**Ventilators Part 2: Assessing Respiratory Mechanics**

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**Objectives:**

1. Identify the key outputs in pressure-targeted and volume-targeted ventilator modes.
2. Define the terms resistance and compliance and predict how changes in resistance and compliance will impact key outputs on the ventilator.
3. Apply a diagnostic approach to high peak pressure alarms in a mechanically ventilated patient.

**Teaching Instructions:**

Plan to spend at least 30-60 minutes preparing for this talk by reaching through the teaching instructions and clicking through the Interactive Board. All clickable elements are denoted with a shaded, rounded rectangle and/or a mouse icon.

**Anticipated time to deliver the talk without cases or other features: 30 minutes; anticipated time with cases: 45 minutes**.

The goal of this talk is to build on concepts introduced in the [Ventilators on the Fly](https://teachim.org/teaching_material/ventilators-on-the-fly/) talk. It assumes basic understanding of common ventilator terminology and focuses on assessing pulmonary mechanics by interpreting key outputs from the ventilator that results from changes in two physiologic parameters: resistance and compliance. It also prompts learners to consider the underlying pathology leading to changes in resistance and compliance.

**Objective 1: Name and define the key outputs in pressure and volume-targeted ventilator modes (*Ky Outputs*).**

*Start with reviewing the key points from* [*Ventilators on the Fly*](https://teachim.org/teaching_material/ventilators-on-the-fly/) *as this talk will build on those topics. Ask your learners to identify the key outputs in pressure and volume targeted modes of ventilation. Click on each corresponding button to reveal the answer.*

* In pressure-targeted modes, the key outputs are tidal volume (Vt) and minute ventilation (VE).
* In volume targeted modes, the key outputs are peak pressure (Ppeak) and driving pressure (Pdriving).

To distill this into a simple principle: when targeting *volume* one must monitor *pressures,* and when targeting *pressures,* one must monitor *volumes*.

*Click on the “minute ventilation”, “peak pressure”, “plateau pressure”, and “driving pressure” buttons to reveal a depiction of each concept and review/introduce each of their definitions.*

* *Tidal volume* is the total volume delivered each breath.
* *Minute ventilation* is the tidal volume multiplied by the respiratory rate. It is typically reported in L/min.
* *Peak Pressure*: measures the total pressure required to deliver the targeted tidal volume *during* inspiration.
* *Plateau pressure:* measures the pressure required to hold air in the lungs at the end of inspiration for a given tidal volume. It is measured during an inspiratory hold maneuver.
* *Driving Pressure:*  the pressure difference required to achieve the desired volume. It is calculated as plateau pressure minus the PEEP.

**Objective 2: Define the terms resistance and compliance and predict how changes in resistance and compliance will impact key outputs on the ventilator. (*Definitions – Ppeak; Pplateau; Pdriving*)**

Next, it is important to learn how to interpret lung mechanics from studying the inputs and outputs measured by the ventilator. The two key concepts are resistance and compliance.

**Definitions:** *Ask your learners to define resistance and compliance and click on the buttons to reveal the definitions.*

* *Resistance*:Resistance is the opposition to airflow through the airways. Because it is measured at the ventilator, the resistance in a ventilated patient includes the airflow through the ventilator tubing and endotracheal tube as well. Resistance is proportional to the difference in pressure across a circuit. In a mechanically ventilated patient, this is assessed by subtracting the plateau pressure from the peak pressure.

$$R∝P\_{peak}-P\_{plateau}$$

If resistance is normal, this should be <10 cm H2O.

* *Compliance*: Compliance is a measure of the “stiffness” of the respiratory system—including lungs, pleura, chest wall, diaphragm, and intra-abdominal pressure. It is calculated as:

$$C=\frac{∆V}{∆P}=\frac{V\_{T}}{P\_{plateau}- PEEP}=\frac{V\_{T}}{Driving pressure}$$

The stiffer the system, the lower the compliance—meaning a patient with good compliance requires smaller pressure changes to achieve the set tidal volume. In the setting of normal compliance, the driving pressure needed to achieve a tidal volume of 4-6 cc/kg of ideal body weight is <10 cm H2O.

Ask your learners what factors influence peak pressure, plateau pressure, and driving pressure sequentially. Click on “Ppeak”, “Pplateau” and “Pdriving” in the left side navigation bar to learn about how these key outputs in volume-targeted modes of ventilation relate to resistance and compliance.

**What influences Peak Pressure? (Ppeak):** It is dictated by both (*1*) resistance and (*2*) compliance. Other factors that influence peak pressure include (*3*) inspiratory flow rate and pattern, and (*4*) the total PEEP in the system (including auto-PEEP).

Click on the numbers as your learners guess them to reveal the factors that influence peak pressure. Point out the portion of the pressure diagram that corresponds to each of these factors to visually show how increases in each of these components leads to increases in peak pressure.

**What influences Plateau Pressure?** **(Pplateau):** Plateau pressure is affected by pressure in and around the lung parenchyma. It is measured when airflow is absent, so there is no resistance in the system. Thus, changes in airways do not directly affect plateau pressure. Generally, plateau pressures should be <30cm H2O. Higher values increase the risk of barotrauma.

**What Influences Driving Pressure? (Pdriving):** All the things that influence plateau pressure also influence driving pressure since they are inextricably linked. Compliance of the respiratory system affects how much pressure is needed to achieve a given tidal volume.

**Objective 3: Apply a diagnostic approach to high peak pressure alarms in a mechanically ventilated patient. (*Peak P Alarm – Step 1; Step 2; Step 3*)**

High peak pressure alarms are common in the care of mechanically ventilated patients managed with *volume targeted modes*. Applying a structured approach helps streamline the assessment of a mechanically ventilated patient with high peak pressures using the concepts introduced above.

*Ask the learners to imagine they are called to a room for elevated peak pressures.* For instance, they might get a message from nursing or respiratory therapy: “I am worried about the patient in room 365. Their ventilator keeps alarming that they are having high peak pressures. Can you come assess them?”

**Step 1: Establish Urgency**

Assess the patient at bedside immediately as some causes of high peak pressures are emergencies. Obtain a full set of vital signs and assess key ventilator outputs. High peak pressure along with any of the following findings may indicate an emergency and should prompt an immediate call for backup:

* Low O2 saturation
* Low VT
* Low VE - since an appropriate VE is relative to individual scenarios, a rough guideline for a “low VE is an approximate decrease of >50%
* Rising PCO2 on blood gas measurement (do not delay evaluation to obtain blood gas)
* Drop in blood pressure

In emergency situations, it is imperative to prioritize calling for assistance first even whilst moving to the next steps. For example, in patients with low O­2 saturations, increase FIO­2 to 100% in addition to calling for back-up.

The goal of steps 2 and 3 (which can be done in either order) is to assess for a resistance problem and/or a compliance problem. High resistance and low compliance result can both result in high peak pressures. Remember that they can co-exist.

**Step 2: Assess Resistance**

Obtain a plateau pressure by performing an inspiratory hold. Resistance is proportional to the difference between peak pressure and plateau pressure. A result > 10 cm H2O is concerning for higher-than-normal resistance.

*Differential?: Ask learners to consider what might cause a higher resistance (e.g., make it to be difficult for air to pass through the tubing and airways)? Click on “differential” to reveal a list of common causes of increased resistance.*

A narrowing or blockage at any point in the system increases resistance:

* Kinked tubing
* Blocked tubing (e.g. mucus, patient biting the tube)
* Bronchospasm
* Large airway obstruction (e.g. mucus plugs or blood clots)

*Action?: Ask learners what actions they can take to address each of these causes. Click on “action” to show next steps in management.*

* Examine the external tubing for kinking or compression.
* Deep suctioning the endotracheal tube can clear mucus plugs and establish patency of the endotracheal tube. In rare cases suctioning may need to be performed with a bronchoscope (performed by attending or fellow)
* In a patient biting an endotracheal tube, adjusting the bite block and increasing analgesia or sedation can help.
* If the above maneuvers fail, kinked, or obstructed endotracheal tubes may need replacement by a clinician trained in airway management.
* Consider bronchodilators to address bronchospasm, especially in patients with history of obstructive lung disease.

**Step 3: Assess Compliance**

Obtain a plateau pressure by performing an inspiratory hold. A plateau pressure >3 0cm H2O is generally considered elevated and may suggest a compliance problem. Compliance is inversely proportional to the driving pressure. Assuming equal PEEP, the higher the plateau pressure, the higher the driving pressure, and the lower the compliance of the respiratory system. A driving pressure > 10 cm H2O suggests low compliance.

*Differential?: Ask learners to consider what processes can lead to a stiffer or less compliant respiratory system. Click on “differential” to reveal common causes of increased compliance.*

Generally, there are two categories to consider: 1) Alveolar filling and 2) alveolar collapse.

* Alveolar filling – alveoli can be filled with blood pus or water. Cardiogenic and noncardiogenic pulmonary edema (ARDS), pneumonia, diffuse alveolar hemorrhage all lead to increased compliance.
* Alveolar collapse – Atelectasis, lobar collapse and extrapulmonary processes that cause alveolar collapse can cause increased compliance. Extrapulmonary processes may be intrathoracic (such as pleural effusions, pneumothoraxes) or extrathoracic (such as abdominal distention, pregnancy, ascites).

*Action?: Ask learners what actions they would take to further differentiate what is going on in a patient with high compliance and start to address the underlying pathophysiology. Click on “actions” to reveal next steps in management.*

* *Get more history.* This might make one cause more likely than another. A patient with severe COPD is more likely to air trap than a patient without obstructive lung disease. The rate of increase in the peak pressure is also telling. A pneumothorax might cause an acute rise in the peak pressure over minutes to hours whereas worsening fibrosis from ARDS may present with a slower rise over hours to days.
* *Perform a targeted physical exam.* Worsening pneumonia or pneumothorax may have decreased lung sounds or new rhonchi. A rigid abdomen might suggest abdominal compartment syndrome. If the patient has burns on the chest or is on a fentanyl drip, stiffening of the chest wall might be to blame.
* *Obtain more clinical data.* CXR and point of care ultrasound can identify worsening pulmonary infiltrates, a new or worsening pneumothorax, or significant pleural effusions. An ABG can give an overall assessment of gas exchange. If the rise in peak pressure is an acute change, ordering basic labs like a CBC, BMP, LFTs, INR, and possibly a lactate is a good starting point. If you suspect abdominal compartment syndrome, a bladder pressure aids in diagnosis. Of course, the clinical scenario will dictate the most important studies.

**Take Home Points:**

1. Peak and plateau pressures are key outputs in volume targeted modes of ventilation. Peak pressure is influenced by the resistance, compliance, PEEP, and inspiratory flow rate. Plateau pressure is obtained by performing an inspiratory hold and generally should be <30 cm H2O.
2. In assessing a patient with a high peak pressure alarm, first establish urgency, then identify whether it is a resistance or compliance issue, or both.
3. Resistance represents the opposition to airflow in the airway and is proportional to Ppeak – Pplateau. Values > 10 cm H2O represent a resistance problem and are caused blockages or narrowing in the tubing or airways.
4. Compliance measures the stiffness of the respiratory system and is inversely proportion to driving pressure, or Pplateau – PEEP. Values > 10 cm H2­­O represent a compliance issue such as alveolar filling processes or disorders resulting in alveolar collapse.