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LETTER

Calculation of mechanical power for pressure-controlled ventilation

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Dear Editor,

The mechanical power (MP) is a single variable encompassing important ventilator-related causes of lung injury that can be calculated using a set of parameters routinely measured during volume-controlled ventilation (VCV) [1]. A recent analysis of two large databases revealed that high MP is independently associated with mortality in critically ill patients on mechanical ventilation [2]. As the equation for calculation of MP used for these analyses is based on the assumption of VCV with a linear rise of airway pressure (P_{aw}) during inspiration, it is not suitable for calculating MP during pressure-controlled ventilation (PCV) [3]. Here, we describe two equations for estimating MP during PCV and assess their validity in patients ventilated with this mode.

We retrospectively analyzed PCV data of patients enrolled in two previously published studies [4, 5]. We excluded datasets obtained during assisted spontaneous breathing and during VCV.

Under the assumption of an ideal "square wave" P_{aw} during inspiration, MP during PCV was calculated according to the simplified equation

$$\mathrm{MP_{PCV}} = 0.098 \cdot \mathrm{RR} \cdot V_T \cdot \left(\Delta P_{insp} + \mathrm{PEEP}\right),$$

where ΔP_{insp} is the change in P_{aw} during inspiration, PEEP is the positive end-expiratory pressure (both cmH_2O), V_T is the tidal volume (l) and RR is the respiratory rate (1/min), with 0.098 as a correction factor to obtain the result in J/min.

Taking into account inspiratory pressure rise time (T_{slope}), MP was additionally calculated according to the comprehensive equation

$$MP_{PCV(slope)} = 0.098 \cdot \mathrm{RR} \cdot \left[(\Delta P_{insp} + \mathrm{PEEP}) \cdot V_T - \Delta P_{insp}^2 \cdot C \cdot \left(0.5 - \frac{R \cdot C}{T_{slope}} + \left(\frac{R \cdot C}{T_{slope}}\right)^2 \cdot \left(1 - e^{\frac{-T_{slope}}{R \cdot C}}\right)\right)\right],$$

where C is the compliance (l/cmH_2O) and R is the resistance ($cmH_2O/l/s$). The derivation of both equations and the determination of respiratory mechanics during PCV are outlined in the ESM.

To obtain reference values (MP_{ref}), data of P_{aw} and flow recorded by the ventilator (Evita XL; Dräger, Lübeck, Germany) at a sampling rate of 100 Hz were integrated to calculate the area of the pressure–volume loop and subsequently multiplied by 0.098·RR to obtain the result in J/min. For each patient, one average value of MP_{ref}, MP_{PCV} and $MP_{PCV(slope)}$ was calculated from all breaths recorded during a period of PCV with unchanged ventilator settings. Intra-individual variability was assessed by calculating the coefficient of variation between all breaths analyzed during this period.

MP_{PCV} and $MP_{PCV(slope)}$ were compared to MP_{ref} by linear regression and the Bland–Altman method comparison. Numerical results are expressed as mean ± standard deviation.

We analyzed PCV datasets obtained from 42 patients (age 55 ± 18 years; 29 male; height 174 ± 9 cm; PaO_2/FiO_2 195 ± 78 mmHg; 29 patients with ARDS) ventilated with external PEEP of 8 ± 5 cmH_2O, RR 14 ± 4/min, ΔP_{insp} 14 ± 4 cmH_2O, V_T 545 ± 161 ml and T_{slope} 0.2 ± 0.03 s. Calculated auto-PEEP was 0.81 ± 0.77 cmH_2O.

On average, MP_{ref} was 15.6 ± 6.9 J/min. With the simplified equation, we calculated values for MP_{PCV} of 16.3 ± 7.1 J/min, which were highly correlated to

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MP_{ref} ($r^2 = 0.981$; bias +0.73 J/min; 95% limits of agreement (LoA) −1.48 to +2.93 J/min; Fig. 1a, b). With the comprehensive equation, the determined values of $MP_{PCV(slope)}$ averaged 15.6 ± 6.9 J/min, almost identical to MP_{ref} ($r^2 = 0.985$; bias +0.03 J/min; 95% LoA −1.91 to +1.98 J/min; Fig. 1c, d). The between-breath coefficients of variation for MP_{ref}, MP_{PCV} and $MP_{PCV(slope)}$ were 0.02 ± 0.02, 0.04 ± 0.05 and 0.03 ± 0.03, respectively.

The simplified equation allows estimation of MP for PCV with a small bias caused by disregarding T_{slope}. The comprehensive equation corrects this bias but requires knowledge of T_{slope}, R and C. If only V_T, RR, PEEP and ΔP_{insp} are known, the simplified equation may still yield acceptable results for most clinical situations.

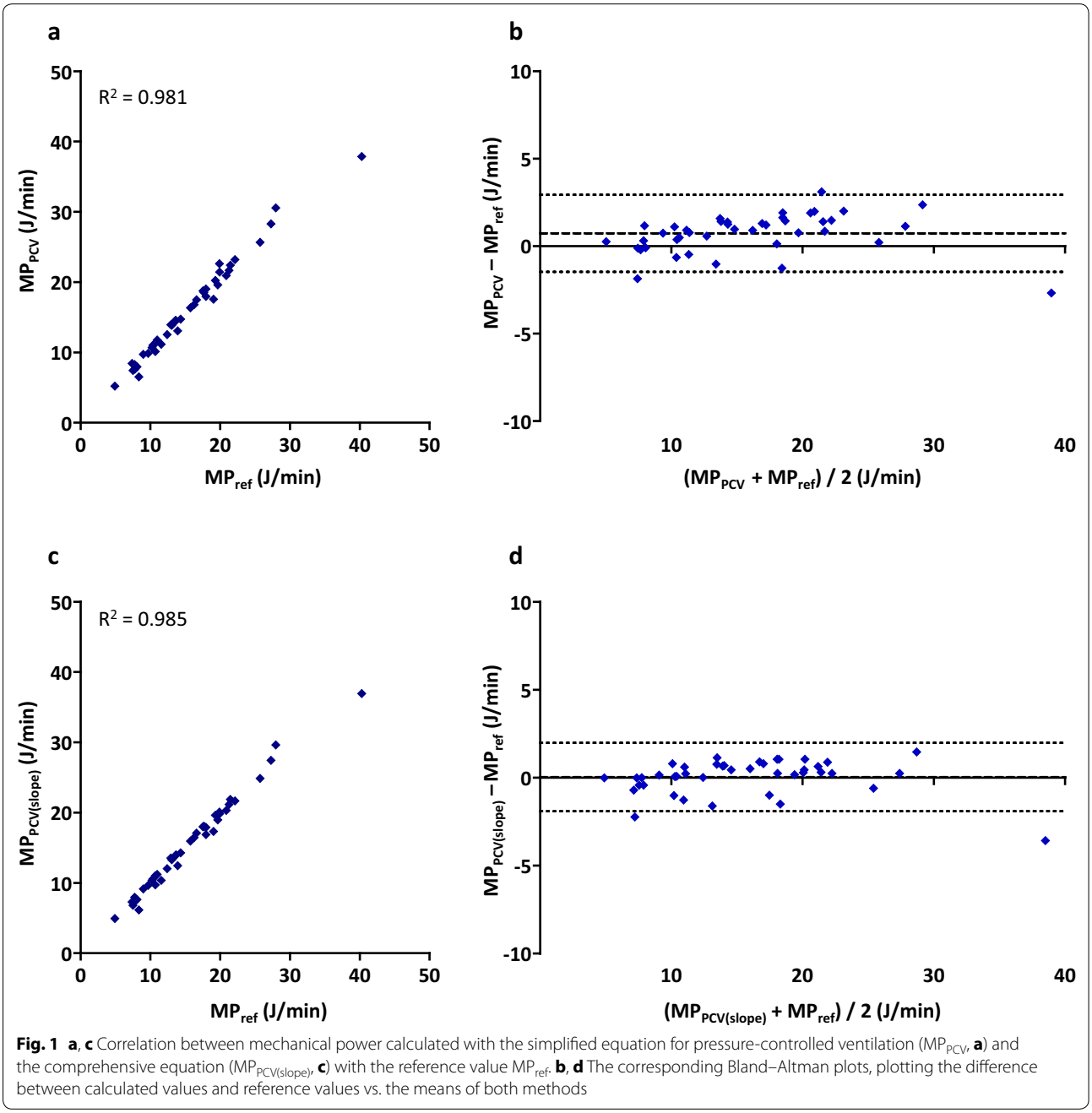

Fig. 1 **a**, **c** Correlation between mechanical power calculated with the simplified equation for pressure-controlled ventilation (MP_{PCV}, **a**) and the comprehensive equation ($MP_{PCV(slope)}$, **c**) with the reference value MP_{ref}. **b**, **d** The corresponding Bland–Altman plots, plotting the difference between calculated values and reference values vs. the means of both methods

Electronic supplementary material
The online version of this article (https://doi.org/10.1007/s00134-019-05636-8) contains supplementary material, which is available to authorized users.

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Compliance with ethical standards

Conflicts of interest
Tobias Becher and Dirk Schädler received lecture fees from Drägerwerk AG & Co. KGaA (Lübeck, Germany). Matthias van der Staay is an employee of imt and works for imtmedical, Buchs, Switzerland. The other authors report no conflicts of interest.

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