Adaptive Support Ventilation May Deliver Unwanted Respiratory Rate-Tidal Volume Combinations in Patients with Acute Lung Injury Ventilated According to an Open Lung Concept

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Abstract

Background: With adaptive support ventilation, respiratory rate and tidal volume (V_T) are a function of the Otis least work of breathing formula. We hypothesized that adaptive support ventilation in an open lung ventilator strategy would deliver higher V_T to patients with acute lung injury.

Methods: Patients with acute lung injury were ventilated according to a local guideline advising the use of lower V_T (6–8 ml/kg predicted body weight), high concentrations of positive end-expiratory pressure (PEEP), and recruitment maneuvers. Ventilation parameters were recorded when the ventilator was switched to adaptive support ventilation, and after recruitment maneuvers. If V_T increased more than 8 ml/kg predicted body weight, airway pressure was limited to correct for the rise of V_T. Results: Ten patients with a mean (±SD) Pao_2/Fio_2 of 171 ± 86 mmHg were included. After a switch from pressure-controlled ventilation to adaptive support ventilation, respiratory rate declined (from 31 ± 5 to 21 ± 6 breaths/min; difference = 10 breaths/min, 95% CI 3–17 breaths/min, P = 0.008) and V_T increased (from 6.5 ± 0.8 to 9.0 ± 1.6 ml/kg predicted body weight; difference = 2.5 ml, 95% CI 0.4–4.6 ml/kg predicted body weight, P = 0.02). Pressure limitation corrected for the rise of V_T but minute ventilation declined, forcing the user to switch back to pressure-controlled ventilation. Conclusions: Adaptive support ventilation, compared with pressure-controlled ventilation in an open lung strategy setting, delivers a lower respiratory rate-higher V_T combination. Pressure limitation does correct for the rise of V_T but leads to a decline in minute ventilation.

What We Already Know about This Topic

* Pressure-controlled ventilation (PCV) in patients with acute lung injury (ALI) allows protection against volutrauma

What This Article Tells Us That Is New

* Switching from PCV to adaptive support ventilation in consecutive ALI patients led to decreased respiratory rates and increased tidal volumes in patients with more compliant lungs

Adaptive support ventilation (ASV), a microprocessor-controlled closed-loop mode of mechanical ventilation, provides automatic selection and continuous breath-by-breath adaptation of respiratory rate (RR) and tidal volume (V_T). With ASV clinicians can set neither RR nor V_T because the delivered RR-V_T combination is a function of the Otis least work of breathing formula. Patients with acute lung injury (ALI) may benefit from measures that prevent repeated collapse and reexpansion of alveoli (i.e., mechanical ventilation according to the "open lung concept"), including the use of higher concentrations of positive end-expiratory pressure (PEEP) and recruitment maneuvers (RMs). Meta-analysis suggests this approach to prevent the need for rescue therapies for life-threatening hypoxemia, and to prevent death of patients with more severe ALI. The use of higher concentrations of PEEP and RMs could make injured lungs more compliant. This change in compliance could cause ASV to alter delivered RR-V_T combinations. The Otis formula determines the RR that minimizes work of breathing for a clinician-set minute ventilation based on the expiratory time constant (RCexp) of the respiratory system. As RCexp is obtained from the expiratory flow–volume curve, delivered RR-V_T combinations should change with alterations of compliance of the respiratory system. In the current study we determined RR-V_T combinations in patients with ALI ventilated according to a local mechanical ventilation guideline using higher concentrations of PEEP and RMs.

Materials and Methods

Patients and Informed Consent

Consecutive patients with ALI were included. The local medical ethical committee of our institute (Academic Medical Center, Amsterdam, The Netherlands) approved the study protocol and waived the need for informed consent because the objective of this study was to evaluate normal patient care.

Study Design

This is a prospective observational study of patients observed during a change in the mechanical ventilation mode, from pressure-controlled ventilation to ASV.

Inclusion Criteria

Patients were eligible for this study if they met the consensus criteria for ALI. Only passive patients (i.e., those who did not trigger the ventilator) who were considered hemodynamically stable (i.e., could safely be subjected to RMs) were included. The ability to withstand RMs was judged by the clinician responsible for the patient.

Mechanical Ventilation Protocols and RM
Patients were observed during mechanical ventilation when the ventilator was switched from pressure-controlled ventilation to ASV, and after additional RMs (fig. 1).

Patients underwent mechanical ventilation with a Hamilton Galileo ventilator (software version GMP03.41f, GCP03.40a, GTP01.00; Hamilton Medical AG, Rhäzüns, Switzerland). Passive humidification of the ventilatory circuit was applied with an HME filter (Medisize Hygrovent S, Medisize, Hillegom, The Netherlands). Predicted body weight (PBW) was calculated using the following formula: in men, PBW (kg) = 50 + 0.91 × (centimeters of height − 152.4); in women, PBW (kg) = 45.5 + 0.91 × (centimeters of height − 152.4).  

Data Collection

The following baseline data were collected: sex, body weight, height, cause of ALI/acute respiratory distress syndrome (ARDS), APACHE II score, duration of mechanical ventilation, length of stay in the intensive care unit, and mortality. The lung injury score was calculated. Delivered RR-V_T combinations were collected with a data logger connected to the ventilator (Hamilton Datalogger, version 3.27.1, Hamilton Medical AG, Rhäzüns, Switzerland). Blood gas parameters were collected from the Patient Data Management System (iMDsoft, Sassenheim, The Netherlands).

Statistical Analysis

Data are presented as the mean with SD or medians with interquartile range where appropriate. Baseline data were analyzed with descriptive statistics. A general linear model for repeated measures (repeated measures ANOVA) was conducted to assess the difference in V_T between pressure-controlled ventilation, ASV before and after RMs, and after switching back to pressure-controlled ventilation. We performed an overall test; if significant differences were found we performed post hoc testing. To control for family-wise error we used protected testing for the follow-up Bonferroni correction was used. The assumption of sphericity was violated, degrees of freedom were corrected using Greenhouse–Geisser estimates of sphericity. Statistical significance was defined as a two-tailed P value < 0.05. All statistical analyses were performed in SPSS 16.0 (SPSS Inc., Chicago, IL).

Results

Patients

Ten consecutive patients with ALI who had been intubated and mechanically ventilated were included in the study. All patients were switched from pressure-controlled ventilation to ASV within 72 h after initiation of mechanical ventilation. Baseline characteristics are shown in table 1.

Changes in RR-V_T Combinations

After a switch from pressure-controlled ventilation to ASV, RR declined (from 31 ± 5 to 21 ± 6 breaths/min; difference = 10 breaths/min, 95% CI 3–17 breaths/min, P = 0.008) and V_T increased (from 6.5 ± 0.8 to 9.0 ± 1.6 ml/kg PBW; difference = 2.5 ml, 95% CI 0.4–4.6 ml/kg PBW, P = 0.02).

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The results of this observational study can be summarized as follows. (1) 
RR decreases and V\textsubscript{T} seems imperative to use a V\textsubscript{T} center, where a mechanical 
and low VT in a setting mimicking ALI. When the compliance of the test 
predefined limits. This scenario may be impossible in the clinical setting. We chose not to sacrifice minute 
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comparisons of this type tend to replicate less often than desired. It should be recognized that the researchers were not blinded for the 
Second, patients were not randomly assigned to an ASV and a control group; they served as their own control group. Furthermore, patients were recruited in one 
In seven patients in whom V\textsubscript{T} was increased more than 8 ml/kg PBW after switching to ASV, the ventilation mode had to be switched back to pressure-controlled 
ventilation because minute ventilation decreased to unwanted low concentrations with pressure limitation (from 13 ± 2 to 8 ± 1 l/min; difference = 5 l/min, 95\% CI 
−6 to −3 l/min, P < 0.001). 
Changes After a Switch Back to Presstudy Ventilator Settings 
At the end of the study, after switching back to pressure-controlled ventilation, differences in prestudy RR-V\textsubscript{T} combinations were not statistically significant (RR, 31 ± 
6 l/min, 32 ± 7 breaths/min; difference = 1 breaths/min, 95\% CI −1–4 breath/min, P = 0.33; V\textsubscript{T}, 6.4 ± 0.8 l/min, 6.5 ± 0.9 ml/kg PBW; difference = 0.1 ml/kg PBW, 95\% CI 
−0.4–0.7, P = 0.56).

Discussion 
The results of this observational study can be summarized as follows. (1) RR decreases and V\textsubscript{T} increases when switching from pressure-controlled ventilation to ASV in patients with ALI ventilated according to an open lung concept; (2) in patients with less compliant (i.e., more injured) lungs, ASV maintains V\textsubscript{T} ≤ 8 ml/kg PBW; (3) in patients with more compliant (i.e., less injured) lungs, ASV delivers V\textsubscript{T} more than 8 ml/kg PBW; (4) pressure limitation on ASV can correct for this change, but leads to an unacceptable decrease of minute ventilation.

Our study has several limitations. First, it must be noted that the sample size of our study is small. Nevertheless, the observed changes are significant and consistent. Second, patients were not randomly assigned to an ASV and a control group; they served as their own control group. Furthermore, patients were recruited in one center, where a mechanical ventilation guideline with strict recommendations on higher concentrations of PEEP and RMs was being applied. This may not be the 
case in other centers and could have led to significantly different results. Another limitation is that we compared RR and V\textsubscript{T} over time. One could postulate that over time, differences in compliance make comparison of RR-V\textsubscript{T} impossible. It should be noted, however, that collection of data was always within a short time span (30 min).

Comparison of pressure-controlled ventilation with ASV may be a limitation. Volume-controlled ventilation was used in the ARDS Network trial,\textsuperscript{14} and is recommended by the National Institutes of Health. However, we explicitly chose to observe changes from pressure-controlled ventilation to ASV, and vice versa, because ASV is a pressure-controlled mode of mechanical ventilation. In addition, because the subgroup analyses were conducted in response to review of the data, comparisons of this type tend to replicate less often than desired. It should be recognized that the researchers were not blinded for the ventilation mode. Patients with ALI undoubtedly benefit from lung-protective mechanical ventilation using decreased V\textsubscript{T}.\textsuperscript{14,15} Therefore, current guidelines recommend using a V\textsubscript{T} of 6–8 ml/kg in patients with ALI.\textsuperscript{14} A subsequent analysis of the landmark study by the ARDS Network showed the beneficial effect of V\textsubscript{T} reduction to be independent of the severity of ALI.\textsuperscript{18} Patients with less severe ALI also benefited from lung-protective mechanical ventilation using decreased V\textsubscript{T}. In light of these findings it seems imperative to use a V\textsubscript{T} close to 6 ml/kg PBW in all patients with ALI. Our findings suggest that ASV is capable of keeping V\textsubscript{T} within the desired range of protective ventilation, but only when lungs are severely injured. Our data show that ASV applies larger V\textsubscript{T} when lungs are subjected to higher concentrations of PEEP and RMs.

One of the components of the ARDS Network’s decreased V\textsubscript{T} strategy was to also limit end-inspiratory stretching pressures (i.e., plateau pressures) to less than 30 cm H\textsubscript{2}O, and to lower V\textsubscript{T} to 4 ml/kg PBW if necessary.\textsuperscript{14} In the current study maximum airway pressures with pressure-controlled ventilation were more than 30 cm H\textsubscript{2}O; maximum airway pressures were even higher with ASV. However, the concentrations of PEEP used in our study were higher than those used in the ARDS Network trial.\textsuperscript{14} In addition, V\textsubscript{T} was decreased to 4 ml/kg PBW with neither pressure-controlled ventilation nor ASV; with ASV, there was an increase in V\textsubscript{T}, despite the high maximum airway pressures.

Results from two recent investigations, which evaluated ASV as a mechanical ventilation strategy in ALI/ARDS, seem to be in contrast with our findings. Sulemanji et al.\textsuperscript{16} studied the performance of ASV in a simulated lung injury model and compared the ability of ASV to maintain plateau pressure below a set target (28 cm H\textsubscript{2}O) in comparison with a fixed V\textsubscript{T} of 6 ml/kg during controlled mechanical ventilation.\textsuperscript{15} It should be noted that minute ventilation was sacrificed when RR and V\textsubscript{T} reached predefined limits. This scenario may be impossible in the clinical setting. We chose not to sacrifice minute ventilation, resulting in unwanted RR-V\textsubscript{T} combinations. Arnal et al.\textsuperscript{18} studied delivered RR-V\textsubscript{T} combinations in a large group of intubated and mechanically ventilated patients. They elegantly showed that ASV delivered decreased V\textsubscript{T} in clinical conditions associated with shorter RCExp (i.e., patients suffering from ALI). In that study, RCExp in patients with ALI were comparable to RCExp in the current study (0.51 ± 0.08, 0.48–0.68 s). Arnal et al. did not report on the relation between RCExp and the size of V\textsubscript{T} applied by ASV, although the report showed that ASV must have applied high V\textsubscript{T} in certain cases. This is in line with our findings.

The results of our current study are in line with a recently published simulation study.\textsuperscript{19} In a bench-to-bedside study we recently showed that ASV delivers high RR and low VT in a setting mimicking ALI. When the compliance of the test lung increased, RR decreased and VT increased. Delivered VT were more than 8 ml/kg PBW when compliance of the test lung was set at concentrations that are achieved when using the open lung concept for ALL.
It is well known that the compliance of injured lungs increases when higher concentrations of PEEP and/or RMs are applied.\(^7\,8\) Lung compliances as high as 50 ml/cm H\(_2\)O are reported in patients with ALI, when the open lung concept is applied.\(^7\) It is also known that the compliance of injured lungs increases when lung injury resolves. Although our study did not investigate RR-V\(_T\) combinations in the setting of resolving lung injury, our current data as well as results from our previous preclinical investigation\(^19\) suggest that ASV may also apply V\(_T\) more than 8 ml/kg PBW in that situation. It is unknown whether this is unwanted in patients with resolving ALI. One could speculate that a minimal work strategy with larger V\(_T\)s and slower rates might produce less lung injury than a fixed 6–8 ml/kg V\(_T\) strategy. This strategy has not yet been tested in randomized controlled trials.

In conclusion, we found ASV to deliver possible unsafe RR-V\(_T\) combinations in patients with ALI ventilated according to an open lung concept. Pressure limitation did correct for the unwanted increase of V\(_T\), but it led to an unwanted decline in minute ventilation.

References


Cited By:

This article has been cited 3 time(s).
Adaptive support ventilation for complete ventilatory support in acute respiratory distress syndrome: A pilot, randomized controlled trial
Agarwal, R; Srinivasan, A; Aggarwal, AN; Gupta, D
Respirology, 18(7): 1108-1115.
10.1111/resp.12126
CrossRef
Seminars in Respiratory and Critical Care Medicine

Novel Modes of Mechanical Ventilation
Al-Hegelan, M; MacIntyre, NR
Seminars in Respiratory and Critical Care Medicine, 34(4): 499-507.
10.1055/s-0033-1351123
CrossRef

Critical Care
A pilot prospective study on closed loop controlled ventilation and oxygenation in ventilated children during the weaning phase
Jouvet, P; Eddington, A; Payen, V; Bordessoule, A; Emeriaud, G; Gasco, RL; Wysocki, M
Critical Care, 16(3): -
ARTN R85
CrossRef

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