**General Terminology**

Paw – Airway pressure.

Pplat – Plateau Pressure is a constant pressure after a lung reaches the end of an inspiration.

PIP – Peak Inspiratory Pressure is the maximum pressure achieved during inspiration. It is dependent on airway resistance and lung compliance.

Vt – Tidal volume is the total volume of gas that is inhaled.

Vd – Dead space volume is the volume that is inhaled but does not take part in gas exchange.

Lung Compliance – lung elasticity dictated by dV/dP. High compliance is very elastic whereas low compliance is very stiff.

TCT – Total Cycle Time is the time required for inhalation and exhalation.

Ti – time required for inhalation and inhalation pause/hold.

Tipause or Tihold – time required for pause or hold.

Te – time required for exhalation.

I:E ratio – ratio of inhalation time to exhalation time.

**Ventilation Modes Terminology**

*Modes of Ventilation*

*(Mechanical Breaths)*

VCV - Volume controlled ventilation will provide a set tidal volume at a constant flow rate irrespective of the pressure.

PCV – Pressure controlled ventilation will provide a constant pressure irrespective of what tidal volume is delivered.

PC-CMV Adaptive (Pressure Regulated Volume Control) – provides a set tidal volume while trying to limit the pressure. It does this by initially using a VC (or PC) breath at the target tidal volume to measure the lung compliance. It then uses the compliance to select a pressure with which to achieve the set tidal volume. The compliance is constantly measured and used to adjust the pressure to achieve that minimum tidal volume.

*(Spontaneous Breaths)*

PS – Pressure support mode is when the ventilator assists the patient by providing a positive pressure, however the patient defines when the inhalation and exhalation phases occur. The ventilator will maintain a pre-set pressure during the inhalation phase and terminate this pressure when exhalation is monitored. Patient controls Ti, and this may change from breath to breath.

CS – Control support mode is when the ventilator assists the patient by providing a tidal volume, however the patient defines when the inhalation and exhalation phases occur.

*Trigger Method / Breath Type*

CMV –Continuous Mandatory Ventilation is a mode that the ventilator dictates when breathes are taken.

CSV – Continuous Spontaneous Ventilation is a mode that allows natural breathing; the person is driving the breathing pattern.

IMV – Intermittent Mandatory Ventilation is a mode whereby mandatory breaths are delivered at a set frequency, tidal volume, and inspiratory flow rate. However, the patient can breathe spontaneously between the machine-delivered breaths.

SIMV - Synchronized IMV (SIMV) is a mode whereby the ventilator attempts to deliver the mandatory breaths in synchrony with the patient’s own inspiratory efforts. The ventilator therefore allows the patient an opportunity to breathe. If the patient makes an inspiratory effort during a window of time determined by the IMV rate, the ventilator delivers a mandatory breath in response to the patient’s inspiratory effort. However, if no inspiratory effort is detected by the ventilator, a time-triggered breath is delivered.

**Physiology of Breathing**

**Lung Compliance**

Compliance is nothing but the measure of how stretchable or elastic the lungs are. It is determined by the change in volume (ΔV) by the change in pressure (ΔP) in the lungs

Normal lung compliance is 60–100 ml/cmH2O.[4] In general, a high compliance is seen in disease conditions such as COPD, where the lungs can easily stretch but do not recoil back to normal due to the obstruction within the airways. It takes a longer amount of time to exhale the volume out. In such cases, air is unable to effectively come out from the lungs causing air trapping and hyperinflation. Poor compliance or low compliance is seen in diseases such as cystic fibrosis where the lung parenchyma is stiff and does not easily stretch. This abnormal lung compliance results in an increased work of breathing. With high compliance, it takes more work for the lungs to remove the air, whereas, with low compliance, more effort is required to fill air in the lungs.

<http://www.ijrconline.org/article.asp?issn=2277-9019;year=2019;volume=8;issue=1;spage=4;epage=7;aulast=Shevade>

**Resistance**

The resistance or opposing frictional forces to the flow of air during respiration are known as airway resistance. It is the difference in pressure at the mouth and pressure in the alveoli (ΔP), divided by the flow of air (Vflow).

Normally, some amount of resistance of about 0.5 cm H2O/L/s–2.5 cm H2O/L/s[7] is always present in the airways. This means, to move 1 L/s flow of gas in or out of the lungs, a healthy individual requires to generate a pressure of about 0.5 cmH2O–2.5 cmH2O less than the atmospheric pressure.[7] This resistance changes through the various generations of the airways within the lungs due to the structural differences.

With increased obstruction in the lungs, the airway resistance increases. Obstruction may be caused by excessive mucous secretions, inflammation in the airway, contraction of the smooth muscle during an asthma exacerbation, or tumors in the wall of airway or outside the surrounding airway. Resistance tends to reduce with bronchodilation.

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**Time constant**

TC is the amount of time taken by the lung unit to fill during inhalation (inspiratory TC) or empty during exhalation (expiratory TC) at a stable pressure.[7],[8] TC is a single parameter that can tell us about the overall respiratory characteristics. It is measured in seconds and is a product of compliance and resistance.

TC ( 1 x Time Constant) = CL (Lung Compliance) × Raw (Airway resistance)

One TC is the time required to fill or empty 63% of the lung unit. Two TCs fill 86% of the lung unit and three TCs fill 95% of the lung unit. At the end of five TCs, the lung is said to be 100% full. This happens when the lung is free from any disease condition. For normal lungs with a total compliance of 0.1 L/cmH2O and Raw of 1.0 cmH2O/L/s, the TC is 0.1 s.

**Diseases Impact on Time Constants**

When obstruction and inflammation is present in the airways of patients with diseases such as COPD and asthma, there is an increase in the airway resistance.[8] Thus, it takes a longer time to fill or empty the lung unit, giving rise to a longer TC. Such patients require higher expiratory times typically followed while setting respiratory rates on the mechanical ventilator. If longer expiratory times are not given to these patients, it may lead to incomplete exhalation causing breath stacking and air trapping.

In fibrotic lung diseases such as cystic fibrosis and interstitial lung diseases, the compliance of the lungs is low. This results in lungs filling with air quicker than lungs with normal compliance. In the same way, they empty quickly due to the high elastic recoil. Thus, the resultant TC is smaller.

The type of mechanical ventilatory mode (volume vs. pressure) that is set results in different TCs and its effects.[7] In disease conditions leading to abnormal compliance and resistance, TCs vary even more.

**TC and Mechanical Ventilation**

It is important to know the TC and the variations in it while managing the patient on the mechanical ventilator.

For example, if the compliance is 0.1 L/cmH2O and resistance is 2 cmH2O/L/sec, the TC is TC = C × Raw = 0.1 × 2 = 0.2 s. The lungs will completely fill after five TCs, i.e., 0.2 × 5 = 1 s. This means that the patient will require 1 s to complete inspiration. Based on this, if one would like to set the I: E ratio to 1:2, then the expiratory time would be 2 s, making the total breath cycle of 3 s. Hence, the respiratory rate would be 60 s/3 s = 20 breaths in a minute.

In a diseased lung, certain portions may be more affected than others. TC for these portions of the lungs may be different. Thus, when selecting settings such as the respiratory rate, a balance needs to be achieved to allow the lung to inflate and deflate for appropriate ventilation. Setting the inspiratory and expiratory rates of <3 TCs results in incomplete inhalation and exhalation.[16] If the rate is set high, the affected lung units do not fill or empty completely while the unaffected portion receives good amount of air.

**Pressure Control Ventilation**

The ventilator is delivering a constant pressure whereby the pressure is being measured at the outlet of the ventilator. However, the lung pressure will be lower and slowly increase as a volume is transferred.

The inspiratory flow will be controlled by the time constant, whereby the time constant is controlled by lung compliance and airway resistance.

<https://www.youtube.com/watch?v=h-I6XE6EfMY>

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Plateau pressure is useful as we then know that we have equilibrium between the mouth pressure (ventilator pressure) and lung pressure. If the plateau is not reached, we do not know what pressure is being achieved within the lungs, and we may be able to deliver a higher volume. Additionally, because we have not achieved a TC x 5 (full inhalation), there isn’t a good distribution of tidal volume throughout the lungs.

You can have a rise time above 0 that ramp up the positive delivery pressure. It is unknown if this improves the control mode but there are parties that advocate for both.

**Building a Control Algorithm**

**Plateau or Alveoli Pressure**

The plateau pressure is the alveoli pressure and is independent of resistance.

Plateau pressure is inversely proportional to compliance only:

PIP is proportional to:

Paw (airway pressure) = resistance of airways + alveoli/plateau pressure.

Therefore if we make the flow rate 0, then the resistance is 0 and Paw = Pplat.

This is done with an inspiratory hold or pause that usually takes about 0,5 seconds by blocking both the inspiratory and expiratory valves.

Pplat should be < 30 cmH20

The difference between PIP and Pplat should be < 5cm H20

If both PIP and Pplat are increasing when no settings have changed there is a decrease in compliance.

If PIP increases and Pplat does not while ventilator settings have not changed there is an increase in ressitance.

<https://www.youtube.com/watch?v=B_4v_zaJxf0>

<https://www.youtube.com/watch?v=SGopIAmIvwM>