


RESEARCH LETTER

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Successful ventilation of two animals with a single ventilator: individualized shared ventilator setup in an in vivo model

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Dear Editor,

As the ongoing COVID-19 crisis is spreading from developed into developing nations, a shortage of ventilators in ICUs can be expected during peak prevalence. Sharing a ventilator among patients has been put forward as a rescue solution [1, 2]; in this setting, the so-called pairing of patients with similar characteristics is needed [3–5]. We have developed a modified shared ventilator design that allows for individualization of tidal volumes and driving pressures, positive end-expiratory pressure (PEEP), and inspired oxygen fraction (FiO₂) [6], which can thus substantially individualize the delivered breaths, removing the need of pairing (see Fig. 1).

We have now successfully used this ventilator setup in an in vivo model in a pair of ventilated sheep with different lung compliance, further supporting the potential of this shared ventilator setup as a lifesaving intervention in a crisis setting.

After ethical approval, two healthy Swifter sheep (62 kg and 60 kg, 1 year old) received general anesthesia (buprenorphine-sevoflurane), intubation, arterial catheter, and a C-section. After baseline blood

gas and respiratory mechanics measurements, both sheep were connected to a single ventilator. Animal 1 had a lung compliance of 38 ml cmH₂O⁻¹, while animal 2 had a lung compliance of 28 ml cmH₂O⁻¹, differences in compliance could be explained by their position. Ventilator settings and measurements are shown in Table 1. The targeted tidal volume of the shared ventilator was set by adding together the individual tidal volumes of animal 1 (600 ml) and 2 (800 ml), creating a combined tidal of 1400 ml. We measured individual airway pressures, with a fluid-air interfaced pressure transducer (Edwards Lifesciences, Irvine, USA), and individual end-tidal CO₂ (etCO₂) levels (see Fig. 1). We then partially closed the inspiratory flow for animal 1 until the measured etCO₂ levels for each animal were similar to those measured at baseline. This titration was successfully achieved within a few breaths, and the total set tidal volume could be distributed accurately among the two animals. With the added in-line individual PEEP valve, animal 2 received a PEEP of 7 cmH₂O, whereas the other received 3 cmH₂O of PEEP. The individually measured airway pressures demonstrated that the set PEEP levels were successfully achieved for each animal. FiO₂ could be adjusted as expected, with one animal receiving an FiO₂ of ~0.3 and the other ~0.8 with added O₂ to its breathing circuit during a short test period. Adequacy of ventilation and oxygenation

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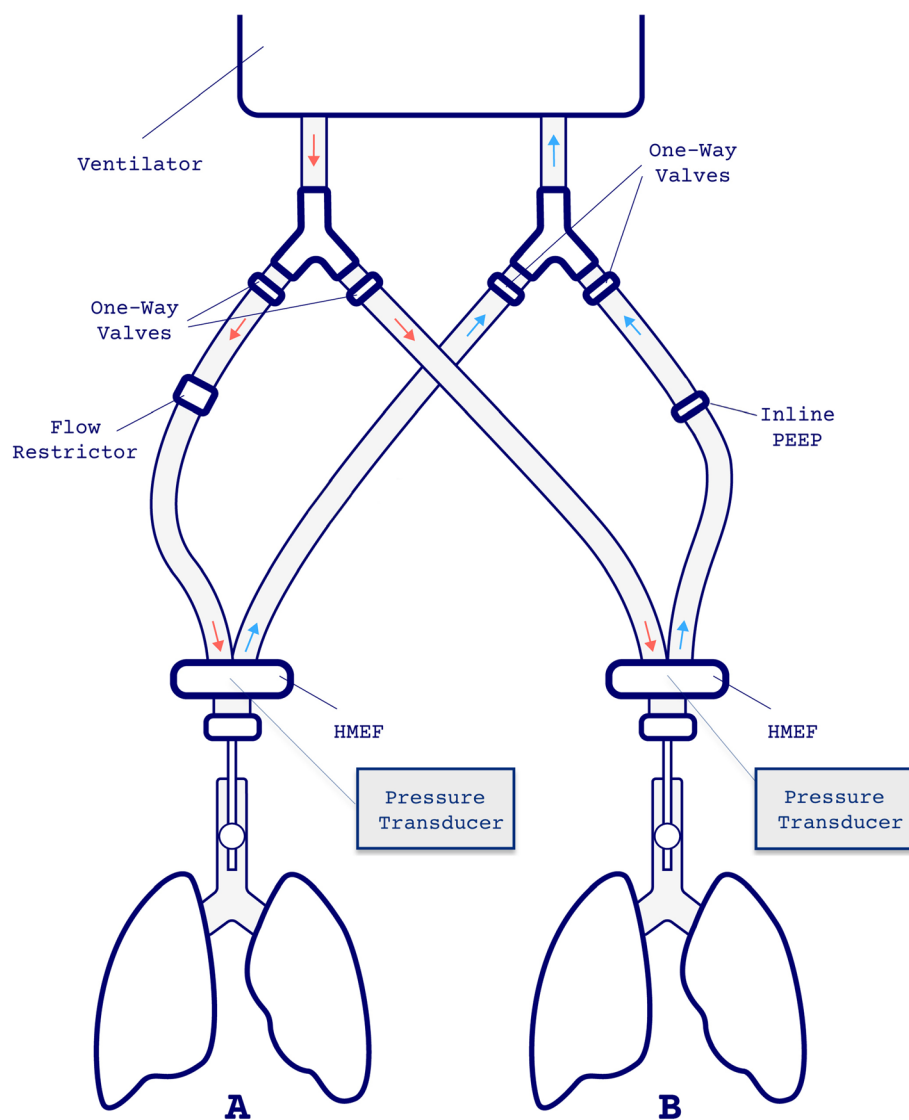


Fig. 1 Individualized shared ventilator setup in an in vivo model. The ventilator we used was a Datex Ohmeda s/5 Aespire, T-connectors split expiratory and inspiratory circuits. The rotatory valve (Sisto-16RGA) is placed in the inspiratory limb to restrict pressure and thus tidal volume to the subject with the highest lung compliance, and an in-line PEEP valve (Intersurgical, ref. 2207000) is added to the expiratory limb of the circuit to set PEEP individually. Side-stream supply of additional oxygen can modulate the FiO_2 that is delivered to each patient. One-way valves (Intersurgical, ref. 1921000) prevent cross-contamination

in this setup was demonstrated with repeated blood gas measurements. Both PaCO_2 , PaO_2 , and pH values remained within normal range, thus we can assume that the individual tidal volumes before and after sharing the ventilator were similar. Hemodynamic parameters remained unchanged from baseline during the shared ventilator period. The animals were sacrificed after 3 h of mechanical ventilation.

We demonstrated the potential to modulate delivered tidal volumes and pressures, PEEP and FiO_2 in a shared ventilator setup in this in vivo model. The added ventilator circuit modifications are inexpensive

and readily available or can be 3D-printed. This setup has allowed to safely ventilate a pair of animals with different lung compliance with a single ventilator, while monitoring and adjusting individual airway pressures and tidal volumes. However, I/E ratios and respiratory remain identical, and supplemental monitoring is required for safety reasons. We must stress that this setup is only to be used temporarily in a crisis setting while arranging for safer and more structural alternatives. The lung compliances were similar to what is frequently seen in ARDS. We think that this is a relevant step in the progressive development

Table 1 Ventilator settings and measurements of in vivo individualized shared ventilation

	Individual ventilation		Shared ventilator	
	Animal 1	Animal 2	Animal 1	Animal 2
Ventilator settings				
Tidal volume (ml)	600	800	1400	
PEEP (cmH ₂ O)	3	4	3	7
FiO ₂	0.3	0.3	1.0	
I/E ratio	1:2	1:2	1:1.5	
Respiratory rate (min ⁻¹)	20	20	20	
Measured ventilatory values				
PEEP (cmH ₂ O)	3	5	4	7
Ppeak vent (cmH ₂ O)	18	32	31	
Ppeak circuit (cmH ₂ O)			19	18
etCO ₂	31	33	32	29
Blood gas values				
pH	7.54	7.54	7.47	7.49
PaO ₂ (mmHg)	112	230	443	376
PaCO ₂ (mmHg)	31	30	39	36
Hemodynamic values				
BP (mmHg)	76/43	83/38	73/40	84/36

Table 1 shows the settings of the ventilator per animal and for the shared ventilator in a volume-controlled ventilation. In animal 2, inline PEEP was applied; in animal 1, the flow restriction with our valve was applied to distribute the pressures as desired among the two animals.

of a shared ventilator solution, but further research needs to be done to better understand its full potential in treating patients with COVID-19.

Abbreviations

PEEP: Positive end-expiratory pressure; FiO₂: Inspiratory fraction of oxygen; I/E: Inspiratory/expiratory time ratio; Ppeak: Peak pressure; vent: As measured by ventilator; Indiv: Individually measured on circuit; etCO₂: End-tidal carbon dioxide; PaO₂: Partial pressure of oxygen, arterial; PaCO₂: Partial pressure of CO₂, arterial

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Authors' contributions

Authorship was based on the ICMJE guidelines. All authors contributed to the study conception and design. Material preparation were performed by MS, TB, MM, LJ, and TS. The data collection and analysis were performed by MS, MM, HP, LJ, and TS. The figure and tables were designed and edited by HP, MS, and TS. The first draft of the manuscript was written by TS and MS. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

All data generated or analyzed during this study are included in this published article and are shown in Table 1.

Ethics approval and consent to participate

Approval by the Ethics Committee for Animal Experimentation of the Animalium of KU Leuven, Belgium (P066/2020), was obtained.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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