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Short Communication

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Feasibility of a High-Volume Filter Sampler for Detecting SARS-CoV-2 RNA in COVID-19 Patient Rooms

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Abstract

Aerosolization of SARS-CoV-2 by COVID-19 patients can put healthcare workers and susceptible individuals at risk of infection. Air sampling for SARS-CoV-2 has been conducted in healthcare settings, but methods vary widely and there is need for improvement. The objective of this study was to evaluate the feasibility of using a high-volume filter sampler, BioCapture z720, to detect SARS-CoV-2 in COVID-19 patient rooms in a medical intensive care unit, a dedicated COVID-19 ward, and at nurses' stations. In some locations, the BioSpot-VIVAS, known for high efficiency in the collection of virus-containing bioaerosols, was also operated. The samples were processed for SARS-CoV-2 RNA with multi-plex nested polymerase chain reaction. One of 28 samples collected with the high-volume filter sampler was positive for SARS-CoV-2; all 6 samples collected with BioSpot-VIVAS were negative for SARS-CoV-2. The high-volume filter sampler was more portable and less intrusive in patient rooms than the BioSpot-VIVAS, but limits of detection remain unknown for this device. This study will inform future work to evaluate the reliability of these types of instruments and inform best practices for their use in healthcare environments for SARS-CoV-2 air sampling.

Keywords: airborne; environmental monitoring; hospital; virus sampling

Introduction

Exposure monitoring is a key strategy to characterize occupational health hazards, including exposure to SARS-CoV-2 among healthcare workers (HCWs). SARS-CoV-2 RNA has been widely detected on surfaces and in the air in healthcare facilities around COVID-19 patients, including in the breathing zone of HCWs (Chia *et al.*, 2020; Santarpia *et al.*, 2020; Birgand *et al.*, 2021), and viable SARS-CoV-2 has also been detected in air around COVID-19 cases (Lednicky *et al.*, 2020; Santarpia *et al.*,

What's Important About This Paper?

This study provides a valuable perspective on the real-world challenges (i.e. adequate battery power or access to a power outlet, not impeding access to the patient or needed supplies, disinfection of instruments following sampling, etc.) of using high-volume filter-based air sampling devices and other bioaerosol sampling devices in healthcare settings. Because this study was conducted in patient rooms on COVID or medical intensive care unit wards where patients may be in need of intensive care, the evaluation of the feasibility of these devices, especially in intrusiveness and portability, is likely conservative for other healthcare environments.

2020). Yet, air sampling for respiratory viruses like SARS-CoV-2 can be difficult to interpret across studies owing to variation in sampling methods (Pan *et al.*, 2019). Further, HCWs are not always enthusiastic about wearing personal sampling devices as they can disrupt personal protective equipment (PPE) changes and workflow. Devices used for area air sampling can operate at higher air flow rates and may be less intrusive for HCWs, but may not capture the peak exposures of HCWs when near patients (Phan *et al.*, 2020).

Given the need to explore the feasibility and performance of devices for sampling respiratory viruses, the objective of this study was to evaluate the feasibility (i.e. portability, battery charge, acceptance of the device by HCWs) of using a high-volume filter-based air sampling device, the BioCapture z720 (BioFlyte, Inc., Albuquerque, NM), to detect SARS-CoV-2 RNA in healthcare facilities. A second instrument, the BioSpot-VIVAS (BSS310, Aerosol Devices, Inc., Fort Collins, CO), which has been used to sample respiratory viruses, including SARS-CoV-2 (Lednicky *et al.*, 2020) was used to contrast with the BioCapture.

Methods

Sampling was performed in February 2021 in two wards of University Hospital, Salt Lake City, UT with COVID-19 patients: the medical intensive care unit (MICU, 25 beds) and the dedicated COVID-19 ward (C-19W, 23 beds). The C-19W occupancy was <40% during the sampling periods. The C-19W layout is shown in Supplementary Fig. S1 (available at *Annals of Work Exposures and Health* online) and is similar to that of the MICU. MICU airflow differed among rooms: One of the sampled rooms was negatively pressured, one had a high efficiency particulate air (HEPA) filter in a permanent ventilation system, and the other three had free-standing HEPA filtration devices. C-19W had standard ventilation but was isolated from other ventilation systems in the hospital. Air exchange rates in all areas exceeded ASHE requirements (Booth *et al.*, 2021), and ranged from >6 to 27.2 per hour in MICU rooms and from >6 to 21.2 in C-19W rooms (personal communication, Scott Amalfitano, HVAC Controls Technician, University Hospital).

COVID-19 patients who had been admitted within the past week were identified by the nursing staff, who communicated their room numbers to the research team. Patient infection status was indicated in the MICU by a sign on the room door, or by occupancy in C-19W. Investigators asked patients for permission to place the sampling devices inside their room prior to sampling, and left the room during sample collection. No information about or observations of the patients were recorded. This study did not involve human subjects, but activities were included in protocol IRB_00131929. Protections for sampling personnel are described in Supplementary Materials (available at *Annals of Work Exposures and Health* online).

Feasibility of devices for sampling was qualitatively evaluated in three ways: (i) ease in portability/transport, (ii) acceptance among HCWs for placement in patient rooms, and (iii) battery charge or outlet requirement. Three air sampling devices were used: (i) BioCapture z720, (ii) BioSpot-VIVAS, and (iii) GRIMM 1.107 (Grimm Instrumenten Produktion GmbH, Pouch, Germany). The BioCapture was operated at 200 l min^{-1} for 20–60 min with one of two types of filters supplied by BioFlyte: (i) a polyester nonwoven fiber filter (mean flow pore diameter of 3.9714 µm) and (ii) a nonwoven surgical mask media comprised of three layers of polypropylene fiber. The filters were secured to the device but open to ambient air and were 47 mm diameter. These two filters were used due to changes in filter choice based on in-house testing by BioFlyte during the study.

The GRIMM 1.107 measures particle number concentrations with a flow of 1.2 l min^{-1}, and contains a filter (1.2 µm pore size, 47 mm polytetralfuoroethylene (PTFE), unsupported). The BioSpot-VIVAS was operated at 8 l min^{-1}, and particles were collected in condensed water in a petri dish. Due to its smaller size, the BioCapture was placed near the patient (i.e. on the patient bed, or on shelves, tables, or the floor), on the

counter of the nurses' station, or on a table in the staff breakroom outside the C-19W. The BioSpot-VIVAS was stationed on a movable cart and positioned next to the nurses' station, or along the wall (window-side or door-side) of the patient rooms. Supplementary Fig. S1 (available at *Annals of Work Exposures and Health* online) depicts approximate sampling locations.

In addition to feasibility evaluations, samples collected in the field were processed for SARS-CoV-2 RNA detection. This study, however, was not designed to evaluate sampler performance. Sample processing methods are described in Supplementary Materials (available at *Annals of Work Exposures and Health* online). Briefly, samples were transported in a cooler marked as biohazard and were either processed to the point of being in the BioFire sample buffer and stored in a fridge overnight with immediate processing the next morning, or processed immediately. Filters were eluted using a sterile buffer (0.075% Tween-20 with 10 mM Tris/HCl, pH 7.5), and eluent was analyzed for SARS-CoV-2 using multi-plex nested polymerase chain reaction with a FilmArray device (BioFire® FilmArray®, BioFire Diagnostics, Salt Lake City, UT) and COVID-19 test with nine SARS-CoV-2 targets (BioFire® COVID-19 Test v.02, BioFire Defense, Salt Lake City, UT). Samples reported as positive for SARS-CoV-2 by the FilmArray algorithm for COVID-19 Test v0.2 were considered positive. Negative controls for evaluating whether sampling equipment and/or materials for RNA processing were contaminated prior to sampling were collected in the laboratory. Positive controls were not conducted due to lack of SARS-CoV-2 stock and concern over health and safety of study personnel.

Results

With respect to sampling logistics, space constraints varied between the wards owing to layout and HCW activity levels. The BioSpot-VIVAS is a relatively large instrument that must be transported on a cart and requires power, which made it difficult to place the instrument for sampling without hindering HCWs' movement. Patient rooms in the C-19W had open doors as the default, allowing easier access. While sampling, the investigators remained near the room in case the sampling instrument disrupted workflow and needed to be removed from the room. This was more challenging in the MICU due to high foot traffic and limited space in the corridor.

The BioCapture is easily portable and maintained its battery charge for the duration of sampling. Its noise level when operated at 500 l min^{-1} was judged to likely be disruptive to patients, so it was operated at 200 l min^{-1} (65 dB at 1 m). Since this study, the 500 l min^{-1} setting of the device is no longer offered. Sampling activities were limited to 3 h day^{-1} to minimize disruption in the wards.

Infection prevention policies at the hospital required that the investigators don PPE (powered air purifying respirators, gowns, and gloves) when entering the C-19W and MICU patient rooms. Upon leaving these areas, PPE was doffed, and investigators disinfected the surfaces of the sampling equipment with wipes. Disinfecting the BioSpot-VIVAS and the cart required more time and planning than disinfecting the BioCapture.

SARS-CoV-2 was not detected in the three negative controls (2 BioCapture samples of 20-min duration and 1 BioSpot-VIVAS sample of 60-min duration). Among the samples collected in the hospital, 1 of 28 BioCapture samples was positive for SARS-CoV-2; all of the 6 BioSpot-VIVAS samples were negative (Table 1). The positive sample had a crossing point of 27.1 cycles and was collected by the BioCapture when it was placed on a shelf near the foot of the patient's bed in the C-19W (Supplementary Fig. S1, available at *Annals of Work Exposures and Health* online). Filters from the GRIMM and respirators worn by the study investigators were negative for SARS-CoV-2.

As measured by the GRIMM, the particles reaching the BioSpot-VIVAS inlet were smaller than 2.75 µm (Supplementary Fig. S3, available at *Annals of Work Exposures and Health* online). The counts for particles

Table 1. Results of SARS-CoV-2 sampling in the MICU and C-19W by instrument and sampling duration. Filter type 1 represent: a polyester nonwoven fiber filter, and 2 represent: a nonwoven surgical mask media comprised of three layers of polypropylene fiber. Negative controls not shown. Details of individual samples can be found in Supplementary Table S2 (available at *Annals of Work Exposures and Health* online).

Device	Duration (min)	No. samples		No. positive
		MICU	C-19W	
BioCapture z720	20	1	8	0
	30	2	13	1
	40	1	—	0
	45	—	2	0
	60	1	—	0
BioSpot-VIVAS	45	—	2	0
	60	—	3	0
	180	—	1	0
GRIMM	90	1		0
	180	1		0
PAPR filters	—	2		0

with size greater than 2.75 µm were zero. Three samples from the C-19W exhibited a spike in particle concentration (size range 0.265–0.425 µm), but these spikes could not be linked to any specific event due to observers not being present in the room during the time of sampling.

Discussion

Air samplers for use in hospitals should ideally be simple to use, easy to transport, have a battery with sufficient capacity to operate the instrument for the duration of sampling, be quiet so as to not disturb patients or HCWs, and small enough as to not impede patient care activities. In addition, samplers should have high sensitivity and specificity for detecting the pathogen of interest, either for culture-dependent or culture-independent analysis methods. The focus of this study was on the former issues related to the feasibility of sampler use; future work will assess sampler performance.

The BioCapture was portable and maintained charge for the full sampling period, and HCWs were less hesitant when asked about access to patient rooms for sampling with the BioCapture than with the Biospot-VIVAS owing to the relatively small size of the device. The BioCapture also requires less preparation time than the BioSpot-VIVAS, which requires programming and attainment of specific temperature conditions before use. Despite the feasibility advantages of the BioCapture over BioSpot-VIVAS, it was still challenging to find sampling spaces near the patient bed, owing to the presence of other items on nearby shelves and tables or patient preference. In one instance, the BioCapture was placed on the floor as no other space was available in the patient room. Limitations in where to place the sampler may limit the relevance of BioCapture results to HCW's exposures, and sampler noise from the higher flow rate may limit sensitivity.

The BioSpot-VIVAS has been demonstrated to effectively detect RNA and infectious SARS-CoV-2 in the rooms of COVID-19 patients (Lednicky *et al.*, 2020). SARS-CoV-2 RNA was not detected by the BioSpot-VIVAS in this study, but the sampling duration was generally shorter (45–180 min) than that used by Lednicky *et al.* (2020) (180 min). The BioSpot-VIVAS utilizes water condensation to facilitate particle growth and collection, and laboratory studies have found that earlier prototypes collected >93% of MS2 coliphage particles that reached the inlet and 74% of nebulized influenza virus (Lednicky *et al.*, 2016; Pan *et al.*, 2016). This performance is remarkable, but the use of the device in the field is challenging owing to its size, weight, and electrical requirements. The ability of the BioSpot-VIVAS to collect virus for culture-dependent analysis, however, is a unique strength of this instrument, and the performance of the BioCapture has not been assessed in this regard. With respect to the BioCapture, filter collection and extraction are opportunities for loss of viral RNA which require further research and may have impacted the detection rate observed in this study.

The low proportion of positive samples in this study is consistent with the most recent studies of SARS-CoV-2 in the air of healthcare facilities (Birgand *et al.*, 2021) and is likely due to the reduction in SARS-CoV-2 shedding over the course of disease (Ferretti *et al.*, 2020), placement of the samplers, patient and environmental characteristics, or sensitivity of sample collection and analysis methods used in this study. Given that this study did not attempt to quantify the limits of detection of the sampling methods employed, the negative results should not be interpreted to mean that SARS-CoV-2 is absent from the air in the wards studied: HCWs should continue to follow the most up-to-date guidance regarding respiratory protection.

Conclusions

The BioCapture z720 was convenient for sampling in patient rooms owing to its portability, but there were still limitations with space, and the highest sampling airflow rate (500 l min^{-1}) was not feasible owing to noise. SARS-CoV-2 was detected at low frequency, but more information, such as filter capture and recovery efficiency, must be collected to determine the limit of detection how this limit relates to infection risks. In addition to limits of detection, more data are needed to elucidate collection efficiency and measures of performance in laboratory and field settings to inform reliability of portable high-volume filter samplers, like BioCapture z720, in comparison to devices known for high collection efficiency.

Supplementary Data

Supplementary data are available at *Annals of Work Exposures and Health* online.

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Conflict of interest

Dr Kelly has a financial interest in Tetrad Sensor Network Solutions, LLC. This company's technology was not involved in this study. The other authors declare no conflicts of interest.

Data availability

Data are available upon request from the corresponding author.

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