Special REPORT

Optimizing Patient–Ventilator Interaction: Proportional Assist Ventilation and Patient–Ventilator Synchrony

Part 2 of a 2-Part Series

Mechanical ventilation (MV) is a potentially lifesaving intervention but is associated with a number of complications such as pneumonia and tracheal stenosis.1 Early weaning or liberating the critically ill patient from mechanical support is an important clinical goal because liberation results in spontaneous breathing and extubation.2 Weaning delays are common in the ICU and may result from patient–ventilator asynchrony (occurring in 24% of patients and in ≥10% of their breaths), which may prolong ventilation up to 17 days and exposes patients to discomfort and increased risk for complications.2-4 Weaning delays with prolonged MV are associated with a high cost of care and higher 6-month mortality rates.2,5

A spontaneous breathing trial (SBT) is the major diagnostic test used to determine if a patient can be successfully extubated.2 The evaluation of objective and clinical criteria (eg, respiratory pattern, adequate gas exchange, hemodynamic stability, and comfort) should be used to determine SBT success.2 Weaning failure, defined as either the failure of a SBT or the need for reintubation within hours following extubation, after a single SBT is relatively common and occurs in approximately 25% to 42% of patients.6-8 Weaning failure has a complex, multifactorial pathophysiology that may have psychological, pharmacologic, medical, and physiologic components.2

Length and difficulty of weaning attempts may be simple (successful first attempt), difficult (3 SBTs or as long as 7 days from initial attempt), or prolonged (failure of 3 weaning attempts or requiring 7 or more days of weaning after the first SBT).2 A failed SBT should prompt the clinician to look for reversible contributing etiologies and to
place the patient on a nonfatiguing mode of MV (either assist-control or pressure support ventilation [PSV]). Approximately 15% of MV patients require prolonged weaning and a tracheotomy may be considered if patients continue to fail to wean after 14 days. Some patients may not be able to wean or fail weaning trials and SBTs because of the sedation level. Depth of sedation in MV was found to be associated with patient–ventilator asynchrony and complications weaning, impairs respiratory drive, and leads to muscle weakness. Despite the association of sedation with poor outcomes and prolonged MV, sedation may be employed in the clinical treatment of asynchrony; as demonstrated by Pohlman and colleagues, 42% of ICU patients required additional sedation due to patient-ventilator asynchrony. Heavy sedation affects the process of discontinuing ventilator support, underscoring a need to consider consciousness and discontinuation of sedation as part of a weaning protocol. Kress and colleagues demonstrated that daily interruptions of sedative infusions reduce the duration of MV and ICU length of stay. More recently, a no-sedation protocol was found to be associated with a decrease in ventilator days in critically ill patients.

Earlier liberation from the ventilator is significant because MV can cause rapid and profound disuse atrophy and weakness of the diaphragm, called ventilator-induced diaphragmatic dysfunction (VIDD). Using a combination of 18 to 69 hours of complete diaphragmatic inactivity and MV, Levine and colleagues demonstrated marked atrophy of slow- and fast-twitch respiratory muscle fibers. To minimize the risk for VIDD, it is important to deliver appropriate partial ventilatory support that facilitates intermittent diaphragmatic contractions.

From PSV to Proportional Assist Ventilation

PSV is currently one of the most commonly used partial ventilatory assist modes. It reduces workload on respiratory muscles by generating a constant pressure that complements patient effort throughout the inspiratory period. Compared with earlier ventilatory modes, PSV gives patients more control over when to end inspiration, as the fixed level of inspiratory muscle unloading and patient triggering of the ventilator results in applied pressure \( (P_{aw}) \) rising to a preset level regardless of patient effort. However, asynchrony can still occur with PSV because patient conditions are constantly changing and flow demands vary from breath to breath. Care must be taken with PSV to avoid both insufficient support, leading to increased respiratory muscle load, and excessive support that may result in delayed cycling and other adverse effects (eg, dynamic hyperinflation, intrinsic positive end expiratory pressure [auto-PEEP]).

Proportional assist ventilation (PAV) is designed to amplify patient efforts in a proportional manner without volume or pressure targets, thus optimizing patient–ventilator synchrony. PAV delivers ventilatory assistance based on the patient’s respiratory effort, which is clinically valuable because inspiratory effort is variable and, therefore, the level of assistance should vary with it. PAV is advantageous because it eliminates the need for clinicians to set traditional ventilator parameters (ie, tidal volume, flow rate, inspiratory time, and respiratory rate); the only clinician-determined setting required with PAV is percent support. The necessity for the measurements of respiratory elastance (or compliance) and airway resistance, however, had been an obstacle to widespread clinical use of conventional PAV. More recently, the PAV+ software option was introduced which automatically measures the patient respiratory elastance and airway resistance. The PAV+ software estimates resistance and compliance every 4 to 10 breaths. The PAV+ software option has greatly helped to extend the usefulness of PAV technology from research to clinical settings.

Benefits of PAV

PAV was demonstrated, in early pathophysiologic studies, to decrease work of breathing (WOB), increase tidal volume, and decrease peak \( P_{aw} \) in intubated patients without chronic obstructive pulmonary disease (COPD) during weaning from MV. Similarly encouraging results were found for PAV in intubated COPD patients including improved minute ventilation, decreased dyspnea, and reduced WOB. Many studies have shown that PAV allows for improved adaptation of the ventilator to the changing flow demands of the patient, thus improving synchrony between patients and ventilator. PAV also has been shown to significantly reduce peak inspiratory pressure over a 24-hour period. Greater muscle effort is required, and more pronounced patient discomfort has been observed in response to added respiratory load during PSV compared with PAV. A retrospective analysis of data from a previous randomized controlled trial demonstrated that PAV+ is associated with fewer interventions in terms of ventilator settings and sedative dose changes compared with PSV.

A randomized study in the ICU setting demonstrated PAV+ to be an efficient mode of ventilatory support compared with PSV. Patients were randomized to receive either PSV \((n=100)\) or PAV+ \((n=108)\) for 48 hours unless patients met predefined criteria for switching to controlled modes or for breathing without assistance. Failure rate was significantly lower with PAV+ than with PSV (11% vs 22%, respectively; \( P=0.040 \)), and the proportion of dysynchronies was significantly lower in the PAV+ group (56% vs 29% respectively; \( P=0.001 \)). The probability of remaining on spontaneous breathing, instead of switching to CMV, was significantly increased with PAV+ when compared with the PSV group (\( P=0.041 \); Figure). The ventilating pressure remained below 30 cm H\(_2\)O in 98.2% of measurements in PAV+. This is clinically important because it is recommended that static end-inspiratory airway pressure \( (P_{plat}) \) be maintained below 30 cm H\(_2\)O to minimize risk for ventilator-induced lung injury.

Short-term respiratory load compensation in critically ill patients may be more efficient during PAV+ than during PSV. Kondili and colleagues examined an index of neuroventilatory coupling (the VT to pressure-time ratio product of the diaphragm) of each breath for patterns of respiratory load compensation in response to added mechanical respiratory load in 10 critically ill patients on MV. With PAV+, this
PAV requires an intact, responsive central controller to maintain an adequate pCO2 and pH. Although patients with altered respiratory drive may be ventilated adequately with PAV, they may have trouble triggering the ventilator.25 PAV is contraindicated if the patient’s central ventilatory drive is unstable due to excessive sedation, central depression of ventilation (eg, brain injury), or central apnea.25 The clinician must correct causes of inefficient drive or switch to a mode with a set rate in the presence of very low respiratory efforts or apnea.25

Patient comfort is an important clinical consideration with PAV, as it is with PSV.49,50 Air leaks have been associated with patient–ventilator asynchrony, particularly in noninvasive ventilation, and should be part of the differential when troubleshooting respiratory distress in a patient receiving MV.51 The ability of PAV to compensate for leaks must be evaluated before use as it may vary between ventilator models.33

PAV use may be limited by leak sensitivity, excessive pressure potential (ie, the runaway phenomenon), and the consequences of dynamic hyperinflation.37,52 Reducing the magnitude of dynamic hyperinflation should be a priority. Bronchodilators or corticosteroids may be used, and external positive end expiratory pressure (PEEP) could be used to counterbalance auto-PEEP.37 Care must be taken, especially in critically ill patients, to avoid treating the lung as if elastance and resistance are linear; alinearity of pressure–volume and pressure–flow relationships may cause volume-assist or flow-assist to be set inappropriately.37 PAV is better suited for responding to changing lung mechanics compared with PSV; however, PAV is similar to other ventilatory modes in that it does not compensate for or overcome the effects of auto-PEEP.33

PAV+ software is intended for use in spontaneously breathing adult patients whose ventilator ideal body weight is at least 55 lb or 25 kg. Patients must be intubated with endotracheal or tracheostomy tubes with an internal diameter of 6 to 10 mm. Patients must have satisfactory neural-ventilatory coupling along with a stable, sustainable inspiratory drive.38

### Cautions When Using PAV

Despite favorable effects that have been demonstrated with PAV and PAV+ (collectively, PAV hereafter), it has limitations. Because the assist varies directly with the intensity of patient effort, and the patient’s respiratory muscles drive the ventilator, PAV must be used with caution in patients with very low respiratory efforts (eg, depression of ventilation, central apneas).25 PAV requires an intact, responsive central controller to maintain an adequate pCO2 and pH. Although patients with altered respiratory drive may be ventilated adequately with PAV, they may have trouble triggering the ventilator.25 PAV is contraindicated if the patient’s central ventilatory drive is unstable due to excessive sedation, central depression of ventilation (eg, brain injury), or central apnea.25 The clinician must correct causes of inefficient drive or switch to a mode with a set rate in the presence of very low respiratory efforts or apnea.25,45

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### More Tips for Using PAV+

Although PAV+ has been associated with fewer required manipulations of ventilator settings relative to PSV, clinicians generally must individualize ventilatory support based on patient comfort.25,51 A basic PAV application principle is to set PAV at 70% assist, a support level at which distress is uncommon, and to make initial adjustments based on respiratory frequency, using PEEP to overcome auto-PEEP and reducing support gradually (based on patient comfort and with a goal of moving toward a SBT).37 The manufacturer also recommends caution when choosing support values higher than 80%, which may be uncomfortable for the patient.25,38

Data monitored and displayed by the PAV+ software include lung compliance and elastance, auto-PEEP, airway resistance, estimated total resistance, spontaneous inspired VT, and normalized rapid shallow breathing index.38 WOB is displayed with PAV+ in the form of a bar graph, with the sum being 100% of the work and the respective work by the patient and ventilator partitioned based on percent work setting and patient variables.25,38 Having multiple patient data readily available through the PAV+ screen display can aid in clinical decision-making that potentially may reduce delays in liberation of patients from MV as a consequence of improved synchrony.

### Figure

Figure. Kaplan–Meier estimates of probability of remaining on spontaneous breathing (assisted or unassisted) in patients randomized to PS and PAV+.

PAV+, proportional assist ventilation with load adjustable gain factors; PS, pressure support

Conclusion

PAV is designed with the aim of improving airflow and phase synchrony between patient and ventilator. In addition to being a user-friendly ventilatory mode, PAV has demonstrated efficacy in reducing the frequency of sedative dosing changes, improving respiratory muscle function, reducing peak pressures, and reducing WOB by shifting the determination of the most appropriate breathing pattern to the patient, thus potentially resulting in a more timely liberation from the ventilator. PAV+, with its capability of automatically measuring respiratory compliance and airway resistance, has greatly helped to extend the usefulness of PAV technology from research to clinical settings.

References

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