Splitting one ventilator

Ventilating multiple patients with one ventilator in a crisis situation

This document was published in Dutch on the website of the Dutch Society of Intensive Care (NVIC.nl on March 25th, 2020) and translated by the authors.

Heder de Vries[1], Prof. Ruud Verdaasdonk[2], Dr. Frans de Jongh[2,3], Marijn Vriens [1], Dr. Jonne Doorduin[4]

Prof. Leo Heunks[1]

1 Department of intensive care, Amsterdam UMC, location VUmc; 2 Techmed, University of Twente,

3 Department of intensive care Amsterdam UMC, location AMC and Medisch Spectrum Twente, Enschede; 4 Department of Neurology, Radboudumc, Nijmegen.

Content

Aim of this document

This document describes the principles and practice of ventilating two patients with one single intensive care ventilator. This can be considered , in extraordinary circumstances, when the number of ventilator-dependent patients acutely exceeds the availability of ventilators.

Background

During severe unexpected health crises, the stock/supply of ventilators might fall short of the number of patients with severe respiratory failure. This might occur in case of terrorist attacks or pandemic infections, such as COVID-19.

A possible (temporary) solution for the understock of ventilators is to ventilate multiple patients with one single intensive care ventilator. The modern ventilators have substantial reserves with respect to tidal volume and pressure delivered, which makes it technically possible to ventilate two patients with one single ventilator. This technique should only be used as a temporary bridge until the patient is transported to a location where sufficient ventilators are available, or until new ventilators are available for the patient at the current location.

This document describes the physiological principles, required components, set-up and potential risks of splitting the ventilator.

Disclaimer

This technique should only be considered in emergency situations. Every patient is unique, the tips in this document cannot replace the evaluation of a healthcare professional. Ventilators are not designed, nor registered to ventilate more than 1 patient at the same time. Thus, this document describes off-label use. The authors emphasize that this technique should only be considered in extraordinary circumstances and after careful consultation of stakeholders.

The demonstration described in this document has been performed with the Servo-U (Getinge, Sweden) and repeated with the Evita Infinity 500 (Draeger, Germany), the Philips V680 and the Hamilton G5 and G6 (Hamilton, Switzerland). For the Evita ventilator the automatic tube compensation should be switched off. The Hamilton ventilator might show a alarm that a fatal leak occurs in the system when the peripheral flow sensors are connected to the ventilator. Prior to applying this technique in practice, we strongly advise to test the breathing circuit with test balloons.

Basic principles

Usually, a patient is connected in series to a closed system with the mechanical ventilator (Figure 1). The ventilator measures the exact amount of generated pressure and the tidal volume delivered to the patient. The volume provided by the ventilator at the inspiratory tube, should in a closed system also return at the expiratory tube. The clinician is in full control of the pressures, volumes and minute ventilation delivered to the patient..

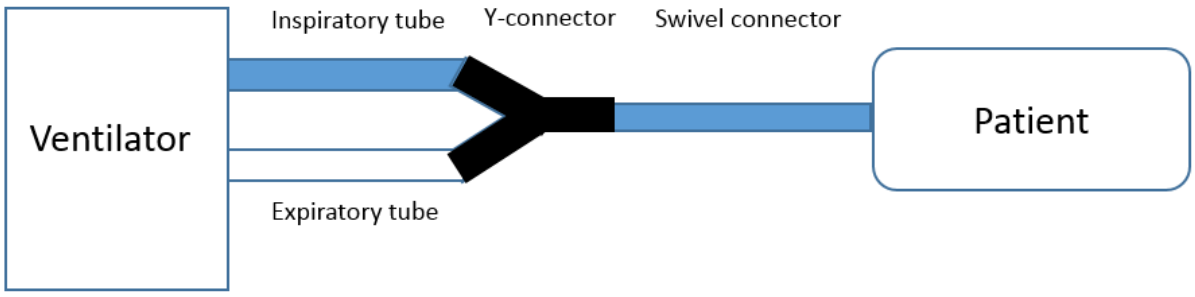

Figure 1 Standard set-up for invasive mechanical ventilation

Technically, it is possible to connect multiple patients in parallel to one single mechanical ventilator (Figure 2). To achieve this, both the inspiratory and the expiratory port of the ventilator are splitted with T- or Y-connectors. This allows the connection of 2 patient circuits to the now-splitted inspiratory and expiration tubes of the ventilator.

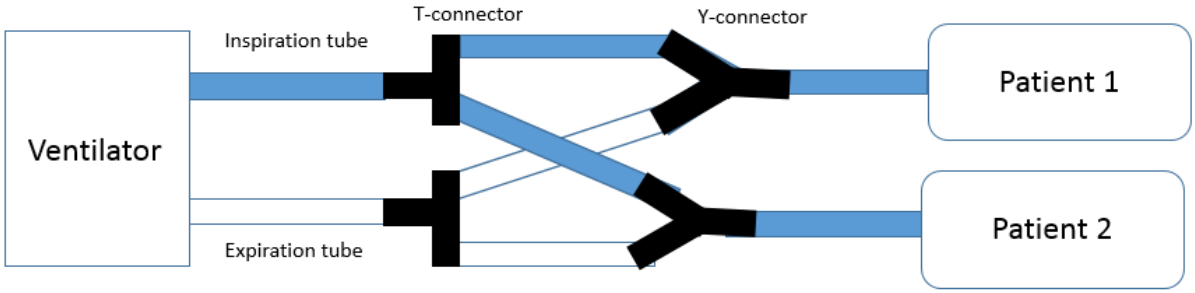

Figure 2 Schematic view how to attach 2 patients to 1 ventilator. One-way-valves are not shown in this figure

In this scenario, the mechanical ventilator will generate pressure and volume for both patients simultaneously. Depending on the ventilator mode, either the volume will be guaranteed (volume control ventilation) or the pressure will be guaranteed (pressure control ventilation). The delivered by the ventilator, is distributed between the two patients. How the total tidal volume is distributed between the 2 patients depends on the mechanical characteristics (compliance of the respiratory system) of each of the patients.

Volume controlled ventilation is not recommended in these circumstances. In case of acute obstruction in the ventilation circuit of one patient, the total tidal volume delivered to the other patient, resulting in very high tidal volumes.

Accordingly, there is a **strong preference for the pressure controlled ventilation mode**. Pressure controlled ventilation ensures equal plateau pressures are reached in both patients in case the inspiratory time is sufficiently long (end-inspiratory flow should reach zero). An acute obstruction in the ventilation circuit of one patient, will have no influence on the tidal volume delivered to the other patient.

This setup with multiple patients attached to a single ventilator is **not feasible, in fact dangerous,** in case one (or both) patients exhibit respiratory effort triggering the ventilator. A strategy should be planned on how patients will be supported in case sedation is decreased and respiratory drive returns.

Equipment & disposables

To ventilate 2 patients with 1 ventilator the following components are needed:

- 1 ventilator
- 2 patient circuits, including per circuit (Figure 3)
    - 1 Y-piece
    - 1 Swivel connector
    - 1 Virus/bacterial filter (HEPA filter)
- Additional disposables required (Figure 4)
    - 1 single inspiratory tube
    - 1 single expiratory tube
    - 2 T-connectors (or 2 additional Y-pieces) with one-way-valves
        - Supplier: https://nl.intersurgical.com/producten/intensive-care/connectoren
    - Alternatively, two regular T-pieces and 4 one-way-valves can be used
- Be aware that components could not fit due to mismatch of the male and female connector interfaces. Try to fit fitting M-F, F-M connections for standard 22mm tubings

Figure 3 Standard patient circuit including test lung

Figure 4 Additional components: one-way-valves are placed in the T-connectors. The direction of the arrows shows the direction of airflow which is unobstructed by the one-way-valve. Be aware of the direction of the airflow!

Figure 5 T-piece with one-way-valve. The direction of the arrows indicates in which direction airflow is possible. This specific T-connector can be used to congregate the expiratory tubes of both patients. Be aware of the direction of the arrows! The direction of the valves can be changed, see supplements!

Set-up

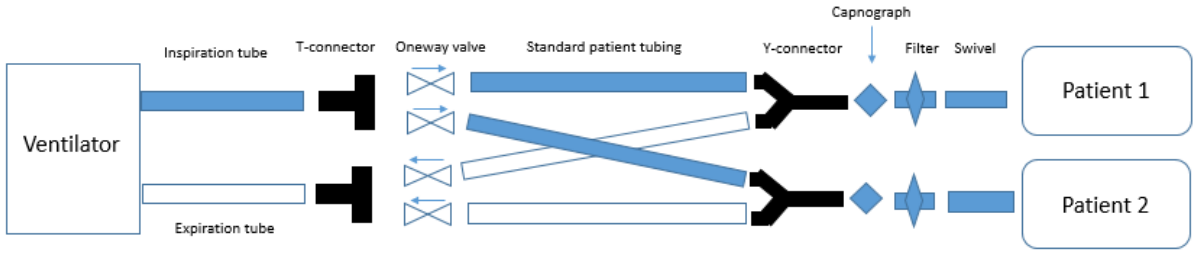

Figure 6 Schematic set-up. The arrows on the T-connectors indicate the direction in which airflow is unobstructed; airflow in the other direction is blocked. See supplement 1 for this figure in more detail and for an option without T-connectors with build in one-way-valve.

Figure 7 Set-up in practice. Every test lung represents 1 patient. The tidal volumes visible on the ventilator are the total tidal volume of the two test lungs in total.

Advantages and constraints

Advantages

- Relatively simple set-up
- Few additional disposables needed

Constraints

- PEEP and FiO2 cannot be controlled for each patient separately
- It is not possible to monitor tidal volume per patient with the ventilator. This would require dedicated equipment (flow sensor at endotracheal tube). The volume delivered to the individual patients will depend on the total compliance of the respiratory system of the

individual patients. It is important to connect only patients with more or less similar respiratory compliance and ARDS severity to one ventilator.

- It is not possible to titrate tidal volumes per patient (see below for some measures how this could be possible indirectly).
- In case inspiratory times are short (and end-inspiratory flow does not reach 0), the resistance of the individual patients will also influence the tidal volume of the patient
- In case one-way-valves are not included to the circuit as described above, backflow is possible between patients. This could cause unwanted high pressures (e.g. during coughing), and exchange of pathogens and other aerosols. See supplement for more information on one-way-valves.
- Every patient requires a separate capnography to monitor end-tidal CO_2 for safety purposes(see below for alternative solutions)
- Alarm limits should be set **very cautiously**, because disconnection of 1 patient may be undetected by the ventilator

Monitoring and practical tips

Delivery of lung-protective ventilation to both patients is extremely challenging when splitting one ventilator. To guarantee long-protective ventilation, we have formulated some practical tips based on our experience with multiple test circuits.

I:E-ratio

It is advisable to set the I:E-ratio in such a way, that inspiratory flow reaches (nearly) 0, resulting in equal end-inspiratory pressures. This is preferred, as it allows evaluation of the plateau pressure for both patients.

Pressure waveforms

The flow and pressure waveforms shown on the ventilator screen are different from regular set up of the circuit, due to insertion of the one-way valves in the tubing. The expiratory flow is slightly obstructed by the one-way-valves, which might appear as a delayed return to baseline in the airway pressure curves(arrows figure 8). This will slightly increase mean airway pressure.

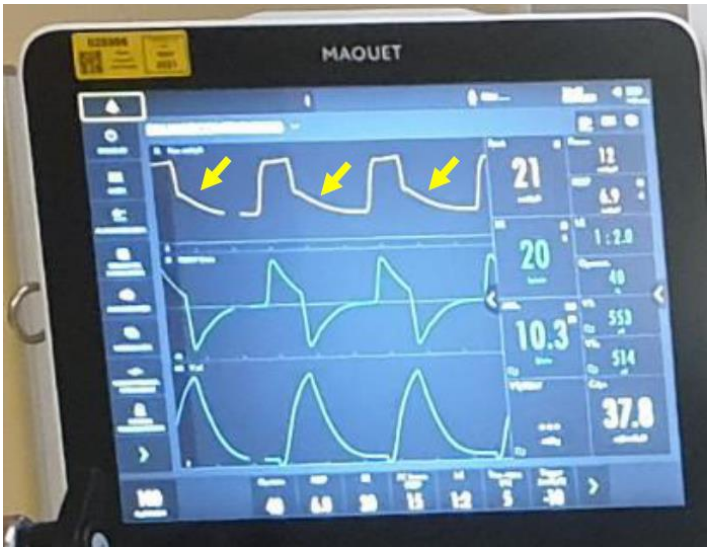

Figure 8 Unusual expiratory flow waveforms caused by using one-way-valves (arrows). Expiratory pressure requires more time than usual to return to the PEEP level because of the increased expiratory resistance in the circuit.

Plateau pressures

The described set-up is a parallel connection. This means that the pressure measured by the ventilator will be administered to both individual patient circuits. The plateau pressure is still valid for both patients with this set-up. To measure the plateau pressure, an inspiratory hold of 5-10 seconds should be applied.

Driving pressure

As with the plateau pressure, the driving pressure remains a valid parameter in this parallel connection. To measure the driving pressure, an inspiratory hold should be applied to measure plateau pressure. After that, an expiratory hold of 5-10 seconds should be applied to measure total PEEP. The driving pressure can be calculated as plateau pressure – total PEEP.

It is possible that the PEEP measured by the ventilator is a slight underestimation of the true intrinsic PEEP in both patients. Thus, the calculated driving pressure can be a slight overestimation (the total PEEP is extracted from the plateau pressure, in case a too small number is extracted, the calculated driving pressure will be an overestimation). This is caused by one-way-valves obstructing the backflow. In our own experimental set-up this was <2 cmH2O, which does not affect driving pressure.

Tidal volumes

It is impossible to continuously monitor tidal volumes of individual patients, except in case additional flow sensors are inserted in the circuit between the distal Y-piece and the endotracheal tube. Alternatively, a surgical clamp can be placed on the endotracheal tube of one patient (for 2 breaths). The volume of the not-occluded patient will be measured by the ventilator. This should be the same volume administered to this patient when both patients are connected to the circuit.

Capnography

It is mandatory to monitor ETCO2 (capnography) for each patient. This is ensures that disconnections and acute changes in respiratory mechanics are noticed.

Resistance per patient

Theoretically, it is possible to influence the tidal volumes administered to the individual patients by adding a variable resistance (using a clamp or valve) to the inspiratory tube of each patient circuit. This could be relevant in case both patients have a markedly different respiratory resistance or compliance. The airflow will choose the least resistant tube, meaning that the patient with the highest compliant lungs and the lowest resistance receives air first. However, this method is only possible in case relatively short inspiratory times are used. In case the I:E-ratio is set in a way the inspiratory flow reaches 0, the resistance does not influence the reached volume (only the time in which this volume is reached). This technique is currently not recommended and requires further research.

Additional references

Some literature is known about ventilating multiple animals with a single ventilator and incidentally about ventilating patients.

Literature

1. Neyman G, Irvin C. A single ventilator for multiple simulated patients to meet disaster surge. *Acad Emerg Med*. 2006;13(11):1246-1249. doi:10.1197/j.aem.2006.05.009

2. Paladino L, Silverberg M, Charchaflieh J, 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(1):121-126. doi:10.1016/j.resuscitation.2007.10.016

3. Branson R, Blakeman T, Robinson B, Johannigman J. Use of a single ventilator to support 4 patients: laboratory evaluation of a limited concept. *Respir Care*. 2012;57(3):399-403. doi:10.4187/respcare.01236

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Videos

1. https://www.youtube.com/watch?v=NER2h9STy7Q

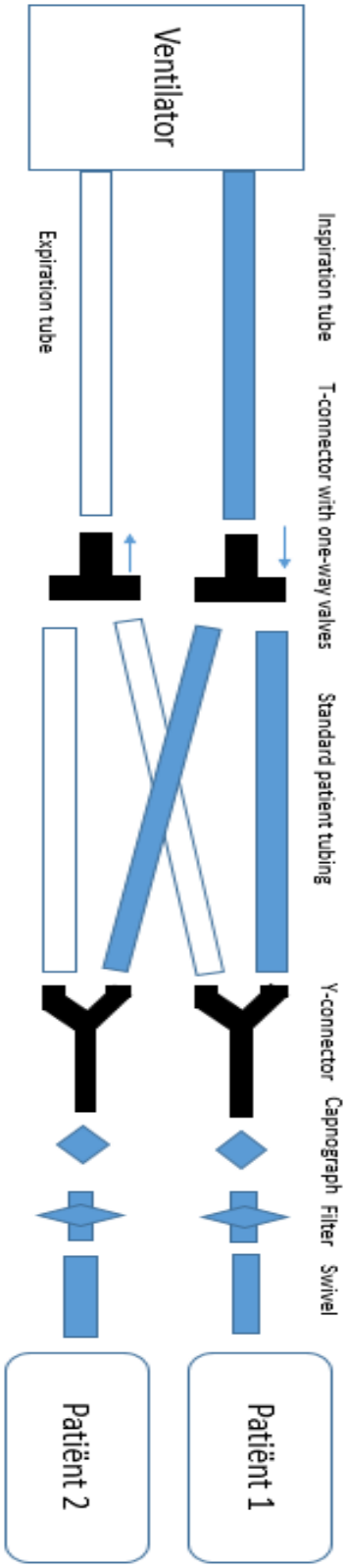
This video demonstrates the same set-up as described in this document, including the use of one-way-valves.

2. https://youtu.be/eSVbwWANqRI

This video demonstrates the use of variable resistance to adjust the ventilation per patient. We explicitly do not recommend the use of variable resistance.

Supplements

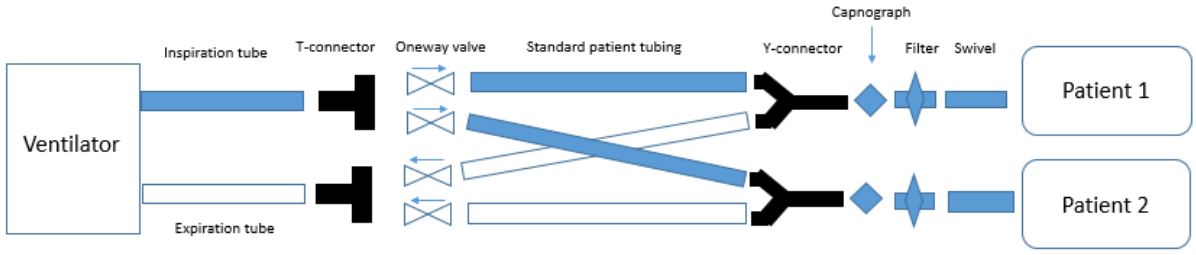
Supplement 1: schematic representation of the set-up



Supplement 2: Instruction to assemble T-connectors with one-way-valves

Option 1: Separate one-way-valves

To prevent backflow between patients it is recommended to insert one-way-valves to the circuit. This could be separate one-way-valves which are added after the T-connectors on the inspiratory and expiratory tube. The schematic drawing of the set-up is as follows:



There are 4 one-way-valves required for a circuit with two patients. It is extremely important to verify that the one-way-valves are positioned in the right direction. The circuit should be tested with test lungs before connecting patients.

Option 2: T-connectors with one-way-valves

Another option is using T-connectors with one-way-valves. These T-connectors are currently used for example in respiratory muscle training. Ensure that the valves are positioned in the right direction (can be adapted). If direction of the valves is changed, also adjust the adhesive markers on the T-connectors to accurately show the direction of the airflow on the T-connectors.

Figure 9 Inside view of T-connector, valve visible. In this direction the airflow is obstructed.

Figure 10 Inside view of T-connector, valve visible. In this direction the airflow is not obstructed.