**Ventilators on the Fly – Teacher’s Guide**

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**Objectives:**

1. Determine the mode of mechanical ventilation by looking at the ventilator settings and curves.
2. Determine the relative amount of oxygen support provided by a ventilator.
3. Determine whether minute ventilation is appropriate.
4. Identify problems with respiratory mechanics.

**INTRODUCTION**

Plan to spend 30-60 minutes preparing for this talk by using the Interactive Board for Learning/Preparing and clicking through the graphics animations to become familiar with the flow and content of the talk. *Print out copies of the Learner’s Handout so learners can take notes as you expand on the pathophysiology and management. The first page of the handout is a blank schematic that learners can fill in as you go through the presentation.* The anticipated time to deliver this talk is about **20-25 min without cases and 30-35 min with cases**.

The talk can be presented in three ways:

1. Project the "Interactive Board" OR
2. Reproduce your own drawing of the presentation on a whiteboard OR
3. Adapted to bedside teaching using actual ventilator waveforms

This talk introduces the basics of mechanical ventilation. There are 4 basic questions to ask when evaluating a patient on a ventilator:

1. What is the mode?
2. What is the level of oxygen support?
3. Is ventilation appropriate?
4. How are the respiratory mechanics?

The talk first orients the learner to a generic, simplified ventilator. The numbers on the right represent the dials for parameters set by the clinician. The numbers on the left side of the screen display the actual values achieved, as measured by the ventilator. Note that the two numbers are not always equal; for instance, the measured respiratory rate may exceed the set rate in the setting of a spontaneously breathing patient. (Note: the actual layout of the clinician settings and readout will vary by brand and model of ventilator.)

This ventilator shows two of the waveforms seen on a typical ventilator: pressure and flow. On the pressure waveform, **PEEP** (positive end-expiratory pressure) is the pressure remaining in the circuit after exhalation. **Peak pressure** is the maximum pressure measured during inspiration. **ΔP** (pronounced “delta P”) is the difference between peak pressure and PEEP. The units of pressure are cm H2O.

On the flow waveform, positive deflections indicate inspiratory flow, and negative deflections indicate expiratory flow.

(Advanced note: because expiration is passive while on a ventilator, expiratory flow is entirely dependent on patient factors, including the elastic recoil of the respiratory system—inverse of compliance—and airway resistance, meaning expiratory flow will appear the same on all modes of mechanical ventilation for any given patient. This contrasts with inspiration, which is influenced by the complex interactions between the ventilator settings and the patient’s respiratory mechanics.)

**OBJECTIVE 1: WHAT IS THE MODE?**

**General Approach**

These slides display typical ventilator parameters in four common modes. *Click on each of the modes for additional details.* Note that there are several other more “advanced” modes not covered in this introductory session.

Ventilators of different brands and models display different nomenclature on their screens despite being in standard modes. All ventilators will indicate the current mode somewhere on the display. However, there are also several clues that can be gathered when looking at the waveforms depending on the brand/model:

* First, find the **square wave forms**. In pressure modes, the square waves should be in the pressure curve. Classic volume modes have pressure waves in the inspiratory flow curve (but these can be changed depending on brand of ventilator). An important caveat is that patient triggering/respiratory effort and dyssynchrony can change the shapes of all these curves, making it harder to decipher what mode the ventilator is in.
* Second, see if there is a **set (or mandatory) respiratory rate** from the settings. Control modes have a set rate. Support modes have no set rate, meaning every breath is spontaneous or patient-triggered. A patient can spontaneously trigger and breathe over the set rate in any mode.
* Third, find the **set target** from the settings and see whether it is a pressure or volume target. True pressure modes target pressure and true volume modes target volume (as opposed to hybrid modes).
* Fourth, determine which variables are being **monitored**. When setting the pressure as the target, the tidal volume becomes the dependent variable that must be monitored, and vice versa.

For each mode, it is essential to know what values are set by the clinician and which values need to be closely monitored. It is also helpful to think about **when this mode is used**. Regardless of mode, the clinician will set the PEEP and fraction of inspired oxygen (FiO2) depending on the level of oxygen support required.

**Specific Modes**

Ask your learners where the square wave is, whether there is a mandatory RR, and what parameters are set and monitored. Click on each of the buttons to reveal the answer.

|  |  |
| --- | --- |
| **Classic square wave** | Pressure |
| **Mandatory respiratory rate?** | Yes |
| **What you target** | Inspiratory Pressure (Pcontrol) |
| **What you monitor** | Tidal Volume (VT) and Minute Ventilation (VE) |

* **Pressure Control:** In Pressure Control, the clinician sets a target Pcontrol (or ΔP) delivered during inspiration above the PEEP. (On some ventilators, a peak pressure is set directly.) Inherent in a pressure mode, **the pressure waveform will typically be square** as a set pressure is delivered throughout the entire breath. As with all control modes, there is a set mandatory (or minimum) respiratory rate over which the patient may breathe. With pressure being the set variable, tidal volume (and by extension minute ventilation) must be monitored. Low or decreasing tidal volumes on pressure control indicate a problem with respiratory mechanics.   
    
  This mode theoretically increases patient comfort because the same amount of pressure is given with each breath – though this has not been proven in large clinical trials. It also allows precise adjustment of airway pressures when this is needed.

|  |  |
| --- | --- |
| **Classic square wave** | Flow |
| **Mandatory respiratory rate?** | Yes |
| **What you target** | Tidal Volume (VT) |
| **What you monitor** | Peak Pressure and Plateau Pressure |

* **Volume Control:** In classic Volume Control, the ventilator gives a constant flow, resulting in a **square wave in inspiratory flow**, until the target tidal volume is reached. However, on contemporary ventilators, the shape of the inspiratory flow can be changed from the default of square wave despite being in volume control. Thus, the absence of a square wave does not exclude volume control as the mode. Because it is a control mode, the clinician also sets a mandatory respiratory rate. With tidal volume being the set variable, peak and plateau pressures must be monitored (more on obtaining a plateau pressure later). Elevations in pressures can indicate problems with respiratory mechanics. This mode is helpful for achieving lung-protective low-tidal volumes in acute respiratory distress syndrome (ARDS).

Note: both Pressure Control and Volume Control are forms of Assist Control, meaning that every breath, whether ventilator or patient-triggered, will receive the same set pressure or tidal volume from the ventilator. These modes are commonly referred to as AC-PC and AC-VC.

|  |  |
| --- | --- |
| **Classic square wave** | Pressure |
| **Mandatory respiratory rate?** | Yes |
| **What you target** | Tidal Volume (VT) |
| **What you monitor** | Peak Pressure, Plateau Pressure, Achieved Tidal Volume (VT) |

* **Pressure Regulated Volume Control (PRVC):** This is a hybrid mode where a target tidal volume is set, and the ventilator employs a proprietary algorithm to determine the pressure control required to achieve that volume based on the previous few breaths. It is essentially a volume-targeted form of pressure control. As such, the **pressure waveform will be square**. Once again, there is a set respiratory rate because it is a control mode. As volume is being targeted, the key parameters to monitor are the peak and plateau pressure. It is also important to monitor whether the achieved tidal volume approximates the set target volume.  
    
  PRVC is labeled differently depending on the ventilator brand; examples include Adaptive Pressure Ventilation-Controlled Mechanical Ventilation (APV-CMV) and Volume Control+ (VC+). The theoretical advantage of this mode is that it combines the benefit of lung-protective tidal volumes with the comfort of pressure control.

|  |  |
| --- | --- |
| **Classic square wave** | Pressure |
| **Mandatory respiratory rate?** | No |
| **What you target** | Pressure support (PSupport) |
| **What you monitor** | Tidal Volume (VT), Respiratory Rate, and Minute Ventilation (VE) |

* **Pressure Support:** This is an entirely spontaneous mode of ventilation, meaning the patient initiates every breath. The ventilator only provides a set positive pressure (the PSupport) on inspiration to augment the patient’s own respiratory effort, with PEEP still present on expiration. Because it is a support mode, **there is no mandatory respiratory rate**, meaning in the absence of any patient-initiated breaths, apnea will occur. Fortunately, the ventilator will alarm and change back to a control mode if the patient is apneic beyond a set duration of time. The pressure curve will show a negative deflection before each inspiration, indicating the negative pressure created by the patient to trigger a breath. Being a pressure targeted mode, there is generally a **square shape in the pressure wave**; however, a strong negative inspiratory force from the patient can blunt the shape of the pressure wave. The key parameters to monitor in pressure support are tidal volume, respiratory rate, and minute ventilation. This mode is most commonly used for spontaneous breathing trials and when the patient requires minimal ventilatory support and is able to spontaneously breathe.

**Ventilator Mode Summary**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Mode** | **Classic square wave** | **Mandatory RR?** | **What you target** | **What you monitor** | **When to use** |
| **Pressure Control** | Pressure | Yes | Inspiratory Pressure (PControl) | Tidal Volume (VT) and Minute Ventilation (VE) | Patient comfort, precise airway pressure adjustment |
| **Volume Control** | Flow | Yes | Tidal Volume (VT) | Peak Pressure and Plateau Pressure | ARDS (lung-protective tidal volumes) |
| **Pressure Regulated Volume Control** | Pressure | Yes | Tidal Volume (VT) | Peak Pressure, Plateau Pressure, Achieved Tidal Volume (VT) | Lung protective tidal volumes with comfort of pressure support |
| **Pressure Support** | Pressure | No | Pressure support (PSupport) | Tidal Volume (VT), Respiratory Rate, and Minute Ventilation (VE) | SBTs, patient providing adequate RR |

**OBJECTIVE 2: WHAT IS THE LEVEL OF OXYGEN SUPPORT?**

The degree of oxygen support provided by the ventilator is indicated by the PEEP and FiO2. The higher the values required to achieve an acceptable SpO2 and PaO2, the higher the level of support. The [ARDSNet PEEP ladder](http://www.ardsnet.org/files/ventilator_protocol_2008-07.pdf) can give a quantitative sense of the continuum of oxygen support between ambient air at 21% FiO2 and 100% oxygen. The ladder also serves as a practical guide for how to increase the PEEP and FiO2 relative to one another. A sample set of values is provided on the slide.

**OBJECTIVE 3: IS VENTILATION APPROPRIATE**

Click on each step to reveal additional information. Assessing the adequacy of ventilation **first** requires identifying the actual minute ventilation recorded on the ventilator. Minute Ventilation (VE) = Tidal Volume x Respiratory Rate. Normal minute ventilation in healthy individuals is 5-7 L/min, but it varies with height, and much higher values are often required when disease is present.

**Second,** it must be determined whether the ventilation is appropriate. The most common and accurate measure of ventilation adequacy is the arterial pH, which requires obtaining an arterial blood gas (ABG). Venous blood gases (VBGs) from central lines are also useful, but interpret pH and PCO2 from peripheral VBGs with caution. A general rule should be to maintain pH between 7.2-7.5. (Review ABG interpretation here.)

Determine the acid-base status of the patient based on the blood gas and determine if the pH is appropriate/at goal. If the pH is at goal, then ventilation is appropriate and no changes are needed. If the pH is not at goal, look at the patient’s minute ventilation (from the actual, not set, tidal volume and respiratory rate).

**Third,** determine if the patient is passive on the ventilator or triggering breaths. Signs of triggering include negative deflections before the pressure curve rises, an actual respiratory rate greater than the set respiratory, and, on some ventilators, a marker indicating patient breaths. Click on “yes”/ “no” buttons to reveal additional information.

* No: If the patient is passive, then the ventilator is determining ventilation fully. The clinician must adjust the minute ventilation to achieve the desired pCO2 and thus pH. This is most commonly done by adjusting the respiratory rate (although in some cases tidal volume must also be manipulated, but this requires close monitoring of airway pressures).
* Yes: If the patient is triggering breaths, the pH is being driven by the patient. A brief differential of underlying causes of either hypo- or hyperventilation is listed below:
  + If the patient is acidemic (pH<7.3) and hypoventilating (VE<5L/min), this is inappropriate – consider CNS suppression of respiratory drive.
  + If the patient is acidemic and hyperventilating (VE>8L/min), this is appropriate.
  + If the patient is alkalemic (pH>7.5) and hypoventilating, this is appropriate.
  + If the patient is alkalemic and hyperventilating, this is inappropriate – consider CNS/brainstem injury, salicylate toxidromes, and pain/agitation as causes.

**OBJECTIVE 4: HOW ARE THE RESPIRATORY MECHANICS?**

The last key question is about respiratory mechanics, which is a combination of compliance (both of the lung and the chest wall) and airway resistance. Most lungs with normal mechanics require a ΔP of <10 cm H2Oto achieve a 6 mL/kg tidal volume by predicted body weight.

The way to assess respiratory mechanics differs for pressure-targeted and volume-targeted modes:

* For a pressure-targeted mode (i.e. Pressure Control), the key parameters are the tidal volume (VT) and the minute ventilation (VE). Low or declining values point to trouble with respiratory mechanics (i.e. poor compliance due to stiff lungs or worsening airways obstruction).
* For a volume-targeted mode (i.e. Volume Control or PRVC), the key parameter is the ΔP (Peak Pressure – PEEP). Larger pressures to deliver the same tidal volumes indicates worsening respiratory mechanics.

A key point is that the patient cannot be triggering their own breaths when ΔP is measured. (See above for signs of triggering breaths.) Patient-triggered breaths contribute extra negative pressure to ΔP that the clinician is not able to measure, so the clinician cannot easily evaluate compliance or resistance.

In volume-targeted modes set to 6ml/kg, if Peak Pressure – PEEP >10 cm H2O, the next step is to perform an **Inspiratory Hold** to determine if it is an airway resistance issue or a compliance issue. In an inspiratory hold, flow is stopped after the tidal volume is delivered, and the resultant pressure is called the **Plateau Pressure**. Click on "Resistance" and then “Compliance” for additional information.

* If Peak Pressure – Plateau Pressure > 3 cm H2O, it points to an airway resistance issue. This could be from things such as a mucus plug, a kinked endotracheal tube, or bronchospasm.
* If Plateau Pressure – PEEP > 10 cm H2O, this points to a compliance issue either in the lungs themselves or in the pleural space, chest wall, or abdomen. This could be due to things like pneumothorax, alveolar filling, fibrosis, mainstem intubation (high pressures to get 6ml/kg into a single lung), abdominal compartment syndrome, etc.
* Note that these thresholds of 3 and 10 cm H2O are ballpark figures, and they are heavily influenced by the mode and the brand of ventilator.

This concept is further explored in the Respiratory Mechanics chalk talk.

**CASES**

*For each case, ask your learners to identify the mode, target parameters (what you target), and key outputs (what you monitor). Reinforce the framework taught in Objective 1 (each step is numbered).*

**TAKE HOME POINTS**

1. For any mode, it is important to know which parameter you are targeting and which parameters you are monitoring. Identifying the square wave on a ventilator can help differentiate between volume and pressure modes. A mandatory respiratory rate indicates a control mode of ventilation where every breath will receive the same set pressure or tidal volume.
2. The level of “O2 support” is determined by the combination of PEEP and FiO2.
3. To evaluate a patient's ventilation:
   1. Identify the actual minute ventilation, which is determined by tidal volume and respiratory rate,
   2. Check a pH to determine the adequacy of ventilation, and
   3. Identify if ventilation is driven by the ventilator settings or a patient's pathology by looking for spontaneous breaths.
4. In a volume-targeted mode, an elevated ΔP (Peak pressure – PEEP) suggests an airway resistance or lung compliance issue. Performing an inspiratory hold to obtain a plateau pressure can help differentiate between these causes.

**REFERENCES**

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