Ventilators and Ventilation

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The Covid pandemic forced ventilator management into mainstream media. Do we have enough ventilators? What can we make into a ventilator? Those in medicine that had no knowledge or interest in ventilator management became experts. Truthfully, all physicians should have a level of expertise in the basic mechanics of a ventilator and modes of ventilation. So, let's see if we can achieve that.

POSITIVE PRESSURE VENTILATION

All mechanical ventilation is "positive pressure ventilation." as opposed to how we naturally breathe which is through the generation of a negative inspiratory force. Instead of generating negative intrathoracic pressure, we raise intrathoracic pressure which will affect the normal cardiopulmonary physiology. Preload will be reduced therefore there will be a reduction in left ventricular volume and cardiac output. We can expect minimal effects with a healthy patient, but few healthy patients are mechanically ventilated in an intensive care unit.

REBREATHING VS NON-REBREATHING

We should understand the difference between a non-rebreathing and rebreathing system. Simply, if the ventilator allows for rebreathing of expired gas, it is a rebreathing system; and if it does not, it is not. The classic ICU ventilator is non-rebreathing therefore the fresh gas flow must be equal to but usually is two to three times higher than the patient's minute ventilation. The classic anesthesia machine is a rebreathing system to allow for maintenance of humidity and warmth and a reduction in anesthetic waste. Therefore, CO2 is removed from the exhaled gas utilizing CO2 absorbers which contain chemicals that remove the CO2 via a set of chemical reactions. Therefore, the majority (semi-closed system) or all (closed system) of the exhaled gas can be reused as inspired gas. Commonly, fresh gas flow during an anesthetic is as low as one liter/minute with a minute ventilation of seven liters/minute or more in an adult.

ICU VENTILATORS

ICU ventilators start with a power supply which is usually electricity powering a compressor or compressed gas. Next, you need an oxygen and air source usually from wall outlets delivering the gases to the room from large tanks or concentrators at around 50 PSI with regulators within the ventilator allowing for further reduction of the PSI leading to the safe administration of the gases to the patient. The concentrations of the air and oxygen can be manipulated to provide the percentage of inspired oxygen desired. Flow control valves are present to manipulate the direction in which the gases travel. Many valves allow for the variation of the orifice size to further control flow. Lastly, there is the control system that will determine the mode of ventilation, fresh gas flow, preset parameters such as tidal volume and/or pressure generated, and so on.

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DEFINITIONS

The **Tidal Volume** is the volume of gas delivered per breath. The **Respiratory Rate** is the number of breaths per minute. The **Minute Ventilation** is the tidal volume times the respiratory rate in liters/minute. The **FiO2** is the concentration of oxygen in the inspired gas as a percentage such as 50% FiO2 or an FiO2 of 0.5. The **I:E ratio** is the time during one breathing cycle spent in inspiration (I) and expiration (E). The common I:E ratio during mechanical ventilation is 1:2, and 1:3 to 1:4 with COPD or other diseases leading to potential alveolar collapse or air trapping. A **breathing cycle**, as stated above, is the time taken for one breath, and the duration of inspiration and expiration will be determined by the I:E ratio. There are four phases to the cycle: inspiratory flow, inspiratory pause, expiratory flow, and expiratory pause. **PEEP** stands for positive end expiratory pressure applied to stent airways open or avoid end-expiratory airway collapse allowing for maximal oxygenation. Commonly PEEP is set at a minimum of 5 cmH2O during mechanical ventilation to as high as 20 cmH2O for patients that are hypoxemic. **CPAP** is continuous positive airway pressure utilized with spontaneously ventilating patients to also help with oxygenation and to maintain airway patency. The **Peak Inspiratory Pressure** is the highest pressure obtained during inspiration and the **Plateau Pressure** is the pressure at the end of inspiration during the inspiratory pause phase. Both are important in determining lung compliance and the risk of barotrauma with goals being under 35 cmH2O for the peak inspiratory pressure and under 30 cmH2O for the plateau pressure when using standard ventilation strategies. Lastly, **Compliance** equals the change in volume over the change in pressure.

INVERSE I:E RATIO

Inverse I:E ratio is an uncommonly used method where the inspiratory time is set longer than the expiratory time. It is usually a rescue maneuver to improve oxygenation when all else has failed. The idea is to increase or maintain mean airway pressure but not further raise peak inspiratory pressure. For example, if PEEP is 5 and peak inspiratory pressure is set at 20 with an I:E ratio of 1:2, the mean airway pressure is 5 x 2/3 + 20 x 1/3 = 10. Now if we reduce the peak inspiratory pressure to 15 and change the I:E ratio to 2:1, the mean ventilatory pressure is 15 x 2/3 + 5 x 1/3 = 11.5. So, we increased mean airway pressure to improve oxygenation but reduced peak inspiratory pressure so as not to cause barotrauma. Inverse I:E ratio is not tolerated well by patients therefore heavy sedation is usually required.

VENTILATION MODE

The modes of ventilation are how the ventilator assists the patient in the act of breathing; what is controlled, what is variable, and preset limits to both the controlled and variable components. The two basic modes are Volume Control and Pressure Control.

Volume control is a mode of ventilation where the tidal volume is preset (or controlled) as well as the respiratory rate and FiO2. Therefore, the minute ventilation would be constant. The variable will then be the peak inspiratory pressure. PaCO2 can be reasonably constant but if lung compliance changes, high peak airway pressures can occur with the potential for barotrauma. If PaCO2 is of the highest importance, this would be the preferred mode of ventilation.

Pressure control is a mode of ventilation where the inspiratory pressure is preset (or controlled) as well as the respiratory rate and FiO2. If lung compliance remains unchanged, the minute ventilation would be constant. However, if compliance changes, the tidal volume will proportionally change up or down leading to variations in the minute ventilation as well as the PaCO2. If the concern is barotrauma, especially in children, this would be the preferred mode of ventilation.

Pressure Support ventilation is a form of pressure control ventilation, however there is no preset respiratory rate. Peak inspiratory pressure, FiO2 and PEEP are preset. The patient's own inspiratory effort will trigger the ventilator to deliver a breath to a preset peak inspiratory pressure. This mode of ventilation was developed to reduce the work of breathing in a patient taking spontaneous breaths. Many times, a backup mandatory rate can be set up in case the patient would become apneic.

Assist/Control (A/C) ventilation is a form of volume control ventilation with a preset tidal volume, respiratory rate, FiO2 and PEEP. However, if the patient tries to take a spontaneous breath, the ventilator will identify this and deliver a full preset tidal volume. This is the most used initial mode of ventilation to allow maximal rest of likely weakened respiratory muscles. The downside of this mode of ventilation is that if the patient is tachypneic for any reason such as due to anxiety or pain, the patient will likely hyperventilate and develop a reduced PaCO2 and respiratory alkalosis.

SIMV (Synchronized Intermittent Mandatory Ventilation) is a form of volume control ventilation where we still have a preset tidal volume, respiratory rate, FiO2 and PEEP; as well as the ability to take spontaneous breaths. However, with the spontaneous breaths, the ventilator will not deliver a full tidal volume, therefore, the tidal volume generated with the spontaneous breath is based on the patient's respiratory effort. Pressure support can be added to the spontaneous breaths if desired by the clinitian. The preset mandatory breaths will be delivered around the spontaneous breaths. This mode of ventilation along with pressure support alone are commonly used for weaning from the ventilator.

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To be clear on our understanding of A/C and SIMV, if the preset portions are the same, and the patient is paralyzed and/or taking no spontaneous breaths, the two ventilation modes would be indistinguishable from one another. The difference is with the spontaneous breaths.

There are many other advanced modes of ventilation utilizing one or a combination of volume and pressure control. Computer algorithms can change modes and parameters from breath to breath, or "find" the optimal tidal volume and peak and plateau pressures. A couple examples of many are described below.

Pressure Regulated Volume Control (PRVC) is an example of a dual mode (both pressure and volume are controlled in some way) of ventilation where it utilizes feedback from the patient to adjust pressure and volume. You set the respiratory rate, FiO2, peep and "target" volume desired. The ventilatory performs a test breath to determine the lung compliance (tidal volume over peak airway pressure). The ventilator will then deliver a "pressure control" breath at that setting then adjust the pressure settings slowly until the target volume is achieved. It will continue to adjust when and if compliance changes. Basically, the computer is doing the changes instead of the operator.

High Frequency Oscillatory Ventilation is an "extreme" form of ventilation for lack of a better word used when adequate oxygenation cannot be achieved with more standard modes. More commonly used in infants and children, it delivers very low tidal volume breaths (as low as one or two milliliters) at a very rapid rate. Both inspiration and expiration could be active processes by "sucking" the volume out during the expiratory phase. The respiratory rate is measured in hertz which is 60 cycles/minute and commonly 10-15 hertz or more are used. Rates well over 1000 may be needed. The mean airway pressure remains relatively constant, but lower than usually required with standard methods to maintain oxygenation. The low tidal volume and mean airway pressures, in theory, reduce the risk of lung trauma as described below, but ventilation occurs due to the high minute ventilation.

LUNG PROTECTIVE VENTILATION

When mechanically ventilating a patient, a commonly used clinical strategy is "Lung Protective Ventilation". It is designed to reduce barotrauma or volume trauma, therefore, reducing the risk of ARDS or acute lung injury or to reduce mortality in patients with ARDS. The lung protective strategy employs low tidal volumes and high respiratory rates to achieve the desired PaCO2. PEEP is used to avoid atelectasis and hypoxemia. Commonly, the initial settings are a tidal volume of 6 ml/kg based on ideal body weight, a respiratory rate of 12-14 breaths/minute, an FiO2 of 100%, and a peep starting at 5 cmH2O. If PaCO2 is high, the respiratory rate is increased, and the peep is increased if the patient is hypoxemic. The tidal volume may be lowered even further if the peak inspiratory pressure is felt to be too high.

NON-INVASIVE POSITIVE PRESSURE VENTILATION: BIPAP (BILEVEL POSITIVE AIRWAY PRESSURE) AND CPAP

These techniques do not use an endotracheal tube. Instead, a tight fitting mask is utilized. CPAP provides constant airway pressure throughout the breathing or respiratory cycle improving oxygenation. Usually, the pressure setting starts at about 5 cmH2O but can go to 20 cmH2O or more. Since this is non-invasive or without an endotracheal tube, the higher the pressure, the more likely you will insufflate the stomach leading to vomiting and possible aspiration. BiPAP is commonly used for patients that have hypercapnic respiratory failure or a combination of hypercapnia and hypoxia. There are two positive airway pressures: inspiratory positive airway pressure (IPAP) and expiratory positive airway pressure (EPAP). When the machine senses an inspiration, it provides the IPAP which is commonly 5 cmH2O to 20 or 30 cmH2O. The EPAP is like CPAP which will help support the airway during expiration. It can be set at zero if the patient does not have hypoxemia. It cannot be set as high as the IPAP though since the difference in pressures provides the tidal volume. The bigger the difference in pressures, the larger the tidal volume the patient will receive and the better the CO2 clearance.

MONITORING DURING MECHANICAL VENTILATION

Arterial blood gases (ABGs) are the gold standard for monitoring the effectiveness of positive pressure ventilation. The ABG provides the level of oxygenation as well as ventilation since arterial PaO2, PaCO2, oxygen saturation, and pH are provided. Pulse oximetry and ETCO2 (end tidal CO2) can be used as surrogates however the ETCO2 should be occasionally "calibrated" with an ABG since changes in the amount of pathologic dead space (ventilated but not perfused areas) will create a larger difference between the two parameters. Patient comfort and level of consciousness are also important parameters to follow especially when attempting to wean from the ventilator.

EXTUBATION CRITERIA

There are many extubation criteria, but here are a few commonly utilized. One is the **Rapid Shallow Breathing Index (RSBI)** which is the tidal volume generated over respiratory rate when spontaneously breathing on a T-piece or with CPAP at 5 cmH2O or less or pressure support of 5 cmH2O (TV/freq). The lower the RSBI, the better. Less than 60 is ideal. The level of secretions generated should be relatively minimal because clearing secretions can be a big problem after extubation. The patients should be hemodynamically stable, and any arrythmias should be controlled. The patients should be able to follow commands. Mental status is vital for airway protection. Lastly, the underlying reason that they needed mechanical ventilation should be improved or resolved. Negative inspiratory force of greater than -20 cmH2O, and an arterial oxygen saturation that is above 90% and stable with an FiO2 below 50% are also commonly used.

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Continuing Education Quiz

To test your knowledge on this issue's article, provide correct answers to the following questions on the form below. Follow the instructions carefully.

1. **All mechanical ventilation is generated through negative inspiratory force.**
   A. True
   B. False

2. **The time is takes to complete one breath is _______________.**
   A. PEEP
   B. Breathing cycle
   C. CPAP
   D. Expiratory phase
   E. Inspiratory phase

3. **What best describes an inverse I:E ratio**
   A. A setting where the expiratory phase is longer than the inspiratory phase
   B. A setting where the expiratory and inspiratory phases are equal
   C. A setting where the inspiratory phase is longer than the expiratory phase
   D. Inverse I:E ratios were not a topic of discussion in this article

4. **In Assist/Control (A/C) ventilation the ventilator will identify a patient spontaneous attempt and deliver the full preset tidal volume.**
   A. True
   B. False

5. **What is the gold standard for monitoring positive pressure ventilation?**
   A. Arterial Blood Gas
   B. Pulse oximetry
   C. ETCO2
   D. Spirometry

6. **When utilizing the RSBI extubation criteria what is the ideal target?**
   A. 100
   B. 90
   C. 80
   D. 70
   E. 60

7. **A negative inspiratory force of greater than -10cmH20 indicates a patient that is ready to be extubated.**
   A. True
   B. False

8. **What is the peak inspiratory pressure threshold to prevent barotrauma from occurring?**
   A. <50cmH20
   B. <45cmH20
   C. <40cmH20
   D. <35cmH20

9. **If lung compliance decreases peak airway pressures ____________.**
   A. Increase
   B. Decrease

10. **What ventilation mode would be preferred in pediatric patients at risk of barotrauma?**
    A. Volume Control
    B. Pressure Control
    C. Pressure support
    D. Assisted/Control (A/C)

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1:	A B	**6:**	A B C D E
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3:	A B C D	**8:**	A B C D
4:	A B	**9:**	A B
5:	A B C D	**10:**	A B C D

Quiz 1 of 2

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