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Major article

Evaluation of dry hydrogen peroxide in reducing microbial bioburden in a healthcare facility

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Key Words:
Environmental contamination
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Automated decontamination
Continuous microbial reduction

Background: Standard manual cleaning and disinfection practices are often inadequate. Persistent contamination in the environment poses an infection risk that may be mitigated by no-touch disinfection systems. This study evaluates the efficacy of dry hydrogen peroxide (DHP) on microbial air and surface contamination as an adjunct to routine cleaning and disinfection in a large urban hospital.

Methods: Surface samples were collected in five different hospital units, two pediatric and three adult, after manual cleaning on multiple days before and after DHP implementation. Air samples were also collected in each unit pre- and post-DHP use. Data outcomes were reported as colony forming units (CFU) with species identification.

Results: The overall mean surface microbial burden was reduced by 96.5 percent for all units post-DHP compared to baseline ($P < 0.001$), with the greatest reductions achieved on privacy curtains (99.5 %). Mean microbial air sample counts were also reduced post-DHP compared to pre-DHP.

Conclusions: This study demonstrates that DHP was effective in reducing both air and surface microbial contamination in a variety of settings within a large, tertiary care hospital.

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INTRODUCTION

Multiple clinical and evidence-based analyses have documented that by reducing the microbial bioburden within the environment of care we can effectively mitigate the risk of healthcare-associated infections (HAI).[1-7] Currently, one in 31 Americans are affected by HAIs, resulting in approximately 72,000 deaths each year.[8] Efforts to reduce the risk of environmental contamination within healthcare has become a significant infection prevention and control priority.[1,9,10] Microorganisms, including multidrug-resistant organisms (MDROs), are shed by infected or colonized patients into the environment, where they can survive for extended periods and be transferred via contact with other patients or by the hands of healthcare personnel.[11-19] Studies document a 6-fold risk of acquiring an infection if the prior room occupant was infected with a clinically-significant organism.[17,20-25]

Current research supports the role of environmental transmission (air and surfaces) as a risk for potential contamination or infection via transient bacteria.[1,16,26,27] Manual cleaning and disinfection by a trained healthcare worker is necessary for effective bioburden reduction in the environment.[1,28] Evidence suggests that organisms such as methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant *Enterococcus* (VRE), and *Clostridiodes difficile* (C. diff) can survive for prolonged periods on environmental surfaces.[19,20,26,29] A study by Carling et al., reported that in a study of 23 acute care hospitals, only 49 percent of the surfaces were adequately cleaned with routine manual cleaning.[30] Common routes of transmission of microorganisms include portable equipment and room surfaces.[16] The most commonly touched surfaces by both healthcare workers and patients include the bed rails, counters, call lights, curtains, and bedside tables.[20]

A surge in innovative technologies designed to enhance environmental cleaning and disinfection, including “no touch” room disinfection units, has occurred in response to these findings.[1,9] Studies have shown that many of these technologies can be highly effective in

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reducing microbial burden in the environment.[1] Many of these technologies are restricted to episodic disinfection because of safety concerns associated with human exposure.[1] As a result, they cannot address in real-time the continual recontamination of the environment—both in air and on surfaces—that occurs from healthcare personnel, visitors, and patients.[1,31]

The present investigation was undertaken to evaluate the efficacy of dry hydrogen peroxide (DHP). Numerous studies have supported airborne hydrogen peroxide to be an effective disinfectant for inanimate surfaces within the healthcare environment but a common disadvantage has been its restriction for use in unoccupied spaces.[1,32] Unlike hydrogen peroxide vapor (HPV) or dry-mist formulations, DHP possesses broad-spectrum antimicrobial activity yet exists as a non-aqueous gas in concentrations far below acceptable safety limits for human exposure established by the Occupational Safety and Health Administration (OSHA).[33,34] The present study assesses the efficacy of DHPas an adjunct to standard manual cleaning in reducing microbial airborne and surface contamination within both adult and pediatric settings of a large inner-city acute care hospital.

METHODS

Sample and setting

The study protocol was reviewed and approved by the facility's institutional review board (IRB). A 1-month cohort analysis was performed between March 2019 and April 2019 at Sunrise Hospital & Medical Center and Sunrise Children's Hospital, a 762-bed acute care facility in Las Vegas, NV. Two units in the Sunrise Children's Hospital, a 24-bed pediatric intensive care unit (PICU) and a 22-bed pediatric emergency department (Peds ED); three units in the Sunrise Hospital and Medical Center, a 23-bed adult oncology services (AOS), a 22-bed adult intensive care unit-cardiovascular trauma unit (CVTU), and a 10-bed adult trauma surgical intensive care unit (TSICU) were chosen for study.

Design, installation, and operation of *DHP* units in the HVAC systems

The DHP units (Synexis, Lenexa, KS) were installed in the respective intervention location's HVAC system at the diffuser level by the manufacturer. Each DHP unit is a standard size (Height: 8.5", Depth: 7", Width: 10") and weight, (5 pounds) and requires an input voltage of 120VAC; 50/60 Hz. The units utilize ambient humidity and oxygen moving through the HVAC system along with a proprietary plasma separation process to generate hydrogen peroxide in a non-aqueous, dry gas form at a range of 5-25 parts per billion (ppb) with transient concentrations as high as 40 ppb when measuring with an InterScan 4000 Series Hydrogen Peroxide Sensor.[35] More recent measurements using a Picarro PI2114 indicate that the DHP™ units generate 0.5-5 ppb of DHP. The gas freely diffuses throughout the intervention location supplied by the HVAC system. The DHP units operated continuously (24/7) throughout the study period in four of the intervention units. The fifth intervention unit (TSICU) did not have the system directly installed in the location, however the HVAC was shared between the TSICU and CVTU allowing for exposure to the DHP.

Microbial sampling

The impact of the DHP systems was assessed by comparing baseline surface and air microbial sampling pre-DHP implementation (Study Days -3, -2, -1) to post-implementation sampling (Study Days 1, 7, and 28). All microbial sampling (Table 1) was performed by a third-party firm (Controlled Environmental Management, Fountain Hills, AZ) between 10 and 11:30 am and after standard manual cleaning was performed in each location. No changes in the hospital's environmental cleaning and disinfection protocols or practices were made during the study period. This includes the protocol for the privacy curtains, which is to change the curtains every six months or when soiled. They were not changed during the course of the study.

Table 1
Department location, bed counts, and number of sample counts collected per site

Department name	Number of beds in unit	Samples collected
Pediatric emergency (Peds ED)	22	7 per day
Adult oncology services (AOS)	23	10 per day
Adult cardiovascular trauma intensive care services (CVTU)	22	7 per day
Adult trauma surgical intensive care (TSICU)	10	7 per day
Pediatric unit (PICU)	24	7 per day

Surface samples

Surface samples were obtained using pre-moistened blue-cap swabs from curtains, bed rails, and counters in each location. Each surface sample was collected by vigorously swabbing a standardized, defined area of 25 cm^2 in a horizontal and then a vertical direction. The curtain collection location was at the grab location approximately 4 feet from the ground, starting at the edge of the curtain. The bed rail sample was collected from the inner and upper portion of the bedrail, approximately 2-3 feet from the top of the bed, which was closest to where the call button resides. Counter specimens were only collected in the pediatric emergency room as this location did not have stationary beds. The counter specimens were collected in random locations on those surfaces. A final specimen was collected above the proximity cabinet in the AOS unit in an area that would possibly be missed during daily cleaning. Nurse station counter samples were collected closest to where the charge nurse computer station was located on the visitor side. Thirty one surface samples were collected per sampling date for a total of 186 surface samples collected.

Air samples

All air sampling was conducted using a bioaerosol sampling impactor (Buck Bio-Culture, A.P. Buck Inc, Orlando, FL) Sampling was taken using a bacterial plate for 5 mins (500 L) and a fungal plate for 5 mins (500 L). Seven air samples were collected per sampling date for a total of 42 air samples throughout the 28-day study. The air samples were collected in the middle of each nursing station of each patient care unit. Additional samples were collected in the hallway beyond the smoke barrier with the doors closed for the adult oncology services hallway, outside the pediatric emergency room hallway beyond the smoke barrier doors with the doors closed, and a final sample taken in the ambulance bay main emergency room entrance as a baseline. A non-nursing air sample was taken as a control comparison between those locations without the DHP installed to locations with the DHP installed. Each air sample consisted of two settling plates, including one with trypticase soy agar (TSA) and one with inhibitory mold agar (IMA).

Specimen processing

All specimens were transported to U.S. Micro Solutions, Inc. (Latrobe, PA) via overnight shipping. Appropriate transport temperatures were maintained by using insulated cold packed shipping boxes. The surface samples were plated to blood agar plates and incubated at 20-25 degrees Celsius for 5 days. Microbial recovery was reported in colony forming units. Selective isolates of epidemiologic importance

were identified to species level. Isolates on TSA from air sampling were TSA incubated at 20-25 degrees Celsius for 5 days. Identification of isolates, including *S. aureus, Enterococcus,* and gram-negative bacilli were completed using MALDI-TOF mass spectrometry.

Statistical analysis

Total surface and air sample Log10-CFU data was analyzed using a paired *t*-test. For all data, a mean of the baseline air and surface samples (Study Days -3, -2, -1) was used as the comparative point for analysis. Statistical analysis was performed using IBM SPSS statistics version 25. A *P*-value of less than or equal to 0.05 was considered significant. The values reported in Figures 1 and 2 represent the calculated mean aggregate values. The final percent reduction values were obtained using a scientific calculator[(P=[(A-B)x 100]/A; where P = % reduction, A= Baseline Value, and B= Value at Timepoint].

RESULTS

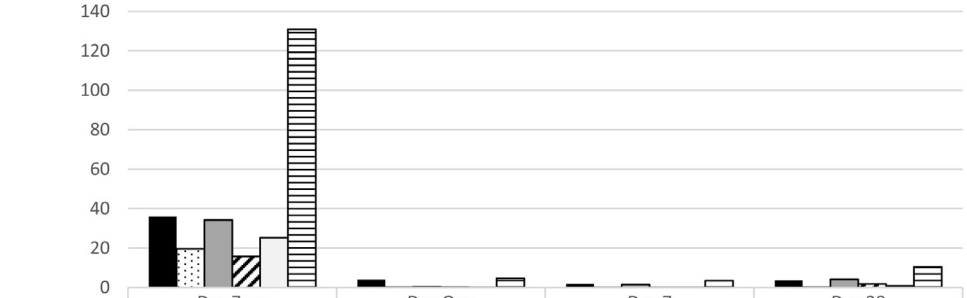
Surface sample results

A mean of the surface sample results of the 3-day window before initiation of the DHP was used to establish the day Zero baseline. The mean count indicates the baseline following the standard cleaning process with one sample of each surface collected each day. The individual department with the highest reduction in microbe recovery was the TSICU, with a total reduction of 99.6% from day Zero to day 1 post-implementation. Similarly, the CVTU experienced a 99.3% reduction from day Zero to day 1 post-implementation. The overall reduction was 96.5% after 1 day of implementation and maintained a microbial reduction of 92.0% by day 28 post-implementation in all combined units. The microbial reduction per hospital area sampled is seen in Figure 1.

A significant microbial reduction was found on both hard and soft surfaces (Fig 2). The soft surfaces (privacy curtains) demonstrated higher microbial reductions than hard surfaces, exhibiting a 99.5% reduction within the first day of implementation and maintaining a reduction of 96.6% by day 28. The hard surfaces experienced a decrease of 94.3% at Day 1, maintaining an 88.8% reduction by day 28.

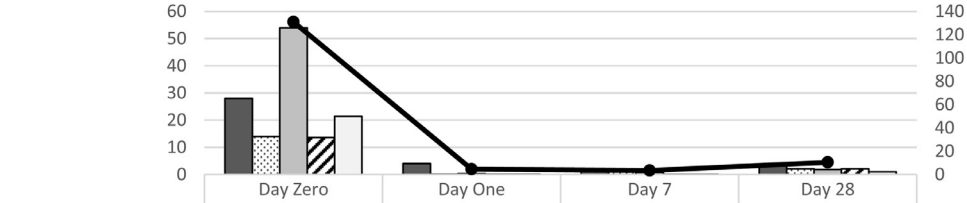
There was a statistically significant difference in mean microbial surface counts ($t_{43.324} = 9.396$, $P < 0.001$) between day Zero and post-day 1. The average microbial surface count on Day One was 96.5% lower than Day Zero. At Day 28, there was a statistically significant difference in mean microbial counts ($t_{39.843} = 9.165$, $P < 0.001$). The average microbial surface count on day 28 was 92.0% lower than day Zero.

The predominant organisms recovered from the sampled surfaces for day Zero included coagulase-negative *staphylococci*, unidentifiable Gram-negative rod, *Micrococcus Kocuria, Bacillus*, and *Acinetobacter lwoffii* documenting the recovery of normal skin flora and potential microbial pathogens. DHP was effective in the reduction of predominant Gram-negative rod for through day 28. *Acinetobacter*



	Day Zero	Day One	Day 7	Day 28
AOS	35.99	3.98	1.85	3.61
CVTU	19.64	0.13	0.11	0.14
Peds_ED	34.22	0.25	1.46	4.13
PICU	15.77	0.18	0.02	1.79
TSICU	25.29	0.11	0.02	0.81
Grand Total	130.92	4.65	3.47	10.49

Fig 1. Aggregate microbial counts by hospital area.



	Day Zero	Day One	Day 7	Day 28
Bedrail	27.98	4.02	1.23	3.37
Counter	14.00	0.13	1.42	2.12
Curtain	53.93	0.29	0.78	1.84
Proximity Cabinet	13.61	0.09	0.03	2.13
RN Station	21.40	0.11	0.01	1.02
Grand Total	130.92	4.65	3.47	10.49

Fig 2. Aggregate microbial counts by surface type.

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lwoffii was found as a primary organism in fewer specimens for day 7. *Bacillus* and *Enterococcus faecalis* were found in fewer specimens for day One. *Enterococcus faecium* was found in fewer specimens on day 7.

Air sample results

A mean of the air sample results of the 3-day window before initiation of the DHP was used to establish the day Zero baseline. A comparison of day Zero to day 1 showed that there was not a statistically significant difference in mean microbial air sample counts ($t_{15.148} = 0.950$, $P = 0.357$). The average microbial air count on Day One was 28.7% lower than the day Zero Counts. At day 28, there was again, no statistically significant difference in mean microbial counts ($t_{15.896} = 0.756$, $P = 0.460$). The average microbial count on day 28 was 23.4% lower compared to day Zero count.

The top five identified airborne organisms included *Micrococcus Kocuria*, coagulase-negative *staphylococci, Bacillus*, unidentifiable Gram-negative rod, and *Enterococcus faecalis* and documents the recovery of normal skin flora, commensal bacteria and pathogens. DHP treatment documented a reduction in Gram-negative rod for each time period through day 28 and *Enterococcus faecalis* by day 7 continuing through day 28. *Micrococcus* was found in fewer specimens on day 1. *Bacillus* was found in fewer specimens on day 1 and day 7. By day 7, a reduction was found in coagulase-negative staphylococci.

DISCUSSION

The hard and soft surfaces sampled after implementation of DHP demonstrated a persistent microbial reduction following standard cleaning processes. These results align with previous research demonstrating statistically significant reductions in surface microbial bioburden with use of DHP as an adjunct to standard manual cleaning protocols.[36,37] Further, a recent study of DHP in a pediatric oncology intensive care unit demonstrated reductions in both air and surface contamination along with a robust safety profile.[37]

In the present study, DHP™ resulted in an overall 96.5% microbial reduction (130.92 million CFU on day Zero to 4.65 million CFU on day 1) for all combined surfaces. However, the greatest reduction in microbial burden was observed on the most difficult surface, the curtains, which documented a reduction of 99.5% from 53.93 million CFU on day Zero to 0.29 million CFU on Day 1. No increase in staff cleaning or housekeeping was implemented, nor were any curtain changes implemented during this period.

Contaminated surfaces play an essential role in the transmission of pathogens via hand contamination of healthcare personnel and increase the risk for future patients occupying the rooms.[21,22] Pathogenic organisms found in the current study, such as *Acinetobacter*, that survive for prolonged periods on surfaces, have been cited as sources of transmission during outbreaks [38,39]*Acinetobacter* has been shown to remain on bed rails up to 9 days, thereby implicating the surfaces in multiple healthcare-acquired infections.[40] Guidelines for cleaning and disinfection of patient care areas indicate at least daily cleaning of a patient room with terminal cleaning completed at discharge as a minimum standard of cleanliness.[41] The level of contamination in a patient's room, whether the patient is newly admitted or has been admitted longer than 3 days, shows that cleaning and disinfection once per day is suboptimal, especially for soft surfaces such as curtains.[1,38,39] Published studies have found that 34% and 17% of surfaces in rooms after routine and terminal cleaning remained contaminated with MDROs.[11,42]

There is a myriad of reasons why standard manual cleaning may be inadequate—including, among others, EVS staffing shortages, the push for rapid room turnover, which may lead to "cutting corners," material and product compatibility, and human error. Additionally, much of the focus on environmental cleaning and disinfection in healthcare settings, particularly patient rooms, is focused on high-touch surfaces. Research has shown, however, that medium and low-touch surfaces can be equally contaminated, and is confirmed by the results from the proximity cabinets in this study.[22,43] Furthermore, the complex interplay that occurs between all surfaces, humans, and air, can frequently lead to the redistribution of residual organisms.[26,44-46] For example, studies have shown that foot traffic in the OR can influence the bioburden in OR air, which can then settle onto open sterile equipment and supplies.[27,46] Similarly, studies have shown that patients colonized with MRSA can contaminate the surfaces of a wheelchair within 20 minutes of being placed in one.[44] As that wheelchair is moved throughout a facility, there is an opportunity for transfer of organisms from the chair to floors and hands of healthcare workers in other areas.[45] Additionally, studies have shown that high-touch objects such as pulse oximetry probes and call buttons can have frequent contact with floors (a low-touch surface) and subsequently transfer pathogens from the floor to hands.[47]

Hydrogen peroxide is a well-known, broad-spectrum disinfectant possessing demonstrated activity against pathogens associated with HAIs as well as spore-forming organisms and mycobacteria.[32,48,49] Hydrogen peroxide has an oxidative effect on microbes, which leads to significant disruptions in the microbes' structure and function and, ultimately, to the loss of infectivity and viability.[50] Airborne hydrogen peroxide is an effective method for environmental disinfection in several clinical studies.[32] A component of this efficacy is the ability of airborne hydrogen peroxide to reach remote and otherwise inaccessible sites that may not be able to be addressed by manual cleaning.[51] Most commercially available forms of airborne hydrogen peroxide (eg, vapors and "dry" mists), however, provide aqueous hydrogen peroxide solutions in concentrations that far exceed OSHA's 1.0 ppm time-weighted average (TWA) and therefore cannot be used in occupied spaces.[1,52] Hydrogen peroxide concentrations achieved by vapor and dry mist systems have been reported as high as 338 ppm and 160 ppm, respectively.[53] By contrast, DHP systems generate hydrogen peroxide in a more dilute yet effective antimicrobial concentration, 0.5-25 ppb, depending on the measurement device.[33,34,54]

DHP systems obviate constraints presented by other available no-touch cleaning systems such as HPV and ultraviolet-C (UV-C) light systems. Although both HPV and UV-C are known to reduce environmental contamination, both systems require episodic vs continual treatment due to the safety of exposed individuals.[1,55-58] This limitation is especially important in light of the ongoing disbursement of organisms due to movement and human interaction or shedding.[1,21,31]

DHP systems can be safely and continuously operated in occupied settings without the need for manual participation, device transport, or room preparation. Its efficacy is not contingent on the use parameters (eg, distance or shadowing) critical to UV-C or HPV efficacy.[1] In fact, the present study demonstrated the ability of DHP to be effective in areas serviced by a shared HVAC system as evidenced by the similar microbial reductions between the CVTU, which had a DHP system, and the TSICU, which did not. Further, microbial reductions were achieved in all units within 24 hours post-DHP implementation. Because DHP systems can safely run continuously, recontamination of the environment is continually addressed, achieving a relatively steady state of microbial reduction.

Reducing microbial contamination on patient care surfaces may impact the environmental services costs and labor. The ability of the DHP to reduce soft surface contamination can reduce the requirement for high-cost cleaning of curtains or other soft surfaces within the facility. While the TSICU did not have DHP directly installed within the primary location, the DHP was installed in an adjacent unit that shared the HVAC (CVTU), and both showed a similar

microbial reduction. The preliminary findings suggest that the DHP may not require installation in every sequestered hospital location. The potential decrease in the risk of airborne contaminants among high-risk patients or during high-risk aerosol-generating procedures in addition to the effectiveness of the DHP in areas serviced by a shared HVAC requires further study.

A limitation of the present study is that the current data is limited to a dual acute care facility with multiple services and sizes of units. These findings, therefore, may be limited to similar-sized departments with similar services and patient populations. Accordingly, further analyses are warranted.

CONCLUSION

DHP shows a significant reduction in surface microbes. DHP can be an acceptable addition to environmental programs to enhance the cleanliness within healthcare facilities, thereby reducing the risk of infection via contaminated surfaces. The DHP system demonstrated a significant reduction in identifiable airborne microbes, creating a safer environment for both the patient and the healthcare worker. Furthermore, the documented efficacy of DHP to reduce soft surface microbial contamination may have a beneficial impact in reducing the requirement for high-cost cleaning of curtains or other soft surfaces within the facility. These and other considerations warrant further study, especially documenting the efficacy of DHP to reduce the risk of disseminating airborne contaminants among high-risk patient populations or during high-risk aerosol generating procedures.

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