Ultraviolet-C decontamination of a hospital room: amount of UV light needed

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Running head:

Insufficient UV-C irradiation?

Abstract

Introduction

Our main aim was to use a professional radiometer to measure the amount of ultraviolet-C (UV-C) light that was delivered to different areas of a hospital room after automated UV-C decontamination. The secondary aim was to validate the use of a disposable indicator.

Methods

Disposable indicators and an electronic radiometer were positioned in different parts of an unoccupied room at the Burn Centre. The Tru-D™-device (set for sporicidal decontamination at 22 000 μWs/cm²) was placed in the centre of the room, and changes in the colour of the disposable indicators, and radiometer readings, were noted for the different areas.

Findings

The results show that doses of UV-C radiation that are received vary considerably in different areas. Indicators and surfaces in the direct line of sight from the UV-C device showed a more distinct change of colour – that is, they received higher UV-C doses than indicators or surfaces in the shadow of equipment or furniture ($p = 0.019$).

Conclusion

The amount of UV-C light that is delivered depends on the location in the room, and any objects that cast shadows will affect the doses of light delivered to the target areas. However, the dose received by these areas will be less than that received by areas that are more in the direct line of the UV-C device. We think that quality controls should be used to find out if enough UV-C will reach the shadowed areas to kill microbes. This can be done by one of several different instruments or by using a disposable indicator. There are several indicators on the market that will function adequately in a hospital.

Keywords:
UV-C-decontamination, efficacy, dosimeter, sterilization, hospital–acquired infections.

Introduction

Hospital–acquired infections are an increasing clinical problem, and clinical and scientific interest in them is rising because of the emergence of antibiotic-resistant organisms. In Sweden (10 million inhabitants), they cost roughly €650 million/year as well as being a major problem for patients' safety [1]. Numerous ways have been suggested to combat them, and it has become obvious that the cleanliness of the personnel, equipment, and facilities is of upmost importance [2]. As well as following basic measures such as education, raising awareness, and personal hygiene (washing of hands followed by alcohol rinse in between contacts) people have started to use decontaminating tools such as specific detergents for manual cleaning, and automated hydrogen peroxide vapour or ultraviolet-C (UV-C) irradiation.

Within the full spectrum of ultraviolet light (10-400 nm) ultraviolet-C (100-280 nm) has the best germicidal capacity (with a peak effect wavelength of 265 nm). The UV-C light is absorbed by RNA and DNA in cells and microbes, which induces changes in the D-/RNA structures that result in their inability to replicate. Without this, the cell is "dead". Many microbes have proved to be susceptible to inactivation using UV-C light [3] including (in order of ease to inactivate) bacteria, viruses, fungi, and spores [4]. The amount of inactivation is directly proportional to the UV-C dose which is delivered, and this in turn is the result of its intensity and duration of exposure. The farther away the light source, the less UV-C will reach the target, so only a quarter of the UV-C remains when the distance doubles [5, 6]. Any object that is between the light source and the target will block the UV-C, resulting in shadowed areas. However, to some degree, the UV light can reflect off surfaces to reach as far as the back of objects. This capacity to reflect is highly dependent on the material of the surfaces. For example, organic material will block the penetration of UV-C, which is why surfaces should be decontaminated with UV-C after manual cleaning to remove organic substances.

Studies conducted with various UV-C equipment such as: Pathogon (Pathogon UV Disinfection System, Steris Corporation, Mentor, Ohio, USA), Spectra 254 LLC (Spectra 254™, LLC, Danbury, CT USA), XENEX™ (GERM-ZAPPING ROBOTS™ New York, USA), and Tru-D™ (Tru-D™ SmartUVC, Lumalier Corporation, Memphis, Tennessee, USA) illustrate the efficacy of UV-C irradiation in the decontamination of hospital rooms [7-9]. It has been claimed that UV-C equipment has a disinfection rate of up to 4 $\log_{10}$, which is 99.99% eradication of *Clostridium difficile*, for example, one of the more resistant bacteria [7, 10, 11].

While the market for UV-C irradiation equipment is growing [5, 12-15] questions about its efficacy have been raised. Its relatively short wavelength makes it most efficient only over short distances and in a direct line with the light source [5, 6]. This in turn raises questions about shadowed areas, for example, and surfaces such as those behind furniture or the lavatory [16].

The mobile automated UV-C device that we used in this study was originally developed for hospital room-decontamination and supposedly allows for quick, automated disinfection of rooms. It has been shown to be effective in the eradication of various pathogens, including multidrug-resistant strains, from hard surfaces [5, 9, 17, 18]. Most devices have sensors that record the amount of UV-C light that is reflected back to the device from the surrounding surfaces during the decontamination process.

However, reflected light is not necessarily the same as the dose received in an area, as has been highlighted in some studies [11, 14, 16]. The UV-C dose received in different areas of the room would therefore need to be measured to ensure that an adequate dose had been used.

Different instruments are available to measure the UV-C dose received; UV-C radiometers, such as biotechnical dosimeters, electronic and spectral radiometers, and different kinds of chemical dosimeters. Even though the electronic devices are accurate, they are too expensive and difficult to be used as a routine.

However, a disposable indicator (dosimeter) has been developed (Intellego Technologies AB, Gothenburg, Sweden) that could be used in decontamination processes where UV-C light is the source of radiation. The dosimeter consists of a substrate with photoactive ink that reacts to the UV-C dose received, and changes colour. The ink can be modified to respond (change colour) at different pre-set levels of energy. The change in the colour of the ink can be separated into several different "steps", with different tones showing at different accumulated energy levels (doses) (Personal communication, Lindahl, 2017-10-27), or it can be read by a photometer.

As the disposable indicator is cheap (about <€0.5/unit) and easy to use, and numerous indicators can be put on doubtful (shadowed) surfaces to make sure that a proper dose of UV-C has been given to these areas. This will give increased quality control, and reassurance that the decontamination process is adequate.

Our primary aim was to find out what dose of UV-C was delivered to different areas of a hospital room after automated UV-C decontamination using a professional radiometer. The secondary aim was to validate the use of a disposable indicator, and in particular ensure that it accurately measured the UV-C dose given. To ensure a realistic clinical setting, an unoccupied room at the Uppsala Burn Centre (a burn intensive care ward at Uppsala University Hospital, Sweden) was used for the experiments. The room was decontaminated using a mobile UV-C device and different areas of the room received different doses that were measured by the disposable indicator and radiometer.

Materials and Methods

The principal experimental design has been described in detail elsewhere. [19] Briefly, disposable indicators and electronic dosimeters were positioned in different areas in an unoccupied room at the Burn Centre (locations and surfaces in frequent contact with the patients or staff, or both, and shadowed areas). The Tru-D™-device (Tru-D™ SmartUVC, Lumalier Corporation, Memphis, Tennessee, USA) was in the centre of the room, which was automatically disinfected using the wavelength UV-C, 254 nm.

The Tru-D™ is a mobile unit that emits UV-C light and, at the top of the unit, there are eight sensors that detect the UV-C light that is reflected from the surroundings during decontamination. UV-C light is emitted until a pre-set reflected dose of either 12 000 µWs/cm² (bactericidal) or 22 000 µWs/cm² (sporicidal) has been recorded by all the sensors. The sporicidal setting was used in this trial.

Radiometer (electronic)

For reference measurements, we used the RM-22 radiometer and UV-C sensor (Opsytec Dr Gröbel GmbH, Ettlingen, Germany). RM-22 is a high-precision, hand-held instrument for measuring irradiation and levels and doses of illumination. The dose is calculated by integrating the irradiance, and ambient light is corrected by an automatic offset. We used the irradiance measurement of 0.001 mW/s/cm² with the accumulated dose at a resolution of 0.001 mJ/cm². The range of dose was: 0 - 1 MJ/cm². The measurement range of illumination was 0 - 200.000 lx with a resolution of 1 lx. The spectral range of the UV-C sensor was 200 - 280 nm.

Disposable indicator

We used a disposable indicator (developed by Intellego Technologies AB, Gothenburg, Sweden). The dosimeter consists of a chemical mixture in the form of a photoactive ink combined with other chemicals. The chemical system reacts to the UV-C radiation, which induces a change in the pH. The change in pH affects the pH-dependent dye that changes colours in separate steps depending on the energy levels to which the indicator has been adjusted.

The indicator therefore changes colour depending on the amount of radiation received. In this study colour changes were divided into; high, medium, and low, and were assessed (blindly) by the human eye (CL). The indicators had been verified by RISE (Research Institutes of Sweden, Borås, Sweden) that evaluated the colour shift for UV sensitive materials using two different irradiance levels at 254 nm. (Further details in Appendix 1).

Experimental design

The experiment was repeated 10 times with the same design. For each repetition we placed 10 disposable indicators at separate locations round the room (Table 1, Figure 1). The electronic radiometer was positioned next to a disposable indicator, however, at various locations for each repetition (Table 1).

The UV-C emitting device was positioned in the middle of the room, next to the bed (Figure 1). The decontamination process (22 000 µWs/cm² sporicidal setting) was started from outside the room using the remote control.

Statistics

To analyse the correlations between the variables "distance" and "dose of UV-C", Spearman's rank order was used and probabilities of less than 0.05 were accepted as significant. To analyse the significance of differences in median dose of UV-C (continuous with respect to "shadowed"), the Mann-Whitney *U* test (two-tailed) was used and again probabilities of less than 0.05 were accepted as significant. Calculations were done using IBM SPSS Statistics for Windows (version 23, IBM Corp, Armonk, NY, USA), and results expressed as box and scatter plots.

Results

The results show that the doses of UV-C radiation received varied widely in different areas in the room (Table 1).

There was a tendency for the variables "distance" and "dose of UV-C" to be correlated, but not significantly ($p<0.054$, Spearman) (Fig 5). Indicators and surfaces in the direct line and vertical to the UV-C device showed a more distinct change of colour, which indicated that the UV-C dose received was higher than that received by indicators or surfaces placed horizontally, or shadowed by equipment or furniture, or both (Fig. 2). The pattern described was confirmed by the radiometer readings from the various locations (Table 1). A significantly lower UV-C dose ($p<0.019$, Mann-Whitney *U* test) was received at shadowed locations compared with those from readings from locations in a direct line (Table 1), the median value being 266 mJ/cm^2 and range was 15.9 mJ/cm^2 - 1068 mJ/cm^2. There was an obvious pattern in that the more objects there were in the way, and the farther away they were from the light source, the lower the dose received. This is clearly shown in Figure 4, in which the indicator was placed vertically on an L-shaped ledge on the wall. The elevation at the front of the ledge shadowed the lower part of the indicator.

Discussion

We investigated the UV-C dose received in different areas in a room after automated UV-C decontamination using a mobile automated UV-C light-emitting disinfector with the sporicidal setting of 22 000 µWs/cm² (22 mJ/cm^2). Manufacturers of decontamination devices based on UV-C light claim that the UV-C light emitted is reflected by surfaces to reach even areas that are not in direct line of sight, so reaching "everywhere".

The reflection of UV-C light is obviously dependent on the type of surfaces and objects in the room. In a recent study, Jelden, Gibbs, Smith, Hewlett, Iwen, Schmid and Lowe [20] proved that UV-reflective paint on the walls improved the disinfection of nosocomial bacteria on various surfaces, compared with standard paint on the walls.

Boyce, Farrel, Towle, Fekieta and Aniskiewicz [11] described a study similar to ours, in which they used a slightly different technique to measure doses of UV-C. We observe that their results correlate with ours. The achieved UV-C dose varied related to the distance and shadowing objects. Several studies have proved the efficacy of bacterial decontamination by UV-C-based devices [7, 9, 19] and there are many appropriate uses of this technology. However, our findings, along with others [21, 22] suggest that one needs to be cautious and not rely only on the disinfection gained from UV-C light-based devices in areas that are not in a direct line with the light source.

Because UV-C decontamination technology is being used more than ever in health care it is crucial to have access to tools that offer quality control, and assurance that the decontamination process has been adequate. One option would be to use disposable indicators that are cheap and easy to use and can be put in questionable or crucial areas. The indicator validated in our study adequately detected the UV-C dose received compared with the readings of the radiometer used. We did not use colour-/UV-C-specific levels for different doses. The indicators can, however, easily be prepared to change colours at pre-specified doses of UV-C.

The doses received in different areas ranged from 15.9 mJ/cm^2 to 1068 mJ/cm^2. If we compare our measured values with the values that are needed to reduce microbes that have been published by other research workers, it seems that the biological effect may still be achieved

for several of the more common microbes (Table 2), even though we still emphasise that quality control and assurance are essential after decontaminating a room using UV-C light.

A limitation of this study was the relatively small number of samples and radiometer readings used. However, the change of colour of the indicator was obvious, and correlated well with the radiometer readings. We did not investigate the biological response of eventual microbials in shadowed areas, and this should be done in future studies.

Conclusions

The UV-C dose that is received in a hospital room after decontamination with an automated UV-C device varies greatly, depending on the distance between the light source and the irradiated area, and any objects in between that are shadowing the areas. One must be sure that an adequate dose has been received in shadowed or critical areas, or both. Disposable indicators that are easy to use can ensure proper decontamination.

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Tables

Table I. Experimental design; location of dosimeters, distance from light source, measured dose of UV-C received, conditions between the light source, dosimeters and indicators, and angle of the indicators (relative to the light source) (see Figure 2).

Position	Description	Distance from the light source (cm)	mJ/cm^2	Shadowed	Angle of indicator
A	On the nurse's desk	144	560	No	Horizontal
B	On the bed	134	440	Partly	Horizontal
C	Under the bed	128	867	No	Vertical
D	In the basin	415	16	Yes	Horizontal
E	In the wardrobe	502	15,9	Yes	Vertical
F	On the ledge of the wall	430	424	No	Vertical
G	In the drawer of the left ceiling mounted pendant	97	108	Yes	Horizontal
H	By the infusion pump on the right ceiling-mounted pendant	230	1068	No	Vertical
I	On the writing surface on the right ceiling mounted pendant	275	45,8	Yes	Horizontal
J	Behind the desk chair	260	92	Yes	Horizontal

Table II. Published reductions of microbes' susceptibility to UV-C doses (adapted from ClorDiSys Ultraviolet Light Disinfection Data Sheet Rev. 10-213). Received UV-C dose not enough to reach X Log_{10} reduction for a specific microbe in location: [D]- In the basin, [E]- In the wardrobe, [G]- In the drawer of the left ceiling mounted pendant, I- On the writing surface on the right ceiling mounted pendant, [J]- Behind the desk chair.

	UV-C dose (mJ/cm^2) necessary for a given log reduction						
	1 Log_{10}	2 Log_{10}	3 Log_{10}	4 Log_{10}	5 Log_{10}	6 Log_{10}	
Spores							Reference
Bacillus subtilis ATCC6633	**24**[D, E]	**35**[D, E]	**47**[D, E, I]	**79**[D, E, I]			Mamane-Gravetz H, et al. Environ Sci Technol 2005; 39: 7845-52.
Bacillus subtilis WN626	0.4	0.9	1.3	2			Marshall MM, et al. Appl Environ Microbiol 2003; 69: 683-5.
Bacteria							
Aeromonas salmonicida	1.5	2.7	3.1	5.9			Liltved H and Landfald B. Water Research. 1996; 30:1109-1114.
Aeromonas hydrophila ATCC7966	1.1	2.6	3.9	5	6.7	8.6	Wilson BR, et al. Water Quality Technology Conference, Nov 15 - 19, 1992, Toronto, Canada, pp. 219-235, Amer. Wat. Works Assoc., Denver, CO.
Campylobacter jejuni ATCC 43429	1.6	3.4	4	4.6	5.9		Wilson BR, et al. Water Quality Technology Conference, Nov 15 - 19, 1992, Toronto, Canada, pp. 219-235, Amer. Wat. Works Assoc., Denver, CO.
Citrobacter diversus	5	7	9	11.5	13		Giese N and Darby J. Water Research, V34, 2000. 4007-4013.
Citrobacter freundii	5	9	13				Giese N and Darby J. Water Research, V34, 2000. 4007-4013.

Ebertelia typhosa	2.14	4.1					Light Sources Inc.2014V (2014). Retrieved 2018 02 from https://www.light-sources.com/solutions/germicidal-uvc-lamps/
Escherichia coli O157:H7 CCUG 29193	3.5	4.7	5.5	7			Sommer R, et al. J Food Prot 2000; 63:1015-20.
Escherichia coli O157:H7 CCUG 29197	2.5	3	4.6	5	5.5		Sommer R, et al. J Food Prot 2000; 63:1015-20.
Escherichia coli O157:H7 CCUG 29199	0.4	0.7	1	1.1	1.3	1.4	Sommer R, et al. J Food Prot 2000; 63:1015-20.
Escherichia coli O157:H7 ATCC 43894	1.5	2.8	4.1	5.6	6.8		Wilson BR, et al. Water Quality Technology Conference, Nov 15 - 19, 1992, Toronto, Canada, pp. 219-235, Amer. Wat. Works Assoc., Denver, CO.
Escherichia coli	3.0	6.6					Light Sources Inc.2014V (2014). Retrieved 2018 02 from https://www.light-sources.com/solutions/germicidal-uvc-lamps/
Escherichia coli ATCC 11229	7	8	9	11	12		Hoyer O. Water Supply 1998,16(1-2): 424-429.
Escherichia coli ATCC 11303	4	6	9	10	13	15	Wu Y, et al. Appl Environ Microbiol 2005; 71: 4140-3.
Escherichia coli ATCC 25922	6	6.5	7	8	9	10	Sommer, R, et alWater Sci. Technol.1998; 38(12): 145150.
Escherichia coli K-12 IFO3301	2.2	4.4	6.7	8.9	11.0		Oguma K, et al. Water Res 2004; 38: 2757-63.
Escherichia coli O157:H7	<2	<2	2.5	4	8	**17**[D, E]	Yaun BR, et al. Food Prot 2003; 66: 1071-3.
Halobacterium elongate ATCC33173	0.4	0.7	1				Martin EL, et al. Can J Microbiol 2000; 46: 180-7.

Halobacterium salinarum ATCC43214	12	15	**17.5** [D, E]	**20** [D, E]		Martin EL, et al. Can J Microbiol 2000; 46: 180-7.
Klebsiella pneumoniae	12	15	**17.5** [D, E]	**20** [D, E]		Giese N and Darby J. Water Research, V34, 2000. 4007-4013.
Klebsiella terrigena ATCC33257	4.6	6.7	8.9	11		Wilson BR, et al. Water Quality Technology Conference, Nov 15 - 19, 1992, Toronto, Canada, pp. 219-235, Amer. Wat. Works Assoc., Denver, CO.
Legionella pneumophila ATCC33152	1.9	3.8	5.8	7.7	9.6	Oguma K, et al. Water Res 2004; 38: 2757-63.
Legionella pneumophila ATCC 43660	3.1	5	6.9	9.4		Wilson, B.R., et al. Water Quality Technology Conference, Nov 15 - 19, 1992, Toronto, Canada, pp. 219-235, Amer. Wat. Works Assoc., Denver, CO.
Legionella pneumophila ATCC33152	1.6	3.2	4.8	6.4	8.0	Oguma K, et al. Water Res 2004; 38: 2757-63.
Pseudomonas stutzeri	**100** [D, E, I, J]	**150** [D, E, I, J, G]	**195** [D, E, I, J, G]	**230** [D, E, I, J, G]		Joux F, et al. Appl Environ Microbiol 1999; 65: 3820-7.
Pseudomonas aeruginosa	5.5	10.5				Light Sources Inc.2014V (2014). Retrieved 2018 02 from https://www.light-sources.com/solutions/germicidal-uvc-lamps/
Salmonella anatum (from human faeces)	7.5	12	15			Tosa, K and Hirata T. IAWQ 19th Biennial International Conference, 1998. Vol. 10, Health-Related Water Microbiology.
Salmonella derby (from human faeces)	3.5	7.5				Tosa, K and Hirata T. IAWQ 19th Biennial International Conference, 1998. Vol. 10, Health-Related Water Microbiology.
Salmonella enteritidis	5	7	9	10		Tosa, K and Hirata T. IAWQ 19th Biennial International Conference, 1998. Vol. 10, Health-

(from human faeces)							Related Water Microbiology.
Salmonella infantis (from human faeces)	2	4	6				Tosa, K and Hirata T. IAWQ 19th Biennial International Conference, 1998. Vol. 10, Health-Related Water Microbiology.
Salmonella spp.	<2	2	3.5	7	14	**29** [D, E]	Yaun BR, et al. J Food Prot 2003; 66: 1071-3.
Salmonella typhi ATCC 19430	1.8	4.8	6.4	8.2			Wilson, B.R, et al. Water Quality Technology Conference, Nov 15 - 19, 1992, Toronto, Canada, pp. 219-235, Amer. Wat. Works Assoc., Denver, CO.
Salmonella typhi ATCC 6539	2.7	4.1	5.5	7.1	8.5		Chang JC, et al. Appl Environ Microbiol 1985; 49: 1361-5.
Salmonella typhimurium (from human feces)	2	3.5	5	9			Tosa, K. and Hirata, T. IAWQ 19th Biennial International Conference, 1998. Vol. 10, Health-Related Water Microbiology.
Salmonella typhimurium	**50** [D, E, I]	**100** [D, E, I, J]	**175** [D, E, I, J, G]	**210** [D, E, I, J, G]	**250** [D, E, I, J, G]		Joux F, et al. Appl Environ Microbiol 1999; 65: 3820-7.
Serratia marcescens	2.42	6.16					Light Sources Inc.2014V (2014). Retrieved 2018 02 from https://www.light-sources.com/solutions/germicidal-uvc-lamps/
Shigella dysenteriae ATCC29027	0.5	1.2	2	3	4	5.1	Wilson, B.R, et al. Water Quality Technology Conference, Nov 15 - 19, 1992, Toronto, Canada, pp. 219-235, Amer. Wat. Works Assoc., Denver, CO.
Shigella sonnei ATCC9290	3.2	4.9	6.5	8.2			Chang JC, et al. Appl Environ Microbiol 1985; 49: 1361-5.
Staphylococcus aureus ATCC25923	3.9	5.4	6.5	10.4			Chang JC, et al. Appl Environ Microbiol 1985; 49: 1361-5.
Staphylococcus aureus	2.6	6.6					Light Sources Inc.2014V (2014). Retrieved 2018 02 from https://www.light-sources.com/solutions/germicidal-uvc-lamps/

Streptococcus faecalis (secondary effluent)	5.5	6.5	8	9	12		Harris, G.D, et al. Wat. Res.1987; 21(6): 687-692.
Streptococcus faecalis ATCC29212	6.6	8.8	9.9	11.2			Chang JC, et al. Appl Environ Microbiol 1985; 49: 1361-5.
Vibrio anguillarum	0.5	1.2	1.5	2			Liltved H and Landfald B. Water Research. 1996; 30:1109-1114.
Vibrio cholerae ATCC25872	0.8	1.4	2.2	2.9	3.6	4.3	Wilson, B.R, et al. Water Quality Technology Conference, Nov 15 - 19, 1992, Toronto, Canada, pp. 219-235, Amer. Wat. Works Assoc., Denver, CO.
Vibrio natriegens	**37.5** [D, E]	**75** [D, E, I]	**100** [D, E, I, J]	**130** [D, E, I, J, G]	**150** [D, E, I, J, G]		Joux F, et al. Appl Environ Microbiol 1999; 65: 3820-7.
Yersinia enterocolitica ATCC27729	1.7	2.8	3.7	4.6			Wilson, B.R, et al. Water Quality Technology Conference, Nov 15 - 19, 1992, Toronto, Canada, pp. 219-235, Amer. Wat. Works Assoc., Denver, CO.
Yersinia ruckeri	1	2	3	5			Liltved H and Landfald B. Water Research. 1996; 30:1109-1114.

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Figures

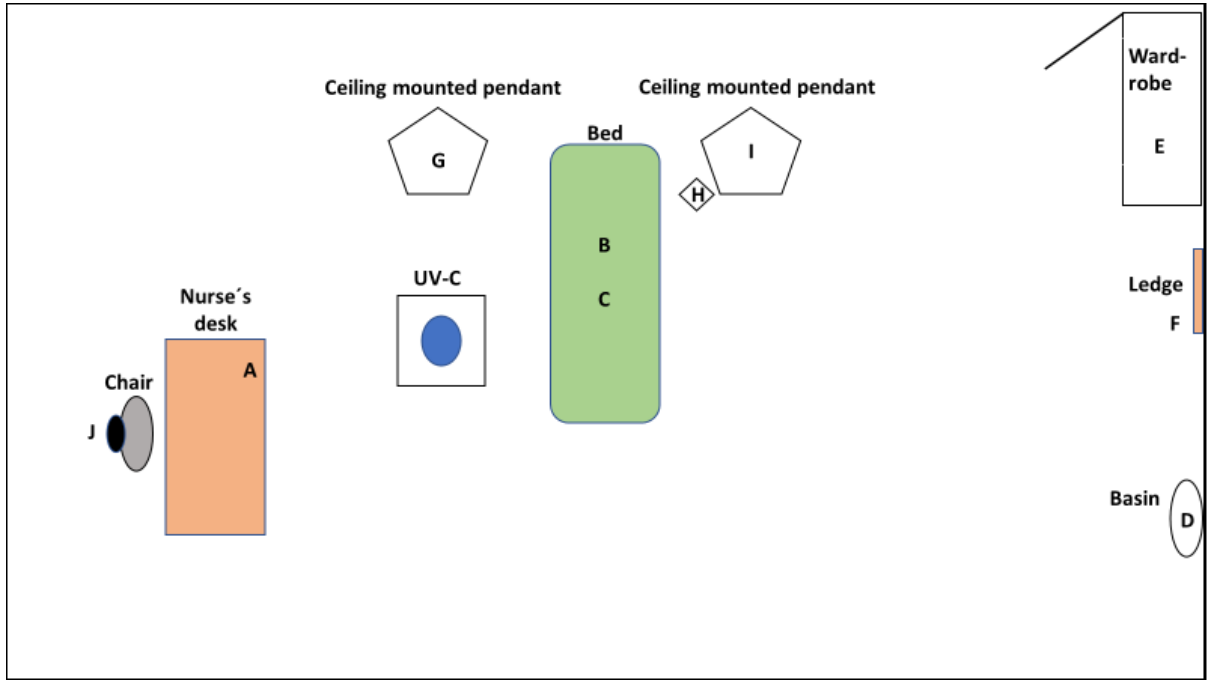

Figure 1. Room overview. Positions of indicators and radiometer A) on the nurse's desk, B) on the bed, C) under the bed, D) in the basin, E) in the wardrobe, F) on the ledge on the wall, G) in the drawer of the left ceiling mounted pendant, H) on the infusion pump, I) on the drawing surface of the right ceiling mounted pendant, and J) behind the desk chair.

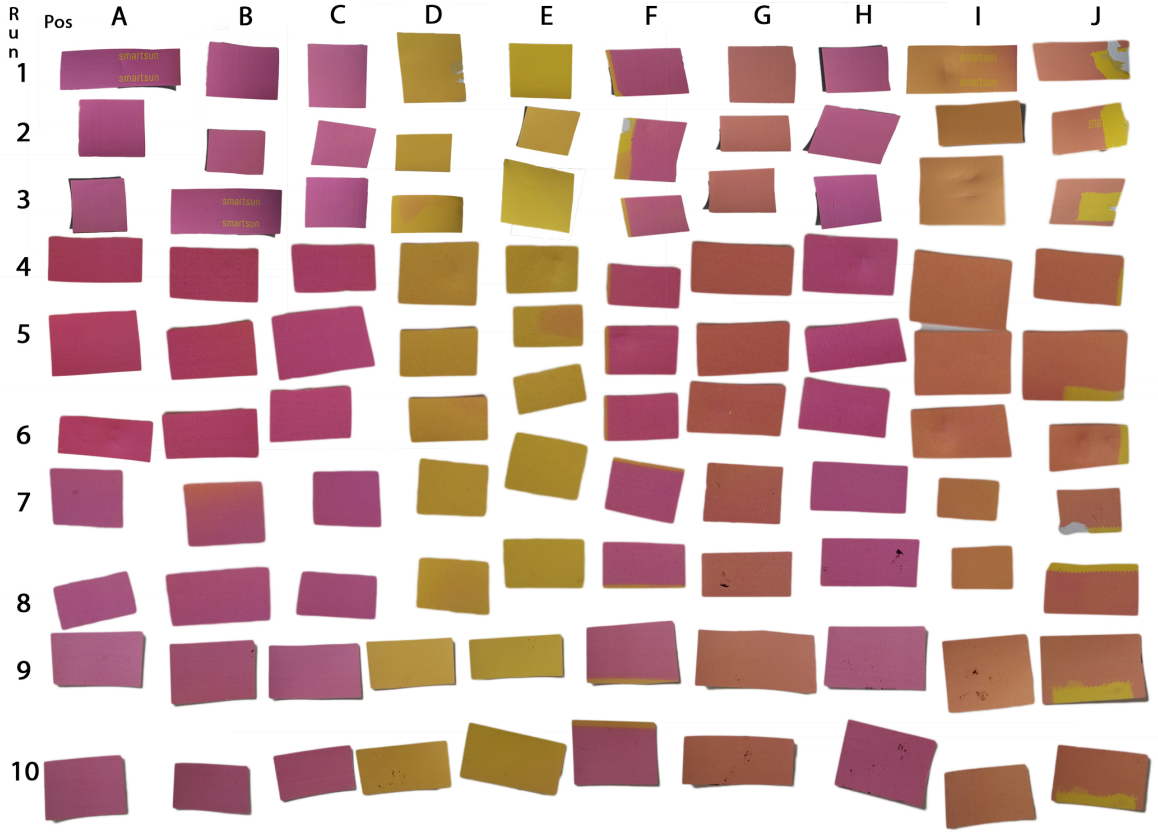

Figure 2A. Representative picture sample of the disposable indicators' colour changes from different locations receiving different UV-C doses. Positions A, B, C, F, and H - High (pink); Positions G, I, and J - Medium (Orange); Positions D and E - Low (Yellow).

Figure 2B. Originally colour of dosimeter = yellow.

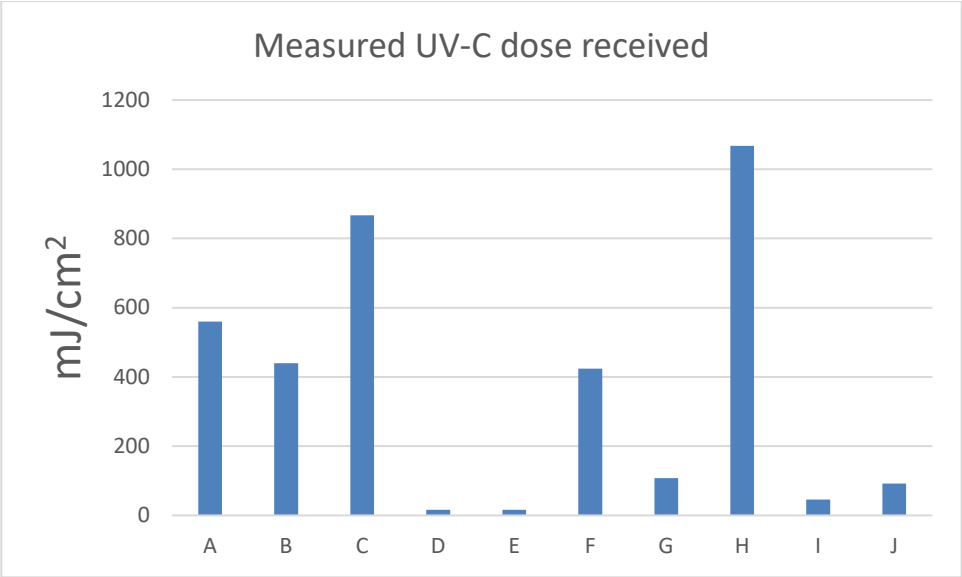

Figure 4. Measured UV-C dose received in different locations. A) on the nurse's desk, B) on the bed, C) under the bed, D) in the basin, E) in the wardrobe, F) on the ledge on the wall, G) in the drawer of the left ceiling mounted pendant, H) on the infusion pump, I) on the drawing surface of the right ceiling mounted pendant, and J) behind the desk chair.

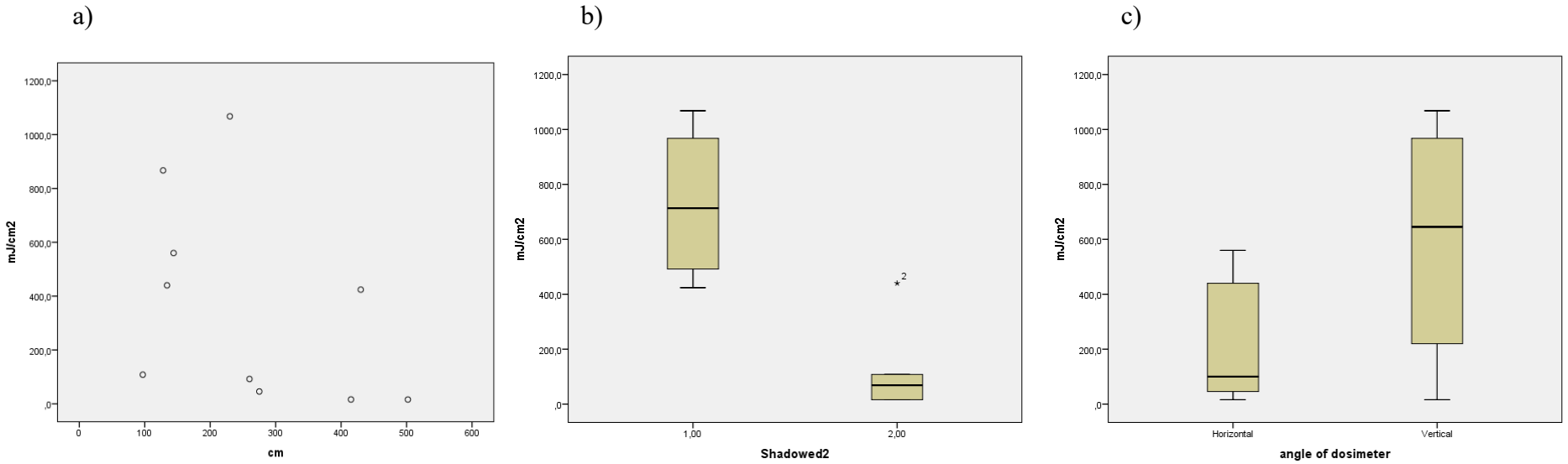

Figure 5. a) Scatter plot showing the measured dose of UV-C and the distance. b) Box plot of the difference between the UV-C dose and the Shadow. c) Box plot of ratio of mJ:cm2 in relation to the angle of the dosimeter.

Appendix 1

The results from the RISE validation showed that the change in colours after a certain UV exposure (dose) is similar for both the irradiance levels 90 and 760 µW/cm^2.

The samples were exposed to UV-radiation at 254 nm wavelength using a UVP Transilluminator equipped with fluorescent UVC-tubes using two different irradiation levels (90 and 760 µW/cm^2 respectively). The irradiation level at the sample plane was established by a calibrated silicone detector with a precision aperture in front of the detector's photosensitive surface. An aperture was used to limit the exposure to a well-defined spot of about Ø 20 mm on the samples.

At certain times (corresponding to exposures of 10, 25, 50, 75, and 100 mJ/cm^2) the exposure was briefly paused and the colour of the exposed area was measured using a PR-735 spectrophotometer. A picture of the sample was also taken. The measurements and pictures were taken with the sample placed in a light booth using D65 illumination with high colour rendering index (> 95).

The result from the testing showed that while the dosimeter was in a direct clear line from the UV-C source, there was a clear change in colour up to 100 mJ/cm^2, whereas the change was hardly noticeable between 75 and 100 mJ/cm^2. At 100mJ/cm^2 the colour had fully matured and almost stopped changing. For specific values of changes in colour , see Table A1 and A2).

Table A1. Exposure with low irradiance (90 μW/cm^2).

Exposure	CIE 1976 L*a*b* color coordinates			Colour difference
mJ/cm^2	L*	a*	b*	ΔE*
0	82,2	-4,0	52,4	0,0
10	77,8	6,3	40,9	16,0
25	73,2	14,2	30,0	30,2
50	69,4	21,3	18,4	44,3
75	67,8	25,4	10,7	53,0
100	66,4	27,8	5,4	58,9

Table A2. Exposure with high irradiance (760 µW/cm^2)

Exposure	CIE 1976 L*a*b* colour coordinates			Colour difference
mJ/cm^2	L*	a*	b*	ΔE*
0	83,0	-4,8	52,5	0,0
10	77,9	7,1	39,8	18,1
25	73,5	16,0	28,0	33,5
50	69,6	23,5	16,0	48,1
75	66,3	28,0	8,0	57,7
100	65,1	31,0	2,0	64,4

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Conflicts of interest
None. CL had no input on the interpretation of critical data or decision to submit manuscript for publication.

Authors' contributions

ML and FH analysed and interpreted data (exception as above), ML was responsible for data acquisition, ML, E.T and FH drafted the paper and revised it for important intellectual content after input from all other authors (exception as above). FH and ML were responsible for the concept and design of the study. All authors read, revised, and approved the final version of the paper (exception as above).