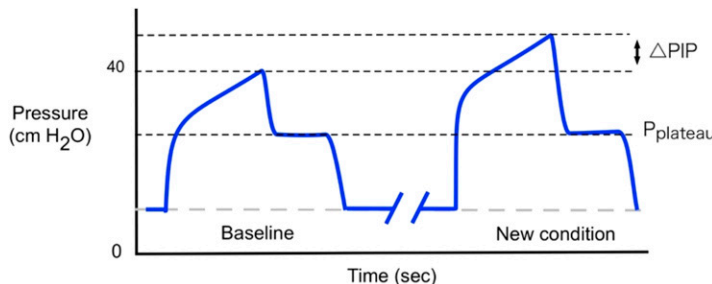
Compliance Problem
(PIP and plateau pressure both increase)

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 H₂O.

- 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

THE RESPIRATORY THERAPIST SAID MY PATIENT HAS AutoPEEP... NOW WHAT DO I DO?

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

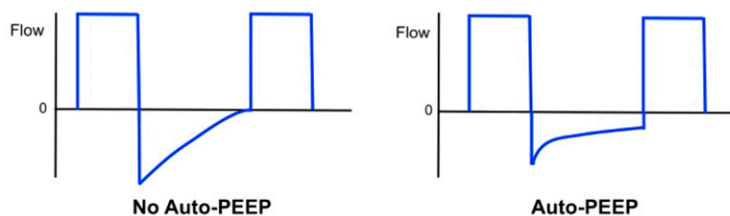
Under normal circumstances, the entire delivered tidal volume is expired during exhalation. If expiratory time is insufficient (*see below*), some portion of the previously delivered breath may remain in the lungs at the time the next breath is delivered. If this happens on a repeated basis, the lungs 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.

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

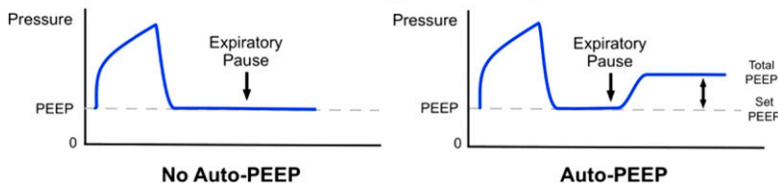
3. How to Recognize AutoPEEP on The Ventilator?

Step 1: Check the flow vs. time curve. Flow should return to zero before the next breath. This tells you if auto-PEEP is present but does not quantify the magnitude.



Note: This figure depicts the situation for volume assist control.

Step 2: Perform an expiratory pause. The pressure should remain at the set PEEP. A rise in pressure confirms auto-PEEP. The bigger the increase, the more auto-PEEP.



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

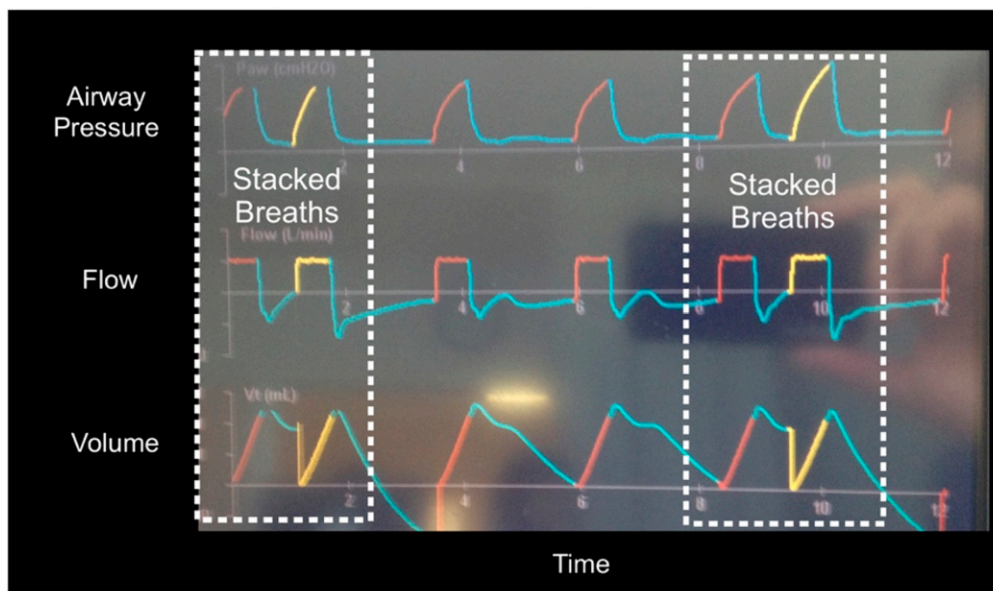
Hypotension and/or bradycardia progressing toward PEA arrest: disconnect from ventilator (the loss of cardiac output is a greater risk than the transient cessation of ventilation). Readjust ventilator settings using the above-noted steps with reconnection.

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-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 V_T , 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 Stepwise 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 s, may require increased sedation).

Call for help if Steps 1–4 do not fix the problem.

- Step 5: Initiate neuromuscular blockade.

Author disclosures are available with the text of this article at www.atsjournals.org.

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