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Operating room disinfection: operator-driven ultraviolet 'C' vs. chemical treatment

Marie-Claire Fickenscher [a], Madeline Stewart [a], Ryan Helber [a], Edward J. Quilligan [a,*], Arthur Kreitenberg [b], Carlos A. Prietto [a], Vance O. Gardner [a]

[a] Hoag Orthopedics Education and Research, Hoag Orthopedic Institute, Irvine, CA, United States
[b] Department of Orthopedic Surgery, Center for Orthopedic & Sports Excellence, Los Angeles, CA, United States

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SUMMARY

Background: In operating room (OR) surfaces, Nosocomial pathogens can persist on inanimate surfaces for long intervals and are highly resistant to traditional surface cleaning.
Aim: This study compares traditional chemical operating room terminal disinfection to a unique operator-driven device that emits germicidal UV light at short distance onto vertical and horizontal surfaces.
Methods: A randomized crossover analogous protocol assigned 40 end-of-day operating rooms into either group A (chemical then UVC treatments) or group B (UVC then chemical treatments). Initial Staphylococcal cultures were obtained prior to disinfection treatment, after the first treatment, and after the second treatment at 16 most commonly contaminated sites to represent overall room contamination. Success was defined as no growth and failure as 1 or more colony forming units. Thoroughness of chemical treatment vs UVC treatment was compared and used to determine if the second treatment was additive to the first treatment within each group.
Findings: The operator driven UVC device outperformed chemical treatment in reducing the number of contaminated sites in the OR by more than half ($P<0.001$). Operator-driven UVC reduced contaminated sites after chemical treatment by nearly half ($P<0.001$). In contrast, chemical treatment after operator-driven UVC did not significantly reduce the number of contaminated sites. The mean employee time of disinfection for chemical treatment was 49 minutes and for the operator-driven UVC emitter 7.9 minutes ($P<0.001$).
Conclusions: This study demonstrates that addition of an operator-driven UVC emitter to OR rooms between cases could be helpful in overall decreasing the number of contaminated sites.

Background

Surgical Site Infections (SSI) such as Prosthetic Joint Infections (PJI), infections of vascular grafts and heart valves are devastating to the patient and costly to the healthcare system

* Corresponding author. Address: Hoag Orthopedics, 16300 Sand Canyon Avenue, Suite 511, Irvine, CA, 92618, United States. Tel.: +1 949 275 3019.
E-mail address: Edward.quilligan@hoagorthopedics.org (E.J. Quilligan).

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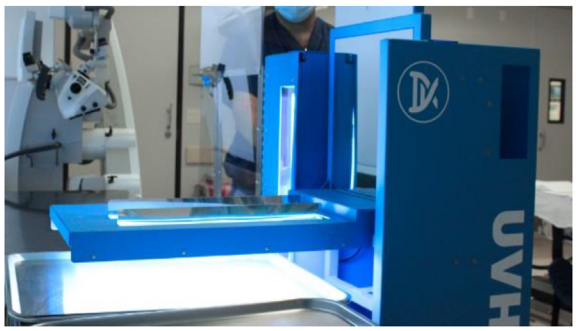

Figure 1. The UVHammer features a wing of UVC lamps that adjusts from full vertical to full horizontal and ranges from the floor to the overhead lights.

[1—5]. Infection prevention strategies have been proven effective within and outside of healthcare.

Contaminated operating room (OR) surfaces have proven to be a major contributor to PJI [6,7]. Nosocomial pathogens can persist on inanimate surfaces for long intervals. *Enterococcus*, *Streptococcus pyogenes* and *Staphylococcus aureus* can survive for seven months on dry surfaces [8] and all three are highly resistant to traditional surface cleaning [9]. Floor contamination is thought to be especially important and improved thoroughness of surface cleaning has been shown to reduce microbial burden of Vancomycin resistant enterococcus (VRE) and Gram-negative bacilli [10].

Surfaces in the OR environment continue to be a source of pathogens responsible for surgical site and implant infections (SSI/PJI). Hospitals continue to develop protocols to aid in and improve disinfecting operating rooms. A 2011 study showed 25—60% of the surfaces in the OR were cleaned and a 2019 study showed hospital surfaces were cleaned an average of 63% of the time [11,12]. Floor surfaces have been shown to transmit fomites to the hands [13]. Door openings and "OR traffic" have been correlated with increased environmental contamination in the OR setting [14]. Personnel in motion can create air currents that "launch" surface viral particles into becoming airborne sources of contamination [15]. Strategies to mitigate all these mechanisms should include a comprehensive and enhanced approach to reduce environmental surface bacterial contamination before every surgical case.

Germicidal Ultraviolet "C" light is currently used in hospital rooms with multiple studies indicating reductions in both bacterial colony forming unit (CFU) counts and healthcare associated infections (HAIs). These devices typically require greater than 20 minutes of treatment time, precluding practical use between most surgical cases. Overnight use has been used attempting to enhance operating room surface disinfection [16].

In 2018, a stationary vertical UV emitter was studied to see if it could reduce environmentally important pathogens in a patient room already disinfected with quaternary ammonium compounds or bleach. Although some potential pathogens were reduced, the device failed to achieve statistically significant MRSA reductions [17] after chemical treatment, precluding practical use in an OR.

In 2019, an observational study evaluated the performance of an automated, focused multivector, ultraviolet (FMUV) light technology with various pieces of operating room equipment undergoing terminal cleaning. The device could distribute UVC to areas that were difficult for the incumbent pulsed Xenon technology to reach. Significant reductions of microbial contamination levels were detected [18]. However, a randomized study was not performed.

The recently introduced UVHammer (Figure 1) utilizes a trained operator propelling the device around the room with no detectable operator exposure due to a UVC blocking shield. Toggle switches adjust the height and angle of UVC lamps to optimally expose both vertical and horizontal surfaces from the floor to the overhead surgical lights. Cross contamination between rooms is eliminated by a dedicated floor lamp exposing the floor and all 4 wheels and a rechargeable battery replacing the power cord. At a comfortable walking pace of 36m/min, third party validated UVC doses to achieve greater than $5\log_{10}$ Staphylococcal reductions are achieved on both vertical and horizontal surfaces [19].

Through dedicated staff practices the institution conducting this study has very low surgical infection rates [20]. As part of this continuing effort, we elected to investigate if this unique UVC disinfection system could potentially allow for UVC disinfection between surgical cases, supplementing and in some instances replacing routine chemical disinfection.

Materials and methods

Forty operating rooms qualified for the study where patients had been present for at least 5 hours undergoing major orthopaedic surgery cases, primarily spine and joint replacement, with multiple personnel and equipment required. All cases were deemed CDC Class 1: an uninfected operative wound in which no inflammation is encountered and the respiratory, alimentary, genital, or uninfected urinary tract are not entered [21,22].

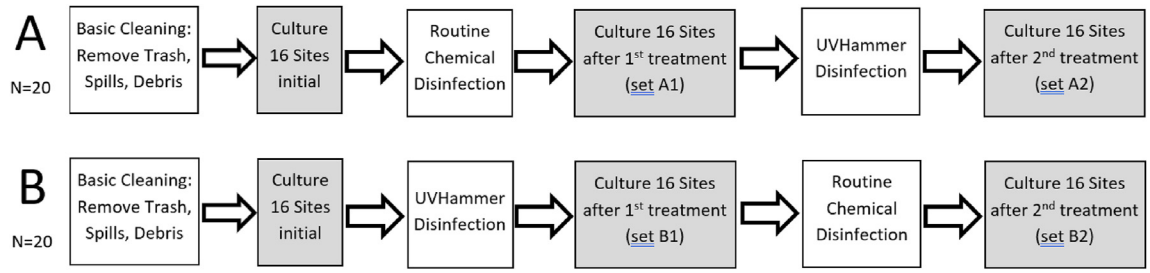

Figure 2. Randomized Cross Over Analogous Design.

Randomization of the rooms into Group A and Group B was performed using a spreadsheet randomizer function with the same sequence maintained throughout the study. Four rooms per day were studied over 10 separate testing days.

The rooms were cleaned per the standard Operating Room protocol prior to disinfection removing trash, linens, spills, and debris from the case just completed. Initial cultures were obtained from the 16 sites listed in Figure 3.

Cleaning procedure sequence

Immediately after the cleaning process, rooms in **Group A** underwent routine chemical (quaternary ammonium) treatment and allowed to dry per protocol. Cultures (labeled after first treatment) were obtained at the same 16 most common sites of contamination, immediately adjacent to the initial culture location. Next the UVHammer was used throughout the room, followed by another set of cultures (labeled after the second treatment) at the same 16 sites, immediately adjacent to the prior culture locations. Rooms in **Group B** were treated identically, with the only variable changed being the order of disinfection treatment. After the initial cultures, the UVHammer was used throughout the room, followed by cultures, then chemical disinfection followed by cultures.

Timing the duration of disinfection method

In addition to the three sample collections per site in each room, the UVHammer and the Routine Chemical Disinfection were timed to determine the duration of each cleaning process.

Time was started when cleaning personnel stepped into the OR to disinfect and ended when they left the room and the floor had dried. This facility utilizes multiple personnel simultaneously for routine chemical disinfection to decrease the amount of time elapsed. Therefore, the duration was multiplied by the number of personnel to determine an equivalent time for one employee.

1. Floor at the Main Door
2. Floor at the Head of the OR Table
3. Floor at the Foot of the OR Table
4. Floor to the left of the OR Table
5. Floor to the right of the OR Table
6. Floor at the Back Table
7. Push Pad to open substerile door
8. OR Table Remote
9. Anesthesia Machine Vertical Surface
10. Anesthesia Machine Horizontal Surface
11. Mayo Stand Legs upper horizontal surface
12. Rolling Stool horizontal sitting area
13. IV Pole at elbow level
14. Keyboard
15. Overhead Light upper surface at rim
16. Table Pad at head of patient

Figure 3. Cultured Sites.

Culture sites

16 sites listed in Figure 3 within each room were cultured at three points in the crossover analogous protocol — initial, after first treatment, and after second treatment. Successive cultures were taken at immediately adjacent locations to the same sites. These sites were based on the literature with additional sites judged by hospital personnel to be most likely contaminated with *Staphylococcus aureus*, posing the greatest risk for spread to subsequent cases.

Sample collection

Baird-Parker Agar contact plates with Lok-Tight friction lid, specific for *S. aureus*, (Hardy Diagnostics, Santa Maria, CA) were utilized. This media is moderately selective for the isolation and differentiation of coagulase positive Staphylococci, especially *Staphylococcus aureus*.

Only 2 experimenters were permitted to obtain the cultures following training on manufacturer's instructions and prevention of contamination. OR uniforms, head covers, masks were worn. Fresh shoe covers and gloves were used before obtaining site cultures.

Each plate was labeled with date of collection, group assignment, site of collection and initial, after first treatment or after second treatment culture. The plates were pressed to the surfaces without twisting or sliding per manufacturer's instructions. Following sampling, the lid was placed and locked. Culturing 3 times at 16 sites in 40 rooms yielded a total of 1,920 plates used in this study.

Incubation and colony forming units (CFUs) determination

The plates were placed into an incubator within 1 hour of sample collection for 36—48 hours at 37 °C per manufacturer instructions. Each incubated plate was photographed with its identifying label.

Counting CFUs, definitions of success and thoroughness

Success was defined as zero CFUs on a plate and failure defined as 1 or more CFUs on a plate. Thoroughness was defined as the total number of disinfected sites out of the 16-test site of Figure 3.

Determination if the count was zero or more than zero was performed independently by two research team members with confirmed concordance. Data were entered into a spreadsheet organized by room, culture site and culture sequence, initial, after first treatment or after second treatment as described above.

Comparative analysis of culture sets

The randomization procedure effectively equalized groups A and B with regards to the initial number of culture positive sites in each group. This allowed direct comparison of culture sets after the first treatment assessed the thoroughness of both routine chemical disinfection and UVHammer disinfection.

Additionally, within each group, we compared the number of culture positive sites before and after the second

Table I
Number (out of 16) of Culture Positive Sites in each room

Group	Initial	1st treatment	After first treatment	2nd treatment	After second treatment
A	9	Chemical	3	UVHammer	2
A	13	Chemical	5	UVHammer	3
A	12	Chemical	6	UVHammer	6
A	13	Chemical	2	UVHammer	0
A	6	Chemical	7	UVHammer	5
A	8	Chemical	4	UVHammer	5
A	10	Chemical	5	UVHammer	3
A	7	Chemical	8	UVHammer	3
A	10	Chemical	6	UVHammer	4
A	8	Chemical	9	UVHammer	5
A	8	Chemical	2	UVHammer	1
A	8	Chemical	2	UVHammer	2
A	9	Chemical	4	UVHammer	2
A	7	Chemical	4	UVHammer	0
A	8	Chemical	5	UVHammer	2
A	9	Chemical	3	UVHammer	0
A	9	Chemical	2	UVHammer	0
A	10	Chemical	3	UVHammer	2
A	7	Chemical	6	UVHammer	3
A	11	Chemical	4	UVHammer	1
Sum	**182**		**90**		**49**
Mean (SD)	**9.1** (7.7)		**4.5** (2.0)		**2.45** (1.8)
Group	Initial	1st treatment	After first treatment	2nd treatment	After second treatment
B	11	UVHammer	1	Chemical	0
B	9	UVHammer	2	Chemical	1
B	2	UVHammer	1	Chemical	1
B	10	UVHammer	2	Chemical	5
B	13	UVHammer	2	Chemical	1
B	9	UVHammer	2	Chemical	4
B	12	UVHammer	6	Chemical	4
B	8	UVHammer	1	Chemical	3
B	8	UVHammer	1	Chemical	2
B	10	UVHammer	2	Chemical	4
B	9	UVHammer	2	Chemical	2
B	7	UVHammer	4	Chemical	2
B	8	UVHammer	2	Chemical	1
B	8	UVHammer	4	Chemical	3
B	10	UVHammer	1	Chemical	3
B	8	UVHammer	0	Chemical	0
B	11	UVHammer	4	Chemical	2
B	9	UVHammer	1	Chemical	2
B	9	UVHammer	1	Chemical	2
B	11	UVHammer	2	Chemical	1
Sum	**182**		**41**		**43**
Mean (SD)	**9.1** (5.3)		**2.05** (1.4)		**2.15** (1.4)

disinfection method to determine if the second disinfection method provided additional disinfection to the first method.

Results

There was no significant difference between the number of contaminated sites initially between Groups A and B. Approximately half the overall sites, 182 of 320 sites tested positive, in both groups. Combining data of both Groups A and B, the 364 culture positive plates out of 640 plates in the initial pre-disinfection culture set, all but 6 plates grew fewer than 20 CFUs. The highest count was 43 CFUs. The mean was 4.3 CFUs (SD 5.4) and the median was 2 CFUs.

Result 1: sequential chemical and UVHammer treatment, in either order, resulted in decreased contamination

Combining all data from Group A and Group B, a repeated-measures ANOVA with a Greenhouse-Geisser correction determined the mean number of contaminants differed significantly between the three treatment time points (initial, after first

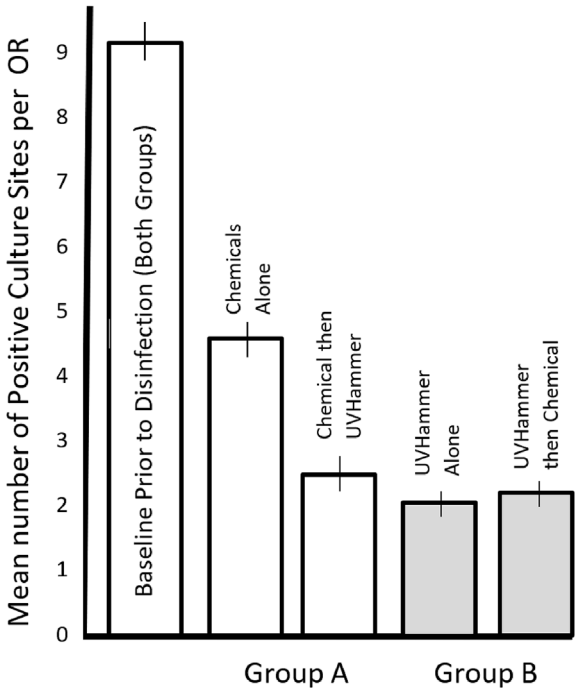

Figure 4. Mean number of residual positive culture sites per OR. All disinfection strategies showed significant reductions of total contaminated sites from baseline pre-disinfection value. Use of the UVHammer alone resulted in fewer contaminated sites than chemicals alone ($P<0.001$). UVHammer after Chemicals resulted in significant reductions compared to chemicals alone ($P<0.001$), whereas Chemicals after UVHammer alone did not. There were no statistically significant differences among the three conditions in which the UVHammer was used.

treatment, after second treatment) ($F(1.468, 55.788) = 6.303$, $P<0.05$). Using both chemical and UVHammer, in either order, resulted in significant reductions in the number of contaminated sites in the OR.

Post hoc analysis with a Bonferroni adjustment revealed the following results depicted in Table I and Figure 4.

Result 2: UVHammer treatment alone was 2 times more thorough than chemical treatment alone

Comparing culture sets A1 and B1 of Figure 2 showed that after the first treatment, UVHammer outperformed chemicals at reducing the number of contaminated sites in the operating room by more than half. In Group A, after the first (chemical) treatment, the number of contaminated sites reduced from 182 to 90 (M for initial = 9.10, M for after first treatment = 4.50, $P<0.001$). In Group B, after the first (UVHammer) treatment, the number of contaminated sites reduced from 182 to 41 (M for initial time = 9.10, M for time after first treatment = 2.45, $P<0.001$).

Result 3: UVHammer treatment reduced the number of contaminated sites after chemical treatment

Between the first treatment and the second treatment in Group A, comparing culture sets A1 and A2 of Figure 2 (chemicals

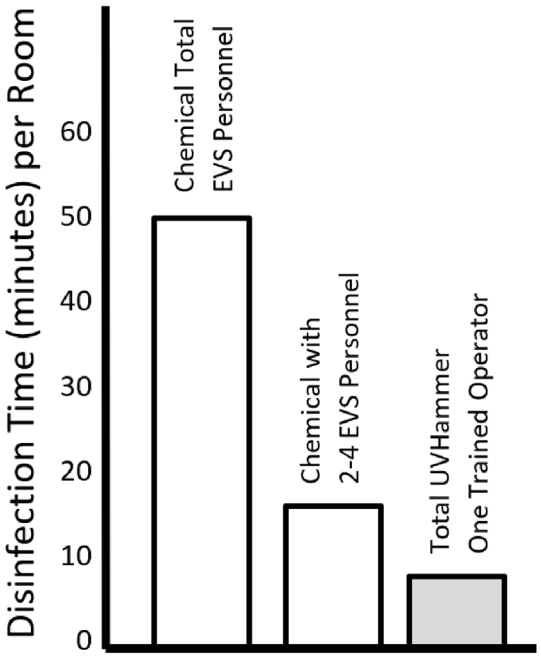

Figure 5. Chemical vs UVHammer Room Disinfection Time Requirement. To minimize elapsed room turnover time, 2–4 personnel apply chemicals simultaneously. The total EVS personnel time is determined by the time required multiplied by the number of personnel.

then UVHammer), the mean number of contaminated sites significantly decreased from 4.50 to 2.45 ($P<0.001$).

Result 4: chemical treatment did not reduce the number of contaminated sites after UVHammer treatment

Between the first treatment and the second treatment in Group B, comparing culture sets B1 and B2 of Figure 2 (UVHammer then chemicals), there was no significant difference with mean number of contaminated sites from 2.05 to 2.15, $P>0.05$.

Result 5: UVHammer treatment was significantly faster than chemical treatment (Figure 5)

The UVHammer required a mean treatment time of 7.56 minutes, whereas the chemical treatment time mean was 13.02 minutes ($t_{38} = -6.22$, $P<0.001$). Considering that chemical treatment was performed with 2–4 persons simultaneously in the room, the mean number of minutes of personnel time required for operating room disinfection was 49 minutes ($t_{38} = -13$, $P<0.001$).

Discussion

Before the 21st century, hospital surfaces were not considered a potential source for surgical wound infections [23,24]. It is now appreciated that contaminated operating room surfaces can significantly contribute to hospital acquired infections [25]. Pathogens can be shed by patients and hospital staff, are found at concentrations sufficient for transmission, survive for

extended periods of time, and can persist despite attempts to remove them [8].

Mitigation efforts such as decreasing the amount of personnel, door closing, isolating the OR from hallway traffic and improved ventilation and filtration have all aided in reducing surgical site infections (SSI). Despite these practices, surfaces can remain contaminated [9,10,12]. Gram negative organisms are more common, but persistent nosocomial pathogens such as S. *aureus*, including MRSA, can remain on dry surfaces for up to weeks or even months [8]. Further, surfaces of many inanimate objects have been found to be significantly contaminated, despite thorough cleaning [25]. Anesthesia equipment, OR tables/controls, Mayo stands, floors, overhead lights, and IV poles are common sources of pathogens [26].

Two modes of transmission of these pathogens are hypothesized − either contaminated surfaces are touched by OR staff and then on to the patient, or contaminated surfaces are disturbed, and pathogens are be swept up into the air and subsequent air current allows for the microbe to settle on the patient's exposed skin or wound [15]. We therefore hypothesized that an operator-driven UVC emitter may provide further, value-based benefit to a hospital or outpatient surgical center.

We defined the disinfection as a "success" if zero CFU's appeared on a plate and a failure as one or more CFU's on a plate. Although the number of organisms required to cause an infection is unknown and multifactorial, at least one pathogen must be present. Staphylococcus has a room temperature doubling time of less than 2 hours [27] so over a long weekend even a few organisms on Friday may pose a threat on Monday. If zero organisms are present at a site, doubling times are irrelevant. Both chemical disinfection and UVC are capable of 3 log reductions of potential infectious pathogens. Therefore, complete elimination of up to 1000 organisms was our objective.

Fortunately, operating rooms are generally free of massive bacterial contamination after a day of clean-case surgery, even prior to disinfection, as confirmed in the present data. 364 of 640 (57%) plates in the initial culture set had positive growth and 276 (43%) showed no growth. Of those plates with growth, the mean CFU was 4.3 (SD 5.4) with a median of 2 CFUs. Only 6 of 364 culture positive plates grew more than 20 CFUs with a maximum of 43 CFUs. This indicates a relatively low level of pre-disinfection bacterial contamination. Both chemicals and UVC are capable of greater than 3−4 log reductions, so both should be able to easily reduce fewer than 100 CFUs to zero. Therefore, there is no practical difference between 1 and 43 CFUs in this study. However, there is a potential clinical difference between a low-level contaminated surface and a surface with no growth whatsoever. The success/fail binary analysis employed is meaningful and valid as the objective should be to start a new case with the fewest contaminated sites.

Thoroughness of disinfection after treatment was defined as the number of successfully disinfected sites out of the 16 in Figure 3. In practice, it makes no difference, and it would be indeterminable if the causative organism had originated from the IV pole, the OR table pad, or the overhead light.

Figure 4 shows chemical treatment reduced the total number of contaminated sites in the rooms of Group A from 182 to 90. This finding is consistent with Jefferson's study [11], showing about 50% of sites are missed by cleaning personnel with chemicals. In contrast, the UVHammer reduced the number of contaminated sites in the rooms of Group B from 182 to 41 ($P<0.001$).

Figure 4 demonstrates that supplemental UVHammer disinfection was "additive" to chemical treatment and reduced the number of contaminated sites by a factor of 1.8 ($P<0.001$). After chemical treatment resulted in a reduction from 182 to 90 sites, use of the UVHammer further reduced the number of sites to 41. Specifically, 17 of the 20 rooms in group A showed overall reductions in the number of contaminated sites. It is left to OR personnel to determine whether it is worth waiting 8 minutes for enhanced disinfection if there is an 85% chance of reducing the number of contaminated sites.

Shorter OR turnover times increase efficiencies, throughput, and productivity. Multi-room operating facilities utilize multiple EVS staff concurrently to minimize turnover times. Figure 5 shows chemical disinfection times, with 2−4 EVS staff members was 13 minutes, significantly longer than the 7.5 minutes for the UVHammer ($P<0.001$).

Smaller surgical centers, including community hospitals and ambulatory surgery centers commonly utilize only one EVS person to disinfect a room between cases. To replicate a single EVS worker's time, we multiplied the number of personnel and the total time elapsed, resulting in a mean of 49 minutes. For the UVHammer, since only one person is required, personnel time and treatment time were the same at 7.9 minutes ($P<0.001$). This represents a reduced turnover time of 40 minutes, potentially adding additional cases during a surgical day.

The authors acknowledge these results challenge traditions and norms of long-standing infection control protocols in OR disinfection and a unique perspective is suggested in interpreting these results. UVC disinfection in healthcare is generally considered supplemental following chemical disinfection. These data support this practice, with the potential to graduate one step further.

These data also strongly support the use of UVC, when properly applied and in the correct circumstances, as a potential substitute for chemical disinfection. UVC cannot remove debris, spills, and trash as a rigorous mechanical chemical wipe down can. However, many surgical procedures result in minimal or no debris, spills and trash including arthroscopy, hand, microscopic spine and some simple ophthalmologic, otolaryngologic, and laparoscopic procedures. Such cases may be appropriate for use of only operator driven UVC between cases with marked cost and time reductions, as well as superior reductions in contaminated sites.

Environmental biofilms produced by SSI producing organisms require mechanical cleaning for removal. However, these biofilms typically take multiple hours or days to fully form. Frequent use of effective UVC destruction of pathogens should disrupt the formation of biofilms [28]. A daily mechanical cleaning can also disrupt biofilm formation.

Chemicals are highly effective when used as directed by the manufacturer, including observing the required wet and dwell times. However, in practice at a busy surgical facility, this is often difficult to emulate as evidenced by the data herein and Jefferson's study [11]. Although UVHammer requires training and diligence in its application for maximum effectiveness, the ability for UVC to readily disperse about the room and disinfect the air between the UVC source and the target surfaces in a timely manner should be considered as a more regular practice. The authors hypothesize that if greater time and diligence were given to the chemical treatment, reductions similar to that of UVC could and should be obtained.

Conclusion

Standard chemical disinfection practices of OR surfaces have improved hospital-acquired infections, but data continue to show contamination still exists. This study shows that effective UVC application alone may provide more thorough and rapid disinfection than chemical application alone. UVHammer application after chemical application is more thorough than chemical application alone, but the converse proved to be untrue. The addition of an 8-minute operator-driven UV emitter to OR rooms between cases should be helpful in reducing the number of OR contaminated sites in a large majority of cases. In addition, in certain situations where contamination risks are low, strong consideration should be given to the use of operator-driven UV treatment alone.

Conflict of interest statement

Hoag Orthopedic Institute performed this research contracted with Dimer, LLC, where Arthur Kreitenberg and/or family have a financial interest.

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