Original Investigation

Split-ventilation for more than one patient, can it be done? Yes

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Abstract

Background:

The COVID-19 pandemic crisis has led to an international shortage of mechanical ventilation. Due to this shortfall, the surge of increasing number of patients to limited resources of mechanical ventilators has reinvigorated the interest in the concept of split ventilation or co-ventilation (ventilating more than one patient with the same ventilator). However, major medical societies have condemned the concept in a joint statement for multiple reasons.

Materials and Methods:

In this paper, we will describe the history of the concept, what is trending in the literature about it and along our modification to ventilate two patients with one ventilator. We will describe how to overcome such concerns regarding cross contamination, re-breathing, safely adjusting the settings for tidal volume and positive end expiratory pressure to each patient and how to safely monitor each patient.

Main results:

Our experimental setup shows that we can safely ventilate two patients using one ventilator.

Conclusion:

The concept of ventilating more than one patient with a single ventilator is feasible especially in crisis situations. However, we caution that it has to be done under careful monitoring with expertise in mechanical ventilation. More research and investment are crucially needed in this current pandemic crisis.

Keywords: COVID-19, mechanical ventilation, Split-Ventilation, differential ventilation, respiratory failure

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Introduction

Since the start of the SARS-CoV-2 (COVID-19) pandemic in China in December of 2019 until now, the virus has spread widely and throughout the globe with more than 18 million cases to the time of writing this paper. It has also claimed more than 700,000 lives mostly through acute respiratory failure. With such overwhelming rates of infection, hospitalizations, and intensive care units admissions, multiple hospitals have found themselves short on many medical supplies especially personal protective equipment (PPE) and mechanical ventilators.

Many centers in the US and around the world have tried to increase their supply of mechanical ventilators through purchasing and obtaining more machines from the Center for Disease Control and Prevention's (CDC) Strategic National Stockpile (SNS) which serves as a repository for ventilators that would be used to supplement the supply in a national crisis. However, despite those measures, still the demand for mechanical ventilators well exceeds the supply, forcing many hospitals and acute care settings to turn to non-conventional methods to maximize their supply. For example using, non-invasive machines and adjusting their circuits to be used invasively, the use of anesthesia ventilators outside of the operating rooms and finally reviving the concept of ventilating more than one patient with a single ventilator.

The concept of ventilating more than one patient with one ventilator is not new. In, 1994 Sommer and colleagues designed and improvised two different circuits for the use in emergencies. In 2006, Neiman and colleagues published a study demonstrating the feasibility of ventilating 4 lung simulators using one ventilator. In 2007, Paladino and colleagues published the first trial of ventilating four adult sized sheep using one ventilator for 12 hours. In 2012, Branson and colleagues published a similar simulator study to Neyman and concluded that despite the concept's attractiveness, it could not support mass-casualty respiratory failure. This concept was put to the test in the clinical setting during the 2017 Las Vegas mass shooting due to the high number of patients who required mechanical ventilation and the shortage of hospital ventilators.

Recently, social media was besieged with talk and bluster from multiple clinicians on how to ventilate more than one patient with a single ventilator during this crisis. However, by the end of March 2020 major medical societies quickly issued a joint statement' condemning such practice advising clinicians that "sharing mechanical ventilators should not be attempted because it cannot be done safely with current equipment' and "it is better to purpose the ventilator to the patient most likely to benefit than fail to prevent, or even cause, the demise of multiple patients".

Though the underlying reasons for the joint statement is understandable, safely co-ventilating patients with current equipment is not as impossible as their statement would suggest and could be overcome. Their reasons given are:

- Volumes would go to the most compliant lung segments.
- Positive end-expiratory pressure, which is of critical importance in these patients, would be impossible to manage.
- Monitoring patients and measuring pulmonary mechanics would be challenging, if not impossible.
- Alarm monitoring and management would not be feasible.
- Individualized management for clinical improvement or deterioration would be impossible.
- In the case of a cardiac arrest, ventilation to all patients would need to be stopped to allow the change to bag ventilation without aerosolizing the virus and exposing healthcare workers
- The added circuit volume defeats the operational self-test (the test fails). The clinician would be required to operate the ventilator without a successful test, adding to errors in the measurement.
- Additional external monitoring would be required. The ventilator monitors the average pressures and volumes.
- Even if all patients connected to a single ventilator have the same clinical features at initiation, they could deteriorate and recover at different rates, and distribution of gas to each patient would be unequal and unmonitored. The sickest patient would get the smallest tidal volume and the improving patient would get the largest tidal volume.
- The greatest risks occur with sudden deterioration of a single patient (e.g., pneumothorax, kinked endotracheal tube), with the balance of ventilation distributed to the other patients.
- Finally, there are ethical issues. If the ventilator can be lifesaving for a single individual, using it on more than one patient at a time risks life-threatening treatment failure for all of them.

Methods

We will describe an assembly of one ventilator with two adjusted circuits that allows the delivery of different tidal volumes (V_T), PEEP, and allows the respiratory monitoring of each patient separately.

We elected to use the Hamilton G5 ventilator (Hamilton Medical Inc, Bonaduz, Switzerland) for an important reason. The ventilator flow sensors are not embedded inside the ventilator but outside proximal to the patient. This gives us the opportunity to monitor every single patient's pressures, volume, flow, and respiratory mechanics individually as explained below.

Setup:

- Ventilator circuit (Figures 1 & 2)
  Equipment:
  (2) Standard Ventilation circuits (6 feet inspiratory and 6 feet expiratory corrugated tubing)
  (2) Wye adaptor
  (2) Bacterial filter
  (2) Heat moisture exchange/filter (HMEF)
  (2) Inline suction catheters
  (2) Tee connector

- Dual flow sensor monitoring setup: (Figure 3 & 4)
  Equipment:
  (2) Hamilton flow sensors
  (4) Connecting tubes with 3-way stopcock attached
  (4) Tubing connectors
  (2) 6-inch tubing

To operate the Dual Flow Sensor Monitoring System and view each patient ventilator data individually, 1) turn handles for the first set of stopcocks so that flow is open to the ventilator and leave in this position, 2) use handles of second set of stopcocks to control the flow direction to swap views between individual patient ventilator data.

- Gate-valve flow restrictor setup (Figures 5 & 6)
  Equipment:
  (4) ½" bore Gate-Valve Flow Restrictor (from hardware store)
  (8) Rubber tube connector
  (4) One-way valve
  (4) Corrugate tubing connector
  (4) Flow Restrictor valve adapter (from hardware store)

Figure 1:
The coupler connection (blue) attaches to the inspiratory and expiratory port of the ventilator. The Tee valve adaptor (transparent) attaches to the coupler and to each circuit from both ends

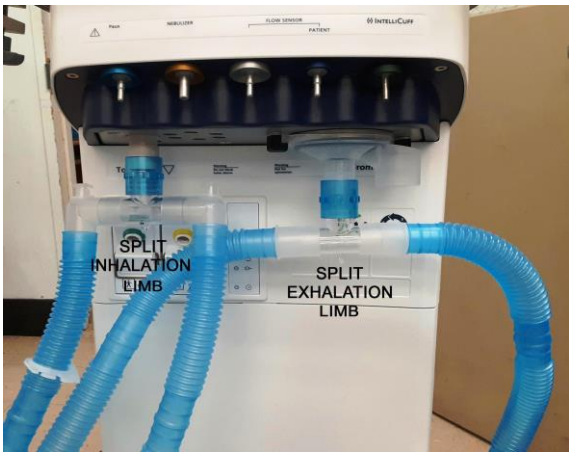


Figure 2:
Final assembly of the coupler and Tee valve attached to the ventilator

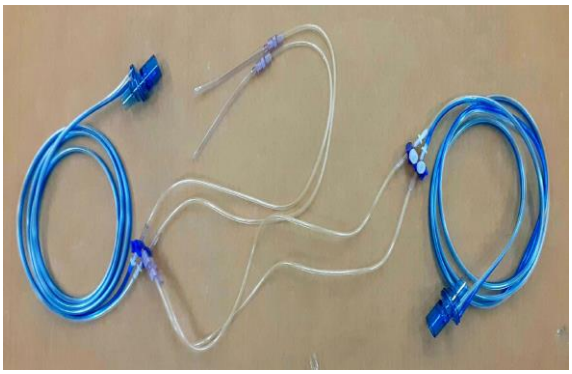


Figure 3
Two flow sensors connected with tubing extension and 3-way stopcock for individual monitoring

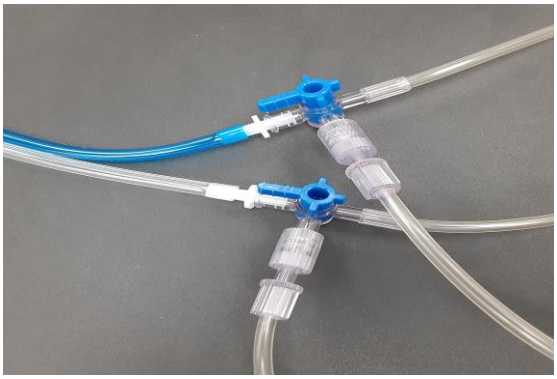


Figure 4
Close up to the 3 way stopcock connection

To confirm the feasibility of this setup, we used 2 lung models each attached to one circuit. One was a fixed compliance of 50 ml/cmH_2O and resistance of 5 cm$H_2$0/l/s and the other was adjustable (compliance adjusted to 20, 40, 60, 80 ml/cmH_2O respectively) and resistance 10, 15, 20, 25 cm$H_2$0/l/s respectively) to simulate ARDS, Normal lungs, and COPD,
The ventilator mode chosen was pressure targeted, continuous mandatory ventilator mode (PCV-CMV). There was no spontaneous breathing allowed.

Using a gate-valve flow restrictor on each inspiratory and expiratory limb of the circuit, we were able to adjust the tidal volume, PEEP to each lung model separately to our desire. Additionally, we were able to monitor each model without any clamping or disconnection of the other circuit. Even respiratory mechanics like compliance, resistance, auto-PEEP, and Volume-Pressure curve was able to be obtained. (Figures 8 & 9)

Of note, having a one-way valve on each limb of each circuit prevented any flow escape from one limb to the other or from one circuit to the other.

Discussion

As mentioned above, six major critical care, respiratory and anesthesia societies issued a joint statement in March 2020 [7] condemning the concept of ventilating more than one patient via one ventilator (split-ventilation or co-ventilation). Though their reasons or fears are legitimate, the statement explicitly says it is impossible. We will address the concerns mentioned in the joint statement and discuss how they can be overcome.

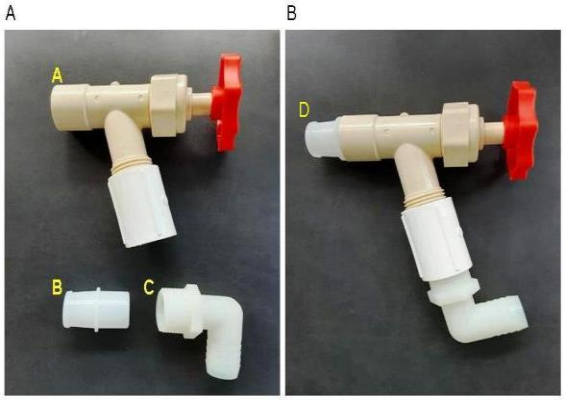


Figure 5
Valve restrictor. (A) Before assembly. A: Gate-valve flow restrictor, B: Corrugate tubing connector, C: Flow Restrictor valve adapter. (B) After assembly. D: One-way valve

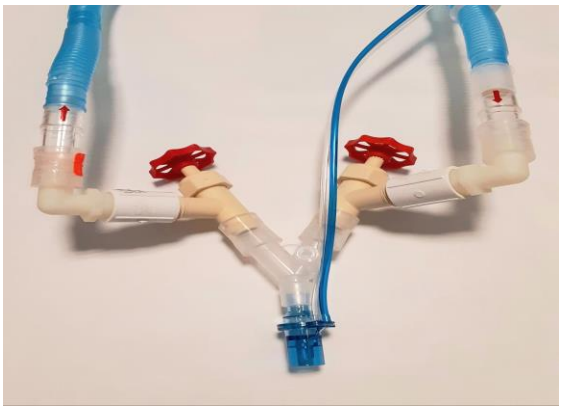
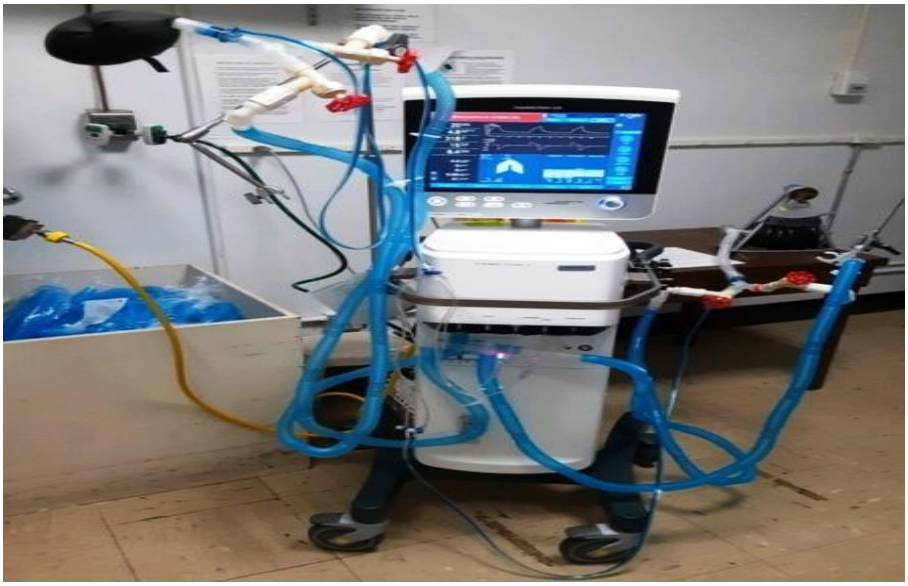


Figure 6
Gate-valve restrictor connected to each inspiratory and expiratory circuit and to the flow sensor adaptor

By using PCV mode and paralytics or heavy sedation to ensure that the patient is passive, adjusting the driving pressure to assure adequate or even higher tidal volume to each patient, then increasing the inspiratory and expiratory limbs to adjust to the needed tidal volume and PEEP individually. Thereby employing the setup above and others described in the literature, we have shown that it is possible to safely deliver different tidal volumes, minute ventilation and PEEP to each lung (the respiratory rate and $Fi0_2$ are the same).

Using a one-way valve on each limb of the circuit prevents flow swings or re-breathing between each limb or from one patient's circuit to the other.



Final setup is shown in figure 7.

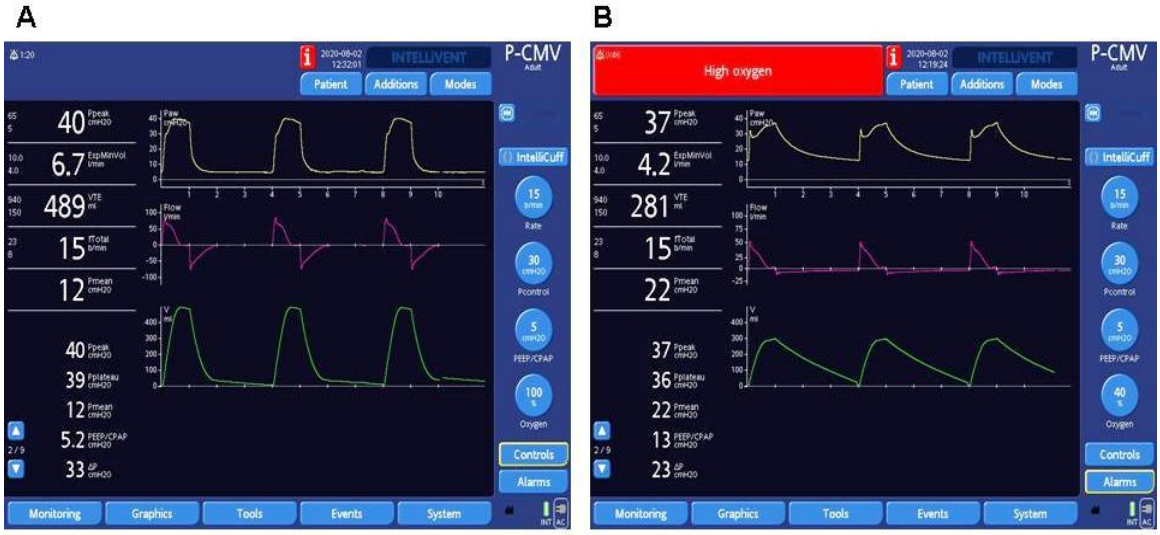


Figure 8: screen shots of test lung. A with compliance 50 ml/cmH_2O and resistance of 5 cm$H_2$0/l/s, with the inspiratory flow resistor tightened to decrease tidal volume. B with low compliance 20 ml/cmH_2O and resistance of 15 cm$H_2$0/l/s, with expiratory flow resistor tightened to increase PEEP to 13 cmH_2O.

Hence, different respiratory mechanics and the changes in those mechanics between two patients would not affect the tidal volumes delivered to the other patient.

Monitoring each patient's respiratory mechanics separately without needing to clamp or disconnect the other patient also can be done using a flow sensor for each lung as above.

In regard to the fear of infections and contamination, carefully selecting patients with proven COVID-19 is essential to avoid the spread of the virus from one patient to another. The addition of HEPA filters and one way valves on each circuit further reduces the risk of co-infection. In a CDC Statement regarding this issue, it states: "The infection control implications of co-venting are not firmly established, since it would not meet general established standards for infection control for ventilated patients. However, with the criteria specified and if done with currently

established infection control interventions to reduce health care associated infections, including ventilator associated infections, any additional risk is likely to be small and would likely be appropriate in a crisis standard of care.

The ethical issues of this concept is a difficult dilemma - how to choose patients to put on a ventilator and how to deny the others because of shortage of equipment. Quite a difficult situation that unfortunately has imposed itself all over the world and goes against the core of ethics and oaths clinicians have made in their careers. With guidelines and ethical discussions still undergoing, we believe that we should maximize our ventilator capacities by all means and ways, and not to abandon a patient in need for a ventilator just because they are all in use. Though we admit it is not the optimal situation, co-venting two or four patients will double or quadruple our ventilator capacity.

The U.S. department of Health and Human services (HHS) along the Federal Emergency Management Agency (FEMA) commissioned a task force that published guidelines to address that issue and were supportive of the co-venting concept during emergencies or crisis Additionally the Food and Drug Administration (FDA) have issued statement that reads: "A single ventilator fitted with the Vent Splitter can be used for multiple patients for ventilatory support during the COVID-19 pandemic when individual ventilators are not available or preemptively to increase the potential of single-use ventilators permitting mechanical ventilation for multiple patients simultaneously" and "FDA does not object to the creation and use of the T-connector that meets specifications described in the instructions provided to us for use in placing more than one patient on mechanical ventilation when the number of patients who need invasive mechanical ventilation exceeds the supply of available ventilators and the usual medical standards of care has been changed to crisis care in the interest of preserving life. The FDA's no objection applies during the duration of the declared COVID–19 emergency."
Along the task force mentioned above 11, some hospitals have already issued their guidelines on split-ventilation and can be used as a framework for those other hospitals facing the same challenges and shortages.

A recent study by Chatburn and colleagues tested the same hypothesis of split ventilation and coined the term "Multiplex ventilation" using PCV and VCV and warned against potential different ventilation and oxygenation for patients with uneven respiratory system impedances. They did not use any flow restrictors on any of the inspiratory or expiratory circuits. Similar to our study they issued some solutions to the issues raised by the societies discussed above. Another new study by Clarke and colleagues also tested the same hypothesis of ventilating two patients using both PCV and VCV, with differential tidal volume using flow restrictor clamp at inspiratory circuit.

To our knowledge, our study is the first one published to use flow restrictors at all the inspiratory and expiratory circuits and have different tidal volume and PEEP to each tested lung.

Finally, we caution that the setup required for ventilating multiple patients and their monitoring and troubleshooting is not easy as portrayed in social media services. Additionally, we believe that it should be done under special circumstances and with clinicians highly trained in mechanical ventilation with good understanding of respiratory mechanics.

Conclusion

Based on our observation with the setup as well as reviewing the limited new research and guidelines regarding the concept of split-ventilation, we believe that it is a feasible and a valid option during emergency or crisis time till more resources are deployed and available. Albeit the progress of research about the topic, much needed investments and research are required to improve the safety and the designs of the equipment for better safety of patients.

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