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Classic therapies revisited

Mechanical ventilation: simplifying the terminology

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Summary

There is presently considerable ambiguity and confusion relating to ventilator terminology. This can be eliminated using a simple approach, visualising mechanical ventilation as an inspiratory pump, and defining trigger, limit, and cycling in this context. The trigger is the signal that starts a breath by opening the inspiratory valve, the limit is the factor which controls the way gas flows into the lung, and the cycle is the signal that stops the breath by closing the inspiratory valve and opening the expiratory valve. By identifying these three basic parameters, one can precisely dissect and interpret any of the vast ventilatory terminology.

Keywords: ventilation

Rapidly changing technology has unfortunately resulted in ambiguity in the terminology used in mechanical ventilation. Different ventilator manufacturers offer similar or identical models with different names, and the same terms may have different meanings on different ventilators. Various consensus statements and reviews[1-5] regarding terminology and use of ventilators have recently been published, but there is still a lack of unanimity in terminology.[6 7]

The aim of this article is to propose a classification system which allows all aspects of ventilator terminology to be expressed in such a way as to be easily understood by inexperienced personnel and yet be completely specific. This is achieved by focusing on three terms which can be used to describe all subsequent terminology.

The basic mechanism of mechanical ventilation

All modern compressor-driven ventilators push in air during inspiration and release it during expiration. This requires a compressor and two valves. The ventilatory phases are as follows:

- inspiration: inspiratory valve open and expiratory valve closed
- inspiratory pause: inspiratory valve and expiratory valve closed at end of inspiration
- expiration: inspiratory valve closed and expiratory valve open
- expiratory pause: inspiratory valve and expiratory (or positive end expiratory pressure (PEEP)) valve closed at end of expiration

Terminology

Using this simple scheme one can define the three basic terms:

- trigger: the signal to start inspiration, ie, to open the inspiratory valve (and close the expiratory valve if there is no PEEP or expiratory pause)
- limit: the factor which limits the way gas flows into the lung during inspiration
- cycling: the signal to stop inspiration, ie, to close the inspiratory valve and to open the expiratory valve.

THE TRIGGER

This is the signal that starts each breath. If the patient makes no effort to breathe, the ventilator will trigger regular breaths at a frequency which will depend on the set respiratory rate, ie, they will be ventilator time triggered. If the patient does make an effort to breathe and the ventilator can sense it (by either sensing a negative inspiratory pressure or an inspiratory flow) and deliver a breath, it will be called a patient-triggered breath. Different manufacturers use different methods to sense flow but all ultimately use some aspect of the patient-generated inspiratory flow to trigger the breath. Auto-triggering is a term used when an excess flow or pressure sensitivity setting causes the ventilator to trigger each breath in the absence of patient effort.

THE LIMIT

When the inspiratory valve is opened, gas from the compressor will rush into the lung (at a compressed pressure of 60 lb/in^2) unless limited by some ventilator mechanism. The term 'limit' denotes the factor which controls the inspiration inflow. It implies that the set limit cannot be overcome and yet, on reaching this limit, cycling will not occur and inspiratory flow will continue.

The ventilator can either deliver gas at a fixed *flow* rate and pattern or at a fixed *pressure* during inspiration. In flow-limited breathing, a fixed inspiratory flow rate and pattern is set by the clinician and maintained throughout inspiration. As the flow is assured, the patient will receive an adequate tidal volume for a given inspiratory time. However, the airway pressure will rise to whatever level is required to deliver the flow and there is therefore an increased likelihood of

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barotrauma. In pressure-limited breathing, the pressure is not allowed to go above a preset limit. The tidal volume will be influenced by the pulmonary compliance and resistance and cannot be guaranteed to be adequate.

Some ventilators (eg, Dragger) allow a super-added pressure limitation in a flow-limited mode of ventilation, while others (Infrasonics Adult Star) allow flow limitation in a pressure-limited mode. In these modes, flow will be limited by both the pressure and flow settings.

CYCLING

This refers to the signal that stops the inspiration and starts the expiration. If there is no inspiratory pause, then one signal will cause both the inspiratory valve to close and the expiratory valve to open simultaneously. If on the other hand there is an inspiratory pause, there are two cycling signals, one which stops inspiratory gas flow (by shutting the inspiratory valve) and the second which starts expiration (by opening the expiratory valve).

Common signals for cycling are volume, time, and flow. Pressure-cycled ventilators are rarely used currently, though pressure cycling often acts as a back-up form of cycling when the airway pressure reaches the set high-pressure alarm level. In the volume-cycled mode, when the prefixed tidal volume is delivered, the inspiratory valve will close (volume cycled) and after a prefixed pause time the expiratory valve will open (time cycled). In the time-cycled mode the inspiratory valve will close and the expiratory valve will open after a fixed inspiratory time which is set directly or indirectly by adjusting the respiratory frequency and inspiratory-to-expiratory-time ratio (I:E ratio). In a flow-cycled mode, the ventilator can sense a decrease of inspiratory flow and shut the inspiratory valve when it has decreased to a fixed level or a fixed percentage of the peak inspiratory flow. Various manufacturers use different end-points (of end inspiratory flow or early expiratory flow) as the signal to cycle into expiration. If a pressure-cycled ventilator is being used, then the inspiration will stop as soon as the prescribed pressure limit is set.

The trigger, limit, cycling classification

The trigger, limit, cycling (TLC) classification consists of the following possibilities:

- trigger: ventilator (time)- triggered or patient (pressure or flow)-triggered
- limit: flow-limited or pressure-limited
- cycling: volume-, time-, flow- or pressure-cycled.

Defining other common terms using the three basic terms

MANDATORY, ASSISTED, AND SPONTANEOUS BREATHS

Chatburn[6] has suggested that these three terms be used to describe various types of breaths. A *mandatory breath* is one which is started (triggered), delivered and terminated (cycled) by the ventilator. An *assisted breath* is one which is triggered by the patient but delivered and cycled by the ventilator. (Sometimes the word *assisted* is used to describe any breath which is triggered by the patient and in which the ventilator delivers a positive inspiratory pressure.) A *spontaneous breath* is one which is both triggered and cycled (by sensing a change of inspiratory flow associated with lung filling) by the patient. As the inspiratory flow is, to a limited extent, influenced by the patient's breathing pattern, it is presumed that the patient has a degree of control over inspiratory cycling.

This terminology can lead to some confusion. For example, in the Synchronised Intermittent 'Mandatory' Ventilation (SIMV) mode, either a mandatory breath or an assisted breath will be taken as a 'mandatory' breath. Some ventilator companies use the term Assisted Spontaneous Breathing to define a mode of ventilation. This clearly does not fit into this proposed classification. These ambiguities can be avoided by clearly stating the TLC factor of the breath delivered.

CONTROL AND SUPPORT

The term *control* is unfortunately used in different contexts to mean different things and is probably the single most ambiguous term in ventilator terminology. The factor which is 'controlled' could either be a triggering, limiting, or cycling parameter. When the term 'control' is used to describe a mode of ventilation, it usually implies that the trigger is controlled by the ventilator and the mode has the ability to ensure ventilator-triggered breaths, regardless of the patient's breathing drive. The term 'control' in the pressure-control mode has been used to describe the fact that the pressure in each breath is controlled, ie, limited. This, however, may cause confusion as the pressure is also 'controlled' in the pressure-support mode. Similarly the term 'volume control' has been used to imply that the tidal volume delivered is controlled, ie, cycled. Describing a controlled breath in terms of its TLC clarifies any confusion arising from different interpretations of the term 'control'.

The term *support* is used to describe a mode of ventilation in which each breath must be patient triggered and there are no ventilator-time-triggered breaths.

Defining modes of ventilation using the three basic terms

When analysing modes of ventilation, it is necessary to clarify whether a mode can give only one type of breath or can allow different types of breaths. Some ventilatory modes have the ability to alter their settings autonomously using servo systems which alter the settings of a ventilator breath depending on the character of the previous few breaths. All modes can be unambiguously described in terms of the TLC description of each breath, the number of types of breaths possible in that mode, and the possibility of a servo mechanism self-adjusting the settings (tables 1 and 2).

CONTINUOUS MECHANICAL VENTILATION ASSIST (CMVa), VOLUME CONTROL ASSIST (VCa), INTERMITTENT POSITIVE PRESSURE VENTILATION (IPPV), OR ASSIST/CONTROL (A/C)

This was the conventional mode of ventilation, and it is still often used in patients with normal lungs and an impaired ventilatory drive, eg, following anaesthesia. Depending on the settings, the ventilator delivers a fixed number of ventilator-triggered, flow-limited and volume- or time-cycled breaths. Additionally, each time the patient triggers a breath, a full flow-limited and volume- or time-cycled breath is delivered.

Table 1 A breath-by-breath trigger, limit, cycling (TLC) classification of the common modes of ventilation. V = ventilator; P = patient

Mode	*Number of types of breaths*	*Trigger*	*Limit*	*Inspiratory cycling*	*Pause cycling (if applicable)*	*Servo*
CMVa or VCa or A/C	1	V or P	Flow	Volume	Time	no
PCV or PCIRV	1	V or P	Pressure	Time	Time	no
SIMV (volume cycled)	2 Mandatory breath	V or P	Flow	Volume	-	no
	Spontaneous breath	P	-	-	-	-
SIMV (pressure limited)	2 Mandatory breath	V or P	Pressure	Time	-	no
	Spontaneous breath	P	-	-	-	-
PS	1	P	Pressure	Flow	-	no
SIMV (volume cycled) + PS	2 Mandatory breath	V or P	Flow	Volume	-	no
	Spontaneous breath	P	Pressure	Flow	-	no
SIMV (pressure limited) + PS	2 Mandatory breath	V or P	Pressure	Time	-	no
	Spontaneous breath	P	Pressure	Flow	-	no
CPAP	1	P	Pressure	Flow	-	no
CPAP + PS	1	P	Pressure	Flow	-	no

Table 2 A breath-by-breath trigger, limit, cycling (TLC) classification of the newer and less common modes of ventilation. In the servo column, the parameter stated is the one which is monitored by the ventilator, against which the adjustment is made. V = ventilator; P = patient; TV= tidal volume; MV= minute volume; RR= respiratory rate

Mode	*Number of types of breaths*	*Trigger*	*Limit*	*Inspiratory cycling*	*Pause cycling (if applicable)*	*Servo (parameter)*
BI-PAP1(same as CPAP+PS)	1	P	Pressure	Flow	-	no
BI-PAP2 (same as PCV)	1	V or P	Pressure	Timed	-	no
BI-PAP3 (same as CPAP)	1	P	Pressure	Flow	-	no
BI-PAP4 (similar to SIMV; pressure limited)	2 I-PAP breath	V	Pressure	Time	-	no
	E-PAP spontaneous breath	P	Pressure	Flow	-	no
BI-PAP5 (same as APRV)	2 I-PAP breath	V	Pressure	Time		no
	I-PAP spontaneous breath	P	Pressure	Flow	-	no
APRV (same as BI-PAP3 or 5)	2 I-PAP breath	V	Pressure	Time		no
	I-PAP spontaneous breath	P	Pressure	Flow	-	no
IMPRV (same as BI-PAP1)	1	P	Pressure	Flow	-	no
PRVC (similar to PCV)	1	V or P	Pressure	Time	-	yes (TV)
Automode (similar to PCV + CPAP)	2 Mandatory	V or P	Pressure	Time	-	yes (TV)
	Spontaneous	P	Pressure	Flow		
VS (similar to PS)	1	P	Pressure	Flow	-	yes (TV)
Minimum minute ventilation (similar to PS)	1	P	Pressure	Flow	-	yes (MV)
Mandatory rate ventilation (similar to PS)	1	P	Pressure	Flow	-	yes (RR)
Proportional assist	1	P	Pressure /time	Flow	-	yes (flow & volume)
High frequency ventilation		V or P	Flow/pressure	Time	-	
Mandatory minute ventilation (MMV)	2 Mandatory	V or P	Flow	Time	-	yes
	Spontaneous	P	-	-	-	(MV)

PRESSURE CONTROL VENTILATION (PCV)

This mode is mainly used in patients with decreased pulmonary compliance. Initially it was used when CMVa resulted in high airway pressures in these patients, but it is increasingly being used as the primary mode in patients with stiff lungs. It can be viewed as a form of Assist/Control in that it allows both ventilator- and patient-triggered breaths. The mandatory breaths are pressure-limited and time-cycled, and will be delivered regardless of the patient's spontaneous drive. Additionally, each time the patient triggers a breath, a full preset pressure-limited and time-cycled breath is delivered. If the inspiratory time is longer than the expiratory time in this mode it is called Pressure Control Inverse Ratio Ventilation (PCIRV).

(SYNCHRONIZED) INTERMITTENT MANDATORY VENTILATION ((S)IMV)

The SIMV mode was initially designed as a weaning mode but is often used as a conventional or standard form of ventilation. This is a mode of ventilation in which two different types of breaths can be inspired. A fixed mandatory rate is set which the patient will get regardless of spontaneous effort. These breaths are ventilator-triggered, flow-limited and volume- or time-cycled, or patient-triggered if the patient breathes just before a mandatory breath is to be delivered (in a prefixed window period). If the patient breathes between mandatory breaths, the ventilator will allow the patient to breathe a normal breath by opening the demand (inspiratory) valve but not offering any inspiratory assistance. The patient will have to trigger the breath but the ventilator will then not assist this breath in any way. Some ventilators (eg, the Siemens Servo 300) allow an SIMV pattern with pressure-control ventilation. In this ventilator mode the mandatory breaths will be either ventilator- or patient-triggered, pressure-limited and time-cycled. If both these options are available, one could use the terms SIMV(volume cycled) for the former and SIMV(pressure limited) for the latter.

PRESSURE SUPPORT VENTILATION (PS) OR ASSISTED SPONTANEOUS BREATHING

This mode was initially used as a weaning mode, but is being increasingly used as the primary mode of ventilation in patients in whom the spontaneous ventilatory drive is preserved. It is a supported mode of ventilation and each breath must be triggered by the patient. Each trigger results in a pressure-limited inspiratory flow with a high initial inspiratory flow. When inspiratory flow decreases to a fixed set flow or percentage of the peak inspiratory flow, the inspiratory valve is shut off. Cycling is therefore based on inspiratory flow. All breaths on PS ventilation are patient-triggered, pressure-limited and flow-cycled.

SIMV + PS

In SIMV + PS mode, the mandatory breaths remain exactly the same as in SIMV and the *additional* spontaneous breaths are pressure-supported as in PS mode.

CONTINUOUS POSITIVE AIRWAY PRESSURE (CPAP)

This is a partial mode of mechanical ventilation used in patients with an adequate ventilation pattern in whom the underlying pulmonary pathology favours the development of atelectasis or alveolar closure. CPAP and PEEP are almost synonymous, the term PEEP being used when a positive pressure form of ventilation is being used and the term CPAP being used when a spontaneous mode of ventilation is being used. Where CPAP differs from conventional PEEP is that in the CPAP mode the usual inspiratory fall of pressure associated with a spontaneous breath is prevented by ensuring an adequate gas flow during inspiration. If the ventilators increase the flow only during inspiration, all breaths will be patient-triggered, pressure-limited and flow-cycled.

CPAP + PS

This mode is essentially the same as PS; all breaths are patient-triggered, pressure-limited and flow-cycled. The only difference is that some PEEP is maintained.

Defining some newer modes of ventilation using the three basic terms

Newer modes are appearing at a rapid rate. To an extent most of them are variations of the pressure control or the pressure support modes. The nomenclature allows individuality for the manufacturers but also results in further confusion of the terminology. All the newer modes are primarily designed either to limit baro- or volu-trauma, to aid weaning, or to allow noninvasive ventilation via a mask rather than a tracheal tube. The more common ones are described in terms of their TLC.

BILEVEL INSPIRATORY POSITIVE AIRWAY PRESSURE (BI-PAP)

This term can mean different things on different ventilators. Ultimately, all pressure-limited modes of ventilation can be called BI-PAP as they have two pressures, inspiratory and expiratory. For the sake of clarity, each different type of BI-PAP has been given a separate number.

BI-PAP Type 1 (Respironics)

The expiratory positive airway pressure (E-PAP) and inspiratory positive airway pressure (I-PAP) are set. This is a fully spontaneous mode in which the patient triggers each breath which is then limited to the I-PAP pressure with a decelerating flow and cycled by flow sensing. It is therefore identical to CPAP + PS. The E-PAP will represent the CPAP or PEEP set and the I-PAP will represent the PS level set.

BI-PAP Type 2

Here too, the E-PAP and the I-PAP are set. One can also set the inspiratory time and the expiratory time. This mode is identical to pressure control with the ventilator triggering and cycling each breath depending on the set inspiratory and expiratory time and with the E-PAP representing the set PEEP and the I-PAP representing the level of pressure control.

BI-PAP Type 3 (Dragger Evita)

This mode is somewhat similar to the BI-PAP Type 2, but the intervals between the upper and lower pressure levels are fairly long, ie, 5–10 seconds. Therefore, in this form of BI-PAP patients breathe spontaneously at both levels, as they do with CPAP. It can be therefore be considered a CPAP mode in which the level of CPAP is alternated between a higher and a lower value every few seconds.

BI-PAP Type 4

This is a further variation of the BI-PAP Type 3 in which the patient only breathes spontaneously at the lower pressure level. The upper pressure is held for a short period of time (and will therefore be a normal pressure-limited, timed-cycled breath). This upper pressure time is too short to allow spontaneous breathing. It is therefore similar to a pressure-limited and time-cycled form of SIMV.

BI-PAP Type 5 or Airway Pressure Release Ventilation (APRV)

This is another variation of the BI-PAP Type 3 in which the patient breathes spontaneously only at the upper pressure level. The upper level is held for a longer period and the patient breathes spontaneously at this level. The pressure is then released for a short period, which is too short to allow spontaneous breathing.

Intermittent Mandatory Pressure Release Ventilation (IMPRV) (Cesar)

Another form of BI-PAP Type 1 with the additional ability to go down to lower PEEP value for a fixed number of times a minute.

SERVO SYSTEMS IN NEWER MODES

With the help of a servo feedback system, modern ventilatory modes can adjust a setting on the basis of an observed value. When analysing a servo mechanism, one needs to define the monitored parameter and the setting which is subsequently altered by the ventilator. For example, in many newer modes, the level of pressure support or pressure control is automatically adjusted (within certain limits) depending on either the tidal volume, the minute volume, or the respiratory rate recorded by the ventilator over the previous few breaths. This is described in more detail below.

Pressure-Regulated Volume Control (PRVC) (Siemens Servo 300)

In pressure-control ventilation one has no control over the tidal volume and the only way to increase the tidal volume is by increasing the level of pressure control. In PRVC one can set a desired tidal volume and the level of pressure control is continuously reset by the ventilator (using data from the last few breaths) to deliver the tidal volume. As in the pressure-control mode, each breath is ventilator- or patient-triggered, pressure-limited and time-cycled. This is not a volume-cycled mode in that the level of pressure control is varied to deliver the desired tidal volume.

Auto Flow (Dragger Evita Dura)

This is similar to PRVC but additionally allows the patient to breathe spontaneously at the upper and lower pressure levels in a manner similar to BI-PAP

Volume Support (VS), (Siemens Servo 300)
In a manner analogous to PRVC, one can set a desired tidal volume in the VS mode and the level of pressure support is continuously reset by the ventilator. As in the pressure support mode, each breath is patient-triggered, pressure-limited and flow-cycled.

Minimum Minute Ventilation (Hamilton Veolar)
Another variation on the pressure-support mode where one sets a desired pressure support and a desired minute volume. Using a servo feedback, the ventilator will reset the level of pressure support to achieve the desired minute volume. This should not be confused with Mandatory Minute Ventilation (see below), which unfortunately has the same acronym.

Mandatory Rate Ventilation (Cesar)
Yet another variation on pressure support where the level of pressure support is adjusted to maintain a target respiratory rate. As the patient gets more tachypnoeic, the pressure-support level increases which then results in a decreased work of breathing and a reversal of tachypnoea.

Proportion Assist Ventilation
This is a new mode not present on most commercially available ventilators. It is a spontaneous mode in which the patient triggers and cycles each breath. Using a servo mechanism, the ventilator adjusts the inspiratory pressure limit to match the patient's effort. It senses the inspiratory effort from the ongoing flow and volume signals. Unlike other servo modes, the pressure limit is actively changed during the breath to match the inspiratory effort. The limiting factor can therefore be viewed as a pressure/time limit, ie, the pressure level changes at different times during a single inspiration. (NB. As this mode is not commercially available, the above analysis is based on a recent review.[8])

Uncommonly used modes of ventilation

HIGH FREQUENCY VENTILATION
Here one uses low tidal volumes and very high frequencies in an attempt to limit airway pressures. This mode is primarily used in paediatric patients and occasionally when ventilation is required for airway-related surgery or procedures. Although the 'tidal' volume may be less than the anatomical dead space, gas exchange is maintained by diffusion of gas between the airway and the alveoli. As far as the TLC is concerned, in this mode, each 'breath' will be ventilator-triggered, and time-cycled. The limiting factor is either flow or pressure, depending on whether a jet or an oscillator is used to generate the volume.

MANDATORY MINUTE VENTILATION (MMV) (ERICA ENGSTROM)
This is a variation of the SIMV mode, which is used as a weaning mode. Using a servo mechanism which monitors the total expired minute volume, the number of mandatory breaths are adjusted to maintain the set total minute ventilation. As the patient's spontaneous breathing increases, the number of mandatory breaths decrease. Unlike SIMV, if the spontaneous minute volume is adequate, the ventilator will not deliver any mandatory breaths.

Conclusion

The use of this simple scheme which specifically defines how an inspired breath is started (triggered), delivered (limited) and terminated (cycled), will clear any ambiguity associated with the various terms used by different ventilator companies to label their modes of ventilation.

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