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Proportional Assist Ventilation: More than Just another Mode

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Abstract

Rationale: Liberating a patient from positive pressure ventilation to spontaneous respiration has long challenged clinicians. Emergent reintubation occurs more commonly than expected and is not without significant complications including aspiration pneumonia and even death. Proportional Assist Ventilation (PAV+) is a new ventilator modality that uses advanced computer algorithms to gauge pressure support (PS) requirements in order to improve patient-ventilator synchrony.

Objectives: To determine whether the additional information provided by PAV regarding patients ‘chest wall compliance, airways resistance, and work of breathing (WOB) may help differentiate patients that were liberated from those that were not.

Methods: We prospectively examined the respiratory mechanics of patients supported with PAV+ ventilation versus standard PS ventilation for spontaneous breathing trials (SBT).

Measurements and Main Results: Our data identified compliance and WOB as major factors predicting successful liberation. Additionally, we found significant differences in respiratory mechanics of obese patients versus non-obese patients undergoing positive pressure ventilation.

Conclusion: Additional information about respiratory mechanics revealed during SBT by PAV+ may assist in the process of liberation from mechanical ventilation.

Keywords: PAV; Proportional assist ventilation; Liberation; Weaning.

Introduction

The goal of proportional assist ventilation (PAV+) is to create a uniquely synergistic relationship between the patient and ventilator thus enhancing patient-ventilator interaction. Traditional mechanical ventilation modalities depend on the clinician estimated respiratory variables largely independent of breath to breath respiratory mechanics [1,2]. PAV+ synchronizes a patient's in spiratory cycle with mechanical assistance uniquely generating pressure in proportion to the patient's instantaneous effort . There is no predetermined target flow, tidal volume, or airway pressure; rather, the clinician determines the amount of ventilator assistance as a percent of the overall work of breathing, acting to amplify each individual breath [3]. PAV is based upon the equation of motion as noted below in a simplified formula: Pmus + Paw= (flow x R) + (V x E)

Where Pmusc=patient generated airway pressure, Paw=ventilator generated airway pressure, R=resistance in the ventilator circuit, V=volume, and E=elastic recoil of the lung. This can be further simplified into the following formula: Pventilation = Presistive + Pelastic

Such that the pressure to generate ventilation (Pventilation, or Ventilation Pressure) is equal to the Resistive pressure of the airways and tubing (Presistive) plus the Elastic pressure (Pelastic) of the lungs and chest wall. These latter two are the forces that need to be overcome by the mechanical ventilator in order to produce a breath. Conven-tional ventilator settings, like PS ventilation, utilize fixed parameters (pressure, tidal volume, etc.) for the patient to generate a breath. By contrast, PAV-capable ventilators noninvasively reassess resistance and elastance every 4-10 breaths, modifying flow-assist and volume-assist settings accordingly [3,4]. Thus PAV shifts control of the ventilatory pattern from the clinician to the patient allowing for mechanical assistance specific to individual respiratory mechanics. A good analogy for comparing PAV to, for example, Pressure Support Ventilation (PSV), is the modern cruise control on a vehicle. Cruise control, like PAV, “reads” the demands of the road—inclines and declines—in order to provide more or less support on a real-time basis and maintain the same speed. As lung dynamics and patient demands change breath-to-breath, so too does the ventilator’s pressure and flow rate. Comparatively, Pressure Support setting is tantamount to a brick on the accelerator pedal, fixing the engine’s force delivery regardless of the demands of the road.

Spontaneous breathing trials (SBT) have been shown to reduce ventilator days, ICU length of stay, and inci-dence of ventilator associated pneumonia [5-7]. While there is ample consensus regarding this fact, there re-mains some debate about how to implement the SBT. Common institutional SBT protocols include placing patients on minimal ventilation settings or a T-piece prior to extubation to assess likelihood of successful libera-tion. There is also ample evidence for using PAV as an alternative mode for performing SBT [8]. PAV+ has two potential advantages over other modes especially in managing the critically ill patient who has been intubated for a prolonged period of time and whose respiratory mechanics may have changed dramatically in that period of time. First, as this is a patient-driven mode, it is possible that the ventilator support will be better able to ad-just to the patient’s dynamic ventilatory needs and therefore may reduce patient-ventilator dis-synchrony. Second, PAV+ acquires information regarding the patient’s respiratory mechanics that are otherwise difficult to obtain, namely compliance, resistance and Work of Breathing (WOB).

The question, then, is what additional information about their respiratory mechanics and likelihood of successful liberation can we glean from PAV+ used on patients during their SBT? First, we compared PAV+ to our standard SBT mode, Pressure Support of 5cm H_2O and PEEP of 5cm H_2O (abbreviated hereafter as PS 5/5). We utilized the patient’s Rapid Shallow Breathing Index (RSBI) as the constant with which to compare respiratory endurance between the two modalities. Secondly, we examined the respiratory mechanics of patients who were liberated from the ventilator compared to those who required reintubation within 24 hours. Lastly, we examined the respiratory mechanics of obese patients (BMI greater than 30) as a subgroup of patients with an intrinsic respiratory impairment that could potentially impact the likelihood of successful liberation.

Some of the results of this study have been previously reported in the form of abstracts [9-11].

Methods

All adult patients on mechanical ventilation for > 48hours in our Trauma Intensive Care Unit (TICU) were eli-gible. Patients were initiated on SBT were placed on PS 5/5 for 10 min and average RSBI was calculated. This value was then used as our target RSBI to determine comparable PAV+ % support. Patients with average RSBI > 100 after 10 min on PS were considered to have failed their SBT and were excluded from this study. Eligible patients were initiated on PAV+ 30% supports for 10 min and respiratory data were collected. At the end of 10 min, if the RSBI was more than 10% deviation from the target RSBI, the percent support was adjusted in ±10% increments. Trials were performed in 2 min intervals and respiratory mechanics were recorded until the target RSBI was achieved. When target RSBI had been reached, patients were maintained on those settings for 10 min and respiratory data recorded, including compliance, resistance, minute ventilation, and WOB. Qualified patients were extubated shortly thereafter. Although we examined the respiratory mechanics from all patients, some patients were not extubated due to concerns for airway protection and altered mental status. Only patients who met all other criteria for extubation were included in the liberation comparison. Patients were then retrospectively categorized into two groups based on Body Mass Index (BMI) as either obese (>/= 30kg/m^2) or non-obese (< 30 kg/m^2). Respiratory mechanics data were analyzed using student’s t-test while the correlation coefficient of BMI and work of breathing (WOB) was analyzed using a linear regression model and Pearson’s coefficient. Institutional Review Board of LSUHSC approved this study prior to data collection.

Results

A total of 59 trials were performed on 53 patients. Average target RSBI did not differ between the two modali-ties (40 +/- 14 on PS 5/5vs 41.6 +/- 15 on PAV+30%). Average respiratory rate, tidal volume, and minute venti-lation were also not statistically different (Table 1). However, we found a significant difference in the mean positive airway pressure (MPAP) as well as the Delta-P (ΔP), calculated as the difference between Peak Inspira-tory Pressure and the Peak End Expiratory Pressure (PEEP) between the two modalities (Table 1). PAV+ pa-tients had a significantly lower ΔP and MPAP compared to PS (Table 1).

	Units	**PS 5/5**	**PAV+ 30%**	**p Value**
Resp Rate (f)	breaths/min	19.98 +/- 0.7	20.48 +/- 0.9	0.66
Tidal Volume (Vt)	mL	522 +/- 16	517 +/- 18	0.84
RSBI		41.6 +/- 14	41.6 +/- 15	0.53
Minute Ventilation (VE)	L/min	10.14 +/- 0.44	10.46 +/- 0.64	0.68

MPAP	cmH$_2$O	7.2 +/- 0.06	6.9 +/- 0.09	0.02*
ΔP	cmH$_2$O	5.6 +/- 0.07	4.8 +/- 0.25	0.003

Table 1: Comparison of SBT modes.

Additionally, when comparing patients who were liberated from ventilation from those who failed, we found no statistical difference in the average RSBI between PS and PAV+30 or in liberated (Lib) vs non-liberated (Non-Lib) patients (Table 2).

	Units	**LIBERATED**	**NOT LIBERATED**	**p Value**
# Trials	breaths/min	35	9	N/A
f on PS 5/5	breaths/min	18.4 +/- 0.9	23.7 +/- 2	0.01*
f on PAV 30%	breaths/min	18.4 +/- 0.9	25.1 +/- 3	0.006*
Vt on PS 5/5	mL	531 +/- 21	515 +/- 24	0.62
Vt on PAV 30%	mL	529 +/- 29	555 +/- 32	0.56
RSBI on PS 5/5		36.6 +/- 2.3	46.2 +/- 4.9	0.07
RSBI on PAV 30%		38.9 +/- 2.6	45.4 +/- 4.6	0.2
VE on PS 5/5	L/min	9.5 +/- 0.4	12.6 +/- 1.1	0.004*
VE on PAV 30%	L/min	9.0 +/- 0.4	14.3 +/- 2.4	0.0007*
MPAP on PS 5/5	cmH$_2$O	7.1+/- 0.07	7.6 +/- 0.05	0.007*
MPAP on PAV-30%	cmH$_2$O	6.8 +/- 0.07	7.5 +/- 0.3	0.003*
ΔP on PAV 30%	cmH$_2$O	4.3 +/- 0.2	6.9 +/- 0.9	0.0003*
WOB on PAV 30%	Joules/L	0.7 +/- 0.05	1.2 +/- 0.1	0.001*
Resistance	mL/cmH$_2$O	5.7 +/- 0.5	6.1 +/- 0.9	0.67
Compliance	mL/cmH$_2$O	88.5 +/- 5.6	52.33 +/- 5.6	0.003*

Table 2: Comparison of Liberated vs. Non-liberated patients.

Surprisingly, our data show significant differences in the respiratory rate (18 vs 23 bpm, p=0.01) and minute ventilation (9.1 vs. 12.3 L/min, p=0.01) but not tidal volumes (488 vs. 518 mL, p=0.4) between the ventilator modes. The PAV+ setting also allowed us to measure WOB in the Lib and Non-Lib groups. We found that pa-tients on PAV+ had significantly less work of breathing compared to the PS5/5 mode, (0.52 J/L vs. 0.72 J/L, p=0.01). Furthermore, the mean positive airway pressure (MPAP, cm H$_2$O) was also significantly different be-tween Lib and Non-Lib groups, 6.8 +/- 0.09cm H$_2$O vs. 7.3 +/- 0.17cm H$_2$O, respectively (p=0.005), as was the ΔP. More notably, when patients were changed from PS to PAV+ 30%, there was often a change in the ΔP, termed "Delta-Delta-P" (ΔΔP). The difference in ΔΔP is most extreme between the Lib group (ΔΔP = -1.2) and those who were initially removed from the ventilator and then had to be placed back on within 24 hours (ΔΔP =1.4, p=0.0004). This indicates that the Lib group typically required lower support pressures to maintain their RSBI while those who were likely to fail liberation required higher support pressures when switched to PAV+. Lastly, these same patients exhibited a lower compliance compared to patients successfully liberated, as meas-ured under the PAV+ setting (liberated= 85.7 +/- 5.7mL/cmH$_2$0 vs. failed-liberation=48.5 +/- 6.7 mL/cmH$_2$O, p=0.008). There was no difference in measured airway resistance between the two groups.

In our subgroup analysis comparing BMI and success of ventilator weaning, obesity did not appear to impact likelihood of successful liberation from the vent. There was also no difference in the ventilator mechanics (RSBI, Minute Ventilation, Tidal Volume) of obese patients versus the non-obese (Table 3).

Parameter	**Obese (N=16)**	**Non-Obese (N=34)**	**P Value**
RSBI	39.19 +/- 2.2	36.84 +/- 3	0.532
Minute Ventilation	12.6 +/- 1.5	9.9 +/- 0.4	0.088
Compliance	70.47 +/- 7.6	80.3 +/- 4.8	0.282
Resistance	6.14 +/- 0.6	6.18 +/- 0.7	0.959
P100	3.45 +/- 0.8	2.45 +/- 0.3	0.25
WOB	1.07 +/- 0.1	0.82 +/- 0.05	0.044*

Table 3: Comparison of Obese vs. Non-Obese patients.

We did, however, find a strong association between WOB and body habitus. Not only did obese patients have a significantly higher average WOB, there appears to be a linear correlation between BMI and WOB (p=0.01, 95% CI 0.06725 to 0.5413).

There were no complications during any SBT in our study and all patients studied tolerated both modalities well.

Discussion

Patients undergo extreme physiologic stress during mechanical ventilation. Compliance changes due to ARDS, pneumonia, muscle atrophy compounded by use of paralytics, malnutrition, as well as the effects of positive pressure ventilation on lung parenchyma profoundly alter the respiratory system. Differences in pulmonary physiology increase as the duration of ventilation increases. In many ways, the patient about to be extubated is profoundly different from the patient that was intubated just days earlier. The RSBI score has been a valuable tool for use in mechanical ventilation weaning due to its relative reproducibility and feasibility for protocol-driven extubation [12,13]. However, extubation failure rates of 10-30% exist, and correlate most with severity of illness [14]. Complications accompanying subsequent re-intubation are associated with prolonged ICU stay and mortality [14-16]. While extubation failure can be attributed to worsened severity of illness, it also reflects the limitations of RSBI scoring to account for factors intrinsic to each patient, including compliance and work of breathing.

Recent studies suggest changes in RSBI scores over time were more accurate indicators of extubation success than RSBI score alone [17,18]. However, no studies to date demonstrate superiority. Thus, with the ease with which information concerning respiratory mechanics can be obtained from patients on PAV+, we hypothesized that these additional data would allow better prediction of ventilator liberation success versus failure in the clin-ical setting.

The higher MPAP and ΔP in non-liberated patients suggest that a compensatory mechanism is in effect, with corresponding higher minute ventilation and respiratory rate in these patients. This compensatory mechanism may yield a normal RSBI score in all patients that does not vary significantly between the two groups. This is unmasked, to some extent, when we compared the pressure support requirements as patients moved from PS5/5 to PAV+, as highlighted by the ΔΔP. The difference between the two groups suggests that the liberated group typically required lower support pressures while those likely to fail extubation required higher support pressures to maintain their RSBI when switched to PAV+. The increased WOB in non-liberated patients further suggests higher likelihood of liberation failure. Furthermore, elevations in MPAP, ΔP, ΔΔP, and WOB acquired during our PAV+ trial suggests that compliance, which was also calculated to be significantly increased in our non-liberated patients, is the common denominator for increase respiratory demand, leading to the need for re-intubation in a significant number of our patients.

The epidemic of obesity is a national healthcare concern. To date, little research has been devoted towards ana-lyzing the effects of body habits on liberation from mechanical ventilation. Approximately 7% of patients re-quiring ICU admission are morbidly obese [19]. Because obesity decreases cardiopulmonary reserve and thora-co-abdominal compliance [20], we further studied respiratory mechanics in this population during mechanical ventilator weaning. Our results show that conventional monitoring indices among patients considered for extu-bation undergoing SBT's do not vary significantly based on BMI. The absence of a significant difference in lung mechanics between these two populations is puzzling, however it may be partially due to the number of obese patients in our study. Additionally, we hypothesize that the obese patients had adapted to their increased WOB over time and thus were able to support their ventilator needs in a fashion similar to those of the non-obese patients. Interestingly, however, the measured WOB using PAV+ may be a more sensitive measure of intrinsic cofactors that may influence ventilator management and outcomes. These results warrant further investigation into the role of WOB as an indicator for intrinsic respiratory function.

Conclusions

In conclusion, we compared the respiratory mechanics of ventilated patients on PAV+ to PS during SBT. We found that PAV+ 30% support was an equivalent mode of ventilation to PS 5/5 with regards to respiratory rate, RSBI, tidal volume, minute ventilation, as well as patient tolerance and patient ventilator synchrony. However, PAV+ offers clinically useful information about respiratory mechanics in real-time that may be instrumental in predicting successful liberation from mechanical ventilation. Similar to previous reports, our results suggest that pulmonary compliance is a significant indicator for successful liberation and cannot be reliably assessed by RSBI score alone [21]. Additionally, PAV+ software has the potential to identify patients with poor respiratory compliance or increased WOB accurately and without need of additional ventilator equipment or maneuvers. While these results support our hypothesis regarding improved prediction of liberation success in our study pop-ulation, our small population size limits the information that can be conclusively drawn from the above data. Further trials are required to confirm reliability across patient populations with varying disease processes, de-termine potential superiority over standard SBT methods, and establish guidelines that can be practically utilized in the ICU. This study supports further investigation into the use of PAV+ ventilation, as an adjunct to RSBI scoring to assess readiness for ventilator liberation in critically ill patients.

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