보건학 석사학위논문

Comparison of the Microbiological Efficacy of Disinfection using Ultraviolet and Hydrogen Peroxide system for Carbapenemase-producing *Enterobacteriaceae* in a Healthcare Setting

자외선과 과산화수소 공간소독기계를 사용한 의료기관 환경소독 시 카바페넴분해효소 생성 장내세균속균종 오염제거 효과비교

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Abstract

Comparison of the Microbiological Efficacy of Disinfection using Ultraviolet and Hydrogen Peroxide system for Carbapenemase-producing *Enterobacteriaceae* in a Healthcare Setting

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Background

Carpanemase-producing *Enterobacteriaceae* (CPE) is a growing problem in the worldwide. Environmental cleaning and disinfection is important strategy to prevent CPE transmission and "no-touch" methods including ultraviolet device (UV) and hydrogen peroxide system (HP) have been evaluated to overcome the shortcomings of manual cleaning. However, data regarding efficacy of UV and HP against CPE are limited. The objective of this study was to compare the microbiological efficacy of disinfection using

ultraviolet-C device (UV-C) and aerosolized hydrogen peroxide system (aHP) as area decontamination in a healthcare setting.

Methods

This study was conducted in empty single patient rooms with dimension of 48.3 m^3 at tertiary hospital, Seoul, South Korea from May to October, 2019. Four rooms were applied with two UV-C and two aHP, respectively and thirty formica sheets contaminated with KPC-producing *Klebsiella pneumoniae* (approximately 10^6 CFUs) were placed in the room, both UV direct (laser pointer pass) and indirect sites (laser pointer didn't pass). After intervention, median $\log_{10}$ reduction and modified decontamination rate (clean plate was defined as less than 2.5 CFUs/plate) were assessed using Rodac plates.

Results

Median $\log_{10}$ reduction was 5.52 $\log_{10}$ reduction after UV-C (n=60) and 5.37 $\log_{10}$ reduction after aHP (n=60) (P=0.86), and modified decontamination rate was 50% after

UV-C and 45% after aHP (P=0.71). At UV direct sites, UV-C showed higher median log_{10} reduction (5.91 vs. 5.61, P=0.002) and modified decontamination rate (83% vs. 53%, P=0.03) than aHP. Conversely, at UV indirect sites, aHP showed higher median log_{10} reduction (4.63 vs. 5.07, P=0.02) and modified decontamination rate (17% vs. 37%, P=0.01) than UV-C.

Conclusions

Both UV-C and aHP reduced bacterial contamination in a single room. aHP was significantly more effective at UV indirect sites and UV-C was significantly more effective at UV direct sites. Considering the features of the machines and the results of this study, healthcare facilities might choose between UV-C and aHP.

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Keywords : Carbapenemase-producing *Enterobacteriaceae*, Environmental cleaning and disinfection, No-touch disinfection method, Area decontaminator, Ultraviolet-C device, aerosolized Hydrogen peroxide system, Log_{10} reduction, Decontamination rate

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I. Background

Multidrug-resistant organisms (MDROs) in a healthcare setting have become a growing problem in the worldwide as the use of antibiotics increases. Among MDROs, the frequency of Carbapenem-resistant *Enterobacteriaceae* (CRE) infections has been increasing and especially Carbapenemase-producing *Enterobacteriaceae* (CPE) belonging to the CRE is an emerging pathogen since it was first reported in 1993. In Korea, the number of CPE cases reported from sentinel surveillance units were 565, 1453, and 2657 in 2015, 2016, and 2017, respectively[1].

There are four main reasons why CPE is epidemiological important. First, there is limited option for treatment of CPE infections. Second, CPE has been associated with high mortality rate[2,3,4]. Third, carbapenemase, one of carbapenem resistant mechanisms, can be transmitted rapidly through plasmids, so concerns are growing over the spread of carbapenem resistant[4]. Finally, *Enterobacteriaceae* is a common cause of community infections as well as healthcare-associated infections. Accordingly, active prevention and control

strategies for CPE are needed.

There are two common modes of pathogen transmission to susceptible patient in a healthcare setting: hands of healthcare workers and contaminated inanimate surfaces[5]. Because contaminated inanimate surfaces can also be transmitted indirectly to patients through hands of healthcare workers, infection control of contaminated surfaces is important. So far the importance of hand hygiene has been recognized and many methods have been applied to improve hand hygiene compliance in a healthcare setting. However, the risks of contaminated environmental surfaces and the importance of environmental management have been relatively overlooked. In recent years, environmental cleaning and disinfection as well as hand hygiene has emphasized in the control of MDROs outbreaks.

As strategies to prevent the spread of CPE transmission within a healthcare setting, hand hygiene, contact precautions, staff education, minimize use of invasive devices, timely laboratory notification, communication of CRE status at admission, antimicrobial stewardship, environmental cleaning, patient and staff cohorting, screening contacts of CRE patients, active surveillance testing, and chlorhexidine bathing are recommended[6].

Among these interventions, environmental cleaning has been presented a fundamental part of infection prevention practice, highlighting its importance.

In Korea, periodic cleaning and disinfection of the environmental surfaces in a room with occupied by a patient with CPE is recommended[7]. In particular, inpatient beds based multi-patient room and the room crowded with caregivers and visitors are likely to spread pathogen to susceptible patients through contaminated surrounding environment in Korea.

Traditionally, environmental cleaning is manual cleaning method performed by Environmental service housekeepers or healthcare workers, but compliance of this method is known to be lower than 50%[8]. So lately, "no-touch" methods that disinfect areas beyond human reach and overcome the shortcomings of manual cleaning have been evaluated as additional methods followed by manual cleaning.

"No-touch" methods include ultraviolet device and hydrogen peroxide system. Ultraviolet device (UV) uses either an ultraviolet-C with a wavelength of 254 nm or an ultraviolet-pulsed xenon with a wavelength of 200-320 nm.

Hydrogen peroxide system (HP) uses 3–7% aerosolized hydrogen peroxide or 30% hydrogen peroxide vapor. Because both methods of UV and HP cannot remove dust or stains during the disinfection process, manual cleaning is essential before treatment. In addition, all persons, including patients and healthcare workers, must leave the room during disinfection and are not allowed to enter the room. UV is known to be ineffective in shadowed areas due to the large number of items inside the room, while has a fast run time and do not require shut-out of air conditioning and ventilation after disinfection. HP is known to be effective in shadowed areas, while require shut-out of air conditioning with sealing the door. In addition, this method has a long run time due to ventilation after disinfection.

There are three major categories of studies that evaluated the decontamination effect of UV and HP: efficacy on reduction MDROs on carriers, effectiveness on reducing MDROs in contaminated patient rooms, and clinical trials for terminal room disinfection to reduce healthcare-associated infections (Table 1). The preceding literature, which was conducted on an inanimate surfaces contaminated with MDROs, showed that $\log_{10}$ reduction is mostly measured higher than 4. In the studies to assess effectiveness on

reduction MDROs in contaminated patient rooms, MDROs positive rate after disinfection significantly decreased than before disinfection. In the clinical trials to evaluate healthcare-associated infections, MDROs incidence rate (per 10,000 patient days) after intervention significantly decreased compared to before intervention.

The effectiveness assessment of Methicillin-resistant *Staphylococcus aureus* (MRSA), Vancomycin-resistant Enterococci (VRE), Multidrug-resistant *Acinetobacter baumannii* (MRAB), and *Clostridium difficile* (CD) was conducted in most studies, including preceding literature[9,10]. However, there are limited data evaluated an efficacy of UV and HP against CPE[11].

The objective of this study was to compare the microbiological efficacy of CPE using ultraviolet-C device (UV-C) and aerosolized hydrogen peroxide system (aHP) for room decontamination in a healthcare setting. This is the first study on the efficacy of UV-C and aHP against CPE simultaneously.

Table 1. Summary of research on effectiveness of UV and HP

1. Efficacy on reduction MDROs on carriers					
Author (Year)	Method	Period (Months)	Hospital type	MDROs	Log_{10} reduction direct (indirect)
Rutala (2010)[12]	UV-C	9	Academic	MRSA VRE MRAB CD	4.31 (3.85) 3.9 (3.25) 4.21 (3.79) 4.04 (2.43)
Piskin (2011)[13]	aHP	-	-	MRSA AB	4.25 4.34
Havil (2012)[11]	UV-C, HPV	4	Community	CD	UV-C: 2.2; HPV: 6

1. Efficacy on reduction MDROs on carriers

Author (Year)	Method	Period (Months)	Hospital type	MDROs	Log_{10} reduction direct (indirect)
Lemmen (2015)[14]	HPV	–	–	MRSA	4.4
				VRE	4.1
				MRAB	5.1
Kanamori (2016)[15]	UV-C	–	Community	MRSA	1 cycle: 5.27 (4.17); 2 cycle: 5.82 (4.55)
				CRE	1 cycle: 5.74 (4.53); 2 cycle: 6.61 (5.39)
Rock (2016)[16]	UV-C	4	Academic	CRE	6

2. Effectiveness on reducing MDROs in contaminated patient rooms

Author (Year)	Method	Period (Months)	Hospital type	MDROs	Positive rate (%)	Log_{10} reduction	Reduction rate (%)
Otter (2017)[17]	HPV	–	Academic	MRSA GNR	40 to 3 10 to 0	NS	93 100
Shapey (2008)[18]	aHP	3	Community	CD	23.6 to 3.4 (P<0.001)	NS	86
Boyce (2008)[19]	HPV	–	–	CD	25.6 to 0 (P<0.001)	NS	100

2. Effectiveness on reducing MDROs in contaminated patient rooms

Author (Year)	Method	Period (Months)	Hospital type	MDROs	Positive rate (%)	Log_{10} reduction	Reduction rate (%)
Rutala (2010)[8]	UV-C	9	Academic	MRSA	20.3 to 0.5 (P<0.001)	1.3	98
Anderson (2013)[20]	UV-C	3	Community	VRE	11 to 1 (P<0.001)	1.68	91
				AB	13 to 3 (P<0.001)	1.71	77
				CD	10 to 5	1.16	50

3. Clinical trials for terminal room disinfection to reduce healthcare-associated infections

Author (Year)	Method	Design	Period (Months)	Hospital type	MDROs	Incidence rate (per 10,000 pt days)
Passaretti (2013)[21]	HPV	Prospective cohort	30	Academic	MRSA	23.0 to 12.0 (P=0.03)
					VRE	72.0 to 24.0 (P<0.01)
					CD	24.0 to 10.0 (P=0.19)
Manian (2013)[22]	HPV	Before-after	35	Academic	CD	8.8 to 5.5 (P<0.001)
Haas (2014)[23]	UV-PX	Before-after	52	Academic	MRSA	4.5 to 3.3 (P=0.007)
					VRE	9.0 to 7.3 (P=0.002)
					MRGNB	5.2 to 4.2 (P=0.04)
					CD	7.9 to 6.5 (P=0.02)
Mitchell (2014)[24]	aHP	Before-after	84	Community	MRSA	9.0 to 5.3 (P<0.001)

3. Clinical trials for terminal room disinfection to reduce healthcare-associated infections

Author (Year)	Method	Design	Period (Months)	Hospital type	MDROs	Incidence rate (per 10,000 pt days)
Peques (2015)[25]	UV-C	Before-after	24	Academic	CD	30.34 to 22.85 (P=0.03)
Anderson (2017)[26]	UV-C	RCT	27	9 hospitals	MRSA VRE	50.3 to 35.3 (P=0.019) 63.4 to 29.4

Note: AB, *Acinetobacter baumannii*; aHP, aerosolized Hydrogen peroxide system; CD, *Clostridium difficile*; CRE, Carbapenem-resistant *Enterobacteriacea*e; GNR, Gram negative rods; HPV, Vaporized hydrogen peroxide system; MDROs, Multidrug-resistant organisms; MRAB, Multidrug-resistant *Acinetobacter baumannii*; MRGNB, Multidrug-resistant gram negative bacilli; MRSA, Multidrug-resistant *Staphlycoccus aureus*; NS, Not stated; RCT, Randomized control trial; UV-C, Ultraviolet-C device; UV-PX, Ultraviolet-pulsed xenon device; VRE, Vancomycin-resistant Enterococci

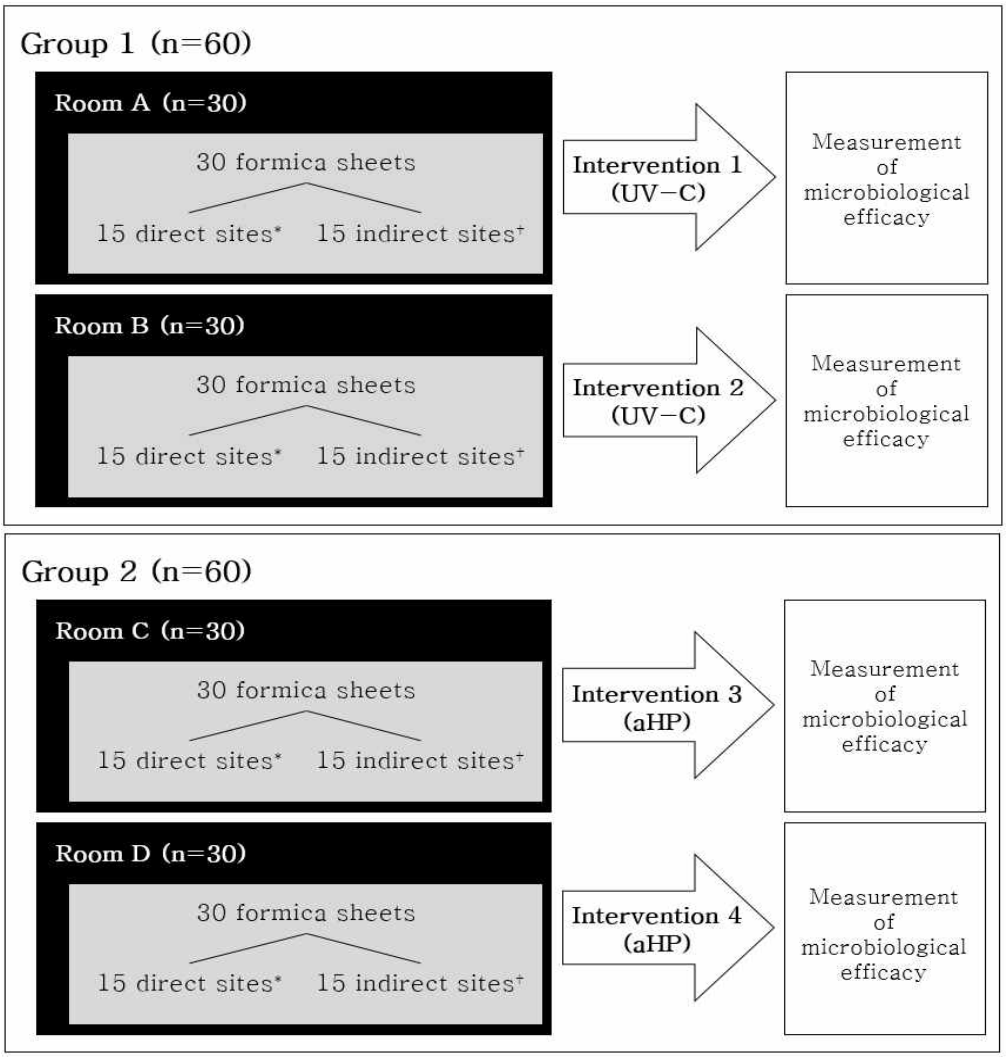
II. Method

1. Study design

This study was conducted at Asan Medical Center, tertiary hospital in Seoul, Korea from May to October, 2019. A total of four empty single rooms were applied with two UV-C (Group 1) and two aHP (Group 2), respectively. All four single rooms were the same structure with bathroom, with the room of 38.9 m^3, the bathroom of 9.4 m^3 and total area of 48.3 m^3. Thirty formica sheets contaminated with CPE were placed in or taped to the designated site of each room, and 15 were at UV direct sites (laser pointer pass) and 15 were at UV indirect sites (laser pointer didn' t pass), respectively. The efficacy of CPE decontamination was identified after UV-C and aHP intervention. Detailed study design is shown in Figure 1, and detailed location and photo of formica sheets are shown in Table 2.

It was not possible to attach formica sheets inside sink drain in the bathroom. So sink drains in the rooms

previously occupied by a patient with CPE were sampled separately using a sterilized brush before and after "no-touch" methods. A total of eight sink drains were applied with four UV-C and four aHP, respectively. All drains were of the same shape and were located in the same structure bathrooms of 9.4 m^3. Of four sink drains applied UV-C, two were cultured at a superficial level and two were cultured at a deep level. Similarly of four sink drains applied aHP, two were cultured at a superficial level and two were cultured at a deep level. 500 ppm sodium hypochlorite was used for disinfection of a patient with CPE discharge room and bathroom at our institution. So in order to take into account that CPE removed due to bleach, the same drain was cultured at three time points: before manual cleaning, after manual cleaning, and after UV-C or aHP intervention. Detailed study design is shown in Figure 2 and drawing and photo of sink drain with cultured level are shown in Figure 3.

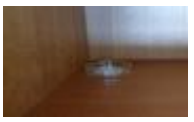


*Direct sites: the sites thorough which laser pointer pass
†Indirect sites: the sites thorough which laser pointer cannot pass
Note: aHP, aerosolized Hydrogen peroxide system; UV-C, Ultraviolet-C device

Figure 1. Main study design

Table 2. Location and photo of formica sheets

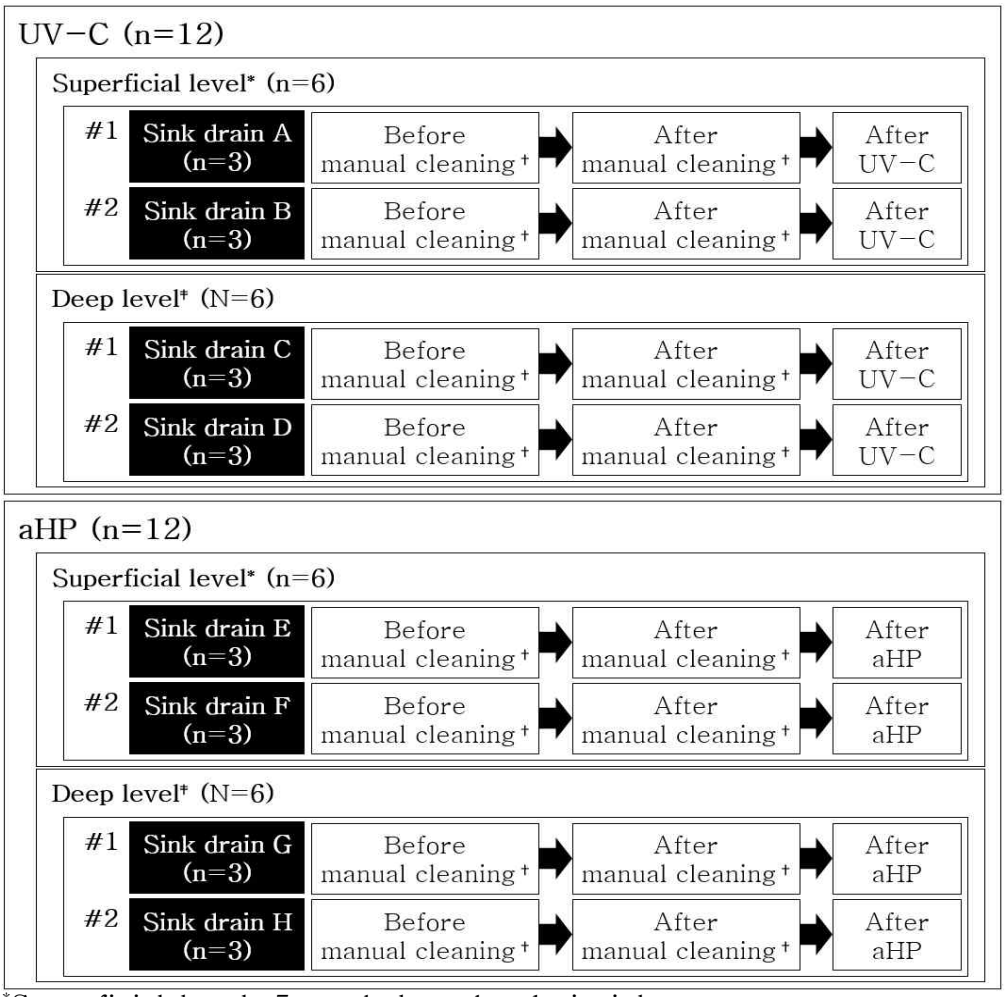
No.	UV line of sight*	Area	Site	Photo
1	Direct	room	bedside rail surface	
2	Direct	room	closet surface	
3	Direct	room	CPS (Control panel systems) panel surface	
4	Direct	room	top of the bed frame	
5	Direct	room	top of the bedside table	
6	Direct	room	top of the caregiver's bed	
7	Direct	room	top of the mattress	
8	Direct	room	top of the overbed table	
9	Direct	room	top of the TV cabinet	

No.	UV line of sight*	Area	Site	Photo
10	Direct	room	top of the window frame	
11	Indirect	room	footside under the bed frame	
12	Indirect	room	headside under the bed frame	
13	Indirect	room	inside the bottom of the bedside table	
14	Indirect	room	inside the bottom of the closet	
15	Indirect	room	inside the FCU (Fan coil unit)	
16	Indirect	room	inside the top of the bedside table	
17	Indirect	room	inside the top of the closet	
18	Indirect	room	inside the TV cabinet	

No.	UV line of sight*	Area	Site	Photo
19	Indirect	room	under the caregiver's bed	
20	Indirect	room	under the mattress	
21	Direct	bathroom	sink basin surface	
22	Direct	bathroom	sink workstation surface	
23	Direct	bathroom	top of the paper towel case	
24	Direct	bathroom	top of the sanitary products container	
25	Direct	bathroom	top of the toilet seat	
26	Indirect	bathroom	back of the toilet lid	
27	Indirect	bathroom	facing the ceiling; top of the bathroom rack	

No.	UV line of sight*	Area	Site	Photo
28	Indirect	bathroom	facing the wall; floor side of toilet	
29	Indirect	bathroom	facing the wall; toilet surface	
30	Indirect	bathroom	floor the bottom of the sink	

*Direct: the sites thorough which laser pointer pass; Indirect: the sites thorough which laser pointer cannot pass



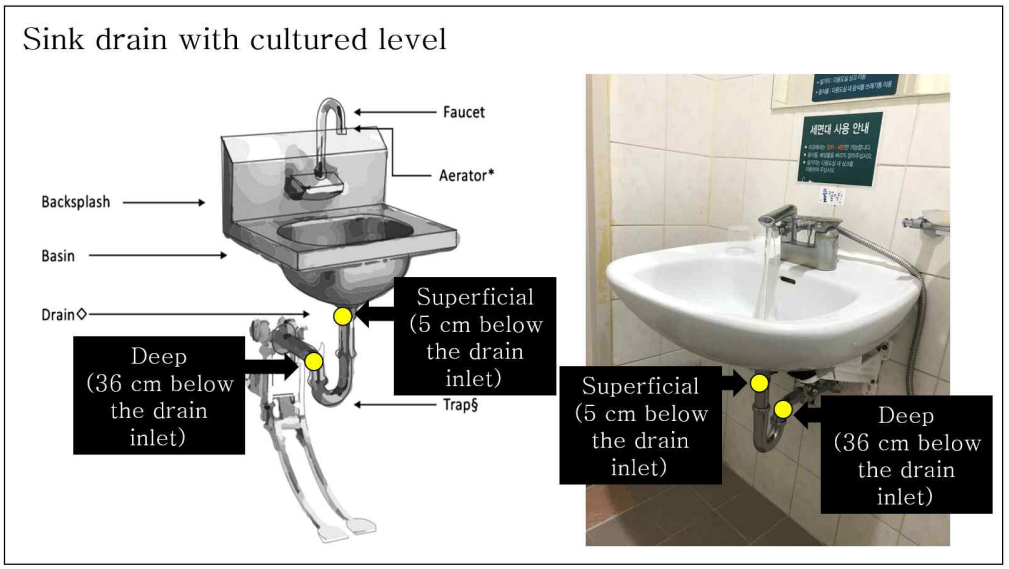
*Superficial level: 5 cm below the drain inlet

†manual cleaning was performed using 500 ppm sodium hypochlorite

‡Deep level: 36 cm below the drain inlet

Note: aHP, aerosolized Hydrogen peroxide system; UV−C, Ultraviolet−C device

Figure 2. Study design about sink drain



Note: The Left figure is a drawing of the sink (image courtesy of Bryan Graham Huck[27]) with cultured level, and the right figure is a actual photo of sink with cultured level.

Figure 3. Drawing and photo of sink drain with cultured level

2. Test organism and Formica sheets

Among the CPE, Klebsiella pneumoniae Carbapenemase (KPC)-producing *Klebsiella pnuemoniae* (clinical isolates) with the highest incidence rate of strains at our institution was selected as test organism. The 8 cm diameter formica sheets were attached to the center of the patri dish and

sterilized individually. Approximate bacterial suspension of KPC-producing *K. pneumoniae* was prepared in concentrations of 1.5×10^9 colony-forming units (CFUs)/ml by adjusting the turbidity equivalent to MacFarland 5.0 standard. A 10 ㎕ of 1.5×10^9 CFUs/ml of the KPC-producing *K. pneumoniae* was spread evenly on each formica sheet using a sterile plastic spreader. In other words, it was estimated that 1.5×10^7 CFUs per formica sheet was applied. The actual CFUs per formica sheet was evaluated as recovery rate by cutting and vortexing the formica sheets.

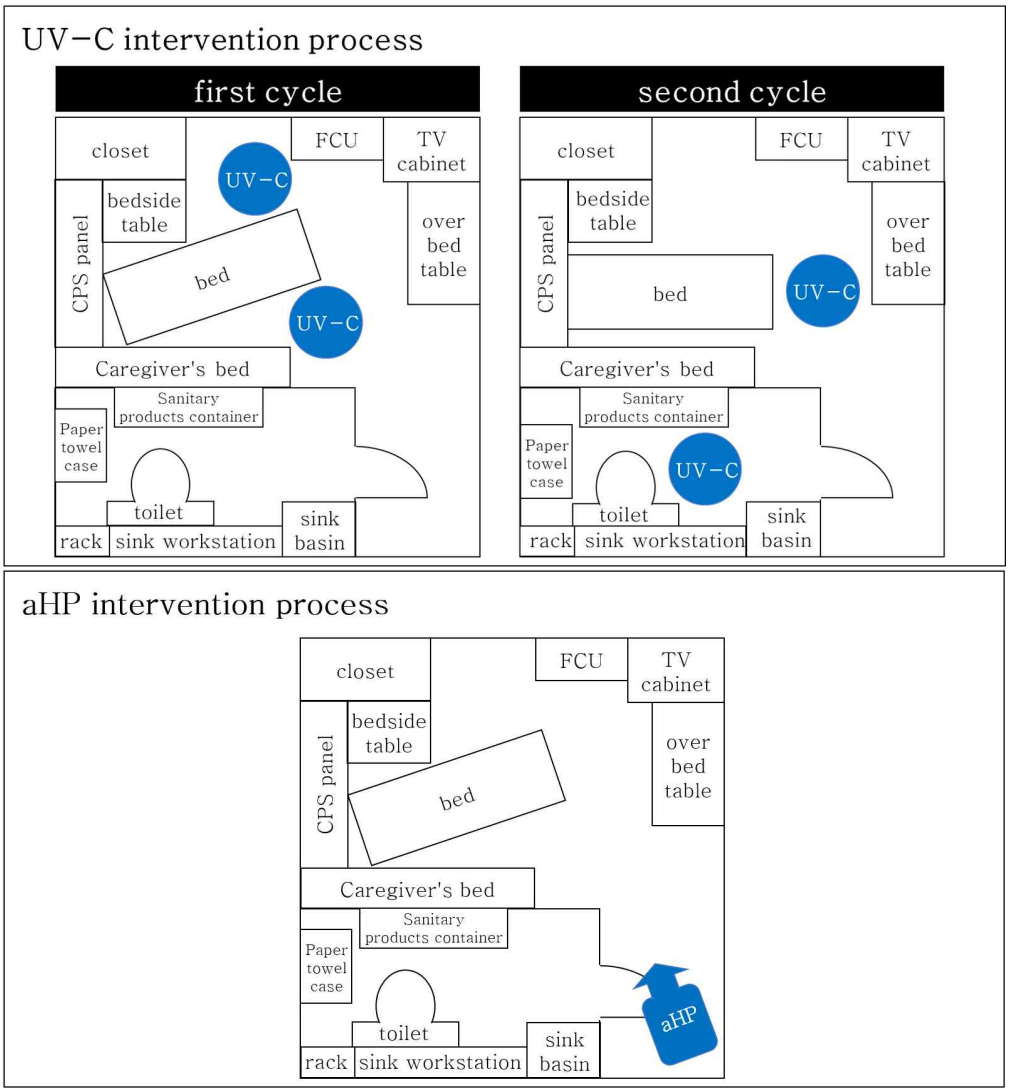
3. Intervention process

Ultraviolet-C device (UV-C) with a wavelength of 254 nm was used for UV intervention (ASEPTX. 2X SILVER; SANUVOX, Canada). The manufacturer claims that there are eight UV-C lamps in one unit and this device delivers a dose of 190,000 ㎼sec/cm^2 at a distance of 1.8 m for 13 minutes (1 cycle). A total of 2 cycles were applied, taking 26 minutes of run time. In the first cycle, two units were placed at both sides of the bed and one unit was placed at the foot of the bed and one unit was placed in the center

of the bathroom in the second cycle. Since UV-C is known to have no effect on where the shadow falls, the doors of all drawers and bathroom were open and the mattress was placed at an angle in the bed frame to minimize the shadow. In addition, the entire room door was closed for human access control. All personnel, including patients and healthcare workers, were immediately accessible after 2 cycles were finished. The total run time, including the pre-preparation time and the time to move machine after the first cycle, was about 30 minutes.

aerosolized Hydrogen peroxide system (aHP) was used for HP intervention (NOCOSPRAY; Oxy Pharm, France). The manufacturer claims that this system is used by attaching NOCOLYSE solution including 6 % hydrogen peroxide and 17 ppm silver nitrate to the system. Also, there is a 22,000 rpm turbin at 80 m/sec in the system, so it can aerosolize NOCOLYSE solution. aHP was applied for 2 hours by setting 300 ml per room, which was 6 times the area dimension (48.3 × 6 = 289.8), according to the manufacturer's IFU (Indications for Use). aHP was placed in front of the bathroom with the door open. And the direction of solution injection was set towards the bed. The mattress and pillow cover and curtain were removed before

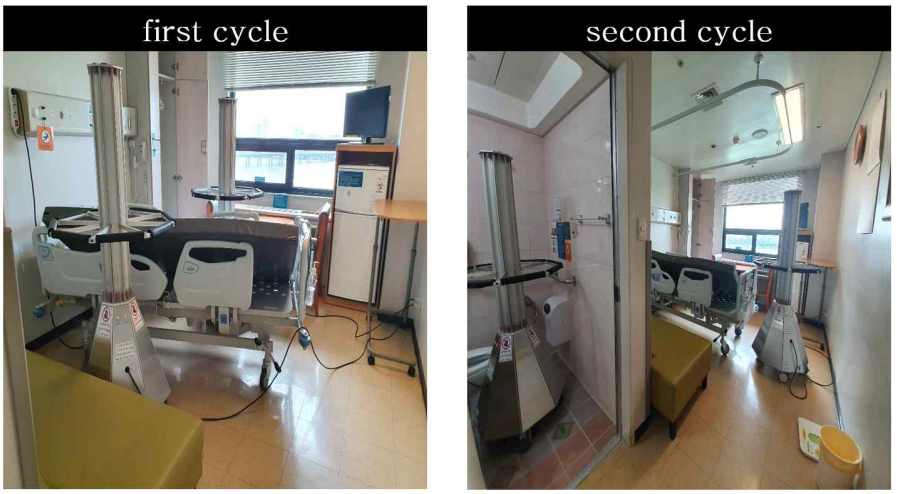
treatment, as linen material is known to decrease effect by absortion aerosols. Also, because it is difficult for aerosols to penetrate into the closed space, the mattress was placed obliquely on the bed frame, with all drawers open, just like UV-C. Facility service staff blocked air conditioning and smoke detection with tape before intervention. After everyone came out, the main door was sealed with tape and the system started with a remote control. After 2 hours of run time, air conditioning and smoke detector shut-off were restored and ventilated for 1 hour until hydrogen peroxide dropped less than or equal to 1 ppm with the main door open. The total application time, including the pre-preparation and post-ventilation time, was approximately 3 hours and 30 minutes. Detailed positioning of the machine in each room is shown in Figure 4 and the photos applied in an actual room are shown in Figure 5.



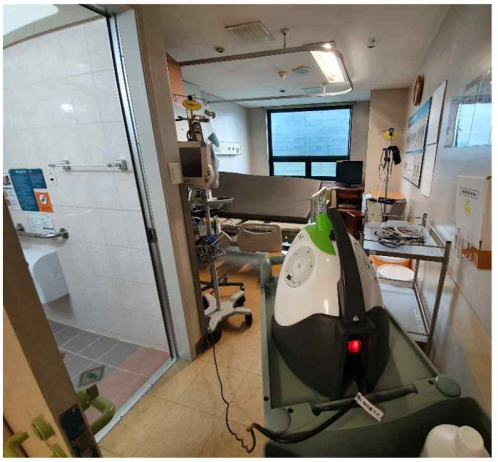
Note: aHP, aerosolized Hydrogen peroxide system; CPS, Control panel systems; FCU, Fan coil unit, UV-C, Ultraviolet-C device

Figure 4. Schematic design of rooms showing positioning of UV-C and aHP

UV-C intervention process



aHP intervention process



Note: aHP, aerosolized Hydrogen peroxide system; UV-C, Ultraviolet-C device

Figure 5. Photo with UV-C and aHP in the actual room

4. Microbial reduction assess

After intervention, each formica sheet was cultured using applicator (APP Count-Tact; BioMerieux, France) with Rodac plates containing naturalizing agar (Irradiated Count-Tact 3P agar; BioMerieux, France). The applicator equipped with the Rodac plates cultured for 10 seconds at a pressure of 500 ± 50 g on the desired surface according to ISO 18593, so the organisms on the surface could be stamped on Rodac plates objectively. Rodac plates were incubated at 37℃ for 24 hours, and after incubation, the CFUs on each plate was counted.

To measure the microbiological efficacy, three methods were used: CFUs, log_{10} reduction, and decontamination rate. CFUs was calculated as median CFUs. Log_{10} reduction was defined as the ratio of the CFUs of before and after intervention using log scale. The numerator was the CFUs on the actual formica sheet and the denominator was the CFUs on Rodac plate after treatment. Maximum log_{10} reduction rate was deined as the % calculation of the ratio of the number of plates achived maxium log_{10} reduction to the total number of plates. Decontamination rate was defined as the % calculation of the ratio of the number of

clean plates to the total number of plates.

Pilot test to check of effectiveness of UV-C and aHP by culturing the environmental surfaces directly using Rodac plates was conducted at out institution. Plates less than 2.5 CFUs/cm^2 are considered scanty growth and defined as clean plates[28,29]. As a result of calculating decontamination rate using the preceding paper, UV-C and aHP were equally measured 100%, so it was difficult to compare. Accordingly, the criteria of clean plates was modified more strictly from 2.5 CFUs/cm^2 to 2.5 CFUs per Rodac plate (same as 0.05 CFUs/cm^2). That is, in this study, modified decontamination rate defined as the % calculation of the ratio of the number of less than 2.5 CFUs per plate to the total number of plates was used.

To assess the decontamination of sink drain, a sterilized brush (5 mm diameter Cleaning brush ; Richard Wolf, Germany) was put inside drain and scratched all the areas within the drain. The brush was consisted of a 5 cm-long cleaning brush and a 32 cm-long stainless steel stick. Using this brush, sink drain was cultured at two levels: a superficial level (5 cm below the drain inlet as length of the cleaning brush) and a deep level (36 cm below the drain inlet as full length except 1 cm of hand held area).

The brush carefully pull out of sink drain was put into a tube (50 ml Polypropylene conical tube; FALCON, USA) containing 20 ml sterilized distilled water and shaked to allow debris to get out of the brush. After inoculating 100 ㎕ (0.1 ml) of the tube solution into the CHROMagar plate, quadrant streaking method was used for Carbapenem-resistant gram negative bacilli (CRGNB) identification. CHROMagar plates were incubated at 37℃ for 24 hours and after incubation, semi-quantitative bacterial counts were used. The results of the semi-quantitative method were expressed in five ways: "many isolated", "moderate isolated", "few isolated", "rare isolated", and "not isolated".

5. Statistical analysis

In this study, I tried to test the hypothesis that there was a significant difference of the microbiological efficacy against CPE between UV-C and aHP. A sample size was calculated based pilot test results previously conducted at our institution (modified decontamination rate UV-C 87.5%, aHP 100%), a significant level of 5% and 80% power. As a result, the total number of sample size was 120, with 60

for each intervention.

CFUs and $\log_{10}$ reduction was a continuous variable, expressed as median (IQR or min−max) and Wilcoxon rank sum test was used for analysis. Maximum $\log_{10}$ reduction rate, modified decontamination rate, and decontamination rate was a categorical variable, displayed as n (%) and was tested using chi−squared test or Fisher's exact test. Statistical analysis was conducted using R software version 3.5.0 and a probability value of $P < 0.05$ was considered significant.

III. Results

1. CPE log_{10} inoculum on formica sheets

1.5×10^7 CFUs KPC-producing *K. pneumoniae* was spread on each formica sheet. The recovery rate measured by cutting and vortexing the formica sheets in the laboratory was 5.4%. In other words, the actual CFUs per formica sheet was 5.91 log_{10} inoculum (Table 3).

Table 3. CPE log_{10} inoculum on formica sheets

	KPC-producing *K. pneumoniae*
Mean bacterial count in the working suspension (CFUs/ml)	1.5×10^9
Mean bacterial count spread on the formica sheets (CFUs per formica sheet)	1.5×10^7
Mean recovery rate after cutting and vortexing formica sheets (%)	5.4%
Mean log_{10} inoculum per formica sheet reflecting recovery rate	5.91

Note: CFUs, Colony-foaming units; CPE, Carbapenemase-producing *Enterobacteriaceae*; KPC, Klebsiella pnuemoniae Carbapenemase

2. Microbiological efficacy of UV-C and aHP

2.1. Comparison of CFUs and log_{10} reduction

A total of 60 sites were sampled after UV-C intervention and median CFUs (IQR) was 2.5 (0-18.3). At UV direct sites, median CFUs (IQR) was 0 (0-1) and at UV indirect sites, median CFUs (IQR) was 19.5 (5.3-51.3). Same as UV-C, a total of 60 plates were cultured after aHP treatment and median CFUs (IQR) was 3.5 (0-13.8). At UV direct sites, median CFUs (IQR) was 2 (0-8.8) and at UV indirect sites, median CFUs (IQR) was 7 (1-23.3). There was no significant difference in total median CFUs between two methods (P=0.99). At UV direct sites, UV-C showed lower median CFUs than aHP (P=0.01). Conversely, at UV indirect sites, aHP showed lower median CFUs than UV-C (P=0.02) (Table 4).

Median log_{10} reduction (min-max) calculated using CFUs remaining on formica sheets contaminated with 5.9 log_{10} inoculum following use of UV-C was 5.52 (3.53-5.91). At UV direct sites, median log_{10} reduction (min-max) was 5.91 (5.13-5.91) and at UV indirect sites, median log_{10} reduction (min-max) was 4.63 (3.53-5.19). In the same

way, median $\log_{10}$ reduction (min−max) measured after aHP intervention was 5.37 (3.54−5.91). At UV direct sites, median $\log_{10}$ reduction (min−max) was 5.61 (4.75−5.91) and at UV indirect sites, median $\log_{10}$ reduction (min−max) was 5.07 (3.54−5.91). There was no significant difference in median $\log_{10}$ reduction between two methods (P=0.86). Where the laser pointer was visible, UV−C showed higher median $\log_{10}$ reduction than aHP (P=0.002) and where the laser pointer was not visible, aHP showed higher median $\log_{10}$ reduction than UV−C (P=0.02) (Table 4).

Of the total 60 plates cultured after UV−C intervention, 27 plates achived maximum $\log_{10}$ reduction, resulting in a maximum $\log_{10}$ reduction rate of 45.0% (27/60). Maximum $\log_{10}$ reduction rate was 80.0% (24/30) and 10.0% (3/30) at UV direct and indirect sites, respectively. Same as UV−C, Of the total 60 plates cultured following use of aHP, 22 plates achived maximum $\log_{10}$ reduction with a maximum $\log_{10}$ reduction rate of 36.7% (22/60). Maximum $\log_{10}$ reduction rate was 43.3% (13/30) and 30.0% (9/30) at UV direct and indirect sites, respectively. There was no significant difference between two methods (P=0.46). At UV direct sites, UV−C showed higher maximum $\log_{10}$ reduction rate than aHP (P=0.01). At UV indirect sites,

maximum $\log_{10}$ reduction rate was 10.0% (3/30) for UV-C and 30.0%% (9/30) for aHP and did not show significant difference between two methods (Table 4).

2.1. Comparison of decontamination rate

Of the total 60 plates cultured after UV-C intervention, 30 plates were identified as clean plates with less than 2.5 CFUs per plate, resulting in a total modified decontamination rate of 50.0% (30/60). Modified decontamination rate was 83.3% (25/30) and 16.7% (5/30) at UV direct and indirect sites, respectively. As same method of UV-C, Of the total 60 plates cultured following use of aHP, 27 plates were identified as clean plates with a total modified decontamination rate of 45.0% (27/60). Modified decontamination rate was 53.3% (16/30) and 36.7% (11/30) at UV direct and indirect sites, respectively. There was no significant difference between two methods (P=0.71). At UV direct sites, UV-C showed higher modified decontamination rate than aHP (P=0.03) and at UV indirect sites, aHP showed higher modified decontamination rate than UV-C (P=0.01) (Table 4).

Decontamination rate suggested in the preceding

study[28,29] was 95.0% (57/60) for UV-C and 98.3% (59/60) for aHP and there was no significant difference between two methods. At UV direct sites, decontamination rate of both methods was 100%. At UV indirect sites, decontamination rate was 90.0% (27/30) for UV-C and 96.7% (29/30) for aHP and did not show significant difference between two methods (Table 4).

Table 4. Microbiological efficacy of UV-C and aHP

		UV-C	aHP	P-value*
Median CFUs (IQR)	Total (n=60)	2.5 (0-18.3)	3.5 (0-13.8)	0.99
	UV direct sites† (n=30)	0 (0-1)	2 (0-8.8)	0.01
	UV indirect sites‡ (n=30)	19.5 (5.3-51.3)	7 (1-23.3)	0.02
Median log_{10} reduction (min-max)	Total (n=60)	5.52 (3.53-5.91)	5.37 (3.54-5.91)	0.86
	UV direct sites† (n=30)	5.91 (5.13-5.91)	5.61 (4.57-5.91)	0.002
	UV indirect sites‡ (n=30)	4.63 (3.53-5.19)	5.07 (3.54-5.91)	0.02

		UV-C	aHP	P-value*
Maximum log_{10} reduction rate	Total (n=60)	27 (45.0%)	22 (36.7%)	0.46
	UV direct sites† (n=30)	24 (80.0%)	13 (43.3%)	0.01
	UV indirect sites‡ (n=30)	3 (10.0%)	9 (30.0%)	0.11
Modified decontamination rate	Total (n=60)	30 (50.0%)	27 (45.0%)	0.71
	UV direct sites† (n=30)	25 (83.3%)	16 (53.3%)	0.03
	UV indirect sites‡ (n=30)	5 (16.7%)	11 (36.7%)	0.01
Decontamination rate	Total (n=60)	57 (95.0%)	59 (98.3%)	0.32
	UV direct sites† (n=30)	30 (100.0%)	30 (100.0%)	-
	UV indirect sites‡ (n=30)	27 (90.0%)	29 (96.7%)	0.32

*P-value of median CFUs and median log_{10} reduction was calculated by Wilcoxon rank sum test and P-value of maximum log_{10} reduction rate, modified decontamination rate, and decontamination rate was calculated by chi-squared test or Fisher's exact test

†Direct sites: the sites thorough which laser pointer pass

‡Indirect sites: the sites thorough which laser pointer cannot pass

Note: aHP, aerosolized Hydrogen peroxide system; CFU, Colony-foaming units; UV-C, Ultraviolet-C device

3. CFUs by specific sites after UV-C and aHP

After UV-C intervention, 20 surfaces in the room and 10 surfaces in the bathroom were cultured and median CFUs was 10.5 and 3.5, respectively. In the room, median CFUs at UV direct sites was lower than indirect sites (0 vs. 16). Also, in the bathroom, median CFUs at UV direct sites was lower than indirect sites (0.5 vs. 41.5). Of the total 30 surfaces, the greatest CFUs was observed on the sites back of the toilet lid (median, 137.5 CFUs) followed by under the caregiver' s bed (median, 113.5 CFUs) and headside under the bed frames (median, 106 CFUs) (Table 5).

In the same way as UV-C, 20 surfaces in the room and 10 surfaces in the bathroom were cultured following use of aHP and median CFUs was 2 and 10, respectively. In the room, median CFUs at UV direct sites was lower than indirect sites (0 vs. 7). In contrast, in the bathroom, median CFUs at UV indirect sites was lower than direct sites (7.5 vs. 11). Of the total 30 surfaces, the greatest CFUs was observed on the sites under the caregiver' s bed (median, 126 CFUs) (Table 5).

Table 5. Median CFUs by sites after UV-C and aHP

Specific site by area	UV-C	aHP	Total
Room (n=80)	10.5	2	2
UV direct sites† (n=40)	0	0	0
bedside rail surface (n=4)	0.5	1	0.5
closet surface (n=4)	0	6	1
CPS panel surface (n=4)	0	0	0
top of the bed frame (n=4)	1.5	3.5	1.5
top of the bedside table (n=4)	2.5	1.5	1.5
top of the caregiver's bed (n=4)	0	1	0
top of the mattress (n=4)	0	0	0
top of the overbed table (n=4)	0	0	0
top of the TV cabinet (n=4)	0.5	3	0.5
top of the window frame (n=4)	3	10.5	5

Specific site by area	UV-C	aHP	Total
Room (n=80)	10.5	2	2
UV indirect sites‡ (n=40)	16	7	11
footside under the bed frame (n=4)	33	6	9.5
headside under the bed frame (n=4)	106	7	18
inside the bottom of the bedside table (n=4)	3.5	7	4
inside the bottom of the closet (n=4)	37	25.5	31
inside the FCU (n=4)	36.5	13	21
inside the top of the bedside table (n=4)	1.5	2	1.5
inside the top of the closet (n=4)	9	12.5	9
inside the TV cabinet (n=4)	38	9	22.5
under the caregiver's bed (n=4)	113.5	126	114.5
under the mattress (n=4)	5	2	2

Specific site by area	UV-C	aHP	Total
Bathroom (n=40)	3.5	10	5.5
UV direct sites† (n=20)	0.5	11	3.5
sink basin surface (n=4)	2.5	21	12.5
sink workstation surface (n=4)	2	10	4
top of the paper towel case (n=4)	2	15	6
top of the sanitary products container (n=4)	0	6.5	0
top of the toilet seat (n=4)	0.5	4	0.5
UV indirect sites‡ (n=20)	41.5	7.5	18.5
back of the toilet lid (n=4)	137.5	25	43.5
facing the ceiling; top of the bathroom rack (n=4)	34	5.5	7
facing the wall; floor side of toilet (n=4)	79	23.5	46
facing the wall; toilet surface (n=4)	28.5	13	17.5
floor the bottom of the sink (n=4)	3	26.5	5

†Direct sites: the sites thorough which laser pointer pass

‡Indirect sites: the sites thorough which laser pointer cannot pass

Note: aHP, aerosolized Hydrogen peroxide system; CFUs, Colony-foaming units; CPS, Control panel systems; FCU, Fan coil unit; UV-C, Ultraviolet-C device

4. Decontamination of sink drain

CRGNB were mostly many isolated in sink drains used by patients with CPE regardless of the cultured level before manual cleaning. CRGNB decreased in four of the eight sink drains after manual cleaning compared to before manual cleaning (UV-C: Deep #1, Deep #2, aHP: Superficial #2, Deep #1). CRGNB also decreased in five of seven sink drains (exclude UV-C Deep #1 due to "not isolated") after UV-C or aHP intervention compared to after manual cleaning (UV-C: Superficial #2, Deep #2, aHP: Superficial #1, Deep #1, Deep #2) (Table 6).

Table 6. Semi-quantitative results of CRGNB in sink drain

		Before manual cleaning*	After manual cleaning*	After intervention
UV-C (n=12)	Superficial† #1 (n=3)	many	many	many
	Superficial† #2 (n=3)	few	few	not isolated
	Deep‡ #1 (n=3)	many	not isolated	not isolated
	Deep‡ #2 (n=3)	many	moderate	few
aHP (n=12)	Superficial† #1 (n=3)	many	many	few
	Superficial† #2 (n=3)	moderate§	rare§	rare
	Deep‡ #1 (n=3)	many‖	rare	not isolated
	Deep‡ #2 (n=3)	many	many	few

*manual cleaning was performed using 500 ppm sodium hypochlorite
†Superficial level: 5 cm below the drain inlet
‡Deep level: 36 cm below the drain inlet
§Stenotrophomonas maltophilia was identified
‖Carbapenem-resistant Pseudomonas aeruginosa was identified
Note: aHP, aerosolized hydrogen peroxide system; CRGNB, Carbapenem-resistant gram negative bacilli; UV-C, Ultraviolet-C device

IV. Discussion

In the preceding paper comparing the microbiological efficacy of UV and HP for carriers contaminated *Clostridium difficile*, hydrogen peroxide vapor showed higher mean $\log_{10}$ reduction than UV-C (6 vs. 2.2)[11]. It also concluded that UV-C had lower efficacy, particularly where there were out of direct line of UV sight. In this study, aHP rather than HPV was used and KPC-producing *K. pneumoniae* were selected by test organism. As a result, it confirmed that UV-C was less effective than aHP where the light were not directly exposed, as was the result with preceding study. However, where the light was directly exposed, both median $\log_{10}$ reduction and modified decontamination rate of UV-C were significantly higher than aHP, indicating that UV-C was more effective. Furthermore, regardless of whether or not laser point was visible, there were no significant differences on decontamination rate suggested in the preceding study[28,29] between two methods.

120 formica sheets contaminated approximately 10^6 CFUs CPE were used in this experiment. However, in actual health care settings, even if these pathogens are

highly contaminated, the amount of microbes is generally known to be less than 10 to 100 CFUs per plate[30]. Thus 2 $\log_{10}$ reduction based on maximum 100 CFUs per plate are considered clinically effective[31]. In this experiment, median $\log_{10}$ reduction is 5.52 and 5.37 following treatment of UV-C and aHP, respectively. Therefore both two methods could be considered clinically effective.

In previously published studies, UV-C demonstrated higher $\log_{10}$ reduction at UV direct sites than indirect sites[13,16]. In this experiment, at UV direct sites, UV-C also showed higher median $\log_{10}$ reduction than indirect sites (5.91 vs. 4.63, $P<0.001$). Similarly, modified decontamination rate was higher at UV direct sites than indirect sites (83.3% vs. 16.7%, $P<0.001$).

Because UV-C radiations can penetrate any surfaces that receives light directly, UV-C is more effective at UV direct sites. However, it is known that surfaces where the light is not directly exposed can also be reflected by other surfaces that receive light, so there may also be an indirect effect of UV-C radiation at UV indirect sites[32]. It also concluded that at UV direct sites, UV-C worked significantly better than UV indirect sites. However, regardless of the direct exposure of light, UV-C could be

considered as clinically effective with $\log_{10}$ reduction greater than 2. In other words, UV-C worked at indirect sites because of being reflected by surrounding objects or walls, even where light was not directly exposed.

Following UV-C treatment, the rear of the toilet lid was identified with the highest median CFUs by sites. If the definition of a clean plate is defined as less than 2.5 CFUs/cm^2 [28,29], the plate was 4.7 CFUs/cm^2, so it was defined by a dirty plate. In this experiment, UV-C was operated with the toilet lid fully opened and a formica sheet placed vertically in a narrow space between the toilet lid and the toilet tank. I assumed that this formica sheet was identified as a dirty plate because it was in a very narrow space in which light could not be reflected from its surroundings. This was in line with a previous paper that found that there was no exposure of UV light to the overlapping areas of the shower curtain so CRE grew too numerous to count on the curtain[16]. In the case of UV-C application as area decontamination, it will be necessary to minimize overlapping spaces so that all surfaces could be exposed to UV light. It is also known that when UV-C is applied in the room of UV-reflective paint coated wall, the run time was significantly reduced and $\log_{10}$ reduction

increased especially at UV indirect sites[33,34,35]. To perform more effective and efficient disinfection using UV-C, UV-reflective wall coating also might be considered.

According to the previous paper comparing the decontamination efficacy of UV-C and aHP, aHP was not affected by line of sight unlike UV-C[11]. Similarly, in this experiment, there was no significant difference in $\log_{10}$ reduction after aHP intervention between at UV direct and indirect sites (5.61 vs. 5.07, P=0.07). Also, modified decontamination rate was not different between at UV direct and indirect sites (53.3% vs. 36.7%, P=0.10).

Even if aHP works better than UV-C where a shadow fall, hydrogen peroxide aerosols are not sprayed through closed spaces. In the preceding paper assessing the decontamination efficacy of aHP for carriers contaminated MRSA and *Acinetobacter baumannii*, it found that the presence of barriers cause failure in the effect of aHP[13].

Following aHP treatment, under the caregiver's bed was identified with the highest median CFUs by sites. If the definition of a clean plate is defined as less than 2.5 CFUs/cm^2 [28,29], the plate was 4.7 CFUs/cm^2, so it was defined by a dirty plate. In this experiment, the space

under the caregiver's bed was partially closed with the caregiver's bed mattress and the wall between the room and the bathroom. Thus, I hypothesize that this site was not sprayed well by hydrogen peroxide aerosols. If aHP is used for as area decontamination, it will be necessary to place space between the barrier (especially wall between the room and the bathroom) and the object so that the barrier does not reduce the effect of aHP.

A systematic literature review of Carbapenem-resistant organism outbreaks found that sink drain/trap, sink basin, and sink faucet in healthcare setting were the most common reservoirs and especially *Enterobacteriacea*e was mostly identified in sink drains[36]. Also, there were report that despite daily disinfection of the patient with CPE room and bathroom with 500 ppm sodium hypochlorite, CPE was identified from the skin drain[37]. In this study, CRGNB were isolated from all sink drains used by patients with CPE regardless of the cultured depth. In addition, similar to the preceding study, in spite of the terminal cleaning using 500 ppm sodium hypochlorite, CRGNB were isolated all sink drains except one.

An experiment conducted under the similar conditions as the hospital environment reported that biofilm incubated sink

P-trap reached the strainer (same as drain inlet) in 7 days (average rate of 1 inch/day) and found in the strainers of the other horizontally connected sink drain[38]. There are two methods to remove biofilm from the sink drain: replacing the sink drain and pouring bleach in sink drain[36]. Procedure for pouring the bleach in skin drain is presented as follows: 1. locking certain parts of drain, 2. pouring a high concentration bleach (5,000 ppm) in the drain, 3. opening the drain at once after contact time and 4. rinsing the drain[39]. In this experiment, the sink drain was not disinfected by the pouring method, but the surface of the sink basin was generally disinfected by 500 ppm bleach and rinsing it with water. As a result, CRGNB was not completely eliminated except one drain.

Since the pouring bleach method is labor intensive, automatically cleaning and disinfecting sink drain using electrochemically activated solutions is also suggested[40]. So in this experiment, I aimed to determine if the "no-touch" methods are effective for decontamination sink drain. As a result, It found that CRGNB was decreased after intervention than before intervention and CRGNB was eliminated in 3 sink drains.

UV-C and aHP were pros and cons of each. UV-C did

not require blocking of air conditioning and smoke detector, sealing the door and ventilation after application. It was residual free, so there was no health and safety concern. UV-C had a maintenance cost of 200 KRW (0.2 USD), which was cheaper than aHP (16,000 KRW (13.7 USD) based on 50 m^3). But machine costs were about 15 times more expensive than aHP. In addition, it was necessary for staff to wait at the door to prevent someone from entering and turning off automatically and change the positioning after first cycle. aHP required blocking of air conditioning and smoke detector and sealing the door. In addition, the remaining hydrogen peroxide must to be no more than 1 ppm for safety, so 1 hour of ventilation time was required after application. Unlike UV-C, it was not necessary for staff to wait in front of the door as the door was sealed during treatment.

Considering this study results and device-specific features, the following points are suggested. First, UV could be recommended for terminal disinfection in ward and operating rooms (OR) setting. A room and a bathroom of the ward have relatively fewer medical devices and OR has a large number of medical devices but a large area of space. Therefore, UV-C is more effective than aHP

because both places have fewer shadowing areas. In addition, when terminal disinfection of the multi-patient room is required, aHP, which has long run time, is difficult to use because patients and caregivers in the room have to be outside during treatment. Also, it may be difficult to apply aHP individual of the operating room, as heating, ventilation and air conditioning system is often linked together in rosette. Second, aHP might be recommended for area decontamination in intensive care unit (ICU) and emergency rooms (ER) setting. ICU and ER have relatively more medical equipment, so there are areas where it cannot be exposed to light from place to place. Therefore, aHP is more effective than UV-C. But, if there is a time limit until the next patient enters the room, UV-C could be applied. However, since detailed structures and characteristics may vary depending on the hospital, based on these suggestions, healthcare facilities healthcare facilities might choose between UV-C and aHP.

There are several limitations in this study. First, It was conducted in single-patient rooms at a single institution. So, it is difficult to expect the same result when applied in multi-patient rooms, ICU, OR and ER. Second, to assess microbial reduction formica surfaces experimentally

contaminated with CPE was used. Thus, it was difficult to confirm that there was a decrease in healthcare-associated infections, such as CPE incidence rate. So, multi-center clinical trials of area decontamination for various kinds of room to evaluate healthcare-associated infections are needed. Finally, sink drain experiment had a small sample size and semi-quantitative results as difficult method of statistical analysis. Therefore, the further studies on microbiological efficacy of disinfection inside sink drain using "no-touch" methods are needed.

V. Conclusions

In this study, I assessed the microbiological efficacy of disinfection using UV-C and aHP as area decontamination, additional methods followed by manual cleaning to prevent transmission to patients due to contaminated environmental surfaces in a single room at a single institution. As a result, both UV-C and aHP reduced bacterial contamination. aHP was significantly more effective at UV indirect sites, and UV-C was significantly more effective at UV direct sites. Also, regardless of the site where the light was exposed, it confirmed that both methods were clinically effective.

UV-C was not effective at the overlapping site, so it is necessary to minimize overlapping spaces before application so that all surfaces can be exposed to UV light. In addition, aHP was not effective at the object directly behind a barrier (such as a wall). Thus, it is necessary to place space between the wall and the object so that the barrier does not reduce the effect of aHP. Considering the merits and demerits of the machines and the results of this study, healthcare facilities might choose between UV-C and aHP.

It concluded that CRGNB was decreased after

"no-touch" method than before intervention and eliminated in 3 sink drains, finally. However, since this experiment was conducted with a small sample size and assessed by semi-quantitative method, additional studies are needed.

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Appendix(List of Abbreviations)

Abbrevi-ations	Full form
AB	*Acinetobacter baumannii*
aHP	aerosolized Hydrogen peroxide system
CD	*Clostridium difficile*
CFUs	Colony-forming units
CPE	Carpanemase-producing *Enterobacteriaceae*
CPS	Control panel systems
CRE	Carbapenem-resistant *Enterobacteriaceae*
CRGNB	Carbapenem-resistant gram negative bacilli
ER	Emergency rooms
FCU	Fan coil unit
GNR	Gram negative rods
KPC	*Klebsiella pneumoniae* carbapenemase
KRW	Korean Won
HP	Hydrogen peroxide system
HPV	Vaporized hydrogen peroxide system
ICU	Intensive care unit

Abbrevi-ations	Full form
IFU	Indications for Use
IQR	Interquartile range
MDROs	Multidrug-resistant organisms
MRAB	Multidrug-resistant *Acinetobacter baumannii*
MRGNB	Multidrug-resistant gram negative bacilli
MRSA	Methicillin-resistant *Staphylococcus aureus*
OR	Operating rooms
RCT	Randomized control trial
USD	United States dollars
UV	Ultraviolet device
UV-C	Ultraviolet-C device
UV-PX	Ultraviolet-pulsed xenon device
VRE	Vancomycin-resistant Enterococci

국문초록

자외선과 과산화수소 공간소독기계를 사용한 의료기관 환경소독 시 카바페넴분해효소 생성 장내세균속균종 오염제거 효과비교

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배경

카바페넴분해효소 생성 장내세균속균종(CPE)은 전 세계적으로 문제가 되고 있다. 환경 청소 및 소독은 CPE 전파를 예방하기 위한 중요한 전략이며, 자외선 장비와 과산화수소 기기를 포함하는 비접촉식 소독 기계가 사람이 손으로 청소하는 방법의 단점을 극복하기 위해 평가되고 있다. 그러나 CPE에 대한 자외선 장비와 과산화수소 기기의 효능을 평가한 자료는 제한적이다. 이

연구에서는 의료기관 환경에서 자외선-C 소독 장비(UV-C)와 과산화수소 에어로졸 소독 기기(aHP)를 이용하여 소독을 시행하고, 효능을 비교하고자 하였다.

방법

이 연구는 대한민국 서울에 위치한 3차 병원의 48.3m^3 면적을 차지하는 1인실 빈 병실에서 2019년 5월에서 10월까지 시행되었다. 4개 병실 중 2개 병실은 UV-C를 적용하였고, 2개 병실은 aHP을 각각 적용하였으며, KPC 생성 *Klebsiella pneumoniae* (대략 10^6 CFUs)를 30개의 formica 시트지에 바른 후, 병실 내 UV 직접 영역(레이저 포인터 통과 영역)과 간접 영역(레이저 포인터 미통과 영역)에 각각 두었다. 중재 후 로그 감소 중앙값 와 수정된 오염제거율(청결 plates는 2.5 CFUs 미만/plate로 정의)을 Rodac plates를 이용하여 평가하였다.

결과

UV-C 적용(n=60) 후 로그 감소 중앙값은 5.52, aHP 적용(n=60) 후 로그 감소 중앙값은 5.27 이었으며(P=0.86),

수정된 오염제거율은 UV-C 적용 후 50%, aHP 적용 후 45%였다(P=0.71). UV 직접 영역에서는 UV-C가 aHP보다 더 높은 로그 감소 중앙값(5.91 vs. 5.61, P=0.002)과 수정된 오염제거율(83% vs. 53%, P=0.03)을 보였다. 이와 반대로 UV 간접 영역에서는 aHP가 UV-C보다 더 높은 로그 감소 중앙값(4.63 vs. 5.07, P=0.02)과 수정된 오염제거율(17% vs. 37%, P=0.01)을 보였다.

결론

UV-C와 aHP 모두 1인실에서 미생물 오염이 감소하였다. aHP는 UV 직접 영역에서 통계적으로 유의하게 더 효과적이며, UV-C는 UV 간접 영역에서 통계적으로 유의하게 더 효과적이다. 기기의 특징과 연구 결과를 고려하여, 의료기관에서 UV-C와 aHP 중 선택하여 적용할 수 있겠다.

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주요어 : 카바페넴분해효소 생성 장내세균속균종, 환경 청소 및 소독, 비접촉식 소독 기계, 공간소독기계, 자외선-C 소독 장비, 과산화수소 에어로졸 소독 기기, 로그 감소, 오염제거율

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