A Proposal for the Engineering World Health Design Competition:
Negative Pressure Chamber for Use in Viral Outbreaks

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PROBLEM DEFINITION

On January 30, 2020, the World Health Organization (WHO) declared the novel coronavirus outbreak COVID-19 a Public Health Emergency of International Concern[1]. This classified the virus as an extraordinary event constituting an international health risk. Research into the virus determined it can be spread via airborne particles presenting great risk to those in isolated spaces with potential COVID-19 patients such as healthcare workers.

With the rapidly growing COVID-19 pandemic and continued lack of personal protective equipment, there is a need for a portable, low-cost negative pressure chamber for use during viral outbreaks in healthcare settings. Negative pressure chambers prevent the spread of infectious particles, such as the novel coronavirus, by creating a negative flow space that filters air to the outside of the chamber. This provides an additional barrier between patients who are positive or presumptive positive for COVID-19 and healthcare workers.

STATEMENT OF IMPACT IN THE DEVELOPING WORLD

Currently, there is not a solution for portable containment of airborne particulate in developing countries. Current technologies being used in developing countries such as the Ebola Holding Units in Sierra Leone are not portable and require the usage of large facilities to contain patients[3]. This negative pressure chamber offers a new solution that is portable and does not require the use of a large facility. This offers several advantages. Primarily, patients can be moved between locations without risk of passing disease due to the containment unit. This allows for easier transportation to medical care facilities without worry of infecting others. In addition, since the device is small and low cost, it is much easier to obtain and use than a separate facility for housing patients which may be cost prohibitive or utilize excessive space. This also allows for housing of multiple potentially infected patients within one room as a negative pressure chamber may be used for each patient keeping the clinicians, as well as the other patients safe.

REQUIRED PERFORMANCE SPECIFICATIONS

<u>Material Selection</u>

The chamber must be constructed quickly and easily using available materials. All of the materials used will be available at an average hardware store in order to prevent any issue regarding lack of availability. The base material must be lightweight for portability, allow for simple construction, and must be easily disinfected. A clear cover will be used over the frame to maximize visibility between the health care worker and patient. Directed air flow will be used to provide a negative pressure environment. When finding a source for the directed air flow, it is important that the device has the capability of using batteries as a power source as well as an AC power source option to maximize the settings for use.

Build

The prototype must remain small enough to be portable. The directed air flow source as well as the filter must be detachable for replacement and/or disinfection and sterilization. When creating a cover for the chamber, it will have appropriate dimensions in order for it to slide on and off of the frame for replacement.

Functionality

The source of the negative pressure environment must provide efficient flow as set by the ASHRAE 110-2016 Standard for fume hood evaluation[2]. A filter with the capacity to block viral particles from passing through will need to be used.

IMPLEMENTATION OF PROTOTYPE

The structure for the negative pressure chamber is constructed using materials from a hardware store including PVC pipes and fittings, a clear sheeting, air filters, weather stripping, duct tape, and fans. The frame of the structure was made to fit a standard hospital bed, and includes hooks to secure the chamber on the edge of the bed when it is raised and lowered. The fans and filters were made to be completely detachable for replacement and/or cleaning and sterilization, and they were secured in place using weather stripping of various widths.

The frame is composed of the PVC pipes and fittings and is the shape of a rectangular prism with a 45-degree chamfer on one of the upper edges. This allows for easier viewing of the patient within the chamber. Below the chamfered section are two small, covered holes that allow the passage of a physician's arms to perform actions on the patient. A small opening is below this to allow passage of small electrical instruments and wiring into the chamber. The fans are situated such that they push air out of the chamber after passage through the air filter which creates negative pressure flow within the chamber. This ensures that potentially airborne viral particles do not escape through the other openings of the chamber.

PROOF OF PERFORMANCE

As noted, the structure is constructed of PVC pipes and fittings, plastic sheeting, air filters, weather stripping, duct tape, and fans (**Appendix A**). These are all materials that can be found in hardware stores removing any issues of their availability. The size of the structure also allows for easy portability while not feeling too constricting for the patient. The clear sheeting allows for easy cleaning of the inside of the chamber or quick replacement if necessary.

Performance of the chamber was evaluated using a variation of the ASHRAE 110-2016 Standard for fume hood evaluation. This was conducted through a visual capture test using dry ice to ensure the airflow was passing solely through the air filters and out the fans. Dry ice was placed at several locations inside in the constructed chamber with the fans on to observe the direction of vapor movement. In all trials, the vapor moved towards the air filters and was successfully filtered as no vapor was observed leaving the chamber through any openings. A similar variation of this test was conducted using a colored ‘smoke bomb’ (**Appendix B**). This test produced a much higher volume of gas and air particulate than would be possible for a patient resting within the chamber. Even in this extreme example, all of the air and particulate matter was observed to pass through the filters. It could be observed the filters also worked effectively and were properly sealed qualitatively as no colored smoke exited the chamber through the fans or any of the other openings.

BUSINESS PLAN

Market

The market for the negative pressure device will include both clinics in the developed world as well as in the developing world.

Funding

The funding for this device will come from grants through the National Science Foundation and National Institutes of Health, specifically those regarding rapid response to the COVID-19 pandemic. The funding will be used to manufacture the device here in the United States for testing. After testing and implementation in the United States is complete, the team will partner with charitable organizations in developing countries to teach them how to manufacture the device.

Sales

The approximate cost of each unit is $146.67. The devices will be sold at an increased cost of $200 in order to cover the cost of labor and other miscellaneous costs related to the creation of the negative pressure chamber.

Manufacturing

The manufacturing and assembly of the device does not require any extensive technology. All components needed to build the negative pressure chamber are available in an average hardware store. The only modification of the purchased materials are that the PVC pipes must be cut to the proper sizes, the frames for the fans and filters must be assembled, and the clear covering must be cut to the proper shape. Otherwise, the construction of the chamber simply requires putting together the frame and securing the cover on the device.

In order to mass produce the device, the team will seek charities in developing countries to assist with the manufacturing and assembly process. The materials should be available in most developing countries, so the charities will only need instructions for how to construct the device and workers to complete the simple modifications of the raw materials. This will create jobs in developing countries and cut the cost of shipping the assembled device.

Distribution

The technology will be distributed worldwide, as the COVID-19 pandemic has created a need across the globe for a portable, easy to manufacture, and efficient means of protecting healthcare workers from those infected with the novel coronavirus. Once testing is completed in the United States, the team will connect with charitable organizations in various developing countries to work with them to build their own devices.

Regulatory/Patent

There is prior art on the topic of low-cost chambers used during viral outbreaks. The use of negative pressure is relatively novel, as is use of filtration. The team has submitted a patent application with Clemson University Research Foundation and is awaiting further approval. The device would be a Class I device and will have a shorter regulatory process to be approved for use in healthcare settings.

APPENDIX

Appendix A: Initial prototype of the negative pressure chamber tested by PRISMA Health Emergency Medicine clinical staff. Feedback from the clinician was used to change the geometry of the opening to allow for easier access during intubation.

Appendix B: Final prototype Negative Pressure Chamber undergoing “smoke bomb” test. This test is modeled after the ASHRAE 110-2016 Standard for fume hood evaluation. As shown in the picture, smoke remains inside the enclosure and particles are not escaping the negative pressure space created by the fan and filter system.

REFERENCES

1. "Coronavirus". Who.Int, 2020, https://www.who.int/emergencies/diseases/nov el-coronavirus-2019.
2. ASHRAE, 2016, “Methods of Testing Performance of Laboratory Fume Hoods”, 110-2016
3. Johnson O, Youkee D, Brown CS, et alEbola Holding Units at government hospitals in Sierra Leone: evidence for a flexible and effective model for safe isolation, early treatment initiation, hospital safety and health system functioningBMJ Global Health 2016;1:e000030.