Reduction of Particles in the Operating Room Using Ultraviolet Air Disinfection and Recirculation Units

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A R T I C L E   I N F O

Article history:
Received 14 September 2017
Received in revised form 6 November 2017
Accepted 24 November 2017
Available online xxx

Keywords:
total joint arthroplasty
ultraviolet
air particles
infection
operating room traffic

A B S T R A C T

Background: Airborne bacteria are a major source for wound contamination during total joint arthroplasty. Crystalline ultraviolet C (C-UVC) filter units were designed to disinfect and recirculate air in the operating room (OR). This preliminary study assessed the particle reducing capacity of C-UVC units in a highly controlled OR setting.

Methods: A particle counter was deployed in a positive-pressure OR to measure total and viable particle counts (TPC/VPC). Thirty 23-minute experiments were performed. At 4 designated times a person would walk through the door to mimic OR traffic. Ten experiments were performed as controls, 10 experiments used a C-UVC unit 4 meters (m) from the door, and 10 cases with the C-UVC unit at 8 m. Outcomes included overall, change (Δ), and maximum TPC/VPC. Mann-Whitney U-tests determined statistical differences in TPC/VPC.

Results: Compared to controls, the cases with the C-UVC unit at 4 m had significantly lower particle levels. Overall TPC/VPC, changes in TPC/VPC, and maximum TPC/VPC were all significantly lower (P < .05) in the C-UVC unit (4 m) group compared to the controls. The C-UVC at 8 m significantly reduced TPC in all 3 outcomes (P < .05) compared to controls; however, it did not significantly reduce changes in VPC (P = .107) and maximum VPC (P = .052). There were no significant differences in any outcomes between the 4 m and 8 m group.

Conclusion: C-UVC units have shown to be capable of significantly reducing TPC and VPC in a highly controlled OR setting. Reducing airborne particles using C-UVC units may reduce infection rates following total joint arthroplasty.

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The annual number of total joint arthroplasty (TJA) surgeries continues to increase, and these surgeries are among the most successful elective procedures available in medicine today. However, an increase in case load logically leads to an increase in the number of surgical site infections and potentially periprosthetic joint infections (PJs). The rate of PJ following total knee and hip arthroplasty (TKA/THA) has been reported to be between 1.5% and 2.5% [1,2]. Infection was reported to be the primary cause of revision for procedures done within 15 years of the index TKA [3]. Revision arthroplasty surgeries are potentially disastrous for patients, notoriously difficult to treat, and much costlier than revision for aseptic loosening [4].

Airborne bacteria have been shown to be a primary source of infection during surgery [5–7]. Regulating the operating room (OR) environment is one of the best strategies to reduce intraoperative infections, along with prophylactic antibiotics [8–10]. Air flow strategies, such as laminar air flow and positive pressure, have been shown to inhibit aerocribiological contamination [10–13], but these systems are not perfect. A recent study reported that when an OR door was opened, it defeated the positive-pressure system 40.3% of the time [14]. This allows contaminated air to blend with the aseptic air in the OR, increasing the airborne bioburden [10,15,16]. In-room, ultraviolet air disinfection and recirculation units (crystalline ultraviolet C [C-UVC] units) were designed to...
significantly decrease airborne bioburden in the OR [17]. However, to the best of our knowledge, the efficiency of these C-UVC units to reduce airborne particulate matter and bacteria in the OR has not been established in the literature.

The purpose of this preliminary study is to measure the ability of a C-UVC unit to reduce airborne particulate matter related to OR foot traffic in a strictly controlled OR setting, prior to measuring its efficacy in an active, dynamic OR environment. More specifically we asked: (1) Can a C-UVC unit significantly reduce total and viable particle counts related to OR traffic; and (2) Does positioning of the C-UVC unit within the OR affect its efficiency at reducing total and viable particle counts related to OR traffic?

Methods

Study Design and Setting

This single institution pilot study was designed to investigate the airborne particle reducing efficiency of the T1 crystalline UVC (C-UVC) air disinfection-recirculation unit (Aerobiotix, Inc, Dayton, OH; Fig. 1). It is a mobile unit that actively filters and disinfects high volumes of OR air using C-band UV light and silicate crystals. The study was conducted in a single, vacant, standard positive-pressure OR. A BioTrak Real-Time Viable Particle Counter (TSI, Minneapolis, MS) was placed at the position of the surgical table to measure total and viable particle counts (TPC/VPC).

Currently, there is a paucity of literature, to the best of our knowledge, describing how to assess filtration efficiency in an OR using a particle counter. This experiment was designed to observe airborne particle counts related to OR foot traffic in a highly controlled setting. Experiment length was set at 23 minutes to allow trends in particle counts to be established over time in relation to multiple door openings and walkthroughs. Prior studies have reported simulated TJA lengths of 20-30 minutes [18,19]. Over the course of one experiment, the particle counter would take 16 to 30-second air samples, with the first sample taken immediately at the beginning of the experiment, and resting 1 minute between sample collections. During the experiment, the door leading to the substerile corridor was opened at 4 predetermined times (3.0, 7.5, 15.0, 19.5 minutes) and a member of the research team walked across the room and back out into the substerile corridor to simulate OR traffic (Fig. 2). Research members wore clean scrub attire, surgical hats, and surgical masks during the experiment. They also remained approximately 2 m from the particle counter during the walkthrough.

In total, 30 experiments were conducted. No C-UVC units were used in the first 10 experiments of the group. The C-UVC unit was turned on and placed 4 m from the substerile corridor door in the next 10 experiments (Fig. 2). The manufacturer suggests placing the C-UVC unit as close to the source of contamination (ie, the door) as possible to maximize filtration efficacy. Four meters from the substerile corridor door was the closest reasonable position the C-UVC unit could be placed during live surgery in this facility without hindering OR staff or blocking access to equipment. Finally, the C-UVC unit was placed 8 m from the door in the final 10 experiments (Fig. 2).

Eight meters from the door was chosen as the second placement of the C-UVC unit to test if positioning in the OR affected the C-UVC unit’s ability to reduce particles caused by OR traffic. This placement was the farthest the C-UVC unit could be away from the door without hindering OR staff or blocking access to the equipment. The C-UVC unit was turned on 30 minutes prior to the beginning of experiments in which it was utilized.

![Fig. 1. The T1 C-UVC air disinfection-recirculation unit (Aerobiotix, Inc).](image)

![Fig. 2. Experimental design depicting operating room floor plan, with the particle counter located adjacent to the surgical table. The C-UVC unit was positioned at either 4 m or 8 m from the door. Traffic pattern shows the route the staff member followed during walkthrough.](image)
Changes (\(\text{particles/m}^3\)) significantly lower compared to the controls (2141 vs 11,211 \(\text{particles/m}^3\)) because it has been reported that a minimum threshold of bacteria is required to cause an infection [22].

To quantify changes in particles we compared overall TPC/VPC, changes (\(\Delta\)) in TPC/VPC immediately after walkthroughs, and the maximum TPC/VPC measured during each experiment. Overall TPC and VPC is the sum of all particles measured throughout one experiment. Change (\(\Delta\)) in TPC/VPC is defined as the particle count at the time of the walkthrough subtracted from the subsequent particle count. This measurement allows us to isolate and quantify the impact OR traffic has on airborne particulate, since baseline particle measurements may differ between cases. The maximum TPC/VPC is the single largest particle count from the 16 samples taken in each experiment. This is an important measurement because it has been reported that a minimum threshold of bacteria is required to cause an infection [22].

Statistical Analysis

Nonparametric univariate analysis was performed using the Mann-Whitney U-test. This allowed us to detect significant differences in TPC/VPC between groups. A \(P\)-value of \(\leq 0.05\) was considered significant. All statistical tests were performed on IBM SPSS Statistics 23 for Mac (IBM Corporation, Armonk, NY).

Results

Trends in TPC and VPC over the course of the 23-minute experiments can be visualized by averaging particle counts. The largest increases in TPC/VPC occurred approximately 90 seconds after each walkthrough event (Figs. 3-5).

Control vs C-UVC Unit (4 m)

Compared to the controls (Table 1), the C-UVC unit (4 m) group had significantly lower mean overall TPC (29,218 vs 99,900 particles/m\(^3\), \(P = 0.003\)). Mean overall VPC was also significantly lower in the C-UVC unit (4 m) group (1675 vs 3950 particles/m\(^3\), \(P = 0.007\)). Changes (\(\Delta\)) in TPC following personnel walkthrough were significantly lower compared to the controls (2141 vs 11,211 particles/m\(^3\), \(P < 0.001\)), and this is true for changes (\(\Delta\)) in VPC also (111 vs 526 particles/m\(^3\), \(P = 0.028\)). In addition, the maximum TPC (8798 vs 31,095 particles/m\(^3\), \(P = 0.005\)) and VPC (593 vs 1611 particles/m\(^3\), \(P = 0.019\)) were significantly reduced in the C-UVC unit (4 m) group compared to the controls.

Control vs C-UVC Unit (8 m)

Unlike the C-UVC (4 m) comparisons, not all the measured outcomes were significantly different between the controls and C-UVC (8 m) group (Table 1). Mean overall TPC (24,363 vs 99,900 particles/m\(^3\), \(P < 0.001\)) and VPC (1392 vs 3950 particles/m\(^3\), \(P = 0.001\)) were significantly lower in the C-UVC (8 m) group. Significant reductions in particles were also found with the C-UVC (8 m) group in regards to mean change (\(\Delta\)) in TPC (2321 vs 11,211 particles/m\(^3\), \(P < 0.001\)) and maximum TPC (9314 vs 31,095 particles/m\(^3\), \(P = 0.023\)). However, although there were numerical reductions in change (\(\Delta\)) in VPC (190 vs 526 particles/m\(^3\), \(P = 0.107\)) and maximum VPC (720 vs 1611 particles/m\(^3\), \(P = 0.052\)) between the controls and the C-UVC (8 m) group, these were not statistically significant.

C-UVC Unit (4 m) vs C-UVC Unit (8 m)

Across all measured outcomes, there were no significant differences in TPC or VPC depending on the location of the C-UVC unit (Table 1). Compared to the C-UVC unit (8 m) from the door, the C-UVC unit (4 m) group had slightly higher, yet insignificant, overall TPC (29,218 vs 24,363 particles/m\(^3\), \(P > 0.999\)) and VPC (1675 vs 1392 particles/m\(^3\), \(P = 0.796\)). In contrast, the C-UVC unit (4 m) group had smaller changes (\(\Delta\)) in TPC (2141 vs 2321 particles/m\(^3\), \(P = 0.814\)) and VPC (111 vs 190 particles/m\(^3\), \(P = 0.395\)) following walkthroughs than the C-UVC unit (8 m) group. Additionally, the C-UVC unit (4 m) group had lower maximum TPC (8798 vs 9314 particles/m\(^3\), \(P = 0.739\)) and VPC (593 vs 720 particles/m\(^3\), \(P = 0.579\)) relative to the C-UVC unit (8 m) group.

Discussion

Postoperative infections have potentially devastating consequences in the setting of TJA. It is important to explore new potential solutions to reduce airborne bacteria as they play a significant role in intraoperative infection. This preliminary study assessed the ability of a novel, in-room, UV air disinfection and recirculation technology to reduce OR airborne particles. The C-UVC unit was found to significantly reduce the amount of overall TPC and VPC, change (\(\Delta\)) in TPC and VPC following staff
walkthroughs, and maximum levels of TPC and VPC when compared to cases without a C-UVC unit. Further testing found that positioning of the C-UVC unit farther away from the door slightly reduced its ability to reduce VPC.

This study has several limitations. We are unable to conclude that the reduction in particle counts seen with the C-UVC unit would translate into fewer infections clinically. However, studies have shown that airborne particle counts are reliable and correlate to colony-forming units when using traditional bacterial plating methods [23–26]. This study was conducted in a single, positive-pressure OR, so these findings cannot be applied to ORs with horizontal laminar flow. Also, the setting of this experiment was highly controlled and does not reflect the dynamic nature of an active OR during a live TJA, but this was a preliminary study with the sole objective of determining if the C-UVC unit could reduce particle levels in a highly controlled OR environment. Furthermore, one disinfection-recirculation unit produced by a single company was tested in this experiment. No comparisons with other similar systems were conducted in this study, although airborne particle densities were compared against a control group. This study was designed to lay a foundation for future prospective, intraoperative studies to assess the particle reduction capability of the C-UVC unit.

Consistent increases in TPC and VPC were observed following OR traffic. Interestingly, the largest increase in particle density occurred approximately 90 seconds after a walkthrough happened instead of at the time of the walkthrough. For example, in Figure 3, it would be expected for the highest particle count to occur at 3 minutes since the particle counter is taking an air sample concurrently with a walkthrough occurring. However, there appears to be a delayed effect and the highest particle count is recorded at 4.5 minutes. It is important to note that although particle density looks like it is increasing in some instances prior to the walkthrough occurring, this is not the case (Figs. 3-5). The samples were taken at 16 distinct time points and the slopes of the graphs are arbitrary. Particle density at the time of walkthrough (ie, 3 minutes) is expected to be higher than prior to walkthrough (ie, 1.5 minutes), which in turn appears to show increasing particle density.

### Table 1

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>C-UVC (4 m)</th>
<th>C-UVC (8 m)</th>
<th>P-Value</th>
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<tr>
<td>Mean (SD) TPC</td>
<td>99,000</td>
<td>29,218</td>
<td>24,363</td>
<td>&lt;.001</td>
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<td>Overall VPC</td>
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<td>1392</td>
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<tr>
<td>Change [D] in VPC</td>
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<td>2141</td>
<td>2321</td>
<td>&lt;.001</td>
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<tr>
<td>Maximum TPC</td>
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<td>8798</td>
<td>9314</td>
<td>.022</td>
</tr>
<tr>
<td>Maximum VPC</td>
<td>1611</td>
<td>593</td>
<td>720</td>
<td>.052</td>
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### Table 2

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density before a walkthrough occurs. Moreover, generalizations about the performance of the C-UVC unit should not be made using Figures 3-5, as each individual data point is subject to significant variability. For instance, the baseline particle count of one experiment may be higher compared to another, but both experiments may experience similar changes in particle counts following OR traffic. Instead, the measured outcomes including overall particle counts, change (Δ) in particle counts following OR traffic, and maximum particle counts should be considered the primary benchmarks for C-UVC unit performance.

Airborne bacteria are a primary source for surgical site contamination in the OR [5–8,11,12,27,28]. In 1982, Lidwell et al [28] conducted a randomized study of 8136 TKA/THA cases to assess the effect ultraclean air had on deep infection rates compared to standard ventilation. They found that cases in rooms with ultraclean air had significantly lower deep joint infection rates than cases in rooms with conventional ventilation (0.6% vs 1.5%, P < .001). Unidirectional airflow was introduced to prevent airborne bacterial contamination of the surgical site, but studies have given conflicting reports on its efficacy to do so. Additionally, increases in OR traffic have been associated with higher rates of airborne bioburden and surgical site contamination [15,29–31]. New strategies need to be evaluated to reduce OR airborne bacteria and postoperative infections related with OR traffic.

UV radiation has been used widely as a disinfectant in healthcare and to maintain ultraclean environments [10,32,33]. Ritter et al [33] conducted a study that compared rooms with UV lighting and without UV lighting during TJA procedures over a 19-year period. Their results revealed that rooms without UV lighting had 3.1 times greater odds of infection than the rooms with UV lighting (P < .001). Conversely, the Center for Disease Control does not recommend UV radiation to be used in the OR due to concerns of exposing healthcare workers to radiation [10,34]. However, unlike previous OR UV light sources, the C-UVC unit used in this study is mobile, safe at the point of care, and does not expose OR staff to UV radiation [17].

Overall, the C-UVC unit significantly reduced TPC and VPC related to OR traffic in a highly controlled OR setting. We recommend placing the C-UVC unit closer to potential sources of contamination for maximum efficacy. This preliminary study has established a foundation for future studies to prospectively assess the ability of C-UVC units to reduce surgical site contamination during live TKA and THA cases. Postoperative infection outcomes should also be studied using this device. The C-UVC unit could potentially be a novel and safe way of reducing airborne bioburden in the OR during TJA.

References


