The Effect of UV Disinfection On Public Restroom Surfaces

proxima
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(Part 1)

Introduction

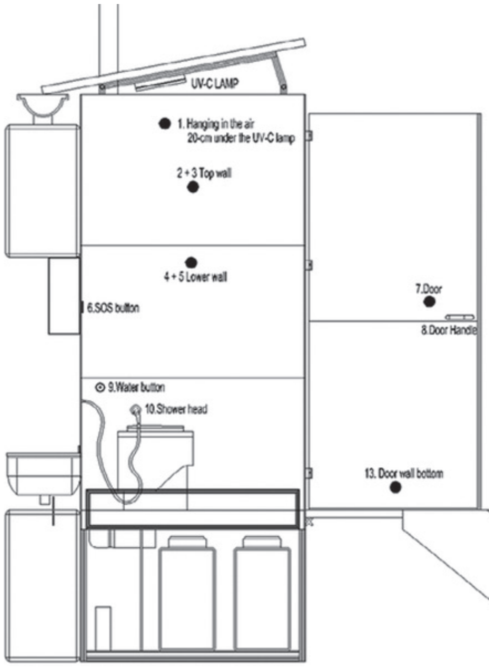
People spend the majority of their lives indoors where they are constantly exposed to bacteria residing on surfaces. However, the diversity of these surface-associated communities is largely unknown. Researchers explored the biogeographical patterns exhibited by bacteria across ten surfaces within each of twelve public restrooms. Using high-throughput barcoded pyrosequencing of the 16 S rRNA gene, they identified 19 bacterial phyla across all surfaces.

While we have known for some time that human-associated bacteria can be readily cultivated from both domestic and public restroom surfaces, little was known about the overall composition of microbial communities associated with public restrooms or the degree to which microbes can be distributed throughout this environment by human activity. The results demonstrate that human-associated bacteria dominate most public restroom surfaces and that distinct pattern of dispersal and community sources can be recognized for microbes associated with these surfaces.

Effectiveness of UV-C light irradiation on disinfection of restrooms

Toilets are commonly cleaned manually using water and cleaning chemicals, where cleaning action includes brushing the toilet bowl, wiping toilet seat and wall surfaces, and mopping the floor. Depending on the degree of dirtiness, toilet cleanings are considered labour intensive. Hence, manual cleaning of a toilet is done usually once or twice a day maximum. Chemicals are particularly used to help with visible stains removal and reducing smell which subsequently lessen the associated manual labours. Manual cleaning is done after a period of multiple users. Therefore, this methodology cannot remove pathogens after each toilet use. To address this issue, automated or self-cleaning method has been searched to be used for public toilets. Research has been done on cleaning innovations that focus on the use of less or no chemicals, while still reducing the labour works.

Some cleaning innovations were explored to be incorporated as part of eSOS toilet surface cleaning regimes. The first self-cleaning technology candidate was the application of nano-coating. However, after preliminary laboratory testing, the nano-coating was found to wear off easily requiring frequent reapplication. Thus, the idea of using nano-coating for self-cleaning technology in eSOS toilet was rejected. The second candidate was ultraviolet (UV) germicidal light. UV is highly effective at controlling microbial growth and at achieving disinfection at most types of surfaces [1]. UV radiation in the wavelength range of 250 ± 10 nm (UV-C) is lethal to most micro-organisms, i.e. bacteria, viruses, protozoa, mycelial fungi, yeasts and algae. The damage inflicted by UV-C involves specific target molecules; a dose in the range from 0.5 to 20 J/m^2 leads to lethality by directly altering microbial DNA through dimer formation [2]. A low-pressure germicidal UV-C lamp produces energy in the wavelength region of 254 nm. It was revealed that 3 min of UV-C light irradiation at 253.7 nm, that is a UV dose of 1.2 kJ/m^2 , could achieve 7.2 log reductions of E. coli in liquid samples (i.e. irradiated cultured E. coli solution). This is in line with another study in the food industry, where a 0.67–1.13 log CFU E. coli reduction was achieved by UV-C irradiation on the surface of the cap of mushroom exposed to an UV-C dose of 0.45–3.15 kJ/m^2 [3]. In general, UV-C disinfection is widely used for drinking water treatment and air treatment. UV is also extensively applied for equipment sterilization in the medical industry [4]. These results were encouraging enough to support wider surface disinfection applications such as toilet disinfection. Providing a toilet with UV-C surface disinfection feature adds the following advantages to the smart eSOS toilet including: (i) easiness to clean; (ii) toilet disinfection after each use; and (iii) potentially less labour-intensive clean



1	Hanging in the air*, right under the UV-lamp	20
2	Top wall left	49
3	Top wall right	49
4	Lower wall left	92
5	Lower wall right	92
6	SOS button	107
7	Above door handle	135
8	Door handle	136
9	Water button	155
10	Shower head	167
11	Toilet seat right (with lid down)	175
12	Toilet seat left	176
13	Door wall bottom	188
14	Floor behind pedestal under shadow	225
15	Floor behind pedestal under shadow, near water button	227
16	Floor middle near left sidewall	229
17	Floor middle near right sidewall	229
18	Floor below door	235

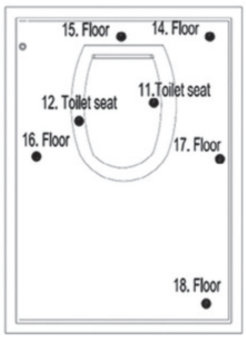


Figure 1. Schematic drawing of the eSOS toilet prototype with sampling points: side view (left); top view (right) [10].

ing. However, the use of UV germicidal light exclusively for toilet surface disinfection has not been evaluated before. There is only limited knowledge about such application, thus its effectiveness needs to be determined.

The indicator bacteria enumeration data which were obtained through swab sampling during the field-testing have high variability, that the results were best represented by comparing the occurrences, rather than reporting the number of bacteria colonies. The occurrences are reported on a daily basis with the UV system on/off as described in Table 1. The indicator bacteria occurrences classified into bacteria type and cleaning methods are presented in Figure 2.

Table 1. UV disinfection performance and cleaning regimes [10].

Cleaning agent	UV status	Observations
Bleach	Off On	5 8
Detergent	Off On	4 2
Water	Off On	2 2

UV-C light was observed to be effective in the reduction of total coliform at the door handle, water button and shower head, but UV-C was less effective at the toilet seat and floor when cleaned with bleach (see Figure 2(a)). While when cleaning with detergent (see Figure 2(c)), UV treatment did not show differences of total coliform occurrences and it was not effective at all at toilet seat and floor. While when cleaning with water only, UV treatment was effective at all points (see Figure 2(e)). Overall, the UV treatment is effective at the door handle, water button and shower head in case of total coliform. UV-C light did not consistently showed any occurrence reduction in toilet seat and floor.

Regarding E. coli inactivation, no E. coli occurrences were detected at the door handle for all cleaning methods (see Figure 2 (b), (d) and (f)), and occasional occurrences were seen at the water button when cleaned with detergent (see Figure 2(d)) and at the shower head when cleaned with detergent and water. E. coli consistently occurred at the toilet seat and at the floor independent of the cleaning method. Similarly as observed with total coliform, UV-C light did not show to be effective to inactivate E. coli at the toilet seat and floor. The almost absence of E. coli at the door handle, water button and shower head made the evaluation of UV treatment effectiveness to be inconclusive. However, this result should not discourage the UV efficacy in this study. Since total coliform was reported to be more resistant to UV than E. coli and Salmonella [5], sufficiency of UV treatment in removing total coliform indicates the capability to remove E. coli.

When observing both indicator bacteria, the UV-C treatment has no impact on bacteria occurrences reduction at the toilet seat and floor locations. Both the floor and the toilet seat are further away from the source of the UV-C light; therefore, these spots received less dose of UV-C irradiation than the door handle, the water button and the shower head. Furthermore, the insignificant effect of the UV-C light at the floor location could have been caused by the presence of high concentrations of other pollution/bacteria from other sources than human faeces. It was observed that users enter the toilet with contaminated footwear caused by the camp conditions outside (rainwater puddles, dog poop surrounding the toilet, among others). The floor in particular was often found with puddles of muddy water. This surface condition caused UV radiation to be less effective for inactivation of bacteria as they are shielded from UV light by particulate matters [6]. Even the presence of particles in clear water with a turbidity of less than 3 NTU was proven to limit the extent of UV inactivation of indigenous micro-organisms [7].

A similar explanation may also be valid for the toilet seat, although there was much less visible muddy water found on toilet seat. From the interviews carried out to the toilet users, approximately 10 % of interviewees admitted that they were squatting instead of sitting. It implies to the likeliness hat while squatting, they contaminated the toilet seat as they put their feet on the pedestal. The high occurrences of E. coli and total coliform on the floor and the toilet seat follow the same pattern.

The fact that UV-C inactivation capability is tampered when the micro-organisms are protected by particulate matters emphasizes the importance of manual cleaning to remove visible dirt and debris that occurred at the floor and toilet seat, as well as other locations in the toilet.

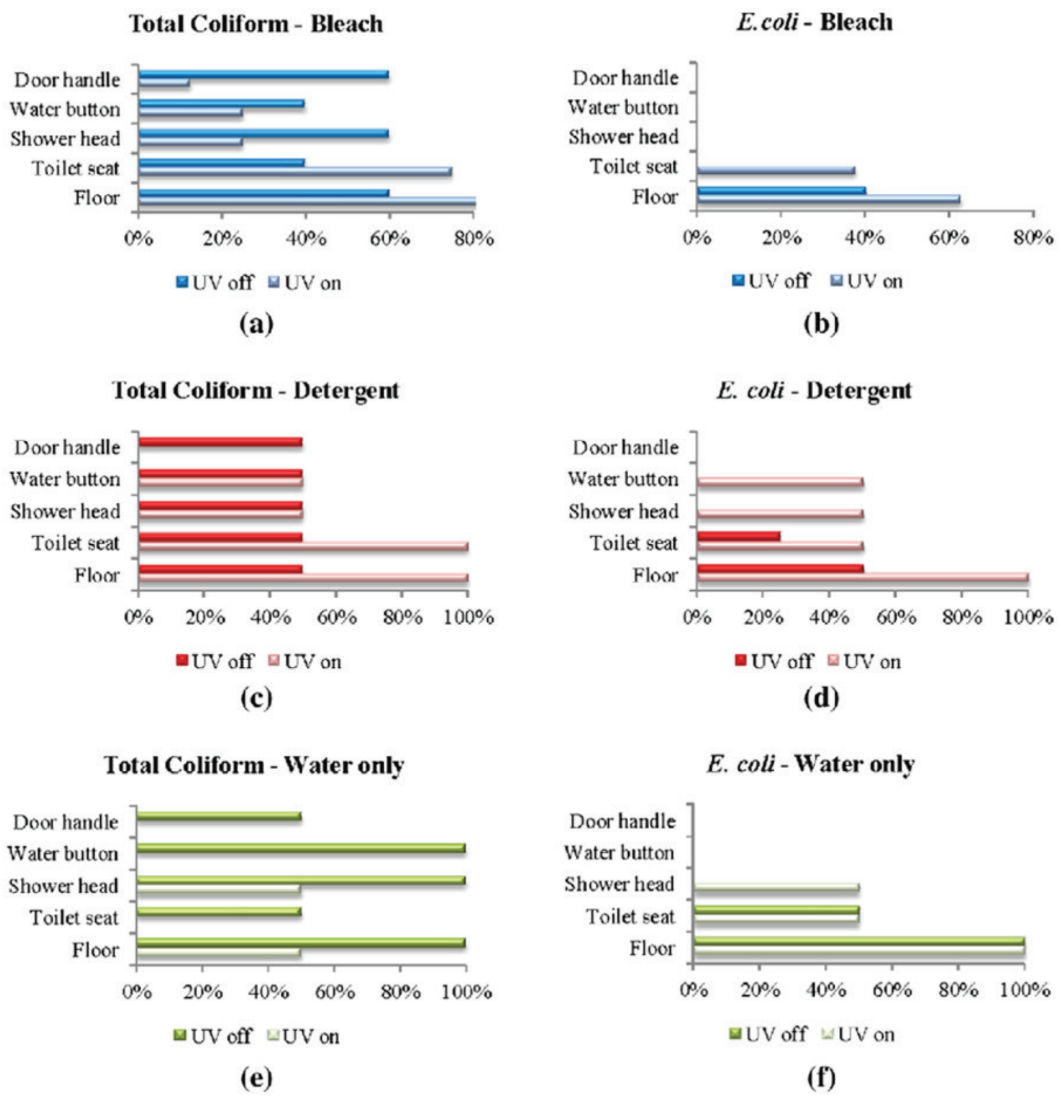


Figure 2. (Color online) Occurrences of total coliform and E. coli when UV was on and off classified considering the different convention cleaning methods simultaneously applied; bleach (a, b), detergent (c, d), water only (e, f) [10].

The experiments of UV-C light on and off were conducted for all types of cleaning in order to investigate whether the type of cleaning correlates with the effectiveness of UV-C irradiation on the toilet surface. It was previously observed that E. coli only occurred once at water button when UV was on, and twice at shower head, once when UV was on and once when UV was off (see Figure 2(b)). These occurrences happened when the toilet was not cleaned using bleach. Effectiveness of different cleaning types is further discussed in the immediate section.

To observe the effect of UV treatment alone without considering the cleaning type, the data were classified into UV-on and UV-off, as presented in Figure 3. The observation from this analysis confirms that UV treatment was not effective to reduce both total coliform and E. coli at the toilet seat and floor. However, it was shown to be effective for total coliform at the rest of sampling points (i.e. door handle, water button and shower head), and some indication to be effective for E. coli at water button. The UV-C effectiveness for E. coli at the shower head was questionably attributed to the fact that the only one-time E. coli occurrence happened when UV was on.

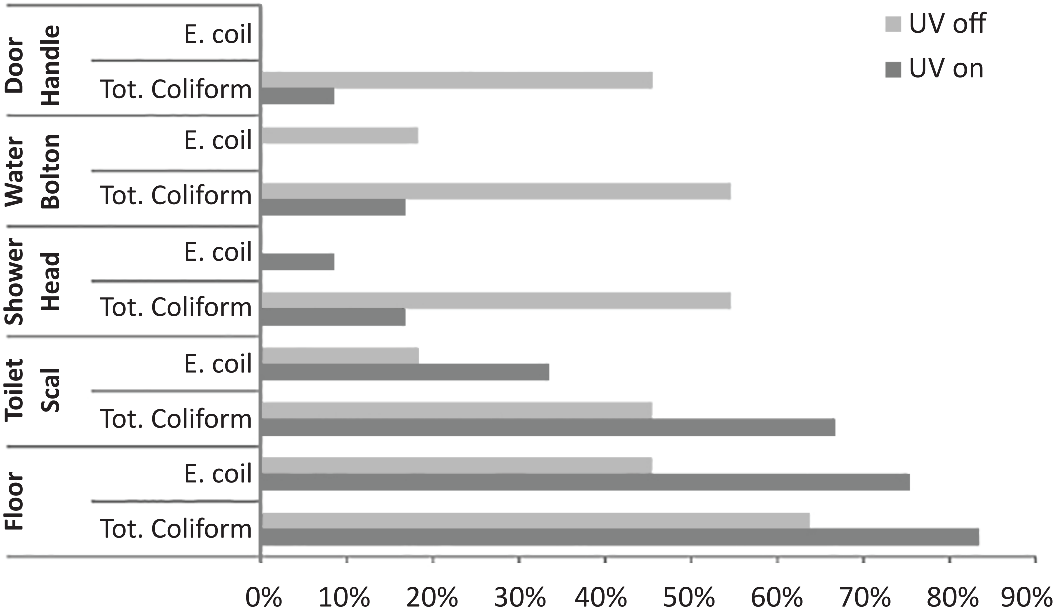


Figure 3. Percentage of occurrences of E. coli and total coliform at sampling points when UV-C light on and off [10].

These results demonstrate the capacity of the UV system in the eSOS toilet to disinfect toilet surfaces under real toilet usage. It was found that while UV-C treatment may have been effective for disinfecting surfaces closer to the UV-C light (i.e. door handle and water button) it is less capable for surfaces that are further away from the UV-C light (i.e. toilet seat and floor). However, the distance was not the only factor determining the efficiency of UV-C. Other factors such as a higher presence of micro-organisms from external source of contamination, together with soil particles that protect the micro-organism from the UV-C radiation, also play a role in reducing the UV-C inactivation capability. Therefore, multiple measures are suggested. The first recommendation is by increasing the UV-C dose using more powerful UV-C lamps, or by placing the UV-C lamp closer to the toilet seat and floor. However, increasing the UV-C dose should be done with caution taking into account the UV effects that could accelerate degradation of plastics [8,9] shortening the shelf life of plastic components of the toilet interior. Another recommendation is applying toilet-management-related measures to reduce external contamination e.g. provision of clean sandals only for the use in the toilet. At all cases, a manual cleaning regime remains a necessity to remove visible stains and dirt as UV-C alone is not able to disinfect surfaces in such condition. In the case of contamination of the floor, a better drainage system including addition of floor grating should be considered to allow soil and debris to fall through a drainage channel. Modifications of the design could be applied to frequently touched surfaces to be positioned perpendicularly to the UV-C light, for example, in case of the touch surface of the water button. To guarantee cleanliness in all corners and shaded areas is difficult, but by the application of the recommendations above the current system will be improved.

Conclusion

The use of UV-C light as a self-cleaning device in the eSOS showed some potential in this field research as it has already demonstrated some effectiveness set at a minimum exposure time (i.e. 3-min instead of the ideal 10-min found on the preliminary phase experiments) corresponding to a minimum power consumption. The current capacity of the system can still be expanded considering that there was abundant power supply as the field research location is situated by the equatorial line receiving strong and consistent solar irradiation to power the toilet. However, reiterating the above-mentioned discussions, increasing UV dosage by adding UV lamps, choosing for stronger UV lamp or positioning the lamp closer to the targeted surfaces – is not the only recommendation to enhance the UV disinfection capacity.

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