Measuring environmental contamination in critical care using dilute hydrogen peroxide (DHP) technology: an observational cross-over study

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ABSTRACT

Background: The environment has an important role in the transmission of healthcare associated infections. This has encouraged interest in novel methods to improve hygiene in hospitals. One such technology is the use of hydrogen peroxide to decontaminate rooms and equipment; there are, however, few studies that have investigated the effect of continuous dilute hydrogen peroxide (DHP) in the clinical environment. The aim of this study was to undertake a feasibility study to assess the use of dilute hydrogen peroxide (DHP) in a critical care unit and measure the microbiological impact on surface contamination.
Methods: We conducted a prospective observational cross-over study in a ten-bed critical care unit in one rural Australian hospital. Selected high-touch sites were screened using dipslides across three study phases: baseline; continuous DHP; and no DHP (control). Quantitative aerobic colony counts (ACC) were assessed against a benchmark standard of ACC >2.5cfu/cm^2 to indicate hygiene failure.
Results: There were low levels of microbial contamination in the unit for baseline; DHP; and no DHP phases: 2.2% (95% CI 0.7-5.4%) vs 7.7% (95% CI 4.3-13.0%) vs 6% (95% CI 3.2-10.4%) hygiene failures, respectively. Significant reduction in ACCs did not occur when the DHP was operating compared with baseline and control phases.
Conclusion: Further work is needed to determine whether continuous DHP technology has a role in decontamination for healthcare settings.

Highlights

- Dilute hydrogen peroxide (DHP) use in a critical care unit
- No significant effect on levels of viable microbial soil on high-touch surfaces
- Further research needed to determine role of DHP in a healthcare setting

Keywords: Infection Control, Health Services, Cross infection, Detergents, Microbiology, Environment, Hospitals, Health Facility Environment, Disinfection.

Introduction

There is evidence to show that the environment plays an important part in the transmission of healthcare-associated infection (HAI) (1). Measures to improve environmental cleanliness in hospitals are an important component of an infection control program and are currently the subject of much research and debate (1–4). Persistent pathogens pose an ongoing risk of transmission between patients (5), since admission to a room previously occupied by a patient with a multidrug resistant organism (MRO) is associated with increased risk of acquisition. Novel strategies to prevent HAIs are required.

New equipment aimed at reducing environmental contamination include the use of dilute hydrogen peroxide (DHP) technology. This technology utilises ambient air to produce hydrogen peroxide as a near-ideal gas, creating concentrations of peroxide that are well below human safety thresholds (6). It is an ozone-free process that produces 0.02 ppm of hydrogen peroxide gas from oxygen and water vapour in the air. The action of hydrogen peroxide requires direct contact with microorganisms without any specific protein or enzyme target.

DHP has demonstrated *in vitro* activity against a variety of bacteria, fungi and viruses, but there is limited work examining the effects of this technology in the healthcare environment. Recent studies have demonstrated the effectiveness of hydrogen peroxide against bacterial biofilms (7,8) as well as decontamination of equipment and rooms (9–12). Many of the published studies have used hydrogen peroxide vapour which is different to the continuous system being assessed in this study. Hydrogen peroxide vapour systems require logistical planning particularly if a patient room is to be decontaminated. Adequate sealing of doors and vents to prevent release of vapour is an important undertaking as hydrogen peroxide concentrations are higher compared with continuous DHP technology. This restricts the use of a room for a period of time and may affect patient and bed flow in a busy working environment. DHP can be used in a facility during routine healthcare in conjunction with established cleaning and decontamination practices.

The aim of this study was to undertake a feasibility study, exploring whether continuous use of DHP reduces microbiological contamination of clinical surfaces. Our hypothesis was that DHP would reduce the proportion of bed areas and high touch sites demonstrating high levels of microbial contamination in a critical care setting.

Methods

The study was designed as a prospective observational cross-over study based in a 10 bed critical care unit (containing both intensive and coronary care beds). The study site is a 160 bed rural hospital in New South Wales (NSW), Australia. The unit has used DHP (CIMR™ Tech) in the ventilation system for a number of years at a concentration of 0.02ppm hydrogen peroxide gas. A level of 1ppm has been assessed as being a permissible level of exposure according to the Occupational Safety and Health Administration and International Labour Organisation (13,14). Prior to commencement of the study, hydrogen peroxide was undetectable at a 0.1ppm level using the Dräger X-am® 5100 (Dräger) when the DHP unit was activated. The primary outcome measure assessed was total aerobic colony count (ACC)/cm^2 on selected high-touch surfaces in the critical care unit.

As the study examined the impact of an existing technology on the environment without patient level data, there was no requirement for ethical consideration. Institutional approval was given for the study.

Sampling

Sampling was undertaken by use of TTC Red Spot Medium (Oxoid) dipslides, which have a surface area of $10cm^2$. Cultures were taken from high-touch sites within five randomly chosen bed areas once per day for five consecutive days. Bed areas were defined as the space temporarily dedicated to an individual patient for that patient's stay in the unit (i.e. the patient zone). The patient zone accommodates the bed and chair, bedside table, medical devices and monitors (15). Eight sites were chosen for sampling in each patient zone and were selected based on previous studies (16) and frequently touched sites within the unit (**Table 1**).

Sampling of sites were performed by the same investigator who applied dipslides with gentle pressure ($25g/cm^2$) to the selected surface for 10 seconds without lateral movement (16,17). Dipslides were then sent via courier to the microbiology laboratory on the day of sampling.

Phases of testing

Phase 1 testing constituted sampling four weeks after the DHP had been turned off in order to establish baseline data. Phase 2 testing was performed after the DHP had been turned on for a period of four weeks. Timing of sampling was undertaken on average 21-23 hours after routine cleaning or 6 – 29 hours after a discharge clean. Sites were sampled within bed areas, regardless of whether a patient was present or not according to the randomisation strategy.

Phase 3 testing was performed following cessation of DHP for a period of four weeks prior to sampling. The study took place between July 2017 and October 2017.

Standard cleaning practices

Cleaning was performed by either domestic staff or occasionally by nursing staff when terminal/discharge cleaning was required. The daily cleaning regimen consisted of: neutral detergent wipes for general surfaces and a disinfectant (Viraclean™; major active ingredient alkyl dimethyl benzyl ammonium chloride) for patients in isolation. Patients with *Clostridium difficile* had bed spaces cleaned with Chlor-Clean™ (sodium dichloroisocyanurate). Floors were cleaned using microfibre mops and hard surface floor cleaner. All medical and most other equipment was decontaminated with Viraclean™ or large alcohol wipes between patient use and always upon discharge.

Clinical data

For each sampling phase background information was collected (**Table 2**). There were high bed occupancy rates for the first two phases and less for phase 3. There were no major differences between average staff and visitor numbers across the three study phases.

Temperature and humidity were averaged across the phases and recorded in the unit using a Fluke® 971 Temperature Humidity monitor on days of sampling were averaged across phases.

Microbiology Testing

Microbiology testing was performed at NSW Health Pathology Laboratory at John Hunter Hospital which is approximately 170km from the rural hospital site. No on-site microbiology laboratory was available at the rural hospital and all specimens were transported to the main testing laboratory on the day of collection. Dipslides were incubated at 30°C in aerobic conditions for 48 hours. Aerobic colony counts were performed manually to obtain quantitative counts (cfu/cm^2). Counts were classified as no growth; scanty growth (<2.5 cfu/cm^2), light growth (2.5 - 12 cfu/cm^2), moderate growth (12 - 40 cfu/cm^2), and heavy growth (>40 cfu/cm^2) (16,17). Hygiene failures were classed as counts of >2.5 cfu/cm^2 (16,17). Colonies were not identified.

Statistics

A sample size of 143 (collected during each of three sampling phases) was calculated with power at 80% to detect a difference with 95% confidence and with the following

assumptions: Firstly, the mean proportion of hygiene failure (all samples) during the control arm (no DHP) would be 22% (proportion with aerobic colony counts (ACC) >2.5 cfu/cm^2) (16), and secondly, that the mean proportion of hygiene failure (all samples) during the intervention arm (using DHP) would be 10% (proportion with ACC >2.5 CFU/cm^2). Computer generated randomisation was performed to select bed areas for sampling.

Proportions of sites positive for an organism for each phase of the study was analysed using ANOVA. Total ACC was analysed using regression analysis, taking into account patient demographic and clinical data collected. Significance levels of 5% were used for the pre-specified hypotheses and 95% confidence intervals for the estimated effects.

Results

Total aerobic colony counts were assessed according to our protocol's original hygiene failure threshold of >2.5 CFU/cm^2.

Phase 1 – Control phase

During the control phase, there were only 2.2% (95% CI 0.7-5.4%) failures detected (**Figure 1**). When the tap and toilet flush button sites were excluded from analysis a failure rate of 2.0% (95% CI 0.5-5.5%) was observed. It was decided to adjust the failure threshold to >1 cfu/cm^2 in order to better determine any significant differences between phases. The adjusted failure rate was 3.4% (95% CI 1.3-7.0%) using the new benchmark; and 2.7% (95% CI 0.9-6.4%) when tap and toilet sites were excluded (since they were not in the near patient area).

Phase 2 – Intervention

In the intervention phase with DHP, the observed failure rate was 7.7% (95% CI 4.3-13.0%) and 8.7% (95% CI 4.8-14.5%) with tap and toilets excluded using the 2.5 cfu/cm^2 threshold. The failure rates increased when the lower threshold was used (>1 cfu/cm^2) to 11.5% (95% CI 6.0-15.7%); this increased to 13.4% (95%CI 8.4-20.4%) with tap and toilet site excluded. It was noted that whichever failure threshold was utilised, the observed failure rates were higher than that of the control phase.

Phase 3 – Control phase

A repeat of the control phase with cessation of DHP demonstrated a failure rate of 6% (95% CI 3.2-10.4%); and 3.4% (95% CI 1.2-7.4%) with tap and toilet button excluded using the 2.5 cfu/cm^2 threshold. Failure rates increased with the >1 cfu/cm^2 threshold to 10.3% (95% CI

6.4-15.8%); and 8.1% (95% CI 4.3-14.2%) with the tap and toilet buttons excluded. Failure rates were lower compared with the intervention phase and higher when compared with phase 1.

The pre- and post-effect of DHP was analysed by pooling results for the two control phases (1 and 3) and comparing this to the intervention phase 2. Using a failure cut off of >2.5 cfu there was a 4.1% failure rate in the absence of DHP compared with a failure rate of 7.7% when DHP was used. This was obviously unexpected, given the hypothesis that presence of DHP would result in lower levels of contamination. Overall, there was a low level background rate of contamination so that implementation of DHP did not result in significant reduction in hygiene failures. However, this is difficult to assess given the already low failure rates at baseline.

Discussion

The results from our feasibility study did not demonstrate a statistically significant effect of DHP on reducing surface contamination within a critical care unit in a rural hospital.

There are a number of confounding factors that could have affected the baseline contamination rates of surfaces. Firstly, the study period occurred during winter and spring months, during which cases of severe influenza A infections were particularly prevalent. This could have altered cleaning practices and behaviour, as there would have been heightened infection control practices. Whilst formal episodes of cleaning by cleaning staff were documented, it was at the discretion of nursing staff to initiate cleaning of surfaces where appropriate. This was not a blinded study and therefore staff in the unit knew when the DHP would, and would not, have been in use. Furthermore, randomly selected bed spaces meant that some unoccupied bed spaces were sampled. While the proportions of occupied and unoccupied bed spaces remained similar throughout the study, there is a possibility that including unoccupied bed sites would have had an impact on total microbial soil recovered. The total number of bed areas sampled remained the same across all phases of the study.

Similar studies investigating the role of hydrogen peroxide in infection control have used a variety of techniques to sample surfaces. This has included pre-moistened swabs and dipslides. Our study used dipslides for sampling, which may have affected pick up rate of organisms on the surface. This was due to the relative rigidity of the dipslides, i.e. it was difficult to manoeuvre the slides on cylindrical surfaces such as a bed rail and IV poles. Furthermore, growth may have been affected by the residual effect of detergents and other

chemical cleaning agents present on sampled surfaces. Recommendations by the CDC suggest inactivation of common surface disinfectants when surface sampling is performed to mitigate the effect on microbial growth (18).

Rutala *et al* 2017 (19) employed a similar strategy of continuous DHP against multidrug resistant organisms (MDROs) on a pre-contaminated surface and found that there was no statistical difference between DHP intervention and control groups. This is similar to the findings reported here. One major difference however, is that the DHP was employed in a model room and hallway in front of the room(19). This would not account for the other factors such as occupancy rate and staff numbers in the unit at any given time which may have affected the efficacy of the hydrogen peroxide. The authors concluded that they were unable to generate a sufficient germicidal level with the particular DHP units employed.

A limitation of our study was that we did not have equipment that could measure the extremely low hydrogen peroxide concentrations delivered by the system. Further studies should factor in regular actual readings throughout testing to demonstrate hydrogen peroxide exposure by the continuous DHP system. Despite negligible levels of hydrogen peroxide detected, this would not account for the low levels of hygiene failures in the study, as the opposite would have been expected. To account for confounders the notion of using pre-contaminated surfaces or coupons with microorganisms would have been useful; however, given the ethical considerations of introducing potential pathogens into a unit with critical care patients this was not a feasible approach. Another limitation of our study surrounds the broader issue of microbial sampling of the environment.

As other studies have demonstrated, hydrogen peroxide has a role in decontamination of equipment and surfaces and has been employed in our healthcare institution for room decontamination. Further work is needed to determine whether continuous DHP technology has a role in infection control within a healthcare setting, as the results from our small study showed no significant change to surface contamination.

Authorship statement

BM, SJD, JKF and ER designed the study. ER performed the sampling and data collection on site. AO performed the microbiology testing, data collection and drafted the manuscript. All authors helped analyse the data and commented and contributed to the manuscript.

Conflict of interest

Three of the authors have an editorial affiliation with Infection, Disease & Health. They played no role whatsoever in editorial handling or decision making regarding this paper. There are no other conflicts to declare.

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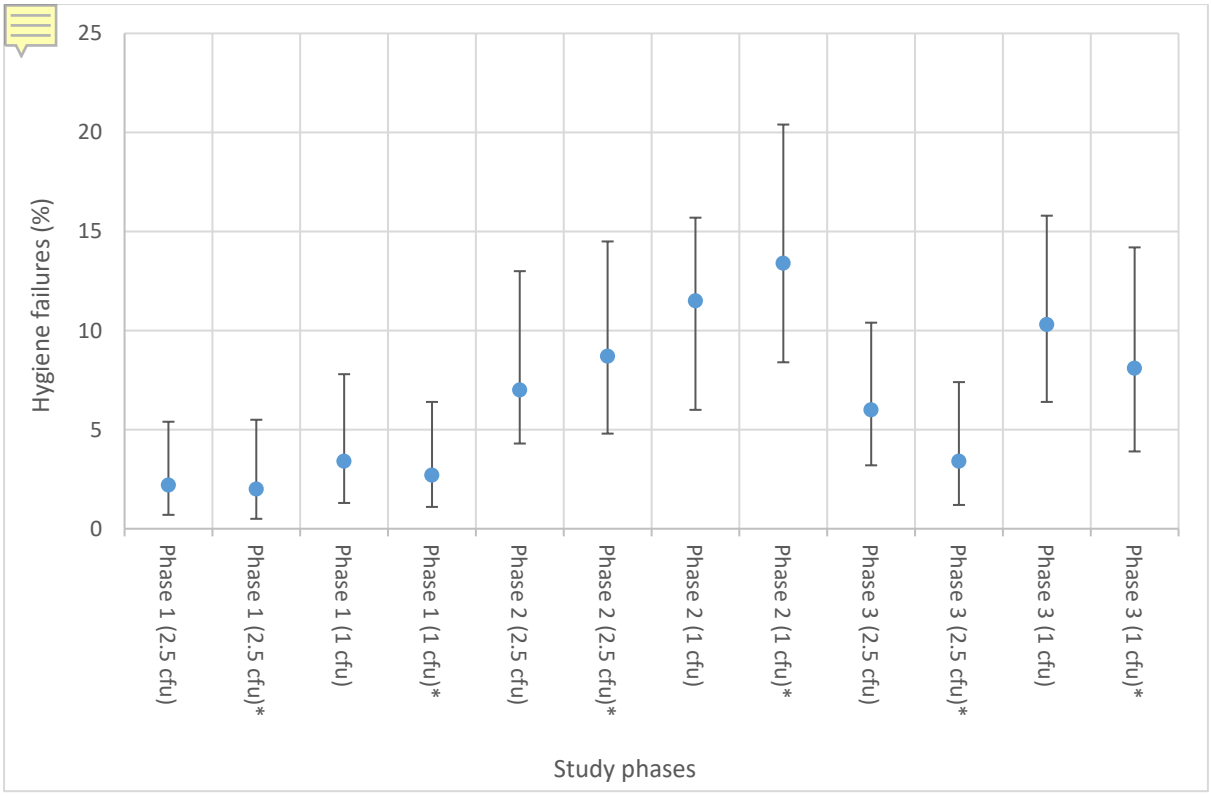
Table 1: Sampling sites selected

Sampling sites			
1.	Bed rail (right)	5.	Hand basin tap handle
2.	Bed rail (left)	6.	IV pole
3.	Over bed table	7.	Monitor button
4.	Bed end/notes Table	8.	Shared bathroom toilet Flush button

Table 2. Background data

Clinical information collected	Phase 1	Phase 2	Phase 3
% bed occupancy rate	96%	94%	74%
Number of staff and visitors present in unit at time of sampling	9.6	8.0	8.2
Temperature (°C) and humidity (%)	20.5°C/40.6%	21.0°C/38.9%	22.0°C/57.1%

Information regarding time cleaning was completed and products used were collected but the data did not allow for accurate calculation of time since cleaning occurred to when the bed area was sampled.



		FAILURE = >2.5 cfu/cm²					**FAILURE = >1 cfu/cm²**			
		All		Excluding tap and toilet buttons			All		Excluding tap and toilet buttons	
		% Fails	95%CI	% Fails	95%CI		% Fails	95%CI	% Fails	95%CI
Phase 1	no H_2O_2	2.2%	.7-5.4%	2.0%	.5-5.5%		3.4%	1.3-7.0%	2.7%	.9-6.4%
Phase 2	H_2O_2	7.7%	4.3-13.0%	8.7%	4.8-14.5		11.5%	6.0-15.7%	13.4%	8.4-20.4
Phase 3	no H_2O_2	6.0%	3.2-10.4%	3.4%	1.2-7.4		10.3%	6.4-15.8%	8.1%	4.3-14.2

*Sampling of hand basin taps and shared bathroom toilet flush buttons were excluded from data analysis to compare range of hygiene failures

Figure 1 – Hygiene failures detected during the study phases .

The points on the graph represent the percentage hygiene failure with the calculated 95% confidence interval across all phases of the study.