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One ventilator for two patients: feasibility and considerations of a last resort solution in case of equipment shortage

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The present emergency caused by the spread of the Covid-19 infection is putting enormous pressure on the healthcare systems worldwide and especially on intensive care units (ICUs).

One of the main fears in this regard is that we may run out of ventilators, a possibility which is getting more and more likely as the pandemic spreads throughout the world and the ICUs are overloaded with ventilated patients.

Many authors have already investigated the possibility of manipulating a ventilator circuit in order to ventilate up to four patients with a single machine. Neyman and Ervin first performed a bench study demonstrating the technical feasibility of ventilating four patients with one ventilator and one modified circuit.¹ The same circuit configuration was used in 2008 by Paladino *et al* in an animal model, resulting in substantial differences in oxygenation and decarboxylation between subjects during the ventilation period.² In 2012 Branson *et al* tested in vitro the Neyman and Ervin system simulating different conditions of compliance and resistance between the simultaneously ventilated test lungs. They observed wide variability in measured tidal volume (Vt) and end-expiratory lung volume, so they concluded that the technique should be avoided because of potential danger.³ Accordingly, the authors argued that the stockpiling of ventilators should be the first-line solution when massive emergencies are forecast; only after their depletion, strategies such as the 'double circuit' should be implemented for the shortest possible duration.^{4,5}

On 20 February 2020, the first case of Covid-19 emerged in the Lombardy region, northern Italy. As of 17 March, a total of 1069 patients had been admitted to ICUs in Lombardy, with a total of 1202 ICU beds available (after a significant expansion from the 720 beds available pre-crisis).⁶ By this time, a potential problem of ventilator shortages began to emerge because of the further spread of the virus in other regions of Italy. Great efforts have been put into place by institutions and industries to provide more ventilators for hospitals, but there is still a high potential for a supply-demand mismatch.

Therefore, we assembled, tested and proposed for production a simple circuit comprising tubing and accessories that are easily available in any intensive care/operating room setting. Indeed, one just needs two regular 'wye' breathing circuits, two 'T' connectors, and four heat and moisture exchanger

(HME) filters to build this system (see [figure 1](#) online supplementary file 1, online supplementary file 2).

The two T pieces are connected to the inspiratory and expiratory ports of the ventilator ([figure 2](#)). We preferred to interpose one HME filter in each expiratory limb (and not one for the entire expiratory circuit) in order to reduce total circuit resistance. At the end of each wye a patient is connected by interposing one HME filter. Total length of the tubing is 9.6 m, and each patient can be located at ~2 m from the ventilator.

We tested the circuit on a turbine ventilator (SIARETRON 4000 T, Siare Engineering International Group, Crespellano-Valsamoggia, Italy) connected by a two-patient circuit (Intersurgical SpA, Mirandola, Italy) to two test lungs (Model 5601 - Michigan Instruments Inc, Grand Rapids, MI, USA). We set ventilation for two patients of 80 kg of predicted body weight (PBW) targeting 6 mL/kg Vt at a respiratory rate (RR) of 20/min with an inspiratory: expiratory (I:E) ratio of 1:1 and a fraction of inspired oxygen (FiO₂) of 100%. Positive end-expiratory pressure (PEEP) was set at 15 cmH₂O and initial inspiratory pressure (P_{insp}) at 10 cmH₂O. We performed an initial 15 hour test with similar conditions between the two simulated patients (static compliance of the respiratory system (C_{stat}) 50 mL/cmH₂O and airway resistance (Raw) 5 cmH₂O/L/sec); in pressure control mode (P_{insp} 11 cmH₂O, PEEP 14 cmH₂O, RR 20 beats/min), measured delivered Vt was 953 mL, while the patients received 470 mL each.

We then performed two more tests:

1. Different C_{stat} (40 mL/cmH₂O vs 60 mL/cmH₂O) and equal Raw (5 cmH₂O/L/sec): as expected, Vt distribution was proportional to C_{stat}—540 mL for the simulated patient with C_{stat} 60 mL/cmH₂O and 340 mL for the one with C_{stat} 40 mL/cmH₂O.
2. Different Raw (5 cmH₂O/L/sec vs 20 cmH₂O/L/sec) and equal C_{stat} (50 mL/cmH₂O): as expected, Vt distribution correlated with Raw—480 mL for Raw 5 cmH₂O/L/sec and 400 mL for Raw 20 cmH₂O/L/sec.

Our tests confirm the in vitro technical feasibility of ventilating two patients with a single ventilator, but the difficulties and potential harm due to this configuration remain. Considering present knowledge on this issue and our data, we suggest a flow chart ([table 1](#)) to initiate this type of ventilation only in cases of extreme emergency due to machinery

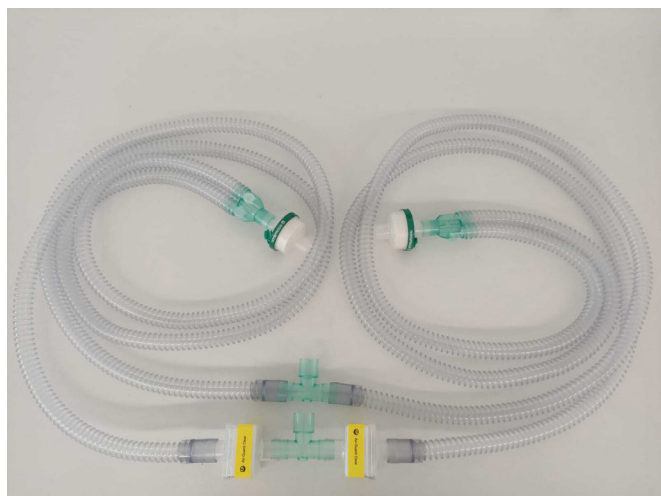


Figure 1 Assembled circuit.

shortages. A critical point is to match patients by compliance and, possibly, by airways resistance. Clinical personnel must remain vigilant, in order to recognise any possible sign of hypo- or overventilation, and must be ready at any time to start manual bag ventilation if any issue would occur.

Compared with manual bag ventilation, our technique allows delivery of ventilation, PEEP and FiO_2 with reasonable accuracy, is safer for operators and avoids the need for additional human resources (no 'human ventilator' is constantly needed at the patient's head). Using one ventilator for two patients instead of four (as proposed by some authors) reduces possible logistical issues (bed and ventilator positioning) and problems related to inadequate patient size matching.

We can conclude that this simple and easily built circuit can theoretically allow the emergency ventilation of two patients with a single ventilator. However, for a clinical application of this 'extreme' technique, several other factors must be taken into account. Indeed, anthropometric features (body weight and body mass index), respiratory mechanics (lung and chestwall compliances, airway resistances, possible auto-PEEP), physiological variables (complete paralysis, oxygen consumption and carbon dioxide production) and the clinical course of the two connected patients play a major role in determining the quality and quantity of ventilation delivered to each patient. Moreover, monitoring respiratory mechanics in each patient would be impossible

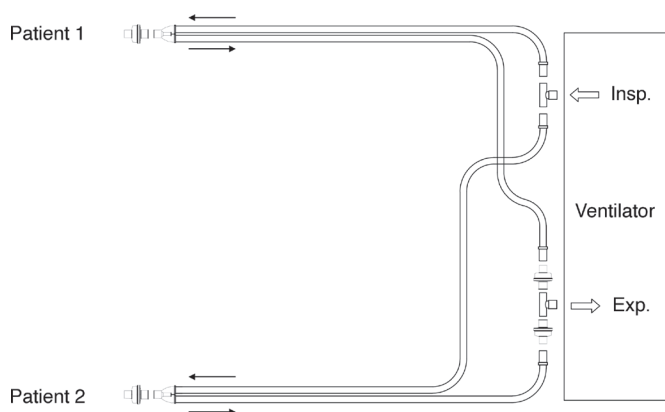


Figure 2 Circuit set-up. Arrows pointing left indicate inspiratory airflow, arrows pointing right indicate expiratory airflow. Insp., inspiratory port; Exp., expiratory port.

Table 1 Connecting two patients to one ventilator.

	<ul style="list-style-type: none"> ▶ Emergency situation, no available ventilators ▶ Mechanical ventilator with internal flow sensor ▶ Double ventilation circuit ▶ Passed leakage test ▶ Double patient ventilation successfully simulated with two test lungs/balloons in the desired ventilatory settings range
Prerequisites:	<ul style="list-style-type: none"> ▶ Deeply sedated or paralysed patients with similar PBW
Settings:	<ul style="list-style-type: none"> ▶ Set PCV and PEEP with driving pressure ≤ 15 cmH₂O ▶ Switch off inspiratory trigger
Starting procedures:	<ul style="list-style-type: none"> ▶ Connect first patient. ▶ Assess Vt and lung mechanics (plateau pressure, static compliance, total PEEP), maintaining the second wye occluded ▶ Connect second patient ▶ Clamp first patient's ET during an expiratory hold and perform lung mechanics assessment on second patient (plateau pressure, static compliance, total PEEP) ▶ Set longer inspiratory ramp time if desired FiO_2 cannot be reached
Monitoring and alarms:	<ul style="list-style-type: none"> ▶ Set alarm on Vt and FiO_2 at least ▶ Monitor SpO_2 at least ▶ Monitor EtCO_2 whenever possible ▶ Perform ABG regularly

Provide another ventilator as soon as possible

ABG, arterial blood gas test; ET, endotracheal tube; EtCO_2 , end-tidal carbon dioxide; FiO_2 , fraction of inspired oxygen; PBW, predicted body weight; PCV, pressure-controlled ventilation; PEEP, positive end-expiratory pressure; SpO_2 , peripheral capillary oxygen saturation; Vt, tidal volume.

or very difficult; however, we cannot neglect the possibility that, besides technical and physiological factors, ethical dilemmas may also arise.⁷ Indeed, the most difficult choice during such an emergency would be to either accept a grim triage reality (in which not all patients receive a ventilator) or accept the fact that trying to save two patients with one ventilator could mean harming at least one of them.

To the best of our knowledge, no significant evidence is available to date on this topic, but very recently New York-Presbyterian Hospital in the USA published a clinical guideline on this topic.⁸ To add to the controversy, however, a very recent consensus statement by several North American scientific societies discourages clinicians from connecting more than one patient to a single ventilator.⁷

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Simple ‘do it yourself’ circuit to ventilate two patients at once is technically feasible

But still not known if split ventilation pros outweigh cons so should only be used as last resort, say specialists

A simple ‘do it yourself’ breathing circuit, using accessories that are readily available in intensive care, can be used to ventilate two critically ill patients at once, should clinicians be faced with equipment shortages, suggests research published online in the journal **Thorax**.

But although technically feasible, it isn’t clear if the pros of split ventilation outweigh the cons, and the approach is fraught with ethical issues, so this circuit should only be used as a last resort, say critical care and respiratory disease doctors in linked opinion pieces.

Prompted by the rapid rise in COVID-19 cases in the Lombardy region of Italy, and the prospect of a ventilator shortage, Italian doctors assembled and tested a simple, easily built breathing circuit on two ‘pretend’ patients.

The circuit comprised routine and readily accessible tubing and accessories found in intensive care and operating theatres.

The 15-hour tests confirmed that it would be technically feasible to use the circuit to ventilate two patients at the same time.

What’s more, the technique is safer for staff than manual bag ventilation and avoids the constant need for a ‘human ventilator’ to work the bag, so freeing up staff, say the researchers.

But the tests also showed that the level of ventilation provided wasn’t evenly distributed when lung function and capacity differed between the two ‘patients.’

It should therefore only be used as a last resort, caution the researchers, because of the need to closely match the physiology of both patients, and the impossibility of being able to monitor separately changes in each patient’s respiratory response.

There are also ethical issues to consider, they point out. “Indeed, the most difficult choice during such an emergency would be to either accept a grim triage reality (in which not all patients receive a ventilator), or accept the fact that trying to save two patients with one ventilator could mean harming at least one of them,” they write.

These concerns are picked up in a linked editorial by respiratory disease and critical care doctors from the University of Chicago.

The idea of ventilator sharing isn’t new, explain Drs Steven Pearson, Jesse Hall, and William Parker. It was first suggested in 2006, for coping with equipment shortages in dire emergencies, and has been revived in anticipation of ventilator supply problems during the COVID-19 pandemic.

But they warn that even if patients can be matched before ventilation, the dynamic nature of the respiratory response means that these initial characteristics could subsequently diverge.

Daily pauses in the sedation needed for mechanical ventilation to check on the patient’s

ability to breathe unaided--which seems to help patients recover--would be extremely difficult if two people were connected to the same device, they point out.

The technical challenges also require other resources in short supply: intensivists and respiratory therapists, they say.

During a severe equipment shortage, clinical decisions would need to be based on ensuring the greatest good for the greatest number of patients, they explain. But what would happen if two patients each had a 50% chance of survival with a single ventilator, but only 20% on split ventilation, they ask?

"Whether or not the benefit of providing support to one additional patient outweighs the harms suffered by the two patients receiving co-ventilation is an impossible question to answer at this point, given the lack of evidence and experience, and these harms are unlikely to be amenable to rigorous quantification at any point in the near future," they write.

Ideally, in the absence of adequate supply, or other breathing support devices, patient (and family) consent should be obtained and strict protocols applied for the circumstances in which split ventilation can be used, and then only as a last resort, they emphasise.

"The role for co-ventilation appeals to the rule of rescue, the natural impulse to save those facing certain death, by freeing mechanical ventilators to support those in respiratory failure who would die without them," they write.

"But to use the lifeboat analogy, is taking on more passengers than the boat was designed to accommodate, worth the risk of sinking the lifeboat?"

Given current supply and demand, doctors will most likely be faced with such decisions, they suggest. "Humankind should realise it has been forced into a lifeboat by this pandemic without the luxury of yesterday's ethical postures until rescue arrives," they conclude.

In a further linked commentary, emergency care doctors in Detroit and New York agree that one patient per ventilator is best. Their YouTube video, setting out the experimental technique for ventilating four patients at the same time, inspired the Italian doctors to experiment with the approach for two patients.

"Everyone agrees one patient on one ventilator will always be the gold standard," write Drs Charlene Babcock and Lorenzo Paladino. "Use of one ventilator for two patients is clearly outside the manufacturer's recommendations and only appropriate in dire circumstances during a disaster."

But reporting on further experiences of the technique can only assist the understanding of how to expand ventilator options, they suggest.

"We commend the [Italian] authors of this study for further advancing documentation of this potential expansion of ventilator availability as a life-saving intervention during a disaster and hope the additional information we have provided may be informative," they conclude.