

EDITORIAL

Supporting more than one patient with a single mechanical ventilator: useful last resort or unjustifiable risk?

John G. Laffey¹, Marc Chikhani^{2,3}, Declan G. Bates⁴ and Jonathan G. Hardman^{2,3,*}

¹Anaesthesia and Intensive Care Medicine, School of Medicine, and Regenerative Medicine Institute at the CURAM Centre for Medical Devices, National University of Ireland, Galway, Ireland, ²Nottingham University Hospitals NHS Trust, Nottingham, UK, ³Division of Clinical Neuroscience, School of Medicine, University of Nottingham, Nottingham, UK and ⁴School of Engineering, University of Warwick, UK

*Corresponding author. E-mail: j.hardman@nottingham.ac.uk

Keywords: COVID-19; ethics; mechanical ventilation; resource allocation; shared ventilation; ventilator

The coronavirus disease 2019 (COVID-19) causes diffuse lung inflammation and injury that can worsen rapidly into acute hypoxaemic respiratory failure and acute respiratory distress syndrome.

At the time of writing, more than 7.1 million people globally have been confirmed to have had COVID-19,¹ with the USA alone approaching 2 million cases. Spain, Italy, Germany, France, China, and the UK have also been severely affected, and the global deaths have exceeded 400 000.¹ Some projections suggest that up to 60% of the global population will contract COVID-19 over the coming months.²

Although about 80% of people who contract COVID-19 will have a mild (or asymptomatic) course, a minority (~10%) will have symptoms of sufficient severity to require hospitalisation, and ~25% of hospitalised patients will require positive pressure pulmonary ventilation. In patients requiring mechanical ventilation, the median duration of ventilation is 6 days, although it should be noted that this figure includes those who die, such that the figure for those surviving to discharge is necessarily greater.³

This enormous global disease burden has resulted in a massive demand for mechanical ventilatory support (and the equipment required to provide it). In some tragic situations, doctors have been obliged to choose which patients should receive ventilatory support (and who should not).⁴ Although these situations are likely to be rare, they have happened and will continue to occur. This obliges healthcare professionals to make treatment allocation decisions based on equipment availability, rather than on what is in the best interest of each individual patient. In the developed world, this is a novel (and disturbing) scenario with significant ethical implications.⁵

The fabrication of ventilators is rapidly scaling up worldwide, and there have been various reports of industries in quite disparate fields repurposing their design and production resources to supplement the supply of ventilators. However, even relatively simple ventilators are highly specialised items of equipment and it is likely that the design, testing, manufacture, and certification of suitable equipment will be inadequate in the time available during this pandemic. Other solutions to the problem of a lack of mechanical ventilators are likely to be needed.

Ventilator sharing as a potential solution

Projections of the likely extent of the requirement for mechanical ventilatory support during the COVID pandemic, coupled with reports of situations in which ventilator requirement has exceeded supply, has prompted reconsideration of the idea of using a single ventilator to ventilate the lungs of more than one patient.⁶ This is not a new idea. There have been various reports of ventilators being used to ventilate more than one patient during mass casualty situations,⁷ and reports of testing the technology on mechanical 'test' lungs⁸ and sheep.⁹ Approaches have included simple splitting of the inspiratory and expiratory outlets from the ventilator and connecting two or more sets of tubing in parallel.

The use of a single ventilator to simultaneously provide ventilatory support to more than one patient could permit rapid upscaling of ventilator capacity at this time of crisis. Furthermore, given that other (perhaps even more dangerous) pandemics are likely to occur in the future, this potential mechanism of upscaling ventilatory equipment is worthy of consideration.

Risks of shared ventilation

There are several relatively simple solutions that could enable a mechanical ventilator to support two (or more) patients.^{6,10,11} In most of these suggested solutions, there is no capacity to safely and effectively control the ventilatory parameters for each patient. Pressure-controlled ventilation is generally used, with identical inspiratory and expiratory pressures, inspired oxygen fraction (FiO₂), PEEP, inspiratory to expiratory ratio, and ventilatory frequency being delivered to both patients. Consequently, the distribution of tidal volume between the two or more patients is dependent on the characteristics of each patient's lungs (i.e. inspiratory and expiratory resistances and thoracic compliance).

Pressure-controlled modes are most safely implemented because changes in the compliance, resistance, or both of one patient's chest will have a smaller effect on the tidal volume delivered to the other patient when a fixed inflation pressure is provided. In contrast, in volume-controlled modes, any inspired volume not delivered to one patient will be redirected to the more compliant chest (or that with lower inspiratory resistance); this risks dangerous hyperinflation and barotrauma or volutrauma in the event of a sudden change in the characteristics of one patient (e.g. mucous plug, coughing, or kinked tracheal or circuit tube).

Basic splitting approaches may be sufficient in the short term, where intense supervision is available and where ventilatory requirements are similar in both patients, and where the same ventilatory settings can be used relatively safely for both patients. However, in COVID-19 patients ventilatory requirements can be quite disparate between patients, and also can evolve over time.^{12,13} This substantially increases the requirement for very sophisticated splitting arrangements, or for intensive vigilance, usually in the face of limitations on the availability of qualified clinicians, in order to provide appropriate adjustments of the ventilator settings and other characteristics of the splitting applied.

Where changes in compliance, resistance, or both, occur, there can be rapid and substantial alteration in the tidal volume delivered to the other patient(s). In the context of the severe ventilation–perfusion mismatch and PaCO₂ dependency shown by COVID-19 patients (where an increase in PaCO₂ can significantly reduce PaO₂, and thus worsen an already perilous PaO₂), such changes in delivered ventilation could be rapidly and severely detrimental to the patient, particularly if individual tidal volumes are not continually observed.

In the scenario of a mismatch in thoracic compliance or resistance (or both) between the two or more patients sharing a ventilator, the only simple way to increase tidal volume to the more severely lung-injured patient is to increase inspiratory pressure (resulting in the other patient receiving a larger than desired tidal volume), or to fit a pressure reducing valve or flow restrictor to the other patient's inspiratory limb. However, with increasing complexity comes an increasing risk of errors, mechanical failure, and consequent patient harm.

Other clear limitations of ventilator splitting include the inability to discretely vary FiO₂, PEEP, and inspiratory to expiratory ratio between patients, reducing the options for fine-tuning ventilation parameters, which have been shown to be of importance in treating COVID-19 patients.^{9,10} Spontaneous breathing presents another problem, in that in the

absence of sophisticated compensatory mechanics, spontaneous inhalation risks reducing the volume delivered to the other patient. Consequently, deep sedation, possibly with muscle paralysis, is likely to be required in the setting of shared ventilation.

Addressing the challenges

Medical device companies and engineering consortia are currently attempting to produce the necessary hardware to allow the ventilation of more than one patient using a single ventilator. In the USA, Prisma Health (Columbia, SC, USA) has designed a simple ventilator expansion device produced using three-dimensional printing technology from material that allows for appropriate filtering of bacteria and viruses in the ventilator tubing. The VESper™ splitter can be produced at minimal cost, and Ethicon Inc. (ridgewater, NJ, USA) is manufacturing and distributing the VESper at no cost to healthcare providers in the USA under emergency use authorisation by the US Food and Drug Administration to address the COVID-19 health emergency.¹⁴

Ongoing developments of ventilator splitter technology currently being implemented include the addition of one-way valves to ensure that exhaled gas from one patient cannot reach the other, and the addition of flow meters in each patient's inspiratory tubing to monitor and adjust individualised tidal volume.

Additional engineering solutions being considered include pressure-reducing valves on expiratory limbs to provide individually configurable PEEP, air entrainment devices to allow individually modifiable FiO₂, and adjustable flow restrictors to compensate for disparate inspiratory resistance. Coping with spontaneous breathing in a split ventilation configuration is complex, but sophisticated engineering solutions are certainly feasible, although it is likely that they will require complex and reactive technology that exceeds simple adaptations available in a crisis. Consideration of the place and likely utility of each of these is beyond the scope of this article.

There are currently few substantive guidelines to assist clinicians in deciding which patients might be selected to share a single ventilator (beyond patient weight); examples include the US COVID-19 co-ventilation task force,¹⁵ but the complexity and sensitivity of the decision-making here is challenging.⁵ Intuitively, patients selected to share a ventilator should have a similar oxygen requirement and thoracic compliance, but beyond this there is little expertise or evidence base besides the cohorting of COVID-19 patients by disease stage or disease 'phenotype'. Previous experience in the treatment of acute respiratory distress syndrome has highlighted the fact that patients with similar disease presentation (PaO₂/FiO₂ ratios, etc.) may have very different underlying pathophysiology, requiring quite different ventilator settings for appropriate management. Computational simulators that include high-fidelity mechanistic representations of integrated organ systems in individual patients could be a useful tool for investigating which patient parameters are most important in selecting patients for shared ventilation.

The additional complexity brought by sharing a ventilator between patients, along with the additional risk, mandates additional training, staffing, and monitoring. For example, the interpretation of a high- or low-pressure alarm on the venti-

lator presents a substantially more complex task to the supervising clinician when two patients are sharing a ventilator. Clinical experience is minimal in this scenario, and care can no longer be considered 'routine' (i.e. based upon robust, time-tested protocols); instead, it will require frequent, active problem-solving, which is likely to be disproportionately more cognitively and emotionally demanding than managing a single ventilated patient. It is thus clear that provision of shared ventilation is not merely a matter of finding an engineering solution, but it will also bring substantial challenges in clinical decision-making, training, supporting staff, and in safeguarding patients in the context of a novel and little-trialled technology.

Competing alternative solutions

Rather than considering shared ventilation as a technical problem whose solution provides an additional needed resource, we must consider the potential gains and losses of implementing such technology.

In the situation where demand exceeds supply (i.e. not enough ventilators), one might expect that the lack of ventilators immediately and inevitably increases the risk of death. However, there are other therapies available to support patients with hypoxaemic respiratory failure (including, but not limited to, CPAP and use of lower-fidelity ventilation). It is not currently clear that mechanical ventilation brings a substantial survival benefit in COVID-19; indeed, some sources are reporting mortality rates over 80% in patients with COVID-19 who receive mechanical ventilation.¹⁶ We must also consider that shared ventilation will inevitably reduce the fidelity (and thus likely benefit) of the ventilation that would have been provided to a single patient (with their own ventilator), creating another ethical dilemma.¹⁷ Thus, the decision to share a ventilator does not bring the same benefit as an additional ventilator would have brought. In that scenario, it might be argued that in many cases the 'net gain' (i.e. expected numbers surviving) might be greater if one patient receives (non-shared) mechanical ventilation, while the other receives alternative support (e.g. CPAP).

Finally, there is of course, another alternative to sharing mechanical ventilation: increasing the availability of mechanical ventilators. Efforts to upscale ventilator production, coupled with redeployment of ventilators around the world to meet local demand, might offer a more effective solution to a respiratory crisis such as COVID-19. However, the unfortunate likelihood of future, unpredictable mass casualty situations, together with the potentially dramatic effects of pandemics on developing countries without adequate healthcare systems, means that further investigation of the implementation of shared ventilation as a last resort is still likely to be needed.

Declarations of interest

JGH is the associate editor-in-chief of the *British Journal of Anaesthesia*. The other authors declare that they have no conflicts of interest.

References

1. Available from, <https://coronavirus.jhu.edu/map.html>. [Accessed 9 June 2020]
2. Available from, <https://www.theguardian.com/world/2020/feb/11/coronavirus-expert-warns-infection-could-reach-60-of-worlds-population>. [Accessed 14 May 2020]
3. Available from, <https://www.icnarc.org/DataServices/Attachments/Download/76a7364b-4b76-ea11-9124-00505601089b>. [Accessed 14 May 2020]
4. Rosenbaum L. Facing Covid-19 in Italy—ethics, logistics, and therapeutics on the epidemic's front line. *N Engl J Med* 2020; **382**: 1873–5
5. An ethical algorithm for rationing life sustaining treatment during the COVID-19 pandemic. *BJA-2020-00718-HH430*
6. Available from, <https://www.hhs.gov/sites/default/files/optimizing-ventilator-use-during-covid19-pandemic.pdf>. [Accessed 14 May 2020]
7. Available from, <https://epmonthly.com/article/not-heroes-wear-capes-one-las-vegas-ed-saved-hundreds-lives-worst-mass-shooting-u-s-history/>. [Accessed 14 May 2020]
8. Branson RD, Blakeman TC, Robinson BR, Johannigman JA. Use of a single ventilator to support 4 patients: laboratory evaluation of a limited concept. *Respir Care* 2012; **57**: 399–403
9. Paladino L, Silverberg M, Charchafieh JG, et al. Increasing ventilator surge capacity in disasters: ventilation of four adult-human-sized sheep on a single ventilator with a modified circuit. *Resuscitation* 2008; **77**: 121–6
10. Neyman G, Irvin CB. A single ventilator for multiple simulated patients to meet disaster surge. *Acad Emerg Med* 2006; **13**: 1246–9
11. Smith R, Brown JM. Simultaneous ventilation of two healthy subjects with a single ventilator. *Resuscitation* 2009; **80**: 1087
12. Gattinoni L, Chiumello D, Caironi P, et al. COVID-19 pneumonia: different respiratory treatment for different phenotypes? *Intensive Care Med* 2020. <https://doi.org/10.1007/s00134-020-06033-2>. Advance Access published on April 14
13. Available from, https://renal.org/wp-content/uploads/2020/04/COVID-19_synthesis-of-clinical-experience-in-UK-intensive-care_04.04.2020_FINAL.pdf. [Accessed 14 May 2020]
14. Available from, <https://www.nsmedicaldevices.com/news/prisma-healths-vesper-covid/>. [Accessed 14 May 2020]
15. Available from, <https://www.sccm.org/getattachment/Disaster/FEMA-Report.pdf?lang=en-US>. [Accessed 14 May 2020]
16. Available from, <https://www.linkedin.com/pulse/over-80-covid-patients-placed-ventilators-new-york-have-colangelo/?trackingId=twCl8vi%2FRVm884hmSkMQGw%3D%3D>. [Accessed 14 May 2020]
17. Cook DC. Implementing shared ventilation must be scientific and ethical, or it risks harm. *Br J Anaesth Advance Access published on April 27, 2020*, doi:10.1016/j.bja.2020.04.061