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ORIGINAL ARTICLE

3D-Printed Splitter for Use of a Single Ventilator on Multiple Patients During COVID-19

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Abstract

During epidemics or pandemics affecting the respiratory systems, hospital equipment such as ventilators may become insufficient and different solutions can be considered. In fast spreading respiratory illnesses such as COVID-19 due to the rapidly increasing number of patients, ventilatory machine insufficiencies may appear. It may be considered to use one hospital ventilator for more than one patient by dividing the airway of the machine with a specially designed splitter. The aim of this study was to determine whether a ventilator can be modified to provide ventilation of two or more patients simultaneously by using 3D designed and manufactured splitters. A two-port and four-port splitter were designed in Autodesk Fusion 360 computer program and manufactured by 3D printer using PolyJet technology (Stratasys J750). Two sets of splitters were used to adapt to the ventilator during trial process: one for inspiratory and one for expiratory outputs. Two intensive care specialists voluntarily tried this study on themselves. It was concluded from the study that 3D designed and manufactured two-port splitter can be used to separate the airway of a single ventilator to multiple patients within a very limited indication and time interval.

Keywords: COVID-19, 3D, printing, ventilator, intensive care

Introduction

Early December of 2019, the world came to know about a new mortal infection spreading from Wuhan, China, which especially affects the respiratory system.[1] This pathogen was named as novel coronovirus-2019 (nCoV-2019), SARS CoV-2, or COVID-19.[2] The World Health Organization (WHO) declared COVID-19 as a pandemic on March 11, 2020.[3] This respiratory pathogen causes fibrosis in the respiratory system and creates breathing difficulties. Severe cases might rapidly progress to acute respiratory distress syndrome (ARDS), septic shock, and difficult-to-tackle metabolic acidosis and bleeding and coagulation dysfunction.[1,2]

In epidemics or pandemics, hospitals and intensive care units rapidly extend to operate with high capacity. If epidemics or pandemics affect the respiratory systems, hospital equipment such as ventilators may become insufficient and different solutions can be considered.[3] Recently, it has been observed from the press and literature that although the governments' resources be available, due to the rapidly increasing number of patients in COVID-19, ventilatory machine insufficiencies may appear.

Since all health care personnel are important in such pandemics, it is impossible to ventilate patients with mechanical ventilation by additional personnel. Therefore, it may be considered to use one ventilator for more than one patient by dividing the airway of the machine with a specially designed splitter.[3–9] In the literature, it has been shown experimentally that in case of a disaster surge, a single ventilator could be modified to ventilate up to four adults for a limited time.[3–8]

The use of 3D technology in the field of health is becoming widespread today, enabling the production of various prototypes or products.[9] During emergencies, this technology enables the manufacturing of some vital parts quickly. Especially, during this worldwide pandemic, researchers

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tried to design and manufacture many products to facilitate the work of doctors and support the patients. Multidisciplinary studies of doctors and engineers in this type of production are important for the emergence of useful and rational products. The aim of this study was to determine whether a ventilator can be modified to provide ventilation of two or more patients simultaneously by using 3D designed and manufactured splitters. The null hypothesis of the study was that an intensive care service ventilator can be used to ventilate multiple patients in emergencies using splitters.

Materials and Methods

Designing and the manufacturing process of this study was performed in Gülhane Medical Design and Manufacturing Center, University of Health Sciences Turkey.

First, two-port and four-port splitters were designed in Autodesk Fusion 360 (San Rafael, CA). The diameter, length, and flexibility of the hoses of the single-limb circle breathing system that are used in the patients and diameter of the outlet pipe of the ventilator are taken into consideration during the design process of the splitters.

For the two-port splitter, the diameter of the extension for ventilator connection was 22.20 mm for inside and 26.20 mm for outside, the diameters of both extensions for breathing system hoses were 18 mm for inside and 22 mm for outside. Total size of the splitter was $60.2 \times 60.2 \times 70.8$ mm ($x \times y \times z$) (Fig. 1). For the four-port splitter, the diameter of the extension for ventilator connection was 22.20 mm for inside and 26.20 mm for outside, the diameters of all extensions for breathing system hoses were 16.50 mm for inside and 22 mm for outside. Total size of the splitter was $53.49 \times 104.41 \times 124.44$ mm ($x \times y \times z$) (Fig. 2). Necessary tolerance dimensions were adjusted to suit the inspiration and expiration inlets of the device.

To achieve equal amounts of air flow without loss through the ports, air outlets were designed symmetrically in the same diameter, and distances to the main outlet were kept short. Especially for the four-port splitter, a special airway distributor pad was designed inside the device. For the two-port splitter, a distinct slope was given from the main entrance to the exit ports. Also, the outer dimensions and wall thicknesses were kept at an optimum level (4 mm) so that the splitter does not take up much space on the ventilator, the outlet pipes are directed separately to the patients without contact with each other and the cost is kept a minimum (~\$18 for two-port splitter, ~\$30 for four-port splitter).

The .stl data were sent to the 3D printer that uses PolyJet technology (Stratasys, J750, MN) with a shore value of 95. The manufacturing process was completed using acrylic resin raw material with a sensitivity of 16 μm layer thickness in 5 h. In production, two sets from each design were produced to attach the splitters to the ventilator's inhalation and exhalation outlets (Figs. 1 and 2). After production, support materials over and inside the splitter were cleaned with water under pressure.

The obtained devices were tried by two voluntary and healthy intensive care specialists at the hospital of our university, in the cardiovascular surgery intensive care unit where no patients were hospitalized. They performed the experiment on themselves and wore full-face continuous positive airway pressure (CPAP) masks with headgear, separately (Fig. 3). One specialist was a 55-year-old 80 kg male with no systemic or respiratory disease. The other specialist was a 36-year-old 73 kg male without systemic or respiratory disease.

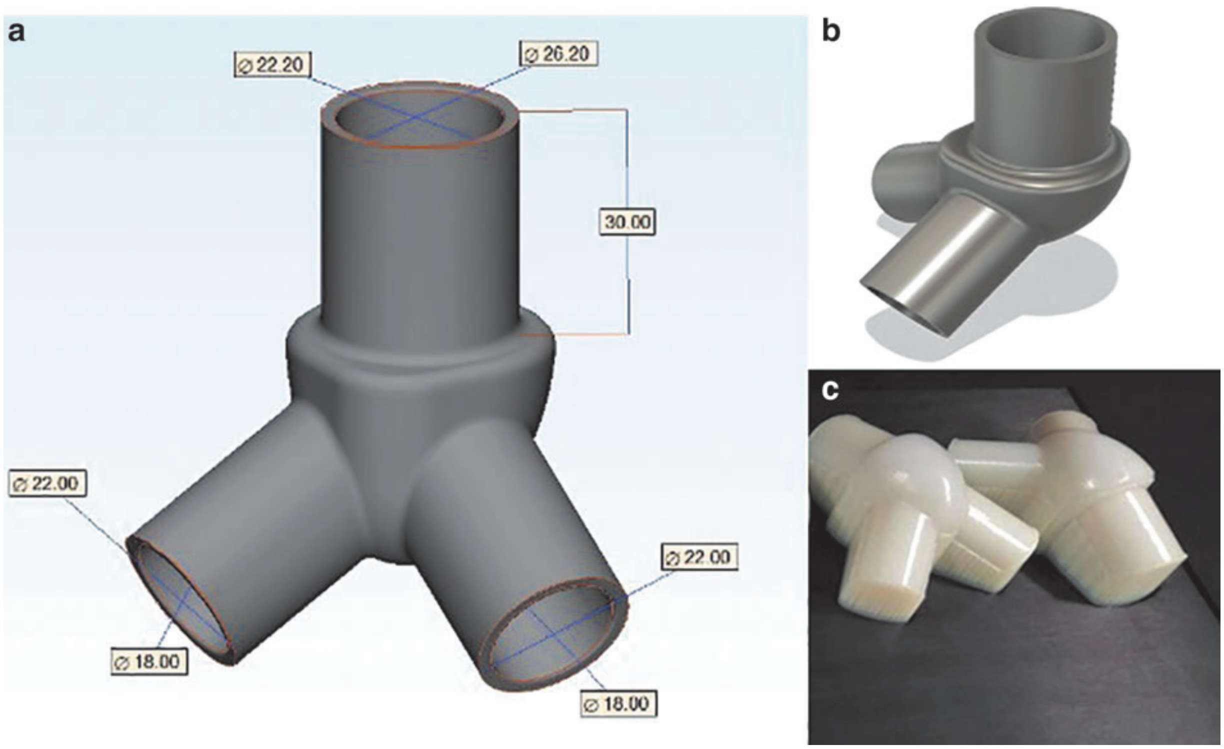

FIG. 1. **(a)** Dimensions, **(b)** final seem, **(c)** manufactured version of the two-port splitter.

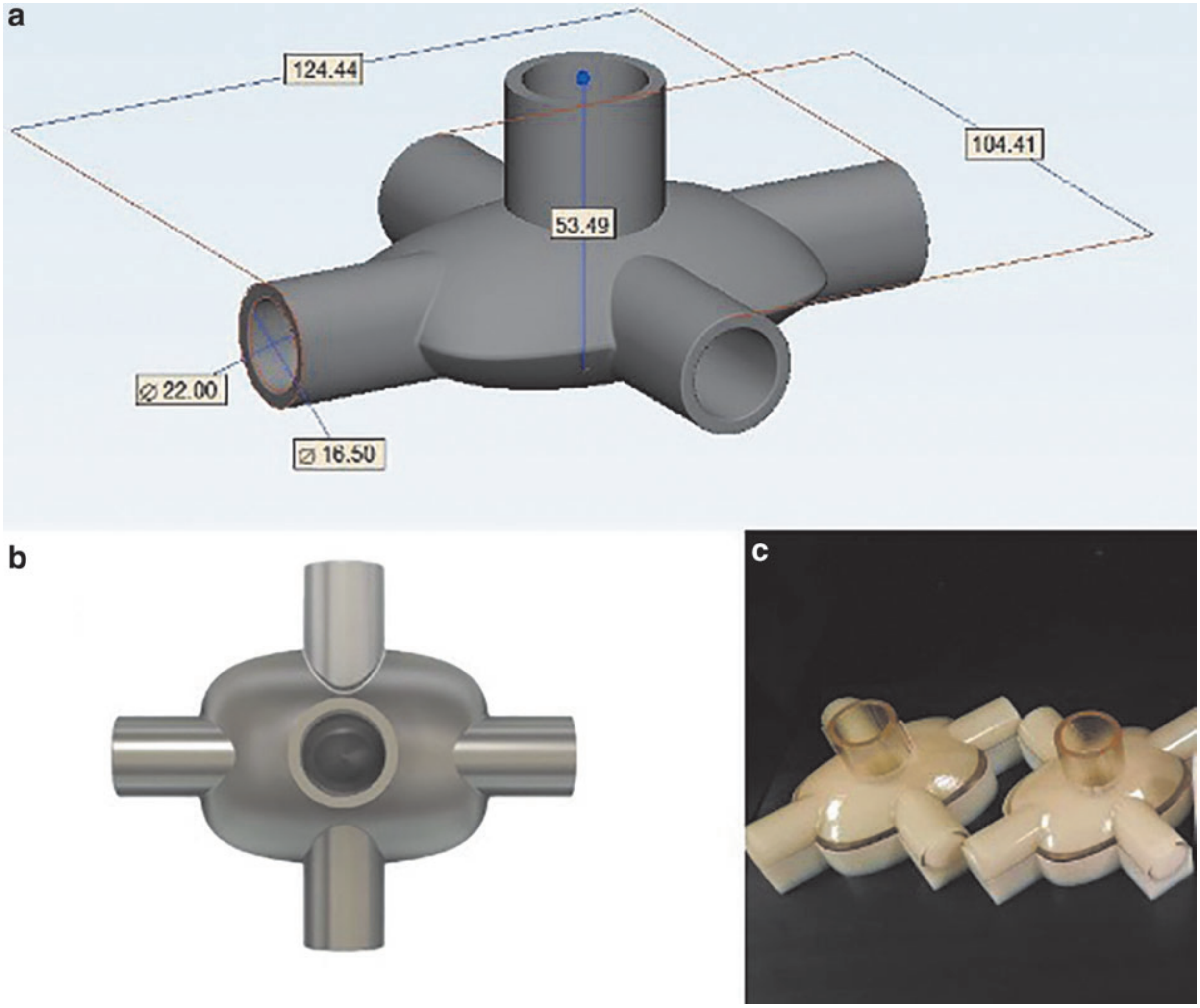

FIG. 2. **(a)** Dimensions, **(b)** final seem, **(c)** manufactured version of the four-port splitter.

First, the two-port splitter was tested using an adult ventilator (Servo-I; Maquet, Solna, Sweden). Synchronized and nonsynchronized inhalation and exhalation simulations were done by specialists to understand the capacity of the separated airway and the probable problems of the ventilator. Two 22 mm anesthesia single-limb circle breathing systems (Altech Septiflow, İzmir, Turkey) were connected in parallel to the ventilator through the splitter. One two-port splitter was attached to the inhalation outlet and another to the expiration outlet of the ventilator. During the test, ventilation parameters

FIG. 3. 3D-printed two-port splitter that adapted both the inspiratory and expiratory outputs of the ventilator and the testing process by two intensive care specialists.

were adjusted as follows: tidal volume was 1100 mL, respiratory rate was set to 12 breaths per minute, positive-end-respiratory pressure (PEEP) was 5 cmH_2O, and the inspiration time was 1.17 s. This tidal volume created 28 cmH_2O pressure in the respiratory system. In addition, the ventilator needed a flow of 65 L/min to provide 1100 mL of tidal volume.

Heart rates of the specialties were not measured during the test as this will not give the real value. Flow rates were adjusted by the ventilator automatically to provide the specified ventilation parameters. Different measurement were not performed for each patient. Pressure and flow measurements were changed automatically in nonsynchronized inhalation. The total test time of the specialists was ~ 30 min.

Results

In the synchronized inhalation, the ventilator did not give any alarm for 15 min. In nonsynchronized inhalation with the same tidal volume, the ventilator gave alarm in very short intervals. Every time the monitor was reset, the tidal volume was rearranged on the display readout of the ventilator. The other parameters were arranged automatically by the ventilator.

Discussion

The null hypothesis of the study was partially rejected as we were able to use only the two-port splitter under limited circumstances.

The description of the use of one mechanical ventilator to multiple patients was made by many researchers in the literature and social media.[3–9] Also, since the beginning, there have also been some studies that advocate that the results obtained from these studies are not suitable to be applied in real time. In this study, as a result of experiments performed by specialists on themselves, it was concluded that there are many limitations for ventilating multiple patients with a single ventilator. In ARDS, it is critical to create suitable tidal volume and PEEP at the ventilator during treatment. Therefore, it would be very risky to use a single ventilator for multiple patients due to the probable decrease in effectiveness of the treatment. As it is known that nCoV-2019 transmitted quickly by droplet contact, extending the breathing circuits to keep patients sufficiently far apart will cause increased dead space ventilation.

For effective ventilation, inhalation of the patients must be synchronized and in similar body weight, but it is not possible in practice. Since COVID-19 is a rapidly progressing disease, even if all the patients are at the same stage at the beginning, the recovery rates will not be the same. For this reason, distribution of ventilation between the patients will be inappropriate. It was stated in the study that this splitter was used in multiple intubated and fully curated patients by dividing the airway of a single ventilator. However, if the ventilator alarms, another limitation will appear, such as the difficulty of determining the source of the problem.

During the design procedure, the free .stl data of the 3D-printed devices were examined.[5,6] It was considered that these angled designs could restrict the air flow or may create dead spaces inside the device. For this reason, it was decided both for two-port and four-port splitters to make more circular designs that will render possible air to flow freely inside the device. However, a computational fluid dynamics (CFD) analysis has not been carried out after the designing process. In future studies, CFD analysis may be done and the obtained results can be interpreted by comparing the results of the clinical tests.

Owing to many limitations of the two-port splitter, the four-port splitter was not evaluated in clinic. The results of this study also show similarity with a recently published consensus about using one ventilator to multiple patients, which has included the drawbacks already mentioned.[10] However, considering the rapidly spreading disease status and insufficient hospital equipment due to COVID-19, patients can be ventilated for a short period of time with these 3D-printed splitters until sufficient ventilation is provided. At least, before the final conscientious phase where doctors should choose patients, it is conceivable to apply such productions to the patients within certain limits.

Conclusion

3D designed and manufactured two-port splitter can be used to ventilate multiple patients with a single ventilator within a very limited indication and time interval. A splitter can be used intermittently, under continuous supervision of health care staff, especially in awake patients who have inadequate nasal oxygen therapy and mainly require noninvasive mechanical ventilation.

Author Disclosure Statement

No competing financial interests exist.

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