

## References

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## Emergency Open-source Three-dimensional Printable Ventilator Circuit Splitter and Flow Regulator during the COVID-19 Pandemic

To the Editor:

We present a novel addition to a previously described solution to address ventilator shortages from severe acute respiratory syndrome coronavirus 2 (SARS-CoV2) pandemic infection surges. Using access to open-source data for

three-dimensional printing, ventilator splitters can be rapidly produced at any location to allow multiple patients to share a single ventilator in disaster situations. The original ventilator circuit splitting solution has been previously described<sup>1</sup> and was implemented during the 2017 Las Vegas mass shooting.<sup>2</sup>

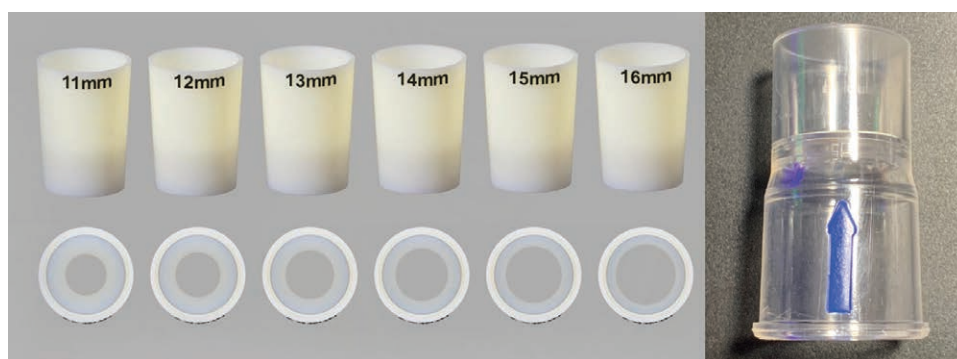
A three-dimensional printable Y-piece (Y-splitter), with an optional inspiratory limb flow limiter to account for differential lung compliance, can function to divide the ventilator's inspiratory and expiratory limbs among patients, based on Neyman and Irvin's concept (figs. 1, 2, and 3). Ideally, patients with comparable lung compliance are paired together. More than two patients may be theoretically possible with nesting additional Y-splitters. However, the required flow may exceed ventilator capacity. With advances in additive manufacturing and the widespread accessibility of three-dimensional printers, local production bypasses global travel barriers or supply chain breakdown.

A single piece is readily printed in approximately 1 h without additional support material using a consumer three-dimensional printer. Production can be scaled to produce 12 Y-splitters at a time on a typical consumer 200 mm × 200 mm × 200 mm three-dimensional printer. We used polylactic acid filament, although other filaments are likely to be applicable.

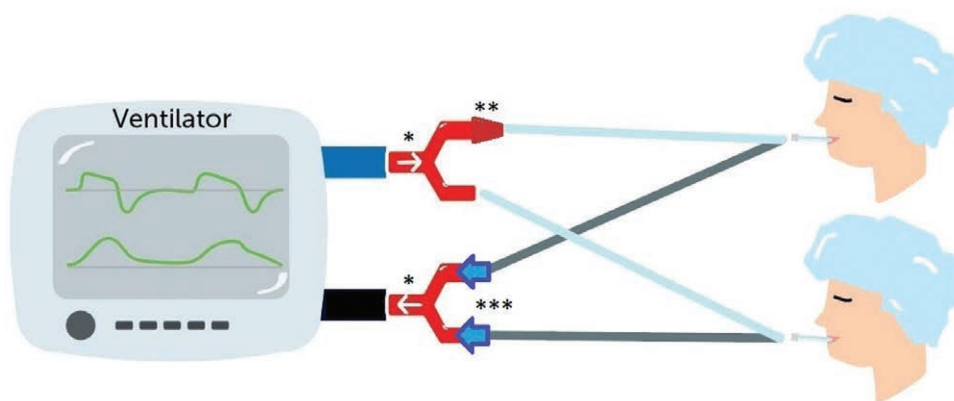
There are limitations to these devices and the concept of ventilator sharing. First, there is a risk of cross-contamination between patients connected to the same ventilator; this can be mitigated with inline filtration. Second, the patients sharing the ventilator must be in close proximity to the machine, which will be restricted to the length of the ventilator tubing. This is a concern where positive cases require airborne or contact isolation. Third, the patients must be paralyzed to facilitate a controlled mode of ventilation. Additionally, to ventilate multiple patients with the same settings, several parameters need to be considered such as patient size, ideal body weight, lung compliance, mode of



**Fig. 1.** Three-dimensional printable Y-splitter (\*) and optional flow limiter (\*\*) attachment.



**Fig. 2.** (Left) Three-dimensional rendition of flow limiters. Longitudinal and cross sectional views shown above. (Right) Commercially available one-way circuit valve.



**Fig. 3.** Two Y-splitters (\*) with in-line flow limiter (\*\*) and dual expiratory limb one-way valves (\*\*\*) for two-patient ventilation.

ventilation, *etc.* Individualized adjustments are possible with flow limiters but also possibly imprecise.

An application for Food and Drug Administration emergency use authorization has been submitted at the time of this publication. The Food and Drug Administration has prioritized ventilators, ventilator tubing connectors, and ventilator accessories similar to this device for the emergency use authorization pathway because of the SARS-CoV2 pandemic.<sup>3,4</sup> We urge that clinicians use their best judgement and adhere to local regulations in the utilization of these three-dimensional printable tools for ventilator splitting.

The three-dimensional print files are free and immediately available for open-source download, production, and emergency utilization around the globe. The files can be found at <https://ventsplitter.org> (accessed April 7, 2020).

### Research Support

Support was provided solely from institutional and/or departmental sources.

### Competing Interests

The authors have no competing interests in the production of this work in the last 36 months. Dr. Eckmann has a financial relationship with AVANOS Medical (Alpharetta, Georgia) as a technical consultant. Dr. Eckmann has been the applicant for education grants received by the institution (University of Texas Health Science Center, San Antonio, Texas) from Medtronic (Minneapolis, Minnesota), Boston Scientific (Marlborough, Massachusetts), and Abbot (Abbot Park, Illinois). None of the above mentioned companies produce equipment related to the work presented here nor are any specific commercial products in this article discussed or promoted.

Bryan K. Lai, M.D., Jennifer L. Erian, M.D., Scott H. Pew, M.D., Maxim S. Eckmann, M.D. University of Texas Health Science Center, San Antonio, Texas (M.S.E.). [eckmann@uthscsa.edu](mailto:eckmann@uthscsa.edu)

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## Rapid COVID-19–related Clinical Adaptations and Unanticipated Risks

### To the Editor:

Addressing protection of patients, providers, and equipment from viral contamination in the evolving coronavirus disease 2019 (COVID-19) pandemic may prove critical for the continued safe delivery of anesthesia care. The addition of viral filters to respiratory circuits is recommended by the American Society of Anesthesiologists (Schaumburg, Illinois).<sup>1</sup>

Our group recently directed that Pall particulate filters (Ultipor 25, Pall Medical, USA) be placed on the Wye-connector of each breathing circuit at our pediatric hospital. On the first day of use, three providers caring for smaller patients (weight range, 4 to 12 kg) undergoing either laparoscopic or nonlaparoscopic surgery encountered severe hypercapnea, with peak end-tidal carbon dioxide levels from 70 to 124 mmHg. Patients' tidal volumes ranged from 36 to 150 ml. The hypercapnea could not be managed by alteration

of the ventilation parameters (rate, pressure, fresh gas flow). Practitioners finally removed the filter, and renormalization of end-tidal carbon dioxide occurred within the next 5 min. The problem was diagnosed as excessive dead space, relative to tidal volume, caused by the imposition of the viral filter. After clinician feedback and review of these instances, clinicians were provided with more detailed communication regarding the intent of the filters and their physical properties for dead space volume (35 ml), and clinicians were specifically informed that they were permitted to place the filter on the expiratory limb if needed to reduce dead space ventilation.

Unprecedented concern for infectious transmission has prompted consideration of unverified interventions to be conceived and applied to patients in real time. A second noted problem was that this intervention of viral filters was “sticky” in the minds of providers. Providers were reluctant to remove the filter even once they knew this was the cause of their ventilation issues. Caught up in the race to “do something” under current pandemic circumstances, clinicians may feel hesitant to reverse an even obviously harmful intervention (the addition of large dead space to small patients), because of concerns for the unknown consequences of a decision to remove the filter.

We caution that from our experience, it is perhaps too easy to implement a hasty change and difficult to anticipate all clinical effects, and decision-makers cannot wholly rely upon subsequent providers to quickly correct our errors even when they become apparent.

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### Competing Interests

The authors declare no competing interests.

Charles R. Schrock, M.D., Michael C. Montana, M.D., Ph.D.  
Washington University in St. Louis, St. Louis, Missouri (C.R.S.).  
schrockc@wustl.edu

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