An Aerosol Containment and Filtration Tent for Intubation During the COVID-19 Pandemic

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Abstract

Background. Exposure to infectious droplets confers a high risk for infection transmission by the SARS-CoV-2 coronavirus. Aerosolizing procedures pose particular concern for increasing healthcare workers’ (HCWs) risks of infection. Multiple creative personal protective equipment solutions have been utilized to minimize exposure to infectious particles; however, the overall benefit of many of these devices is limited by a number of factors. Methods. We designed an intubation tent consisting of a metal frame and a clear plastic sheet. The flexible walls of our tent offer increased maneuverability & access, although the efficacy in reducing risk of transmission to HCWs remained unclear. Using an atomizer, particle generator, and matchstick smoke, we simulated the generation of infectious respiratory droplets and aerosols and tested whether our device effectively decreased the concentration of these particles to which a provider might be exposed. Finally, we tested whether the addition of a vacuum fan fit with a high efficiency particulate air filter designed to evacuate contaminated air would influence particle concentrations inside and outside the tent. Results. Droplet dispersion tests with the tent in place showed that the simulated droplet distribution was limited to surfaces within the tent. Aerosol testing under a variety of circumstances consistently showed only a minor rise in particle concentration in the air outside the tent despite an initial peak of particle concentration during generation within. All testing demonstrated declining inside concentrations over time. Conclusions. Our simulations suggest our device has the potential to effectively decrease HCWs’ exposure to infectious droplets and aerosolized viral particles.

Keywords
global surgery, general surgery, acute care surgery

Background

Amidst the COVID-19 pandemic, exposure to infectious droplets confers a high risk for infection transmission, especially for frontline clinicians.1 Head-of-bed procedures such as endotracheal intubation and noninvasive positive pressure support pose particular concerns for increasing healthcare workers’ (HCWs) risks of infection by the SARS-CoV-2 coronavirus.2 The potential for infection via exposure to patient-generated aerosols is likely, although less clearly quantifiable at this time.3-5 Multiple creative personal protective equipment (PPE) solutions have been utilized to minimize HCWs’ exposure to infectious particles. One proposal presented an acrylic box designed to fit over the patient’s head and allow access for procedures via precut openings.6 Although this device demonstrated decreased contaminant exposure to infectious droplets when tested with a fluorescent dye model, its overall benefit was limited by a lack of mobility for the laryngoscopist, a lack of side access for assistants, and concerns about bulk and open exposure to the foot of bed.7 The purpose of this study is to create an alternative design for head-of-bed procedural PPE and test its protective properties in a real-life clinical setting. We present an innovative design that is easily constructed and offers increased provider mobility with multiple points of

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access, while demonstrating decreased exposure to both droplet and aerosolized particles during and after simulated procedures.

Methods

Design and Materials

We designed an intubation tent consisting of a metal frame (material available at most hardware stores) and a clear plastic sheet that can be made from a standard clear shower curtain or similar clear plastic material. This device does not require sourcing of acrylic material, which is more expensive and often in short supply. The plastic sheet can be replaced after each use or wiped down and reused with the frame. The flexible walls of the tent offer the laryngoscopist with increased maneuverability (when compared to the rigid acrylic box), which can be helpful during difficult procedures. Side access allows extra handling of equipment by assistants. The metal frame slides under the mattress at the head of the bed and remains stable when elevating the patient’s head, regardless of the head-of-bed angle (Figure 1). Additionally, it can be used during patient transport, during vent disconnection, or with other noninvasive airway interventions such as CPAP or aerosolized medication delivery procedures. See design instructions “Open Source PPE: Aerosol Containment Tent.”

Testing of Protective Properties

Over a series of simulations, we tested whether our device effectively decreased HCWs’ exposure to infectious droplets and aerosolized particles. Testing was carried out in several steps and setups.

First, the basic intubation tent was tested using an atomizer device loaded with 5 mL fluorescent dye to simulate infectious droplets expelled from the airway of an infected patient. Using black light, we sought to demonstrate dispersion of droplets during simulated intubation and patient manipulation on health workers (Figure 2).

Second, we tested the aerosol containment properties of the tent by measuring suspended particles in the center of the inside of the tent and in the ambient air outside the tent. Using a TSI PortaCount 8038 particle counter, we placed measurement probes at chest/shoulder height outside the tent and inside the center of the tent. Particles similar in size distribution to patient aerosols were generated using matchsticks (4 testing cycles) and a standard particle generator (2 testing cycles). Both the particle generator & matchstick smoke were generated under the tent/vacuum system to simulate the presence of infectious particles aerosolized during a procedure.

Third, we tested the aerosol tents after being additionally outfitted with a vacuum fan (model Dyson V8; airflow 54 cubic feet per minute = 1529 l pm) fit with a high efficiency particulate air (HEPA) filter to evaluate if addition of an evacuation system of contaminated air would influence particle concentrations inside and outside the tent.

Testing procedures: During a series of 6 testing cycles, we measured serial concentrations of aerosolized particles under the tent enclosure and in the ambient air outside the tent over 10 minutes and under a range of device setups. The first measurement was taken .5 minutes (30 seconds) after particle generation began; both inside and outside ambient particle concentrations were measured every minute thereafter. At 4 minutes, we performed a simulated procedure which required opening the tent for 30 seconds to manage the patient; serial measurements resumed immediately afterward. These experiments were conducted in an 11 × 10 foot room.
room with 9 foot ceilings (3.5 × 3.0 × 2.75 m), and the probe for ambient measurement outside the tent was positioned at the bedside, where HCWs would stand.

**Results**

Droplet dispersion tests with the tent in place showed that the dye distribution was limited to the inside surfaces of the tent and the portions of the laryngoscopist’s arms distal to the tent access points (i.e., within the tent). When the tent was not used, dye droplets were visible on the chest, chin, and neck of the laryngoscopist’s PPE (Figure 2). This performed similarly to the previously described acrylic intubation box.\(^7\)

Table 1. Concentration of Ambient Particles Over Time.

| Particle source | Vacuum | Measurement location | 0   | 0.5 | 1.5 | 2.5 | 3.5 | 4.5 | 5   | 6   | 8   | 10  |
|-----------------|--------|----------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Particle generator | No     | Inside               | 4500| 1300| 000 | 512 | 000 | 370 | 000 | 330 | 000 | Open|
|                  | No     | Ambient              | 5600| 8560| 8813| 16  | 012 | 14  | 800 | Open| 11  | 260 |
| Particle generator | No     | Inside               | 4400| 4000| 000 | 282 | 000 | 130 | 000 | 38  | 000 | Open|
|                  | No     | Ambient              | 5977| 10  | 208 | 7974| 8106| 7855| Open| 7120| 6829| 6267|
| 3 matches        | No     | Inside               | 4661| 470 | 000 | 370 | 000 | 480 | 000 | 150 | 000 | Open|
|                  | No     | Ambient              | 5864| 11  | 944 | 11  | 286 | 10  | 498 | 9652| Open| 8911|
| 3 matches        | Yes    | Inside               | 4300| 1700| 000 | 12  | 000 | 840 | 000 | 770 | 000 | Open|
|                  | Yes    | Ambient              | 5369| 40  | 000 | 8800| 8461| 7877| Open| 6896| 6140| 5924|
| 3 matches        | No     | Inside               | 4750| 400 | 000 | 33  | 000 | 19  | 000 | 11  | 000 | Open|
|                  | No     | Ambient              | 5500| 15  | 263 | 27  | 820 | 11  | 248 | 9112| Open| 7486|
| 3 matches        | Yes    | Inside               | 4300| 3000| 000 | 450 | 000 | 400 | 000 | 21  | 000 | Open|
|                  | Yes    | Ambient              | 4790| 14  | 800 | 9832| 6170| 4832| Open| 4200| 3904| 3531|

Figure 3. Particle concentration with tent alone.
after the generation of aerosolized particles, to simulate a procedure being performed, decreased inside concentrations as expected, but only minimally increased the concentration of ambient particles outside the tent. These results are summarized in Table 1 and visualized in Figures 3 and 4. Baseline concentrations of aerosolized particles were consistently slightly lower inside the tent before particle generation began.

**Discussion**

Our simulations suggest our device has the potential to effectively decrease HCWs’ exposure to both droplets and aerosolized viral particles. Aerosol exposure of HCWs during and after procedures poses a significant risk, especially in high acuity settings such as the emergency department, intensive care unit, and during aerosolizing procedures. Our study demonstrates that the majority of particles can effectively be contained within this tent, which simultaneously allows for nearly unrestricted access to the patient’s airway and other critical body parts. In addition to reduction and containment of droplets and aerosols within the tent, this approach could also minimize aerosol deposits and contamination on the outer surfaces of HCWs’ PPE (gowns, etc.) and of adjacent room surfaces. When pairing our tent with a vacuum device, we demonstrated rapid & effective clearance of aerosolized particles within the tent and return to near baseline concentration within 1 minute of vacuum operation. Paradoxically, baseline concentrations of aerosolized particles were consistently slightly lower inside the tent before particle generation began; potential etiologies for such findings could include static electric charge of suspended particles as well as additional ambient aerosols originating from exhaled air of personnel outside the tent while conducting the testing.

Our findings are consistent with previous reports that aerosol containment during procedures significantly decreases the extent of exposure to potentially hazardous aerosolized particles and droplets. Our design setup differs from previous versions, in that it addresses significant operational barriers (limited range of motion in rigid boxes and poor access to critical patient body areas) and can be outfitted with a commercially available vacuum system, further enhancing protective capabilities.

**Limitations**

A limitation of our study lies with the difficulty of determining whether our simulated production of droplets and aerosolized particles accurately reflects a true patient encounter. Quantities and escape velocities of particles generated in true encounters would vary according to the wide heterogeneity of clinical scenarios possible. Further, the addition of the vacuum device increases both the cost and complexity of our basic tent. We know that droplets constitute a known high-risk infectious transmission mechanism, but the risks from aerosols are less clearly quantifiable, and thus, it is also difficult to quantify the added incremental benefit, if any, of the vacuum device.

**Conclusion**

Multiple devices have been created in order to protect HCWs during head-of-bed aerosol-generating procedures. We present a model for a novel protective barrier device that provides a cheaper and less restrictive option than previously described acrylic boxes. Our device is not intended to substitute for standard PPE methods which...
remain essential. However, due to potential limited PPE availability, our tent offers an additional level of protection during high-risk procedures which place HCWs at increased risk of exposure.

**Declaration of Conflicting Interests**

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