# 2020 Year in Review: Shared Ventilation for COVID-19

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**COVID-19 resulting from severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) has resulted in a pandemic of respiratory failure previously unencountered. Early in the pandemic, concentrated infections in high-density population cities threatened to overwhelm health systems, and ventilator shortages were predicted. An early proposed solution was the use of shared ventilation, or the use of a single ventilator to support ≥ 2 patients. Spurred by ill-conceived social media posts, the idea spread in the lay press. Prior to 2020, there were 7 publications on this topic. A year later, more than 40 publications have addressed the technical details for shared ventilation, clinical experience with shared ventilation, as well as the numerous limitations and ethics of the technique. This is a review of the literature regarding shared ventilation from peer-reviewed articles published in 2020.** *Key words: COVID-19; mechanical ventilation; ARDS; PEEP/CPAP; gas exchange.* [Respir Care 2021;66(7):1173–1183. © 2021 Daedalus Enterprises]

## Introduction

Concerns over ventilator shortages during the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) pandemic spurred a number of initiatives to augment ventilator capacity. One early proposal resurrected the idea of shared ventilation, which is the support of > 1 patient with a single device. While the focus early in the pandemic was on the concept in general and a series of "how to" publications, human use was limited. Naïve systems that simply used 2 connectors, commonly called splitters, to deliver flow to individual circuits were shown to have significant limitations, possibly leading to lung injury and additional risk to patients. Circuit modifications were developed to allow titration of tidal volume ($V_T$) to each patient and delivery of differential PEEP, and external monitoring was added.

Despite the flurry of activity and coverage in the lay press, as hospitalizations fell and treatments improved, fewer than half a dozen pairs of patients were ever subjected to shared ventilation. In those who received shared ventilation, the duration of exposure was < 48 h. To our knowledge, none of the human trials of shared ventilation were undertaken as a consequence of ventilator shortages. These trials were performed to evaluate the feasibility of shared ventilation in anticipation of impending need.

Perhaps in a classic case of putting the cart before the horse, concerns over safety and the ethics of shared ventilation lagged behind the rush to develop methods to perform the technique. These issues will be reviewed first here, hopefully to place the concept and utility of shared ventilation in context. The certainty of death by denying 1 patient access to a ventilator while another receives the standard of

care has to be balanced with the possibility of poor outcomes for both patients when the ventilator is shared.

This review includes the ethics dilemmas surrounding shared ventilation, the brief pre-COVID history of shared ventilation, systems descriptions for providing shared ventilation, and the limited human use. Of note, shared ventilation has also been called co-ventilation and multiplex ventilation; all of these terms refer to the use of 1 ventilator for $\geq 2$ patients.

## Methods

A PubMed search was conducted to identify articles published during 2020 related to shared ventilation. Searches used the terms shared ventilation, co-ventilation, and multiplex ventilation. References from published works were reviewed for papers published outside PubMed. Papers published as preprints are not included in this review.

## Brief History

Prior to 2020, there were just over half a dozen papers related to shared ventilation. While Neyman and Irvin[1] are commonly credited with the earliest discussion of shared ventilation, the first publication was by Sommer et al in 1994.[2] Sommer and others improvised an anesthesia-style, bag-in-the-box system with separate fresh gas flows to allow individual $V_T$, inspired oxygen concentration ($F_{IO_2}$), and PEEP. The descriptions suggest that the system was easy to assemble, but there was little in the way of a formal bench evaluation and the paper attracted little attention.

Of note, in 2002, Lerner[3] received a patent for multiplex ventilation as a system for mass casualty care. This open system provided gas delivery to up to 8 patients using a single gas source, controller, and series of flow regulators to provide support. However, there was no monitoring, nor were there any alarms or provision for PEEP. Similarly, the original paper by Neyman and Irvin[1] simply added connectors to 4 circuits, attaching a rubber test-lung to the circuit and visually observing the test lung rise and fall. No scientific measurements were attempted. Branson and Rubinson[4] published a letter detailing the numerous limitations and potential dangers of that system. In 2020, those warnings were clearly not recalled.

In 2008, Paladino et al[5] tested the method described by Neyman and Irvin in 4 anesthetized adult sheep with normal lungs. The authors reported adequate ventilation and oxygenation in all 4 animals up to 12 h. However, a close analysis of the data demonstrates both relative hypoxemia and hypercarbia occurred in one or more of the animals. Hourly arterial blood gases were required to monitor gas exchange and prompted changes in animal position to improve distribution of ventilation to each animal. Branson and Rubinson[6] again cautioned against oversimplification of the technique and overstating of the findings. In normal animals, gas exchange could only be assured with hourly blood gas analysis and, as predicted, distribution of volume and impact of PEEP varied with the respiratory mechanics of each animal. Hourly blood gases for every patient during a mass respiratory failure event is not a tenable solution. Importantly, these complications were seen in animals with normal lungs, not in critically ill patients with hypoxemic respiratory failure.

Finally, in 2012, Branson and colleagues[7] undertook a bench study using a single ventilator to ventilate 4 test lungs with matched and variable compliance and resistance in both pressure and volume control ventilation. As predicted, differences in compliance resulted in an uneven distribution of $V_T$ and variable impact of PEEP on end-expiratory lung volume.[7] The intent of this paper was to provide data that, under normal circumstances, the naïve approach carried considerable risks. This paper also details the main concerns related to shared ventilation using only simple circuit modifications (Table 1).

## Ethics Issues

The technical challenges of shared ventilation and the sense of urgency surrounding the possible need for the technique seem to have overshadowed the ethics issues related to patient use. Shared ventilation has a host of limitations as shown in Table 1. However, even when circuit modifications and additional monitoring are provided, there remain shortcomings and ethics concerns.

In many discussions, implementation of shared ventilation has asked 2 questions: (1) Can we do it? (2) Should we do it? One question has a technical answer, whereas the second requires significantly more thought and a response rooted in ethics. Cook states that, to consider use of shared ventilation, the technique must be both scientific and ethical or the risk of harm is too great.[8] He argues that

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Table 1. Shared Ventilation Limitations in the Absence of Circuit Modifications

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|---|
| Uneven distribution of $V_T$ between patients resulting in both hyperventilation and lung injury or hypoventilation. |
| Uneven response to PEEP resulting in variable end-expiratory lung volume, further uneven distribution of $V_T$, atelectrauma or overdistention, and hemodynamic compromise in the healthiest lung. |
| Sharing of exhaled gases between patients at end inspiration as gas equilibrates resulting in cross infection. |
| Spontaneous breathing has to be suppressed (paralysis) or 1 patient controls the breathing frequency and exhaled gases can move from 1 patient to the other resulting in cross infection. |
| Inability to monitor airway pressures and volumes for each individual patient. |
| Alarms can only be set for the system as a whole, precluding identification of a clinical problem. |
| Requirement for increased attention by the medical team to assure safety, taking away attention from other patients in a situation where staff is already short. |
| Even if patients are matched for respiratory mechanics and ventilator requirements, it is highly unlikely for both patients to improve or decline in the same trajectory over a given timeframe. |
| Sudden deterioration in 1 patient (eg, pneumothorax, occluded endotracheal tube) can result in deterioration in the other patient (over-ventilation, loss of ventilation). |
| Requirement for a back-up ventilator to treat 1 patient in a catastrophic situation. |

$V_T$ = tidal volume

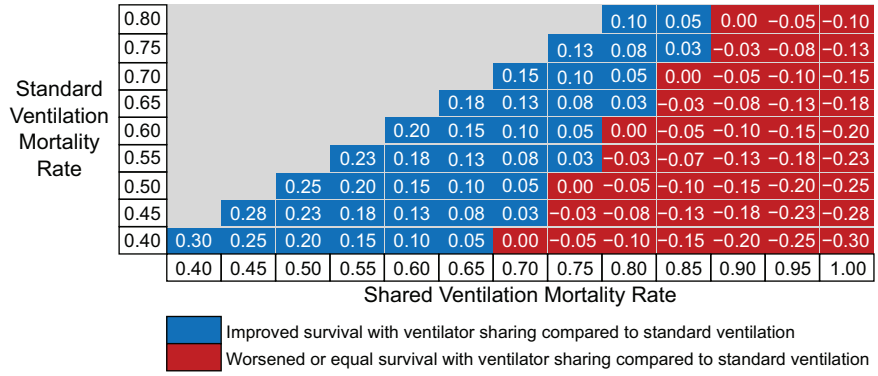


Fig. 1. Comparing survival differences with shared or standard ventilation by their hypothetical mortality rates. The numbers within each cell represent the proportional change in survival with shared ventilation for a population of patients comparing the shown mortality rates. Four key assumptions are made in this analysis: (1) the shared ventilation strategy doubles treatment capacity (a condition that is unlikely to be met in practice), (2) all patients receive either shared ventilation or standard ventilation, (3) all patients not receiving ventilator treatment will die, and (4) the mortality rate of shared ventilation will not be less than standard ventilation. From Reference 8, with permission.

depriving a patient of the standard of care (ie, 1 ventilator, 1 patient) to potentially save the life of another requires an assessment of mortality in each instance because increasing ventilator capacity might actually worsen mortality overall.

Cook provides a conceptual algebraic framework for assessing risk.[8] Using an example of a hospital with 200 patients requiring ventilatory support and 100 ventilators along with a standard of care mortality rate of 50%, the mortality cost of shared ventilation can be estimated. Using the standard of care, 50 of the 200 patients will survive (this assumes that all patients require support on the same day and that all patients denied ventilation will die). If mortality rate is identical for shared ventilation, then 100 patients will survive. Given the limitations described here, it is fair to assume that the mortality rate of shared ventilation would be greater. If mortality rate of shared ventilation is 75%, then only 50 patients will survive, and the additional complexity and effort expended on shared ventilation is wasted. Figure 1 depicts the mortality breakpoints on the basis of mortality for each technique described by Cook.

Hess and colleagues[9] considered the multiple limitations of shared ventilation and argued that shared ventilation would only be justified if the alternative is death for a patient denied ventilatory support and the risks to each patient are minimized. They also encouraged involvement of local ethics boards, administrative oversight, and surrogate consent prior to use.[9] Laffey et al[10] suggested that the certain increase in mortality with shared ventilation over the standard of care argues for use of alternative means of

support including CPAP and noninvasive ventilation (NIV). This idea increases capacity for support and maintains the standard of care for 1 patient.[10] Similar arguments have been made by others.[11-13]

The risks and potential harms of shared ventilation are serious and should not be minimized. However, a more positive outlook can be taken. Von Düring and co-workers[14] contend that, regardless of training and experience, intensive care clinicians are not equipped to make or cope with life-or-death decisions related to resource scarcity. The authors propose that short-term use of shared ventilation in specific circumstances justifies its use, and that desperate times call for desperate measures.[14] The ethics conundrum surrounding shared ventilation is influenced by the safety of the shared ventilation system, the options for other treatments, the shared ventilation mortality rate, and ICU staffing. Safety can only be assured through the development of more reliable systems and staff training.[15] Prior to the next mass respiratory failure event, we hope that the ethics issues are at the forefront of shared ventilation decisions.

## Bench Studies

In a rush to achieve proof of concept, a number of authors published their proposed solutions for allowing shared ventilation. These ran the gamut from the simplest systems, using splitters or T-pieces to add additional circuits, to modifications allowing separate control of $V_T$, PEEP, and $F_{IO_2}$. These will be considered here in 2 groups, the naïve group (ie, systems with no modifications for separate control of ventilation variables) and systems with modifications for differential control.

### Naïve Systems

Naïve systems are those similar to one of the early descriptions.[1] The focus of the circuit modification is the addition of a T-piece in the inspiratory and expiratory limb to split the circuit for delivery to each patient. It is worthwhile to note that while some social media posts suggested 4, 8, and even 9 patients per ventilator, any serious use of shared ventilation focuses on 2 individuals.[16] This group includes the systems using 3D-printed splitters to simplify connections, but these are hardly much of an advancement over plastic components available in any respiratory therapy department.[17]

Several authors performed limited bench assessments using circuit components assembled in the fashion of Neyman and Irwin.[1,18-22] In each case, the authors cautioned against the use of shared ventilation predominantly due to uneven gas distribution.[19] Additional concerns included the requirement for constant monitoring of patients and uncoupling of patients when the disparity in lung mechanics becomes too large.[20] Cherry et al[22] listed the requirement for neuromuscular blockade, cross-contamination, loss of airway pressure in both circuits with one disconnection, and staff inexperience as barriers to success. The naïve systems include a number of limitations that caution against the use of shared ventilation.[23]

Kheyfets and co-workers[24] described the concept of assigning pairs of patients to a single ventilator based on each patient's position on the ARDSNet PEEP/$F_{IO_2}$ table. Using computational modeling the authors demonstrated that ventilators could be pre-set at lung-protective settings and patients could be moved from ventilator to ventilator as lung mechanics changed.[24] This was all based on a mathematical model; the logistics, intensity of care, and infection control risks are all practical concerns that were not considered. However, this study helped define the limitations and risks of such a strategy. Others have described the use of high-fidelity simulators to evaluate shared ventilation, coming to similar conclusions.[25,26]

Chatburn et al[16] performed a detailed evaluation of naïve circuit use in 2 lung simulators, evaluating the impact of breath delivery (volume vs pressure control), lung mechanics, and PEEP on the distribution of $V_T$ and end-expiratory lung volume. The authors also used imputed values for pH and $P_{aCO_2}$ based on simulated body weight, carbon dioxide production ($V_{CO_2}$), and the ratio of dead space to $V_T$ ($V_D/V_T$). The goal of the study was to define the limits for shared ventilation and parameters that would result in failure to support one or both simulated patients. Six pairs of simulated patients were studied with matched and mismatched respiratory mechanics. The authors reported that the impact of PEEP on end-expiratory lung volume resulted in differences of $> 10\%$ in 50% of cases.[16]

Chatburn et al were also among the first to note the importance of one-way valves in the expiratory limb of each circuit to reduce sharing of expired gases and possible cross-contamination of patients.[16] They noted that many current ventilators detect inspiratory effort in the expiratory components of the ventilator and this modification would preclude triggering. As one tenet of shared ventilation is neuromuscular blockade, this issue is less concerning. They also noted that pressure control ventilation might be safer than volume control ventilation because complete occlusion of the endotracheal tube in 1 patient limits overdistention in the other. These investigators identified 3 problems with shared ventilation that must be overcome to allow safe use: (1) partitioning of inspiratory flow from the ventilator individually between the 2 patients, (2) measurement of $V_T$ delivered to each patient, and (3) provision for individual PEEP.

These investigations identify a number of imitations and potential dangers that caution against the use of shared ventilation with a naïve circuit setup without additional monitoring for each patient. Because the impetus for shared ventilation is an overwhelmed health care system, the need

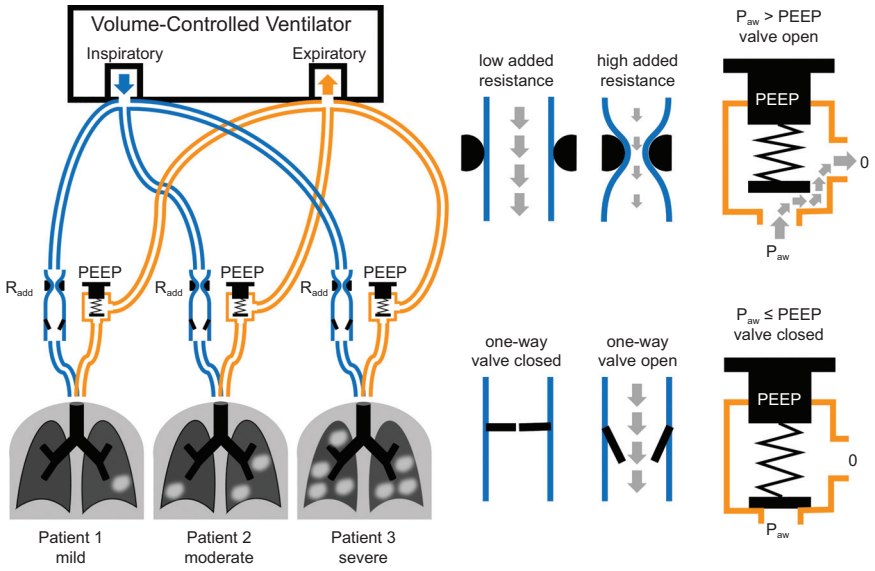


Fig. 2. Proposed modifications to breathing circuits during shared volume control ventilation. A variable resistance ($R_{add}$ such as an adjustable constriction) and a one-way valve are added to the inspiratory limb of the breathing circuit, and a pressure-relief valve (or PEEP valve) is added to each expiratory limb. One-way valves and PEEP valves prevent flow reversal and flow between patients. PEEP valves allow individualization of end-expiratory pressure level for each patient. $R_{add}$ allows the optimization of inspired volume distribution. For example, $R_{add}$ may be increased for a patient with more compliant lungs to limit the inspiratory flow and tidal volume delivered to that patient, redistributing this flow to the other connected patient(s). For this approach, the ventilator setting for PEEP is zero. $P_{aw}$ = airway pressure. From Reference 29.

for more intensive monitoring seems a logistical limitation that will be difficult to overcome. If shared ventilation is to be a potential solution, circuit modifications will be required.

### Systems With Modifications

Modification of ventilator circuits to improve safety and assure gas exchange with shared ventilation typically includes a flow control valve to partition volume between patients, separate controls for PEEP, one-way valves to prevent sharing of gas between patients, and individual monitoring of airway pressure and volume delivered to each patient. Investigators have described modifications that include as few as of one of these changes or all of them. These will be considered in groups of related functionality.

A simple method for partitioning $V_T$ between subjects is the use of the splitter and fixed orifice resistor in 1 limb of the circuit. This was described by Lai and colleagues[27] with an emphasis on the design and 3D printing. They printed 6 resistors from 11 mm to 16 mm in diameter that could be used to restrict flow to the patient with the best compliance. No bench testing was performed.[27] The authors did not address the need for differential PEEP, external volume monitoring, or the logistical challenges of having to break the circuit to replace resistors as lung mechanics are altered. Plummer and co-workers[28] provided a sophisticated model to predict the required flow restriction to individualize $V_T$ to each patient. The model closely predicted the performance in a mechanical model.[28]

Hermann et al[29] described the modification of the circuit based on the breath type. In volume ventilation, the circuit included a PEEP valve on each expiratory limb and a flow restrictor and one-way valve in the inspiratory limb (Fig. 2). For pressure ventilation, the circuit included a PEEP valve on each expiratory limb and a pressure relief valve on each inspiratory limb (Fig. 3). Hermann et al[29] evaluated their system in a mathematical model and on test lungs simulating 3 patients. As previously shown, the naïve circuits resulted in unsafe ventilation, but the described modifications allowed safe distribution of $V_T$ and PEEP. They noted that changes in respiratory mechanics in any one model were more likely to affect the other models when using volume ventilation. As noted by Chatburn et al,[16] Hermann et al[29] concluded that pressure control was the safest method for shared ventilation.[29]

Clarke and colleagues[30] described the use of a clamp to externally compress one of the inspiratory limbs in a lung model study of shared ventilation. They found they could adequately control the driving pressure to each test lung with this method.[30] This system did not address the use of one-way valves or differential PEEP. Chen and others[31] described a similar system, adding a pressure regulator to both inspiratory limbs in a bench test; this system included one-way valves but also did not address PEEP.

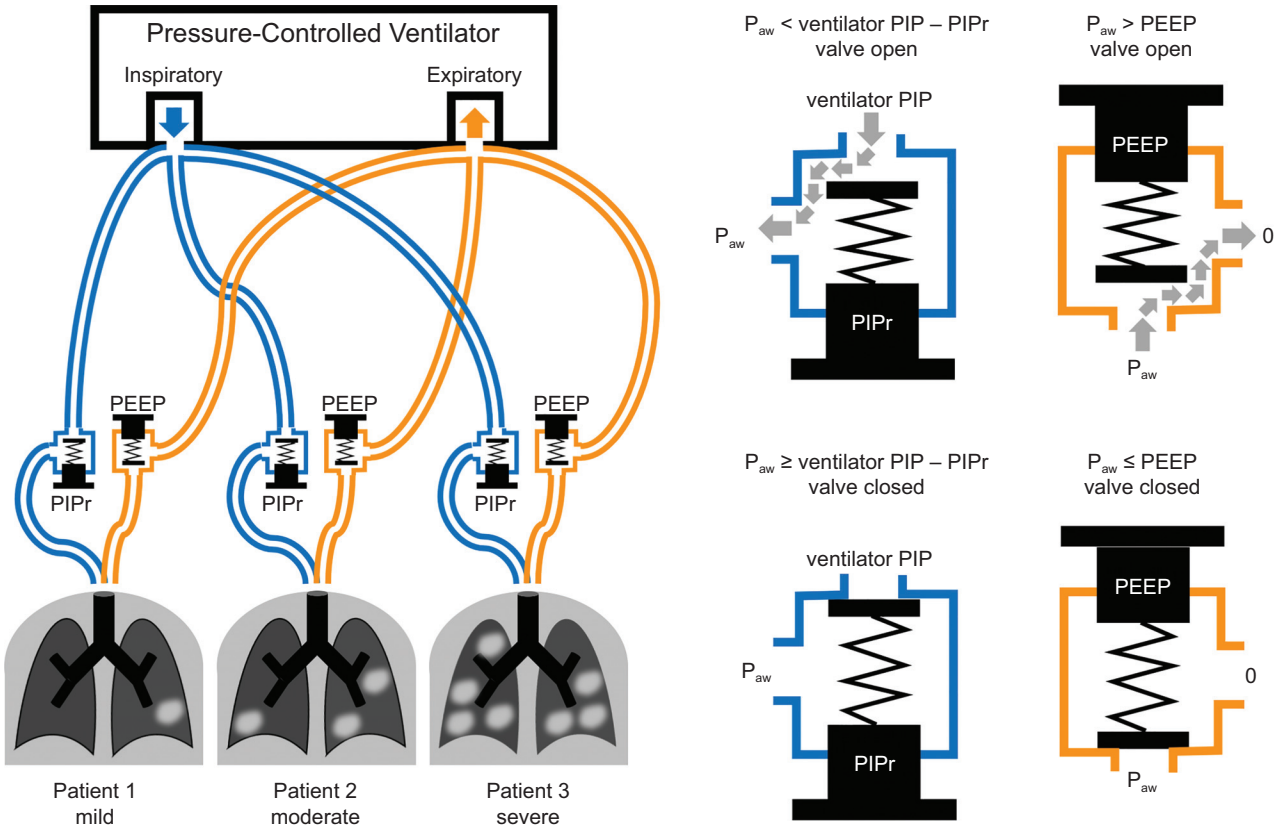


Fig. 3. Proposed modifications to breathing circuits during shared pressure control ventilation. Adjustable pressure-relief valves are added to both the inspiratory and expiratory limbs of each breathing circuit. The pressure-relief valve in the expiratory limb provides individualized PEEP, whereas the pressure-relief valve in the inspiratory limb provides individualized peak inspiratory pressure reduction (PIPr). Note that the PIPr valve is oriented with the intake toward the ventilator, whereas the PEEP valve is oriented with intake toward the patient. For this approach, the ventilator setting for PEEP is zero. $P_{aw}$ = airway pressure. From Reference 29.

Stiers et al[32] developed a system to provide ventilation to 2 patients while controlling $V_T$, PEEP, and $F_{IO_2}$. In this methodical evaluation, the authors began with adding the splitter and then adding one-way valves, inline PEEP, flow restrictors, and a separate oxygen inlet in succession. This system was used to ventilate 2 test lungs and included a method for determining auto-PEEP.[32] The use of inline PEEP valves to control inspiratory and expiratory pressure without venting gas to atmosphere (risk of environmental contamination) has been stressed by others as well.[33,34]

Solís-Lemus and colleagues[35] described a complete system for control of $V_T$ and PEEP. This evaluation simulated 7 matched and unmatched compliance and resistance values, and the authors reported that control of the desired variables was possible. Their system used flow and PEEP controls in each limb of the circuit. Other systems have simplified the circuit by only adjusting flow or PEEP in 1 limb, allowing the ventilator settings to determine $V_T$ and PEEP for the contralateral patient.[27] Srinivasan et al[36] described a system (iSAVE) with individual flow and pressure control for each subject, filters, and one-way valves as well as individual monitoring of pressure, volume, and $CO_2$. They tested the circuit with an anesthesia and a critical care ventilator in a lung model and found the system was capable of providing appropriate ventilation to each model.[36]

Han and colleagues[37] described a system based on the initial work of Sommer.[2] This system included 2 bag-in-the-box anesthesia-type circuits with the ability to provide differential $F_{IO_2}$ as well as $V_T$ and PEEP. In one side, the ventilator settings were controlled by the ventilator, while the other used modifications to the circuit. This is perhaps the most complicated, and Rube Goldberg-like approach to shared ventilation. The authors concluded that the system is a last-ditch approach and expressed hope that it would never be needed.[37] Another completely different approach has been described by Chase et al[38] (Fig. 4). This system uses one-way valves and PEEP valves but provides ventilation in series. The modification of the circuit allows delivery of inspiration to one patient while the other patient is in the expiratory phase. The system doubles the breathing frequency on the ventilator while maintaining other ventilator

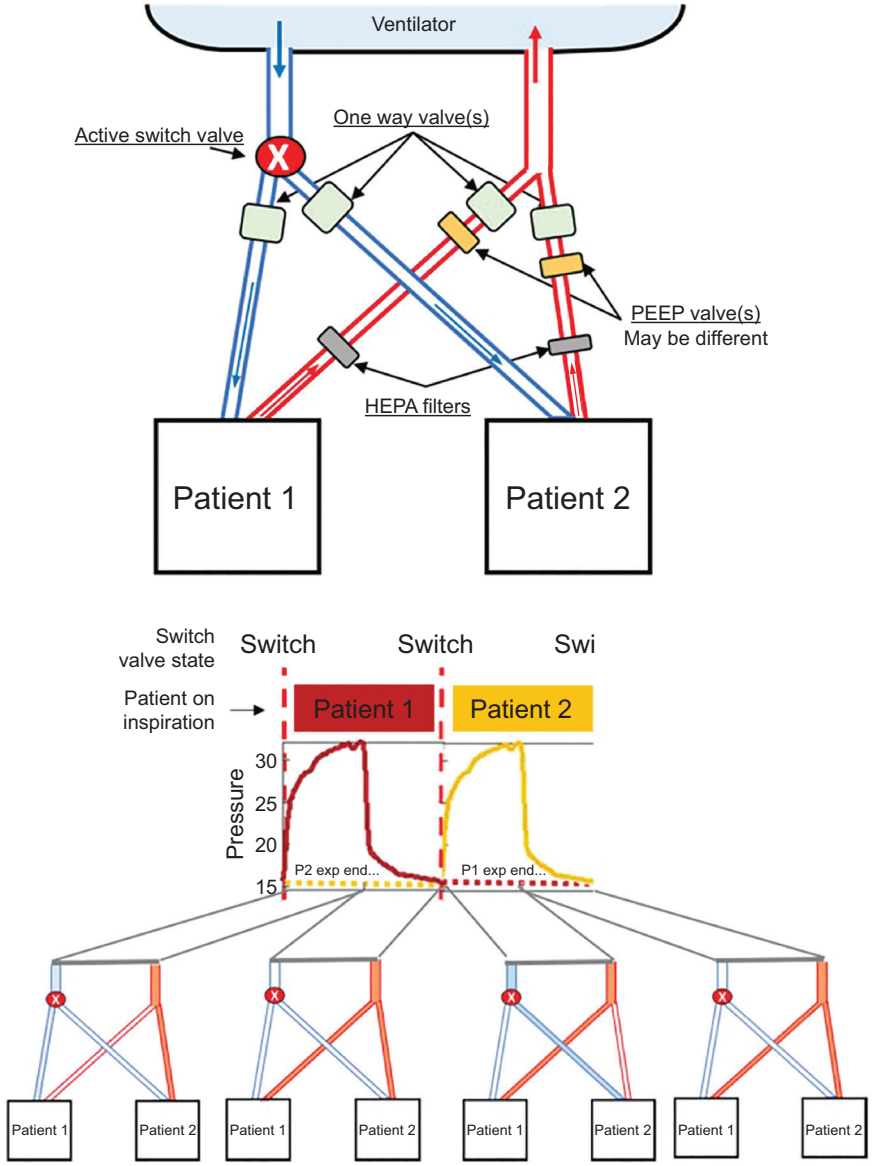


Fig. 4. Top: Schematic of a proposed in-series breathing circuit for 2 patients using an active inspiration valve. Bottom: Resulting ventilation waveforms and active (filled in) and in-active (not filled) inspiratory and expiratory circuit lines at any given 2-s period for 2 × 4-s breaths, one by each patient. The ventilator will display the given patient data in each breath. Patients are color-coded for clarity and to show how end expiration of Patient 1 overlaps inspiration and initial expiration of a Patient 2, although using different parts of the circuit. From Reference 38, with permission.

settings constant. Unique to this system is the ability of the ventilator to continue to monitor airway pressure, volume, and flow for each patient. The modification requires that an active switch (ie, a solenoid) direct gas flow into one circuit or the other. A unique limitation is that the inspiration to expiration ratio cannot be > 1:1 and adequate time for delivery of minute ventilation to both patients is required. These limitations have been further elaborated on by Freebairn and Park.[39]

Sojar and colleagues[40] described a modification of the LTV-1200 ventilator circuit for shared ventilation, demonstrating the ability to control $V_T$ and PEEP in a lung model. The LTV-1200 is one of the ventilators in the strategic national stockpile, and the reported modification is unique compared to others because the ventilator uses an external exhalation valve. These modifications are substantial and rely on the ventilator to control PEEP in one circuit and an external PEEP valve to control PEEP in the other.

Shared ventilation modifications include simple and complex modifications in an attempt to increase ventilator capacity. It is important to note that none of these systems are approved by the Food and Drug Administration and for

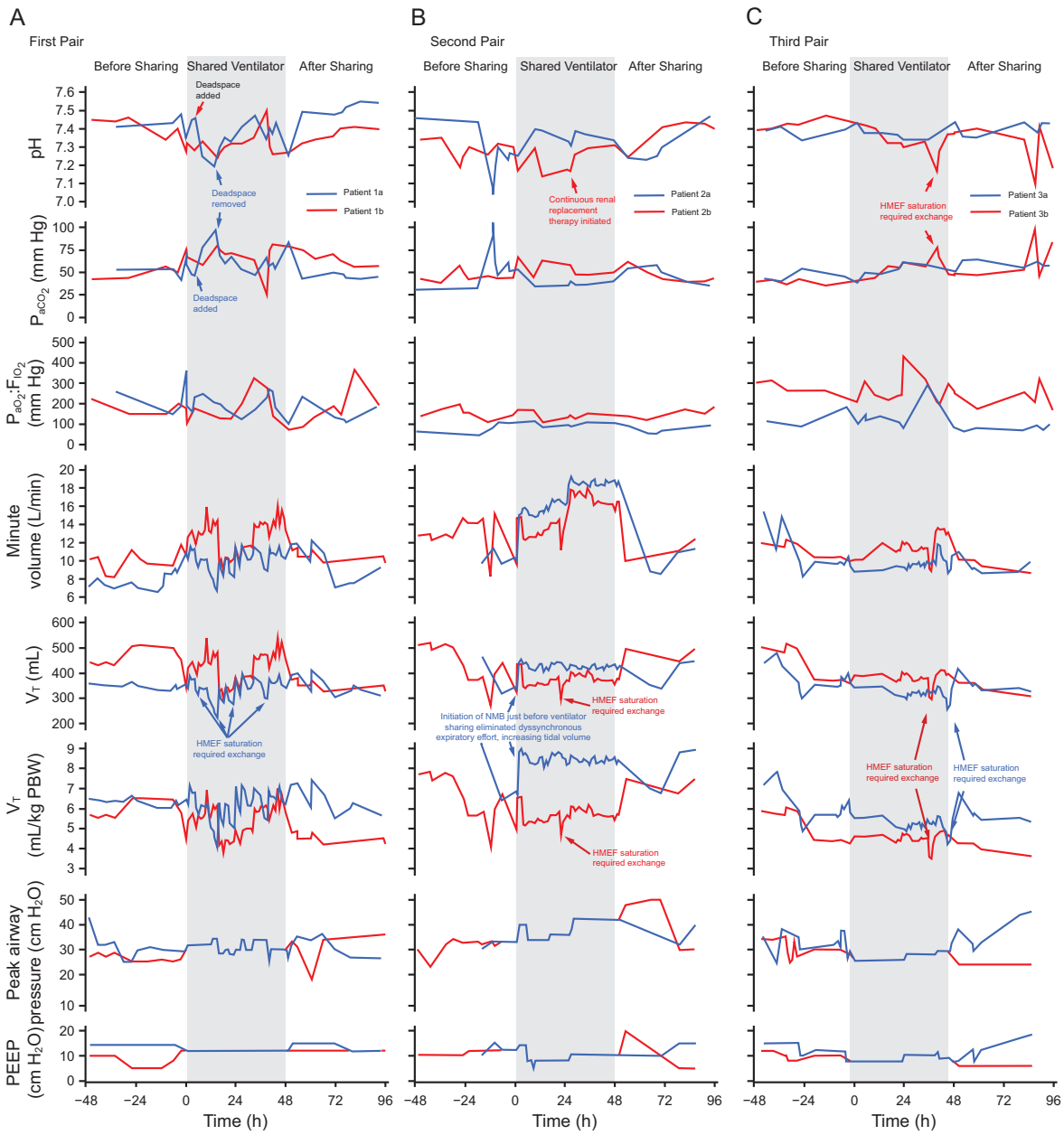


Fig. 5. Clinical course of patients during ventilator sharing and for 48 h preceding and afterward. A: The first pair of subjects shared a repurposed anesthesia machine. Approximately 4.5 h after initiating ventilator sharing, Patient 1a became alkalemic (pH 7.46), whereas Patient 1b remained acidemic (pH 7.28). To treat alkalemia, dead space tubing was added to the circuit of Patient 1a, but the resulting pH was lower than intended; with removal of this dead space tubing, acidemia promptly improved. The HMEF had to be changed frequently for both patient circuits as $CO_2$ absorbent–related moisture buildup increased resistance, an effect most pronounced in Patient 1a. B: The second pair of subjects shared a full-feature ICU ventilator. Patient 2a's course illustrated the importance of ensuring steady-state ventilator requirements and reconfirming compatibility on neuromuscular blockade before initiating sharing. Patient 2a was intubated for 16 h prior to ventilator sharing. During compatibility assessment, ventilator settings were matched and well tolerated but compatibility was not reconfirmed after starting neuromuscular blockade in Patient 2a; the patient exhibited overt, dyssynchronous expiratory effort before paralysis, and eliminating respiratory muscle activity substantially increased $V_T$ for a given driving pressure. Patient 2b was initiated on renal replacement therapy at 28 h for renal failure, which promptly increased pH. The patient's renal failure and plan for renal replacement predated ventilator sharing. C: The third pair of subjects shared a full-feature ICU ventilator. $V_T$ and acid–base balance were well controlled during ventilator sharing, reflecting cumulative experience and protocol refinement with incorporation of lessons learned. Patient 3b experienced a transient decrease in $V_T$ and pH and an increase in $P_{aCO_2}$ around 36 h due to HMEF oversaturation, which promptly resolved with its exchange. HMEF = heat and moisture exchanging filter; NMB = neuromuscular blockade; $V_T$ = tidal volume. From Reference 45, with permission.

the most part have only been tested in a bench model or in simulation. A number of the limitations in Table 1 still come into play. Both patients have to be paralyzed to prevent triggering, and monitoring the patients requires increased scrutiny in a time when the caregiver to patient ratio is strained.

### Animal Studies

Srinivasan et al[36] further evaluated their iSAVE system in a porcine model and were able to maintain normal gas exchange and hemodynamics. An interesting aspect of this study was the testing of cross-contamination by aerosolizing trypan blue into one of the circuits and looking for the cross-over to another circuit by examining the filter. Both animals had different respiratory mechanics, but no lung injury was produced. Similarly, Stiers and colleagues[41] used their system to successfully ventilate 2 ovine models with normal lungs (although position of the animals resulted in a difference in compliance of 10 mL/cm $H_2O$). The investigators considered this a next step in development but reiterated the need for additional independent monitoring of each patient.

Lugones et al[42] evaluated their system, known as the DuplicAR device, in a porcine model of 6 pairs of animals. The DuplicAR system is housed in an enclosure where PEEP and $V_T$ can be altered by use of pressure and flow regulators. As with other devices, control of flow using ball-valves is applied to both circuits, while PEEP is controlled by the ventilator in one circuit and by the PEEP valve in the other. Lugones et al[42] were able to provide adequate gas exchange in all 6 pairs of animals for up to 6 h. The authors used several different ventilators to evaluate the universal application of the system. None of the animals had lung injury. They concluded that the DuplicAR system might be useful as a bridge during a sudden ventilator shortage.

### Human Trials

Raredon and colleagues[43] described the PReVentS system for shared ventilation, which uses modified PEEP valves in the inspiratory and expiratory limbs of each circuit to control inspiratory and expiratory pressures. They describe the ventilation of a pair of subjects with respiratory failure due to COVID-19. Compliance for one subject was 22 mL/cm $H_2O$ and for the other was 26 mL/cm $H_2O$. Both subjects received pressure control ventilation, and the investigators noted the development of auto-PEEP of 2–3 cm $H_2O$. The added dead space and volume of the circuit also resulted in a slight rise in $P_{aCO_2}$ for each subject. This trial continued for 4 h, and gas exchange was maintained. No adverse events were noted. $F_{IO_2}$ and breathing frequency remained the same for each subject with this system.

Levin et al[44] described the ventilation of 2 pairs of subjects with COVID-19 for 1 h each. Subjects were matched for PEEP, $F_{IO_2}$, and breathing frequency. Arterial blood gases were measured every 30 min, and tidal volume was adjusted independently using flow control valves during pressure control ventilation. Despite subjects with disparate lung mechanics, the maintenance of gas exchange was satisfactorily achieved.

Beitler and colleagues[45] described the largest series of subjects receiving shared ventilation; a set of 3 pairs of individuals with ARDS due to COVID-19 were ventilated for 48 h. Following informed consent, the investigators paired subjects matched by driving pressures. No circuit modifications were made, although a respiratory monitor was used for each subject to determine airway pressure, volume, flow, and end-tidal $CO_2$ continuously. All subjects were ventilated in pressure control ventilation, and all received neuromuscular blockade. The first set of subjects were ventilated using an anesthesia ventilator. This resulted in a number of issues including excess humidity and resultant increased resistance of heat and moisture exchangers as well as frequent exhaustion of the $CO_2$ absorbent. On 4 occasions, heat-and-moisture exchangers had to be replaced as tidal volumes fell and $P_{aCO_2}$ rose (Fig. 5). These problems are unique to use of the anesthesia ventilator in the ICU and while not related to shared ventilation, further complicated its use. This has been described elsewhere.[46,47]

The remaining pairs of subjects were ventilated with ICU ventilators for 48 h without incident, although heat-and-moisture exchanger resistance continued to be an issue requiring replacement. No other adverse events were reported. The investigators concluded that shared ventilation was feasible for ARDS associated with COVID-19.[45] They emphasized that development of a rigorous clinical protocol, carefully selected patient pairs, the use of continuous neuromuscular blockade and informed consent were critical to success. The course of all 3 pairs is shown in Figure 5.

An early use of shared ventilation by face mask in healthy volunteers was reported.[48] This is included for completeness but provides little additional insight.

### Summary

Shared ventilation is a last resort in the face of overwhelming numbers of patients requiring mechanical ventilation. There is a fascination with the idea as demonstrated by the number of proposed solutions in under a year since the emergence of COVID-19. We have mentioned the social media influence here, stoking interest by the lay press. We have not provided links to these videos for two reasons. First, we don't want to promulgate the ill-

conceived ideas to others and risk careless use that might result in patient harm. Second, we don't want to call any further negative attention to the authors.

Even when modifications are made to enhance the safety of shared ventilation, patients must still be paralyzed to prevent triggering and complicating care. The few short-term descriptions of patient use suggest that shared ventilation adds to staff burden, considering the additional surveillance and monitoring required. This fact alone should temper the enthusiasm for this technique. Future use should only be in emergent situations with administrative and ethics oversight.

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