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Effectiveness of ultraviolet devices and hydrogen peroxide systems for terminal room decontamination: Focus on clinical trials

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Over the last decade, substantial scientific evidence has accumulated that indicates contamination of environmental surfaces in hospital rooms plays an important role in the transmission of key health care–associated pathogens (eg, methicillin-resistant Staphylococcus aureus, vancomycin-resistant enterococci, Clostridium difficile, Acinetobacter spp). For example, a patient admitted to a room previously occupied by a patient colonized or infected with one of these pathogens has a higher risk for acquiring one of these pathogens than a patient admitted to a room whose previous occupant was not colonized or infected. This risk is not surprising because multiple studies have demonstrated that surfaces in hospital rooms are poorly cleaned during terminal cleaning. To reduce surface contamination after terminal cleaning, no-touch methods of room disinfection have been developed. This article will review the no-touch methods, ultraviolet light devices, and hydrogen peroxide systems, with a focus on clinical trials which have used patient colonization or infection as an outcome.

Multiple studies have demonstrated that ultraviolet light devices and hydrogen peroxide systems have been shown to inactivate microbes experimentally plated on carrier materials and placed in hospital rooms and to decontaminate surfaces in hospital rooms naturally contaminated with multidrug-resistant pathogens. A growing number of clinical studies have demonstrated that ultraviolet devices and hydrogen peroxide systems when used for terminal disinfection can reduce colonization or health care–associated infections in patients admitted to these hospital rooms.

Health care–associated infections (HAIs) remain an important source of patient morbidity and mortality. Based on a large sample of U.S. acute care hospitals, approximately 4% of patients on any given day have at least 1 HAI. Overall, there were an estimated 722,000 HAIs in U.S. acute care hospitals in 2011; approximately 75,000 hospital patients with an HAI died during their hospitalization. It has been estimated that the source of pathogens causing an HAI in the intensive care unit was the patients’ endogenous flora (40%-60%); cross-infection via the hands of health care personnel (HCP; 20%-40%); antibiotic-driven changes in flora (20%-25%); and other (including contamination of the environment; 20%). Further, contamination of the hands of HCP could result directly from patient contact or indirectly from touching contaminated environmental surfaces. It has been shown that the gloves or hands of HCP are just as likely to become contaminated from touching a patient as touching an environmental surface in a patient’s room.

Over the last decade, substantial scientific evidence has accumulated that contamination of environmental surfaces in hospital rooms plays an important role in the transmission of several key health care–associated pathogens, including methicillin-resistant Staphylococcus aureus (MRSA), vancomycin-resistant enterococci (VRE), Clostridium difficile, Acinetobacter spp, and norovirus. In general, all of these pathogens share the following characteristics:

- They are typically acquired by patients without pre-existing immunity.
- They are more likely to be transmitted in nosocomial than in community settings.
- They are transmitted from patient to patient via the hands of health care personnel (HCP), environmental surfaces, and/or medical equipment.
- They are associated with an increased risk of morbidity and mortality.

Research has shown that the hands of HCP are the most common source of patient contamination with multidrug-resistant pathogens including Methicillin-resistant Staphylococcus aureus (MRSA), vancomycin-resistant enterococci (VRE), Acinetobacter baumannii, and Pseudomonas aeruginosa. Thus, reducing the contamination of HCP’s hands is a critical component of an effective infection control program.
ability to survive for prolonged periods of time on environmental surfaces, ability to remain virulent after environmental exposure, frequent contamination of the hospital environment, ability to colonize patients, ability to transiently colonize the hands of HCP, and transmission via the contaminated hands of HCP. Norovirus and C difficile also are noted for a small inoculating dose and relative resistance to antiseptics and disinfectants used on environmental surfaces. Evidence supporting the role of the contaminated surface environment in the transmission of several key health care–associated pathogens is summarized as follows:

- The surface environment in rooms of colonized or infected patients is frequently contaminated with the pathogen.
- The pathogen is capable of surviving on hospital room surfaces and medical equipment for a prolonged period of time.
- Contact with hospital room surfaces or medical equipment by HCP frequently leads to contamination of hands or gloves.
- The frequency with which room surfaces are contaminated correlates with the frequency of hand or glove contamination of HCP.
- The patient admitted to a room previously occupied by a patient colonized or infected with a pathogen (eg, MRSA, VRE, C difficile, Acinetobacter spp) has an increased likelihood of developing colonization or infection with that pathogen.
- Improved terminal disinfection of rooms leads to a decreased rate of individual patient colonization and infection.
- Improved terminal cleaning of rooms leads to a decreased facility-wide rate of colonization and infection.
- Improved terminal disinfection with a no touch method leads to a decreased rate of infection in patients subsequently admitted to a room where the prior occupant was colonized or infected.
- Improved terminal disinfection with a no touch method leads to a decreased rate of facility-wide colonization and infection.

This article will review no touch methods for terminal room disinfection, specifically ultraviolet (UV) light devices or hydrogen peroxide systems, with a focus on studies that have assessed whether use of these technologies has been demonstrated to reduce HAIs.

RATIONAL FOR USING A NO TOUCH METHOD FOR TERMINAL ROOM DISINFECTION

Multiple studies have demonstrated that surfaces in hospital rooms are poorly cleaned during terminal cleaning. Although methods of assessing the adequacy of cleaning varied (ie, visibly clean, adenosine triphosphate bioluminescence, fluorescent dye, aerobic plate counts), several studies have demonstrated that <50% of room surfaces were properly cleaned. Several reviews have concluded that improved cleaning leads to reductions in HAI. However, there is a paucity of high-quality studies demonstrating that improved cleaning and disinfection reduces HAIs. Importantly, the studies that have assessed interventions to improve cleaning have reported that after the intervention, approximately 5%-30% of surfaces remain potentially contaminated. Because of the demonstrated failure of interventions to achieve consistent and high rates of cleaning and disinfection of room surfaces, new no touch methods of room disinfection have been developed. The most promising no touch methods use either UV light devices or hydrogen peroxide systems.

UV LIGHT DEVICES FOR TERMINAL ROOM DECONTAMINATION

Background

UV irradiation has been used for control of pathogenic microorganisms in a variety of applications, such as control of legionellosis, and disinfection of air, surfaces, and instruments. At certain wavelengths, UV light will break the molecular bonds in DNA, thereby destroying the organism. Most UV room disinfection devices use UV-C irradiation which has a characteristic wavelength of 200-270 nm (eg, 254 nm) that lies in the germicidal active portion of the electromagnetic spectrum of 200-320 nm. Another UV device uses pulsed-xenon radiation, which produces UV light in the 200- to 320-nm range.

The efficacy of UV irradiation devices used for hospital room disinfection is a function of many parameters, including organic load, pathogen, intensity, dose, distance from the device, exposure time, direct line of sight from device or shaded exposure, lamp placement, room size and shape, and surface. Few studies have systematically investigated how these parameters affect the effectiveness of UV irradiation. Nerlandzic et al studied 2 UV room disinfection devices (Tru-D [Tru-D SmartUVC, Memphis, TN] and PATHOGRON® [STERIS, Mentor, OH]) and reported the following: (1) pathogen concentration did not significantly impact the killing efficiency of the devices; (2) both a heavy and light organic load had a significant negative impact on the killing efficacy of the devices; and (3) increasing the distance to ~3.05 m from the devices reduced the killing efficacy to ≤3 log10 colony forming units/cm2 for MRSA and VRE and <2 log10 colony forming units/cm2 for C difficile spores.

Cadnum et al studied how various parameters affected the effectiveness of a UV-C device (Optimum–UV™, Clorox, Oakland, CA) and reported the following: (1) spreading the inoculum over a greater surface area significantly enhanced killing of MRSA and C difficile; (2) orientation of the carrier disks in parallel rather than perpendicular with the UV-C enhanced killing; (3) presence of an organic load also impacted the measured efficacy of UV-C under certain test conditions; (4) use of plastic, formica, and glass slides resulted in similar killing when compared with steel carrier disks, provided manual spreading was used; and (5) heights from floor level to 6 ft did not affect killing at 1.83 m using Optimum.

UV device effectiveness to reduce intentionally contaminated sites

Multiple studies have assessed the effectiveness of UV devices to inactivate microbes inoculated onto various test surfaces which are then placed in a typical hospital room (Table 1). In general, the inoculating doses were <4 log10 in order to fully assess the level of bacterial inactivation. The most commonly tested organisms were epidemiologic important health care–associated pathogens and included MRSA, VRE, C difficile, and Acinetobacter spp.

One can conclude from the following results: (1) >3 log10 vegetative organisms can be killed in 5–25 minutes by UV-C; (2) it requires greater time and energy to kill a spore-forming organism, such as C difficile; (3) the level of inactivation of pulsed xenon may be less than for UV-C; however, this is based on a limited number of published results; and (4) the level of inactivation on surfaces in direct line of sight of the UV device may be up to 2 log10 greater than for C difficile not in the direct line of sight. There appears to be substantial consistency across many studies regarding the effectiveness of UV-C; however, most studies have used the same device (ie, Tru-D), and only a few of the UV devices commercially available have actually been studied. The time needed to inactivate pathogens has been demonstrated to be shortened by use of UV reflective wall paint for multiple different UV-C devices.

UV device effectiveness to reduce actual contaminated sites

Multiple studies have assessed the effectiveness of UV devices to decontaminate actual hospital rooms after discharge of a patient colonized or infected with a multidrug-resistant pathogen (Table 2). Pathogens evaluated included MRSA, VRE, Acinetobacter spp, and C difficile. Cycle times for vegetative
bacteria ranged from 10-25 minutes, and for \textit{C difficile} cycle times ranged from 10-45 minutes. In all cases the frequency of positive surface sites post-treatment was <1%, and in many cases it was <1%. The reported log_{10} reductions were always <2.

It is important to understand that the bioburden on contaminated surfaces in hospital rooms is relatively low; therefore, the reduction in frequency of positive surface sites is a better measure of UV effectiveness than the log_{10} reduction.

### HYDROGEN PEROXIDE SYSTEMS FOR TERMINAL ROOM DECONTAINTMENT

#### Background

Hydrogen peroxide is an oxidizing agent which produces highly reactive hydroxyl radicals that attack DNA, membrane lipids, and other essential cell components.38 Two major types of hydrogen peroxide room disinfection systems are generally available: aerosolized hydrogen peroxide (aHP) systems (eg, GLOSIR; Advanced Sterilization Products, Irvine, CA, previously Sterinis; BioGenie; Steris, Mentor, OH; Nocospray; Oxyl'pharm, Champigny-sur-Marne, France) and \textit{H}_{2}O_{2} vapor systems (eg, Bioquell, Andover, Hampshire, UK; VHP Biodecontamination Systems; Steris, Mentor, OH). \textit{H}_{2}O_{2} room disinfection systems have been reviewed.39-40 The \textit{H}_{2}O_{2} vapor systems use 30%-35% \textit{H}_{2}O_{2}. The Steris VHP system requires approximately 8 hours for disinfection, whereas the Bioquell hydrogen peroxide vapor (HPV) system requires 15-2.5 hours. The aHP systems combine 5%-7% \textit{H}_{2}O_{2} with <50 ppm Ag cations. Process time is 2-3 hours.

### Hydrogen peroxide systems effectiveness to inactive microbes

Only limited data are available on the activity of aHP systems based on laboratory studies or evaluation of experimentally contaminated carriers assessed in hospital rooms. An aHP system (Sterinis) was able to kill >4 log_{10} \textit{MRSA} and \textit{Acinetobacter} \textit{bacillus} using a carrier test in a hospital room.41 Another study reported a 1.0-1.7 log_{10} reduction of experimentally contaminated surfaces with \textit{VRE} in a hospital room.42 No significant decontamination of \textit{Mycobacterium tuberculosis} was observed when the aHP system (Sterinis) was used to decontaminate a test surface contaminated with air-dried \textit{M tuberculosis}.43 When used in an operating department, 3 cycles of \textit{H}_{2}O_{2} aerosol (Sterinis) were required to kill \textit{Bacillus atropaheus} spore strips (4-5 hours); 2 cycles were ineffective.44 The effectiveness of \textit{H}_{2}O_{2} vapor systems has been well studied. For example, a hydrogen peroxide device (Bioquell) was tested for its microbiologic efficacy in a purpose-built room where nosocomial pathogens had been inoculated onto disks and allowed to dry over varying amounts of time. All pathogens were inactivated within 90 minutes of exposure to \textit{HPV}.45 Similarly, the same system was evaluated in an operating room using experimentally contaminated carriers; the device inactivated all spore biologic indicators (\textit{Geobacillus} \textit{stearothermophilus}; >6 log_{10} reduction), and no \textit{MRSA}, \textit{VRE}, or multidrug-resistant \textit{A baumannii} were recovered from stainless steel and cotton carriers (>4 log_{10} reduction, depending on the starting inoculum).46 Multiple studies have demonstrated excellent sporidical activity, and the system has been shown to inactivate a number of important viruses, including feline calicivirus (surrogate for human norovirus), human adenovirus type 1, severe acute respiratory syndrome coronavirus, and several viruses of veterinary importance.47 Inactivation (>3 log_{10}) of a nonenveloped virus (MS2) occurred within 30 minutes.48 In the presence of large protein loads, inactivation is slower.48

### Table 1

Effectiveness of UV devices on reducing MDROs on carriers

| Author, year | UV system | MDROs | Time (min) | Energy (μW/cm²) | Log_{10} reduction direct (indirect) |
|--------------|-----------|-------|------------|----------------|--------------------------------------|
| Rutala, 201042 | UV-C, Tru-D | MRSA, VRE, A | <15 | 12,000 | 4.31 (3.85), 3.90 (3.25), 4.21 (3.79) |
| Rutala, 201042 | UV-C, Tru-D | Cd | <50 | 36,000 | 4.04 (2.43) |
| Boyce, 201128 | UV-C, Tru-D | Cd | 67.8 (1 stage) | 22,000 | 1.7-2.9 |
| Havill, 201229 | UV-C, Tru-D | Cd | 73 (mean) | 22,000 | 2.2 |
| Rutala, 201330 | UV-C, Tru-D | MRSA | 25 | 12,000 | 4.71 (4.27) |
| Rutala, 201330 | UV-C, Tru-D | Cd | 43 | 22,000 | 3.41 (2.01) |
| Mahida, 201331 | UV-C, Tru-D | OR: MRSA, VRE | 49 | 12,000 | >4.0 (>4.0), 3.5 (2.4) |
| Mahida, 201331 | UV-C, Tru-D | Single patient room: VRE, A, As | 23-93 | 12,000 | >4.0 (2.3), >4.0 (1.7), >4.0 (2.0) |
| Rutala, 201444 | UV-C, Optimum | MRSA | 5 | NS | 4.10 (2.74) |
| Rutala, 201444 | UV-C, Optimum | Cd | 10 | NS | 3.35 (1.80) |
| Nerandzic, 201544 | UV, PX, Xenex | Cd, MRSA, VRE | 10 at 4 ft (2 cycles) | NS | 0.55, 1.85, 0.6 |

A. \textit{Acinetobacter} spp, \textit{Aspergillus}; \textit{Cd}, \textit{Clostridium difficile}; \textit{MDRO}, multidrug-resistant organism; \textit{MRSA}, methicillin-resistant \textit{Staphylococcus aureus}; \textit{NS}, not stated; \textit{OR}, operating room; \textit{PX}, pulsed xenon; \textit{UV}, ultraviolet light; \textit{VRE}, vancomycin-resistant enterococci.

### Table 2

Effectiveness of UV devices on reducing MDROs in contaminated patient rooms

| Author, year | UV system | MDROs | Time (min): energy (μW/cm²) | Positive sites (before and after) (%) | Log_{10} reduction |
|--------------|-----------|-------|-----------------------------|--------------------------------------|-------------------|
| Rutala, 201042 | UV-C, Tru-D | MRSA | 15; 12,000 | 20.2, 0.5 | 1.30 |
| Nerandzic, 201044 | UV-C, Tru-D | MRSA, VRE | 20; 12,000 | 10.7, 0.8; 2.7, 0.38 | 0.68; 2.52 |
| Nerandzic, 201044 | UV-C, Tru-D | Cd | 45; 22,000 | 3.4, 0.38 | 1.39; |
| Stibich, 201154 | UV, PX, Xenex | VRE | 12; NS | 8.2, 0 | 1.36 |
| Anderson, 201336 | UV-C, Tru-D | All, VRE, A | 25; 12,000 | NS; 11; 1; 13, 3 | 1.35; 1.68; 1.71 |
| Anderson, 201336 | UV-C, Tru-D | Cd | 45; 22,000 | 10, 5 | 1.16 |
| Jinadatha, 201554 | UV, PX, Xenex | MRSA | 15 (3 cycles of 5 min); NS | 70, 8 | 2.0 |
| Jinadatha, 201554 | UV, PX, Xenex | MRSA, VRE, Cd | 10 (2 cycles of 5 min); NS | 10; 2; 4; 0.9; 19, 8 | 0.90, 1.08, NS |
| Jinadatha, 201554 | UV-PX, Xenex | MRSA | 15 (3 cycles of 5 min); NS | NS, NS | 0.63 |

A. \textit{Acinetobacter} spp; \textit{All}, all target organisms; \textit{Cd}, \textit{Clostridium difficile}; \textit{MDRO}, multidrug-resistant organism; \textit{MRSA}, methicillin-resistant \textit{Staphylococcus aureus}; \textit{NS}, not stated; \textit{PX}, pulsed xenon; \textit{UV}, ultraviolet light; \textit{VRE}, vancomycin-resistant enterococci.
contaminating surfaces in hospital rooms (Table 3). The device used in most of these studies was a HPV device (Bioquell). In most of the studies, the number of contaminated surfaces was reduced to 0% and in all cases to <5%. Of note, none of the studies described the log_{10} reduction in pathogens.

### COMPARATIVE TRIALS USING NO TOUCH ROOM DECONTAMINATION DEVICES

Most of the studies in the literature have only assessed a single type of room decontamination device. However, several studies have assessed different devices using the same methodology, compared devices using different methodologies, or compared a room decontamination device with chemical disinfection.

Holmdahl et al compared a HPV system (Bioquell) with an aHP system (Sterinis). All biologic spores and microbial load indicators were inactivated for the 3 HPV tests, compared with only 10% in the first aHP test and 79% in the other 2 aHP tests. In a similar comparison, Fu et al reported that the HPV system inactivated >90% of the 6 log_{10} biologic indicators (BIs) containing G. stearothermophilus and >95% of the 4 log_{10} BIs. In contrast, the aHP system inactivated <10% of the powdered 6 log_{10} BIs, <15% of the unpouched BIs, and approximately 1/3 of the 4 log_{10} BIs, regardless of whether they were powdered or unpouched.

French et al compared room cleaning without use of a disinfectant to HPV decontamination and reported HPV was superior in eliminating MRSA. Chantoji et al compared a pulsed-xenon system with 10% dilution of bleach for decontamination of C difficile rooms and found there were no significant differences in final contamination levels between the 2 methods of decontamination. Barbut et al compared the effectiveness of 0.5% hypochlorite to a hydrogen peroxide dry-mist device (Sterinis) for the disinfection of rooms of patients with C difficile and reported a 50% decrease in C difficile contamination after hypochlorite compared with a 91% reduction after hydrogen peroxide decontamination ($P < .005$). Importantly, there was no assessment of the effectiveness of cleaning.

### CLINICAL TRIALS USING HPV ROOM DECONTAMINATION DEVICES

Multiple clinical trials have assessed the efficacy of UV or hydrogen peroxide room decontamination units for reducing HAIs (Table 4).

Several studies warrant detailed discussion, including the studies by Passaretti et al, Pegues et al, and Anderson et al. Passaretti et al performed a 30-month prospective cohort (before-after study) intervention using a hydrogen peroxide vapor device (Bioquell) on 6 high-risk units in a 994-bed tertiary care hospital. Patients admitted to rooms decontaminated using HPV were 64% less likely to acquire any multidrug-resistant pathogen (IRR, 0.36; $P < .001$) and 80% less likely to acquire VRE (IRR, 0.20; $P < .001$). The risk of acquiring C difficile, MRSA, and multidrug-resistant gram-negative bacilli was reduced, but not significantly. The proportion of rooms environmentally contaminated with multidrug-resistant organisms was reduced significantly on the HPV units (RR, 0.65; $P = .03$).

Pegues et al performed a prospective cohort (before-after study) in 3 hematolog-oncology units to assess the efficacy of a UV-C device (Optimum) to reduce C difficile infection. Importantly, rooms were disinfected with bleach prior to use of the UV-C device. A significant association between UV-C use and a decline in C difficile infection incidence was noted on study units (IRR, 0.49; 95% confidence interval, 0.26-0.94; $P = .03$) but not on the nonstudy units (IRR, 0.63; 95% confidence interval, 0.38-1.06; $P = .08$). Importantly, hand hygiene compliance, which was monitored by observation, and room cleaning compliance, which was
| Author, year | Design | Setting | Modality tested | Pathogen(s) | Outcome (HAI) | Assessment of HH compliance | Assessment of EVS cleaning | Other HAI prevention initiatives |
|-------------|--------|---------|-----------------|-------------|---------------|--------------------------|--------------------------|-------------------------------|
| Boyce, 2008 | Before-after (CDI high-incidence wards) | Community hospital | HPV (Bioquell) | CDI | 2.28 to 1.28 per 1,000 Pt days (P = .047) | No | No | NA |
| Cooper, 2011 | Before-after (2 cycles) | Hospitals | HPV (NS) | CDI | Decreased cases (incidence NS) | No | No | Yes |
| Levin, 2013 | Before-after | Community hospital | UV-PX, Xenex | MRSA | 9.46 to 4.45 per 10,000 Pt days (P = .01) | No | No | Yes |
| Passaretti, 2013 | Prospective cohort (comparison of MDRO acquisition; admitted to rooms with or without HPV decontamination) | Academic center | HPV (Bioquell) | CDI | 2.3 to 1.2 (P = .30) | No | No | No |
| Manian, 2013 | Before-after | Community hospital | HPV (Bioquell) | CDI | 0.88 to 0.55 cases per 1,000 Pt days (P < .0001) | Yes | No | No |
| Hass, 2014 | Before-after | Academic center | UV-PX, Xenex | MRSA, VRE, CDI | 0.79 to 0.65 per 1,000 Pt days (P = .02) | No | Yes | Yes |
| Mitchell, 2014 | Before-after | Acute care hospital | Dry hydrogen vapor (Nocospray) | MRSA (colonization and infection) | 9.0 to 5.3 per 10,000 Pt days (P < .001) | Yes | No | Yes |
| Miller, 2015 | Before-after | Urban hospital | UV-PX, Xenex | CDI | 23.3 to 8.3 per 10,000 Pt days (P = .02) | No | No | Yes |
| Nagaraja, 2015 | Before-after | Academic center | CV-C (Optimum) | CDI | 1.06 to 0.83 per 1,000 Pt days (P = .06) | No | No | No |
| Pegues, 2015 | Before-after | Academic center | UV-PX, Xenex | CDI | 30.34 to 22.85 per 10,000 Pt days (IRR = 0.49; 95% CI, 0.26-0.94; P = .03) | Yes | Yes | No |
| Anderson, 2015 | RCT | 9 hospitals | UV-C (Tru-D) | MRSA, VRE, CDI | 51.3 to 33.9 per 10,000 Pt days (P = .036)* | Yes | Yes | No |

CDI, Clostridium difficile infection; CI, confidence interval; EVS, environmental service; GNB, gram-negative bacteria; HAI, health care–associated infections; HH, hand hygiene; HP, hydrogen peroxide; HPV, hydrogen peroxide vapor; IRR, incidence rate ratio; MDRO, multidrug-resistant organism; MRSA, methicillin-resistant Staphylococcus aureus; NA, not applicable; NS, not stated; Pt, patient; RCT, randomized clinical trial; UV, ultraviolet light; UV-PX, ultraviolet light, pulsed-xenon device; VRE, vancomycin-resistant enterococci.

*Outcome includes new colonization plus HAI.
monitored using 3M™ Clean-Trace Surface ATP test device (3M, St. Paul, MN), were similar in the baseline and intervention periods (D. Pegues, personal communication, October 16, 2015).

The study by Anderson et al is the first randomized clinical trial to assess a no touch method (UV-C; Tru-D) for terminal room disinfection. Specifically, this was a prospective, multicenter, cluster-randomized, crossover trial in 9 hospitals which evaluated 3 strategies for enhanced terminal room disinfection: standard quaternary ammonium compound plus UV-C, bleach alone, and bleach plus UV-C. Patients colonized or infected with MRSA, VRE, or with *C difficile* infection were considered seed rooms with exposed patients being patients subsequently admitted to a seed room. Exposed patients were followed for the development of an HA1 caused by a targeted pathogen. Compliance with hand hygiene and terminal room cleaning were measured, and there were no differences in these potential confounders among the baseline group (quaternary ammonium compound alone) and the 3 intervention arms. The study showed that enhanced room decontamination strategies (ie, bleach or UV-C decontamination) decreased the clinical incidence of acquisition of target multidrug-resistant organisms (ie, MRSA, VRE, *C difficile*) by approximately 10%-30% (*P* = 0.036).

No touch room disinfection devices have been used as a component to control health care–associated outbreaks. The outbreaks involved *S aureus*, multidrug-resistant gram-negative bacilli, *C difficile*, and *A baumannii* plus MRSA. The device used in most cases was a HPV system (Bioquell).

**DEMONSTRATING THAT NO TOUCH ROOM DECONTAMINATION UNITS REDUCE HAI**

One may assess the efficacy of no touch room decontamination using a hierarchy of research methods. In increasing order of demonstrating efficacy to reduce HAIs, the following methods may be used: (1) in vitro studies demonstrating that the no touch device eliminates or reduces relevant pathogens (eg, MRSA, VRE, *C difficile*, *A baumannii*, multiple drug-resistant gram-negative bacilli); (2) studies in used patient rooms demonstrating that the no touch device eliminates or reduces relevant pathogens inoculated onto appropriate carriers and placed throughout the patient room; (3) studies following patient discharge in patient rooms demonstrating elimination or reduction of relevant pathogens on naturally contaminated environmental surfaces; (4) before-after studies demonstrating that the no touch system reduces HAI incidence; (5) cross-over studies with multiple sites or multiple cross-over points so as to minimize the potential biases in a single cross-over study (eg, before-after study); and (6) randomized clinical trials demonstrating that the no touch device reduces HAI incidence.

In clinical trials (ie, before-after studies, cross-over studies, randomized clinical trials), it is important that potential confounders be measured, especially hand hygiene compliance and compliance with surface cleaning. In all clinical trials, the only test variable should be the use of the no touch device (ie, multiple interventions should not be undertaken or if undertaken should be standardized across study arms).

As previously noted, UV device may vary because of differences in UV wavelength, bulb size, energy output, ability to measure energy delivery, and cost. Similarly, hydrogen peroxide systems differ with regard to concentration, use of other microbicides, method of injecting hydrogen peroxide into a room or space, and cost. For these reasons, infection control professionals should review the peer-reviewed literature and choose for purchase only devices with demonstrated bactericidal capability as assessed by the carrier test method or ability to disinfect actual patient rooms. Ultimately, one should choose only devices that have demonstrated the ability to reduce HAIs.

Further, infection control professionals should be aware of the advantages and disadvantages of both UV and hydrogen peroxide systems. The major advantages of both systems are the ability to consistently decontaminate hospital room surfaces. Both systems are residual free. The major disadvantage of both systems is that they may only be used for terminal disinfection. Neither system will physically clean a room (e.g., remove dust or stains), hence room cleaning must precede disinfection. Other differences include the following: (1) UV systems require a shorter delivery time; (2) UV systems can only inactivate pathogens in direct or indirect line of sight (ie, they may not effectively decontaminate all surfaces in adjacent rooms, such as bathrooms); (3) hydrogen peroxide systems require that the HVAC system be sealed; and (4) hydrogen peroxide systems have demonstrated greater kill against spore-forming organisms (although the clinical impact requires further studies).

For the future, additional well-designed randomized clinical trials of UV devices and hydrogen peroxide systems would further define their potential benefits. It would be very useful to compare a UV light device with a hydrogen device in a randomized clinical trial. Randomized clinical trials would also allow calculation of the cost-effectiveness of these devices. However, logistic and cost reasons are likely to preclude randomized clinical trials. Rather, decisions on use of these devices will need to be based on consistent demonstration of effectiveness in killing pathogens as previously detailed and quasi-experimental studies.

**References**

1. Magill SS, Edwards JR, Bamberg W, Beldavs ZG, Dumyati G, Kainer MA, et al. Multistate point-prevalence survey of health care-associated infections. N Engl J Med 2014;370:1198–208.

2. Weinstein RA. Epidemiology and control of nosocomial infections in adult intensive care units. Am J Med 1991;91(Suppl):1795-1845.

3. Otter JA, Yezli S, French GL. The role played by contaminated surfaces in the transmission of nosocomial pathogens. Infect Control Hosp Epidemiol 2011;32:687-99.

4. Steifel U, Cadnum JL, Eckstein BC, Guerrero DM, Tima MA, Donskey CJ. Use of a fluorescent chemical marker to assess a no touch method (UV-C; Tru-D) for terminal room disinfection. In: Best practice in healthcare environmental decontamination. Siani H, Maillard J-Y, editors. 2015.

5. Goodman ER, Platt R, Bass R, Onderdonk AB, Yokoe DS, Huang SS. Impact of environmental cleaning intervention on the presence of methicillin-resistant *S aureus* in patient rooms. J Hosp Infect 2013;83(Suppl):S6-11.

6. Carling PC, Parry MM, Rupp ME, Po JL, Dick B, von Beheren S. Improving cleaning of the environment surrounding patients in 36 acute care hospitals. Infect Control Hosp Epidemiol 2008;29:1035-41.

7. Carling PC, Parry MF, Bruno-Murtha LA, Dick B. Improving environmental hygiene in 27 intensive care units to decrease multidrug-resistant bacterial transmission. Crit Care Med 2010;38:1054-9.

8. Peleg AA, Lior H. The role of contaminating microorganisms in hospital infections. Curr Opin Infect Dis 2013;26:338-44.

9. Sian H, Maillard J-Y. Best practice in healthcare environmental decontamination. Eur J Clin Microbiol Infect Dis 2015;34:1-11.

10. Hayden MK, Bonten MJM, Blom DW, Lyle EA, van de Vlijvjer DAMC, Weinstein RA. Reduction in acquisition of vancomycin-resistant enterococcus after enforcement of routine environmental cleaning measures. Clin Infect Dis 2006;42:1552-60.

11. Blue J, O'Neill C, Speziale P, Ramage L, Ballantyne L. Use of a fluorescent chemical as a quality indicator for a hospital cleaning program. Can J Infect Control 2008;23:216-9.

12. Carling PC, Parry MM, Rupp ME, Po JL, Dick B, von Beheren S. Improving cleaning of the environment surrounding patients in 36 acute care hospitals. Infect Control Hosp Epidemiol 2008;29:1035-41.

13. Carling PC, Parry MF, Bruno-Murtha LA, Dick B. Improving environmental hygiene in 27 intensive care units to decrease multidrug-resistant bacterial transmission. Crit Care Med 2010;38:1054-9.

14. Goodman ER, Platt R, Bass R, Onderdonk AB, Yokoe DS, Huang SS. Impact of environmental cleaning intervention on the presence of methicillin-resistant *S aureus* in patient rooms. J Hosp Infect 2013;83(Suppl):S6-11.

15. Otter JA, Yezli S, Salkeld JAG, French GL. Evidence that contaminated surfaces serve as a quality indicator for a hospital cleaning program. Can J Infect Control 2008;23:216-9.

16. Otter JA, Yezli S, Salkeld J, French GL. Evidence that contaminated surfaces serve as a quality indicator for a hospital cleaning program. Can J Infect Control 2008;23:216-9.

17. Otter JA, Yezli S, Salkeld JAG, French GL. Evidence that contaminated surfaces serve as a quality indicator for a hospital cleaning program. Can J Infect Control 2008;23:216-9.
Staphylococcus aureus and vancomycin resistant enterococci on surfaces in intensive care unit rooms. Infect Control Hosp Epidemiol 2008;29:593-9.

2. Boyce JM, Havill NL, Havill ML, Mangione E, Dumigan DG, Moore BA. Comparison of the microbiological efficacy of hydrogen peroxide vapour room decontamination technology. J Hosp Infect 2013;83(Suppl):S36-41.

3. Otter JA, Yezli S, Peri LM, Barbut F, French GL. The role of “no-touch” automated room disinfection systems in infection prevention and control. J Hosp Infect 2011;83:1-13.

4. Nelson MM, Fisher CW, Donskey CJ. Sorting through the wealth of options: comparative evaluation of two ultraviolet disinfection systems. PLoS ONE 2014;9:e107444.

5. Cadmus JL, Tomas ME, Sankar T, et al. Effect of variation in test methods on performance of ultraviolet-C radiation for terminal decontamination. Infect Control Hosp Epidemiol 2016 Jan 26; 1-6. [Epub ahead of print]

6. Rutala WA, Gergen MF, French GL. Room decontamination with UV radiation. Infect Control Hosp Epidemiol 2010;31:1025-9.

7. Boyce JM, Havill NL, Moore BA. Terminal room decontamination of patient rooms using an automated mobile UV light unit. Infect Control Hosp Epidemiol 2011;32:737-42.

8. Havill NL, Moore BA, Boyce JM. Comparison of the microbiological efficacy of hydrogen peroxide vapor and ultraviolet-C room decontamination. Infect Control Hosp Epidemiol 2012;33:507-12.

9. Rutala WA, Gergen MF, Weaver DJ. Rapid hospital room decontamination using ultraviolet (UV) light with a nanostructured UV-reflective wall coating. Infect Control Hosp Epidemiol 2012;33:528-30.

10. Mahida N, Vaughan N, Boswell T. First UK evaluation of an automated ultraviolet-C room decontamination device (Tru-D™). J Hosp Infect 2013;84:332-5.

11. Rutala WA, Gergen MF, Tande BM, Weaver DJ. Room decontamination using an ultraviolet-C device with short ultraviolet exposure time. Infect Control Hosp Epidemiol 2014;35:1070-1.

12. Nerenz DC, Thota P, Sankar CT, Jencson A, Cadmus JL, Ray AJ, et al. Evaluation of an automated mobile ultraviolet-C germicidal light system for reduction of healthcare-associated pathogens in hospital rooms. Infect Control Hosp Epidemiol 2015;36:192-7.

13. Nerenz DC, Cadmus FL, Pultz MJ, Donskey CJ. Evaluation of an automated ultraviolet-C room decontamination system for controlling Clostridium difficile and other healthcare-associated pathogens in hospital rooms. BMC Infect Dis 2010;10:197.

14. Stichboh M, Stanchowik J, Tanner B, Jencson A, Cadmus JL, Ray AJ, et al. Evaluation of a pulsed-xenon ultraviolet room disinfection device for impact on hospital operations and microbial reduction. Infect Control Hosp Epidemiol 2011;32:286-8.

15. Anderson DJ, Gergen MF, Smathers E, Sexton DJ, Chen LF, Weaver DJ, et al. Decontamination of targeted pathogens from patient rooms using an automated ultraviolet-C-emitting device. Infect Control Hosp Epidemiol 2013;34:466-71.

16. Jinadatha C, Villamaria FC, Restrepo MJ, Ganachari-Mallappa N, Liao IC, Stock EM, et al. Is the pulsed xenon ultraviolet light no-touch disinfection system effective on methicillin-resistant Staphylococcus aureus in the absence of manual cleaning. Am J Infect Control 2015;43:878-81.

17. Davies A, Potage T, Bennett A, Walker J. Caseous and air decontamination techniques for Clostridium difficile in the healthcare environment. J Hosp Infect 2011;77:159-203.

18. Otter JA, Yezli S. A call for clarity when discussing hydrogen peroxide vapour and aerosol systems. J Hosp Infect 2011;77:76-92.

19. Falagas JE, Thomaidis PC, Kotsantis IK, Sgouros K, Samonis G, Karageorgopoulos DE. Hydrogen peroxide for disinfection of hospital rooms: a systematic review. J Hosp Infect 2011;78:171-7.

20. Piskin N, Celebi G, Kulah C, Mengeloglu Z, Yumusak M. Activity of a dry mist-generated hydrogen peroxide disinfection system against methicillin-resistant Staphylococcus aureus and Acinetobacter baumannii. Ann J Infect Control 2011;39:757-62.

21. Chan H-T, White P, Sheorey H, Cocks J, Waters M-J. Evaluation of the biological efficacy of hydrogen peroxide vapor decontamination in wards of an Australian hospital. J Hosp Infect 2011;78:125-8.

22. Andersen BM, Syversen G, Thoresen H, Rasch M, Hochlin K, Seljordslia B, et al. Failure of dry mist hydrogen peroxide 5% to kill Mycobacterium tuberculosis. J Hosp Infect 2010;76:257-62.

23. Anderson BM, Rasch M, Hochlin K, Jensen F-H, Wissmar P, Fredriksson J-E. Decontamination of rooms, medical equipment and ambulances using an aerosol of hydrogen peroxide disinfectant. J Hosp Infect 2006;62:149-55.

24. Otter JA, French GL. Survival of nosocomial bacteria and spores on surfaces and inactivation by hydrogen peroxide vapor. J Clin Microbiol 2009;47:205-7.

25. Lemmen S, Scheithauer S, Hafner H, Yezli S, Mohr M, Otter J. Evaluation of hydrogen peroxide vapor for the inactivation of nosocomial pathogens on porous and nonporous surfaces. Am J Infect Control 2013;41:83-2.

26. Goyal S, Chander Y, Yezli S, Otter JA. Evaluating the virucidal efficacy of hydrogen peroxide vapor. J Hosp Infect 2014;86:255-9.

27. Pottage T, Richardson C, Parks S, Walker JT, Bennett AM. Evaluation of hydrogen gaseous disinfection systems to decontaminate viruses. J Hosp Infect 2010;74:55-61.

28. French GL, Otter JA, Shannon KP, Adams NMT, Watling D, Parks MJ. Tackling contamination of the hospital environment by methicillin resistant Staphylococcus aureus (MRSA): a comparison between conventional terminal cleaning and hydrogen peroxide vapor decontamination. J Hosp Infect 2004;57:31-7.

29. Bates CJ, Pearse R. Use of hydrogen peroxide vapor for environmental control during a Serratia outbreak in a neonatal intensive care unit. J Hosp Infect 2005;61:364-6.

30. Jeanes A, Rao G, Osman M, Merrick P. Eradication of persistent environmental MRSA. J Hosp Infect 2005;61:85-6.

31. Hardy KJ, Gossain S, Henderson N, et al. Rapid decontamination with MRSA of the environment of a patient room after decontamination with hydrogen peroxide vapor. J Hosp Infect 2007;66:360-9.

32. Otter JA, Cummins M, Ahmad F, van Tonder C, Drabu YJ. Assessing the biological efficacy and rate of decontamination following hydrogen peroxide vapor use on healthcare-associated surfaces. J Hosp Infect 2015;90:182-9.

33. Shaper S, Machin K, Levi K, Boswell TC. Activity of a dry mist hydrogen peroxide system against environmental Clostridium difficile contamination in elderly care wards. J Hosp Infect 2008;70:136-41.

34. Dryden M, Parmaby R, Davis L, Lewis T, Davis-Blues K, Otter JA, et al. Hydrogen peroxide vapor decontamination in the control of a polyclonal methicillin-resistant Staphylococcus aureus outbreak on a surgical ward. J Hosp Infect 2008;68:190-2.

35. Barbut F, Menuet D, Verajhten M, Girou E. Comparison of the efficacy of a gaseous disinfection system and ultraviolet-C light for terminal cleaning and decontamination. J Hosp Infect 2013;84:327-9.

36. Bryant LS, Kristofferson CA, Fogel T, Roehr SM, Lundgren B, Westh E. Environmental methicillin-resistant Staphylococcus aureus (MRSA) disinfection using dry-mist-generated hydrogen peroxide. J Hosp Infect 2008;70:35-41.

37. Otter JA, Yezli S, Schouten MA, van Zanten ARH, Houmes-Zielman G, Nolhams-Paulsen MKE. Hydrogen peroxide vapor decontamination of an intensive care unit to remove environmental reservoirs of multidrug-resistant gram-negative rods during an outbreak. Am J Infect Control 2010;38:754-6.

38. Holmdahl T, Lanbeck P, Wullit M, Walder MH. A head-to-head comparison of hydrogen peroxide and sodium hypochlorite for decontamination of critical care rooms, and other healthcare-associated pathogens in hospital rooms. BMC Infect Dis 2010;10:197.

39. Barbut F, Menuet D, Verajhten M, Girou E. Comparison of the efficacy of a hydrogen peroxide dry-mist disinfection system and sodium hypochlorite solution for eradication of Clostridium difficile spores. Infect Control Hosp Epidemiol 2009;30:153-8.

40. Otter JA, Barnicot M, Down J, Smyth D, Yezli S, Jeanes A. Hydrogen peroxide vapor decontamination of a critical care unit room to treat a patient with Lassa fever. J Hosp Infect 2010;75:325-7.

41. Otter J, Mepham S, Atan S, Mack D, Smith R, Jacobs M, et al. Terminal decontamination of an intensive care unit by Free London High Level Isolation Unit (HLIU) following a case of Ebola virus disease using hydrogen peroxide vapor. Available from: http://www.his.org.uk/index.php/download_file/view/349/409/; Accessed October 2015.

42. Cooper T, O'Leary M, Yezli S, Otter JA. Impact of environmental decontamination using hydrogen peroxide vapour on the incidence of Clostridium difficile infection in one hospital trust. J Hosp Infect 2011;78:238-45.

43. Levin J, Riley LS, Parrish C, English D, Ahn S. The effect of portable pulsed xenon ultraviolet light after terminal cleaning of hospital associated-Clostridium difficile infection rooms. J Hosp Infect 2015;90:182-9.

44. Passaretti CL, Otter JA, Reich NG, Myers J, Shepard J, Ross T, et al. Evaluation of environmental decontamination with hydrogen peroxide vapor for reducing the risk of patient acquisition of multidrug-resistant organisms. Clin Infect Dis 2015;62:27-35.

45. Manian FA, Griesnauer S, Bryant A. Implementation of hospital-wide enhanced terminal cleaning of targeted patient rooms and its impact on endemic Clostridium difficile infection rates. Am J Infect Control 2013;41:537-41.
69. Hass JP, Menz J, Dusza S, Montecalvo MA. Implementation and impact of ultraviolet environment disinfection in an acute care setting. Am J Infect Control 2014;42:586-90.

70. Mitchell BG, Digney W, Locket P, Dancer SJ. Controlling methicillin-resistant Staphylococcus aureus (MRSA) in a hospital and the role of hydrogen peroxide decontamination: an interrupted time series analysis. BMJ Open 2014;4:e004522.

71. Miller R, Simmons S, Dale C, Stibich M, Stachowiak J. Utilization and impact of a pulsed-xenon ultraviolet room disinfection system and multidisciplinary care team on Clostridium difficile in a long-term acute care facility. Am J Infect Control 2015;doi:10.1016/j.ajic.2015.07.029.

72. Najaraja A, Visintainer P, Haas JP, Menz J, Wormser GP, Montecalvo MA. Clostridium difficile infections before and during use of ultraviolet disinfection. Am J Infect Control 2015;43:940-5.

73. Pegues D, Gilmar C, Denno M, Gaynes S. Reducing Clostridium difficile infection among hematology-oncology patients using ultraviolet irradiation for terminal disinfection. Abstract 1715. Abstract presented at: IDweek, San Diego, CA, October 7-11, 2015.

74. Anderson D, Chen LF, Weber DJ, Moehring RW, Lewis SS, Triplett P, et al. The BETR-disinfection study. Presented at: IDweek, San Diego, CA, October 7-11, 2015.

75. Barbut F, Yezi S, Mimoun M, Pham J, Chaouat M, Otter JA. Reducing the spread of Acinetobacter baumannii and Staphylococcus aureus on a burns unit through the intervention of an infection control bundle. Burns 2013;39:395-403.

76. Landelle C, Legrand P, Lesprit P, Cizeau F, Ducellier D, Goulet C, et al. Protracted outbreak of multidrug-resistant Acinetobacter baumannii after intercontinental transfer of colonized patients. Infect Control Hosp Epidemiol 2013;34:119-24.

77. Gopinath R, Savard P, Carroll KC, Wilson LE, Landrum BM, Perl TM. Infection prevention considerations related to New Delhi metallo-β-lactamase Enterobacteriaceae: a case report. Infect Control Hosp Epidemiol 2013;34:99-100.