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ORIGINAL ARTICLE

A Head-to-Head Comparison of Hydrogen Peroxide Vapor and Aerosol Room Decontamination Systems

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OBJECTIVE. New technologies have emerged in recent years for the disinfection of hospital rooms and equipment that may not be disinfected adequately using conventional methods. There are several hydrogen peroxide–based area decontamination technologies on the market, but no head-to-head studies have been performed.

DESIGN. We conducted a head-to-head in vitro comparison of a hydrogen peroxide vapor (HPV) system (Bioquell) and an aerosolized hydrogen peroxide (aHP) system (Sterinis).

SETTING. The tests were conducted in a purpose-built 136-m^3 test room.

METHODS. One HPV generator and 2 aHP machines were used, following recommendations of the manufacturers. Three repeated tests were performed for each system. The microbiological efficacy of the 2 systems was tested using 6-log Tyvek-pouched *Geobacillus stearothermophilus* biological indicators (BIs). The indicators were placed at 20 locations in the first test and 14 locations in the subsequent 2 tests for each system.

RESULTS. All BIs were inactivated for the 3 HPV tests, compared with only 10% in the first aHP test and 79% in the other 2 aHP tests. The peak hydrogen peroxide concentration was 338 ppm for HPV and 160 ppm for aHP. The total cycle time (including aeration) was 3 and 3.5 hours for the 3 HPV tests and the 3 aHP tests, respectively. Monitoring around the perimeter of the enclosure with a handheld sensor during tests of both systems did not identify leakage.

CONCLUSION. One HPV generator was more effective than 2 aHP machines for the inactivation of *G. stearothermophilus* BIs, and cycle times were faster for the HPV system.

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A recent editorial called for head-to-head studies comparing hydrogen peroxide vapor (HPV) and aerosolized hydrogen peroxide (aHP) systems, and, to date, none has been published.[1] Therefore, we conducted a study to investigate and compare the efficacy of an HPV system and an aHP system in terms of their ability to inactivate *Geobacillus stearothermophilus* biological indicator (BI) spores distributed around a large single- or dual-occupancy patient room to reflect our intended use.

In Skåne University Hospital (SUS) Malmö, a new infectious disease facility has been built. The facility has 50 standard isolation rooms. These rooms are larger than most single-occupancy hospital rooms and could be used as small double rooms if necessary. In this setting, we are interested in modernizing our hygiene routines and trying new equipment. During the construction phase for our new facility, we built a full-scale mock-up of an isolation room. In this mock-up, new materials and decontamination methods could be tested.

There is now good evidence that contaminated surfaces make a significant contribution to the transmission of nosocomial pathogens, including *Clostridium difficile*, methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant enterococci (VRE), and *Acinetobacter baumannii*.[2,3] Surfaces in patient areas have frequently been found to be contaminated after conventional cleaning,[4,5] and, linked to these findings, patients admitted to rooms previously occupied by patients positive for VRE, MRSA, *A. baumannii*, and *Pseudomonas aeruginosa* are at increased risk of acquiring these pathogens.[6,7] Given these findings, several area decontamination methods have emerged.[4,8,9] These methods do not rely on the operator to distribute the active substance; thereby, they can achieve coverage of all surfaces in a room and are likely to be more repeatable than conventional methods.

There are 2 commonly used hydrogen peroxide–based methods on the market, the Bioquell HPV system and the Sterinis aHP system.[1,10] These systems have important differences that have been outlined in recent correspon-

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TABLE 1. Biological Indicator (BI) Location and the Number of BIs Inactivated by the Hydrogen Peroxide Vapor (HPV) and Aerosolized Hydrogen Peroxide (aHP) Systems

	HPV			aHP		
Test no.	1	2	3	1	2	3
Main room, top right, near corner	−	−	−	+	−	−
Main room, bottom right, far corner	−	−	−	+	−	+
Main room, top left, far corner	−	−	−	+	−	−
Main room, bottom left, near corner	−	−	−	+	−	−
"In" air lock, top left, near corner	−	−	−	+	+	−
"In" air lock, bottom left, far corner	−	ND	ND	+	ND	ND
"In" air lock, top right, far corner	−	ND	ND	+	ND	ND
"In" air lock, bottom right, near corner	−	ND	ND	+	ND	ND
"In" air lock, bottom right, far corner	ND	−	−	ND	−	−
Bathroom, top left, near corner	−	ND	ND	+	ND	ND
Bathroom, bottom left, far corner	−	ND	ND	+	ND	ND
Bathroom, top right, far corner	−	ND	ND	+	ND	ND
Bathroom, top left, far corner	ND	−	−	ND	+	−
Bathroom, bottom right, near corner	−	−	−	−	−	−
"Out" air lock, top left, near corner	−	ND	ND	+	ND	ND
"Out" air lock, bottom left, far corner	−	ND	ND	+	ND	ND
"Out" air lock, bottom left, near corner	ND	−	−	ND	−	−
"Out" air lock, top right, far corner	−	−	−	+	+	+
"Out" air lock, bottom right, near corner	−	ND	ND	+	ND	ND
"Out" air lock, inside cupboard	−	−	−	+	−	−
Main room, inside cupboard	−	−	−	+	−	−
Back of drawer, open 10 cm	−	−	−	−	−	−
Bathroom, underneath washer/disinfector	−	−	−	+	−	+
Total positive	0	0	0	18	3	3
No. of BIs	20	14	14	20	14	14
% Positive	0	0	0	90	21	21
Control 1	+	+	+	+	+	+
Control 2	+	+	+	+	+	+
Control 3	+	+	+	+	+	+

NOTE. ND, not done.

dence.[10-12] The HPV system generates HPV by adding 35% liquid hydrogen peroxide to a vaporizer heated to 130°C. This produces a vapor, which is distributed in the gas phase until it begins to condense on surfaces in the room.[4,12] After the exposure, an active aeration unit catalyzes the breakdown of HPV to oxygen and water vapor. The HPV achieves a 6-log reduction on bacterial endospores, including *C. difficile*; common hospital bacteria such as MRSA, VRE, and *A. baumannii*; and viruses.[13,14] Surface sampling after HPV shows that it usually eradicates contamination with *C. difficile* and other hospital pathogens.[12,15] Several studies have linked the use of HPV with the control of outbreaks,[16,17] and the use of HPV has been shown to reduce the incidence of *C. difficile* infection.[12]

The aHP system uses pressure to produce an aerosol with a particle size of approximately 8–10 μm from a mixture of 5% hydrogen peroxide, less than 50 ppm silver cations, and less than 50 ppm orthophosphoric acid. After the exposure period, the aerosol is left to decompose passively. The aHP system results in a 4-log reduction of *C. difficile* spores and incomplete inactivation in situ.[8,18] The efficacy of the aHP system against common hospital bacteria such as MRSA and *A. baumannii* has to be fully established. The efficacy against *Mycobacterium tuberculosis* is uncertain.[19,20] The Sterinis system has recently been relaunched as the ASP Glosair system.

METHODS

Description of the Test Facility

The tests were conducted in a 136-m^3 test room in Malmö, Sweden. The area was split into 4 rooms: 2 air locks, a main room, and a bathroom. The area had a dedicated air-handling system that extracted to the outside of the building.

Biological Indicators

The microbiological efficacy of the 2 systems was tested using 6-log Tyvek-pouched *G. stearothermophilus* BIs (Apex Laboratories). The BIs were placed at 20 locations in the first

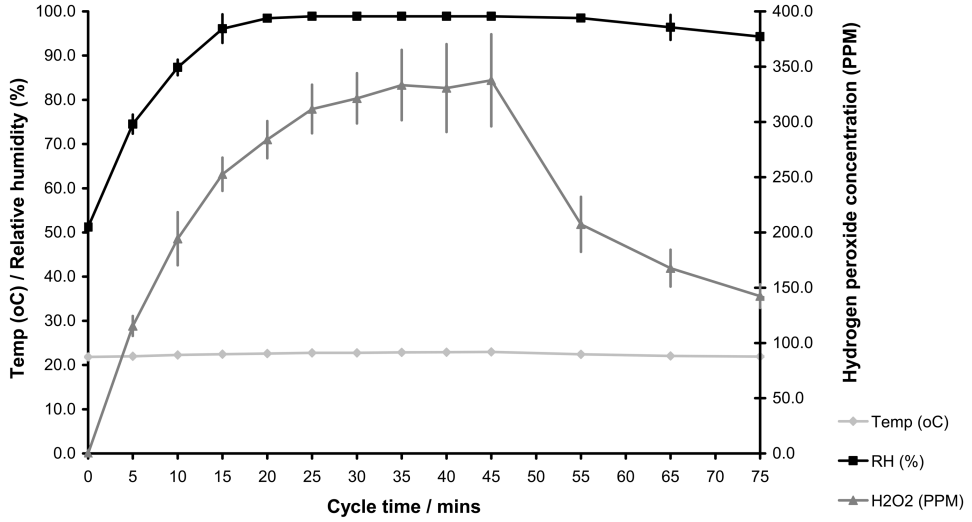

FIGURE 1. Cycle data from 3 hydrogen peroxide vapor cycles. Aggregate data from 3 repeat cycles; error bars represent ±1 SD.

test and 14 locations in the subsequent 2 tests for each system. BIs were located in the main room, the bathroom, the air locks in opposing high and low corner locations, and several challenging locations, such as inside cupboards and drawers, to test the distribution of the systems (see Table 1 for specific BI locations). After exposure to either HPV or aHP, the BIs were transferred into tryptone soya broth, incubated, and read according to the manufacturer's instructions.

Decontamination Equipment and Configuration

Two aHP machines were used, following recommendations of the manufacturer (Sterinis). The 2 generators were placed in the center of the main room, and external doors were sealed using adhesive tape. The concentration of hydrogen peroxide was measured by a Draegar sensor (Polytron 7000) inside the enclosure. For each of the 3 tests, 3 back-to-back injections of 6 mL/m^3 hydrogen peroxide were performed. Aeration was assisted using the air-handling system. The test was considered ended when the readings on the handheld sensor were less than or equal to 1 ppm in the air lock and less than or equal to 2 ppm at any point in the room. (The Health and Safety limit for hydrogen peroxide exposure in Sweden is 1 ppm for a working day or 2 ppm for 15-minute period.)[21]

One Bioquell Q10 suite was used, following recommendations of the manufacturer. The HPV generator (Q10) was placed in the center of the main room, the R10 (aeration unit) was placed in the doorway of the main room air lock, oscillating pedestal fans were placed in the doorway of the bathroom and the other air lock, and the control pedestal was placed outside the door of the main room. External doors were sealed using adhesive tape, and the handheld sensor was used to monitor for leakage periodically. The concentrations of hydrogen peroxide, temperature, and relative humidity in the room were monitored by the Q10, and readings were recorded every 5 minutes during the injection phases and regularly during aeration (the removal of HPV). For the 3 tests, 900 mL of hydrogen peroxide was injected, with 30 minutes dwell, which equates to approximately 6.6 g/m^3. Aeration was assisted using the air-handling system. The test was considered ended when the readings on the handheld sensor were less than or equal to 1 ppm in the air lock and less than or equal to 2 ppm at any point in the room.

RESULTS

Data from the HPV cycles are presented in Figure 1. The increase and plateau in relative humidity and HPV concentration are consistent with the saturation of the air with hydrogen peroxide and subsequent condensation onto surfaces.[22] The peak hydrogen peroxide concentration was 338 ppm. The total cycle time (including aeration) for the 3 HPV tests was 3 hours. All BIs were inactivated in each of the 3 tests (Table 1).

The hydrogen peroxide concentration from the aHP tests is presented in Figure 2. The tests were performed sequentially on the same day, and it appears that there was an accumulation of hydrogen peroxide in the enclosure because the peak hydrogen peroxide concentration increased from less than 100 ppm in the first test to approximately 130 ppm in the second test and to greater than 150 ppm in the third test. Ten percent of BIs were inactivated in the first test, compared with 79% in the second and third tests (Table 1). Total cycle times were approximately 3.5 hours.

Monitoring around the perimeter of the enclosure with a handheld sensor during tests did not identify leakage for either system.

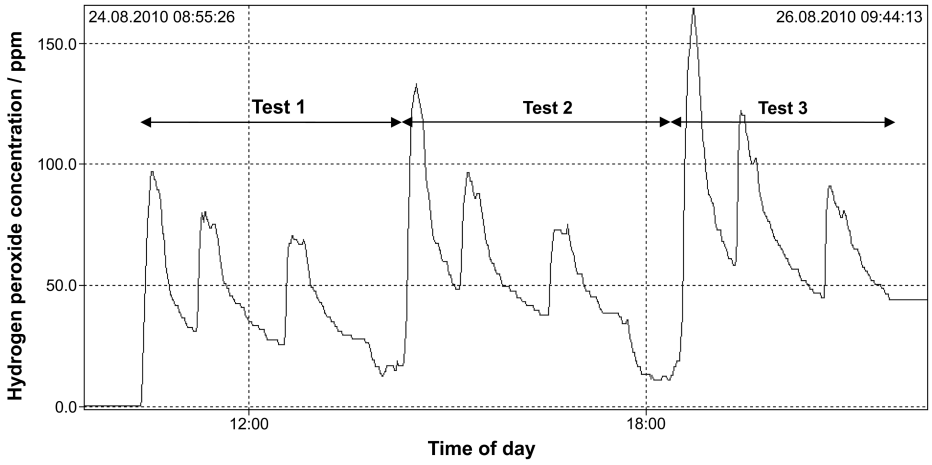

FIGURE 2. Hydrogen peroxide concentration from the 3 aerosolized hydrogen peroxide tests.

DISCUSSION

Hydrogen peroxide is a potent disinfectant and sterilant that penetrates the bacterial cell wall by passive diffusion and then acts by denaturing proteins, DNA, and other components inside the bacterial cell.[23] It is not harmful to the environment because it breaks down to water and oxygen, leaving no toxic by-products. We consider hydrogen peroxide decontamination an important method in terminal disinfection of rooms previously occupied by patients positive for MRSA, VRE, *Acinetobacter* spp., *C. difficile*, or other problem bacteria.

We tested 2 different types of hydrogen peroxide–based whole-room decontamination systems. The main difference between the 2 technologies is the formation of the HPV or aerosol. HPV creates a vapor in gaseous form from 35% w/w hydrogen peroxide, whereas aHP creates an aerosol from 5% hydrogen peroxide, with drops of 8–10 μm. The aHP aerosol is stabilized using silver ions and other chemicals to avoid aggregation before the drops reach the target. Other differences between the 2 systems are the peak hydrogen peroxide concentration, which is twice as high in HPV as in aHP, and the total hydrogen peroxide concentration (measured as area under the curve), which is higher for HPV.

Bacterial endospore BIs are typically used to monitor the effectiveness of sterilization and high-level disinfection procedures, such as autoclaves and vapor-phase decontamination methods.[24] In our study, the HPV system inactivated BIs at all locations in each of the 3 tests, suggesting a homogenous and repeatable distribution. BIs are used routinely to monitor HPV decontamination systems.[4,12,22]

Several studies have used BIs to monitor aHP systems. After 3 back-to-back cycles, 13% of 146 BIs grew in hospital rooms in 1 study, although 3 cycles inactivated all BIs in separate experiments in 22 rooms in a surgery department and inside ambulances.[25] In this study, 1 or 2 cycles had little impact on the BIs. Therefore, we chose to use 3 back-to-back cycles for each test of the aHP machine. However, even after 3 back-to-back cycles were used, the aHP system inactivated only 10% of BIs on the first test and 79% of BIs on the subsequent tests. According to the manufacturer, the failure in decontamination in the first aHP test was probably a result of miscalculation of air humidity, which should be done automatically by the system. This was corrected by the machine for the following tests. Even with optimal function, the aHP system failed to inactivate 3 of 14 BIs in the second and third tests. The BIs that grew were not always in the same location, suggesting that the distribution was not consistent between tests.

One conclusion of our study can be that a higher hydrogen peroxide concentration during a longer time is superior for achieving disinfection.

One HPV generator was used, but 2 aHP machines were used. Despite this, the HPV system was more effective for the inactivation of BIs and produced a shorter total cycle time (3 vs 3.5 hours). Turnaround time is a crucial component of vapor-phase disinfection technologies. Several recent studies have used a single cycle rather than the 3 back-to-back cycles that we used for the aHP system.[8,18] The use of 1 cycle for the aHP system would have reduced the total cycle time but would have further reduced the microbiological impact of the system; on the basis of the results from Andersen et al,[25] it is unlikely that any BIs could have been inactivated using fewer than 3 cycles.

The peak concentration of HPV (338 ppm) and other cycle parameters such as changes in relative humidity during the HPV cycles are consistent with the findings of others.[4,22] However, the concentration of hydrogen peroxide identified in the aHP tests was higher than that in other studies. For example, 1 study recorded hydrogen peroxide concentration peaks of 2–60 ppm[23] and another 43–114 ppm,[19] compared with greater than 150 ppm in our study. Given the higher concentration of liquid hydrogen peroxide used in the HPV system (35% vs 5%), the higher concentration of hydrogen per-

oxide measured in the air when using the HPV system is not surprising. Hydrogen peroxide sensors differ in their performance,[26] and since 2 different types of sensor were used, it is not possible to compare these values accurately and directly.

The aim of this study was not to measure whether there was any corrosive activity attributable to either of the systems. There are no reports on this important question in the literature. It is possible that the residues of silver ions left after the aHP cycle are problematic in the environment because silver exposure is known to trigger resistance in bacteria.[27]

Since hydrogen peroxide reaches levels that would be toxic for patients and staff during decontamination with both the HPV and aHP systems, ventilation and doors have to be sealed during treatment. It is also important that the process is monitored and handled by specially trained and experienced staff. In hospitals with a high prevalence of these bacteria, it might be rational for departments to own their equipment, to train dedicated persons of their staff, and to run disinfection cycles on a regular basis. In low-prevalence hospitals, it might be more rational to hire the equipment only for outbreak situations.

Our study has showed that 1 HPV system was more effective than 2 aHP systems for the inactivation of *G. stearothermophilus* BIs and that cycles were faster for the HPV system. Since the data suggesting a clinical impact relate to the HPV system and not to the aHP system, the aHP system lacks published in vitro efficacy against key nosocomial bacteria (especially the catalase-positive bacteria[13]), and on the basis of the results of our study, the HPV system was superior in our setting.

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Potential conflicts of interest. All authors report no conflicts of interest relevant to this article.

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