Pilot study on the decontamination efficacy of an installed 222-nm ultraviolet disinfection device (Care222™), with a motion sensor, in a shared bathroom

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1. Background

The toilet environment, including toilet seats, lids, and the surrounding floor, is contaminated with various pathogens by users’ hands and toilet flush aerosols [1], and it may be a vector for disease transmission via the toilet users’ hands. In addition, bacterial contamination of the toilet environment may lead to infectious disease outbreaks, especially acute gastroenteritis [1–3]. Therefore, adequate disinfection of bathrooms, especially shared bathrooms, is important to prevent disease transmission.

Ultraviolet C (UVC) disinfection systems are effective adjuncts to manual cleaning of patients’ rooms, including bathrooms [4,5]. However, UVC disinfection is usually performed in unoccupied spaces because of the negative effects of UV on human skin and eyes [4,5]. In addition, manual cleaning using chemical disinfectants, which is the standard cleaning procedure used in most hospitals, may be inadequate if not carried out correctly [6,7]. Therefore, continuous UVC disinfection of shared bathrooms may be a more effective strategy. However, only a few studies have investigated the effects of automated, permanently installed UVC devices in a shared bathroom [8,9]. In this study, the efficacy of an automated 222-nm UVC disinfection device with a motion sensor significantly reduced AB surface contamination of a shared bathroom.

Methods: Two automated UVC devices, deactivated by motion sensors, were mounted on the ceiling of two bathrooms; the emission window of the UVC device was covered in the non-treated bathroom. After irradiation, samples were collected from five surfaces at four time points/day for 5 days, and colony-forming units (CFUs) of aerobic bacteria (AB) were determined. The irradiation time was also measured.

Results: UVC source deactivation time did not significantly differ between the bathrooms. There was a significant difference in the total AB CFUs between the treated and non-treated bathrooms. In the treated bathroom, the CFUs of AB on the toilet seat, control panel of the electric toilet seat, and top of the toilet paper holder were significantly lower than those of the control. The CFUs of AB at 9:00, 15:00, and 18:00 h in the treated bathroom were significantly lower than those of the control.

Conclusions: The automated 222-nm UVC disinfection device with a motion sensor significantly reduced AB surface contamination of a shared bathroom.

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2. Methods

2.1. Study Design

This study was conducted in men’s bathrooms shared by staff at our institution between August 3 and 7, 2020. Two automated 222-nm UVC disinfection devices with motion sensors (Care222™; Ushio Inc., Tokyo, Japan) were mounted on the ceiling of two bathrooms with the same room volume (0.9 m × 1.5 m × 2.5 m) with an electric toilet (TOTO Ltd., Fukuoka, Japan). The dimensions of the UVC device were 205 mm × 150 mm × 50 mm. One bathroom was a UVC-treated bathroom and the other bathroom was a non-treated bathroom, in which the emission window of the UVC device was covered with aluminum foil.

2.2. Sample Collection and Bacterial Culture

Sampling of bathroom surfaces was conducted at 9:00, 12:00, 15:00, and 18:00 h every day. Mopping and manual cleaning of the toilet with a disinfectant were performed in both bathrooms at 10:30 h every day. Environmental sampling was performed using 25-cm² replicate organism detection and counting (RODAC) contact plates containing trypti-case soy agar with lecithin and polysorbate (Nippon Becton Dickinson Co., Ltd., Tokyo, Japan). The RODAC plate was firmly pressed onto the following surfaces for 10 s: the toilet seat, control panel of the electric toilet seat, top of the toilet paper holder, door handle, and floor. Because the bathrooms were small and the UV irradiators were on the ceiling, the floor area near the toilet bowl was shaded by the toilet bowl itself and thus was not sampled as the effect of 222-nm UVC disinfection may not have been sufficient in this area. After sample collection, the contact plates were immediately transferred to the clinical laboratory at our institution and aerobically incubated at 36 °C for 48 h. Plate counts were then conducted to estimate the total number of colony-forming units (CFUs) for all aerobic bacteria (AB) present in each sample.

2.3. UVC Light Source and Settings

A 222-nm UVC-emitting Kr-Cl excimer lamp module (Care222™) was used in this study. This lamp comprises an optical filter with a restricted light emission range of 200–230 nm, with a maximum output wavelength of 222 nm [10]. The toilet seat, control panel of the electric toilet seat, top of the toilet paper holder, door handle, and floor were approximately 2.0, 2.0, 1.5, 1.4, and 2.4 m apart from the Care222™ emission window installed in the ceiling, respectively (Fig. 1).

The irradiance of the 222-nm UVC irradiator at 1.5 and 2.0 m was approximately 0.006 and 0.003 mW/cm², respectively, as measured using an S-172/UIT250 UV meter (Ushio Inc.). Care222™ has a motion sensor comprising infrared sensors. UVC disinfection was initiated only after 1 min of no motion, as detected by the infrared sensors, after which the UVC device functioned until the next detection of motion. The irradiation time of UVC light was measured by attaching a data-logger to the Care222™. UVC disinfection was started at 0:00 h on August 3 (day 1).

2.4. Ethics

Ethical approval was not sought because this study evaluated bacterial contamination in shared bathrooms with or without exposure to 222-nm UV irradiation. The purpose of this experiment was explained to staff who usually use these bathrooms before the experiment. During the study, a poster indicating an ongoing experiment using 222-nm UV irradiation was posted at the entrance of the shared bathrooms and in each bathroom separately. Even if the staff sat on the toilet seat for 1 min

Fig. 1. The scale of the bathroom. All dimensions are in cm.
without motion and UV irradiation started, they would easily notice this because of the sound created by the fan spinning when the UV irradiation started. When they moved a little, the motion sensor would detect it and the UV irradiation would immediately stop. The average sitting height of an adult male is approximately 90 cm [11], and the height of the toilet seat was 40 cm, so the height of the top of the crown was approximately 110 cm from the Care222™ installed in the ceiling; irradiance at that height was approximately 0.012 mW/cm². According to the ultraviolet radiation threshold limit value (TLV) recommended by the American Conference of Governmental Industrial Hygienists (ACGIH) or the requirements of the International Electrotechnical Commission (IEC) 62471, the limit of human exposure time at a wavelength of 222 nm per day (8 h) is 22 mJ/cm². Therefore, the limit of 222-nm UVC exposure time at the height of the top of the crown was calculated to be approximately 30 min. This information was also included in the poster.

2.5. Statistical analysis

Because of the non-normal distribution of the microbiological data, Wilcoxon matched-pairs signed rank test was used to determine differences in AB counts between the UVC-treated and the non-treated bathrooms. The difference in irradiation time between the UVC-treated and non-treated bathrooms was computed using a two-sided independent-samples t-test. The data were analyzed using JMP version 14.0 (SAS Institute Inc., Cary, NC, USA), and results with p < 0.05 were considered significant.

3. Results

During the 5-day study period, there was no significant difference in the time for which the two UVC sources were deactivated (171.8 vs. 169.4 min/day, p = 0.87) (Table 1).

Two hundred samples were collected (treated bathroom, 100 samples; non-treated bathroom, 100 samples). The CFUs per site and sampling time for AB are shown in Table 2. There was a significant difference in the total CFUs between the treated and non-treated bathrooms (p < 0.001) (Tables 2 and 3).

In the treated bathroom, the CFUs of AB on the toilet seat, control panel of the electric toilet seat, and top of the toilet paper holder was significantly lower than that in the non-treated bathroom (Table 2). In contrast, there was no significant difference between the bathrooms at the door handle and floor.

The CFUs of AB at 9:00, 15:00, and 18:00 h in the treated bathroom was significantly lower than that in the non-treated bathroom (Table 3). There was no significant difference in the total AB CFU between the two bathrooms at 12:00 h. The median AB CFUs of the samples from the treated bathroom at 9:00 h was the lowest.

4. Discussion

In this study, 222-nm UVC disinfection with Care222™, with a motion sensor, significantly reduced AB contamination of a shared bathroom. In the treated bathroom, total AB CFUs of the toilet seat, control panel of the electric toilet seat, and top of the toilet paper holder were significantly lower than those in the non-treated bathroom. The surfaces of these sites were easily contaminated by users’ hands and toilet flush aerosols, because these sites were often touched and were near the toilet bowl. Additionally, the surfaces of these sites were flat and hard, horizontal to Care222™, and there was nothing to shade the UVC. These characteristics of the surface may be associated with the result obtained. In contrast, a significant difference was not observed on the door handle and floor. In this study, we used contact plates and sampled the vertical surface of the door handle because the horizontal surface of the door handle was very small. However, many users may have touched the horizontal surfaces with their contaminated fingers because the door lock had a sliding mechanism. Therefore, the AB CFUs of the door handle contaminated by toilet users may not have been accurately assessed. In addition, the door handle was farther and far above the ground from the toilet bowl compared to the toilet seat, control panel of the electric toilet seat, and top of the toilet paper holder. Thus, the door handle might be less likely to be contaminated by toilet flush aerosols. These characteristics of the surface may be associated with the CFUs of the door handle of both bathrooms; the counts were less than those on other sites and no significant differences were observed. On the floor, other factors may have affected the efficacy of UV disinfection. First, the UV irradiation was relatively low because the UV-irradiation distance was longer than that on the other sampling sites. Second, the floor was easily contaminated by the shoes of users, in addition to toilet flush aerosols or droplets. Third, the floor of the bathroom had a rougher surface to prevent users from slipping. In contrast, the other sampling surfaces were flat and hard. These characteristics make the floor more easily contaminated than other sites, and the effects of 222-nm UVC light may be weaker. Residual burden after UVC treatment may be associated with material characteristics, such as porosity, roughness, and stability for bacterial adherence [12].

Samples were collected during the day at several time points. The bathrooms investigated in this study were rarely used at night. Therefore, the total AB CFU per sampling time of the treated bathroom was the lowest at 9:00 h, which indicated that 222-nm UVC irradiation was performed for a long time at night when the bathroom was not being used. In addition, total AB CFU per sampling time of the treated bathroom tended to increase over time up to 18:00 h, except at 12:00 h. These results indicated recontamination when the bathroom was used and that the bioburden was cumulative during the day compared with that at night, because people use the toilet more frequently. Although

### Table 1

| Site                  | Treated bathroom (Mean (SD)) | Non-treated bathroom (Mean (SD)) | p-value |
|-----------------------|------------------------------|----------------------------------|---------|
| Toilet seat           | 17.5 (1–46)                 | 45.0 (18–203)                   | <0.001  |
| Control panel of electric toilet seat | 12.5 (0–40)                          | 35.0 (6–180)                   | <0.001  |
| Top of the toilet paper holder | 6.0 (0–43)                            | 37.5 (5–92)                   | <0.001  |
| Door handle           | 5.5 (0–28)                  | 8.5 (0–26)                      | 0.071   |
| Floor                 | 29.5 (14–72)                | 32.5 (18–55)                    | 0.78    |

### Table 2

| Site                  | Treated bathroom (Mean (SD)) | Non-treated bathroom (Mean (SD)) | p-value |
|-----------------------|------------------------------|----------------------------------|---------|
| Toilet seat           | 17.5 (1–46)                 | 45.0 (18–203)                   | <0.001  |
| Control panel of electric toilet seat | 12.5 (0–40)                          | 35.0 (6–180)                   | <0.001  |
| Top of the toilet paper holder | 6.0 (0–43)                            | 37.5 (5–92)                   | <0.001  |
| Door handle           | 5.5 (0–28)                  | 8.5 (0–26)                      | 0.071   |
| Floor                 | 29.5 (14–72)                | 32.5 (18–55)                    | 0.78    |

### Table 3

| Sampling time | Treated bathroom (Mean (SD)) | Non-treated bathroom (Mean (SD)) | p-value |
|---------------|------------------------------|----------------------------------|---------|
| 9:00          | 5 (0–25)                    | 38 (1–171)                      | <0.001  |
| 12:00         | 16 (1–72)                   | 23 (5–51)                       | 0.12    |
| 15:00         | 13 (5–55)                   | 21 (6–81)                       | 0.014   |
| 18:00         | 22 (0–59)                   | 37 (6–203)                      | 0.015   |
| Total         | 11.5 (0–72)                 | 32 (0–203)                      | <0.001  |

CFU counts are shown as the median (minimum–maximum).
the treated bathroom was also contaminated over time, UV irradiation resulted in a significantly reduced contamination at 15:00 and 18:00 h compared with that of the control bathroom. There was no significant difference in the total AB CFU between the bathrooms at 12:00 h. In this facility, daily routine manual cleaning with a disinfectant was performed once a day at 10:30 h. Therefore, the bioburden of the non-treated bathroom at 12:00 h was reduced by manual cleaning, which affected the results.

A few studies have investigated the effect of installed UVC devices on toilet bacterial contamination. Cooper et al. evaluated the efficacy of a permanently installed, wall-mounted automated UVC (254-nm) device with a motion sensor for UVC irradiation for 5 min after each use [6]. Bacterial bioaerosol loads and bacterial contamination of the surface of the toilet seat and handwashing sink counter were evaluated using a contact plate. The authors showed that a 254-nm UVC disinfection system, with motion sensors, significantly reduced bacterial bioaerosol loads and contamination of shared bathrooms [8]. They also showed outlier samples that may represent highly contaminated droplets deposited on the seat after flushing. Irradiation with UVC light, especially 254-nm UVC, in intermittently occupied spaces was used only when there are no people, using a motion sensor, because it negatively affects the eyes and skin [5]. However, 222-nm UVC is less harmful to the skin and eyes than 254-nm UVC [13–16]. Therefore, although the UV radiation TLV recommended by the ACGIH should be followed, 222-nm UVC disinfection systems might be more suitable for occupied spaces than 254-nm UVC. Additionally, 222-nm UVC, as well as 254-nm UVC, inactivates various vegetative bacteria and viruses, including severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) [17–19]. The 222-nm UVC also had more potent germicidal effect on bacterial endospores, including Clostridium difficile, than 254-nm UVC [17]. As the bathroom of the isolation room of patients with C. difficile infection is contaminated with C. difficile [20], this technology may contribute to the reduction of environmental contamination with C. difficile in these bathrooms. In addition, this technology could be used in the bathrooms of healthcare and non-healthcare settings, such as transportation, public facilities, and commercial facilities. Moreover, the potential applications of this technology in every space that is intermittently occupied, such as elevators and conference rooms, are intriguing.

Manual cleaning is the most common method, but it has the problem of selecting inappropriate disinfectants; furthermore, some areas might remain uncleaned due to human errors [6,7]. A previous study showed that only 50% of the surfaces in hospital rooms are sufficiently cleaned [21]. In contrast, UVC disinfection is not prone to human errors; however, shadowed areas and organic load of surfaces decrease the efficacy of UVC disinfection [22,23]. Therefore, UVC disinfection systems may not be a substitute for manual cleaning, but they are good methods as an adjunct to manual cleaning.

The present study has some limitations. First, this study was not a crossover trial. However, there was no significant difference in the UV-irradiation time between the bathrooms. This suggests that there was no significant difference in the time during which the toilets in the two bathrooms were used. Second, only AB were cultured and anaerobic bacteria, such as C. difficile, or specific multidrug-resistant bacteria were not cultured. Third, the frequency of toilet use and interval time between the last toilet use and sample collection was not evaluated. Fourth, the adequacy of the manual cleaning procedure was not evaluated. Fifth, the effect of 222-nm UVC disinfection on bacterial aerosols was not investigated. Finally, a relatively non-frequently used bathroom was selected because this was a pilot study. Therefore, further study is needed in more frequently used bathrooms or bathrooms used by patients with multidrug-resistant organisms and C. difficile to evaluate the efficacy of Care222™ in reducing bacterial aerosols and contamination.

5. Conclusions

This study showed that an automated 222-nm UVC disinfection device, with a motion sensor, significantly reduced surface AB contamination in a shared bathroom. This technology may be applied not only in bathrooms but also in all spaces that are intermittently occupied, such as elevators and conference rooms. Further studies are required to investigate the effectiveness of this technology in such spaces.

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Declaration of Competing Interest

HO received a research grant from Ushio Inc. The other authors declare that they have no competing interests.

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