Effect of respiratory effort on target minute ventilation during Adaptive Support Ventilation

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Abstract

Background:

Adaptive support ventilation (ASV) is an intelligent mode of mechanical ventilation protocol which uses a closed-loop control between breaths. The algorithm states that for a given level of alveolar ventilation, there is a particular respiratory rate and tidal volume which achieve a lower work of breathing. The mode allows the clinician to set a desired minute ventilation percentage (MV%) while the ventilator automatically selects the target ventilatory pattern base on these inputs and feedback from the ventilator monitoring system. The goal is to minimize the work of breathing and reduce complications by allowing the ventilator to adjust the breath delivery taking into account the patient's respiratory mechanics (Resistance, and Compliance). In this study we examine the effect of patients' respiratory effort on target tidal volume (VT) and Minute Ventilation ($\dot{V}_e$) during ASV using breathing simulator.

Methods:

A bench study was performed by using the ASL 5000 breathing simulator to compare the target ventilator to actual VT and $\dot{V}_e$ value in simulated patients with various level of respiratory effort during ASV on the Hamilton G5 ventilator. The clinical scenario involves simulated adult male with IBW 70kg and normal lung mechanics: respiratory compliance of 70 mL/cm H_2O, and airway resistance of 9 cm H_2O/L/s. Simulated patients were subjected to five different level of muscle pressure (P_{mus}): 0 (Passive), -5, -10, -15, -25 (Active) cm H_2O at a set respiratory rate of 10 (below targeted VT) set at three different levels of minute ventilation goals: 100%, 200%, and 300%, with a PEEP of 5 cm H_2O. Fifty breaths were analyzed in every experiment. Means and standard deviations (SD) of variables were calculated. One way analysis of variants was done to compare the values. Pearson correlation coefficient test was used to calculate the correlation between the respiratory effort and the VT, $\dot{V}_e$, and peak inspiratory pressure (PIP).

Results:

The targeted VT and $\dot{V}_e$ were not significant in the passive patient when no effort was present, however were significantly higher in the active states at all levels of Pmus on the 100%, 200% and the 300 MV%. The VT and $\dot{V}_e$ increase correlated with the muscle effort in the 100 and 200 MV% but did not in the 300%.

Conclusions:

Higher inspiratory efforts resulted in significantly higher VT and $\dot{V}_e$ than targeted ones. Estimating patients' effort is important during setting ASV.

Keywords: Mechanical ventilation, ASV, InteliVent, Pmus, tidal volume, percent minute ventilation

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Introduction

Adaptive support ventilation (ASV) is an inter-breath closed-loop protocol for positive pressure ventilation that use an optimal or intelligent scheme. [1] Adaptive support ventilation (ASV) is called an intelligent mode of mechanical ventilation which uses a closed-loop control between breaths. Automated "modes" of ventilation are better characterized as "automated ventilator protocols" or "ventilator processor-based protocols"; because, in ASV the ventilator chooses the "mode" according to the imbedded algorithm. The modes used in ASV are full pressure controlled (PCV) in passive patients, pressure controlled-intermittent ventilation mode (PCV-IMV) if both ventilator and patient-triggered breaths, and complete spontaneous mode with pressure support (PSV) if all breaths are patient-triggered breaths.

ASV is based off the Otis equation for work of breathing, [2] the algorithm states that for a given level of alveolar ventilation, lower work of breathing can be achieved by targeting a particular respiratory rate and tidal volume. During ASV, clinicians set a desired minute ventilation based on the patient's ideal weight determined by gender and height. The ventilator automatically adjusts the target ventilatory pattern based on the inputs and feedback from the monitoring system taking into account the patients' respiratory mechanics. [3]

This mode of ventilation has many proven benefits in respiratory failure, weaning of mechanical ventilation compared to conventional and other automated modes. [4] Additionally, it had proven to minimize patient's work of breathing and choosing safe targeted tidal volumes reduce complications associated with ventilatory support. [5]
In this study, we examine the effect of patient's respiratory effort on the target tidal volume (VT) and minute ventilation ($\dot{V}_e$) during ASV using a breathing simulator.

Methods

This is a bench study performed by using the ASL 5000 breathing simulator (IngMar Medical, Pennsylvania, USA) to compare the target ventilator goal to actual VT and $\dot{V}_e$ value recorded in simulated patients with various level of respiratory effort during three levels of Minute Ventilation support percentage (%MinVol): 100%, 200% and 300%.

Simulated patient settings:
Adult male with ideal body weight of 70 kg. Normal lung mechanics: respiratory compliance of 70mL/cm H_2O, and airway resistance of 9 cm H_2O/L/s. [6]
Respiratory effort simulated by increasing levels of muscle pressure (P_{mus}): 0, -5, -10, -15, -25 cm H_2O at a set respiratory rate of 10 in the active simulation (rate was chosen to be below the targeted rate in all %MinVol). All spontaneous breaths were sinusoidal in pattern, (inspiratory parameters were as follows: 10 % rise, 5 % hold, and 10% release while exhalation is passive).

ASV settings:
Hamilton G5 ventilator (Bonaduz, Switzerland) was used. Percentage minute ventilation set at three different levels of 100%, 200%, 300% of predicted minute volume, PEEP 5 cm H_2O, FiO_2 21%, inspiratory trigger: Flow trigger (2 L/min), expiratory trigger sensitivity (25%), maximum airway pressure limit: 40 cmH_2O

Data collection/Analysis:
Actual values of VT, $\dot{V}_e$ and PIP were recorded. Fifty breaths were analyzed in every experiment and expressed as mean ± SD. One way analysis of variants (ANOVA) was conducted to compare the targeted and the actual values. P value of < 0.05 was considered significant. Pearson correlation coefficient test was conducted to check the correlation between the Pmus and resultant parameters (R).

Results

Results are summarized in tables 1, 2 and Figures 1, 2 and 3.

The observed VT and $\dot{V}_e$ were at goal when no patient effort were present (P_{mus} 0). However, both were significantly higher than the targeted value with increased muscle pressure in all levels of minute ventilation measured.

There was a strong positive correlation between the Pmus and the resultant TV in 100% (R: 0.96) and 200% (R: 0.91), but very weak correlation the 300% (R: 0.12).

There was a moderate negative correlation between the Pmus and the resultant inspiratory pressure in 100% (R: - 0.61) but strong ones in the 200% (R: - 0.86), and in the 300% (R: - 0.81).

Table 1: Minute ventilation in each level of inspiratory effort (Pmus) at each percentage minute ventilation support

Pmus	0	-5	-10	-15	-20	-25	P Value
100%	6.61	6.91 ± 0.03	10.31 ± 0.02	11.28 ± 0.02	16.91 ± 0.03	20.41 ± 0.03	< 0.001
200%	13.3	13.3 ± 0.01	13.9 ± 0.01	14.2 ± 0.02	14.7 ± 0.04	16.2 ± 0.12	< 0.001
300%	19.9	20.1 ± 0.01	20.1 ± 0.01	20.4 ± 0.03	19.7 ± 0.15	20.1 ± 0.24	< 0.001

Table 2: Tidal volume in each level of inspiratory effort (Pmus) at each percentage minute ventilation support

Pmus	0	-5	-10	-15	-20	-25	P Value
100%	482	493 ± 4	1037 ± 5	805 ± 7	1209 ± 9	1450 ± 16	< 0.001
200%	598	603 ± 6	630 ± 13	620 ± 20	660 ± 24	667 ± 31	< 0.001
300%	690	689 ± 6	701 ± 14	702 ± 15	697 ± 17	698 ± 13	< 0.001

Figure 1: Muscle pressure on x-axis versus tidal volume in y-axis

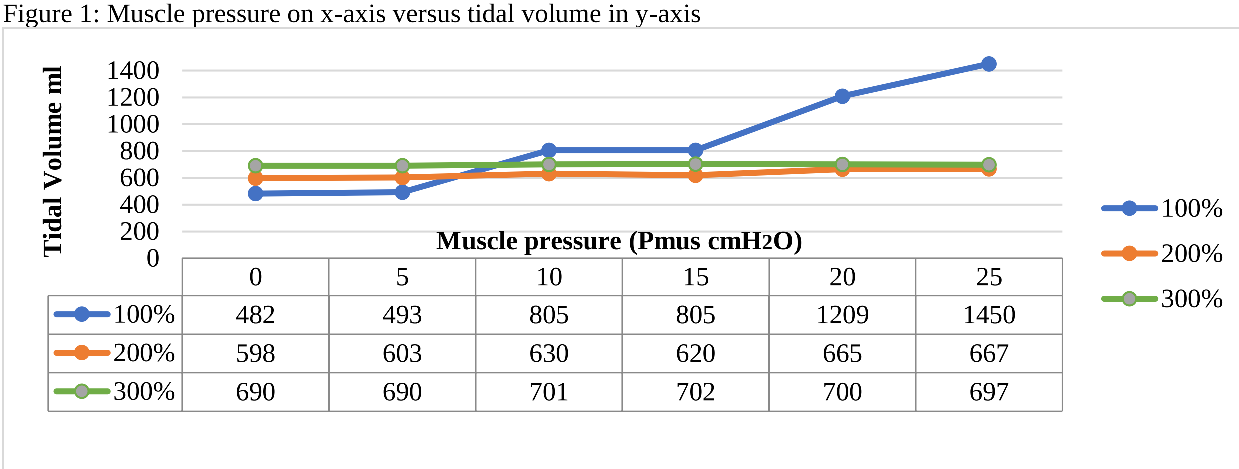


Figure 2: Muscle pressure on x-axis versus minute ventilation in y-axis

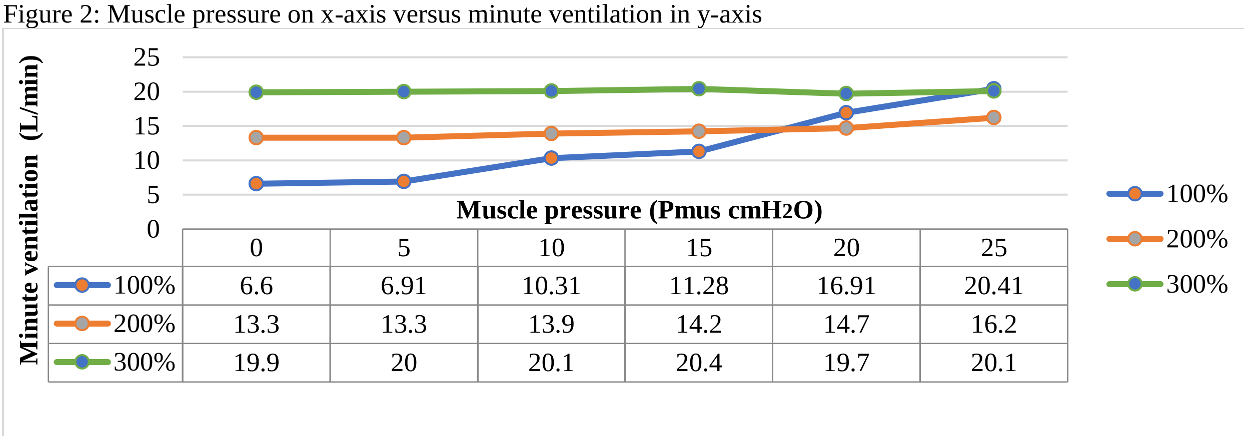
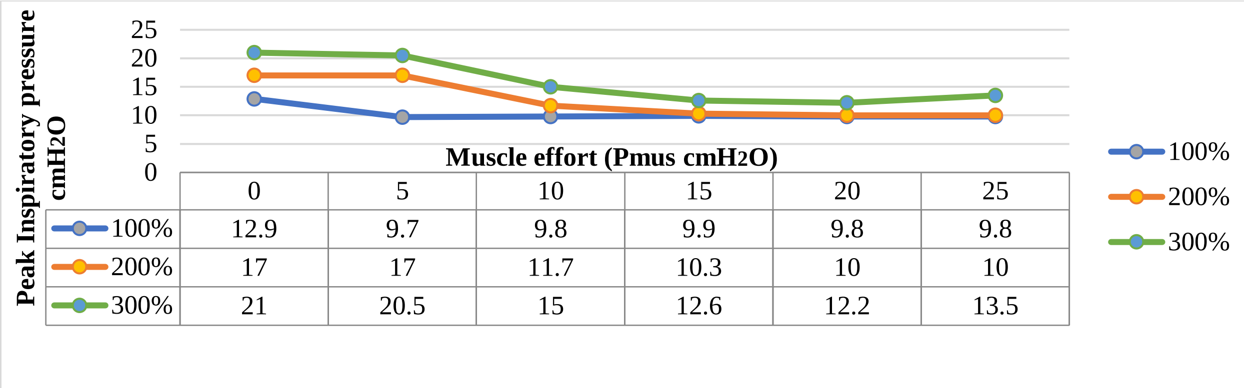


Figure 3: Muscle pressure on x-axis versus peak inspiratory pressure in y-axis



	0	5	10	15	20	25
100%	12.9	9.7	9.8	9.9	9.8	9.8
200%	17	17	11.7	10.3	10	10
300%	21	20.5	15	12.6	12.2	13.5

Discussion

Our results show that with the increased inspiratory muscles effort, the resultant tidal volumes, and minute ventilation statistically increased significantly and correlated with the increased Pmus in the 100% and 200% minute ventilation. Though both were statistically increased in the 300% MV, it is probably not clinically significant and had weak correlation with the increased muscle pressure.

Additionally, the inspiratory pressure (PIP) was significantly reduced with the increased inspiratory effort. That drop also correlated strongly with the Pmus in the 200% and 300% and moderately in the 100%. To be noted, the PIP did not drop below 10 cmH_2O as minimum safety pressure (5 cmH_2O above applied PEEP).

The goal of ASV is to ensure adequate alveolar ventilation as inputted by the clinician while minimizing risk of barotrauma, volutrauma, and air-trapping by continuous monitoring and adapting to patient's respiratory mechanics. If the patients' respiratory rate below the target, the ventilator will give additional breaths in a pressure-controlled mode. If the target VT is lower than the target one, the ventilator will increase the applied inspiratory pressure (driving pressure in passive patient or pressure support in active patient). However, if the respiratory rate and $\dot{V}_e$ are higher than the target, the mode applies less pressure (to set minimum) to achieve the target levels. Additionally, if the tidal volume is higher than the target and patient is passive, the mode will attempt reducing the respiratory rate if possible and applied pressure to a minimum level.

The next generation of intelligent ventilation, INTELLiVENT-ASV has taken further steps in automatic adjustments of its settings based on physiologic parameters from the patient. For ventilation, the exhaled partial pressure of end-tidal CO_2 ($ETCO_2$) is used to automatically adjust the percent minute ventilation according to a pre-set range. [7] For oxygenation, the PEEP and FiO_2 are adjusted according to SpO_2, according to a table derived from ARDS network. [8]

Though we did not perform our study on INTELLiVENT-ASV, and our simulator study can't be performed in that mode that requires SpO_2 and $ETCO_2$. The worry is a higher patient effort and or higher respiratory rate that could result in lower $ETCO_2$ might result in lower %MinVol that might shift more load on the patient.

In all fairness to ASV, and INTELLiVENT-ASV, the ventilator has a visual and sound alarms to alert the clinician if the targeted levels could not be reached and further trouble shooting need to be done.

In a passive-breather where no muscle pressure is applied, ASV successfully reached and remained at target goals. This finding is consistent with an earlier study by Arnal et al. [4] where 243 patients with various lung conditions underwent ASV and the result indicated that ASV selected different ventilatory pattern on the basis of respiratory mechanics in passively ventilated patients.

In a bench study done by Sulemanji et al, [9] ASV was compared to fixed VT of 6ml/kg in its ability to keep plateau pressure below the set maximum during changing respiratory mechanics. The actual delivered tidal volume in ASV varied to a low of 2.6ml/kg to avoid exceeding the plateau pressure limit inputted, however, the plateau pressure still exceeded the limit in 24 of the 108 scenarios. This is similar to the findings in our study.

Although ASV allows clinicians to input target minute ventilation and plateau pressure limit, it is important to closely monitor the actual values delivered. Patient's respiratory effort and dynamic lung mechanics must be frequently evaluated by clinicians with appropriate adjustments made to the ventilator and other ongoing treatment including sedation, analgesics, and paralytics to optimize ventilatory support and avoid mechanical ventilation associated injuries.

We believe that knowledge of the patients' respiratory effort (Pmus) that can be measured directly, or one of its surrogates that can be easily measured for example, the work of breathing (WOB), pressure-time product (PTP), [10] or airway occlusion pressure at 100 msec (P0.1) [11] are particularly important in setting any mode of mechanical ventilation.

Ventilator modes that proportionally adjusts its output according to patients' efforts for example Proportional assist ventilation (PAV), and Neurally adjusted ventilatory assist (NAVA) are designed to increase their output if increased estimated WOB (PAV), or the electrical signal to diaphragm (EAdi) in NAVA. [12]

Indeed, not all increased inspiratory effort could be or expected to be corrected by the ventilator mode. There are so many factors that need to be addressed by the clinician at the bedside. Analgesia and sedation are imperative during mechanical ventilation. [13] Recently, COVID-19 patients with respiratory failure were noted to have a high respiratory drive as part of the disease syndrome. [14]

Limitations

There are some limitations to this study, and the results should be interpreted accordingly. This study was performed by using a simulator, not in real patients with the inherent limitations of lung simulation [15]. However, use of a lung simulator allows for precise definition of lung mechanics and muscle pressure applied during ASV which cannot be done in a real patient. The simulated patient is in an adult male with a set ideal body weight which does not represent all the population of patients requiring mechanical ventilation. The automatic adjustments made during ASV based on ventilator feedback monitoring can help minimize the work of breathing in a real patient with respiratory pathology, this cannot be done in a simulated patient as the muscle pressure is set at a certain level. Finally, the dynamic respiratory mechanics and changes during mechanical ventilation cannot be adequately assessed in a simulation study. We did not test the effect of different respiratory rates or combination of different respiratory rates and inspiratory effort.

Conclusion

ASV delivered the targeted minute ventilation in the passive conditions where no muscle pressure is applied. However, targeted minute ventilation was exceeded with the increased muscle pressure. Knowledge of patient's muscle effort and work of breathing is imperative when setting target minute ventilation during ASV. Further studies in actual patients for the validation of this bench study are warranted

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