Should Adaptive Pressure Control Modes Be Utilized for Virtually All Patients Receiving Mechanical Ventilation?

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Traditional mechanical ventilation is provided with either a constant volume or constant pressure breath. In recent years, dual-control (adaptive pressure control) has been introduced in an attempt to combine the attributes of volume ventilation (constant tidal volume and minute ventilation) with the attributes of pressure ventilation (rapid, variable flow and reduced work of breathing). Adaptive pressure control is a pressure-controlled breath that utilizes closed-loop control of the pressure setting to maintain a minimum delivered tidal volume. Prior to the introduction of adaptive pressure control, no clinical studies were accomplished. Studies have shown that adaptive pressure control reduces peak inspiratory pressure, compared to volume control. When compared to traditional pressure-control ventilation, no differences have been identified. While adaptive pressure control can guarantee a minimum tidal volume, it cannot guarantee a constant tidal volume. One concern is that the ventilator cannot distinguish between improved pulmonary compliance and increased patient effort. Clinicians should be aware of the limitations of adaptive pressure control and understand when other breath delivery techniques are more suitable. *Key words: acute lung injury, acute respiratory distress syndrome, pressure control ventilation, volume control ventilation, dual*

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Introduction

Conventional mechanical ventilation is commonly accomplished using either a constant-volume or constant-pressure breath.[1] Pressure-controlled or volume-controlled breaths can be delivered in a continuous mandatory ventilation (CMV), an intermittent mandatory ventilation (IMV), or a continuous spontaneous ventilation (CSV) mode. Volume-controlled breaths are delivered using a flow set by the clinician and an inspiratory flow waveform (commonly rectangular) determined by the ventilator. Delivered tidal volume (V_T) is constant as long as no alarm settings are violated. Airway pressure is variable, based on patient effort, respiratory-system compliance, and airways resistance.

Pressure-controlled breaths are delivered using as much flow as needed to achieve the preset pressure limit. For a passive inspiration, the flow waveform is an exponential decay, and peak flow depends on respiratory-system compliance and resistance. For an active inspiration, flow is highly irregular, depending on the patient's inspiratory effort. Airway pressure is constant, and delivered V_T is a function of patient effort, respiratory-system compliance, and airways resistance.

A comparison of volume-controlled and pressure-controlled breaths is outside the realm of this debate, but this issue has been addressed elsewhere.[2] However, it is important to summarize the differences, to understand the genesis of a new type of "self-adjusting" breath control that attempts to achieve the best features of volume and pressure control. Volume control allows a guarantee of V_T and minute volume, which can be particularly helpful in a patient with varying pulmonary compliance, hypercarbia,

and in implementing lung-protective ventilation. The fixed flow of volume control, however, can lead to flow asynchrony and excessive work of breathing (WOB). Pressure control limits the maximum airway pressure experienced by the lung while reducing WOB, as a virtue of the variable flow and volume waveform, so pressure control might reduce ventilator-induced lung injury, reduce WOB, and enhance patient-ventilator synchrony in the active patient. However, during pressure-control ventilation (PCV) the V_T is variable and both hyperventilation and hypoventilation are possible. Adaptive pressure control is a means to assure patient-ventilator synchrony by allowing as much flow as the patient demands while also attempting to guarantee a minimum V_T.[3,4]

Definition

During adaptive pressure control, inspiration is machine-triggered or patient-triggered, pressure-limited, and machine-cycled or patient-cycled. The breathing pattern can be CMV, IMV, or CSV. The unique aspect of adaptive pressure control is that the pressure limit is not constant, but varies from one breath to the next, based on a comparison of the set and delivered inspiratory V_T. The logic for controlling the output of the current breath based on the previous breath has led this technique to be called "dual-control breath-to-breath."[4–10] It is important to remember that the ventilator can only control pressure or volume during a breath, not both. So adaptive pressure control is a pressure-controlled inspiration with a volume target (ie, it is called a target because, unlike volume control, the V_T may be higher or lower than planned, in which case an alert may be activated). Adaptive pressure control is provided by a number of ventilators, under a variety of names (Table 1).

Though there are some subtle differences in the algorithms that control these techniques, their operation is fairly similar. Upon selecting a mode with adaptive pressure control, the ventilator provides a test breath. This test breath can be at a constant pressure or volume. The test breath allows the total respiratory-system compliance to be measured. The algorithm can then calculate the pressure required to deliver the V_T set by the clinician. The ventilator may initially deliver 75–100% of the calculated pressure. The V_T leaving the ventilator is then compared to the set V_T, and the pressure on the subsequent breath is either held constant (if the set V_T is met) or adjusted (decreased if the delivered V_T is greater than the set V_T, increased if the delivered V_T is

Table 1. Commercial names for Modes That Use Adaptive Control

Ventilator	Adaptive Control Mode
Dräger Evita 4 and XL	AutoFlow
Hamilton Galileo	Adaptive Pressure Ventilation
	Adaptive Support Ventilation*
Maquette Servo-*i*	Pressure Regulated Volume Control
	Volume Support
Puritan Bennett 840	Volume Control +
Newport E500	Volume Target Pressure Control
Viasys/Pulmonetics PalmTop Ventilator	Pressure Regulated Volume Control
Viasys Avea	Pressure Regulated Volume Control

*Adaptive support ventilation uses optimal control, an advanced form of adaptive control.
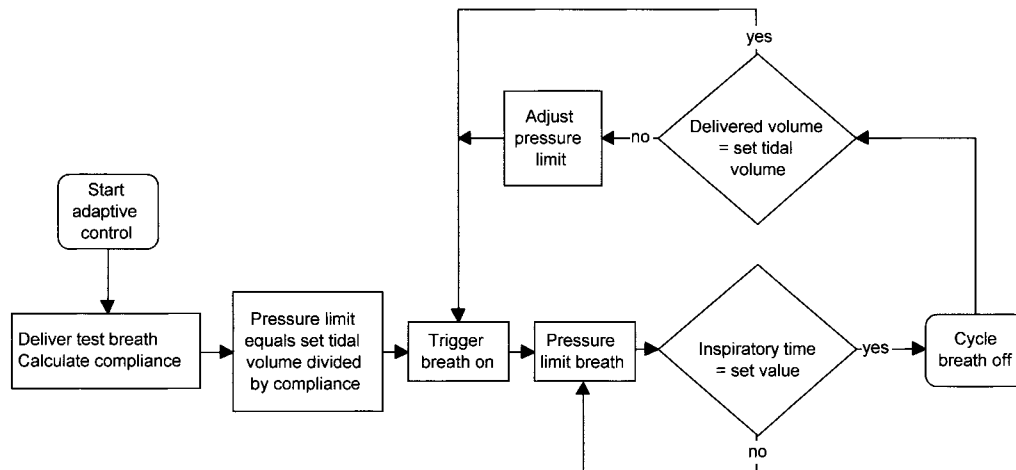
Fig. 1. Operational algorithm for AutoFlow (adaptive pressure control) on the Dräger Evita 4 ventilator.

less than the set V_T). Most ventilators limit the maximum change (from one breath to the next) to 3 cm H_2O. The minimum inspiratory pressure is typically positive end-expiratory pressure (PEEP) plus 5 cm H_2O, and the peak inspiratory pressure (PIP) is the high-pressure alarm setting minus 5 cm H_2O. If the set V_T cannot be delivered because of the high-pressure setting, an alert is generated. This alert typically provides a message such as "volume not constant" or "check pressure limit," so the clinician is aware that the desired V_T is not being delivered. Figure 1 illustrates the operational algorithm typically used during adaptive control.

Figure 2 shows the routine used by the Dräger Evita 4 to initiate adaptive control, with a feature Dräger calls AutoFlow. The ventilator initially uses conventional PCV. When AutoFlow is selected, the ventilator switches to volume control with a constant inspiratory flow. On subsequent breaths the ventilator switches to adaptive pressure control and the pressure limit is either increased or decreased to maintain the preset target V_T.

Volume Control Versus Pressure Control Versus Adaptive Pressure Control

While volume control provides a constant volume and variable airway pressure, and pressure control provides a constant airway pressure and variable V_T, the goal of adaptive pressure control is to provide a constant V_T by automatic adjustment of the pressure limit. So, while adaptive pressure control was designed to combine the positive attributes of both volume and pressure control, the response to changes in patient condition can result in a variable response with each breath type. As discussed earlier, adaptive pressure control cannot guarantee a set V_T if the patient's respiratory-sys-

tem compliance is low enough and the high-pressure alarm is set too low. Similarly, adaptive pressure control cannot limit the inspired V_T beyond reducing the peak airway pressure. If the patient can generate an inspiratory pressure great enough, the delivered V_T may be greater than the set V_T. On the other hand, if the patient makes no effort at all and the ventilator is set properly, the volume will not be less than the desired volume. Table 2 lists characteristics of the 3 breath types and the response to common clinical conditions.

Literature Review

There have been no randomized controlled trials with large numbers of patients to study modes that use adaptive pressure control. In fact, the literature remains sparse with regard to the utility of this control scheme, although the same can be said for many newer ventilator techniques and modes. This review then will concentrate on the findings of smaller trials and case series.

Piotrowski et al compared pressure-regulated volume control (PRVC, ie, adaptive pressure-controlled CMV) on a Siemens Servo 300 ventilator to volume-controlled IMV in 60 neonates with respiratory distress syndrome, using a randomized prospective design.[11] Thirty patients received IMV and 27 received PRVC. All patients suffered from either respiratory distress syndrome or congenital pneumonia, and weighed < 2,500 g. The main outcome variables were duration of mechanical ventilation and incidence of bronchopulmonary dysplasia. Secondary outcomes were complications, including the incidence of air leaks, intraventricular hemorrhage, and hemodynamic instability. There were no significant differences in the main outcome variables, but there was a lower incidence of intraventricular hemorrhage grade II and greater in the PRVC group. During data mining they found that in the
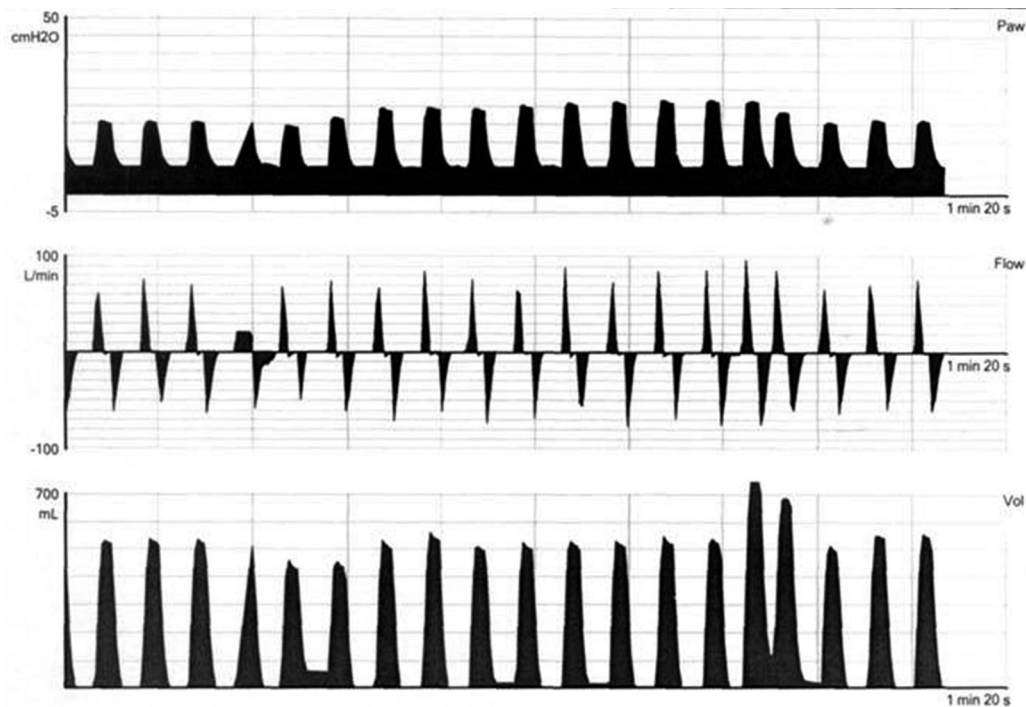
Fig. 2. Waveforms from the implementation of AutoFlow on the Dräger Evita 4 ventilator. The first 3 breaths are plain pressure-controlled breaths. AutoFlow is initiated and a test breath is delivered using volume control at a constant flow. Successive breaths use adaptive pressure control to increase airway pressure until the target tidal volume (V_T) is reached (550 mL). When compliance increases, V_T exceeds the target and the airway pressure is reduced over 3 breaths until V_T reaches the target.

Table 2. Characteristics of Volume Control, Pressure Control, and Adaptive Control Breaths and Response to Common Clinical Conditions

	Volume Control	Pressure Control	Adaptive Control
Tidal volume	Constant	Variable	Variable
Peak inspiratory pressure	Variable	Constant	Variable
Peak inspiratory flow	Constant	Variable	Variable
Flow waveform	Constant	Variable	Variable

Response to Common Clinical Conditions

	Volume Control		Pressure Control		Adaptive Control	
	P_{aw}	V_T	P_{aw}	V_T	P_{aw}	V_T
Decreased compliance	Increase	Constant	Constant	Decrease	Increase	Constant
Increased compliance	Decrease	Constant	Constant	Increase	Decrease	Constant
Increased patient effort	Decrease	Constant	Constant	Increase	Decrease	Constant or greater than set
AutoPEEP	Increase	Constant	Constant	Decrease	Increase	Constant

P_{aw} = airway pressure
V_T = tidal volume
autoPEEP = intrinsic positive airway pressure

infants who weighed < 1,000 g the duration of ventilation was shorter and the incidence of hypotension was lower with PRVC. This post-hoc analysis included only 10 patients in each group.

Alvarez et al compared volume-controlled ventilation (VCV), pressure-limited time-cycled ventilation, and PRVC in 10 adult patients with acute respiratory failure, and reported that PRVC resulted in a lower peak airway pressure and a slight improvement in carbon dioxide elimination, compared to VCV.[12] The patients received VCV with a constant-inspiratory-flow waveform, PCV, and PRVC, for 1 hour each. Not surprisingly, the PIP was

highest with the constant-flow waveform and there were no differences between PCV and PRVC.

Kesecioglu et al compared VCV and PRVC in a pig model of ARDS, in a series of publications.[13–15] These animal studies utilized short observational periods following saline-lavage-induced ARDS. The main findings were reduced airway pressure and small improvements in gas exchange with PRVC, compared to VCV with a constant inspiratory flow. In each of these studies, PRVC was delivered using an inverse inspiratory-expiratory ratio.

Guldager et al compared VCV with a constant flow to PRVC in a prospective, open, crossover trial of 44 patients with acute respiratory failure.[16] Patients were evaluated during an 8-hour stabilization period and then randomized to one mode or the other. After 2 hours, measurements were obtained and the patient was switched to the other mode for 2 hours. At the end of this second 2-hour period, measurements were obtained and the patient was returned to the initial ventilation mode for the duration of ventilatory support. During the short-term observations, blood gases, airway pressure, and mean arterial pressure were recorded. Long-term observations included duration of mechanical ventilation, days with a PIP > 50 cm H_2O, and survival. During ventilation with either mode, V_T was set at 5–8 mL/kg and the inspiratory-expiratory ratio was 1:3. PIP was significantly lower with PRVC (24 cm H_2O vs 20 cm H_2O), but plateau pressure was not recorded. All other short-term observational variables were not clinically or statistically different. Survival and duration of ventilation were similar. Two patients in the VCV group had a PIP > 50 cm H_2O, compared to no patients in the PRVC group. That difference was not statistically significant, nor is it surprising, since pressure can be limited during PRVC.

Kocis et al compared PRVC to VCV in infants after surgery for congenital heart disease.[17] Nine patients were studied after repair of either tetralogy of Fallot or atrioventricular septal defects. Patients were initially stabilized using VCV for 30 min. At the end of this period, blood gas values and hemodynamic and ventilation variables were recorded. Patients were then placed on PRVC for 30 min and had the same data collected. This was followed by a second period of VCV. The only statistically significant change in any of the measured variables was a PIP decrease of 19% during PRVC (from 31 cm H_2O to 25 cm H_2O). As in other studies, plateau pressures were not recorded.

Jaber et al recently evaluated volume support (ie, adaptive pressure-controlled CSV) on the Siemens Servo 300 ventilator and pressure support during an increase in ventilatory demand.[18] They added dead space to the ventilator circuit to cause rebreathing and to stimulate ventilatory drive. This was not done using volume support, but the mechanisms would be very similar. With volume support, rebreathing increased WOB and pressure-time product. During volume support the increases in WOB and pressure-time product were 2.5–4 times greater than during pressure support. The increase in patient effort resulted in a 6-cm H_2O pressure decrease during volume support (from 15 cm H_2O to 9 cm H_2O). In 2 patients, this resulted in "overt respiratory distress," according to the authors.

Kallet et al compared VCV, PCV, and PRVC during implementation of a low-V_T strategy, to determine changes in WOB.[19] Though the pressure-controlled breaths reduced the WOB, this was achieved by delivering a larger V_T, which exceeded the 6-mL/kg goal. When the pressure was reduced to achieve the V_T target, WOB was actually higher with the pressure-controlled breaths. This study prompts some important questions regarding the choice of V_T and whether a higher V_T at a low plateau pressure is safe. It also demonstrates the difficulty in comparing breath-delivery techniques in an actively breathing patient population. It is possible that the variable V_T during PCV and the ability to exceed 6 mL/kg when airway pressure is < 25 cm H_2O might reduce the WOB while still providing lung protection.

The support for the use of adaptive pressure control confirms that PIP is lower than in VCV with a constant-flow waveform. Studies have failed to show any advantage in reducing the duration of ventilation, reducing complications, improving survival, or improving patient-ventilator synchrony. The total number of patients studied remains small (133), and half of those were neonates, and over a quarter of those were patients without lung disease. The comparison of adaptive pressure control to VCV with a constant-flow waveform and demonstration of a lower PIP is easily explained and predictable. The use of adaptive pressure control is quite popular for a number of reasons. However, similar effects can be accomplished with traditional PCV or VCV with a descending-ramp flow waveform.[20]

Pro: Adaptive Pressure Control Should Be Used With Virtually All Mechanically Ventilated Patients

The function and attributes of adaptive pressure control suggest a number of potential advantages, compared to both volume control and conventional PCV, including lower airway pressure, better patient-ventilator synchrony, eliminating the flow asynchrony seen with VCV, reducing the number of ventilator manipulations required by the clinician, and automatic weaning or escalation of ventilatory support to meet patient demand. These will be considered separately.

Lower Airway Pressure

The function of adaptive pressure control is such that the peak airway pressure provided is the lowest possible pressure to maintain the desired V_T. These adjustments are made on a breath-to-breath basis, without the need for clinician intervention. In essence, it is as if the ventilator is attended by a respiratory therapist, constantly manipulating airway pressure to assure the desired V_T. This method of breath-delivery matches nicely with the goals of the ARDS Network trial that found that lower V_T along with lower plateau pressure is associated with better outcomes.[21]

Better Patient-Ventilator Synchrony

During VCV the WOB is influenced by both patient and ventilator characteristics. The major determinants of WOB during VCV are the trigger setting, the V_T, and the inspiratory flow.[22–25] Adaptive control allows the ventilator to alter both the V_T and the flow to meet patient demand, and guarantees a minimum delivered V_T, which is a feature not available with PCV. During VCV the flow and V_T are fixed at arbitrary values, and an increase in patient demand is associated with an increase in the WOB and worsening of patient-ventilator interaction.

Less Clinician Intervention and Automated Weaning

Over the past decade the number of patients admitted to intensive care units (ICUs) and the severity of illness of those patient seem to have both increased markedly. With these increases there has also been a shortage of ICU staff. One potential answer to this problem is the use of smart ventilators or closed-loop ventilation.[4–10] Several papers have suggested that with adaptive pressure control there are fewer alarms (high-pressure alarms are eliminated) and fewer manipulations of the ventilator than with conventional ventilation. This was recently confirmed in a study by Lellouche et al.[26] With a pressure-limited, flow-cycled breath that is controlled by the current V_T, respiratory frequency, and end-tidal carbon dioxide, they found less clinician intervention and faster weaning than with physician-directed weaning.

Con: Adaptive Pressure Control Modes Should Not Be Used With All Mechanically Ventilated Patients

The con argument is not based on an extensive review of the literature that supports or refutes the notion that adaptive pressure control is the most appropriate ventilation mode for all patients. There has never been a study that supplied clear evidence that any mode is superior to any other mode for all patients. And there will probably never be such irrefutable evidence, simply because the

ventilation mode is not all that influential a factor, compared to the vast array of factors that affect morbidity and mortality in the ICU. The signal-to-noise ratio may be just too small to discern in a practical manner. In fact, the notion of treating a critically ill patient with a single invariant mode may become extinct as ventilators are programmed with ever more powerful means to continuously (and automatically) adjust ventilator output.[27,28]

Lower Airway Pressure

The marketing literature for adaptive pressure control modes suggests that the peak airway pressure provided is the lowest possible pressure to maintain the desired V_T. However, this is a red herring. The risk of volutrauma is related to the transalveolar pressure (or static transpulmonary pressure), which is purely a function of the V_T and lung compliance. Thus, the fact that a pressure-controlled breath reduces peak inspiratory pressure (at the airway opening) compared to a volume-controlled breath is irrelevant. For the same V_T, both pressure-controlled and volume-controlled breaths generate the same transalveolar pressure and thus presumably the same risk for lung damage. The fact remains that (1) there is evidence to suggest that a lower V_T is safer than a higher V_T and (2) any form of pressure control, adaptive or not, cannot guard against unanticipated and possibly unsafe V_T in the face of active inspiration. There is no evidence to suggest that the lack of precision in V_T control with adaptive pressure control results in comparable or better safety than traditional volume control.

Better Patient-Ventilator Synchrony

Better patient-ventilator synchrony is not guaranteed with adaptive pressure control, because this control type still requires a human decision about the target V_T. If the volume is inappropriate and the alarm threshold is set very low, the patient inspiratory demand may not be met. At that point, the clinician must make a choice between tolerating asynchrony and tolerating the risk of volutrauma. Given the survival benefit of lung-protective ventilation strategies, lung protection should remain the priority and should not be abandoned for fear of patient-ventilator asynchrony.[29]

Less Clinician Intervention and Automated Weaning

The concept that adaptive pressure control automates weaning applies only to the scenario in which the work of breathing is appropriately shifted from the ventilator to the patient as the patient's ability to breathe spontaneously improves. But, as pointed out above, adaptive control cannot distinguish improving lung mechanics from a deranged

ventilatory demand. Thus, weaning time may actually be prolonged if the patient's increased demand is due to anxiety, fever, or other factors not indicative of progress, because the ventilator may decrease support enough to exacerbate the underlying problem.

Adaptive pressure control is perhaps a step in the right direction of improving the quality of the patient-ventilator interaction while decreasing the human workload. However, though modes that use this strategy are a step above tactical control (ie, that require the operator to select and adjust all ventilator output set points), they are still a step below intelligent control (ie, those that allow the ventilator to mimic human decision making).[4] Thus, one could argue that adaptive pressure control is not even theoretically the best approach for all patients in terms of reducing clinician intervention.

Summary

In some ways we are as confused as ever, but we believe we are confused on a higher level and about more important things.

—A.R. Feinstein MD
unpublished paper
University of Miami, Florida, 1976

Adaptive pressure control is clearly an advance in the evolution of ventilator design. Any clinician who breathes on adaptive pressure control versus volume control is likely to be convinced that the former provides better comfort. If comfort was the only goal, then adaptive pressure control would arguably be the best mode for all patients receiving mechanical ventilation. Unfortunately, in ventilated patients many goals compete, and the way to optimize all variables associated with the ventilator is far from view. More experience and study is required before we can even begin to suggest that one mode is best above all others. And perhaps the idea of a discrete "mode" comparable to some other mode will become obsolete as ventilators become more sophisticated at anticipating and meeting the changing needs of patients with respiratory failure.

Adaptive pressure control is but another step in the continuing evolution of mechanical ventilation. Its only clear advantages seem to be:

- More stable gas exchange than conventional pressure-controlled ventilation

- Better patient-ventilator synchrony than conventional VCV

- Probably less human time spent at the bedside making sure the ventilator is meeting the patient's needs

Nevertheless, adaptive pressure control is only a strategic control algorithm, meaning that it still requires an arbitrary

clinician-selected V_T set point. And no matter how skilled the human may be at assessing the patient's needs (V_T, PEEP, fraction of inspired oxygen, etc), there simply is no way to provide that skill continuously 24 hours a day. Thus, we may expect continued evolution toward more automation in the service of increased clinical and technical benefit, at reduced cost. Yet every step of the way, the industry will need knowledgeable and attentive clinicians to provide critique and scientific examination of new developments.

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Discussion

MacIntyre: Rich, I'm going to be a "splitter" here. It seems to me the argument for pressure-assist control or pressure control dual-control, where you target V_T around 6 mL/kg, makes a lot of sense. If we're worried about fluctuating V_T, this may be a solution to that issue. Having said that, I get far more confused in the so-called "weaning" application of this dual-control, where I don't know what the V_T ought to be. I've seen this happen on more than one occasion, where people have tried to use volume support to wean. They pick a V_T that is more than the patient really wants, and as a consequence the pressure never goes down, because the machine is always trying to push in a larger V_T. PRVC at least makes some sense to me, because I think I know what the V_T should be, but volume support makes less sense because I don't know what the V_T should be. Does that make sense?

Branson: They are 2 different modes used in 2 different ways. One's flow-cycled and one's time-cycled. Clearly, there's no evidence that volume support facilitates weaning. Sometimes I think about this and mechanical ventilation seems so simple. When you set the V_T, you set a high peak pressure alarm on it. If you're going to use pressure-control or PRVC, you just need to set a high V_T limit and make sure that you're alerted of it.

Dr Hurford and I have been discussing that at our own hospital. They put everybody on AutoFlow, and it's not unusual for a patient to be on IMV with AutoFlow and a set V_T of 500 mL, and the pressure of the AutoFlow breaths is 15 cm H_2O, and the pressure of the pressure support breaths is 20 cm H_2O! That's because the patient's out of synch with the ventilator and working so hard that the ventilator doesn't recognize that for what it is. It recognizes it as improved compliance. And that's the problem.

You can kill a lung with pressure control. You can kill a lung with volume control. You can inadequately ventilate the patient with pressure control or volume control or PRVC. It's who's choosing the settings that matters. Unfortunately, people have pushed the ventilator and the mode, as opposed to the understanding, which is the important part.

I like adaptive support ventilation because it takes many inputs. Adaptive support ventilation is based on Otis's least-work-of-breathing concept.[1] But the only time it applies any of that is when the patient's not breathing. So when the ventilator is delivering all mandatory breaths, the ventilator changes the peak pressure, the inspiratory time, and the inspiratory-expiratory ratio, but as soon as the patient starts breathing, it is just volume support. Pressure support goes up and down. And that's all SmartCare is—closed-loop pressure support. The ventilator is giving pressure support; it's just that the pressure support is changing, based on various inputs. And I'm not sure that's the answer, either.

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Cheifetz: More important than the nuances of individual modes is how you use the modes. For years most of our patients were ventilated with PRVC; then we switched ventilators for our entire unit and the new venti-

lator allowed us to use PRVC for pediatric and adult circuits but not neonatal circuits. Our staff thought it would be a shock to our unit that we could no longer use PRVC for our infants, but there was no change in duration of ventilation, patient outcomes, or sedation. Within just a few days, practice adapted to the new mode. Having a dual-regulated mode did not really matter at all. How you use the available modes is more important than what modes you have available. No randomized controlled trial has ever clearly shown that one conventional ventilation mode leads to better outcomes than another mode.

Chatburn: One thing that people seem to always ignore in talking about what's good, is the cost. As you just pointed out, maybe you didn't have any differences in duration of stay or morbidity or mortality, but I bet you had a difference in the amount of time at the bedside.[1] If the ventilator is making these adjustments, then a human doesn't have to do it, and labor cost is a big issue, particularly in this environment, when there's a severe labor shortage in respiratory care. And, of course, if the intelligence built into the machine shortens the duration of ventilation and ICU stay, the cost advantage is obvious.

1. Linton DM, Renov G, Lafair J, Vasiliev L, Friedman G. Adaptive support ventilation as the sole mode of ventilatory support in chronically ventilated patients. Crit Care Resusc 2006;8(1):11–14.

Cheifetz: That is a great theoretical point. Maybe it is taking less time per respiratory therapist per ventilator, but we need to consider this in a more global sense. Before and after our change, we still had 2 respiratory therapists in our unit every shift. So staffing was not affected, as we did not have any change from 2 therapists per shift. We didn't need more therapists when we decreased our use of PRVC, and if we started using PRVC again we would not be able to have just one

therapist per shift. Any potential time saving per ventilator was clearly not important from a global staffing point of view.

Branson: Yes, we have to be careful in assessing potential savings in staff time, because the only way to save money in staff time is to get rid of a respiratory therapist. I think the ventilator can make quicker modifications to meet patient demand, but that may actually require more respiratory therapists to monitor it—not necessarily less. I don't see the therapists spending a lot of time at the bedside making changes on the ventilator. The difference is that with dual-control the ventilator changes to meet the patient's condition; in regular control it doesn't do anything. And we don't do anything, either.

Kallet: One of the things that should be pointed out about the Dräger Auto-Flow function is the active expiratory valve. One of the traditional problems is the therapist being preoccupied with a patient who just can't get in synch with the ventilator on a breath-by-breath basis unless they're completely snowed. But if you have a ventilator mode with an automatic active expiratory valve, the patient can't pop off the ventilator quite as easily when they get out of synch. So I think one advantage of this mode is that it frees up the therapist from constantly having to return to the patient's bedside when they don't need to be there. There's also the advantage of reduced expiratory workload for the patient and perhaps less sedation required.

One of the disadvantages, I think, is that you can't predict how individual patients are going to react. If you take a surgical patient who requires short-term ventilation and doesn't have important gas-exchange abnormalities, you can use AutoFlow to wean, because as the peak airway pressure comes down, they're ready, and they don't need the support. However, in someone with severe ARDS, in

whom you're trying to control V_T, and they require 20 cm H_2O of mean airway pressure to support their oxygenation, you limit their V_T and they become asynchronous with the ventilator because they want more volume. When they inevitably exhale against the circuit but can't pop off the ventilator's high-pressure alarm, then the first alarm that tends to go off is the S_{pO_2} [oxygen saturation measured via oximetry] alarm. We've occasionally had this problem, particularly if people aren't paying careful attention. Now with the new SmartCare by Dräger, it gets even more complicated. What I was told is there are 13 different scenarios, or algorithms, involved with his mode. Is that correct?

Chatburn: You have to search way back in the literature. They've been studying this for about 10 years, and they never explicitly say what the expert system is doing in terms of explicit algorithms. It's probably proprietary, and goes way back to a program they used to call NeoGanesh.[1] So, yeah, there are a lot of rules based in there. Interestingly, Ganesh is the elephant-headed Hindu God of categories, wisdom, and good fortune.

1. Dojat M, Pachet F, Guessoum Z, Touchard D, Harf A, Brochard L. NeoGanesh: a working system for the automated control of assisted ventilation in ICUs. Artif Intell Med 1997;11(2):97–117.

Kallet: My response when this was pitched to us about a month ago is that before we put this on a patient, the therapists are going to have to know what each of those 13 algorithms are, to be safe.

Chatburn: You can forget that!

Kallet: Yeah!

Hess: I'd like to try to reconcile something that Rich Branson said in response to something Neil MacIntyre said earlier. When Dave Pierson brought up the question about main-

taining a constant V_T during pressure-control, I think I heard Neil say that it's no problem: pressure control—we do it all the time; maintains constant V_T of 6 mL/kg. Rich just showed that the V_T on dual-control, which is pressure-control, for all intents and purposes, varies by 200 mL, breath-to-breath. For patients I take care of on 6 mL/kg predicted body weight, 200 mL V_T fluctuations could be from 6 mL/kg to 9 or 10 mL/kg.

MacIntyre: Are you arguing for or against PRVC?

Hess: I would be arguing against it. I'm curious as to how it is you can keep the V_T constant on pressure control, and Rich cannot?

MacIntyre: The argument for PRVC is that you *will* have a more constant V_T.

Branson: If you're listening to the manufacturers; but everybody has a marketing strategy. PRVC supposedly guarantees V_T and pressure control, but it's actually only a guaranteed *minimum* V_T and pressure control. I see patients who inhale 100% more than the set V_T during PRVC, especially in the neurologic ICU. You lose control of V_T during dual-control. We'd have to ask the question, if a patient breathes in on his own and draws in 12 mL/kg, is that bad? Or is that OK?

Hess: Another way of asking the question is, can patients breathe themselves into ventilator-induced lung injury?

MacIntyre: Sometimes a patient wants to pull in a huge V_T. My philosophy is, don't make it worse by supplying them with unnecessary pressure. But one of the beauties of pressure-control versus PRVC is with the patient who gets stiff, or has an airway occlusion, or a bronchus gets plugged. Pressure-control under those conditions won't let the peak pressure

rise, whereas PRVC will defeat this by elevating pressure. We've been criticizing pressure control for being something that might encourage excessive V_T, but the flip side is also true. It may protect the patient when regional lung mechanics are worsening.

I want to go back to the subject of weaning. The idea that we can automatically wean people sounds attractive, but the whole idea of knob-twirling during the weaning process might be unnecessary and a waste of time. Indeed, when a patient is ready to come off the ventilator, they are going to pass a spontaneous breathing trial and be extubated. If they fail the spontaneous breathing trial, just leave them alone. No data I'm aware of indicate that decreasing the pressure support facilitates weaning. It may actually drag out the weaning process. We should do spontaneous breathing trials at least daily in patients who pass the screening criteria for the trial. And then the whole idea of automatic weaning with volume support becomes unnecessary.

Chatburn: Believe it or not, that's what SmartCare does. It'll do spontaneous breathing trials on its own. Lellouche et al[1] found that SmartCare decreased weaning duration from 5 days to 3 days, decreased the total duration of ventilation from 12 days to 7.5 days, and decreased median ICU duration from 15.5 days to 12 days, compared to physician-controlled weaning using written practice guidelines.

1. Lellouche F, Mancebo J, Jolliet P, Roeseler J, Schortgen F, Dojat M, et al. A multicenter randomized trial of computer-driven protocolized weaning from mechanical ventilation. Am J Respir Crit Care Med 2006; 174(8):894–900.

MacIntyre: Compared to daily spontaneous breathing trials?

Deem: Actually, they had a protocol. It was basically protocolized humans versus the protocolized ventilator. And the time reduction with the

ventilator was substantial—much better than in any of the other so-called protocol trials.

Branson: What SmartCare does, though, is take end-tidal CO_2, V_T, and the respiratory rate, but all it does is adjust the pressure support. And what happens is that if the pressure support goes down to 9 cm H_2O pressure and stays there for 2 hours (depending on which technique you use), a little sign comes up that says "Consider a spontaneous breathing trial on this patient." The fully automated version just does the trial and tells you if the patient passed it.

Chatburn: Yes, but that is "all a human does" too. And the computer does not just suggest, as with some computer-driven "decision-support" systems; it actually makes the changes on its own. Indeed, the computer made an average of 56 pressure-support changes per 24 hours, compared to only 1 per 24 hours in the physician-controlled group. Furthermore, patients spent 93% of the time in the "comfort zone" when the computer was in control, compared to 66% when humans were in control.

Branson: I agree, Neil, that we've spent a lot of time weaning patients who don't need to be weaned, and fatiguing them in the process, when we're not careful and we're not paying attention. I tend to be enthralled with new technology, but when you get down to the basic question, what is SmartCare, it's pressure support in which the pressure goes up and down. It's just not that different. And I don't see how it's any better than volume support, necessarily, except that there are more inputs changing the pressure, not just V_T alone.

Chatburn: That's a big "just"— that's everything! That's the difference between someone coming to the bedside and periodically adjusting the target V_T and the intelligence being built

into the machine to decide the target itself, 24 hours a day. Volume support is strategic control, which is a step above tactical control but a step below intelligent control, where Smart-Care lives.[1]

1. Chatburn RL. Classification of ventilator modes: update and proposal for implementation. Respir Care 2007;52(3):301-323.

MacIntyre: I'm telling you, you don't need to stand by the bedside or have an automatic machine. You just leave them alone and do your spontaneous breathing trials at 8:00 every morning.

Chatburn: You might be right.

MacIntyre: Of course.

Chatburn: Rich, you said that we have to be careful, because if we decrease the clinician work at the bedside, then you have to lay somebody off. I think a lot of managers today would tell you that that's not the case. They would simply no longer struggle to fill some of their many vacancies.

Branson: I know there aren't enough therapists or nurses, but the point remains; I just don't think that having the ventilator doing things automatically is going to reduce the need for respiratory therapists. It might actually increase the need to monitor what is happening. I don't see us laying off therapists, nurses, or doctors if the ventilator does more or even weans automatically. It's just not practical.

Cheifetz: I agree with Rich Branson. You only can improve staffing efficiency if your ventilator is able to do *so much work* (ie, improve efficiency to such a degree) that you can actually eliminate an employee—not shorten someone's day by 30 minutes—because you still need the same number of therapists

per shift. It would have to be a dramatic improvement in ventilator management efficiency, or a dramatic decrease in the need for staffing, to make a real difference.

Kallet: As modes become more automated and closed-loop ventilation shuts the clinician outside of the loop, what happens with the first big malpractice case, where someone dies on some fully-automated mode and we can't explain what happened or how to intervene? You can't keep the clinician out of the loop. If we're going to use these things, we have to fully understand what these modes do under a wide array of circumstances we might not be able to predict. We have to be the people who safeguard this.

And that was one of the first things we saw with AutoFlow. We started doing some work-of-breathing lung modeling on it, and we saw weird stuff begin to happen when the V_T demand exceeded the pre-set target. At first we didn't know what was going on, and we sure were not going to use it on a patient until we figured it out. But when you start adding in ventilator algorithms that include work of breathing, compliance, and P_{CO_2}, at some point it just becomes ludicrous. And I think there is a real ethical issue here for us as the professionals of mechanical ventilation, if we have people on modes that we don't fully understand and know exactly what's going on between the patient and the ventilator.

Branson: At ventilator conferences, invariably somebody who's head of an ICU somewhere says, "Explain to me one more time the difference between CPAP and pressure support"! So the situation you just described is happening now: people don't understand what they're doing. But if you believe that protocols work, then you can put any protocol inside a com-

puter and have it work. Why can't we just have the ventilator measure the oxygen saturation and automatically climb the ARDS Network PEEP-F_{IO_2} [fraction of inspired oxygen] table? What's the big deal? From an engineering perspective, that's very easy. Dr Hurford did a lot of work about weaning and cardiac function, so that's the problem, as Dean Hess pointed out. If you're in the middle of a spontaneous breathing trial that the ventilator decided to do, and the patient has left-ventricular failure and his oxygen consumption is going up, the ventilator may suggest extubating at a time when cardiac function is poor.

So I don't think we'll ever fully automate things, with the exception of in certain environments. When does automation really become important? It's not at Duke, and it's not at Harborview. It's in Iraq or Afghanistan, where the medic has had just 9 weeks of training to care for an intubated victim of an improvised explosive device. Automated ventilation works when the caregivers don't have extensive experience and skills. I don't think it's necessarily very useful in a major teaching hospital.

Hess: So the PEEP-F_{IO_2} table would be great if we could automate it?

Branson: We're starting to do that. The people at Hamilton company are looking at automating PEEP using the inspiratory and expiratory P-V curve, selecting the point of maximum curvature on the expiratory side, and automatically setting the PEEP there. All this stuff could be done. It's just—as Dave Pierson used to point out in one of his favorite slides—where you draw the box and put a cross in it, and the different sides say, "Can we do it?" and then "Should we do it?" And that's really the important question, because yeah we can do it. It's very easy.