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CORRESPONDENCE

Calculating mechanical power for pressure-controlled ventilation

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Dear Editor,
Mechanical power (MP) is the amount of energy applied to the respiratory system per minute during mechanical ventilation. Calculation of MP was only described for Volume-Controlled Ventilation (VCV) [1, 2], until Becher et al. [3] proposed both a comprehensive and a simplified power equation for Pressure-Controlled Ventilation (PCV). We, however, think that the power equation, proposed by Becher et al. [3], is physiologically not entirely correct and propose an alternative power equation which is simpler than Becher's approach and matches the physiology of pressure-controlled ventilation better. It is important to remark that the equation can only be used when mechanical ventilation is completely passive. Furthermore, our equation is an approximation of reality and is based on certain assumptions which are explained in the Electronic supplemental material (ESM).

The work of a single breath is defined by the area of the PV-loop including PEEP [1]. In PCV the first part is nonlinear (Fig. 1) and depends on the pressure difference (ΔP_{insp}), resistance and compliance of the respiratory system [4]. This can be mathematically described by Eq. (1), where 0.098 is a conversion factor to J/min, RR is the respiratory rate in beats/min, V_t is the tidal volume in L, PEEP is the positive-end expiratory pressure in cmH_2O, ΔP_{insp} is the inspiratory pressure in cmH_2O, T_{insp} is the inspiratory time in s, R is the resistance in $cmH_2O/L/s$ and C is the compliance in L/cmH_2O. See the (ESM) for the derivation of this equation.

$$\mathrm{MP}_{\mathrm{PCV}} = 0.098 \cdot \mathrm{RR} \cdot V_t \cdot \left[\mathrm{PEEP} + \Delta P_{\mathrm{insp}} \cdot \left(1 - e^{\frac{-T_{\mathrm{insp}}}{R \cdot C}}\right)\right] \quad (1)$$

The power equation was validated using the area enclosed by the dynamic pressure–volume loop. Regression and Bland–Altman analyses were performed for testing of agreement. The comprehensive equation of Becher et al. [3] ($MP_{computed,Becher}$) was compared to the power equation stated in this article ($MP_{computed}$). Validation of Eq. (1) was performed by analysis of 25 PV-loops from 17 patients being ventilated in the P-CMV mode (pressure-controlled mandatory ventilation) at the ICU of the Leiden University Medical Center (LUMC, an academic regional hospital with a 30 bed ICU). The patients were ventilated with the Hamilton C6 ventilator, which has a default pressure rise time of 50 ms.

All patients were sedated and were without spontaneous breathing activity. Mean measured mechanical power using the PV-loop was 15.62 ± 6.76 J/min. Mean computed mechanical power using Eq. (1) was 15.68 ± 6.75 J/min. Further ventilation characteristics are shown in Table 1. The computed mechanical power using Eq. (1) was highly correlated with MP measured using the PV-loop, according to the following regression equation: $MP_{computed} = 0.98 \times MP_{measured} + 0.43$; $R^2 = 0.99$. Bland–Altman analysis (shown in Fig. 2) showed a mean difference between the two methods of 0.06 J/min ($p = 0.67$), the upper limit of agreement (+ 1.96SD) was 1.4 J/min and the lower limit of agreement (− 1.96SD) was − 1.3 J/min. Limits of agreement were within 8.6%.

We used the equation of Becher et al. [3] on the same dataset. The regression equation was $MP_{computed,Becher} = 1.12 \times MP_{measured} - 0.10$; $R^2 = 0.97$. Bland–Altman analysis showed a mean difference between the two methods of 1.8 J/min, the upper limit of agreement (+1.96SD) was 4.8 J/min and the lower

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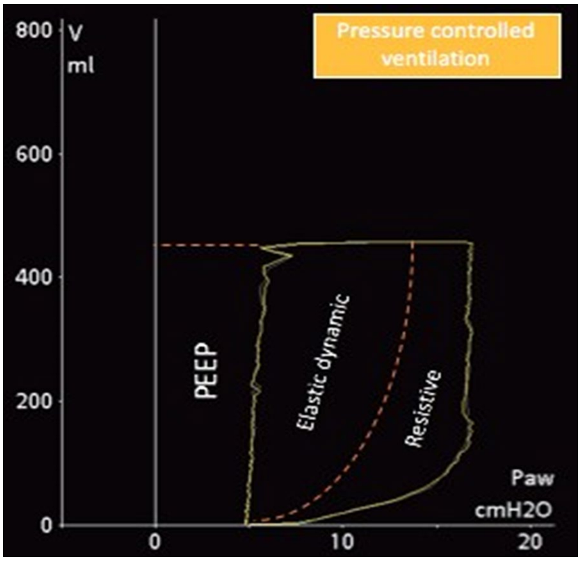

Fig. 1 Dynamic pressure volume loop showing the three components of mechanical power for pressure controlled ventilation. This image also shows the non-linear shape of the first part of the PV-loop

limit of agreement (−1.96SD) was − 1.2 J/min (Fig. 3). Limits of agreement were within 13%, which was worse in comparison with our power calculation method. We found for larger values of MP the method of Becher [3] increasingly inaccurate.

Table 1 Ventilation characteristics and mechanical power in different patient groups

Characteristic	Median (interquartile range)
MP—all patients ($n=17$) (J/min)	13.34 (11.40–17.82)
Tidal volume (mL)	442 (406–496)
Minute volume (L/min)	7.2 (6.3–9.6)
PEEP (cmH_2O)	8 (5–12)
Peak pressure (cmH_2O)	22 (18–26)
Respiratory rate (/min)	16 (15–20)
Compliance (mL/cmH_2O)	45.5 (37.5–53.8)
Resistance ($L/cmH_2O/s$)	13 (11–15)
Mechanical power in different patient groups	
MP—ARDS patients ($n=5$) (J/min)	24.31 (17.52–26.18)
MP—post surgery patients ($n=8$) (J/min)	11.49 (10.83–13.13)
MP—other patients ($n=4$) (J/min)	14.54 (11.40–17.82)

The power equation we propose is not too complicated, takes into account the important physiologic parameters that govern pressure-controlled ventilation and is a good approximation of the Mechanical Power in Pressure Controlled Ventilation. The parameters required are readily available from most ventilators and can be implemented in a patient data management system. We therefore advocate its use although it should be tested in a larger dataset with a more heterogeneous population.

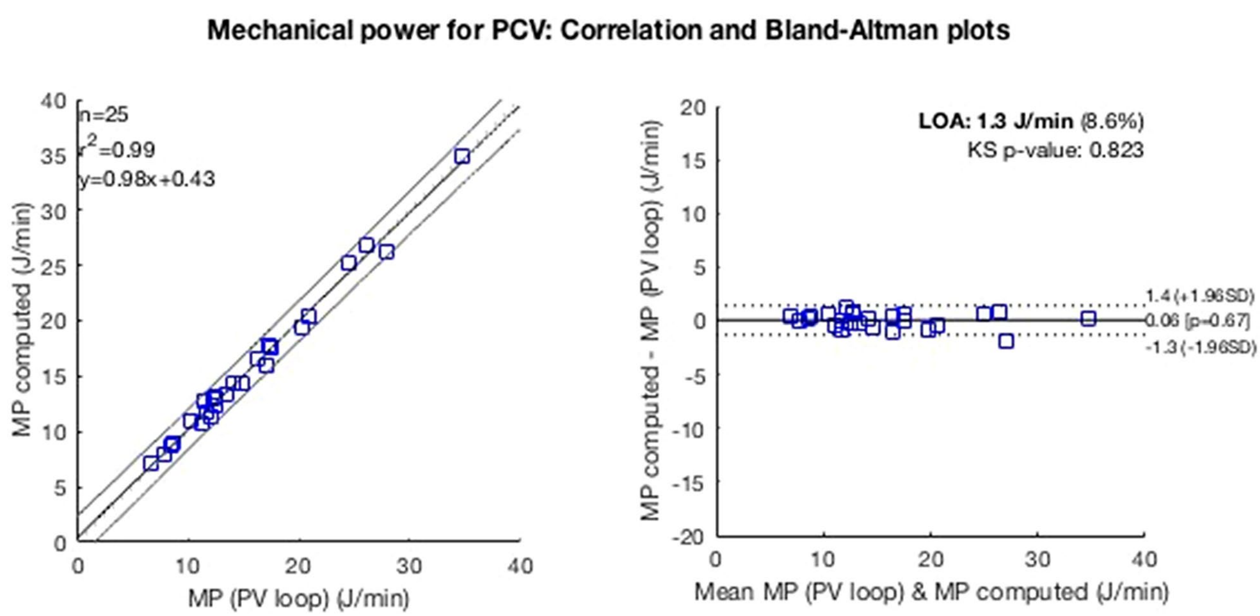

Fig. 2 Correlation and Bland-Altman plots for $MP_{computed}$ using the proposed power equation

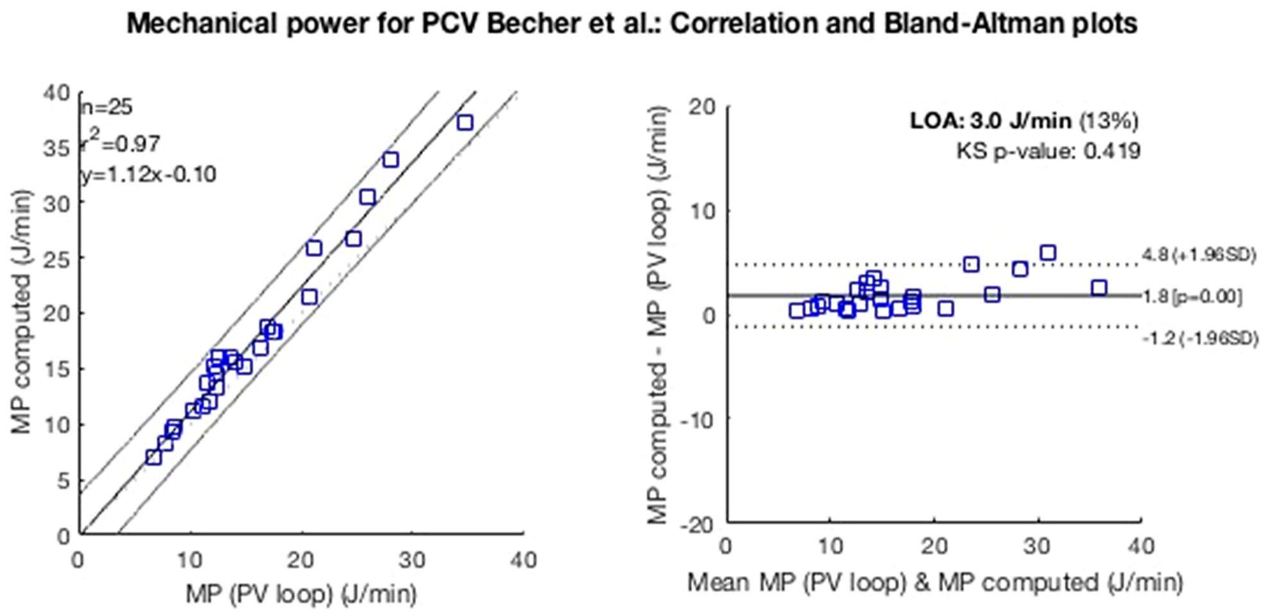

Fig. 3 Correlation and Bland-Altman plots for $MP_{computed,Becher}$

Electronic supplementary material

The online version of this article (https://doi.org/10.1007/s00134-019-05698-8) contains supplementary material, which is available to authorized users.

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