3. Rescue ventilators (as a safety measure if shared ventilation fails) may not be available or may understandably also be in use in such a situation.
4. Pressure control when patients breathe together does not ensure that lung damage from divergent patient courses does not occur. Driving pressure and barotrauma are an issue if compliance rises significantly for one patient and similarly for underventilation and a need for greater pressure in one patient. This approach thus puts great weight on not only patient matching but also matching and tracking patient course to avoid damage. It may work in a limited trial and study but not necessarily in a COVID-19 "overrun" situation, in which staffing capability is stretched to the limit.
5. The authors state, "Patient selection and management require considerable expertise to ensure safety. Therefore, we recommend a regional referral model wherein ventilator sharing is restricted to expert centers, and patients and ventilators move throughout the region accordingly." However, it requires significant time, cost, and effort to move infectious patients. It also implies greater risk for a select set of patients in the receiving center(s), which may not be ethical or provide equity of access to care for patients.

Importantly, we admire this result but feel in-parallel ventilation carries too much risk and difficulty to implement safely.

We would thus draw the authors' attention to the concept of in-series breathing (patients breathe one after the other) in a simply implemented active circuit (3) as a safer alternative. It allows individualized positive end-expiratory pressure and driving pressure to account for differences between patients and reduces risk of harm because patients breathe separately (not together).

Thus, Beitler and colleagues (1) developed excellent results in a limited test situation but added significant complexity and cost per patient, which may not be feasible in general or in COVID-19 overrun. The use of in-parallel breathing requires significant matching of patient condition and monitoring of time course to assess risks of barotrauma or volutrauma (even with pressure control) as well as a risk of underventilation. All these risks are well-known to be difficult to monitor and assess in the best of times. A COVID-19 overrun situation demanding ventilator doubling is not the best of times. We suggest in-series breathing as a safer solution. ■

Author disclosures are available with the text of this letter at www.atsjournals.org.

J. Geoffrey Chase, Ph.D.
University of Canterbury
Christchurch, New Zealand

Yeong-Shiong Chiew, Ph.D.
Monash University
Bandar Sunway, Malaysia

Bernard Lambermont, M.D.
Philippe Morimont, M.D., Ph.D.
University of Liège Hospital
Liège, Belgium

Geoffrey M. Shaw, M.B. Ch.B., F.A.N.Z.C.A., F.C.I.C.M.
Christchurch Hospital
Christchurch, New Zealand

Thomas Desaive, Ph.D.*
University of Liège
Liège, Belgium

*Corresponding author (e-mail: tdesaive@uliege.be).

References

1. Beitler JR, Mittel AM, Kallet R, Kacmarek R, Hess D, Branson R, *et al*. Ventilator sharing during an acute shortage caused by the COVID-19 pandemic [letter]. *Am J Respir Crit Care Med* 2020;202:600–604.
2. SCCM, AARC, ASA, ASPF, AACN, and CHEST. Consensus statement on multiple patients per ventilator. 2020 [accessed 2020 Jun 15]. Available from: https://www.sccm.org/Disaster/Joint-Statement-on-Multiple-Patients-Per-Ventilato.
3. Chase JG, Chiew YS, Lambermont B, Morimont P, Shaw GM, Desaive T. Safe doubling of ventilator capacity: a last resort proposal for last resorts. *Crit Care* 2020;24:222.

Ventilator Sharing Using Volume-controlled Ventilation during the COVID-19 Pandemic

To the Editor:

In a recent article, Beitler and colleagues described their methodology and lessons learned from ventilator sharing during the acute shortage caused by the coronavirus disease (COVID-19) pandemic (1). We applaud their efforts during unprecedented circumstances, as we similarly assessed the safety and feasibility of ventilator sharing at a time of near depletion. In their assessment, each patient was matched with identical ventilator settings before sharing pressure-control ventilation. In our assessment, we used the Vent Multiplexor device to modulate flow in a volume-control mode and permit individual adjustments of V_T to two patients.

At baseline, patient A had a V_T of 350 ml (5.5 ml/kg predicted body weight), driving pressure of 14 cm H_2O with positive end-expiratory pressure (PEEP) of 14 cm H_2O, and pH 7.36 with Pa_{CO_2} 56 mm Hg; patient B had a V_T of 450 ml (6.8 ml/kg predicted body weight), driving pressure of 12 cm H_2O with PEEP of 10 cm H_2O, and pH 7.42 with Pa_{CO_2} 54 mm Hg. Each had different static lung compliances (A = 25 ml/cm H_2O; B = 37.5 ml/cm H_2O). Both had a respiratory rate of 20 breaths/min and required vasopressor support and neuromuscular blockade for the assessment; neither had underlying lung disease. Before the assessment, consent was obtained from both patients' families. The Vent Multiplexor was assembled within the circuit described in Figure 1. In the assessment, the device was adjusted to deliver different flow ratios to patients, with vitals, end-tidal carbon dioxide, plateau pressures, and arterial blood gases monitored over a 2-hour period.

Originally Published in Press as DOI: 10.1164/rccm.202006-2452LE on August 3, 2020

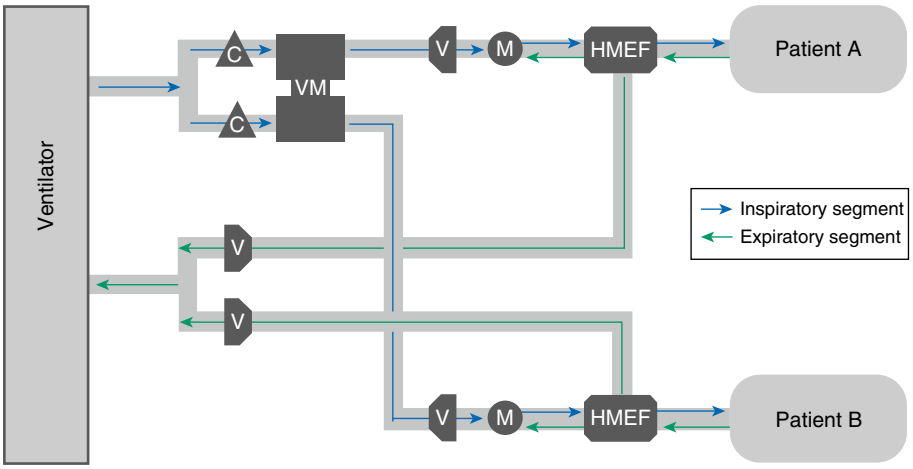

Figure 1. Circuit diagram showing the inspiratory and expiratory segments of 2 patients on the Vent Multiplexor, including placement of one-way valves, filters, and monometers. C = clamp; HMEF = heat moisture exchanger filter; M = manometer; V = one-way valve; VM = Vent Multiplexor.

During the assessment, both were initially placed on volume assist control mode with total V_T of 800 ml split at a 1:1 ratio through the device and PEEP at 12 cm H_2O, with increased end-tidal carbon dioxide noted for each patient. The device was adjusted to deliver unequal V_Ts at a ratio of 6:5 (Patient A:B), noting plateau pressure of 32 cm H_2O for patient A compared with 28 cm H_2O for patient B. In response, the device was adjusted to deliver a flow ratio of 5:6 resulting in plateau pressures of 30 cm H_2O each, calculated V_T of 373 ml for patient A and 447 ml for patient B. At the conclusion of the 2-hour assessment, patient A had Pa_{CO_2} 57 mm Hg with pH 7.38, whereas patient B had Pa_{CO_2} 63 mm Hg with pH 7.36.

Our assessment demonstrated that the Vent Multiplexor allowed for successful coventilation, using individual and adjustable V_Ts to maintain standard-of-practice lung-protective ventilation, in two patients with COVID-19. This is distinct from pressure-controlled ventilation used by Beitler and colleagues, and the ability to deliver individualized volumes would permit the correction of respiratory alkaloses and acidosis without the addition or removal of dead space, respectively, to the circuit, as was required in their study. Beitler and colleagues matched patients by exact ventilator requirements, and a recent *in vitro* study by Tonetti and colleagues proposes matching patients by compliance (2). Matching compliance is both inherently challenging and potentially harmful, as it varies over time. We demonstrate that exact matching of compliance and V_T is not required with this device. Individualized pressure monitoring is available to inform flow adjustments and mitigate the risk of barotrauma, which is not modifiable in uncontrolled vent splitting.

Ventiltor sharing has been previously explored in laboratory and animal models to assess feasibility (3, 4), and noninvasive coventilation has been demonstrated in healthy volunteers (5). The COVID-19 pandemic required an assessment of feasibility and safety of coventilation in diseased lungs, which brings up several issues, both physiologic and ethical, as detailed in a recent consensus statement (6). This device addresses some of these issues by allowing low-V_T ventilation and adjustable settings for each patient. Both our assessment and the parameters set by Beitler and colleagues allow ventilator alarms to detect circuit disconnections when sum measurements fell beyond the set limit. Individual pulse oximetry and capnography alert for life-threatening disconnections. We agree with the authors that this approach is not intended for clinically deteriorating patients, but the Vent Multiplexor device allows for additional control of coventilation in settings of severe ventilator shortages. Critical care physicians would be able to support patients, while mitigating possible harm, until additional ventilators are obtained. ■

Author disclosures are available with the text of this letter at www.atsjournals.org.

Aidan Milner, M.D.
Jonathan M. Siner, M.D.
Thomas Balcezak, M.D.
Elaine Fajardo, M.D.*
Yale School of Medicine
New Haven, Connecticut

ORCID ID: 0000-0003-4183-2586 (A.M.).

*Corresponding author (e-mail: elaine.fajardo@yale.edu).

References

1. Beitler JR, Mittel AM, Kallet R, Kacmarek R, Hess D, Branson R, *et al*. Ventilator sharing during an acute shortage caused by the COVID-19 pandemic [letter]. *Am J Respir Crit Care Med* 2020;202:600–604.
2. Tonetti T, Zanella A, Pizzilli G, Irvin Babcock C, Venturi S, Nava S, *et al*. One ventilator for two patients: feasibility and considerations of a last resort solution in case of equipment shortage. *Thorax* 2020;75: 517–519.
3. Neyman G, Irvin CB. A single ventilator for multiple simulated patients to meet disaster surge. *Acad Emerg Med* 2006;13:1246–1249.
4. Paladino L, Silverberg M, Charchaflieh JG, Eason JK, Wright BJ, Palamidessi N, *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;77:121–126.
5. Smith R, Brown JM. Simultaneous ventilation of two healthy subjects with a single ventilator. *Resuscitation* 2009;80:1087.
6. SCCM, AARC, ASA, ASPF, AACN, and CHEST. Joint statement on multiple patients per ventilator [accessed 2020 Apr 26]. Available from: https://www.sccm.org/getattachment/Disaster/Joint-

Statement-on-Multiple-Patients-Per-Ventilato/Joint-Statement-Patients-Single-Ventilator.pdf?lang=en-US.

Reply to Chase *et al.* and to Milner *et al.*

From the Authors:

Surges in cases of coronavirus disease (COVID-19)–associated respiratory failure have caused acute regional shortages of ventilators. Repurposing of anesthesia machines and noninvasive ventilators unquestionably has helped support additional patients but may be insufficient during dramatic increases in caseload. Proposed actions to address acute shortages have included ventilator rationing, manual bag ventilation, and "splitting" the external ventilator circuit to support multiple patients simultaneously. None of these options is ideal. None is risk-free. None negates the need for more ventilators. However, these were the options we were forced to consider in New York City just a few months ago (1).

In our view, rationing ventilators among multiple potentially rescuable patients is a last resort and should be considered only if all reasonable alternatives are exhausted. Extended-duration manual bag ventilation requires prolonged exposure with high risk for severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) transmission to those performing the ventilation, and yet it still seems unlikely to provide appropriate support to severely lung-injured patients. With these considerations in mind, ventilator sharing seems a more palatable stopgap.

When developing our ventilator-sharing protocol (2), we followed several guiding principles: *1*) maximization of safety for each patient, *2*) maintenance of lung-protective ventilation, *3*) prevention of harm during equipment issues or clinical events, *4*) potential for human error, and *5*) practical scalability in context. The context in New York included extremely high patient-to-clinician ratios, adoption of a tiered staffing strategy in ICUs, clinicians practicing outside their specialty, caring for critically ill patients in makeshift ICUs, and minimal lead time for planning or onboarding.

There are many potential engineering solutions to share one ventilator among two or more patients, including those advocated by Chase and colleagues and Milner and colleagues. Proposals that increase circuit complexity also may increase risk of (potentially fatal) adverse events from equipment issues, clinical events, or human error (3). Reliance on components that are not routinely used in similar clinical applications, are not medical grade, and/or have not undergone rigorous testing increases these risks; this is especially true for mechanical components that regulate airflow, in which component failure could cause abrupt cessation of ventilator support for one or both patients. Circuit configurations that require unconventional ventilator settings, such as a near-doubling of preset V_T or respiratory rate, increase these risks even further.

We do not question the altruistic intent with various proposals for configuring a shared ventilator. However, the extent to which complex configurations offer meaningful benefits to patients over simpler circuitry should be carefully weighed against their potential to cause unintended harm. Regardless of the circuit configuration, responsible implementation requires adequate safeguards (including patient monitoring), multidisciplinary planning, and a carefully detailed clinical protocol.

Experts can disagree reasonably on the best approach to ventilator sharing or whether it should even be entertained. However, we hope broad consensus exists for the most important issue: regional (and global) coordination is needed to respond to acute ventilator shortages (4). The problem in New York was unequivocally regional; ventilators elsewhere in the United States sat idle as New York hospitals began preparations to implement rationing protocols. Had New York hospitals reached the point of rationing ventilators, it would have signified a moral failure of our profession and our healthcare system. We came frighteningly close. We must work together to ensure future crises cannot get to that point again. ■

Author disclosures are available with the text of this letter at www.atsjournals.org.

Aaron M. Mittel, M.D.
Columbia University Vagelos College of Physicians and Surgeons and New York-Presbyterian Hospital
New York, New York

Dean Hess, Ph.D., R.R.T.
Robert Kacmarek, Ph.D., R.R.T.
Massachusetts General Hospital
Boston, Massachusetts

Richard Kallet, M.Sc., RRT
San Francisco General Hospital and University of California San Francisco
San Francisco, California

Richard Branson, M.Sc., R.R.T.
University of Cincinnati
Cincinnati, Ohio

Daniel Brodie, M.D.
Columbia University Vagelos College of Physicians and Surgeons and New York-Presbyterian Hospital
New York, New York

Laureen L. Hill, M.D., M.B.A
New York-Presbyterian Hospital
New York, New York

Jeremy R. Beitler, M.D., M.P.H.*
Columbia University Vagelos College of Physicians and Surgeons and New York-Presbyterian Hospital
New York, New York

ORCID ID: 0000-0003-0797-2374 (J.R.B.).

*Corresponding author (e-mail: jrb2266@cumc.columbia.edu).

Originally Published in Press as DOI: 10.1164/rccm.202007-2959LE on August 3, 2020