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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[1] create an alternative design for head-of-bed procedural PPE and[2] 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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Figure 1. Aerosal containment tent and testing setup.

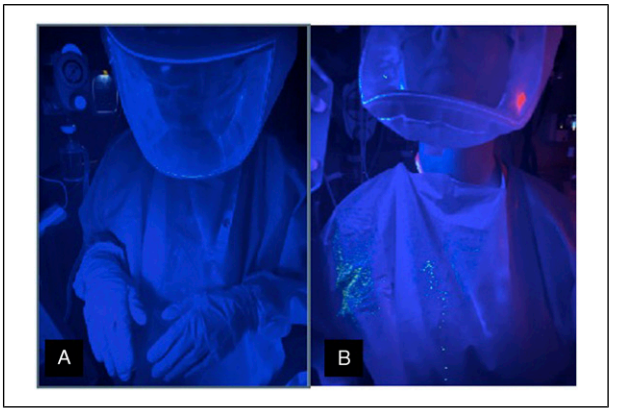

Figure 2. Fluorescent dye atomized to simulate contaminant exposure during intubation. (A) With use of intubation tent: droplets visualized only on distal arms. (B) Without the use of the intubation tent: droplets visualized on arms, chest, neck, and chin.

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."[6]

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 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]

When testing the effect of our device on the concentrations of aerosolized particles both inside and outside the tent, all six testing cycles showed a peak of particle concentration inside the tent immediately after particle generation associated with an only minor rise in particle concentration in the ambient air—the overall curve showed declining inside concentrations over time. When using the tent without vacuum, after an initial rise in concentration following the onset of particle generation, particle concentration inside the tent gradually but progressively decreased, while corresponding ambient particle concentrations rose only slightly. When using the vacuum fan fit with a HEPA filter for 30 seconds, interior aerosol counts precipitously decreased to baseline concentrations within 1.5 minutes. Opening the tent 4 minutes

Table 1. Concentration of Ambient Particles Over Time.

			Particle concentration (ppm) over time elapsed in minutes									
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	1 300 000	512 000	370 000	330 000	Open	23 000	15 000	12 000	10 000
		Ambient	5600	8560	8813	16 012	14 800	Open	11 260	10 800	9600	8700
Particle generator	No	Inside	4400	400 000	282 000	130 000	38 000	Open	12 000	10 000	6000	5400
		Ambient	5977	10 208	7974	8106	7855	Open	7120	6829	6267	6044
3 matches	No	Inside	4661	470 000	370 000	480 000	150 000	Open	12 000	9000	5600	4700
		Ambient	5864	11 944	11 286	10 498	9652	Open	8911	7400	6619	6063
3 matches	Yes	Inside	4300	1 700 000	12 000	8400	7700	Open	6000	5700	5000	4700
		Ambient	5369	40 000	8800	8461	7877	Open	6896	6140	5924	5569
3 matches	No	Inside	4750	400 000	33 000	19 000	11 000	Open	7400	6100	4800	4400
		Ambient	5500	15 263	27 820	11 248	9112	Open	7486	6648	5734	5210
3 matches	Yes	Inside	4300	3 000 000	450 000	400 000	21 000	Open	6800	3900	2900	2500
		Ambient	4790	14 800	9832	6170	4832	Open	4200	3904	3531	3311

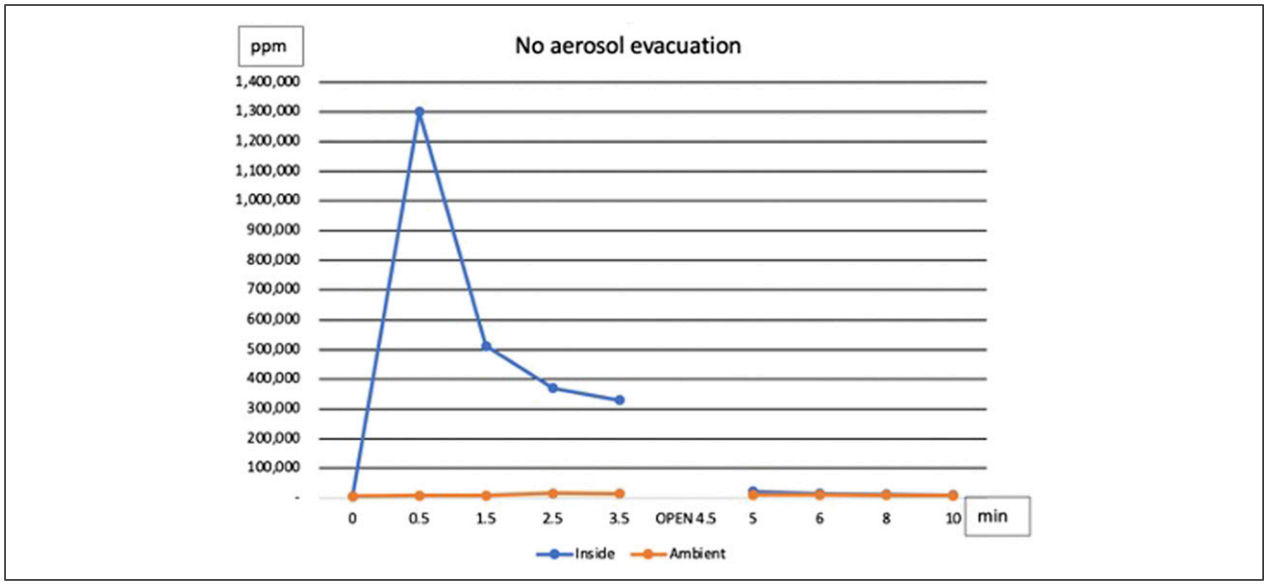

Figure 3. Particle concentration with tent alone.

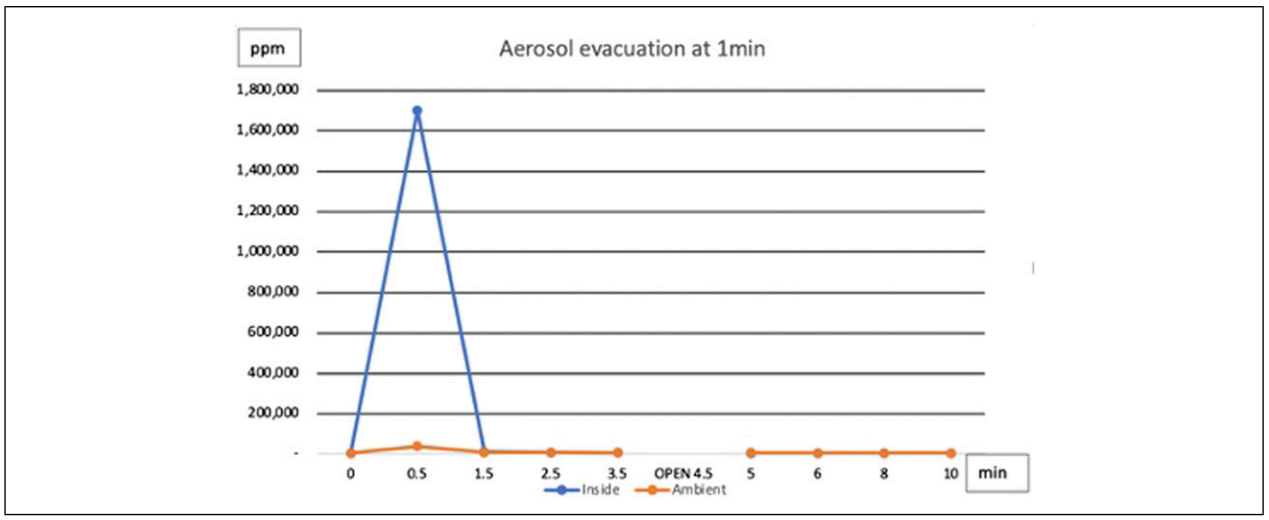

Figure 4. Measured particle concentration with tent combined with vacuum evacuation.

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 [7,8] 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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References

1. World Health Organization. Transmission of SARS-CoV-2: Implications for infection prevention precautions. 2020. https://www.who.int/news-room/commentaries/detail/transmission-of-sarscov-2-implications-for-infection-prevention-precautions.
2. Cook TM, et al. Consensus guidelines for managing the airway in patients with COVID-19: Guidelines from the difficult airway society, the association of anaesthetists the intensive care society, the faculty of intensive care medicine and the royal college of anaesthetists. *Anaesthesia* 2020;75(6):785-799.
3. Oran DP, Topol EJ. Prevalence of asymptomatic SARS-CoV-2 infection: A narrative review. *Ann Intern Med* 2020;173(5):362-367.
4. van Doremalen N, Bushmaker T, Morris DH, et al. Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1. *N Engl J Med*. 2020;382(16):1564-1567. doi:10.1056/NEJMc2004973
5. Vuorinen V, Aarnio M, Alava M, et al. Modelling aerosol transport and virus exposure with numerical simulations in relation to SARS-CoV-2 transmission by inhalation indoors. *Saf Sci*. 2020;130:104866. doi:10.1016/j.ssci.2020.104866
6. Center for Medical Innovation. Open source personal protective equipment: Aerosol containment tent University of Utah Health. https://uofuhealth.utah.edu/center-for-medical-innovation/files/cmi-open-source-aerosol-tent-assembly-instructions
7. Canelli R, et al. Barrier enclosure during endotracheal intubation. *NEJM* 2020;382:1957-1958.
8. Rosenblatt WH, Sherman Jodi D, Kovatsi PG, et al. Barrier enclosure during endotracheal intubation. *NEJM*. 2020;382(20):1957-1958.