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Comparison of Mechanical Power During Adaptive Support Ventilation Versus Nonautomated Pressure-Controlled Ventilation—A Pilot Study

OBJECTIVES: The aim of this pilot study was to compare the amount of “mechanical power of ventilation” under adaptive support ventilation with nonautomated pressure-controlled ventilation.

DESIGN: Single-center, observational prospective pilot study adjoining unitwide implementation of adaptive support ventilation in our department.

SETTING: The ICU of a nonacademic teaching hospital in the Netherlands.

PATIENTS: Twenty-four passive invasively ventilated critically ill patients expected to need of invasive ventilation beyond the following calendar day.

MEASUREMENTS AND MAIN RESULTS: In patients under adaptive support ventilation, only positive end-expiratory pressure and F_{iO_2} were set by the caregivers—all other ventilator settings were under control of the ventilator; in patients under pressure-controlled ventilation, maximum airway pressure (Pmax), positive end-expiratory pressure, F_{iO_2} , and respiratory rate were set by the caregivers. Mechanical power of ventilation was calculated three times per day. Compared with pressure-controlled ventilation, mechanical power of ventilation with adaptive support ventilation was lower (15.1 [10.5–25.7] vs 22.9 [18.7–28.8] J/min; $p = 0.04$). Tidal volume was not different, but Pmax ($p = 0.012$) and respiratory rate ($p = 0.012$) were lower with adaptive support ventilation.

CONCLUSIONS: This study suggests adaptive support ventilation may have benefits compared with pressure-controlled ventilation with respect to the mechanical power of ventilation transferred from the ventilator to the respiratory system in passive invasively ventilated critically ill patients. The difference in mechanical power of ventilation is not a result of a difference in tidal volume, but the reduction in applied pressures and respiratory rate. The findings of this observational pilot study need to be confirmed in a larger, preferably randomized clinical trial.

KEY WORDS: closed-loop ventilation; critical care medicine; mechanical power; mechanical ventilation

The mechanical power of ventilation (MP) is the amount of energy per time transferred from the ventilator to the respiratory system. Although this energy is mainly used to overcome airway resistance (R_{aw}) and respiratory system compliance (C_{RS}), part of it acts directly on lung tissue, potentially causing ventilator-induced lung injury (VILI) (1, 2). MP has been shown

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to be associated with important patient-centered outcomes in critically ill patients in need of invasive ventilation (3, 4).

MP is a summary variable that includes all components suggested to play a role in VILI (5), including tidal volume (V_T), peak pressure (P_{peak}) and driving pressure (ΔP), and the respiratory rate (RR). The complex interplay between these components makes it difficult to set a ventilator so that the least amount of energy per time is transferred from the ventilator to the respiratory system in an individual patient.

Adaptive support ventilation (ASV) is a closed-loop ventilation mode that provides pressure-controlled ventilation (PCV) or pressure-support ventilation (PSV) depending on patient's activity. With ASV, all components that considered important in prevention of VILI are under control of the ventilator, and it adapts breath-by-breath to the R_{aw} and C_{RS} (6). We hypothesized ASV delivers ventilation with less MP than nonautomated PCV.

MATERIALS AND METHODS

This was an observational prospective pilot study adjoining unitwide implementation of ASV in the ICU of the Reinier de Graaf Hospital in Delft, the Netherlands. Ethical approval was given by the Medical Ethics Review Committee South-West Holland (number 19-031). The need for informed consent was waived. Before implementation of ASV, PCV and PSV were the standard modes. Ventilator settings were adjusted by caregivers with extensive experience in invasive ventilation, with normocapnia and sufficient oxygenation as the targets.

MP was calculated from ventilator variables collected in 12 consecutive patients directly before unitwide implementation of ASV and 12 consecutive patients after implementation. In both periods, patients were eligible if: 1) ≥ 18 years old and 2) expected to receive controlled ventilation for at least 24 hours. In the first group, PCV was used exclusively when patients were passive, and maximum airway pressure (P_{max}), positive end-expiratory pressure (PEEP), F_{IO_2} , and RR were set by the caregivers—meaning that V_T and ΔP were set indirectly. In patients in the second group, ASV was used when patients were passive or active, and ΔP , V_T , and RR were under control of the ASV algorithm—meaning that only PEEP and F_{IO_2} were adjustable by the caregivers. At all times,

during collection of ventilator data for calculating MP, patients had to be passive.

MP was calculated three times a day and at least one time per nursing shift that lasted 8 hours, between 07:00 AM and 24:00 AM, when a patient was in a stable condition, and for a maximum of 96 hours. If a patient became active, or when a patient was weaned from the ventilator, data collection stopped.

MP, expressed in J/min, was calculated using the following equation (5):

$$0.098 * V_T * RR * (P_{peak} - \frac{1}{2} * \Delta P)$$

V_T was in liters and ΔP was calculated using the following equation:

$$\Delta P = P_{max} - \text{total PEEP}$$

P_{max} was determined by performing an inspiratory hold, and total PEEP was determined by performing an expiratory hold.

MP, the primary end point, and other ventilation parameters were expressed as medians. A Mann-Whitney U test was used for the comparison, as data were not normal distributed and because of the small sample size. A linear mixed-model regression was used to assess the association between ventilation mode and MP. The model was adjusted for the following covariates: gender, time, and APACHE IV score. A possible interaction effect between ventilation mode and time was tested including the interaction (ventilation * time) in the model. Linear mixed model was chosen because of the repeated measures in the study and to account for the small amount of missing data and different time intervals between the repeated measures.

Cumulative distribution plots (Fig. 1; and eFigs. 1 and 2, <http://links.lww.com/CCX/A500>) and box plots (eFigs 3 and 4, <http://links.lww.com/CCX/A500>) were used to visualize differences in MP and other ventilator parameters. A p value of less than 0.05 was considered statistically significant.

RESULTS

Twenty-four patients were studied; the two groups were comparable with regard to baseline characteristics (Table 1). Data were collected median 6 hours (5–8 hr) apart. Compared with PCV, median MP was lower with ASV (15.1 J/min [10.5–25.7 J/min] vs 22.9 J/min [18.7–28.8 J/min]; $p = 0.04$) (Fig. 1; and eFigures 1 and 2, <http://links.lww.com/CCX/A500>). Median V_T was not different (7.1 mL/kg [6.7–7.6 mL/kg] vs 7.3 mL/kg

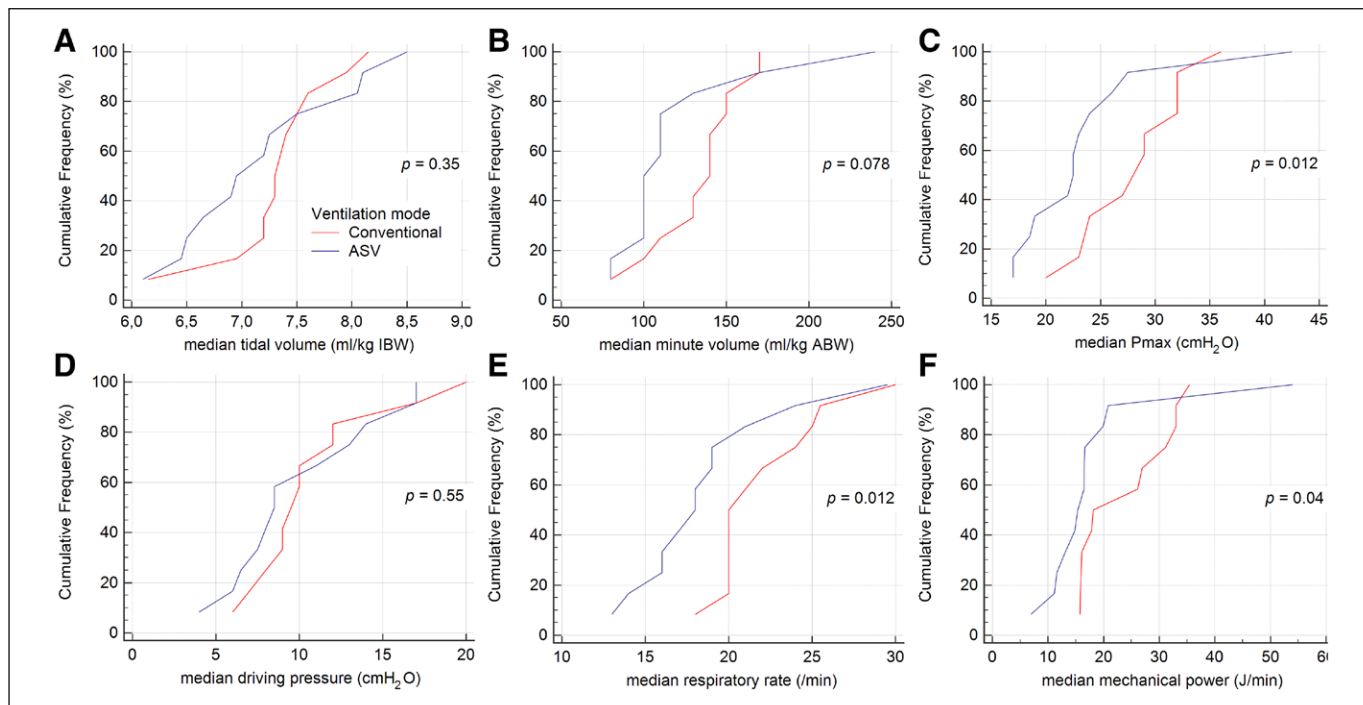


Figure 1. Cumulative frequency distribution plots for ventilation parameters used for calculation of mechanical power. **A**, Tidal volume in mL/kg ideal body weight (IBW), **B**, minute volume in mL/kg actual body weight (ABW), **C**, Pmax in cmH₂O, **D**, driving pressure in cmH₂O, **E**, the respiratory rate per minute and **F**, the mechanical power in J/min. Per each patient, the median for the ventilation parameter of interest was calculated and plotted. ASV = adaptive support ventilation.

[7.0–7.7 mL/kg] predicted body weight; $p = 0.35$), but median Pmax (23 cm H₂O [19–28 cm H₂O] vs 28 cm H₂O [25–31 cm H₂O]; $p = 0.012$), and median RR (18 [16–22] vs 23 [20–25]; $p = 0.012$) were lower with ASV. At all time points and in all patients, MP was lower with ASV (eTable 1, <http://links.lww.com/CCX/A500>; and eFigures 3 and 4, <http://links.lww.com/CCX/A500>). Linear mixed-model regression analysis showed that the variable “ventilation mode” was statistically significant (effect estimate = 6.2 J/min; 95% CI = 1.06–11.29; $p = 0.019$). Time as well as interaction effect between ventilation mode and time were not significant ($p = 0.493$ and $p = 0.998$, respectively).

DISCUSSION

In this observational study, ASV was found to deliver a lower MP compared with PCV. Of the other ventilation parameters, Pmax and RR, but not V_T was lower with ASV. ASV was able to provide ventilation at a lower MP, probably because its algorithm is based on the minimal work of breathing principle, as described by Otis et al (7), and the minimal force of breathing, as described by Mead (8). ASV adapts, breath-by-breath, RR and ΔP to R_{aw} and C_{RS} to achieve these two goals.

Our findings are in line with a recently published randomized clinical trial in postcardiac surgery patients (9). That study showed a decrease in MP with INTELLiVENT-ASV, an automated ventilation mode that uses similar algorithms as ASV. The current findings add to our knowledge by showing that ASV reduces MP also in sicker critically ill patients.

This pilot study has strengths and limitations. Strength is the prospective analysis, in which we pre-defined the analysis plan from which we did not deviate. However, the study was small and performed in only one center, and patients were not randomized or crossed over. Another limitation is the unadjusted analysis presenting median MP. Therefore, the effect of ventilation mode on MP was assessed by means of linear mixed-model method. In addition, missing values occur in both groups (17 out of a possible total amount of 144 values in the conventional group and 28 out of 144 in the ASV group). Although a linear mixed model accounts for missing values, the greater amount of missing values in the ASV group may have affected the result. MP was calculated using the simplified equation; there are other ways to calculate MP (10), but we did not collect sufficient data to use those other formulas. Last

TABLE 1.
Baseline Characteristics

Characteristic	Conventional <i>n</i> = 12	Adaptive Support Ventilation, <i>n</i> = 12	<i>p</i>
Age, yr	65 (58–72)	69 (49–79)	0.73
Gender, male	7 (58)	8 (67)	0.67
Height, cm	170 (162–180)	175 (173–182)	0.06
Weight, kg	72 (61–89)	91 (68–94)	0.38
Body mass index, kg/m ²	26 (21–31)	27 (23–30)	0.97
Predicted body weight, kg	65 (54–75)	70 (66–76)	0.99
Acute Physiology and Chronic Health Evaluation IV score	104 (74–124)	100 (65–125)	0.88
Reason of admission			
Pneumonia	2 (17)	2 (17)	
Sepsis	3 (25)	0	
Postoperative	0	2 (17)	
Cardiovascular	3 (25)	4 (33)	
Exacerbation of chronic obstructive pulmonary disease	1 (8)	0	
Pancreatitis	0	1 (8)	
Suicide attempt	0	1 (8)	
Influenza A	1 (8)	0	
Interstitial lung disease	1 (8)	0	
Hydropneumothorax	0	1 (8)	
Epiglottitis	1 (8)	0	
Gastrointestinal bleeding	0	1 (8)	
Vital signs at the beginning of ventilation			
Heart rate (beats/min)	104 (85–115)	88 (70–125)	0.43
Mean arterial blood pressure (mm Hg)	69 (56–77)	66 (63–174)	0.71
SpO ₂ (%)	94 (91–98)	95 (93–100)	0.18
Laboratory data at the beginning of ventilation			
pH	7.29 (7.18–7.36)	7.28 (7.24–7.31)	0.73
PaO ₂ (kPa)	12 (9.8–15.5)	12.4 (10.0–19.8)	0.52
PaCO ₂ (kPa)	7.3 (6.4–8.9)	6 (5.6–9.3)	0.74
Bicarbonate (mmol/L)	27 (24–30)	26 (19–31)	0.94

Data are median (interquartile range) or *n*/total (%).

but not least, the exact and causative role of MP, and the effects of a reduction in MP to prevent VILI are still not yet fully understood.

CONCLUSIONS

Findings of this pilot study suggest ASV may have benefits compared with conventional ventilation with respect to the MP transferred from the ventilator to the respiratory system of critically ill passive patients. This effect is not achieved by a limitation of V_T , but by a reduction in applied pressures and RR. The findings of this observational pilot study need to be confirmed in a larger, preferably randomized clinical trial.

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Dr. Schultz attended a workshop organized by Hamilton, expenses for lodging was covered for the invited experts, and participants from abroad had their travel expenses reimbursed and speakers received a speaker's fee of CHF 800. The remaining authors have disclosed that they do not have any potential conflicts of interest.

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REFERENCES

1. Protti A, Andreis DT, Monti M, et al: Lung stress and strain during mechanical ventilation: Any difference between statics and dynamics? *Crit Care Med* 2013; 41:1046–1055
2. Cressoni M, Gotti M, Chiurazzi C, et al: Mechanical power and development of ventilator-induced lung injury. *Anesthesiology* 2016; 124:1100–1108
3. Serpa Neto A, Deliberato RO, Johnson AEW, et al; PROVE Network Investigators: Mechanical power of ventilation is associated with mortality in critically ill patients: An analysis of patients in two observational cohorts. *Intensive Care Med* 2018; 44:1914–1922
4. Urner M, Jüni P, Hansen B, et al: Time-varying intensity of mechanical ventilation and mortality in patients with acute respiratory failure: A registry-based, prospective cohort study. *Lancet Respir Med* 2020; 8:905–913
5. Gattinoni L, Tonetti T, Cressoni M, et al: Ventilator-related causes of lung injury: The mechanical power. *Intensive Care Med* 2016; 42:1567–1575
6. Arnal JM, Wysocki M, Nafati C, et al: Automatic selection of breathing pattern using adaptive support ventilation. *Intensive Care Med* 2008; 34:75–81
7. Otis AB, Fenn WO, Rahn H: Mechanics of breathing in man. *J Appl Physiol* 1950; 2:592–607
8. Mead J: Control of respiratory frequency. *J Appl Physiol* 1960; 15:325–336
9. De Bie AJR, Neto AS, van Meenen DM, et al: Fully automated postoperative ventilation in cardiac surgery patients: A randomized clinical trial. *Br J Anaesth* 2020; 125:739–749
10. Silva PL, Ball L, Rocco PRM, et al: Power to mechanical power to minimize ventilator-induced lung injury? *Intensive Care Med Exp* 2019; 7:38