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# Advanced Ventilator Modes and Techniques

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In addition to improving gas exchange by mechanical ventilation, minimizing iatrogenic lung injury and making the patient comfortable are important goals. This article reviews advanced ventilator modes and techniques that might help to accomplish these goals. Small tidal volumes (VT) and low ventilation pressure minimize ventilator-induced lung injury. Airway pressure release ventilation and high-frequency oscillatory ventilation may provide lung-protective ventilation in certain patients with refractory hypoxemia. Adaptive support ventilation (ASV) automatically adjusts VT and rate on the basis of the patient's respiratory mechanics to provide "safe" settings. When ventilator output does not match patient respiratory center timing, patient-ventilator asynchrony occurs. Proportional assist ventilation and neutrally adjusted ventilatory assist are unique modes of ventilation that provide ventilatory support in direct proportion to patient effort and therefore may be able to better match patient need and improve comfort. Weaning protocols reduce duration of ventilation and intensive care unit stay. Certain ventilator modes purport to automate part of the ventilator discontinuance process. The ASV progressively reduces support as the patient's lung condition improves, while SmartCare/pressure support (Dräger, Lübeck, Germany) reduces support and then initiates a spontaneous breathing trial. Further research is required to determine the proper place these new modes have in the intensive care unit. **Key words:** *adaptive support ventilation*, *airway pressure release ventilation*, *asynchrony*, *high-frequency oscillatory ventilation*, *lung-protective ventilation*, *neutrally adjusted ventilatory assist*, *proportional assist ventilation*, *SmartCare/PS*, *weaning*

MECHANICAL VENTILATION is a technology commonly used in all intensive care units (ICUs). In addition to supporting gas exchange, important goals of ventilator management include making the patient as comfortable as possible and not causing additional lung injury. This article reviews new advances in ventilator management that may minimize ventilator-induced lung injury, enhance patient-ventilator synchrony, and shorten the duration of ventilation.

## PROVIDING LUNG-PROTECTIVE VENTILATION

It is recognized that the manner in which patients are mechanically ventilated influences lung injury. Oxygen toxicity from high inspired oxygen concentrations[1,2] and barotrauma (eg, pneumothorax, pneumomediastinum, subcutaneous emphysema) from excessive ventilation pressures[3] has been a concern for decades, but other forms of injury are more recently recognized and are most likely more important on impacting outcome.[1] Excessive alveolar stretch (volutrauma)[4-6] and repetitive opening and collapse of lung units during tidal ventilation (atelectrauma)[6] can trigger release of inflammatory mediators and bacterial translocation,[7] which leads to end-organ failure (biotrauma) and death.[8-10]

To date, the only ventilator strategy shown to improve mortality is the low tidal volume (VT) management reported in 2000 by the National Heart, Lung, and Blood Institute acute

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respiratory distress syndrome (ARDS) Network (ARDSnet).[11] Targeting VT to approximately 6 mL/kg of predicted body weight (PBW) and limiting inspiratory plateau pressure ($P_{\text{plat}}$) to 30 cm $H_2O$ have become key tenants of best practice management for patients with acute lung injury (ALI) and ARDS. In particular, this management addresses minimizing volutrauma by limiting inspiratory alveolar stretch. Setting the proper positive end-expiratory pressure (PEEP) to maintain alveolar recruitment and minimize atelectrauma is still hotly debated and controversial and beyond the scope of this article.[12-16]

Lung recruitment by applying and maintaining a modest mean airway pressure ($P_{\text{mean}}$) generally improves oxygenation and may minimize atelectrauma. Two unconventional ventilator strategies that theoretically accomplish this effectively include airway pressure release ventilation (APRV) and high-frequency oscillatory ventilation (HFOV). It should be emphasized that when used as part of an ARDS management algorithm, these strategies should only be used after applying the ARDSnet strategy and the patient then does not respond adequately, as neither APRV nor HFOV has evidence supporting improved mortality. Figure 1 shows an abbreviated version of the ventilator management algorithm used at our institution.[17]

## Airway Pressure Release Ventilation

APRV was reported by Downs and Stock in 1987.[18,19] They used a special system that allowed "unrestricted breathing" at 2 levels of continuous positive airway pressure (CPAP). The APRV system has been described as "upside-down IMV" in that intermittent mandatory ventilation (IMV) allows the patient to breathe at a low CPAP level and raises the pressure intermittently to augment spontaneous minute ventilation by providing mechanical tidal inflation (ie, a mandatory breath). In its purest form, APRV encourages the patient to breathe at a high CPAP level, which is intermittently released to a lower CPAP level in an attempt to augment spontaneous minute ventilation by releasing volume. Debate exists on how to set the lower CPAP level and the duration of release. One practice is to set the low CPAP to 0 cm $H_2O$ with a release time short enough to create air trapping (auto-PEEP).[20] The other management practice sets the low CPAP level to a more traditional PEEP level (eg, 10-15 cm $H_2O$) and the release time such that the patient just completes exhalation before transition to the high CPAP level.[21] In both methods, most of the breathing cycle is spent at the higher CPAP level, resulting in a higher $P_{\text{mean}}$ than conventional pressure and volume ventilation modes. All potential spontaneous breathing occurs at the high CPAP level. The release period is to allow volume to be exhaled but is not long enough to permit any spontaneous breaths. Spontaneous breathing during APRV is associated with improved ventilation–perfusion distribution in dependent lung regions, enhanced venous return, and maintenance of cardiac output in the face of increased $P_{\text{mean}}$ and less sedation.[22] Although APRV-like settings can be applied to a passive patient, it is essentially inverse ratio pressure-controlled ventilation (PCV) if the patient is not spontaneously breathing.

Eight clinical studies have reported using APRV in ALI/ARDS patients, although each enrolled relatively few patients (range, 15-58). Three prospective crossover trials suggest similar levels of ventilation, with a lower peak inspiratory pressure using APRV[23,24] and alveolar recruitment to be progressive over time.[25] Two retrospective reviews suggest less sedation and vasopressor use and improved oxygenation with APRV than volume-controlled ventilation (VCV).[26,27] Liu and colleagues[27] suggested improved mortality in the APRV group (31%) versus the synchronized IMV (SIMV) group (59%) in their study of 58 patients with severe ARDS ($P = .050$).

Three studies are randomized controlled trials (RCTs). Putensen and colleagues[21] randomized 30 multiple-trauma patients at risk for ARDS to either APRV or PCV group. This study is often referenced in support of APRV, as it was associated with shorter duration of ventilation (15 days vs 21 days) and length

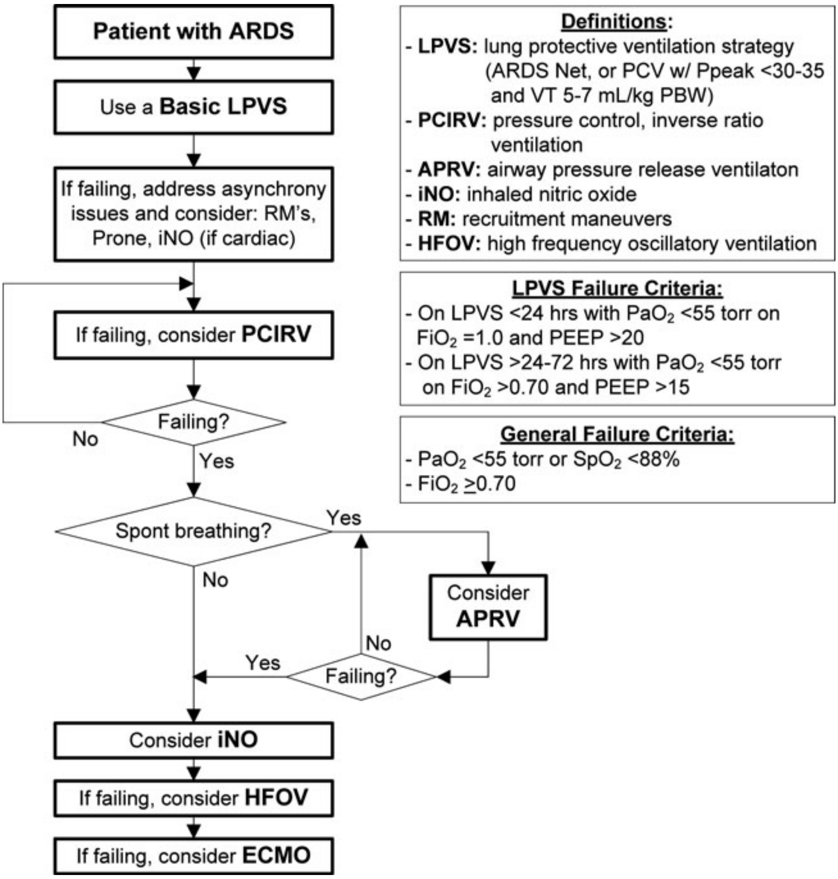

**Figure 1.** Abbreviated version of an acute respiratory distress syndrome ventilator management strategy. From Haas[17] with permission.

of ICU stay (23 days vs 30 days), as well as less use of vasopressors and inotropes. Unfortunately, the control group was paralyzed for the first 72 hours, which may have given a bias toward the patients in the APRV group who were allowed to spontaneously breathe. It is a study in support of allowing spontaneous respiratory effort but not necessarily superiority of APRV. Varpula and colleagues[28] randomized 58 ARDS patients to APRV or SIMV and found lower inspiratory pressure (26 cm vs 29 cm $H_2O$) but no difference in gas exchange, hemodynamics, or ventilator-free days at day 28. Varpula and colleagues[29] performed computer-assisted tomography on 37 ALI patients at baseline and 7 days after randomization to APRV or SIMV group. The change in the amount of nonaerated lung tissue was similar in the APRV (14.7%) and SIMV (9.6%) groups ($P = .65$).

Of note, each of the RCTs set the low PEEP level to 2 cm $H_2O$ above the lower inflection point on a pressure-volume curve, resulting in a mean pressure of approximately 10 to 12 cm $H_2O$. Setting low PEEP to 0 cm $H_2O$ and creating auto-PEEP have become a common practice and may result in better outcome, but it has not been studied. Concerns with the auto-PEEP method of setting low CPAP include a potential for lung derecruitment if the release time is not adjusted when lung mechanics change and the tendency for larger exhaled release volumes, which are often larger than 8 mL/kg PBW.[30]

Although APRV is now available on all current-generation ventilators and has become popular in many centers, the evidence at this time does not support routine use.

## High-Frequency Oscillatory Ventilation

HFOV delivers very small VTs (0.1-3 mL/kg PBW) at rapid rates (180-900 cycles/min or 3-15 Hz).[31] Conceptually, it is "high-level CPAP with a wiggle," and, ideally, the wiggle should be minimal. Oxygenation is supported by increasing $F\text{IO}_2$ and $P_{\text{mean}}$, whereas ventilation is improved by increasing drive pressure or reducing rate. Counterintuitively, reducing the rate improves minute ventilation by allowing more time for the piston to move to and fro, generating a larger stroke or VT.[32]

Animal studies have shown HFOV to aid in lung recruitment, improve oxygenation, and reduce histologic lung damage and inflammation.[33-36] Most adult clinical reports are case series and suggest that HFOV is safe and at least as effective as conventional ventilation (CV) but have generally applied it as rescue therapy for refractory hypoxemia.[37-45] There are only 2 RCTs comparing HFOV with CV in ARDS patients. Derdak and colleagues[46] randomized 148 patients and found early oxygenation improvement in the HFOV group, but the difference was not sustained beyond 24 hours. There was no difference in any other measured parameter, although there was a nonsignificant ($P = 0.102$) trend toward improved mortality in the HFOV group (37%) compared with the CV group (52%). Bollen and colleagues[47] randomized 61 ARDS patients and found no difference in outcomes. A post hoc analysis found a better treatment effect in patients with a higher oxygenation index (oxygenation index = $[P_{\text{mean}} \times F\text{IO}_2]/\text{PaO}_2$) at baseline. There are also 2 RCTs of HFOV in conjunction with prone positioning in ARDS patients, which found that proning, regardless of ventilation method, improved oxygenation[48] and that HFOV maintained the oxygenation gained from the prone position better than CV when returned to the supine position.[49]

To provide the most lung-protective settings when applying HFOV, it is suggested to use a high-oscillation pressure amplitude (starting at 90 cm $H_2O$) coupled with the fastest frequency tolerated (ideally $\geq 6$ Hz) targeting a pH of 7.25 to 7.35.[42,50,51]

Two large RCTs are underway to hopefully answer whether HFOV results in better outcomes than conventional management.

## Adaptive Support Ventilation

Adaptive support ventilation (ASV) is a novel mode of ventilation that purportedly provides lung-protective levels of VT and respiratory rate.[52] Clinicians set a target minute ventilation, and the ventilator determines an optimal VT and rate combination that result in the least work of breathing, based on the "minimum work of breathing" concept described by Otis et al.[53] Theoretically, when the patient's compliance is reduced (ie, has ALI), a smaller VT and faster rate are chosen, whereas in patients with obstructive lung disease, a larger VT and slower rate are chosen to minimize air trapping. There is concern that large VTs and high pressure may also increase the risk of developing ALI or ARDS in patients without lung disease.[54-58] A ventilator mode that automatically adjusts inspired volume on the basis of the patient's actual respiratory mechanics is intriguing and may help to minimize iatrogenic lung injury, particularly in settings where constant vigilance and frequent manual adjustment are not practical.

Clinical studies of ASV have focused on 2 areas: initial settings and subsequent adjustment to provide "protective settings" and as a weaning mode. Weaning will be discussed later in this article.

Sulemanji and colleagues[59] used a bench model to compare ASV with VCV having a VT of 6 mL/kg PBW. A variety of lung compliance and resistance combinations were used, as PEEP was adjusted on a simulated ARDS patient with a PBW of 60 and 80 kg. The ASV was equivalent to the 6 mL/kg fixed VT (mean ASV VT of 6.3 vs 6.1 mL/kg in 60-kg group and 5.2 vs 6.1 mL/kg in the 80-kg group); however, when mechanics worsened, VT decreased with ASV whereas $P_{plat}$ increased with VCV. The authors concluded that ASV automatically adjusted the ventilator in a manner similar to what a clinician would do at the bedside.

Two observational studies using ASV in a variety of patients found it to make appropriate adjustments in most situations but cautioned of occasional excessive VT.[60,61] Dongelmans and colleagues[60] reported data on 346 patients after cardiothoracic surgery who were placed on ASV (n = 262) or pressure-control/pressure-support ventilation (n = 84) targeted to a VT of approximately 6 mL/kg PBW. Mean VT for ASV was 8.3 mL/kg PBW versus 7.3 mL/kg PBW for PCV/pressure support (PS). Of note, VT in ASV was more than 8 mL/kg PBW in 55% of patients and more than 10 mL/kg PBW in 12%.[60] Arnal and colleagues[61] used ASV in 246 patients with a variety of lung conditions, including normal, chronic obstructive pulmonary disease (COPD), and ALI/ARDS. In passive patients, ASV delivered a VT of 8.3, 9.3, and 7.6 mL/kg PBW for normal, COPD, and ALI patients, respectively. During active breathing, the VT was reduced for normal (7.9 mL/kg) and COPD (8.5 mL/kg) but increased for ALI (8.0 mL/kg PBW) patients. The ASV "failed" in 5 patients because of $P_{plat}$ greater than 35 cm $H_2O$.

Choi and colleagues[62] prospectively studied 13 pharmacologically paralyzed patients with ALI/ARDS sequentially with VCV, ASV, and VCV. The VT was set to 6 to 7 mL/kg PBW in VCV, resulting in a VT of 405 ± 50 mL, which increased to 463 ± 88 mL during ASV. Veelo and colleagues[63] reported a combined bench and clinical study. In the simulation of normal, COPD, and ALI lungs, ASV delivered a VT of 8 to 10 mL/kg, more than 10 mL/kg, and 6 to 8 mL/kg PBW, respectively. In their postoperative cardiac patients, VT was between 7 and 9 mL/kg PBW and never exceeded 10 mL/kg.

Iotti and colleagues[64] studied 83 patients in a prospective crossover multicenter study. Patients without lung disease and those with restrictive or obstructive lung disease were assessed during CV and ASV set to obtain the same minute ventilation as with CV (isoMV) and to obtain the same $Pa{CO_2}$ ($isoCO_2$). Compared with CV, ASV set to isoMV resulted in a lower $PaCO_2$, and when set to $isoPaCO_2$ resulted in a lower minute ventilation, suggesting better efficiency of ventilation with ASV. They confirmed previous observations that ASV automatically adopts a pattern of ventilation dependent on respiratory system mechanics and similar to those chosen by clinicians. They also observed extremely high VTs in 3 COPD patients with severe airways obstruction (~19, 20, and 22 mL/kg PBW) and expressed caution and the need to set appropriate alarm limits.

Dongelmans and colleagues[65] reported a prospective observational study of 10 ALI/ARDS patients ventilated with PCV set to 6 mL/kg PBW and switched to ASV. Respiratory rate decreased (from 31 to 21 breathes per minute) and VT increased (from 6.5 to 9.0 mL/kg PBW) with ASV. The authors concluded that ASV may result in excessive VT in ALI/ARDS patients.

The concept of allowing the ventilator to make adjustments based on changing respiratory mechanics is attractive because that is what bedside clinicians must do to apply mechanical ventilation safely. Although ASV generally chooses settings that are considered safe, several studies have shown reason for concern and the need for careful monitoring and the setting of proper limits and alarms. Adjustments to the internal ASV algorithm could bring the target VTs in line with current practice and prove to be a valuable tool in the future.

## IMPROVING PATIENT-VENTILATOR SYNCHRONY

When gas delivery from the ventilator does not match the patient's respiratory center neural output, patient-ventilator asynchrony can occur.[66] This mismatch can occur in 3 major areas: not turning on (trigger), not keeping up (flow), and not turning off (cycle), as the patient desires. There is no specific ventilator manipulation that works either for all patients or for a given patient in all situations, so it becomes a matter of "trial and error" at the bedside. Obvious asynchrony is apparent in the patient using accessory muscles; is tachypneic, tachycardic, and diaphoretic, has nasal flaring or sternal retractions, or shows other signs of respiratory distress. More subtle asynchrony can be detected by observing the ventilator waveforms, particularly the pressure and flow scalars.

Trigger asynchrony can occur in the presence of auto-PEEP, as the patient has to pull down to a pressure equal to the auto-PEEP plus the set trigger threshold to initiate a breath. Adjustments to minimize or to offset auto-PEEP may help.[67] Conversely, the ventilator may autocycle from too sensitive of a set trigger, a leak in the system, or cardiac oscillations.[68,69]

Flow asynchrony may be present when the ventilator pushes either faster or slower than the patient pulls. In VCV, increasing the set flow rate may help to match the patient's flow demand, and using a decelerating flow pattern (if the ventilator provides it) will allow a faster initial flow for the same inspiratory time, but, unfortunately, the flow in VCV is fixed and does not adjust with changing patient demands. Pressure modes of ventilation allow a variable inspiratory flow, which may be more comfortable. Another approach is to use a volume-targeted variable flow mode, such as pressure-regulated volume control.[70] In this mode, a target VT is set and the ventilator uses a closed-loop form of PCV to adjust inspiratory pressure to maintain VT. Flow is influenced by patient demand and inspiratory pressure automatically adjusted on the basis of the previous exhaled VT to maintain target. Although this mode may be comfortable for most patients, those with a small target VT present a challenge. Should the patient consistently exceed the target VT, inspiratory pressure is reduced and the ventilator provides less support when the patient actually requires more support.[70]

Cycle asynchrony is present when the ventilator inspiratory (Ti-vent) and expiratory times are different from that of the patient's neural inspiratory (Ti-pt) and expiratory times. Double cycling in VCV suggests that the patient is still inspiring when the ventilator is turned off (Ti-pt > Ti-vent). Lengthening inspiratory time by adding an inspiratory pause or reducing flow may help, as might increasing VT. An end-inspiratory spike in the pressure-time waveform suggests that the patient is trying to exhale, while the ventilator is still pushing (Ti-pt < Ti-vent); increasing the set flow or reducing VT might alleviate this. The PCV may be helpful in this situation, but the inspiratory time is still constant and may not be comfortable. A trial of high-level PS might be attempted, although some new ventilators allow PCV to be flow cycled and to function like PS with a backup rate.

Two unique ventilator strategies designed to improve patient-ventilator synchrony are proportional assist ventilation (PAV) and neurally adjusted ventilatory assist (NAVA). Both provide support in direct proportion to patient effort.[71]

The original description of PAV compared conventional modes of ventilation with PAV,[72] but this description also applies to NAVA. Figure 2 shows the relationship of instantaneous patient effort on applied ventilator pressure and inspired flow and volume. In VCV with no patient effort, a certain level of pressure is required to deliver the volume, and as patient inspiratory effort increases, ventilator pressure is reduced (Figure 2A). Regardless of effort, a fixed inspiratory flow and constant volume are provided with VCV (Figure 2B). During pressure modes of ventilation (eg, PS, PCV, APRV/BiLevel), by definition, airway pressure remains relatively constant as effort changes (Figure 2A). With minimal effort, a certain amount of volume and flow is provided, and as effort increases, the level of each increases (Figure 2B). With PAV and NAVA, minimal patient effort results in minimal

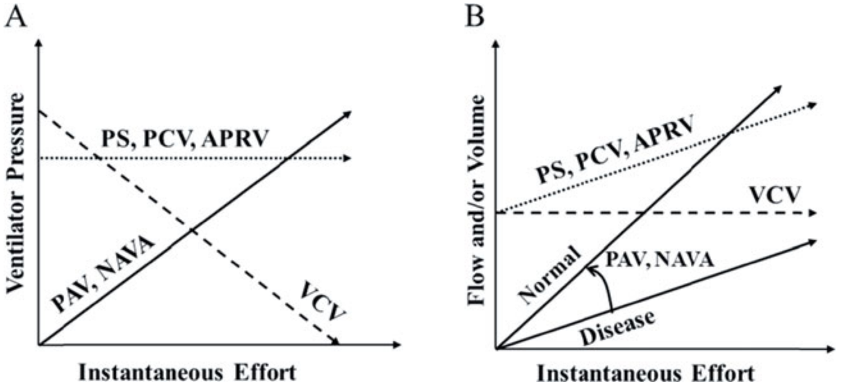

**Figure 2.** Comparison of various modes of ventilation showing (A) ventilator pressure, and (B) flow and volume output for a given instantaneous patient effort. See text for detailed description. Modified from Younes[72] with permission from the author.

applied ventilator pressure and a small volume, whereas increased effort results in increased ventilator pressure and volume (Figure 2A). Notice in a spontaneous breathing individual with no lung disease (normal) that as effort increases, a larger volume and faster flow are provided and that this normal relationship is blunted by lung disease in that for a given effort, less volume and a slower flow are now inspired. Both PAV and NAVA attempt to take work away from the diseased or stressed system so that for a given effort, a larger volume is moved, normalizing the relationship (Figure 2B). The harder the patient pulls, the more the ventilator pushes. This is a much different response from that of any other modes traditionally used. Rather than providing a fixed pressure, volume, or flow, PAV and NAVA amplify the patient's inspiratory efforts, with the objective of allowing the patients to determine their own breathing pattern.

Proportional assist ventilation uses the traditional airway signal of pressure and flow to turn on and off (Figure 3), which means that it is affected by a reduced ability to trigger on

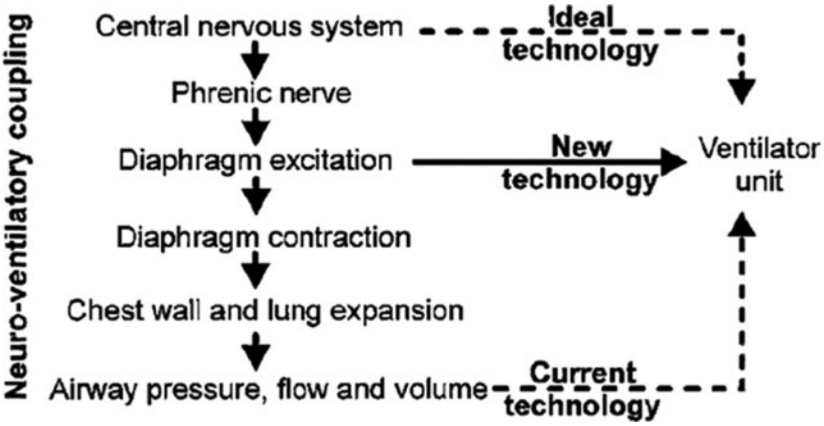

**Figure 3.** Depiction of the steps necessary to transform central respiratory drive into an inspiration. Most ventilator modes, including proportional assist ventilation, are triggered from an airway pressure, flow, or volume signal, whereas neutrally adjusted ventilatory assist uses a signal from the electrical activity of the diaphragm. From Sinderby et al[73] with permission.

in the presence of air trapping from obstructive lung disease and reduced ability to cycle off in the face of a system leak. Neutrally adjusted ventilatory assist uses a signal from the electrical activity of the diaphragm to adjust support.[73] A special nasogastric tube containing an array of electrodes is placed at the level of the diaphragm. Neutrally adjusted ventilatory assist turns on and off when the brain sends a signal to the nerves innervating the diaphragm, so it is not affected by either a leak in the system or auto-PEEP[74] and theoretically responds to demand more quickly.

Most studies compare PAV and NAVA with PS, another common spontaneous mode of ventilation. Studies assessing patient-ventilator synchrony suggest that the breathing pattern during PS and PAV is similar at low levels of support, but as support is increased, VT increases and rate decreases with PS while volume and rate remain relatively unchanged with PAV. This can result in frequent missed triggered breaths with PS, which is nearly abolished with PAV.[75-78] Neutrally adjusted ventilatory assist responds similar to PAV to higher levels of support and is also associated with fewer missed breaths.[79-82] In addition, NAVA is associated with a faster ability to trigger on and to cycle off in response to patient effort than PS.[81]

Further studies are required with both modes to determine whether improved patient-ventilator synchrony results in improved outcomes.

## FACILITATING THE VENTILATOR DISCONTINUANCE PROCESS

As soon as a patient is committed to mechanical ventilation, clinicians should be looking for the earliest opportunity to safely reduce and remove support. Lengthened duration of intubation and mechanical ventilation can increase the incidence of ventilator-associated pneumonia, ventilator-induced lung injury, and other iatrogenic complications.[83] A weaning process or protocol that includes a daily sedation holiday in conjunction with a wean assessment followed by a spontaneous breathing trial (SBT) has become the standard of care for patients who meet criteria.[74] A recent systematic review and meta-analysis of weaning protocols that included 11 RCTs and 1971 patients found that protocols were associated with a reduced duration of ventilation by 25%, duration of weaning by 78%, and ICU stay by 10%.[84]

The decision making and manual adjustments required to reduce ventilator support to a level where the patient can be assessed for spontaneous breathing capabilities are generally made by the bedside team of physicians, nurses, and respiratory therapists. Progress in moving the patient toward ventilator liberation is dependent on the expertise, the degree of delegation, and, importantly, the availability of team members.

The introduction of closed-loop ventilator technology has led to the ability for automatic adjustment of support according to changes in the patient's respiratory mechanics and ventilatory demands. Several ventilator modes suggested to hasten the weaning process include ASV and SmartCare/PS.

The ASV system was discussed earlier with regard to applying a lung-protective VT-respiratory rate combination, but it is also capable of automatic reduction in ventilator support. As the patient begins to spontaneously breathe, the ASV algorithm switches from PCV to PS and continues to monitor VT and rate. The ASV system titrates inspiratory pressure to achieve a calculated VT and progressively reduces pressure as the patient's lung mechanics improve. Weaning is considered complete when all breaths are spontaneous with stable gas exchange and hemodynamics on a low inspiratory pressure.

Four RCTs have compared ASV with other methods of weaning, all in postoperative cardiac patients.[85-88] Generally, ASV was associated with a similar[86,88] or shorter[85,87] duration of ventilation and a similar[87] or fewer[85,86] number of ventilator manipulations during the weaning process.

SmartCare/PS is a specialized form of PS that uses a rules-based expert system to provide a ventilator-led automatic weaning process.[89] To initiate SmartCare/PS, the clinician enters patient weight, the presence of COPD and/or a central neurological disorder, the artificial airway type, and the humidification type. The patient characteristics determine the limits for VT, rate, and end-tidal $CO_2$, and the equipment-related information governs the PS level at which an SBT is initiated.[90] Once initiated, the ventilator takes the patient through 3 distinct phases of weaning: adaptation, observation, and maintenance. During the adaptation phase, support is reduced. After establishing a diagnosis, SmartCare/PS determines an intervention and instructs the ventilator to adjust PS to keep the patient in a defined zone of respiratory comfort.[91,92] Once the PS level is minimal, SmartCare/PS automatically initiates an observation phase consisting of an SBT. If the patient remains stable, the ventilator suggests that the clinician "considers separation" of the patient from the ventilator. The ventilator has a variety of maintenance strategies depending on the outcome of the SBT.

Lellouche and colleagues[91] reported a multicenter RCT comparing SmartCare/PS with physician-controlled weaning protocols on 144 patients. SmartCare/PS was associated with a reduced duration of weaning (3.0 days vs 5.0 days), total duration of mechanical ventilation (7.5 days vs 12.0 days), duration of ICU stay (12.0 days vs 15.5 days), and use of noninvasive ventilation postextubation (19% vs 37%). Rose and colleagues,[93] on the contrary, reported no difference between SmartCare/PS and nursing-directed weaning in a single-center Australian RCT of 102 patients. Importantly, the critical care specialty nurse-to-patient ratio in this study was 1:1. It appears that this closed-loop system performs as well as expert clinicians staffed at an ideal provider-to-patient ratio and possibly faster when conditions are not so ideal. More research is required on ASV and SmartCare/PS to determine their place in the busy ICU.

## SUMMARY

Several of these newer modes of ventilation are theoretically attractive and have potential to provide protective settings to minimize further lung injury, to provide ventilation more in tune with patient demand and improve comfort, and to automatically make adjustments in support to possibly reduce the duration of ventilation. Considerable research is still required before these modes can be recommended for routine use, but the future holds promise.

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