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Method for classifying modes of ventilation from different manufacturers

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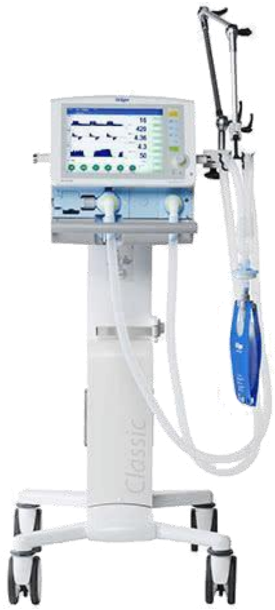

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Abstract:

Healthcare personnel especially respiratory therapists struggles in distinguishing between different names of modes of ventilations used by different manufacturers. This study aims to introduce a unified system that classifies these names used in different mechanical ventilators. The mode of ventilation used in these ventilators were classified according to three variables including control variable, breath sequence, and targeting scheme. The control variable can be pressure or flow. In addition, the breath sequence can be classified into Continuous spontaneous ventilation (CSV), Intermittent mandatory ventilation (IMV), or Continuous mandatory ventilation (CMV). The targeting scheme can be set-point, dual, servo, adaptive, optimal, or intelligent. This method successfully classified all modes of ventilation available in the well-known manufacturer of mechanical ventilators. The classification of these modes according to the control variable, breath sequence, and targeting scheme resulted in a classification that is much easier for the operator to understand and apply in the intensive care unit.

Keywords: Mechanical ventilator, Control variable, Breath sequence, Targeting scheme, Continuous spontaneous ventilation, Intermittent mandatory ventilation, Continuous mandatory ventilation.

Introduction:

A ventilator is a medical device that provides a mixture of air and oxygen and eliminates carbon dioxide from patients who cannot breathe on their owndue to certain illnesses or to perform surgeries that require general anesthesia. Covid 19 pandemic has increased the need for this medical device because it might cause respiratory complications such as pneumonia and acute respiratory distress syndrome (ARDS)[1]. The ventilator is designed to control and/or assist the delivery of breaths to patients in a way that promotes patient's comfort and safety. This can be achieved by using a suitable mode of ventilation that guarantees sufficient gas exchange with minimum duration of ventilation and without causing lung injury. More than 170 names for the modes of ventilation are used in the United States only[2]. Different manufacturer uses different names. There is a need for using a unified system to classify these names. This articlewill explain how different name of modes of ventilation are classified according to three variables: control variable, breath sequence, and targeting scheme.

Method:

Control Variable:

There are three variables that can be controlled during delivering a breath to a patient including volume, flow, and pressure. Since the flow is the derivative of the volume, controlling the volume means at the same time controlling the flow. Consequently, a breath is either volume controlled, or pressure controlled. Volume controlled breath has an advantage of a stable minute ventilation and consequently a stable partial pressure of O_2 and CO_2in the blood. However, a change in the mechanics of the lung such as a decrease in the compliance of a ventilator results in a high pressure that might exceed the limits. This entails using a pressure-controlled breath to prevent lung injury. This means that according to the physiological status of the patient, an operator should select either volume or pressure-controlled breath[3].

Breath Sequence:

To explain the meaning of breath sequence, it is needed to define the breath first. A breath is a cycle of inspiration and expiration. A breath is spontaneous if the timing and size are determined by the patient without any machine intervention. Thus, the patient determines the start and end of inspiration and expiration.A spontaneous breath can be assisted or unassisted. In the assisted spontaneous breath as in pressure support mode, the ventilator assists the patient by providing an increase in pressure up to the predetermined pressure support setting above PEEP. However, in the unassisted spontaneous breath as in the continuous positive airway pressure (CPAP), the ventilator does not assist the patient in delivering the breath and the timing and size of the breath are all determined by the patient. A breath is mandatory if the timing and/or size of the breath is controlled by the ventilator. Hence, when the start and/or end of inspiration is machine-controlled, the breath is described as a mandatory breath[4].

A breath sequence can be determined by the types of breaths that constitute this sequence. The following are three different breath sequences that are essentials in all ventilator machine:

- Continuous spontaneous ventilation (CSV):The patient is allowed to breath on his/ her own without any intervention from the machine. Consequently, all breaths delivered in this sequence are spontaneous.
- Intermittent mandatory ventilation (IMV): In this mode, the patient is allowed to take spontaneous breaths between the mandatory breaths. This mode is called synchronizedIMV when the mandatory breaths are patient triggered.
- Continuous mandatory ventilation (CMV): All breaths are mandatory. The patient is not permitted to take any spontaneous breath in this mode. This means that the machine has a full control over the patient.

Five ventilatory patterns can becreated when combining control variables and breath sequences: volumecontrolled continuous mandatory ventilation (VC-CMV), volumecontrolled intermittent mandatory ventilation (VC-IMV), pressure controlledcontinuous mandatory ventilation (PC-CMV),pressure controlledintermittent mandatory ventilation (PC-IMV), andpressure controlledcontinuous support ventilation(PC-CSV)[4].

Targeting Schemes:

A targeting scheme is a description of the method used to deliver a specific ventilatory patternto the patienton a ventilator.These targeting schemes include set-point, dual, servo, adaptive, optimal, and intelligent.

Set-Pointtargeting scheme:

In a set-point scheme, certain parameters such as tidal volume or inspiratory pressure are set by the operator. Ventilator machine reachesthe target by changing the flow to reduce the error between the measured and set parameter in a closed loop feedback system[5].

Dual targeting scheme:

Ventilator machine in this schemecan change from volume-control to pressure-control and vice versaduring the same breath. This could happen in two ways. Firstly, the machine starts with volume control and switches to pressure control if one or more preset parameters are reached such as peak airway pressure. Secondly, the ventilator delivers a pressure-controlled breath to the patient and then switches to pressure controlif the preset tidal volume has not been reached. The advantage of this scheme is the improvement in the patient-machine synchrony as compared to when applying the Set-Point scheme. This is because delivering the preset tidal volume to the patient is guaranteed when using the pressure control in this scheme. In addition, if the machine starts with volume control, the maximum airway pressure will not be exceeded when using this scheme[5].

Servo targeting scheme:

Servo targeting scheme refers to any scheme in which feedback from the patient such as a patient effort is used determine the magnitude of the output.The delivered breath is directly proportional to the varying input (patient effort). Patient effort can be a change in flow, pressure, volume, or diaphragmatic electrical signals. This scheme is used to maximize the synchrony between patient and ventilator machine[5].

Adaptive targeting scheme:

Adaptive scheme recognizes that patient conditions change with time. Thus, the ventilator machine sets the within-breath parameters to adapt the varying patient conditions. An example of this scheme is pressure-regulated volume control mode. The inspiratory pressure in this mode is adjusted by the ventilator to maintain the average tidal volume target. Another example is the mandatory minute ventilation mode where the ventilator achieves the minute ventilation target by automatically adjusting the frequency of mandatory breaths[5].

Optimal targeting scheme:

Optimal scheme has some similarity with the adaptive scheme butoffers advanced features. In this scheme, the operator inputs just the patient weight, and the automated control system will automatically estimate the minute ventilation, the optimal respiratory rate, the tidal volume target. As can be seen in the adaptive scheme discussed previously, the inspiratory pressure within the breath and between breaths are controlled by the ventilator to reach the estimated tidal volume. In this scheme, the target tidal volume is estimated from the weight of the patient using Otis equation. However, it is identified by the operator in the adaptive scheme[5].

Intelligent targeting scheme:

Intelligent targeting scheme is based on artificial intelligence (AI)techniques which exploit large amount of patient's data to extract beneficial relationships between the inputs and outputs of the AI model.SmartCare/PS technology available on the Dräger Evita XL ventilator is an automated weaning system that utilizes the intelligent targeting scheme. Some variables such as tidal volume, end-tidal CO_2, and spontaneous respiratory rate are monitored and provided as inputs to the AI model. The output of the AI model is a value of the inspiratory pressure that the ventilator controller should deliver to the patient to keep him/her in the comfort zone of respiration[5].

As a result of these classifications, any name for the mode of ventilation can be classified according to three variables as shown in the following equation:

Ventilator Mode = Breath Control Variable + Breath Sequence + Targeting Scheme [1]

Results:

Applying Equation 1 to commercially available modes of ventilation demonstrates that this method of classification makes education of the operator straightforward, and consequently leads to significant improvements in patient care and outcomes.

Pressure Control Assist Control in Covidien 840 ventilator is a mode of ventilation that utilizes Pressure as a breath control variable, Continuous Mandatory Ventilation (CMV) as a breath sequence and Set-Point as the targeting scheme. This means that Pressure Control **Assist** Control in Covidien 840 ventilator can be expressed as P-CMV-(Set-Point). Volume Control Plus Assist Control mode has the same breath control variable and breath sequence as inPressure Control

Assist Controlmodebut they differ in the targeting scheme. The targeting scheme in Volume Control Plus Assist Control mode is the adaptive scheme. Thus, Volume Control Plus Assist Control mode can be expressed as P-CMV-(Adaptive). Pressure Support mode in this ventilator is a mode that can be exhibited as P-CSV-(Set-Point) which means that itdeliversa pressure-controlledbreath with a continuous spontaneous ventilation sequence using a Set-Point scheme. Almost similar mode toPressure Support mode that has the same control variable and sequence, but differenttargeting scheme is Tube Compensation mode. In this mode the Servo targeting scheme is used and consequently it is represented as P-CSV-(Servo).Volume Control/Assist Control modelooks similar to Pressure Control Assist Controlmode except that it is volume-controlled ventilation mode[2].

Applying equation 1 to modes of ventilation used in Dräger Evita XL ventilator results in the following tags: P-CMV-(Set-Point) for Pressure Controlled Ventilation Plus Assistedmode, P-IMV-(Set-Point) for Pressure Controlled Ventilation Plus Pressure Support mode, V-CMV-(Dual) for Continuous Mandatory Ventilation with Pressure Limited Ventilation mode, and P-IMV-(Adaptive) for Mandatory Minute Volume with AutoFlow mode. These modes of ventilation carry the same tag as that used in other commercialized ventilators but using different names. These classifications made it easier for the operator to understand how the ventilator controller delivers the breath and the pattern of breaths to the patient[2].

Conclusion:

There are more than 100 names for the modes of ventilation in the ventilators commercially available in the market. There is a lot of redundancy in these modes which means that the same modes carry different names among different manufacturers. The classification of these modes according to the control variable, breath sequence, and targeting scheme resulted in a classification that is much easier for the operator to understand and apply in the intensive care unit.

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