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Major article

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.[1] 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%).[2] Further, contamination of the hands of HCP could result directly from patient contact or indirectly from touching contaminated environmental surfaces.[3] 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.[4,5]

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.[6-11] In general, all of these pathogens share the following characteristics:

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ability to survive for prolonged periods of times 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.[8] 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 cleaning 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.

RATIONALE 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.[12-18] Several reviews have concluded that improved cleaning leads to reductions in HAI.[11,19] However, there is a paucity of high-quality studies demonstrating that improved cleaning and disinfection reduces HAIs.[20,21] Importantly, the studies that have assessed interventions to improve cleaning have reported that after the intervention, approximately 5%-30% of surfaces remain potentially contaminated.[12-18]

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.[22-24]

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.[22] 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. Nerandzic et al studied 2 UV room disinfection devices (Tru-D [Tru-D SmartUVC, Memphis, TN] and PATHOGON® [STERIS, Mentor, OH]) and reported the following: (1) pathogen concentration did not significantly impact the killing efficacy 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 $\log_{10}$ colony forming units/cm^2 for MRSA and VRE and <2 $\log_{10}$ colony forming units/cm^2 for *C difficile* spores.[25] 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.[26]

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).[27-33] In general, the inoculating doses were >4 $\log_{10}$ 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 the following from the reported results: (1) > 3 $\log_{10}$ 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 $\log_{10}$ 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.[30,32]

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).[27,33-37] Pathogens evaluated included MRSA, VRE, *Acinetobacter* spp, and *C difficile*. Cycle times for vegetative

Table 1
Effectiveness of UV devices on reducing MDROs on carriers

Author, year	UV system	MDROs	Time (min)	Energy ($\mu W/cm^2$)	Log_{10} reduction direct (indirect)
Rutala, 2010[27]	UV-C, Tru-D	MRSA, VRE, A	~15	12,000	4.31 (3.85), 3.90 (3.25), 4.21 (3.79)
Rutala, 2010[27]	UV-C, Tru-D	Cd	~50	36,000	4.04 (2.43)
Boyce, 2011[28]	UV-C, Tru-D	Cd	67.8 (1 stage)	22,000	1.7-2.9
Havill, 2012[29]	UV-C, Tru-D	Cd	73 (mean)	22,000	2.2
Rutala, 2013[30]	UV-C, Tru-D	MRSA	25	12,000	4.71 (4.27)
Rutala, 2013[30]	UV-C, Tru-D	Cd	43	22,000	3.41 (2.01)
Mahida, 2013[31]	UV-C, Tru-D	OR: MRSA, VRE	49	12,000	≥4.0 (≥4.0), 3.5 (2.4)
Mahida, 2013[31]	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, 2014[32]	UV-C, Optimum	MRSA	5	NS	4.10 (2.74)
Rutala, 2014[32]	UV-C, Optimum	Cd	10	NS	3.35 (1.80)
Nerandzic, 2015[33]	UV, PX, Xenon	Cd, MRSA, VRE	10 at 4 ft (2 cycles)	NS	0.55, 1.85, 0.6

A, *Acinetobacter* spp; *As*, *Aspergillus*; *Cd*, *Clostridium difficile*; *MDRO*, multidrug-resistant organism; *MRSA*, methicillin-resistant *Staphylococcus aureus*; *NS*, not stated; *OR*, operating room; *PX*, pulsed xenon; *UV*, ultraviolet light; *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 ($\mu W/cm^2$)	Positive sites (before and after) (%)	Log_{10} reduction
Rutala, 2010[27]	UV-C, Tru-D	MRSA	~15; 12,000	20.2, 0.5	1.30
Nerandzic, 2010[34]	UV-C, Tru-D	MRSA, VRE	20; 12,000	10.7, 0.8; 2.7, 0.38	0.68; 2.52
Nerandzic, 2010[34]	UV-C, Tru-D	Cd	45; 22,000	3.4, 0.38	1.39;
Stibich, 2011[35]	UV, PX, Xenex	VRE	12; NS	8.2, 0	1.36
Anderson, 2013[36]	UV-C, Tru-D	All, VRE, A	25; 12,000	NS; 11, 1; 13, 3	1.35; 1.68; 1.71
Anderson, 2013[36]	UV-C, Tru-D	Cd	45; 22,000	10, 5	1.16
Jinadatha, 2015[37]	UV, PX, Xenex	MRSA	15 (3 cycles of 5 min), NS	70, 8	2.0
Nerandzic, 2015[33]	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, 2015[37]	UV-PX, Xenex	MRSA	15 (3 cycles of 5 min); NS	NS, NS	0.63

A, *Acinetobacter* spp; *All*, all target organisms; *Cd*, *Clostridium difficile*; *MDRO*, multidrug-resistant organism; *MRSA*, methicillin-resistant *Staphylococcus aureus*; *NS*, not stated; *PX*, pulsed xenon; *UV*, ultraviolet light; *VRE*, vancomycin-resistant enterococci.

bacteria ranged from 10-25 minutes, and for *C difficile* cycle times ranged from 10-45 minutes. In all cases the frequency of positive surface sites post-treatment was <11%, 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 DECONTAMINATION

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, GLOSAIR; Advanced Sterilization Products, Irvine, CA, previously Sterinis; BioGienie; Steris, Mentor, OH; Nocospray; Oxy'pharm, Champigny-sur-Marne, France) and H_2O_2 vapor systems (eg, Bioquell, Andover, Hampshire, UK; VHP Biodecontamination Systems; Steris, Mentor, OH). H_2O_2 room disinfection systems have been reviewed.[24,39,40] The H_2O_2 vapor systems use 30%-35% H_2O_2. The Steris VHP system requires approximately 8 hours for disinfection, whereas the Bioquell hydrogen peroxide vapor (HPV) system requires 1.5-2.5 hours. The aHP systems combine 5%-7% H_2O_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} MRSA and *Acinetobacter* spp 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 VRE in a hospital room.[42] No significant decontamination of *Mycobacterium tuberculosis* was observed when the aHP system (Sterinis) was used to decontaminate a test surface contaminated with air-dried *M tuberculosis*.[43] When used in an operating department, 3 cycles of H_2O_2 aerosol (Sterinis) were required to kill *Bacillus atrophaeus* spore strips (4-5 hours); 2 cycles were ineffective.[44]

The effectiveness of H_2O_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 HPV.[45] Similarly, the same system was evaluated in an operating room using experimentally contaminated carriers; the device inactivated all spore biologic indicators (*Geobacillus stearothermophilus*; >6 log_{10} reduction), and no MRSA, VRE, or multidrug-resistant *A baumannii* were recovered from stainless steel and cotton carriers (>4-5 log_{10} reduction, depending on the starting inoculum).[46] Multiple studies have demonstrated excellent sporicidal 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]

Hydrogen peroxide systems effectiveness to reduce actual contaminated sites

Multiple studies have demonstrated the ability of hydrogen peroxide systems to reduce multidrug-resistant organisms

Table 3
Effectiveness of hydrogen peroxide systems on reducing multidrug-resistant organisms in contaminated patient rooms

Author, Year	HP system	Pathogen	Before HPV (% surfaces positive)	After HPV (% surfaces positive)	Reduction (%)
French, 2004[49]	HPV (Bioquell)	MRSA	72 (61/85)	1 (1/85)	98
Bates, 2005[50]	HPV (Bioquell)	*Serratia marcescens*	10 (4/42)	0 (0/25)	100
Jeanes, 2005[51]	HPV (Bioquell)	MRSA	36 (10/28)	0 (0/50)	100
Hardy, 2007[52]	HPV (Bioquell)	MRSA	24 (7/29)	0 (0/29)	100
Otter, 2007[53]	VHP (Bioquell)	MRSA, GNR	40 (12/30), 10 (3/30)	3 (1/30), 0 (3/30)	93, 100
Shapey, 2008[54]	HP dry mist (Sterinis)	*Clostridium difficile*	23.6 (48/203)	3.4 (7/203)	86
Dryden, 2008[55]	VHP (Bioquell)	MRSA	27.6 (8/29)	3.4 (1/29)	88
Boyce, 2008[56]	VHP (Bioquell)	*C difficile*	25.6 (11/43)	0 (0/37)	100
Bartels, 2008[57]	HP dry mist (Sterinis)	MRSA	28.6 (4/14)	0 (0/14)	100
Otter, 2010[58]	HPV (Bioquell)	GNR	48 (10/21)	0 (0/63)	100

GNR, Gram-negative rod; *HP*, hydrogen peroxide; *HPV*, hydrogen peroxide vapor; *MRSA*, methicillin-resistant *Staphylococcus aureus*.
Adapted from Felagas JE, et al. J Hosp Infect 2011;78:171-7.

contaminating surfaces in hospital rooms (Table 3).[49-58] 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).[59] 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.[60] In contrast, the aHP system inactivated <10% of the pouched 6 $\log_{10}$ BIs, <15% of the unpouched BIs, and approximately 1/3 of the 4 $\log_{10}$ BIs, regardless of whether they were pouched or unpouched.

French et al compared room cleaning without use of a disinfectant to HPV decontamination and reported HPV was superior in eliminating MRSA.[49] Ghantoji 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.[61] 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 ($P < .005$).[62] Importantly, there was no assessment of the effectiveness of cleaning.

Nerandzic et al compared 2 UV-C devices (Tru-D and PATHOGON) in a laboratory setting.[25] Both devices were equally effective for killing *C difficile* spores, MRSA, and VRE. Rutala et al using the same methods studied 2 different UV-C devices.[30,32] For MRSA, one device (Tru-D) required approximately 25 minutes for inactivation compared with the other device (Optimum), which required approximately 5 minutes. Both devices achieved >4 $\log_{10}$ inactivation for when carriers were placed in direct line of site. For *C difficile*, both devices achieved a statistically similar kill; however, the duration of exposure was different (approximately 43 minutes for Tru-D and 10 minutes for Optimum). Cadnum et al studied the effectiveness of 2 UV-C devices (Tru-D and Optimum) to kill MRSA and *C difficile* and reported there was no difference in $\log_{10}$ pathogen reductions on experimentally contaminated steel carrier disks irradiated at ~1.22 m between the 2 devices. For MRSA, a >3 $\log_{10}$ reduction was achieved with 5-minute exposure, whereas for *C difficile* increasing exposure led to increasing kill (20-minute exposure required to achieve a reduction of approximately 2 $\log_{10}$).[26]

Havill et al compared UV-C (Tru-D) with HPV (Bioquell) for decontamination of patient rooms by assessing aerobic bacteria present on high-touch surfaces (ie, bedside rail, overbed table, television remote, bathroom grab bar, toilet seat) and by using carrier disks contaminated with *C difficile*.[29] The percent of sites yielding aerobic growth pre- and postdecontamination was as follows: 91% to 49% for UV-C and 93% to 7% for HPV, respectively. For *C difficile*, UV-C achieved an average reduction of 2.2 $\log_{10}$ (range, 1.7-3.0), whereas HPV achieved a 6 $\log_{10}$ reduction. Importantly, UV-C showed substantially better results for the sites in the patient room (eg, overbed table) than in the patient bathroom (eg, toilet seat).

HPV (Bioquell) has been used to decontaminate rooms previously occupied by patients with Lassa fever[63] and Ebola viral disease[64]; however, before and after viral cultures were not performed.

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).[56,65-74]

Several studies warrant detailed discussion, including the studies by Passaretti et al,[67] Pegues et al,[73] and Anderson et al.[74] 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.[67] 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 hematology-oncology units to assess the efficacy of a UV-C device (Optimum) to reduce *C difficile* infection.[73] 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

Table 4
Clinical trials using UV or HP devices for terminal room disinfection to reduce health care–associated infections

Author, year	Design	Setting	Modality tested	Pathogen(s)	Outcome (HAI)	Assessment of HH compliance	Assessment of EVS cleaning	Other HAI prevention initiatives
Boyce, 2008[56]	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[65]	Before-after (2 cycles)	Hospitals	HPV (NS)	CDI	Decreased cases (incidence NS)	No	No	Yes
Levin, 2013[66]	Before-after	Community hospital	UV-PX, Xenex	CDI	9.46 to 4.45 per 10,000 Pt days ($P = .01$)	No	No	Yes
Passaretti, 2013[67]	Prospective cohort (comparison of MDRO acquisition; admitted to rooms with or without HPV decontamination)	Academic center	HPV (Bioquell)	MRSA VRE CDI All MDROs; MRSA, VRE, CDI	2.3 to 1.2 ($P = .30$) 7.2 to 2.4 ($P < .01$) 2.4 to 1.0 ($P = .19$) 12.6 to 6.2 per 1,000 Pt days ($P < .01$)	No	No	No
Manian, 2013[68]	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[69]	Before-after	Academic center	UV-PX, Xenex	CDI MRSA VRE MDRO-GNB Total	0.79 to 0.65 per 1,000 Pt days ($P = .02$) 0.45 to 0.33 per 1,000 Pt days ($P = .007$) 0.90 to 0.73 per 1,000 Pt days ($P = .002$) 0.52 to 0.42 per 1,000 Pt days (($P = .04$) 2.67 to 2.14 per 1,000 Pt days ($P < .001$)	No	Yes	Yes
Mitchell, 2014[70]	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[71]	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[72]	Before-after	Academic center	UV-PX, Xenex	CDI	1.06 to 0.83 per 1,000 Pt days ($P = .06$)	No	No	No
Pegues, 2015[73]	Before-after	Academic center	CV-C (Optimum)	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[74]	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.[74] 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 HAI caused by a target 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% ($P = .036$).

No touch room disinfection devices have been used as a component to control health care–associated outbreaks.[6,50,51,55,56,58,75-77] 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.[22,23] 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 (eg, 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 site (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 peroxide 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.

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