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Pressure Modes of Mechanical Ventilation

The Good, the Bad, and the Ugly

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ABSTRACT

Numerous pressure modes are currently available on ventilators. The application of microprocessor technology has resulted in sophisticated mode options that are very responsive to patient-initiated efforts, yet little is known about how to use the modes or their effect on patient outcomes. This article describes a wide variety of pressure modes including traditional modes such as pressure support and pressure-controlled ventilation in addition to less traditional new modes such as airway pressure release ventilation, biphasic positive airway pressure, Pressure Augmentation (Bear 1000, Viasys Healthcare, Yorba Linda, California), Volume Support (Maquet, Bridgewater, New Jersey), Pressure Regulated Volume Control (Maquet, Bridgewater, New Jersey), Volume Ventilation Plus (Puritan Bennett, Boulder, Colorado), Adaptive Support Ventilation (Hamilton Medical, Switzerland), and Proportional Assist Ventilation (Dräger Medical, Richmond Hill, Ontario, Canada). The "good, the bad, and the ugly" issues surrounding the application, evaluation, and outcomes of the modes are discussed.
Keywords: advanced pressure modes, mechanical ventilation, pressure modes of ventilation

Mechanical ventilator modes have become progressively more sophisticated with the advent of microprocessor-controlled technology. The ability of engineers and scientists to develop ventilators that respond rapidly to patient-initiated breaths and cycle extremely quickly between ventilatory phases has resulted in modes that are very attractive for use with some of our most critically ill patients.[1] Unfortunately, the best use of the modes, especially as they relate to the management of the critically ill patient with respiratory failure, has not been clearly elucidated. In the past, volume modes of ventilation were the standard, but now a wide variety of pressure modes have emerged and are in use. Many of the modes are complicated, and despite a paucity of clinical trials that demonstrate their efficacy, proponents suggest their superiority. Understandably, bedside clinicians and APNs, who manage the patients and are charged with educating others about the application and assessment of the modes, are unsure of when and how best to use them.

Confusion related to mode application is, in part, a result of the manufacturer-selected mode names that are often different from one another despite the fact that the modes may function quite similarly and are iterations, albeit more sophisticated and purportedly improved versions, of traditional modes. This distressing fact is further complicated by the tendency of the ventilators to have numerous other parameter settings available for adjustment that have little

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demonstrated scientific effect on patient outcomes. Thus clinicians often feel undereducated about the modes and the best use of the same. This is unfortunate because understanding the modes is essential if optimal care is to be ensured.

The purpose of this article is to describe selected pressure modes and the science related to their efficacy and use. When possible, the modes are classified in categories to better illustrate the similarities and important differences between the modes. This article discusses both traditional and nontraditional pressure mode options such as pressure support ventilation (PSV), pressure control (PCV) and pressure-controlled inverse-ratio ventilation (PC-IRV), airway pressure release ventilation (APRV), biphasic positive airway pressure, volume-assured pressure modes (ie, Pressure Augmentation, Volume Support [VS] [Maquet, Bridgewater, New Jersey], Pressure Regulated Volume Control [Maquet, Bridgewater, New Jersey], and Volume Ventilation Plus [Puritan Bennett, Boulder, Colorado]), automatic tube compensation (although not really a mode per se, some use it as such), Adaptive Support Ventilation (Hamilton Medical, Switzerland), and proportional assist ventilation (PAV). The use of the modes from the acute to the weaning stages of ventilation is discussed as applicable.

Throughout this article, selected specific ventilator mode names are referenced as representative examples of mode options in an effort to help clarify similarities and differences. It is not the intention of the author to provide an exhaustive list of those available on all ventilators today but rather to provide information to the reader so that ventilator pressure modes and their application might be better understood.

Pressure Mode Characteristics: An Overview

Traditional volume modes of ventilation, most notably assist control (AC) and synchronized intermittent mandatory ventilation (SIMV), although still widely used are becoming less popular than pressure modes. In contrast to volume modes, pressure modes were initially configured to ensure that a clinician-selected inspiratory pressure level (IPL) was provided on a breath-to-breath basis, volume varied with each breath. All pressure modes are associated with a "decelerating" flow pattern during inspiration. This decelerating flow pattern represents the speed of the gas, which is initially very high but gradually lowers as the chest fills. This characteristic flow pattern is considered more physiologic than that associated with volume-based ventilation and may contribute to better gas distribution as well (Figures 1 and 2).[2] In part, it is the decelerating flow pattern that has driven the development of newer and more sophisticated pressure modes of ventilation.

In many of the earlier ventilator models, the selection of a pressure mode required that the clinician select the mode (ie, PSV or PCV) and the desired pressure level. With these pressure modes, pressure is stable and volume is variable dependent on compliance (lungs and chest wall) and resistance (airways). However, some newer pressure modes require that the clinician select first the mode (which may or may not have "pressure" in the title) and then the related parameters that further define the characteristics

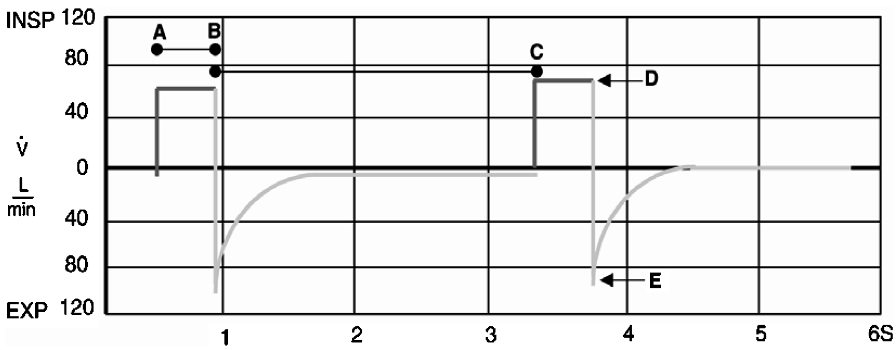

Figure 1: Square flow waveform: Volume breath, where the path from A to B represents insipiration, the path from B to C represents expiration, D represents end-insipiration, and E indicates peak expiratory flow. Abbreviations: INSP, inspiration; EXP, expiration; V̇, flow; L/min, liters per minute; S, seconds. Used with permission from Nellcor Puritan Bennett LLC, Boulder, Colorado, part of Covidien (formerly Tyco Healthcare).

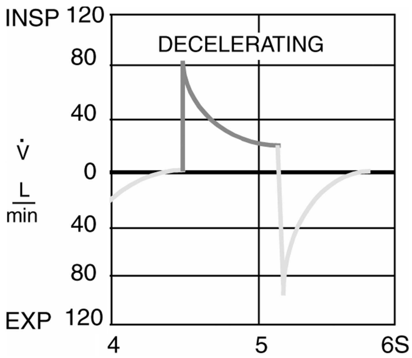

Figure 2: Decelerating flow waveform: Pressure breath. Abbreviations: INSP, inspiration; EXP, expiration; V̇, flow; L/min, liters per minute; S, seconds. Used with permission from Nellcor Puritan Bennett LLC, Boulder, Colorado, part of Covidien (formerly Tyco Healthcare).

of the mode such as the desired tidal volume (VT). In addition, many of the new modes while providing a decelerating flow pattern, as described above, may sacrifice pressure limitation in an effort to ensure the desired volume. In still other pressure modes, variations in both volume and pressure are allowed with patient-initiated breaths during the inspiratory and expiratory (I/E) ventilator respiratory cycles. Descriptions of these and other selected pressure modes follow and are summarized in Table 1.

Pressure Support Ventilation

Description

Pressure support ventilation is a mode of ventilation that augments or supports a spontaneous inspiration with a clinician-selected pressure level. The mode is a popular and commonly used mode of ventilation. Although initially proposed to be a mode for weaning, PSV is also used to ventilate less stable conditions. This mode is available on virtually all ventilators for use as a stand-alone mode or in combination with others. It is relatively easy to apply and manage because it requires few parameter adjustments.

Once the clinician selects a PSV level, the pressure rises rapidly to a plateau (the selected pressure) and the pressure is maintained throughout inspiration (Figure 3). Termination of inspiration occurs when flow diminishes to one fourth of the original flow (or depending on the ventilator, some predetermined diminution of flow). Because this is a spontaneous breathing mode, no rate is set, and the patient controls the inspiratory time (T_i), respiratory frequency (f_x), and VT with each breath. The work of breathing associated with the mode is dependent, in large part, on the selected pressure level. Higher levels may provide nearly total ventilatory support,[3,4] and the level can be adjusted gradually to provide for graded endurance-training intervals.[4,5]

Pressure support ventilation is often used in conjunction with other modes such as SIMV. When combined with SIMV, it is used to offset the work of breathing associated with spontaneous breathing through artificial airways and circuits.[6] Thus the adjustment of the PSV level provides either more or less work accordingly. There is some evidence that the combination of SIMV and PSV when used as a mode for weaning may contribute to longer weaning times.[7] In addition, very high levels of PSV, especially in patients with obstructive disease conditions, may increase the incidence of auto–positive end-expiratory pressure (auto–PEEP) and ineffective patient efforts to trigger the ventilator.[8]

Parameters

Parameters used to set PSV include PSV level, sensitivity, positive end-expiratory pressure (PEEP), and the fraction of inspired oxygen (FIO_2).

Pressure Control and Pressure-Controlled Inverse-Ratio Ventilation

Description

Modes with "control" or "mandatory" in the title suggest that the mode has a set respiratory frequency (f_x) and, by extension, a preselected T_i for the mandatory breaths. Pressure control ventilation is one such mode. When the mode was first introduced, it was proposed for use in patients with acute respiratory distress syndrome (ARDS). The goal of the mode was to control the airway pressure (it was unclear at the time if peak, plateau, or mean pressures contributed to lung injury) and optimize gas distribution by means of the decelerating flow pattern. It could be used with traditional I/E ratios or the ratios could be inverse, thus the name inverse-ratio ventilation.[9–12] Because the lungs of patients with ARDS are noncompliant, stiff, and prone to collapse, investigators hypothesized that by changing the I/E ratios from the traditional 1:2, 1:3 patterns to inverse ratios (ie, 1:1, 2:1, 3:1, 4:1), the ARDS lung might be "kept open"—essentially what we now refer to as "recruitment"—and prevented

Table 1: Examples of Pressure Modes and Parameters

Mode Name	Main Parameters	Comments
Pressure support	Pressure support level, sensitivity, FIO_2, and PEEP	Often, pressure is arbitrarily selected (eg, 10–20 cm H_2O) and then adjusted up or down to attain the desired tidal volume. Some use the plateau pressure if transitioning from volume ventilation as a starting point.
Pressure control ventilation	Inspiratory pressure level, f_x, T_i, sensitivity, FIO_2, and PEEP	Variants of pressure control ventilation include volume-assured pressure options and some other modes such as airway pressure release ventilation and BiLevel ventilation. They are listed below.
Pressure-controlled inverse-ratio ventilation	As for pressure control ventilation, but an inverse inspiratory/expiratory ratio is attained by lengthening the T_i. Inverse ratios include 1:1, 2:1, 3:1, and 4:1.	Some ventilators allow for the inspiratory/expiratory ratio to be selected.
Airway pressure release ventilation	Pressure high: high CPAP level; pressure low: generally 0–5 cm H_2O; time high; time low, and FIO_2.	Generally, the CPAP level is adjusted to ensure adequate oxygenation, and the f_x of the releases are increased or decreased to meet ventilation goals. VT is a variable dependent on the CPAP level, compliance and resistance of the patient, and the patient's spontaneous effort.
Volume-assured pressure modes (1–5 below)	These modes provide pressure breaths with a volume guarantee.	These modes are ventilator specific. Although the similarities are greater than the differences, they are called by different names. Often, the names suggest that the mode is a volume mode, yet a decelerating flow pattern (associated with pressure ventilation) is always provided.
1. Pressure augmentation (Bear 1000)	Spontaneous mode: VT, sensitivity, FIO_2, and PEEP Control mode: As per spontaneous mode plus f_x and T_i	This mode starts the breath as a pressure breath. If calculations automatically done by the ventilator determine that the desired VT will not be attained, the ventilator provides the remainder of the breath as a volume breath. This changes both the flow pattern and the pressure level of the breath.
2. Volume Support (Siemens)	VT, sensitivity, FIO_2, and PEEP	The pressure level is automatically adjusted to attain the desired VT. If control of pressure is desired, it must be carefully monitored.
3. Pressure Regulated Control (Siemens)	f_x and T_i set in addition to those set for VS.	As with VS. The difference is that this is a control mode. However, spontaneous breaths may also occur.

(continues)

Table 1: Examples of Pressure Modes and Parameters *(Continued)*

Mode Name	Main Parameters	Comments
4. Volume Support (Puritan Bennett 840)	VT, sensitivity, FIO_2, and PEEP	This mode is one option in a category called *Volume Ventilation Plus*. This is the spontaneous breathing option in this category and is similar to VS above.
5. Volume Control Plus (Puritan Bennett 840)	f_x and T_i are set in addition to those set for VS.	This mode is also a mode option listed in the category called *Volume Ventilation Plus*. To access this mode, the user selects the synchronized intermittent mandatory ventilation or assist control (both control modes) and then selects volume control plus. For some clinicians, this is confusing because it appears that the patient is on 2 different modes versus Volume Control Plus.
BiLevel Positive Airway Pressure (Puritan Bennett 840) (other forms of this exist by different manufacturers)	$PEEP_H$, $PEEP_L$, f_x, and T_i	If additional support is desired for patient-initiated breathing, P_{SUPP} may be selected as well. Attention to VT is important because the patient can augment VT significantly with supported spontaneous breaths.
Adaptive Support Ventilation (Galileo and Raphael [Hamilton Medical])	Body weight, %MinVol, and high pressure limit	Once basic settings are selected, adaptive support ventilation is started and %MinVol is adjusted if indicated. Spontaneous breathing is automatically encouraged and when the inspiratory pressure (P_{INSP}) is consistently 0 and fx control (rate) is 0, extubation may be considered.
Automatic tube compensation	Endotracheal tube internal diameter and percent compensation	This is not a mode but rather a pressure option to offset the work associated with tube resistance. It can be combined with other modes or used alone as in a CPAP weaning trial.
Proportional assist ventilation	Proportional pressure support (Drager Medical, Richmond Hill, Ontario, Canada): PEEP, FIO_2, percent volume assist, and flow assist Proportional assist ventilation plus (Puritan Bennett, now Covidien) PEEP, FIO_2, and percent support	Depending on the ventilator, the amount of "assist" to be provided is determined by the clinician, and different parameters are selected to do so. Default percent support numbers are recommended, but the clinician must determine the timing of reductions of the same.

Abbreviations: CPAP, continuous positive airway pressure; FIO_2, fraction of inspired oxygen; f_x, respiratory frequency; PEEP, positive end-expiratory pressure; $PEEP_H$, PEEP High; $PEEP_L$, PEEP Low; %MinVol, minute volume; P_{SUPP}, pressure support; T_i, inspiratory time; VS, volume support.

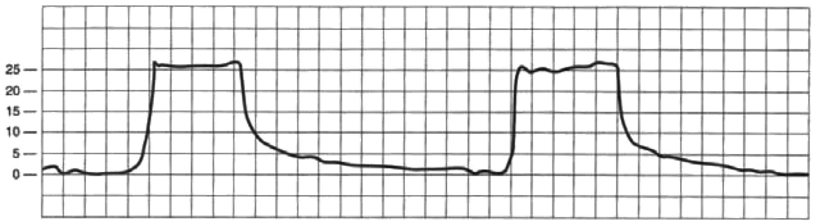

Figure 3: Square pressure waveform: Pressure breath.

from "derecruiting" during the expiratory phase of ventilation.[9–13] Although the idea was right on target with what we now know about recruiting a lung with ARDS, studies did not demonstrate an improvement in mortality. This is in part because the assessment of lung recruitment often focused on the effect of the mode on oxygenation versus lung protection;[9–12] tidal volumes and pressure levels were not controlled nor was the effect of PEEP and/or auto-PEEP induced by the inverse ratios.[14] Recent studies have demonstrated that low-VT ventilation[15] and the use of relatively high levels of PEEP are necessary to prevent "volu-trauma" and repetitive opening injury secondary to inadequate lung recruitment.[13] The studies have shown that the appropriate application of the protective lung strategies does decrease mortality in these patients.

Earlier iterations of PCV modes did not allow for adequate flow delivery during a patient-initiated breath. Patient-initiated breathing, and even patient movement in some cases, resulted in oxygen desaturation. Sedation and neuromuscular blockade were frequently necessary to ensure control. Ventilator manufacturers have subsequently addressed this and other related issues by designing and introducing modalities that allow for adequate flow delivery for spontaneous breathing during control breaths.

Parameters

Pressure control ventilation parameters include pressure level (often called *inspiratory pressure level* to distinguish it from PSV), f_x, T_i, FIO_2, PEEP, and sensitivity (ie, pressure or flow-triggering). If PC-IRV is desired, the same parameters are adjusted, but T_i is lengthened to attain the desired I/E ratio.

Airway Pressure Release Ventilation

Description

Airway pressure release ventilation is a mode that allows for spontaneous breathing at a preset continuous positive airway pressure (CPAP) level and that is interrupted at a clinician-determined f_x by a short (1- to 1.5-second) pressure release (to a lower baseline or to zero pressure). The mode is designed for spontaneously breathing patients such as those with ARDS who require a high level of pressure to effectively recruit alveoli. In the case of APRV, this CPAP level is often in the 15 to 20 cm H_2O range. The short "releases" assist with CO_2 elimination (they allow for more uniform emptying of alveoli with different time constants) and are increased or decreased accordingly. Derecruitment of alveoli occurs if the f_x releases are greater than 1.5 to 2.0 seconds in duration. The short airway pressure releases are the hallmark of APRV and set it apart from PCV and biphasic ventilation (there are many ventilator-specific names for this mode option; see below) in that there is no true conventional expiratory phase. This may be considered a form of PC-IRV in that the idea is to encourage lung recruitment by prolonging inspiration at a set pressure while preventing derecruitment with a very short pressure release.[16–19] The mode appears to be as safe and effective as conventional volume or PC ventilation[16–22] with the additional advantage of allowing spontaneous breathing throughout all phases of the respiratory cycle, thus obviating the need for heavy sedation and paralytic agents.[21,23] In the past, the use of sedation infusions and paralytic agents has been recommended to ensure patient-ventilator synchrony especially with the use of some traditional control modes of ventilation. Studies have demonstrated that this practice is associated with negative clinical outcomes such as increased ventilator duration, longer critical care unit and hospital lengths of stay,[24–26] and other morbidities (eg, ventilator-associated pneumonia, gastrointestinal bleeding, deep-vein thrombosis, and bacteremia) and thus is to be discouraged.[27] In reality, the spontaneous breathing pattern of patients on this mode of ventilation is often very rapid. Although generally a "rapid-shallow" breathing pattern heralds fatigue, it is unknown whether this is true in a fully recruited (distended) lung.

Parameters

Airway pressure release ventilation parameters include the pressure high (P_{HIGH}), which is the high CPAP level; pressure low (P_{LOW}), which is generally 0–5; the time high (T_{HIGH}); the time low (T_{LOW}); and FIO_2. Generally, the CPAP level is adjusted to ensure adequate oxygenation, and f_x of the releases are increased or decreased to meet ventilation goals. Tidal volume is a variable dependent on the CPAP level, compliance and resistance of the patient, and the patient's spontaneous effort.

Biphasic modes

BiLevel Positive Airway Pressure (Puritan Bennett 840 [Puritan Bennett, Boulder, Colorado]);[28] Bi-Vent (Servo I [Maquet, Inc., Bridgewater, New Jersey]);[29] BIPAP (Evita XL [Dräger Medical, Inc., Telford, Pennsylvania]);[30] DuoPAP (Galileo [Hamilton Medical, Reno, Nevada]);[31] Biphasic (AVEA [Viasys Healthcare, Yorba Linda, California]).[32]

Description

Biphasic modes are similar to PCV and APRV in that the clinician selects IPL and PEEP levels as well as f_x and T_i (in the case of APRV the low level is very short, as previously described). But unlike conventional PCV, the modes allow for unrestricted spontaneous breathing during the I/E cycles. The modes employ an active exhalation valve that vents excess flow during the patient's spontaneous breathing while maintaining the pressure level of the control breaths. Names for what would conventionally be called *IPL* and PEEP vary with the ventilator. For example, with the Puritan Bennett model, the high pressure level is referred to as *PEEP High* (*$PEEP_H$*), which is the same as IPL in traditional PCV, and PEEP Low ($PEEP_L$), which is PEEP in traditional PCV. Spontaneous breathing at both levels can be augmented with PS (P_{SUPP}) or tube compensation (described below) dependent on the ventilator. Tidal volume is dependent on the $PEEP_H$ and $PEEP_L$ levels and resistance and compliance of the lung and chest wall, however, is augmented by the patient's spontaneous breathing at the high level. This may make the attainment of a lung protective range of V_T (ie, 6 mL/kg) difficult. Plus, as noted earlier, breathing patterns at the 2 levels of high and low support vary and are often rapid. Dependent on the specific ventilator, APRV and biphasic modes may be accessed via the same mode parameters. Time in inspiration and expiration distinguishes the distinct mode. Some ventilators call this T_{HIGH} and T_{LOW}. However, as noted earlier, with APRV, the release time to the $PEEP_L$ level is very short.

Although biphasic ventilation is often considered a form of PCV, studies have sought to determine whether the mode decreases the work of breathing using PSV as the comparison mode. Two studies comparing PSV to biphasic defined the work of breathing by measuring the pressure-time product.[33,34] Interestingly, although the work of breathing was increased in BiLevel in comparison with PSV, the increased work of breathing did not translate into an increased oxygen consumption or carbon dioxide production.[34] As noted in the studies on APRV, the ability to breathe spontaneously throughout the respiratory cycle without adversely affecting oxygenation may be a distinct advantage because rapid breathing patterns associated with desaturation of oxygen suggests ventilator tolerance and the need for analgesics and sedatives.[21,23] In another study of adult cardiac surgery patients, the use of biphasic ventilation was compared with controlled volume ventilation and intermittent mandatory ventilation. The biphasic group required significantly less analgesics and sedatives.[35] A 70% reduction in neuromuscular blockade and a 30% reduction of benzodiazepine use were required to maintain a bispectral index level of 70 in the patients.

Parameters

Parameters for setting biphasic modes vary between ventilators but include $PEEP_H$, $PEEP_L$, f_x, and T_i. If additional support is desired for patient-initiated breathing, P_{SUPP} may be selected as well. In other ventilators, the high and low levels may be defined by IPL and PEEP, and I/E times as T_{HIGH} or T_{LOW}, as described for APRV.

Volume-Assured Pressure Modes

Description

Volume-assured pressure modes are modes that combine PSV with a decelerating flow pattern and a guaranteed volume.[36] The modes were developed to ensure that the desirable characteristics of pressure ventilation were available for use without sacrificing volume (especially in the case of unstable patients or with changes in patients' conditions). Early reports suggested that in patients with acute respiratory failure, the mode resulted in lower workload and ventilatory drive, better patient-ventilator synchrony, and less auto-PEEP while ensuring a desired VT.[36] This category includes numerous modes developed for specific ventilators. The modes, while bearing different names, are similar as are many of the parameters required to apply the modes.

Pressure Augmentation (Bear 1000 [Viasys Healthcare, Yorba Linda, California])[37]

With this ventilator mode, the breath starts as a pressure breath, but if the calculated mechanical properties of the airways, lung, and thorax predict that the patient will not attain the desired VT, the ventilator will deliver the rest of the breath as a volume breath (Figure 4). Thus, if the desired volume is set inappropriately high, the goal of pressure breath delivery (decelerating flow) is lost as is the limitation of pressure. It is important that when using the mode, the clinician monitor transitions between pressure breath delivery and volume breath delivery. One way to do this is to observe the respiratory waveforms (see Figure 4). If the clinician observes frequent transitions from pressure breath delivery to volume breath delivery, the cause(s) should be identified.

Parameters

Both spontaneous and control modes are available. They are distinguished by the selection of ventilator parameters. Spontaneous mode parameters include VT, sensitivity, FIO_2, and PEEP. For a control mode, the clinician must also set f_x and T_i.

Volume Support, Pressure Regulated Control (Maquet, Bridgewater, New Jersey)[29]

This ventilator manufacturer distinguishes the spontaneous breathing mode from the control mode by using distinctly different names. Volume Support is a spontaneous breathing mode that adjusts the pressure level automatically (on the basis of lung mechanics) to attain the clinician-selected VT. Once the clinician selects the VS, the ventilator provides a test breath and then adjusts the pressure level in 3 cm H_2O increments, with each subsequent breath to ensure the desired volume (Figure 5). Pressure Regulated Volume Control (PRVC) is similar, but as noted in the name, it is a control option that means that in addition to the parameters selected for VS, the clinician must set f_x and T_i. The patient may initiate a spontaneous breath between the control breaths and receive a pressure breath. In this way, it is very similar in design to the pressure mode called *pressure assist/control*.

Parameters

Volume Support requires a set VT, sensitivity, FIO_2, and PEEP. Pressure Regulated Volume Control requires that f_x and T_i be set in addition to those set for VS.

Volume Ventilation Plus (Puritan Bennett 840 [Puritan Bennett, Boulder, Colorado)[38]

This manufacturer has 2 volume-guaranteed pressure modes that are classified under a category called *Volume Ventilation Plus*,

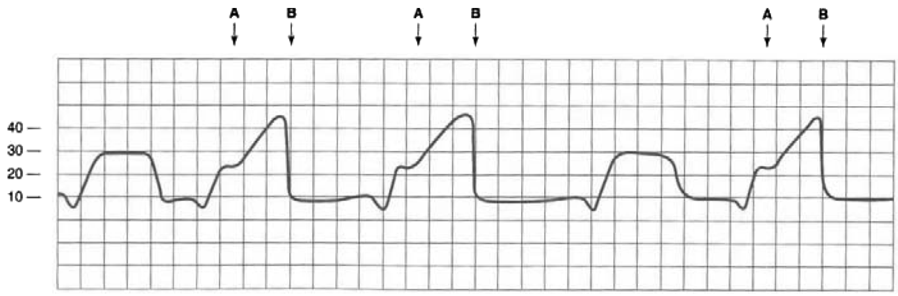

Figure 4: Pressure waveform of pressure augmentation: When desired tidal volume cannot be delivered, the ventilator supplies the remainder of the breath as a volume breath. A indicates beginning pressure breath (square pressure waveform), and B, volume delivery (accelerating pressure waveform).

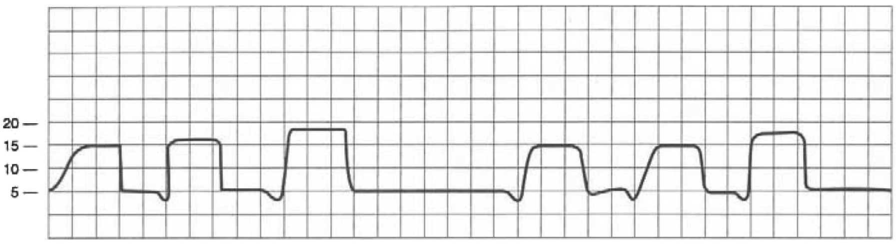

Figure 5: Pressure waveform of volume support: The pressure is increased in increments with each breath to attain the desired tidal volume.

which includes VS and Volume Control Plus (VC+). Although both sound like volume modes, they are not. Instead, they are, like the others discussed in this category, pressure modes that guarantee a volume. They can be patient or ventilator initiated. Volume Support is described as a spontaneous mode that delivers a desired volume as a pressure breath (pressure is automatically adjusted breath by breath to ensure VT). Volume Control Plus is the mandatory option, and thus, f_x and T_i are set. This manufacturer has integrated an active exhalation valve into the mechanics of the ventilator that allows for the patient's spontaneous breathing (excess flow is vented and patient-ventilator synchrony enhanced) while maintaining the pressure level of the control breaths. This function is not clinician controlled.

Parameters

Volume Support requires that VT, sensitivity, FIO_2, and PEEP be set. Volume Control Plus requires that f_x and T_i be set in addition to those set for VS (similar to PRVC described earlier). To access this mode, the user selects the SIMV or AC (both control modes) and then selects VC+. For some clinicians, this is confusing because it appears that the patient is on 2 different modes (ie, PC and SIMV) versus VC+. The difference between the settings of SIMV and AC is how the spontaneous breaths are delivered. In the SIMV mode, the VT and T_i are patient determined versus in the AC mode, where the spontaneously initiated breaths receive the pressure required to attain the desired VT.

Automatic Tube Compensation

Description

Automatic tube compensation (ATC) is not really a mode but rather a ventilatory adjunct available on many current ventilators that is designed to overcome the work of breathing imposed by the artificial airway. To that end, ATC adjusts the pressure (proportional to tube resistance) required to provide a variable fast inspiratory flow during spontaneous breathing. Automatic tube compensation is increased during inspiration and lowered during expiration, thus decreasing the work of breathing secondary to tube resistance.

The accuracy of ATC in compensating for tube resistance has been studied using a mechanical model with 4 ventilators. The authors used a prototype model as the criterion standard and compared results to ATC models currently employed by newer ventilators.[39] The study found that the tube-related inspiratory work of breathing was significantly decreased but the expiratory work of breathing was not. They found that the adapted and simplified ATC systems on the newer ventilators were inferior to the original prototypes.

Although this option does appear to be potentially quite useful to decrease the work imposed by artificial airways, there is much to be learned especially about how it works in combination with other modes of ventilation. Use of the option may increase auto-PEEP if obstructive disease is present.

Parameters

The clinician enters the internal diameter size of the endotracheal tube and the desired percentage of compensation.

Adaptive Support Ventilation (Galileo and Raphael [Hamilton Medical, Bonaduz, Switzerland])[40]

Description

Adaptive Support Ventilation (ASV) may be one of the most unique ventilator modes available today. Referred to by the ventilator manufacturer as "intelligent ventilation," the mode is designed to assess lung mechanics on a breath-to-breath basis (controlled-loop ventilation) for spontaneous and control settings.[40] It achieves an optimal V_T by automatically adjusting the mandatory respiratory f_x and inspiratory pressure. The working concept with this mode is that the patient will breathe at an f_x and V_T that minimizes elastic and resistive loads. In all modes, the opportunity for spontaneous breathing is promoted (the user does not have to switch back and forth from one mode to another to encourage spontaneous breathing because this is automatically done). Thus the interactions required by the clinician are few. The manufacturer suggests that this aspect of "intelligent ventilation" may decrease the potential for operator error and save time—both desirable outcomes of any ventilator system. Built into the mode are algorithms that are "lung protective." The protective strategies are designed to minimize auto-PEEP and prevent apnea, tachypnea, excessive dead space, and excessively large breaths.[40]

Outcomes associated with ASV are favorable.[41,42] In a study of 36 cardiac surgery patients, randomly assigned to either ASV- or SIMV-protocolized weaning, weaning time was significantly less with ASV.[41] In addition, in a preliminary study of 10 patients early in the weaning phase, ASV was compared with SIMV plus PSV to determine the mode's effect on respiratory central drive, arterial blood gases, sternocleidomastoid electromyographic activity and hemodynamics.[42] Adaptive Support Ventilation performed comparably to SIMV plus PSV in most measures, with the exception of sternocleidomastoid activity, which was significantly less than with the use of PSV. The results suggest that ASV is as effective as conventional ventilation and that the work of breathing may be decreased with the mode.

Parameters

Parameters in this mode are very different from those in most modes but include very few settings. They are ideal body weight, %MinVol (minute volume), and high pressure limit. Once these are set, ASV is started, and %MinVol is adjusted if indicated.

Proportional Assist Ventilation

Proportional Pressure Support (PPS) (Dräger Medical, Richmond Hill, Ontario, Canada),[43] Proportional Assist Ventilation Plus (PAV+) (Puritan Bennett, Boulder, Colorado).[44]

Description

First introduced in the early 1990s,[45] the concept with Proportional Assist Ventilation (PAV) is to prevent fatiguing workloads while still allowing the patient to spontaneously breathe. To that end, current PAV modes take measurements throughout the I/E cycle and then automatically adjust the pressure, flow, and volume proportionally to offset the resistance and elastance of the system with each inspiration (patient and circuit). Recognizing that inspiratory effort is a reflection of ventilatory demand, PAV may provide a more physiologic breathing pattern. Different names for the modes are provided by specific manufacturers, and parameters that require adjustment vary somewhat between the ventilators.

Studies testing the effect of PAV on variables of interest have yielded mixed results. In a study of 12 patients with acute respiratory failure,[46] the authors sought to determine whether PAV would provide better compensation to an increased ventilatory demand than PSV. Results suggest that the effect of PAV alone, and of PAV with ATC, on cardiorespiratory function and inspiratory muscle unloading was not significantly different from that of PSV. In another study,[47] 14 ventilator-dependent patients were monitored on PSV and PAV. Despite some differences noted in breathing patterns between the modes, no difference was noted in gas exchange or other variables of interest. Reports of volunteers' subjective assessment of comfort on PAV and PSV[48] noted that although PAV was more comfortable, both modes were uncomfortable at high levels of support. And finally, in sleeping patients,[49] PAV was associated with fewer patient-ventilator asynchronies and arousals compared with PSV. Although it is tempting to draw conclusions about potential uses of PAV, especially as a weaning mode similar to PSV, an editorial on the topic[50] cautions that it should not be simply investigated as a weaning modality but also as a mode that may be used in sicker patients as well. They note that this mode, like others discussed previously, allows for more patient control and, ultimately, perhaps better outcomes in these patients. Studies are still required to help us determine the use of PAV in different populations.

Parameters

Proportional Pressure Support (PPS) (Dräger Medical, Richmond Hill, Ontario, Canada) includes PEEP, FIO_2, volume assist, and flow assist (eg, volume and flow assist are set in percentage [%]; if set at 80%, that is how much support will be provided during the breath). Proportional Assist Plus (PAV+) (Puritan Bennett, Boulder, Colorado) requires that a "% support" setting be adjusted (again the higher the level, the more the support).

What we know about pressure modes: the good, the bad, and the ugly

The new pressure modes of ventilation appear to be safe and as effective as conventional modes, although more studies are required in different populations and conditions before definitive recommendations can be made as to their use in practice. They are attractive for use for a number of reasons. The associated decelerating flow pattern is desirable, and the modes provide us with many different potential uses in a wide variety of conditions from the acute phase to the weaning phase. The microprocessor technology supporting the modes ensures faster flow responses and, subsequently, the ability of the patient to participate in breathing potentially without negatively affecting oxygenation, ventilation, and the work of breathing. In addition, this feature of patient participation, even with high levels of support, suggests that the application of at least some of the modes may obviate the need for heavy use of analgesics and sedatives, which we know compromise other outcomes such as ventilator duration and the intensive care unit and hospital lengths of stay.

To date, however, no studies demonstrate the superiority of the modes in any patient population. Most of the studies are not randomized controlled trials and suffer from the deficiencies of design, small sample size, and limited trial duration in selected categories of patients. And, although the modes do allow for much improved patient ventilator interaction, much has yet to be learned about the effect of the modes on work of breathing, especially during the acute phase of respiratory failure when unloading the respiratory muscles has traditionally been the goal to offset fatigue. Does a fatiguing pattern of breathing result in respiratory failure if the lung is optimally recruited and how best do we use the modes to recruit the lung? Studies are needed to help us determine such outcomes.

The sophistication of the new pressure modes and the profusion of the same, although commendable from a technology perspective, have provided us with a bit of a conundrum. Unfortunately, the mode names are often confusing, and the application is complicated in many cases. This is indeed an issue because such complicated use of names and parameters leads to increased variation in practice and the potential for error. As studies using protocols for sedation management and weaning trials have demonstrated, decreasing practice variation does improve outcomes.[24,25,51] It is also clear that the more complex the protocol the harder it is to attain compliance.[52,53] It is unlikely that decreased variation related to the use of the current new complex pressure modes will be easily accomplished. In the experience of this author, even the product user manuals are somewhat difficult to navigate. The modes are sophisticated and often require numerous parameter adjustments (ASV is an exception). Some modes are activated using settings that have names that are not descriptive of the actual mode but are necessary to activate selected characteristics of the mode (eg, PC-SIMV). This makes the education of clinicians a challenge and is often hard to accomplish in busy critical care units. Even more concerning is the reality that in many critical care units across the country, standardization of ventilators does not occur; instead, a potpourri of ventilators exists in the units, which means that clinicians must learn a wide variety of modes. Anecdotally, clinicians report that many of the modes available on ventilators today are not used; perhaps this is due to the learning curve that may be quite steep.

Do we need these "better" modes to be so complex? Is "better" really "better"? Much like respiratory waveforms and other digital displays available on ventilators today, the new pressure modes potentially could be used to improve the care we provide. Many are elegant and have been designed to correct problems identified by clinicians in the past (flow response time, etc). But, often they are understood by only a handful of clinicians; too often, the bedside nurse is the least informed and relies on the understanding of the physician or respiratory therapist. This is unfortunate and much like a pilot flying without a copilot; it is a mistake waiting to happen. Until the modes are better understood and easier to apply by all clinicians who care for the patients, we may not be doing our patients a service by using them. Simple may indeed be better.

As we consider the requirements necessary to care for patients during a mass casualty or disaster event, one of the major requirements of ventilators and other equipment is that they are easy to use by professionals with a minimum amount of training. Certainly, the automatic external defibrillator is an example of one such technology that years ago was unthinkable. From the perspective of this author, clinicians should advocate for ventilator technology that is safe and user-friendly and requires little clinician decision making and interaction (basically adapts ventilation to the requirements of the patient). The idea of "intelligent ventilation" as promoted with ASV is indeed attractive and to be encouraged.

For clinicians like APNs who must order the modes, it is important that the approach to the same be one that is logical and safe. The first step is to decide on the goal of ventilation. If it is lung protection, then the science related to lung protection dictates that V_T be controlled and that attention to lung recruitment with PEEP be ensured. The mode of ventilation to attain the goal should be one that the practitioner understands so that the parameters are selected appropriately and the patient is monitored to ensure the attainment of the goal. In weaning patients, spontaneous breathing trials are well tested and generally can be accomplished with CPAP, T-piece, and/or PSV. These methods are readily understood and require little in the way of complicated parameter setting. Understanding the available modes on specific ventilators in one's work setting is essential if we are to provide quality safe care.

Summary

Many new pressure modes exist on ventilators today; however, little evidence exists as to their efficacy or superiority. Until additional studies are done testing the modes in a wide variety of patient populations and conditions, recommendations for the best use of the modes will be difficult to make. Inherent issues related to the modes continue to be the complexity of the modes and the profusion of names that make understanding and application difficult. When all is said and done, simple and familiar may indeed be better.

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