Abstract

The overarching goal of positive pressure mechanical ventilation is to provide adequate gas exchange support while not causing harm. Indeed, positive pressure mechanical ventilators are only support technologies, not therapeutic technologies. As such they cannot be expected to “cure” disease; they can only "buy time" for other therapies (including the patient's own defenses) to work. Conventional approaches to positive pressure ventilation involve applying ventilatory patterns mimicking normal ones through either masks or artificial airways. This is usually done with modes of support incorporating assist/control breath-triggering mechanisms, gas delivery patterns governed by either a set flow or pressure, and breath cycling based on either a set volume, a set inspiratory time, or a set flow. Often this support includes positive end-expiratory pressure and supplemental oxygen. In recent decades several novel or unconventional approaches to providing mechanical ventilatory support have been introduced. For these to be considered of value, however, it would seem reasonable that they address important clinical challenges and be shown to improve important clinical outcomes (e.g., mortality, duration of ventilation, sedation needs, complications). This article focuses on challenges facing clinicians in providing mechanical ventilatory support and assesses several novel approaches introduced over the last 2 decades in the context of these challenges.

Clinical Challenges Facing Clinicians Providing Mechanical Ventilatory Support

Ventilator-induced Lung Injury

Probably the most important challenge facing clinicians providing mechanical ventilatory support today is managing the balance between providing adequate gas exchange and avoiding lung injury associated with positive airway pressure and oxygen exposure. On the one hand, patients in respiratory failure need adequate tissue oxygenation and acid-base balance; on the other hand, the lungs are fragile structures easily injured by excessive stretch, alveolar collapse-reopening, and high oxygen exposure. This challenge is made more difficult by the fact that lung injury is usually heterogeneous and thus what may benefit gas exchange in one region (e.g., higher pressure) may cause worse injury in another.\(^1\)

Lung injury from mechanical ventilatory support is often termed ventilator-associated lung injury, or more commonly, ventilator-induced lung injury (VILI).\(^2\)\textsuperscript{2–7} Pathologically, VILI resembles in many ways the inflammatory response seen in other forms of acute lung injury and the acute respiratory distress syndrome (ALI/ARDS).\(^2\)\textsuperscript{2,3} The principal cause of VILI is alveolar injury induced by alveolar overstretch at end inspiration (overdistension), extended periods of tidal breath delivery above normal physiological values, and cyclic atelectasis-recruitment that occurs during positive pressure ventilation ([Fig. 1]).\(^2\)\textsuperscript{2–7} In general, the risk for VILI increases as end-inspiratory transpulmonary pressures exceed 30 to 35 cm H\(_2\)O, as tidal volumes exceed 8 to 10 mL/kg (ideal body weight), and as
regions of repetitive alveolar opening-closing develop.\[^{12}\] Other ventilatory pattern factors may also be involved in the development of VILI. These include frequency of stretch\[^{13}\] and the acceleration/velocity of stretch.\[^{14}\]


**Figure 1.**

Ventilator-induced lung injury during positive pressure ventilation comes from several factors. Depicted is the sigmoidal-shaped pressure-volume relationship seen in the acutely injured lung. Injury can occur from end inspiratory overdistension (upper right region), repetitive excessive tidal breath delivery (middle region), and repetitive collapse-reopening of alveolar units (lower left region).

Importantly, VILI is associated with cytokine release\[^{4-6}\] and bacterial translocation.\[^{15}\] These are often implicated as important contributors to the systemic inflammatory response with multiorgan dysfunction that results in VILI-associated mortality. The incidence of VILI has been reported to be as high as 24% of patients who are receiving mechanical ventilation for reasons other than ALI/ARDS, although estimates widely vary.\[^{5,7,16}\]

Another conceptual source of injury during mechanical ventilatory support is oxygen toxicity. Oxygen concentrations approaching 100% are known to cause oxidant injuries in airways and lung parenchyma.\[^{17}\] A "safe" oxygen concentration or duration of exposure is not clear in sick humans, however, because most of the data supporting the concept of oxygen toxicity come from animals. Most consensus groups have argued that FiO\(_2\) values less than 0.4 are safe for prolonged periods of time and that FiO\(_2\) values greater than 0.80 should be avoided if at all possible.\[^{18}\]

**Ventilator Discontinuation Process—patient-ventilator Synchrony**

A second major challenge facing clinicians providing mechanical ventilatory is to assure
that the duration of mechanical ventilation is kept to a minimum. The shorter the duration of mechanical support, the lower the risk for VILI, infections, airway injury, delirium, and respiratory muscle atrophy.\[19-23\] This challenge involves both vigilance in assessing the need for continued support every day as well as in providing comfortable support that promotes normal muscle function and minimizes the need for sedation.\[19\]

The available evidence strongly supports the routine (daily) assessment of the need for continued ventilatory support through the use of spontaneous breathing trials (SBTs) in patients recovering from acute respiratory failure.\[19\] In those patients deemed to require continued support after the SBT assessment, the available evidence would further suggest that this support be provided as patient-triggered interactive support aimed at promoting comfortable respiratory muscle activity that avoids both fatigue and disuse atrophy.\[19-23\]

Comfortable interactive support requires that the clinician optimize all three phases of breath delivery: breath triggering, flow delivery, and cycling. In general, patient-ventilator synchrony is best assessed by clinical observations and by analyzing the airway pressure graphic over time. Clinical signs of dys-synchrony are tachypnea, dyspnea, diaphoresis, and tachycardia, and the patient is often described as "fighting" the ventilator. Graphically, trigger dys-synchrony is manifest by excessive negative airway pressure signals preceding breath triggering or absence of any flow delivery in response to observed effort. Flow dys-synchrony is manifest by the airway pressure graphic during flow delivery being pulled (or "sucked") downward during inspiration. Cycle dys-synchrony is manifest by continued patient effort and sometimes double triggering if the cycle is too early. Cycle dys-synchrony can also be manifest as rises in airway pressure from expiratory muscle activity if the cycle is too long.

Conventional strategies to optimize synchrony during breath triggering, flow delivery, and cycling include several options. Optimal breath triggering involves assisted breath trigger sensitivity being as sensitive and responsive as possible without autocyling.\[24\] In patients with flow-limited airways and resulting intrinsic positive end-expiratory pressure (PEEPi), judicious amounts of applied positive end-expiratory pressure (PEEP) can reduce the imposed trigger load (from PEEPi).\[25\] Optimizing flow synchrony when using set flow modes (e.g., volume-assist control or volume-targeted synchronized intermittent mandatory ventilation [SIMV]) involves careful selection of flow magnitude and pattern. Indeed, flow synchrony is often easier to achieve with pressure-targeted modes (e.g., pressure-assist control, pressure-targeted SIMV, or pressure support) because of the adjustable flow features of these modes.\[26,27\] Finally, cycle synchrony requires proper setting of the target volume and inspiratory time.

**Novel Strategies Addressing the Challenge of Balancing Gas Exchange versus VILI**

**Airway Pressure Release Ventilation**

Airway pressure release ventilation (APRV, also known as Bi-Level (Covidien, Boulder, CO) and Bi-phasic (CareFusion, Yorba Linda, CA), among other trade names) is a time-cycled, pressure-targeted form of ventilatory support.\[28-31\] APRV is actually a variation of pressure-targeted SIMV that allows spontaneous breathing (with or without pressure support) to occur during both the inflation and the deflation phases. APRV differs from conventional pressure-targeted SIMV in the inspiratory:expiratory (I:E) timing. Specifically, conventional pressure-targeted SIMV uses a "physiological" inspiratory time with I:E ratio less than 1:1. Spontaneous breaths thus occur during the expiratory phase.
In contrast, APRV uses a prolonged inspiratory time producing so-called inverse ratio ventilation (IRV with I:E ratios of up to 4 or 5:1). Spontaneous breaths thus now occur during this prolonged inflation period.

The putative advantages of this approach are similar to those of other long inspiratory time (IRV) strategies. Specifically, the long inflation phase recruits the more slowly filling alveoli and raises mean airway pressure without increasing tidal volume or applied PEEP (although intrinsic PEEP can develop with short expiratory or deflation periods). Unlike older IRV strategies that required paralysis, however, the additional spontaneous efforts during lung inflation may enhance both recruitment and cardiac filling as compared with other controlled forms of support. Although IRV strategies are usually reserved for very severe forms of respiratory failure in which airway pressures and FiO\textsubscript{2} levels are approaching potentially injurious levels, the recruitment potential associated with APRV may prompt consideration of its use in less severe forms of lung injury.

APRV is generally set up to provide tidal breaths (inflations) of 6 to 8 mL/kg (ideal body weight) and set breathing rates to control PCO\textsubscript{2} and pH. The expiratory (deflation) time setting is controversial. Although the IRV pattern requires a short expiratory time, whether consequent intrinsic PEEP is desirable (and if so, how much) is often debated.

Good gas exchange, often with lower maximal airway pressures than control ventilation, has been demonstrated with APRV in several small observational clinical trials. However, the end inspiratory lung distention in APRV may not be necessarily less than that provided during other forms of support (and, indeed, it could be substantially higher) because spontaneous tidal volumes add to lung volume while the lung is inflated with the APRV set pressure.

Several randomized, controlled trials have been done with APRV. The first of these appeared to show an outcome benefit to APRV but is difficult to interpret because the control strategy required 3 days of paralysis, and it seemed to markedly worsen gas exchange. A later trial compared APRV to a more conventional SIMV strategy and showed no difference in outcome. The most recent trial compared APRV to ARDS Network low tidal volume ventilation in 64 patients with trauma-induced ALI ARDS. In this study, there were no significant differences in any of the clinical outcomes. Specifically ventilator days, intensive care unit (ICU) length of stay, and mortality were all comparable regardless of mode. Finally, an interesting reanalysis of the database of a very large ventilator usage survey was recently published. In this database, 234 subjects were identified who were receiving APRV. A case control group of matched patients based on a propensity score and who were receiving assist-control ventilation were also identified. Comparing the APRV group with this matched assist control group found no differences in mortality, ventilator-free days, or length of stay. Taken together these studies would suggest that APRV, although a physiologically interesting mode, has not been shown as yet to improve clinical outcomes in patients with severe ARDS.

**High-frequency Oscillatory Ventilation**

High-frequency oscillatory ventilation (HFOV) uses very high breathing frequencies (120 to 900 breaths per minute [bpm] in the adult) coupled with very small tidal volumes (usually less than anatomical dead space and often less than 1 mL/kg at the alveolar level) to provide gas exchange in the lungs. Gas transport up and down the tracheobronchial tree under these seemingly unphysiological conditions involves such mechanisms as Taylor dispersion, coaxial flows, and augmented diffusion.
device to deliver HFOV in adults uses a to-and-fro piston mechanism to literally vibrate a fresh bias flow of gas delivered at or near the tip of the endotracheal tube. Indeed, because HFOV supplies substantial mean airway pressures but applies very little pressure or volume fluctuations in the alveolus, it is sometimes termed continuous positive airway pressure (CPAP) with a wiggle.

The putative advantages to HFOV are twofold. First, the very small alveolar tidal pressure swings minimize cyclical overdistension and derecruitment. Second, a high mean airway pressure can also prevent derecruitment. Interestingly, mean pressures used during HFOV are often reported to exceed the 30 to 35 cm H₂O threshold employed during conventional ventilation. The reason this is possible may be explained by alveolar membrane expansion, which could occur when a slowly applied constant pressure is applied rather than the cyclical brief tidal pressures of conventional ventilation.

In the adult, common initial settings are a frequency of 300 bpm and a mean pressure of 5 cm H₂O above the previous conventional ventilation settings. Oxygenation is largely controlled by the mean pressure setting and the FiO₂. CO₂ clearance is largely controlled by the "power setting," which controls the oscillatory pressure amplitude. Ironically, lower frequencies favor enhanced CO₂ clearance, largely because slower frequencies allow larger volume changes with the applied oscillatory power setting.

Clinical experience with various high-frequency ventilation techniques has been most extensive in the neonatal and pediatric populations. From these studies, a general consensus has arisen that high-frequency ventilation appears to improve long-term clinical outcomes in these patients.

There is less experience with use of high-frequency techniques in adults because only recently have HFOV devices been available to adequately support gas exchange in this setting. In 2010 the McMaster University Evidence Based Medicine Group updated a meta-analysis of HFOV in acute respiratory distress syndrome (ARDS). They analyzed eight clinical trials of HFOV in patients with ARDS. This population included some pediatric patients who met the criteria for ARDS. In this analysis, six of the eight studies applied HFOV within 48 hours of intubation, and in five of the eight studies the ARDS Network low tidal volume strategy was used as the control group. Four hundred nineteen patients were included in these studies. The resulting meta-analysis showed that HFOV produced a significant reduction in mortality with a risk ratio of 0.77 and a 95% confidence interval range from 0.61 to 0.98. This suggests that there may be a role for HFOV in severe respiratory failure from ARDS. This conclusion, however, has been called into question with the recent publication of two large randomized control trials of HFOV in moderate ARDS. In one HFOV offered no benefit and in the other HFOV was associated with harm. These results underscore the notion that HFOV is going to be used, it should be: (1) reserved for patients min whom conventional lung protective strategies are falling and (2) provided by clinicians with expertise in the technology.

A variation on high-frequency ventilation is high-frequency percussive ventilation (HFPV)—a technique that uses high-frequency pressure pulses superimposed on a conventional ventilation pattern. This technique is thought to do two things: First, the high-frequency pulsations may enhance gas mixing and thus gas exchange. Second, the high-frequency pulses may enhance secretion clearance. Indeed, it is this latter application that has driven its popularity in burn units where supporters claim improved pulmonary toilet in patients with airway burns. One of the few randomized trials with this
A technique was reported in 2010.[40] This study was conducted in a military burn unit where 62 patients were randomized to HFPV or a conventional lung protective ventilator strategy. Approximately one third of the patients had significant inhalational injuries. Although the HFPV group met gas exchange goals more readily, the ultimate outcomes in terms of survival, ventilator-free days, and hospital length of stay were not statistically different. HFPV thus remains an attractive theoretical adjunct in patients, especially those with severe airway injuries, but evidence supporting improved outcomes from its use remains minimal.

**Adaptive Support Ventilation**

Adaptive support ventilation (ASV) is an assist-control, pressure-targeted, time-cycled mode of ventilation that automatically sets the frequency-tidal volume pattern according to respiratory system mechanics to minimize the ventilator work.[47-54] Conceptually, this minimal ventilator work may translate into minimal stretching forces on the lungs, which may, in turn, reduce VILI.

ASV calculates minimal work settings by first measuring respiratory system mechanics using several test breaths. It then uses a measurement of the expiratory time constants (RCe = resistance × compliance) to ensure an inspiratory time of at least one RCe and an expiratory time of at least three RCes. These data are then inserted into the following formula to calculate the frequency associated with minimal work for a given alveolar ventilation:

$$f = \sqrt{1 + \frac{2aRC(V_A/V_D) - 1}{aRC}}$$  

(1)

where, RC is the respiratory time constant, $V_A$ and $V_D$ are alveolar ventilation and dead space ventilation, respectively, and $a$ is a constant that depends on the flow waveform. Boundary rules exist to prevent excessive (runaway) settings. Clinicians must set the desired minute ventilation and the proportion of that minute ventilation that the machine is to supply. Ideal body weight can also be used to calculate the desired minute ventilation based on metabolic demands and predicted dead space. Clinicians must also set the PEEP and FiO2.

ASV as a pure control mode has been evaluated in several ways. Initial lung model testing[50] demonstrated that the ASV algorithm responded properly to abrupt changes in lung mechanics. Several early clinical studies have compared initial ASV settings with traditional clinician-selected settings and have found that ASV tends to select a lower tidal volume and faster rate (and thus lower inspiratory pressures) than do clinicians.[50-53] Two other early studies suggest that ASV also appropriately adapts to changes in patient position and double- to single-lung anesthesia.[50-56] One other study suggested that the I:E algorithm of ASV produced less air trapping in patients with chronic obstructive pulmonary disease (COPD).[54] Longer-duration clinical studies with ASV have shown that the algorithm provided adequate ventilator support in anesthetized patients,[50-53] as well as in patients with respiratory failure.[57]

More recent evaluations of ASV have focused on its ability to provide appropriate lung protective small tidal volumes. Indeed, when respiratory system compliance is poor, the ASV algorithm supplies a protective low tidal volume ventilator pattern similar to that recommended by the ARDS Network.[49] Problems arise, however, when respiratory system compliance is less deranged (e.g., patients with milder forms of acute lung injury). Under these conditions, the ASV algorithm tends to deliver tidal volumes often in excess...
of 10 mL/kg ideal body weight.\[35\] The clinical significance of this is unknown, but the potential harm from this should be considered by clinicians wishing to use this mode.

### Novel Modes Addressing Improved Patient Ventilator Interactions

#### Volume Feedback Control of Pressure-Targeted Breaths

As noted previously, pressure-targeted breaths with variable flow features often synchronize with patient flow demands better than fixed flow, volume-targeted breaths. A drawback to pressure targeting, however, is that a tidal volume cannot be guaranteed. This may be particularly important if the patient's respiratory drive is variable or lung mechanics are unstable such that a desired minute ventilation or tidal volume target (e.g., 6 to 8 mL/kg ideal body weight) cannot be reliably achieved.

Over the last 2 decades, several engineering innovations have attempted to combine features of pressure- and flow-targeted breaths by producing feedback algorithms that allow some control of volume with pressure targeting. The most common approach is to use a measured volume input to manipulate the applied pressure level of subsequent pressure-targeted breaths.\[59-64\] When these breaths are exclusively supplied with time cycling, the mode is commonly referred to as pressure-regulated volume control (PRVC), although there are several proprietary names (e.g., Autoflow [Draeger, Andover, MA], VC+ [Covidien], Adaptive Pressure Ventilation [Hamilton Medical Inc., Reno, NV]). When these breaths are supplied exclusively with patient-triggered, flow-cycling characteristics, the mode is commonly referred to as volume support (VS). Some ventilators will switch between these two breath types depending on the number of patient efforts. Both animal and human studies have shown that these feedback algorithms function as designed.\[62-66\]

Conceptually, the assist-control, time-cycled PRVC mode could be a useful tool in providing more synchronous lung protective ventilation. Specifically, a tidal volume target of 6 to 8 mL/kg could be selected, and the ventilator would then automatically adjust the applied inspiratory pressure (with its synchronous variable flow feature) to the airway. Indeed, several clinical observational studies have demonstrated that this can be done.\[67,68\] However, one study found that, although these feedback breaths did provide a more reliable small tidal volume ventilatory pattern than pure pressure assist control, in a minority of patients, up to 14% of tidal volumes were above the desired target value.\[68\] Whether this variability is an acceptable tradeoff to improve comfort during lung protective ventilation needs further study.

The patient-triggered, flow-cycled, volume-feedback mode VS has been evaluated primarily during the ventilator withdrawal process. Theoretically, the VS mode could be used to automatically reduce applied inspiratory pressure as the patient's ability to breathe improved. Conversely, inspiratory pressure would increase if patient effort diminished or respiratory system mechanics worsened. These responses have been demonstrated in several small studies, often involving the rapidly recovering (e.g., postoperative) patient.\[69,70,71,72\] A common finding in these studies is that the VS mode required fewer ventilator manipulations. Unfortunately, the simplicity of the VS mode may produce problems.\[73\] For instance, if the clinician-set volume is excessive for patient demand, a recovering patient may not attempt to take over the work of breathing for that volume, and thus support reduction and weaning may not progress. In addition, if the pressure level increases in an attempt to maintain an inappropriately high set tidal volume in the patient with airflow obstruction, PEEPi may result. On the other hand, a patient may receive inadequate support if the clinician-set tidal volume is not adequate for patient demand. Under these conditions, a patient will perform excessive work to maintain a
patient-desired tidal volume all the while the inspiratory pressure is being reduced because volume exceeds the clinician setting. Clinicians need to be aware of the behavior of VS under a variety of circumstances to properly use this mode.

Enhancements on Volume Feedback Control of Pressure-targeted Breaths

Airway occlusion pressure (P_{0.1}), \[^{74}\] oxygen saturation (SpO\_2), \[^{70-72}\] and end-tidal CO\_2 concentrations\[^{75,76}\] have been incorporated into PRVC and VS mode-control algorithms to adjust either the target V_T or the breath-delivery pattern. The one system that is commercially available uses end tidal CO\_2 and respiratory rate along with the tidal volume to adjust the applied inspiratory pressure.\[^{76}\] Known by the proprietary trade name SmartCare (Maquet Medical Systems USA, Wayne, NJ), the computerized feedback system attempts to find an inspiratory pressure that maintains the respiratory rate and tidal volume in a clinician-set "comfort zone." The end-tidal CO\_2 serves as a backup signal to assure adequate ventilation is occurring. The system is designed to wean the inspiratory pressure to as low a level as possible within these boundaries and then alert the clinician to perform a spontaneous breathing trial (SBT) when this pressure reaches 9 cm H\_2O.

Several small observational trials have been done showing that the SmartCare system (Maquet Medical Systems) did indeed keep patients in the clinician-selected "comfort zone" for 95% of the time.\[^{75,76}\] In a larger randomized clinical trial, this approach appeared to remove ventilator support more quickly than did physician-controlled weaning.\[^{77}\] Unfortunately, this control group did not have a protocolized SBT approach and thus may have had support removal delayed. Moreover, a subsequent trial was unable to duplicate the superiority of this automated feedback approach.\[^{78}\] Even if it is not superior, however, an automated system that is "just as good" as control by a clinician could have applications in settings with rapidly recovering patients or low availability of clinicians to make frequent assessments.

When patient efforts occur during the ASV mode described earlier, the control algorithm continues to try to conform to the minimal work tidal volume considerations already described, and in that sense resembles the feedback features of VS.\[^{79}\] However, the ASV feedback control is more complex than VS in that respiratory system resistance, compliance, and the resulting time constant modulate the tidal volume target. Several studies have evaluated ASV in patients being weaned from mechanical ventilation.\[^{57,80-85}\] In general, these studies showed that ASV safely provided adequate ventilator support and had similar (or faster) weaning times as compared with various SIMV and SIMV + pressure support protocols. These studies also generally showed fewer ventilator manipulations with ASV. Larger trials in patients with different forms of lung injury clearly are needed to establish the appropriateness of the ASV algorithms in facilitating ventilator withdrawal.

Proportional Assist Ventilation

Proportional assist ventilation (PAV) is a novel approach to assisted ventilation that uses a clinician-set "gain" on patient-generated flow and volume.\[^{86,87}\] PAV uses intermittent controlled "test breaths" to calculate resistance and compliance. It can then use measured flow and volume to calculate both resistive and elastic work. The clinician is required to set a desired proportion of the total work that should be performed by the ventilator. The ventilator then measures the patient flow and volume demand with each breath and adds both pressure and flow to provide the selected proportion of the breathing work. PAV has been compared with power steering on an automobile, an
analogy that has much truth. Like PAV, power steering reduces the work to turn the wheels but does not automatically steer the car—the driver must control the car’s ultimate direction just as the patient ultimately must control the magnitude of the breath and the timing of the breathing pattern.

With PAV, the greater the patient effort, the greater the delivered pressure, flow, and volume. This is in contrast with volume assist where flow and volume are not affected by effort and where, in fact, applied pressure may be "pulled down" by effort. PAV also contrasts with pressure assist/support where flow and volume are affected by effort but pressure is not.

Because PAV requires sensors in the ventilator circuitry to measure patient effort, it is susceptible to the same sensor performance and intrinsic PEEPi issues that affect breath triggering in other assisted modes. Also, like conventional assisted modes, the clinician must set PEEP and FiO$_2$. Finally, breath termination (cycling) is much like pressure support and is determined by a clinician-adjustable percentage of maximal inspiratory flow.

PAV has been shown in multiple studies to perform as designed. These studies have also shown that safety mechanisms to prevent excessive pressures ("runaway") are effective. These studies also emphasize the importance of having appropriate alarms and backup positive pressure modes because PAV provides minimal support with small efforts and no support if effort ceases. Thus PAV must be used with caution in patients with unreliable respiratory drives (e.g., neurological disorders, fluctuating sedation/opioid use).

Clinical studies have compared PAV with other forms of assisted ventilation, and it has been found to be useful in terms of muscle unloading and patient comfort. However, consensus on what level of support to begin with and how it should be subsequently manipulated does not exist. Some argue to start at a high level and wean as tolerated whereas others point out that maintaining a constant level coupled to regular SBTs makes the most sense. Whether PAV improves meaningful clinical outcomes (e.g., sedation needs, shorter needs for mechanical ventilation) remains to be determined.

**Neurally Adjusted Ventilatory Assistance**

Neurally adjusted ventilatory assistance (NAVA) utilizes a diaphragmatic electromyographic (EMG) signal to trigger and govern the flow and cycle of ventilatory assistance. The EMG sensor is an array of electrodes mounted on an esophageal catheter that is positioned in the esophagus at the level of the diaphragm. Ventilator breath triggering is thus virtually simultaneous with the onset of phrenic nerve excitation of the inspiratory muscles, and breath cycling is tightly linked to the cessation of inspiratory muscle contraction. Flow delivery is driven by the intensity of the EMG signal (electrical activity of the diaphragm [EAD$i$]), and the clinician sets a mL/mV gain factor.

Like PAV, NAVA depends exclusively on patient effort for timing, intensity, and duration of the breath. Thus, as with PAV, clinicians must set appropriate alarms and backup positive pressure ventilation, especially for patients with unreliable respiratory drives. Also as with PAV, clinicians must set PEEP and FiO$_2$.

Small clinical studies have demonstrated improved trigger and cycle synchrony with NAVA compared with conventional assisted modes. However, consensus on what level of support to begin with and how it should be subsequently manipulated does not exist. As with PAV, some argue to start at a high level and wean as tolerated, whereas...
others point out that maintaining a constant level of support coupled with regular SBTs makes the most sense. Also as with PAV, data demonstrating improved outcomes (e.g., duration of mechanical ventilation, sedation needs) are lacking. Another concern with NAVA is the expense associated with the EMG sensor.

Conclusions

As noted at the beginning of this chapter, the overarching goal of positive pressure mechanical ventilation is to provide adequate gas exchange support while not causing harm. Important challenges face clinicians every day in providing mechanical ventilatory support. Two of the most important of these challenges are balancing adequate gas exchange with the risk of VILI in acute respiratory failure; and assuring patient comfort during interactive support in the recovery period. Over the last 2 decades several novel approaches have been introduced that may help clinicians address these challenges. Although all of these approaches have conceptual appeal, most still await good clinical outcome data to justify their widespread use.

References


31. Myers TR, MacIntyre NR. Respiratory controversies in the critical care setting: does airway pressure release ventilation offer important new advantages in mechanical ventilator support? Respir Care 2007;52(4):452–458, discussion 458–460


36. Froese AB. High-frequency oscillatory ventilation for adult respiratory distress syndrome: let's get it right this time!. Crit CareMed 1997;25(6):906–908


44. Bollen CW, Uiterwaal CS, van Vught AJ. Cumulativemetaanalysis of high-frequency versus conventional ventilation in premature neonates. Am J Respir Crit Care Med 2003;168(10):1150–1155


55. Tassaux D, Dalmas E, Gratadour P, Jolliet P. Patient-ventilator interactions during partial ventilatory support: a preliminary study comparing the effects of adaptive


59. Branson RD. Dual control modes, closed loop ventilation, handguns, and tequila. Respir Care 2001;46(3):232–233


67. MacIntyre NR, Sessler CN. Are there benefits or harm from pressure targeting during lung-protective ventilation? Respir Care 2010;55(2):175–180, discussion 180–183


74. Iotti GA, Braschi A. Closed-loop support of ventilatory workload: the P0.1 controller. Respir Care Clin N Am 2001;7(3):441–464, ix


78. Rose L, Presneill JJ, Johnston L, Cade JF. A randomised, controlled trial of conventional versus automated weaning from mechanical ventilation using SmartCare/PS. Intensive Care Med 2008;34(10):1788–1795


83. Sulzer CF, Chioléro R, Chassot PG, Mueller XM, Revelly JP. Adaptive support ventilation for fast tracheal extubation after cardiac surgery: a randomized
controlled study. Anesthesiology 2001; 95(6):1339–1345


