Evaluation of air cleaner device at an urgent care clinic

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Objectives: To test the hypothesis that the use of portable stand-alone air cleaners at various sites within an urgent care clinic is effective in reducing airborne bioburden in the environment.
Design: Single centre, four locations within the centre, two phase (test and control), 5-day per phase, non-randomized trial.
Setting: One urgent care clinic, four environments within the clinic: staff breakroom, examination room, nurse station, and waiting room.
Intervention: Use of one air cleaner set to process air at an airflow rate of 108 CFM (184 m^3/h) at each of the four environments within the urgent care clinic.
Main outcome measure(s): Measure of airborne bioburden as bacterial colony forming units (CFU/m^3) from air samples collected during control and test phases, and identification of most prominent species found in air samples.
Results: Overall colony counts reduction of 52% between control and test samples (p-value< 0.05). Per environment reductions: breakroom 72%, examination room 65%, nurse station 11%, and waiting room 57%; none of these were statistically significant. Identification of 5 bacterial pathogens and 16 bacterial opportunistic pathogens. Based on the shape and dimensions of species identified, 4 pathogens and 11 opportunistic pathogens are smaller than 2.5 μm and therefore can penetrate deeply into the lung.
Conclusions: The use of portable stand-alone air cleaners in an urgent care clinic has shown substantial reduction in airborne bacterial bioburden overall.

Keywords: Air cleaner, airborne bioburden, air sampling

I. INTRODUCTION

Transmission of infectious diseases via the airborne route poses a risk at healthcare institutions[1–5]. Furthermore, the recent COVID-19 pandemic, driven by a highly contagious airborne virus, severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), has stressed the importance of airborne infection control measures everywhere from educational settings, the workplace and the community, in addition to health institutions[6–9].

Portable air cleaners can complement existing infection prevention practices such as built-in heating, ventilation and air conditioning (HVAC) systems, social distancing, hand and surface disinfection, and the use of masks. To demonstrate the efficacy of portable air cleaners in a healthcare setting, a field study was carried out at an urgent care clinic.

The aim of this study was to measure airborne bioburden at four different environments within this clinic and to evaluate the effectiveness of portable air cleaners in reducing the bioburden loads. In general, it is expected that a lower airborne bioburden shall result in lower number of infections occurring on-site. A study by Arikan et al. (2022) have shown that the use of air purifiers, in addition to HVAC systems, in hospitals may be an effective way to reduce microbial load in the air and on surfaces[10]. This study also showed an impact in infection rates at intensive care units (ICUs). Further, at the time of writing, there is a major ongoing study to investigate the cause-and-effect relationship between air purifying intervention in operating rooms (ORs) and surgical site infections (SSIs)[11]. Results of this study are expected in 2023.

II. MATERIALS AND METHODS

II.A. Study design

The study reported here was carried out at an urgent care clinic: Cape Regional Urgent Care, Wildwood, 406 W. Rio Grande Ave., NJ 08260, USA. The clinic offers services including the treatment of illness and injuries as well as performing COVID-19 testing. The clinic operates 7 days per week from 8:30 am to 8:00 pm. Four environments within the clinic were selected for the study: a staff breakroom, an examination room, a nurse station, and a waiting room. The floor area of these environments is 16.7 m^2 (180 ft^2), 8.9 m^2 (96 ft^2), 51.1 m^2 (550 ft^2), and 83.2 m^2 (896 ft^2), respectively.

The study was carried out in two phases. The first phase consisted of air sampling at these four sites for five consecutive days without the use of air cleaning devices. The first phase was therefore a *control* or *baseline* reference phase. The second phase consisted of air sampling again for five consecutive days with the use of air cleaning in place. Portable stand-alone air cleaner devices, one for each site, were deployed in phase two. The second phase was therefore an *intervention* or *test* phase.

The control phase air samples were taken from Thu Oct 28 to Mon Nov 1 (2021), i.e., control days 1–5. The test phase air samples were taken from Thu Nov 18 to Mon Nov 22 (2021), i.e., test days 1–5. Air samples were taken between 12:00 pm

and 2:00 pm each day at each environment.

The urgent care clinic visit log recorded a total of 303 visitors during the control phase and a total of 306 visitors during the test phase. Rounding up numbers, the average number of visitors per day is 60 for both, control and test, phases. The urgent clinic was open daily, 12 hours per day. The average and median number of visitors per hour is 5 for both, control and test, phases. On a daily average over control and test phase dates, the most active hours were between 9:00 am and 11:00 am, with a mean value of 8 visitors per hour. Similarly, the least active hours were between 7:00 pm and 8:00 pm, with a mean value of 1 visitor per hour. A total of 50 visitors during the control phase in between sampling hours were recorded by the visitors log. Similarly, a total of 51 visitors during the test phase in between sampling hours were logged.

The visit log record does not show any substantial difference in visitor daily trends or number of visits between the control and test phase. Therefore, there was no bias factor observed or correction/adjustment required due to visitor number and frequency.

FIG. 1 Photo of the breakroom environment with the air sampler placed on a table.

FIG. 2 Photo of the examination room environment with the air sampler placed on a workbench countertop.

II.B. Equipment used

A Defend 400 device (WellAir, 290 Harbor Drive, 2nd Floor, Stamford, Connecticut 06902, US) was set in each site at the urgent care clinic for the test phase. The WellAir Defend 400 device is a portable stand-alone air cleaner. Figures 1, 2, 3 and 4 show the location of the air cleaner within each environment. The devices were set at speed 3, 108 CFM (184 m^3/h), on Wed Nov 17, 2021 and were turned on for the duration of the test phase. The device has an optional variable speed setting ranging from minimum setting of 7 CFM (12 m^3/h) to 210 CFM (356 m^3/h) at the maximum setting.

WellAir offers a range of portable air cleaners designed to inactivate microorganisms. The core technology in the WellAir portable air cleaners is an atmospheric plasma discharge, called NanoStrike^{TM} Technology. Two device models of the WellAir portables have been cleared by the Food and Drug Administration (FDA): the Defend 1050 and the Defend 400. In these two devices, the plasma technology is complemented with high-efficiency particulate arrestance (HEPA) filters. These devices have been tested at independent laboratories against various microorganisms to show their efficacy in inactivating and removing them[12].

II.C. Sample collection and laboratory analysis

An impaction air sampler, MAS-100 Eco Microbiological Air Sampler (MBV AG, Industriestrasse 9, CH-8712 Staefa, Switzerland), was used to obtain each sample. The air sampler used in this study was calibrated by Lennox Labs, Ireland, on June 10, 2021. The air sampler was placed on top of a table in the breakroom (figure 1), a workbench countertop in the examination room (figure 2), a desk at the nurse station (figure 3), and on a reception counter in the waiting room (figure 4). Every sample was taken at the same location within each environment for consistency. The height of the sampler varied with the support selected at each environment and was in the range of 0.71–0.86 m (28–34 in.) above the ground. During the test phase, the distance between the air cleaner and the air sampler was 2.4 m (96 in.) in the breakroom, 0.6 m (24 in.) in the examination room, 2.5 m (100 in.) in the nurse station, and 1.3 m (53 in.) in the waiting room.

The media used in the agar plates was Tryptone Soy Agar (TSA). This agar is a general purpose media which can support a broad range of microorganisms (bacteria), and is therefore suitable for this type of study. Pre-poured agar plates were

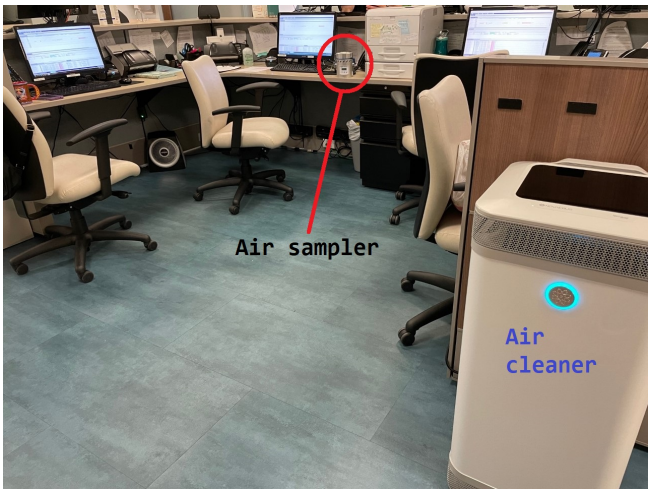

FIG. 3 Photo of the nurse station environment with the air sampler placed on a desk.

FIG. 4 Photo of the waiting room environment with the air sampler placed on a reception counter.

obtained from EMSL and used with the MAS-100 Eco air sampler during sampling.

The air sampler was set to collect air at a rate of 100 l/min. Each sample was collected for 1 minute, therefore sampling a 100 liter of air. Air samples were taken in duplicate, one after the other, at each location. A total of 76 air samples were collected: 38 during the control phase, and 38 during the test phase.

After sampling was complete, the agar plates were sealed and refrigerated for no longer than 2 days. Following this, they were delivered directly to an external laboratory, EMSL Analytical, Inc. (200 Route 130 North, Cinnaminson, NJ 08077, USA), where they were incubated and analyzed under their code *M010 Bacterial ID (3MPT)*, following their own internal method, *MICRO-SOP-132*, with a turnaround time of two weeks. The air sample agar plates were analyzed for bacterial counts and identification of three most prominent species (3MPT) present in each agar plate. The bacterial counts are presented in this document as colony forming units per cubic meter (CFU/m^3).

II.D. Data analysis

The data analysis comprised the identification of most prominent species in air samples, ranking the species by pathogenicity (pathogens, opportunistic pathogens and non-pathogenic), determining the shape and size of the microorganisms, and enumeration of colony counts per species, per pathogenicity, per location, per date, and overall counts.

Statistical analysis of overall colony counts to compare test and control samples comprised of determining the test statistic as per equation 1; where $\bar{x}$ is the mean value, s is the sample standard deviation (SD), and n is the number of samples for each data set (control and test)[13].

$$t_{\text{stat}} = \frac{\bar{x}_{\text{test}} - \bar{x}_{\text{control}}}{\sqrt{\frac{s^2_{\text{test}}}{n_{\text{test}}} + \frac{s^2_{\text{control}}}{n_{\text{control}}}}} \quad (1)$$

The null hypothesis (H_0) was that the mean values of the control and test air data sample sets are the same. The probability value (p-value) of a two-tail t-student distribution (with $n-1$ degrees of freedom) for the test statistic was used to detemine if the results are statistically significant. A standard cut-off probability or significance level of $\alpha = 0.05$ (5%) was used[14]. The null hypothesis is rejected if the p-value is less than the significance level; i.e., if p-value$< \alpha$ then it is highly improbable to observe a difference between the control and test data by mere chance and therefore there must be a factor affecting the air samples. In the case of the present study, the factor is the amount of additional air cleaning provided by the use of portable stand-alone air cleaning devices during the test phase.

Often, data from air sampling may be skewed to the right and a logarithmic (log) transformation may be required before hypothesis testing. Log transformation is a typical conversion method for skewed data[15]. The control and test data was transformed and the hypothesis testing was applied under same hypothesis and significance level conditions.

All calculations were made in a Microsoft Excel spreadsheet using built in functions for mean, sample standard deviation, t-distribution, and other mathematical expressions.

III. RESULTS

III.A. Bacterial species identification

A total of 24 different bacterial species were identified in the agar plates collected during the control phase. A total of 28 different species were identified in the agar plates of the test phase. There were 8 species identified in common between control and test samples.

The bacterial species identified were ranked by pathogenicity and summarized in table I. The top five species in this ta-

ble are pathogens, while the next 16 species are opportunistic pathogens. All other species identified are non-pathogenic.

Bacterial species identified are either round or rod shaped. The short and long dimensions in μm are shown in table I. Some of the dimensions are reported as a range. The long dimension is not applicable to round shaped species. All dimensions reported here for the microorganisms identified were found on PubMed Central® (PMC), a free full-text archive of biomedical and life sciences journal literature at the U.S. National Institutes of Health's National Library of Medicine (NIH/NLM).

The scatter-plot shown in figure 5 shows the relative size of the species identified. The middle value of dimensions reported as a range was used to generate the graph. The horizontal axis represents the short dimension, and the vertical axis the long dimension in the case of rod shaped miroorganisms. Round shaped microoganisms fall on the 1:1 dotted line in the figure. The gray box marks the 2.5 μm x 2.5 μm size range. Microorganisms, and particulate matter in general, with nominal diameter under 2.5 μm can penetrate deeply into the lung[16]. The size of coronavirus[17] and influenza[18] virus (round shaped viruses) are also included in the figure for reference only; the study method reported here did not include virus detection. Bacterial species within the 2.5 μm x 2.5 μm box include 4 pathogens (out of 5 identified), 11 opportunistic pathogens (out of 16 identified, and 13 non-pathogenic (out of 22 identified).

Colony counts for pathogenic and opportunistic pathogens identified are shown in table II. The bacterial species and counts for control and test air samples are shown in different columns. Total counts of both, pathogens and opportunistic pathogens, are lower in test air samples than those in control air samples. No pathogenic bacterial species were identified in common between the control and test air samples. Six opportunistic bacterial pathogen species were identified in common between the control and the test air samples.

III.B. Colony counts

Air samples were taken in duplicate, one after the other, at each location/date. The average of every duplicate colony count at each location, collected during control and test phase, are summarized in table III. Note that no control or test air sample data is available for the first date of each phase in the breakroom environment. The breakroom was not included in the original plan for the study. Air sampling readings in the breakroom were taken from day 2.

Colony counts are compared on a day-to-day basis at each location and the corresponding percentage change in colony forming unit counts are plotted in figure 6. The differences are presented in percentage as calculated using expression 2. Negative values indicate a reduction in colony counts at test phase when using control as a reference baseline. Positive values indicate an increase in colony counts.

$$\text{Change}(\%) = 100 \times \left(\frac{\text{count}_{\text{test}} - \text{count}_{\text{control}}}{\text{count}_{\text{control}}} \right) \qquad (2)$$

The day-to-day differences contain 19 data pairs (figure 6).

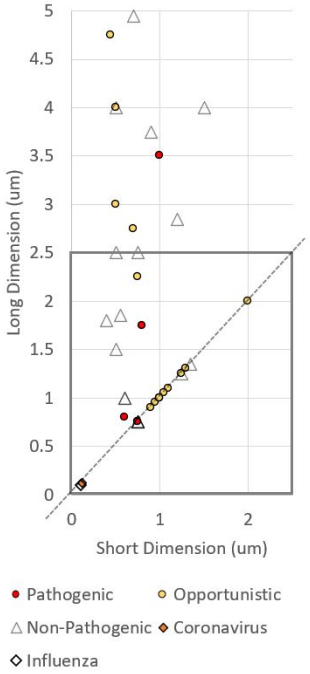

FIG. 5 Long and short dimensions for microorganisms identified in control and test samples.

The results show 3 instances where the counts increased, 1 instance where there was no change in counts, and 15 instances where the counts were reduced.

Colony counts are compared on a per location basis. The five day counts for each environment are averaged and the average control and test values are compared. Note that for the breakroom, the average is over four days. Figure 7 shows a bar chart with the comparison. The average changes over all consecutive days per environment show reduction in counts for all four sites. The reductions in percentage, from the highest to the lowest, are as follow: breakroom 72%, examination room 65%, waiting room 57% and nurse station 11%.

The average of all control and test counts were taken to determine the overall difference between control and test results. The difference betwen the averages over all consecutive days, and over all shows that there was a greater than 52% reduction in the overall colony counts between control and test. Statistical analysis and hypothesis testing was applied resulting in a p-value of 0.0131 ($< \alpha = 0.05$). Hence, the null hypothesis is rejected and the results were deemed statistically significant. A Box-Whisker plot of all control and test data, irrespective of date or location, is shown in figure 8.

The Box-Whisker plot suggests the data is positive skewed (also referred as skewed to the right). The control mean (97.63 CFU/m^3; standard deviation (SD) 74.78 CFU/m^3) is greater than the median (75 CFU/m^3). The test mean (46.32 CFU/m^3; SD 31.79 CFU/m^3) is greater than the median (40 CFU/m^3). The colony counts were transformed using the logarithm function (base 10) and similar analysis was applied resulting in a p-value of 0.0116 ($< \alpha = 0.05$); i.e., similar result of statical significance.

TABLE I Bacterial species identified during control and test phase air sampling. Species indentified in control agar plates are marked C, and those identified in test agar plates are marked T. Short and long dimensions in μm (if applicable) are tabulated. Some dimensions are given as a range.

Pathogenicity	Bacterial Species	Control (C) / Test (T)	Short dim. (μm)	Long dim. (μm)
Pathogen	*Staphlococcus caprae*	T	0.5–1.0	N/A (round)
	Acinetobacter ursingii	C	0.7–0.9	1.0–2.5
	Bacillus cereus	C	1.0	3.0–4.0
	Microbacterium aurum	T	0.6	0.8
	Staphlococcus aureus	T	0.5–1.0	N/A (round)
Opportunistic Pathogen	*Staphlococcus hominis*	C, T	1.2–1.4	N/A (round)
	Micrococcus luteus	C, T	0.5–3.5	N/A (round)
	Bacillus pumilus	C	0.5–1.0	4.0–10.0
	Corynebacterium aurimucosum	C	0.5	3.0
	Corynebacterium minutissimum	T	0.3–0.6	1.5–8.0
	Corynebacterium pseudodiphtheriticum	T	0.5	2.0–6.0
	Kocuria sedentarius	C	0.8–1.1	N/A (round)
	Kytococcus sedentarius	T	0.5	2.0–6.0
	Lysinibacillus fusiformis	T	0.5–0.9	2.5–3.0
	Pantoea agglomerans	T	0.5–1.0	1.5–3.0
	Staphlococcus simulans	C	0.8–1.0	N/A (round)
	Micrococcus lylae	C, T	0.5–2.0	N/A (round)
	Staphlococcus epidermidis	C, T	0.5–1.5	N/A (round)
	Staphlococcus haemolyticus	C, T	0.8–1.3	N/A (round)
	Staphlococcus capitis	C, T	0.8–1.2	N/A (round)
	Staphylococcus saprophyticus	C	0.8–1.2	N/A (round)
Non-Pathogen	*Staphylococcus auricularis*	T	0.5–1.0	N/A (round)
	Kocuria rhizophila	C, T	1.3–1.4	N/A (round)
	Dermacoccus nishinomiyaensis	C, T	0.9–1.6	N/A (round)
	Curtobacterium flaccumfaciens	C	0.3–0.5	0.6–3.0
	Bacillus megabacterium	T	1.5	4.0
	Kocuria kristinae	C	0.5–1.0	N/A (round)
	Brevibacillus choshinensis	T	0.6–0.8	2.6–7.3
	Bacillus sp.	T	0.25–1.0	4.0–10.0
	Microbacterium sp.	T	0.2–0.6	1.0–10.0
	Gram positive Cocci	C	0.5–1.0	N/A (round)
	Gram Positive Rod	C	0.25–1.0	1.0–10.0
	Gram negative Rod	T	0.5	1.0–2.0
	Sphingomonas sp.	C	1.2	1.2–4.5
	Brevibacterium sp.	T	0.6–1.2	1.5–6.0
	Brevundimonas sp.	C	0.5	1.0–4.0
	Staphlococcus sp.	T	0.5–1.0	N/A (round)
	Arthrobacter aurescens	T	0.6	1.0
	Arthrobacter oxydans	C	0.6	1.0
	Bacillus simplex	T	0.5–1.0	1.0–4.0
	Corynebacterium flavescens	C	0.5	2.0–6.0
	Sphingobium yanoikuyae	T	0.3–0.8	1.0–2.7

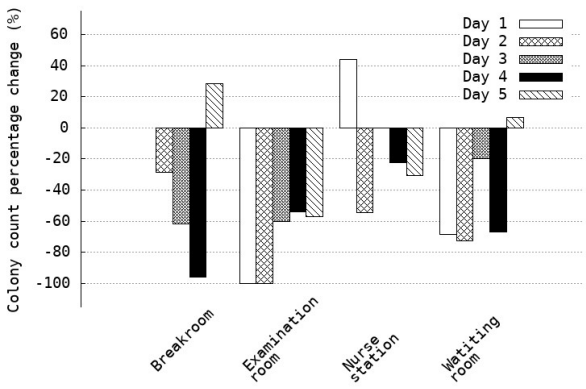

FIG. 6 Percentage reduction in colony counts on a day-to-day comparison between control and test data. The comparisons include all control days vs all test days at each of the four locations sampled.

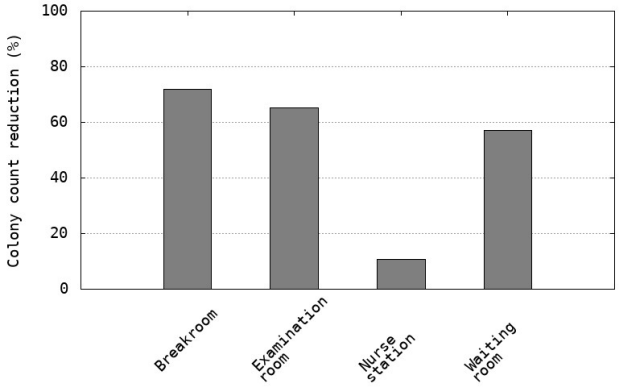

FIG. 7 Percentage reduction in colony counts on a per environment comparison between control and test data. The comparisons include the average of multi-day control counts vs the average of multi-day test counts at each of the four locations sampled.

TABLE II Colony counts of pathogenic and opportunistic pathogen bacterial species identified in control and test samples.

Pathogens			
Control	CFU/m^3	Test	CFU/m^3
Acinetobacter ursingii	30		
Bacillus cereus	40		
		Microbacterium arurum	10
		Staphylococcus caprae	20
		Staphylococcus aureus	10
Total	70	Total	40
Opportunistic Pathogens			
Control	CFU/m^3	Test	CFU/m^3
Staphlococcus hominis	180	*Staphlococcus hominis*	70
Micrococcus luteus	1730	*Micrococcus luteus*	580
Micrococcus lylae	430	*Micrococcus lylae*	90
Staphlococcus epidermidis	360	*Staphlococcus epidermidis*	200
Staphlococcus haemolyticus	110	*Staphlococcus haemolyticus*	130
Staphlococcus capitis	10	*Staphlococcus capitis*	50
Staphlococcus saprophyticus	60		
Bacillus pumilis	20		
Corynebacterium aurimucosum	10		
Staphlococcus simulans	50		
Kocuria sedentarius	20		
		Lysinibacillus fusiformis	10
		Corynebacterium pseudodiphtheriticum	10
		Corynebacterium minutisimum	20
		Pantoe agglomerans	10
Total	2980	Total	1180

TABLE III Averaged air sample data collected during control and test phase at four different locations at the urgent care clinic.

	Control		Test	
Location	Date	CFU/m^3	Date	CFU/m^3
Breakroom	Thu Oct 28	N/A	Thu Nov 18	N/A
	Fri Oct 29	35	Fri Nov 19	25
	Sat Oct 30	105	Sat Nov 20	40
	Sun Oct 31	250	Sun Nov 21	10
	Mon Nov 1	35	Mon Nov 22	45
Exam Room	Thu Oct 28	25	Thu Nov 18	0
	Fri Oct 29	40	Fri Nov 19	0
	Sat Oct 30	50	Sat Nov 20	20
	Sun Oct 31	130	Sun Nov 21	60
	Mon Nov 1	70	Mon Nov 22	30
Nurse Station	Thu Oct 28	80	Thu Nov 18	115
	Fri Oct 29	55	Fri Nov 19	25
	Sat Oct 30	75	Sat Nov 20	75
	Sun Oct 31	45	Sun Nov 21	35
	Mon Nov 1	115	Mon Nov 22	80
Waiting Room	Thu Oct 28	285	Thu Nov 18	90
	Fri Oct 29	220	Fri Nov 19	60
	Sat Oct 30	75	Sat Nov 20	60
	Sun Oct 31	90	Sun Nov 21	30
	Mon Nov 1	75	Mon Nov 22	80

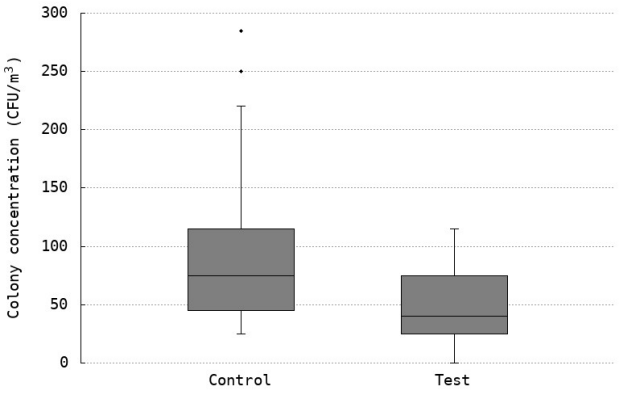

FIG. 8 Box-Whisker plot of all control and all test data, irrespective of date and environment.

IV. DISCUSSION AND CONCLUSION

The range of bacterial species expected to be identified in healthcare settings may vary from ubiquitous soil bacterium to pathogenic species, including those that have developed resistance to antibiotics. Here we report a wide spectrum of organisms, from non-pathogenic, through opportunistic pathogens, to pathogenic species. The highest colony counts were retrieved from the breakrooms and waiting rooms.

For example, in the opportunistic pathogen category, the most prominent species identified, found in every environment sampled, was *Micrococcus luteus*, which has been associated with a variety of illnesses including meningitis, septic arthritis, endocarditis, chronic cutaneous infections in human immunodeficiency virus (HIV) positive patients, and catheter infections. A reduction in colony counts of *Micrococcus luteus* was observed from control to test measurements (table II). *Micrococcus lylae*, another prevalent hospital opportunistic bacterial species also achieved a combined decline in the colony numbers when comparing the control and the test results. *Micrococcus lylae* has been associated with similar illnesses as *Micrococcus luteus*.

In addition to the two *Micrococcus species*, bacteria identified in both the control and test samples included *Staphylococcus*, *Dermacoccus* and *Kocuria species*. While other species identified, but not limited to, included *Acinetobacter*

and *Corynebacterium species*. The most abundant type of bacteria were found to be opportunistic pathogens, some of which would not cause infection or illness until it colonizes an immunosuppressed patient. Non-pathogenic bacteria were also found, these were identified as normal dermal flora, soil or water bacteria or bacteria that inhabit plants. Finally, pathogenic bacteria were found in small numbers and they were all found in two rooms: the waiting room and/or the examination room. This is not surprising as patients are well known to be a source of airborne pathogens in hospitals and healthcare settings.

While bacteria and other microorganisms may be found attached to particulate, dust, skin cells, within droplets and other aerosol carriers, on their own, most of the species identified in this study, based on their dimensions, could penetrate deep into the lung.

Table IV summarizes bacteria colony count concentrations reported in the literature. When comparing the results in this study to those in the literature[19–27], the counts reported here are particularly on the lower end of the scale. This was however somewhat expected due to the current COVID-19 pandemic, were there was an influx in hygiene regimes, better hygiene etiquette and mask wearing which may have had an effect on the airborne microbial load.

The break room control phase in this study retrieved counts of between 35–250 CFU/m^3 which are more comparable to a previous study conducted in patient rooms with counts of 198, 254, 185 CFU/m^3 in a government hospital and 145, 163, 137 CFU/m^3 in a private hospital[25]. The general consensus would indicate that more people would congregate in these areas thus somewhat comparable to the breakroom in this study. Once the air cleaner device was deployed the bacterial levels decreased vastly to 10–45 CFU/m^3, a 72% reduction. These colony counts are somewhat on par with colony counts from a private hospital's neonatal ward and operating room with mean CFU/m^3 results of 33, 46, 27 and 34, 25, 29 respectively. As neonatal wards and operating rooms would have stricter cleaning regimes and standards; the similar results of colony counts obtained using an air cleaning device is a very positive result.

The examination room saw a 65% reduction when implementing the air cleaner device, with the control results ranging between 25–130 CFU/m^3 and test results ranging between 0–60 CFU/m^3. Again, these results are on the lower end of the spectrum and considerably lower colony counts compared with what was found in literature in all areas in table IV.

The literature for the nurse station also retrieved a non-like for like search result. The nurse station saw the least reduction in colony numbers with an 11% reduction when the air cleaner device was deployed. This saw the range of results decrease from the control average of 74 CFU/m^3 to a test average of 66 CFU/m^3. The results are again on the lower end of the scale for both the control and test samples. The control samples were lower than those observed in patient rooms, hospital rooms, lobbies, the intensive care unit (ICU) rooms as well as a government hospital ICU. The private hospital ICU room was much lower than the control average of 74 CFU/m^3, however, so was the average test result. The test result of 66 CFU/m^3 was more relatable to the result obtained from a maternity ward, averaging 67 CFU/m^3 from Qudiesat et al. (2009)[25].

Lastly, the waiting room showed a reduction of 57% with the control results ranging from 75–285 CFU/m^3 and the test results ranging from 30–90 CFU/m^3. Some of the control results were higher than those retrieved from patient rooms[21,25,26] but were not as high as previous studies results from lobby areas as well as the clinical outpatient rooms[22]. The results from the test sampling were comparable to the results of a neonatal ward in both private and government hospitals which ranged from 27–95 CFU/m^3.

Although the comparisons can be made using the literature in table IV, there are many other variables to note. Different volumes of air, different method of air sample collection, collection times, room or area size/volume, and the number of staff or patients in a room all could have an affect on the colony count results.

In conclusion, reduction in colony counts between control and test phase measurements at each environment of the urgent care clinic are reported here. While none of these reductions are statistically significant due to small number of samples in each individual location, the overall difference, a reduction of more than 52% in colony counts, is statistically significant. In addition, when comparing the number of colonies of pathogen and opportunistic pathogen species (see table II), reductions in both cases from control to test measurements are also observed; no statistical analysis was carried out on the subset of pathogen and opportunistic pathogen colony counts.

The data reported here suggests that the use of portable stand-alone air cleaning devices can reduce the airborne bacterial bioburden at an urgent care clinic setting. Further testing at similar institutions and/or other healthcare settings is recommended to evaluate the performance of air cleaning under similar and/or alternate conditions.

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Appendix A: Definitions

Subjects of the study: (*Individuals participating in the study*). While the study does not aim to make any measurements on the individuals participating in the study, nonetheless, these individuals are to take part in the study as the source of airborne bioburden or pollutants. These airborne pollutants shall be monitored in the controlled environment in which the subjects are placed for the purpose of the study. Ideally, subjects should be of a wide range of ages (e.g., 20 to 60 years of age) and with/without health conditions (e.g., no respiratory conditions, allergy and/or asthma sufferers). Subjects may include patients, staff and visitors.

Experiment: (*A study in which treatment is applied in a controlled situation to measure the effect of the treatment*).

TABLE IV Airborne sample colony counts (CFU/m^3) as reported in the literature.

Area	Range (CFU/m^3)	Mean (CFU/m^3)	Reference
Clinical outpatient rooms		1,000	Pastuszka et al. (2005)[22]
Hospital rooms	4–1,293	124	Ortiz et al. (2008)[24]
Hospitals in Poland	100–1,000		Pastuszka et al. (2005)[22]
Patient rooms (gov. hospital)		198, 254, 185	Qudiesat et al. (2009)[25]
Patient rooms (private hospital)		145, 163, 137	Qudiesat et al. (2009)[25]
Ward	42–325		Obbard & Fang (2003)[21]
Maternity wards	14–224	67	Ortiz et al. (2008)[24]
Neonatal ward (gov. hospital)		95, 82, 69	Qudiesat et al. (2009)[25]
Neonatal ward (private hospital)		33, 46, 27	Qudiesat et al. (2009)[25]
Pneumonological dept.	257–436		Augustowska & Dutkiewicz (2006)[23]
ICU (gov. hospital)		109, 107, 121	Qudiesat et al. (2009)[25]
ICU (private hospital)		149, 197, 147	Qudiesat et al. (2009)[25]
Operating room	25–847	370	Greene et al. (1962)[19]
Operating room (gov. hospital)		79, 107, 93	Qudiesat et al. (2009)[25]
Operating room (private hospital)		34, 25, 29	Qudiesat et al. (2009)[25]
Operating rooms	35–6,356		Favero et al. (1968)[20]
Operating theatres	1–157		Ortiz et al. (2008)[24]
Overall hospital areas	353–2,472		Greene et al. (1962)[19]
Lobbies		720	Park et al. (2013)[26]
Lobby	445–890		Obbard & Fang (2003)[21]
Main enterance (gov. hospital)		174, 229, 163	Qudiesat et al. (2009)[25]
Main enterance (private hospital)		120, 115, 87	Qudiesat et al. (2009)[25]
Pharmacy	201– 827		Obbard & Fang (2003)[21]
Personal (cleaners)	103– 1,710	351	Lu et al. (2020)[27]
Waste storage		6,709	Greene et al. (1962)[19]
Industrial clean rooms	35–353		Favero et al. (1968)[20]

The treatment shall be applied to the air in the form of air cleaning by recirculating air through a portable stand-alone air cleaner. The air cleaner comprises of a fan impeller, dielectric barrier discharge plasma technology for microorganism inactivation, and high efficiency particulate arrestance (HEPA) filtration. Therefore, no direct treatment will be applied to the subjects of the study.

Response: (*The variable whose outcome the study aims to measure*). The study is aimed at determining if the use of air cleaning shall result in a reduction in the bioburden in the air in the controlled environment where the subjects shall carry out an activity (e.g., triage at an examination room, break activity at the breakroom, etc.).

Factor: (*The variable whose effect on the response is being studied*). The study aims to determine if the bioburden in the air would be reduced when using portable stand-alone air cleaning devices. The factor is the amount or use of air cleaning. Note that conditions for control shall be determined (e.g., no ventilation, natural ventilation, building ventilation) in addition to the intervention (i.e., air cleaning device(s)).

Level: (*One possible outcome of a factor*). Possible levels to consider for this study may include the speed setting of the air cleaning device and/or the number of air cleaning devices used to treat the air.

Treatment: (*A combination of the levels of factors being studied*). The study aims to determine the effect of air cleaning; therefore, the factor is air cleaning. However, unless there is only one factor, the levels and the treatment are the same thing (e.g., one air cleaning device only operating at only one of the possible speed settings). Alternatively, if different air speed settings or more than one air cleaning device is used to treat the air, the levels are a combination of these treatments.

Cause and effect: (*A factor response have a cause-and-effect relationship if a change in the factor results in a direct change in the response*). If the study is designed to control any possible confounding variables, then their effect on the response can be minimized. It is the aim of the study to limit these so that a cause-and-effect can be determined between the use of air cleaning and the reduction in bioburden in the air.

[1]C. B. Beggs, "The airborne transmission of infection in hospital buildings: Fact or fiction?" Indoor and Built Environment **12**, 9–18 (2003).
[2]I. Eames, J. W. Tang, Y. Li, and P. Wilson, "Airborne transmission of disease in hospitals," Journal of The Royal Society Interface **6**, S697–S702 (2009).
[3]A. Fernstrom and M. Goldblatt, "Aerobiology and its role in the transmission of infectious diseases," Journal of Pathogens **2013** (2013).
[4]W. E. Bischoff, K. Swett, I. Leng, and T. R. Peters, "Exposure to Influenza Virus Aerosols During Routine Patient Care," The Journal of Infectious Diseases **207**, 1037–1046 (2013).
[5]C. C. Wang, K. A. Prather, J. Sznitman, J. L. Jimenez, S. S. Lakdawala, Z. Tufekci, and L. C. Marr, "Airborne transmission of respiratory viruses," Science **373**, eabd9149 (2021).
[6]N. Wilson, S. Corbett, and E. Tovey, "Airborne transmission of covid-19," BMJ **370** (2020).
[7]Y. Li, H. Qian, J. Hang, X. Chen, P. Cheng, H. Ling, S. Wang, P. Liang, J. Li, S. Xiao, J. Wei, L. Liu, B. J. Cowling, and M. Kang, "Probable airborne transmission of sars-cov-2 in a poorly ventilated restaurant," Building and Environment **196**, 107788 (2021).
[8]K. K. Coleman, D. J. W. Tay, K. S. Tan, S. W. X. Ong, T. S. Than, M. H. Koh, Y. Q. Chin, H. Nasir, T. M. Mak, J. J. H. Chu, D. K. Milton, V. T. K. Chow, P. A. Tambyah, M. Chen, and K. W. Tham, "Viral Load of Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) in Respiratory Aerosols Emitted by Patients With Coronavirus Disease 2019 (COVID-19) While Breathing, Talking, and Singing," Clinical Infectious Diseases (2021), ciab691.
[9]Z. J. Zhai, R. Bahl, K. Trace, B. Gupta, and H. Li, "Mitigating COVID-19 in

public spaces: Central HVAC Filtration vs. Portable Air Purifier Filtration," ASHRAE Journal **63** (2021).

[10] I. Arikan, O. Genc, C. Uyar, M. Tokur, C. Balci, and D. Percin Renders, "Effectiveness of air purifiers in intensive care units: an intervention study," Journal of Hospital Infection **120**, 14–22 (2022).

[11] A. Persson, I. Atroshi, T. Tyszkiewicz, N. Hailer, S. Lazarinis, T. Eisler, H. Brismar, S. Mukka, P.-J. Kernell, M. Mohaddes, O. Sköldenberg, and M. Gordon, "Epos trial: the effect of air filtration through a plasma chamber on the incidence of surgical site infection in orthopaedic surgery: a study protocol of a randomised, double-blind, placebo-controlled trial," BMJ Open **12** (2022).

[12] `https://www.wellairsolutions.com/research`.

[13] D. J. Rumsey, *Statistics*, 2nd ed. (Wiley Publishing, Inc., 2011).

[14] J. L. Peacock and P. J. Peacock, *Oxford Handbook of Medical Statistics*, 2nd ed. (Oxford University Press, 2020).

[15] A. Petrie and C. Sabin, *Medical statistics at a glance*, 4th ed. (John Wiley and Sons, 2020).

[16] Y.-F. Xing, Y.-H. Xu, M.-H. Shi, and Y.-X. Lian, "The impact of pm2.5 on the human respiratory system," Journal of Thoracic Disease **8** (2016).

[17] M. M. Lai and D. Cavanagh, "The molecular biology of coronaviruses," (Academic Press, 1997) pp. 1–100.

[18] W. M. Stanley, "The size of influenza virus ," Journal of Experimental Medicine **79**, 267–283 (1944).

[19] V. W. Greene, D. Vesley, R. G. Bond, and G. S. Michaelsen, "Microbiological contamination of hospital air," Applied and Environmental Microbiology **10**, 561–566 (1962).

[20] M. S. Favero, J. R. Puleo, J. H. Marshall, and G. S. Oxborrow, "Comparison of microbial contamination levels among hospital operating rooms and industrial clean rooms," Applied Microbiology **16**, 480–486 (1968).

[21] J. P. Obbard and L. S. Fang, "Airborne Concentrations of Bacteria in a Hospital Environment in Singapore," Water, Air, and Soil Pollution **144**, 333–341 (2003).

[22] J. S. Pastuszka, E. Marchwinska-Wyrwal, and A. Wlazlo, "Bacterial aerosol in Silesian Hospitals: Preliminary results," Polish Journal of Environmental Studies **14**, 883–890 (2005).

[23] M. Augustowska and J. Dutkiewicz, "Variability of airborne microflora in a hospital ward within a period of one year," Annals of Agriculturural and Environmental Medicine **13**, 99–106 (2006).

[24] G. Ortiz, G. Yague, M. Segovia, and V. Catalan, "A study of air microbe levels in different areas of a hospital," Curr. Microbiol. **59**, 53–58 (2009).

[25] K. Qudiesat, K. Abu-Elteen, A. Elkarmi, M. Hamad, and M. Abussaud, "Assessment of airborne pathogens in healthcare settings," African Journal of Microbiology Research **3**, 066–076 (2009).

[26] D.-U. Park, J.-K. Yeom, W. J. Lee, and K.-M. Lee, "Assessment of the levels of airborne bacteria, gram-negative bacteria, and fungi in hospital lobbies," International Journal of Environmental Reserach in Public Health **10**, 541–555 (2013).

[27] R. Lu, K. Tendal, M. W. Frederiksen, K. Uhrbrand, Y. Li, and A. M. Madsen, "Strong variance in the inflammatory and cytotoxic potential of Penicillium and Aspergillus species from cleaning workers' exposure in nursing homes," Science of the Total Environment **724**, 138231 (2020).