Cost-effective protection of ground and helicopter ambulance workers and patients from airborne pathogens with a portable negative pressure respiratory shield

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Abstract

During the SARS-COVID-19 epidemic of 2020-2022, the fugitive emissions of viral particles from infected patients through coughing, sneezing or use of aerosol therapies were identified as sources of virus transmission. Emergency medical services personnel were exposed as much if not more to these viral emissions due to their close proximity to COVID positive patients during ground or air transport to hospital. Precautions ranging from thorough use of PPE to modification of vehicles to incorporate negative pressure cabins to adding specially designed patient isolation units inside airplanes were put in place. However, such modifications were limited by availability, expense and trained personnel. In this study we introduce a portable negative pressure system (PNPS) and respiratory kit that can be fitted directly over the patient's face, negating the necessity of expensive ambulance retrofits. Through a series of particle count measurements at diameters of 0.3 µm, 0.5 µm, 1 µm, 2.5 µm, 5 µm and 10 µm (encompassing the size of most virus particles, bacteria and nebulizer droplet diameters) in ground and helicopter ambulance cabins, the PNPS was found to reduce particle counts at all measured size fractions. The reductions were close to 100% at the smallest particle sizes which are most relevant to viruses and bacteria. Furthermore, the portability of this system makes it ideal for keeping viral particles from the patient isolated during transfer from hospital emergency ward entrances to isolation or negative pressure hospital rooms in hospital, reducing the possibility of airborne transmissions in hospital hallways and elevators.

Background

For most regions around the world, the impact of the COVID-19 pandemic has subsided. Despite all the tragedies and hardships that accompanied it, opportunities to identify areas of weakness in patient triage and care during a pandemic situation were provided. By addressing these issues, health care workers and patients will benefit from increased protection from disease transmission under normal circumstances or during future endemics or pandemics.

One such issue that became readily apparent at the beginning of the pandemic was the airborne transmission of the virus to not only health care workers in hospitals but also to emergency medical service (EMS) workers transporting COVID positive patients. During transport, space between patient and EMS personnel is even more confined and prevention of virus transmission more difficult, requiring more ingenuity in design of solutions. This was exemplified in the study of Cheng et al.[1], who simulated transportation and basic life support on ambulances carrying modified mannequins which could emit fluorescent tagged droplets much like a real patient. They determined that the most frequently contaminated areas of an ambulance in the driver's cabin were the left front door's outer handle, driver's handle, the gear lever, and the mat. In the rear, the most contaminated regions were the rear door, rear door lining, and the handle over the roof. On EMS PPE, the most frequently contaminated areas were the lower chest to the belly area, hands, lower rim of the gown, and shoes. After the removal of PPE, traces of fluorescence could still be observed on the neck, hands, and legs. It is clear from this study the ease with which EMS workers could become infected.

Such potential risks have been borne out in several case studies[2] and analyses. In a large cohort of Mexican health care workers, Robles-Peres[3] found that COVID team workers had higher rates of infection compared to all active workers and those under home protection, while a large Scandinavian study indicated that ambulance staff were the most vulnerable to infection of all health care workers[4]. Doctors were even found to have a lower risk of infection compared to nurses, respiratory therapists, and patient transporters. However, in a study of EMS workers in the state of Washington, training and proper PPE attire were found to have a marked effect on reducing transfection from patients to EMS workers in an ambulance environment. Less than 0.5% of EMS providers experienced COVID-19 illness within 14 days of caring for a patient with laboratory-confirmed case after implementation of these fairly simple risk mitigation strategies[5].

To reduce the risk of virus transmission in ambulances, several potential solutions with varying degrees of sophistication have been examined. For example, use of negative pressure ambulances was shown to have a positive influence on the containment of the COVID virus. Newly confirmed cases decreased dramatically from 800 to 8 with the use of negative pressure ambulances in the Hubei Province[6]. Other reported solutions for sanitization of ambulances include UV-C irradiation, which efficiently reduced the presence of the COVID virus by greater than 99.99% on surfaces such as plastic, stainless steel or rubber. The system was also found to be effective against drug resistant bacteria after 10 to 30 min of irradiation[7]. Even fairly simple aids, such as a portable transparent vinyl chloride shields for use in an ambulance, were found to be effective, albeit still prone to aerosol leakage[8].

An equal amount of concern for EMS workers has been documented for those working in air or helicopter transport[9]. In fact, during the early COVID period, the rate of COVID infection amongst Dutch helicopter ambulance EMS personnel was a staggering 23%,[10] and it was thus no wonder that other crews during the initial periods were anxious, noting that hospital PPE was neither appropriate nor the best solution for the confined spaces on aircraft and helicopters.[11] Other studies, however, suggest that with proper PPE and caution, transport of COVID patients may not be as risky as this figure suggests.[12,13] Others developed quite sophisticated solutions such as patient isolation units (PIU) whose benefits included the fact that accompanying medical personnel need not wear PPE during transport but full patient access was still maintained[14,15]. The device in this specific work allowed patients that were either spontaneously breathing or mechanically ventilated to be transported in pressurized airplane cabins, helicopters or ambulance vehicles, and remained air-tight even during the event of a sudden loss of cabin pressure. On the other hand, the experience with another PIU on an airplane was met with mixed reviews[16]. The main limitations were identified as reduced levels of dexterity when delivering care through porthole gloves, limited access to the patient, and disconnection of lines and tubes during patient loading and unloading procedures. They concluded that transport over large distances was possible but imposed significant additional risk and each case should be individually examined to determine the risk-benefit relationship. Other air transport crews have offered advice, including dividing larger planes into zones (which was shown in a separate study[17] to provide some protection to the crew when a barrier was in place) and flying at low altitudes, at the expense of travel time, to avoid a decompression situation which would require all passengers to don oxygen masks and result in the necessary removal of proper surgical masks.

Bredmose et al.[18] drafted a set of guidelines and suggestions for the transport of COVID patients by helicopter and advocated for the use of PIU's, but also mentioned that most providers would not have these available nor the personnel trained in their proper usage. Osborn et al.[19] have also weighed in on this with guidelines and suggestions of their own, which included avoidance of nebulization procedures en-route. Nonetheless, in a survey of USA-based helicopter EMS services, aerosol generating procedures remained in some use and included bilevel positive airway pressure (40.4% of cases) and high-flow nasal oxygen (66.0% of cases).[20]

Not every ambulance can be realistically made to operate under negative pressure and patient isolation units on aircraft are limited by availability, expense and trained personnel. A small, portable and comparatively inexpensive device that would allow nebulization treatments without putting healthcare workers or EMS responders at risk would be a welcome addition to their toolkits under normal circumstances or during future outbreaks of disease. In this study, the effectiveness of a new, portable negative pressure system for use in all environments including ground and helicopter ambulances is examined.

Experimental

The effectiveness of the SafER Medical Products (Branson, MO, USA) portable negative pressure system with the respiratory kit (Figure 1) was tested in both ground and helicopter (MD 902 Explorer) ambulances. The volume of the respiratory shield is 1000 ml, resulting in 4 air exchanges per second under shield. The vacuum is rated at 260 liters/min and operates with < 60 dB noise and provides an open negative pressure of vacuum of .757 PSI. The vacuum filtration is an ultra-low penetration air filter (ULPA), which can remove from air at least 99.999% of pollen, dust, bacteria, mold and other airborne particles with a minimum particle penetration size of 120 nm.

Figure 1: SafER Medical Products portable negative pressure system with respiratory kit

Particle count data was acquired using a Temtop PMD 331 particle counter (Milpitas, CA, USA), which uses a 50 mW, 780 nm wavelength laser to determine particle counts using the Mie-scattering principle. It provides counts for 0.3µm/ 0.5µm/ 0.7µm/ 1µm/ 2.5µm/ 5µm/ 10µm particle sizes.

Both ground and helicopter studies were performed on a manikin sitting at a 45-degree angle on a cot with the particle counter positioned at the head of the manikin by the attendant seat in the forward of the cabin. An aerosol mask and acorn nebulizer (Invacare Select IRC1705, Elyria, OH, USA) with compressed air delivered via the nebulizer compressor at an approximate rate of 0.5 ml of 0.083% Albuterol Sulfate solution (2.5 mg/3 ml) as an aerosol particle surrogate (this is a commonly used as test surrogate). A volume of 3 ml of this solution was placed in the nebulizer and allowed to run for 5 minutes. The particle counter recorded 5 one minute recordings per session on 7 simultaneous channels to measure particle count rates at different sizes (0.3, 0.5, 0.7, 1, 2.5, 5, and

10 microns). The procedure was repeated 10 times resulting in 50 one minute readings in both the ground and helicopter ambulance cabins.

All statistical analysis was performed using JMP V15 software (Cary, NC, USA). The data was first examined to observe if it was normally distributed such that the correct statistical comparison tests (parametric versus non-parametric) could be chosen. Enough evidence was observed of fairly strong deviations from a normal distribution that non-parametric tests were chosen for statistical comparisons (Wilcoxan tests).

Results

When the PNPS with the respiratory shield is switched on in the ground ambulance cabin, the particle count rates for all size fractions decrease (Figures 2a and 2b). The extent of the reduction is 96%, 98%, 98%, 97%, 86 and 87% for the 0.3, 0.5, 1, 2.5, 5 and 10 μm size fractions, respectively. These differences were observed to be statistically significantly different for all particle size fractions ($P < .0001$).

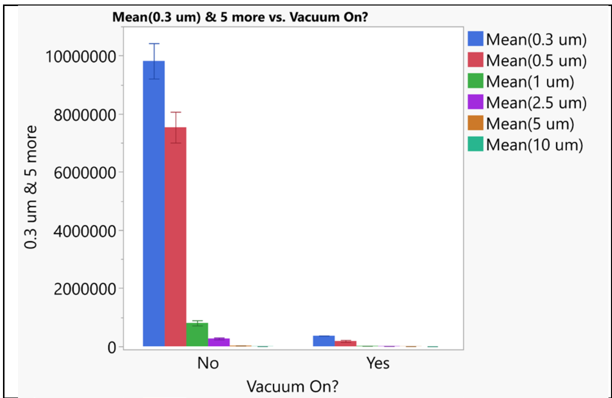

Figure 2a: Particle counts measured in ambulance with nebulizer running. Effect of PNPS is shown. Linear scale.

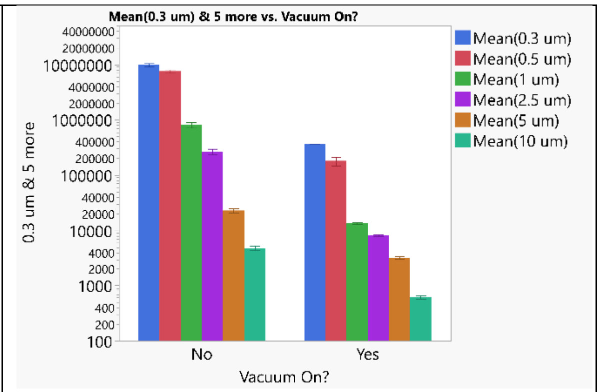

Figure 2b: Particle counts measured in ambulance with nebulizer running. Effect of PNPS is shown. Log scale.

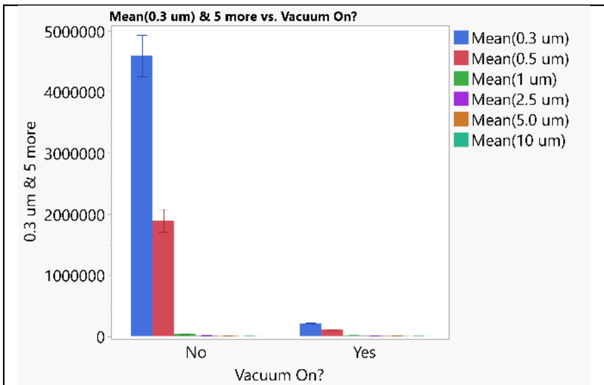

Figure 3a: Particle counts measured in helicopter with nebulizer running. Effect of PNPS is shown. Linear scale.

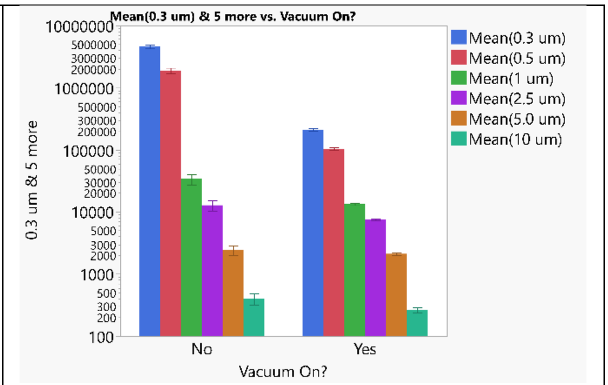

Figure 3b: Particle counts measured in helicopter with nebulizer running. Effect of PNPS is shown. Log scale.

Similar data from the helicopter cabin is presented in Figures 3a and 3b and the results also show the beneficial effect of the PNPS. The mean count rate is observed to decrease for all size fractions by 95%, 95%, 61%, 42%, 13% and 34% for the 0.3, 0.5, 1, 2.5, 5 and 10 μm particle size fractions, respectively, when the PNPS is in use. Up to a particle size of 1 μm, there is a significant reduction in the particle count rates ($P < .0001$). However, for the larger particle sizes, no significant difference is observed ($p > .05$).

Discussion

The results of this study were provided by extensive particle count data sets from both ground and helicopter ambulance cabins. The effectiveness of the PNPS with the respiratory shield attachments at reducing particle count rates near the patient was clearly demonstrated, in particular at the smaller particle sizes that are most relevant for prevention of disease transmission, where the extent of reduction is approximately 100%. This reduction is substantially better when compared to the results of the study by Lindsley et al.[21] who examined the effect of ground ambulance ventilation systems on aerosol particle circulation throughout the cabin. Even with the system running to provide 12 complete air changes per hour, the maximum at which it was tested, only a 68% decrease in the particle count rate was observed. They also observed that the ventilation system recirculated the particles, dispersing them throughout the cabin to negate the ultimate effectiveness of the system. With the PNPS, the particles are self-contained within the vacuum system. While other solutions to the problem of aerosol and droplet transmission have been proposed with varying degrees of success, they lack the portability of the SafER Medical Products PNPS system which makes it ideal for any environment, especially those where space is limited such as in ground and air ambulance vehicles.

Conclusions

1. In a Type 1 class ground ambulance, the PNPS with a respiratory shield was found to reduce particle counts at all measured size fractions by between 86 – 98%. This covers the size range of many viruses, bacteria and droplets emitted from coughs.

2. In a MD 902 Explorer helicopter ambulance the PNPS was also found to be highly effective, showing particle count reductions for all size fractions ranging from 13% up to 95%, with the highest effectiveness observed for the 0.3, 0.5 and 1.0 μm sized particles. These dimensions again correspond to the sizes of many common disease transmitting viruses and bacteria.

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