Review article

Recognising, describing and comparing modes of mechanical ventilation

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Introduction

Discussions about mechanical ventilator technology are hampered by the lack of a standardised vocabulary related to ventilator function, and in particular, to modes of ventilation. In general, a *'mode'* is a predetermined pattern of interaction between the ventilator and the patient. Manufacturers give certain patterns names and ignore other patterns. The result is that many ventilators have functionality that is not explicitly recognised as distinct modes. Some names of modes are so commonly used that they are virtually default classifications, *e.g., 'Assist/Control'* or *'Pressure Support' albeit* without any consensus on their exact meanings. Others are so rare that they are used as marketing devices, *e.g., 'SmartCarePS'* or *'Neurally Adjusted Ventilatory Assist'*. The most popular textbook on equipment for respiratory therapy in the United States[1] lists 174 unique names of modes but offers no way to classify them. I have personally identified almost 300 unique mode names using just the terms created by manufacturers in operators' manuals. Clearly, a classification system (formal taxonomy) is required in order to recognise, compare and contrast modes or to contemplate future mode designs. What follows is a very brief overview of a standardised vocabulary and a taxonomy I have developed and described in the literature over the last 20 years.[2,3]

Recognising and describing modes

A taxonomy is a simply a classification system. The taxonomy of mechanical ventilator modes is a hierarchical system based on 10 maxims of ventilator design:

1. A breath is one cycle of positive flow (inspiration) and negative flow (expiration) defined in terms of the flow-time curve. Inspiration is defined as the period from the start of positive flow to the start of negative flow. Expiration is defined as the period from the start of expiratory flow to the start of inspiratory flow. The flow-time curve is the basis for many variables related to ventilator settings.

2. A breath is assisted if the ventilator does work on the patient. An *assisted breath* is one for which the ventilator does some portion of the work of breathing. For constant flow inflation, work is defined as inspiratory pressure multiplied by tidal volume. Therefore, an assisted breath is identified as a breath for which airway pressure (displayed on the ventilator) rises above baseline during inspiration. An unassisted breath is one for which the ventilator simply provides the inspiratory flow demanded by the patient and pressure stays constant throughout the breath.

3. A ventilator assists breathing using either pressure control or volume control based on the equation of motion for the respiratory system. Providing assistance means doing work on the patient, which is accomplished by controlling either pressure or volume. A simple mathematical model describing this fact is known as the *equation of motion* for the passive respiratory system:

$$\text{Pressure} = (\text{Elastance} \times \text{Volume}) + (\text{Resistance} \times \text{Flow})$$

Volume control means that *both* volume and flow are preset prior to inspiration. In other words, the

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right hand side of the equation of motion remains constant while pressure changes with changes in elastance and resistance.

Pressure control means that inspiratory pressure is preset as either a constant value or it is proportional to the patient's inspiratory effort. In other words, the left hand side of the equation of motion remains constant while volume and flow change with changes in elastance and resistance.

4. Breaths are classified by the criteria that trigger (start) and cycle (stop) inspiration. The start of inspiration is called the trigger event. The end of inspiration is called the cycle event.

5. Trigger and cycle events can be initiated by the patient or the machine. Inspiration can be patient triggered or patient cycled by a signal representing inspiratory effort. Inspiration may also be machine triggered or machine cycled by preset ventilator thresholds.

Patient triggering means starting inspiration based on a patient signal independent of a machine trigger signal.

Machine triggering means starting inspiratory flow based on a signal (usually time) from the ventilator, independent of a patient trigger signal.

Patient cycling means ending inspiratory time based on signals representing the patient determined components of the equation of motion, (*i.e.*, elastance or resistance and including effects due to inspiratory effort). Flow cycling is a form of patient cycling because the rate of flow decay to the cycle threshold is determined by patient mechanics.

Machine cycling means ending inspiratory time independent of signals representing the patient determined components of the equation of motion.

6. Breaths are classified as spontaneous or mandatory based on both the trigger and cycle events. A *spontaneous breath* is a breath for which the patient both triggers and cycles the breath. A spontaneous breath may occur during a mandatory breath (*e.g.*, Airway Pressure Release Ventilation). A spontaneous breath may be assisted or unassisted. A *mandatory breath* is a breath for which the machine triggers and/or cycles the breath. A mandatory breath can occur during a spontaneous breath (*e.g.*, High Frequency Jet Ventilation). A mandatory breath is, by definition, assisted.

7. There are 3 breath sequences: Continuous mandatory ventilation (CMV), Intermittent Mandatory Ventilation (IMV), and Continuous Spontaneous Ventilation (CSV). A breath sequence is a particular pattern of spontaneous and/or mandatory breaths. The 3 possible breath sequences are: *continuous mandatory ventilation*, (CMV, spontaneous breaths are not allowed between mandatory breaths), *intermittent mandatory ventilation* (IMV, spontaneous breaths may occur between mandatory breaths), and *continuous spontaneous ventilation* (CSV, all breaths are spontaneous).

8. There are 5 basic ventilatory patterns: VC-CMV, VC-IMV, PC-CMV, PC-IMV, and PC-CSV. The combination VC-CSV is not possible because volume control implies machine cycling and machine cycling makes every breath mandatory, not spontaneous.

9. Within each ventilatory pattern there are several variations that can be distinguished by their targeting scheme(s). A *targeting scheme* is a description of how the ventilator achieves preset targets. A *target* is a predetermined goal of ventilator output. Examples of *within-breath targets* include inspiratory flow or pressure and rise time (set-point targeting), tidal volume (dual targeting) and constant of proportionality between inspiratory pressure and patient effort (servo targeting). Examples of *between-breath targets* and targeting schemes include average tidal volume (for adaptive targeting), percent minute ventilation (for optimal targeting) and combined PCO_2, volume, and frequency values describing a "zone of comfort" (for intelligent targeting, *e.g.*, SmartCarePS or IntelliVent-ASV). The targeting scheme (or combination of targeting schemes) is what distinguishes one ventilatory pattern from another. There are 7 basic targeting schemes that comprise the wide variety seen in different modes of ventilation:

Set-point: A targeting scheme for which the operator sets all the parameters of the pressure waveform (pressure control modes) or volume and flow waveforms (volume control modes).

Dual: A targeting scheme that allows the ventilator to switch between volume control and pressure control *during a single inspiration.*

Bio-variable: A targeting scheme that allows the ventilator to automatically set the inspiratory pressure or tidal volume randomly to mimic the variability observed during normal breathing.

Servo: A targeting scheme for which inspiratory pressure is proportional to inspiratory effort.

Adaptive: A targeting scheme that allows the ventilator to automatically set one target (*e.g.*, pressure within a breath) to achieve another target (*e.g.*, average tidal volume over several breaths).

Optimal: A targeting scheme that automatically adjusts the targets of the ventilatory pattern to either minimise or maximise some overall performance characteristic (*e.g.*, minimise the work rate done by the ventilatory pattern).

Intelligent: A targeting scheme that uses artificial intelligence programs such as fuzzy logic, rule based expert systems, and artificial neural networks.

10. A mode of ventilation is classified according to its control variable, breath sequence, and targeting scheme(s). The preceding 9 maxims create a theoretical foundation for a taxonomy of mechanical ventilation. The taxonomy is based on these theoretical constructs and has 4 hierarchical levels:

- Control Variable (Pressure or Volume, for the primary breath)
- Breath Sequence (CMV, IMV, or CSV)
- Primary Breath Targeting Scheme (for CMV or CSV)
- Secondary Breath Targeting Scheme (for IMV)

The *'primary breath'* is either the only breath there is (mandatory for CMV and spontaneous for CSV) or it is the mandatory breath in IMV. The targeting schemes can be represented by single, lower case letters: set-point = s, dual = d, servo = r, bio-variable = b, adaptive = a, optimal = o, intelligent = i.

A tag is an abbreviation for a mode classification, such as *PC-IMVs,s.* Compound tags are possible, *e.g.*, *PC-IMVoi,oi.*

How to classify a mode

Step 1: Identify the primary breath control variable. If inspiration starts with a preset inspiratory pressure, or if pressure is proportional to inspiratory effort, then the control variable is pressure. If inspiration starts with a preset tidal volume *and* inspiratory flow, then the control variable is volume. If neither is true, the control variable is time.

Step 2: Identify the breath sequence. Determine whether trigger and cycle events are patient or machine determined. Then, use this information to determine the breath sequence.

Step 3: Identify the targeting schemes for the primary breaths and (if applicable) secondary breaths.

Example Mode Classification

Mode Name: A/C Volume Control (Covidien PB 840)

Step 1: Inspiratory volume and flow are preset, so the control variable is volume.

Step 2: Every breath is volume cycled, which is a form of machine cycling. Any breath for which inspiration is machine cycled is classified as a mandatory breath. Hence, the breath sequence is continuous mandatory ventilation.

Step 3: The operator sets all the parameters of the volume and flow waveforms so the targeting scheme is set-point. Thus, the mode is classified as volume control continuous mandatory ventilation with set-point targeting (VC-CMVs).

Mode Name: Volume Control Plus" (Covidien PB 840)

Step 1: The operator sets the tidal volume but not the inspiratory flow. Because setting volume alone (like setting flow alone) is a necessary but not sufficient criterion for volume control, the control variable is pressure.

Step 2: Spontaneous breaths are allowed between mandatory breaths so the breath sequence is IMV.

Step 3: The ventilator adjusts inspiratory pressure between breaths to achieve an average preset tidal volume, so the targeting scheme is adaptive. The mode tag is PC-IMVa.

Mode Name: Pressure Support

Step 1: Inspiratory pressure is preset, so the control variable is pressure.

Step 2: All breaths are patient triggered and patient cycled (note what was said about flow cycling above in Maxim 5) so the breath sequence is CSV.

Step 3: Because the ventilator does not adjust any of the parameters of the breath, the targeting scheme is set-point and the tag is PC-CSVs.

Comparing modes of ventilation

The appropriate use of current modes, or the development of new modes, relies on the ability to compare and contrast their relative advantages (assuming that we can identify and understand the functionality of modes in the first place; see Appendix 1). In the larger context of medicine, patients are linked to their data by the process of assessing their needs (diagnosis). They are also linked to treatment options (biomedical innovation). But the fundamental responsibility of caregivers is to appropriately match patient needs to available treatments (planning). In the more restricted context of mechanical ventilation, patient needs can be expressed as three fundamental goals of mechanical ventilation (safety, comfort and liberation). Treatment options can be viewed as the technological capabilities of various modes to serve these goals. Thus, appropriate matching of technology to needs reduces to identifying which of the available modes best serves the immediate clinical goals.[4]

Why compare modes?

We need to compare modes because there are so many of them and because they differ enough in technological capability that they cannot possibly all offer the same benefits to the patient. Hence, there is a need for comparison and choice. The issue is whether the comparisons are based on logic and information or on personal bias. Unfortunately, the amount of good animal and clinical data is relatively small. Thus, we tend to use mechanical ventilation based on tradition and the available technology rather than on evidence-based medicine. In fact, after decades of clinical research, the only thing we seem to know is that smaller tidal volumes are better than larger ones.

Which modes should be compared?

As with any technology of sufficient complexity, the ability to compare and contrast objects requires a shift of focus away from names to tags, using a formal classification system, or taxonomy. To briefly recap our discussion of taxonomy, all modes can be divided into two broad orders, volume control and pressure control. Within these orders are families based on the breath sequences (possible combinations of mandatory and spontaneous breaths). There are only 3 possible sequences of breaths a mode can generate: all spontaneous breaths, called continuous spontaneous ventilation (CSV), mandatory breaths with the possibility of spontaneous breaths between them, called intermittent mandatory ventilation (IMV), and mandatory breaths with no possibility of spontaneous breaths between them, called continuous mandatory ventilation (CMV). Within the families are genus and species, identified by the targeting schemes used for primary breaths (for CMV and CSV) and secondary breaths (for IMV). Major benefits accrue from using this classification system; It allows us to start with a relatively large set of unique mode names on common ventilators and greatly reduce it to a more manageable set of mode tags (classifications). In that set, redundancies are easily recognised and eliminated, leaving only unique mode tags (at least to four or five levels of discrimination) that are amenable to comparison.

How can modes be compared?

Despite the availability of a wide variety of modes, only the simplest set-point targeting schemes (mainly volume control continuous mandatory ventilation) are used most of the time in daily practice. Such practice may be justified by the uncomplicated reliability of these modes and the lack of evidence that any other mode is better in terms of major clinical outcomes. Yet we could also argue that *'lack of evidence is not evidence of lack of differential effectiveness'*. It takes little effort to understand why there will never be enough clinical evidence to appropriately compare modes. Consider, for example, randomised controlled trials of 50 modes (approximately the number of unique modes currently available), would require 1,225 head-to-head comparisons (ie, combinations of 50 modes taken 2 at time). Using the ARDSnet experience to estimate the resource cost per study of about 4 years and 38 million dollars (in 1999), gathering evidence would take 4,900 labor years and over 46 billion US dollars! Thus, a complete set of clinical evidence required to compare all modes of ventilation does not exist, and never will. Thus, to rationally compare the relative merits of various modes, we must resort to deductive reasoning from first principles. We posit that a mode of mechanical ventilation has certain design features that implement a general *technological capability*. These capabilities (identified in the next section) are defined on the basis of an extensive analysis of all modes such that they can be used as unique identifiers whose benefits are intuitively obvious (again, we have no data to prove their merits). Each technological capability serves a clinical aim. Each clinical aim, in turn, serves specific objectives and general goals of mechanical ventilation based on the clinician's assessment of the patient (*Figure 1*). Using this rubric, any current or proposed feature of a mode should have a direct and logical link to specific patient needs.

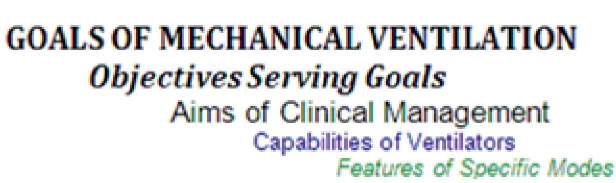

Figure 1. Hierarchy of priorities showing how specific features of modes ultimately serve the goals of ventilation for the patient.

The utility of this hierarchical approach is that we can start on familiar ground (the general goals of mechanical ventilation) and progress deductively to a linkage with specific ventilator capabilities and features, some of which might seem questionable without such a line of reasoning to justify their existence. More to the point, the capabilities form the basis for comparing the relative benefits of modes to guide appropriate selection for a given patient at a given time. The capabilities as described here are, by definition, beneficial (given that the underlying assumptions of the targeting schemes are not violated). It follows that the more capabilities a mode has, the better it serves the specific goals of mechanical ventilation that are judged to be most important in any given clinical situation. *Note that this approach explicitly ignores the issue of how modes are used.* This conceptual distinction is essential because of the huge variation in outcomes that can be attributed to the different knowledge base and skill levels of clinicians. Few would argue that given current technology, a highly skilled clinician using a technologically simple mode would likely achieve better results than, for example, a naïve clinician using a complex mode.

The three goals of mechanical ventilation

Any number of indications for mechanical ventilation may be found in the literature, but they can all be condensed into three goals and their associated objectives:

1. Promote **Safety**
   a. Optimise ventilation/perfusion of the lung (maximise ventilation and oxygenation)
   b. Optimise pressure/volume curve (minimise risk of atelectrauma and volutrauma)
2. Promote **Comfort**
   a. Optimise patient-ventilator synchrony (minimise occurrence of trigger, flow, and cycle asynchronies)
   b. Optimise work demand versus work delivered (minimise inappropriate shifting of work from vent to patient)
3. Promote **Liberation**
   a. Optimise the weaning experience (minimise duration of ventilation and risk of adverse events)

Technical capabilities of modes

The procedure for identifying the most appropriate mode for a particular clinical goal starts with a list of available modes (*e.g.*, on ventilators owned by a particular institution) identified by applying the mode taxonomy. Next, we construct a matrix that allows the identification of the presence or absence of the technological capabilities that fulfill a clinical goal as described above. Finally, we simply tabulate the capabilities for each mode. Three of the most common modes used in the world for adults are Volume Assist/Control (classified as VC-CMVs), Pressure Control SIMV (classified as PC-IMVs,s) and Pressure Support (classified as PC-CSVs). We will contrast these modes (Table 1) with more sophisticated modes, AutoMode PRVC-VS (classified as PC-IMVa,a) and IntelliVent, classified as PC-IMVoi,oi; not available in the US). Ideally, this type of analysis should be applied to all unique modes for a complete comparison. Note that there are some capabilities that are not matched to the modes in this example but do match other modes.

Table 1. Comparison of technical capabilities of some modes of mechanical ventilation. A/C = Assist/Control, PS = Pressure Support, PC-IMV = Pressure Control Synchronised Intermittent Mandatory Ventilation.

Goal	Technical Capability	A/C	PC-SIMV	PS	AutoMode	IntelliVent
Safety	Automatic minute ventilation target adjustment					x
	Automatic support adjustment for changing lung mechanics				x	x
	Automatic frequency and/or tidal volume adjustment				x	x
	Manual frequency and tidal volume settings	x			x	
	Automatic FiO_2 adjustment					x
	Automatic PEEP adjustment					x
	Automatic lung protection limits					x
	Minimises tidal volume					
Comfort	All breaths can be spontaneous			x	x	x
	Trigger and cycle on diaphragm movement					
	Coordination of mandatory and spontaneous breaths		x		x	x
	Automatic limits to avoid autoPEEP					x
	Unrestricted inspiratory flow		x	x	x	x
	Automatic adjustment of flow based on frequency					
	Automatic adjustment of support based on breathing pattern					
	Automatic adjustment of support to meet inspiratory effort					
Safety	Ventilator initiated weaning					x
	Ventilator initiated spontaneous breathing trial					x
	Automatic reduction of support with increased inspiratory effort				x	x

From this type of analysis we can identify a logical reason for preferring one mode over others on the basis of how well it serves the clinical goal of mechanical ventilation for a particular patient at a particular point in time.

Conclusions

There are so many names of modes of mechanical ventilation that we need a classification system (called a taxonomy) to identify and describe them. This taxonomy is based on 10 simple concepts that describe ventilator technology. Classifying a mode is a simple 3 step process: Identify the control variable (pressure control or volume control), identify the breath sequence (CMV, IMV, or CSV), and then determine the targeting schemes used for primary and (if necessary) the secondary breaths. The 3 goals of mechanical ventilation are to provide for (1) safety, (2) comfort, and (3) liberation. The most appropriate mode of ventilation for a particular patient depends on the goal and the technical features of the available modes that serve the goal.

References

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Appendix - standardized vocabulary of mechanical ventilation[1]

assisted breath A breath during which all or part of inspiratory (or expiratory) flow is generated by the ventilator doing work on the patient. In simple terms, if the airway pressure rises above end expiratory pressure during inspiration, the breath is assisted (as in the Pressure Support mode).

breath A positive change in airway flow (inspiration) paired with a negative change in airway flow (expiration), associated with ventilation of the lungs. This definition allows the superimposition of, for example, a spontaneous breath on a mandatory breath or vice versa. The flows are paired by size, not necessarily by timing.

breath sequence A particular pattern of spontaneous and/or mandatory breaths. The 3 possible breath sequences are: continuous mandatory ventilation, (CMV), intermittent mandatory ventilation (IMV), and continuous spontaneous ventilation (CSV).

compliance A mechanical property of a structure such as the respiratory system; a parameter of a lung model, or setting of a lung simulator; defined as the ratio of the change in volume to the associated change in the pressure difference across the system.

continuous mandatory ventilation Commonly known as "Assist/Control"; CMV is a breath sequence for which spontaneous breaths are not possible between mandatory breaths because every patient trigger signal in the trigger window produces a machine cycled inspiration (*i.e.*, a mandatory breath). Machine triggered mandatory breaths may be delivered at a preset rate. Therefore, in contrast to IMV, the mandatory breath frequency may be higher than the set frequency but never below it. In some pressure controlled modes on ventilators with an active exhalation valve, spontaneous breaths may occur during mandatory breaths, but the defining characteristic of CMV is that spontaneous breaths are not permitted *between* mandatory breaths.

continuous spontaneous ventilation A breath sequence for which all breaths are spontaneous.

elastance A mechanical property of a structure such as the respiratory system; a parameter of a lung model, or setting of a lung simulator; defined as the ratio of the change in the pressure difference across the system to the associated change in volume. Elastance is the reciprocal of compliance.

control variable The variable (ie, pressure or volume in the equation of motion) that the ventilator uses as a feedback signal to manipulate inspiration. For simple set-point targeting, the control variable can be identified as follows: If the peak inspiratory pressure remains constant as the load experienced by the ventilator changes, then the control variable is pressure. If the peak pressure changes as the load changes but tidal volume remains constant, then the control variable is volume. Volume control implies flow control and *vice versa*, but it is possible to distinguish the two on the basis of which signal is used for feedback control. Some primitive ventilators cannot maintain either constant peak pressure or tidal volume and thus control only inspiratory and expiratory times (*i.e.*, they may be called time controllers).

equation of motion for the respiratory system A relation among pressure difference, volume, and flow (as variable functions of time) that describes the mechanics of the respiratory system. The simplest and most useful form is a differential equation with constant coefficients describing the respiratory system as a single deformable compartment including the lungs and chest wall connected in series to a single flow conducting tube:

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$$P_R(t) + P_{mus}(t) = EV(t) + R\dot{V}(t) + autoPEEP$$

where

$P_{TR}(t)$= the change in transrespiratory pressure difference (i.e., airway opening pressure minus body surface pressure) as a function of time (t), measured relative to end expiratory airway pressure. This is the pressure generated by a ventilator, *Pvent*(t), during an assisted breath.

$P_{mus}(t)$= ventilatory muscle pressure difference as a function of time (t); the theoretical chestwall transmural pressure difference that would produce movements identical to those produced by the ventilatory muscles during breathing maneuvers (positive during inspiratory effort, negative during expiratory effort)

$V(t)$ = volume change relative to end expiratory volume as a function of time (t)

$\dot{V}(t)$ = flow as a function of time (t), the first derivative of volume with respect to time

E = elastance (inverse of compliance; E = 1/C)

R = resistance

autoPEEP = end expiratory alveolar pressure above end expiratory airway pressure

For the purposes of classifying modes of mechanical ventilation the equation is often simplified to:

$$P_{vent} = EV + R\dot{V}$$

where

P_{vent}= the transrespiratory pressure difference (ie, "airway pressure") generated by the ventilator during an assisted breath

inspiratory pressure change The change in transrespiratory system pressure associated with delivery of the tidal volume as described in the equation of motion for the respiratory system. For pressure control modes, if inspiratory pressure is set relative to atmospheric pressure, the term "peak inspiratory pressure" is used to describe the setting. If inspiratory pressure is set relative to PEEP, the term "inspiratory pressure change" is used.

intermittent mandatory ventilation Breath sequence for which spontaneous breaths are permitted between mandatory breaths. For most ventilators, a short "window" is opened before the scheduled machine triggering of mandatory breaths to allow synchronisation with any detected inspiratory effort on the part of the patient. This is referred to as synchronized IMV (or SIMV).

Three common variations of IMV are: (1) Mandatory breaths are always delivered at the set frequency; (2) Mandatory breaths are delivered only when the spontaneous breath frequency falls below the set frequency; (3) Mandatory breaths are delivered only when the spontaneous minute ventilation (*i.e.*, product of spontaneous breath frequency and spontaneous breath tidal volume) drops below a preset or computed threshold (*aka* Mandatory Minute Ventilation). Therefore, in contrast to CMV, with IMV the mandatory breath frequency can never be higher than the set rate but it may be lower.

For some modes (*e.g.*, Airway Pressure Release Ventilation), a short window is also opened at the end of the inspiratory time. Because spontaneous breaths are allowed during the mandatory pressure controlled breath, this window synchronizes the end of the mandatory inspiratory time with the start of spontaneous expiratory flow, if detected. With these technological developments, potential confusion arises as to whether inspiration that is synchronized (either start or stop) is considered patient triggered/cycled or machine triggered/cycled. If we say synchronized breaths are patient triggered and cycled, we have the awkward possibility of a spontaneous breath occurring during another spontaneous breath. This is avoided by distinguishing between a *trigger window* and a *synchronisation window.*

There are some modes where the idea of IMV may be vague: With Airway Pressure Release Ventilation, relatively high frequency spontaneous breaths are superimposed on low frequency mandatory breaths. However, the expiratory time between mandatory breaths is often set so short that a spontaneous breath is unlikely to occur between them. Other ambiguous modes are High Frequency Oscillation, High Frequency Jet Ventilation, Intrapulmonary Percussive Ventilation and Volumetric Diffusive

Respiration. With these modes, high frequency mandatory breaths are superimposed on low frequency spontaneous breaths and again, there is no possibility of a spontaneous breath actually occurring between mandatory breaths. Nevertheless, we classify all these modes as forms of IMV because spontaneous breaths can occur along with mandatory breaths and because spontaneous efforts do not affect the mandatory breath frequency.

mandatory breath A breath for which the patient has lost control over timing. This means a breath for which the start or end of inspiration (or both) is determined by the ventilator, independent of the patient. That is, the machine triggers and/or cycles the breath. A mandatory breath can occur during a spontaneous breath (eg, High Frequency Jet Ventilation). A mandatory breath is, by definition, assisted.

primary breaths Mandatory breaths during CMV or IMV or spontaneous breaths during CSV.

resistance A mechanical property of a structure such as the respiratory system; a parameter of a lung model, or setting of a lung simulator; defined as the ratio of the change in the pressure difference across the system to the associated change in flow.

secondary breaths Spontaneous breaths during IMV.

spontaneous breath A breath for which the patient retains substantial control over timing. This means the start and end of inspiration may be determined by the patient, independent of any machine settings for inspiratory time and expiratory time. That is, the patient both triggers and cycles the breath. Note that use of this definition for determining the breath sequence (ie, CMV, IMV, CSV) assumes normal ventilator operation. For example, coughing during VC-CMV may result in patient cycling for a patient triggered breath due to the pressure alarm limit. While inspiration for that breath is both patient triggered and patient cycled, this is not normal operation and the sequence does not turn into IMV. A spontaneous breath may occur during a mandatory breath (eg Airway Pressure Release Ventilation). A spontaneous breath may be assisted or unassisted.

synchronisation window A *short period, at the end of a preset expiratory time* or *at the end of a preset inspiratory time*, during which a patient signal may be used to synchronise a mandatory breath trigger or cycle event to a spontaneous breath. If the patient signal occurs during an expiratory time synchronisation window, inspiration starts and is defined as *a machine triggered* event. This is because the mandatory breath would have been time triggered regardless of whether the patient signal had appeared or not and because the distinction is necessary to avoid logical inconsistencies in defining mandatory and spontaneous breaths which are the foundation of the mode taxonomy. If inspiration is triggered in a synchronisation window, the actual ventilatory period for the previous breath will be shorter than the set ventilatory period (determined by the set mandatory breath frequency). Some ventilators add the lost time to the next mandatory breath period to maintain the set frequency. Sometimes a synchronisation window is used at the end of the inspiratory time of a pressure controlled, time cycled breath. If the patient signal occurs during such an inspiratory time synchronisation window, expiration starts and is defined as *a machine cycled* event. Some ventilators offer the mode called Airway Pressure Release Ventilation (or something similar with a different name) that makes use of both expiratory and inspiratory synchronisation windows.

target A predetermined goal of ventilator output. Targets can be viewed as the goals of the targeting scheme. *Within-breath targets* are the parameters of the pressure, volume, or flow waveform. Examples of within-breath targets include inspiratory flow or pressure and rise time (set-point targeting), tidal volume (dual targeting) and constant of proportionality between inspiratory pressure and patient effort (servo targeting). Note that preset values *within a breath* that end inspiration, such as tidal volume, inspiratory time, or percent of peak flow, are also cycle variables. *Between-breath targets* serve to modify the within-breath targets and/or the overall ventilatory pattern. Between-breath targets are used with more advanced targeting schemes, where targets act over multiple breaths. Examples of between-breath targets and targeting schemes include average tidal volume (for adaptive targeting), percent minute ventilation (for optimal targeting) and combined PCO_2, volume, and frequency values describing a "zone of comfort" (for intelligent targeting).

targeting scheme A model of the relationship between operator inputs and ventilator outputs to achieve a specific ventilatory pattern, usually in the form of a feedback control system. The targeting scheme is a key component of a mode description.

tidal volume The volume of gas, either inhaled or exhaled, during a breath. The maximum value of the volume vs time waveform.

trigger window The period comprised of the *entire expiratory time* minus a short "refractory" period required to reduce the risk of triggering a breath before exhalation is complete. If a signal from the patient (indicating an inspiratory effort) occurs within this trigger window, inspiration starts and is defined as a *patient triggered* event.