

Accuracy evaluation of an ultraviolet-C dosimeter based on CIELAB colour difference and its application in monitoring clinical surface disinfection

Youjian Zhang

Henan Provincial People's Hospital

Li Tan

Tongji Hospital

Cong Shi

s721219454803@163.com

Tongji Hospital

Research Article

Keywords: UVC dosimeter, ultraviolet-C, disinfection efficacy monitoring, colour difference, healthcare-associated infection control

Posted Date: October 13th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-11134967/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: No competing interests reported.

Abstract

Background: Ultraviolet-C (UVC) disinfection is widely used for air and object surface disinfection in healthcare facilities, and serves as an adjunct to manual terminal cleaning. However, the dose actually delivered to clinical surfaces is often far below the theoretical value because of shadowing, surface roughness and distance from the lamp, and such dose deficiency cannot be detected immediately by eye or by routine colony sampling.

Aim: To verify the accuracy of a UVC dosimeter in clinical settings and to evaluate its practical value for monitoring the efficacy of UVC disinfection.

Methods: Four categories of medical environment (Class I–IV: laminar-flow intensive care unit (ICU), general ICU, general inpatient ward and fever clinic) were selected. UVC irradiance and cumulative dose were measured at distances of 1 m, 1.5 m, 2 m and 3 m from the UVC lamp using a UV radiometer and the UVC dosimeter. Colour difference (ΔE) of the dosimeter was calculated in the CIELAB colour space, and the correlation between UVC dose and ΔE was assessed by Pearson correlation analysis. In a consultation room, 20 object surfaces were selected and exposed for 30 min and 60 min, and the dosimeter colour was read to determine the UVC dose range received by each surface.

Findings: The irradiance at 1 m from all tested UVC lamps exceeded $70 \mu\text{W}/\text{cm}^2$ (range 79.3–184.8 $\mu\text{W}/\text{cm}^2$), and decreased markedly with increasing distance. The dosimeter colour changed from yellow to orange-yellow, orange-red and red as the UVC dose increased, and ΔE showed a very strong positive correlation with UVC dose ($r > 0.9$, $P < 0.001$). In the surface application test, after 30 min of exposure, 45% (9/20) of surfaces received $<25 \text{ mJ}/\text{cm}^2$; after extension to 60 min, 40% (8/20) still received $<50 \text{ mJ}/\text{cm}^2$.

Conclusion: The UVC dosimeter provides an intuitive and accurate indication of the cumulative UVC dose received on object surfaces and helps to identify dose "blind spots" in clinical disinfection. Simply extending exposure time does not fully resolve dose inhomogeneity; dosimeter-guided optimization of lamp layout and irradiation strategy is required.

Introduction

Ultraviolet (UV) disinfection has notable advantages in hospital infection control and is widely used for disinfecting air and object surfaces, and is a routine means of disinfection in healthcare facilities and other public places [1]. The UV lamps widely used in healthcare facilities emit UVC short-wave UV at a wavelength of 254 nm; their core microbicidal mechanism is damage to nucleic acids and proteins, which blocks nucleic acid replication and renders micro-organisms non-viable [2]. Multiple studies have shown that 254 nm UVC effectively kills bacteria, viruses and fungi on environmental surfaces and in the air in healthcare settings, and can be used as an adjunct to manual terminal cleaning and disinfection [3]. The application of UV disinfection also helps to reduce the incidence of healthcare-associated infections (HAIs). After installation of UV devices in a special care unit of a long-term acute care

hospital, HAI surveillance data showed significant reductions in common HAIs, including a decrease in annual cases of *Clostridioides difficile* infection from 8 to 1 ($P = 0.01$), a decrease in annual cases of catheter-associated urinary tract infection from 20 to 9 ($P = 0.012$), and a decrease in the mean monthly infection rate from 20.3 to 8.6 ($P = 0.001$) [4].

The efficacy of UV disinfection is closely related to its irradiance and radiation dose. Irradiance is the radiant flux per unit area on the irradiated surface, expressed in $\mu\text{W}/\text{cm}^2$; radiation dose is the UV energy received per unit area, that is, the integral of UV irradiance over time, usually expressed in mJ/cm^2 . UV radiation dose plays a crucial role in the disinfection process. Theoretically, the microbicidal effect is proportional to the UV radiation dose: the higher the dose, the higher the inactivation rate [5]. Only when a specific UV radiation dose threshold is reached can the target micro-organisms be effectively killed. Studies have shown that a UVC dose of $22 \text{ mJ}/\text{cm}^2$ inactivates SARS-CoV-2 by 99.9999%, whereas methicillin-resistant *Staphylococcus aureus* (MRSA) and *Clostridioides difficile* require approximately $50 \text{ mJ}/\text{cm}^2$ and $100 \text{ mJ}/\text{cm}^2$ of UVC radiation, respectively, to achieve $> 99.9\%$ inactivation [6].

Although clinical studies have confirmed that UV significantly reduces environmental colony counts, the complexity of the environment to be disinfected poses serious challenges. Rough surfaces, crevices and shadowed "blind spots" in clinical environments mean that even when UV irradiance meets regulatory requirements ($> 70 \mu\text{W}/\text{cm}^2$), the dose actually received is often far below the expected value, and this dose deficiency cannot be detected immediately by eye or by routine colony sampling. There is a wide variety of UV lamp devices in clinical use, including mobile, fixed and handheld types, and there is a lack of unified validation criteria for whether the disinfection efficacy of these devices meets clinical needs. Studies have shown marked differences in irradiance and effective range among different types of UV germicidal lamps. In one study of four types of UV germicidal lamp (medical, suspended, portable and upright), the mean irradiance of a medical UV disinfection trolley within a 6 m^3 area was $199 \mu\text{W}/\text{cm}^2$; a portable handheld UV germicidal lamp achieved irradiance $\geq 70 \mu\text{W}/\text{cm}^2$ only within 50 cm, falling below $40 \mu\text{W}/\text{cm}^2$ at 150 cm [7]. These practical clinical problems highlight the need for monitoring of UV device radiation dose. Traditional monitoring of UV disinfection efficacy mainly uses UV intensity indicator cards or UV radiometers to qualitatively or quantitatively detect the irradiance of UV lamps. Compliance of irradiance with standards such as GB 19258 *Ultraviolet radiation sources for germicidal use* only indicates that the UV lamp has qualified irradiance at a specific distance; it does not guarantee the actual killing effect on complex micro-organisms in the clinical environment.

The Likang Space® UVC Dosimeter (Likang Medical Technology Jiangsu Co., Ltd.) uses a patented material sensitive only to a specific UV band. When exposed to UVC energy, the central part of the test card changes colour, allowing intuitive verification of the effectiveness of the disinfection procedure and determination of whether the optimal dose of UVC disinfection energy has been delivered to high-touch object surfaces. The product provides visual indication of three UV dose levels required for effective disinfection: $25 \text{ mJ}/\text{cm}^2$ (orange), $50 \text{ mJ}/\text{cm}^2$ (orange-red) and $100 \text{ mJ}/\text{cm}^2$ (red), representing low-level disinfection efficacy (inactivation of ordinary enveloped viruses such as SARS-CoV-2, killing of *Escherichia coli*, *Staphylococcus aureus*, etc.), intermediate-level disinfection efficacy (killing of

mycobacteria) and high-level disinfection efficacy (killing of *Bacillus subtilis* var. *niger* spores, *C. difficile* spores, etc.), respectively. This study aimed to verify the accuracy of this dosimeter in the clinical environment and to evaluate its application.

Methods

Test materials

Likang Space UVC Dosimeters were provided by Likang Medical Technology Jiangsu Co., Ltd. The UV radiometer used was model LS127C (Shenzhen Linshang Technology Co., Ltd.).

Test environments

To verify whether different categories of hospital environment affect the dosimeter, one department was selected as the test site for each of four categories of hospital environment: ICU Ward 1 with clean technology for air purification (Class I environment); ICU Ward 2 with a centralized air-conditioning and ventilation system for air purification (Class II environment); a general inpatient ward (Class III environment); and a fever clinic (Class IV environment).

Test methods

Measurement of UV lamp irradiance: 5 min after the UV lamp was switched on, the UV radiometer probe was placed at four test positions at distances of 1 m, 1.5 m, 2 m and 3 m from the UV lamp. After the instrument had stabilized, the displayed value was taken as the irradiance of the UV lamp. UVC dosimeters were placed at the four test positions, the UV lamp was switched on, and the radiometer was observed; when the energy value fell within the ranges 0–25, 25–50, 50–100 and > 100 mJ/cm², the UV lamp was switched off, photographs were taken to record the colour of the UVC dosimeter, and the measurement was repeated three times.

Quantitative analysis of dosimeter colour difference

Based on the CIELAB (also known as L*a*b*) visual perceptual colour space theory proposed by the International Commission on Illumination (CIE) in 1976, the distance between two points in the space approximately reflects the difference in colour in terms of lightness, chroma and hue.

In the Lab colour space, each colour is represented by three numbers, L*, a* and b*. L* represents lightness (range 0–100), where 0 is black and 100 is white; a* represents the component from green to red (range – 128 to 127); and b* represents the component from blue to yellow (range – 128 to 127). Red-green and yellow-blue here do not refer to standard pure colours. The formula for the colour difference ΔE between the colour after UV exposure and the colour before exposure is as follows:

$$\Delta E_{a*b^*} = \sqrt{(L_2^* - L_1^*)^2 + (a_2^* - a_1^*)^2 + (b_2^* - b_1^*)^2}$$

Correlation analysis between UV dose and colour difference

Pearson correlation analysis was used to calculate the correlation coefficient between UV dose and colour difference and to perform statistical testing. The strength of correlation is usually classified according to the absolute value of the correlation coefficient: 0.8–1.0 is generally considered "very strong correlation"; 0.6–0.8 "strong correlation"; and 0.4–0.6 "moderate correlation".

Results

Irradiance of UV lamps

As shown in Table I, the irradiance of the UV lamps was measured at 1.0 m, 1.5 m, 2.0 m and 3 m from the centre of the UV lamp in each test site. The irradiance at 1 m exceeded the required 70 $\mu\text{W}/\text{cm}^2$ at all test sites, with the highest in the Class IV environment (184.8 $\mu\text{W}/\text{cm}^2$) and the lowest in the Class II environment (79.3 $\mu\text{W}/\text{cm}^2$). UV irradiance decreased markedly with increasing distance from the UV lamp.

Table I Irradiance of the tested UV lamps in different environmental categories ($\mu\text{W}/\text{cm}^2$)

	Distance (m)	Environmental categories*			
		I	II	III	IV
Test position					
1	1.0	126.8	79.3	104.5	184.8
Test position					
2	1.5	48.1	60.2	40.1	75.3
Test position					
3	2.0	32.6	43.1	32.0	29.8
Test position					
4	3.0	20.5	22.9	20.0	15.2

*Class I–IV environments correspond to the four categories defined in GB 15982-2012. Class I environment: laminar-flow ICU; Class II environment: general ICU; Class III environment: general inpatient ward; Class IV environment: fever clinic.

Correlation between cumulative UVC dose and dosimeter colour difference

As shown in Fig. 3, after the dosimeter was exposed to different dose ranges of UV at different test positions, the colour-changing area of the dosimeter showed visible colour changes, evolving from yellow (no UV exposure) to yellow-orange, orange, orange-red and red. By comparison with the standard colour blocks for dose, the range within which the UV dose received by the dosimeter fell could be read directly.

To quantitatively analyse the relationship between UV exposure dose and colour change, the change from the yellow colour of the unexposed dosimeter was directly correlated with the cumulative UV irradiation level (dose). Photoshop software was used to measure the L, a and b parameters of each colour block, the colour difference ΔE between the colour after UV exposure and the colour before exposure was calculated using the colour difference formula, and a scatter plot of UV exposure dose against colour difference ΔE was drawn. As shown in Fig. 4, the scatter points for all four environmental categories were distributed towards the upper right, indicating a positive correlation between UV exposure dose and colour difference ΔE . Table II shows the mean UV exposure dose and mean colour difference for three repeated experiments within each test dose range at the different test positions in the four environmental categories. Pearson correlation analysis showed that the correlation coefficients between UV exposure dose and colour difference ΔE were all above 0.9, that is, a very strong correlation.

Table II Correlation between UV dose and colour difference for three repeated tests at each test position in different environmental categories				
	Test position 1	Test position 2	Test position 3	Test position 4
I	0.948	0.964	0.964	0.949
II	0.986	0.991	0.983	0.986
III	0.973	0.980	0.953	0.989
IV	0.911	0.940	0.950	0.932

Application of the UV lamp dose indicator card

As shown in Fig. 5, 20 object surfaces in the room were selected for placement of UV lamp dose indicator cards, and the UV lamp irradiation time was 30 min and 60 min, respectively. As shown in Fig. 6, after 30 min of irradiation, the colours of the indicator cards showed that 45% (9/20) had a cumulative UV dose < 25 mJ/cm², 40% (8/20) had a cumulative UV dose < 50 mJ/cm², and 15% (3/20) had a cumulative UV dose < 100 mJ/cm². After 60 min of irradiation, 5% (1/20) had a cumulative UV dose < 25 mJ/cm², 40% (8/20) had a cumulative UV dose < 50 mJ/cm², 40% (8/20) had a cumulative UV dose < 100 mJ/cm², and 15% (3/20) had a cumulative UV dose > 100 mJ/cm².

Discussion

This study systematically evaluated the application of the Likang Space UVC dosimeter in four categories of hospital environment. The results showed a very strong correlation between the colour change of the dosimeter and the cumulative UV dose ($r > 0.9$, $P < 0.001$), indicating that it can intuitively reflect the UV dose actually received on object surfaces and provides a convenient, visual tool for monitoring the efficacy of clinical UV disinfection.

Using quantitative analysis in the CIELAB colour space, this study found that the colour difference ΔE of the dosimeter maintained a highly consistent positive correlation with UVC dose in both Class I (laminar-flow ICU) and Class IV (fever clinic) environments. This indicates that the colour reaction of the dosimeter is essentially unaffected by confounding factors such as environmental cleanliness, temperature and humidity, and has good environmental adaptability. From a practical point of view, operators do not need to rely on professional instruments; comparison with standard colour blocks alone allows rapid determination of whether the dose has reached the 25, 50 or 100 mJ/cm² threshold, corresponding respectively to the requirements for low-level disinfection (inactivation of ordinary enveloped viruses, killing of *E. coli*, *S. aureus*, etc.), intermediate-level disinfection (killing of mycobacteria) and high-level disinfection (killing of *Bacillus subtilis* spores, *C. difficile* spores, etc.) [6]. Overseas researchers have placed UVC dosimeters and electronic radiometers at different positions in burn wards, disinfected the wards using UV disinfection devices, and recorded and compared the colour changes of the UVC dosimeters with the radiometer readings for consistency [8, 9]. In comparison, we used correlation analysis between colour difference and UV dose, which can more accurately and quantitatively reflect the validity of the dosimeter.

In this study, 20 high-touch object surfaces in a ward environment were selected for UV irradiation testing. Even after 30 min of irradiation according to the routine disinfection procedure, nearly half (45%) of surfaces received a UVC dose below 25 mJ/cm², failing to reach the minimum threshold for killing ordinary enveloped viruses such as SARS-CoV-2. Even when the irradiation time was extended to 60 min, 40% of surfaces still received a dose below 50 mJ/cm², meaning that these areas could not effectively kill common drug-resistant bacteria such as *S. aureus*. The indicator card that appeared yellow was on a computer monitor; the main reason for this result was that the monitor was located in shadow. This phenomenon is consistent with previous reports that shadows, rough surfaces and mutual shielding between equipment in clinical environments create large numbers of "irradiation blind spots", causing the actual received dose to be far below the theoretical calculated value [10]. The indicator cards on the floor, on both side walls, on the consultation bed at the entrance and on the table and chairs near the window appeared orange or orange-red, mainly because they were too far from the UV lamp and the UV irradiance had attenuated markedly, similar to test position 4 (3 m from the centre of the UV lamp) in each environmental category; these sites usually require 1.2–2 h to reach the highest indicated dose. The dose indicator card in this study visually revealed this problem, suggesting that we should not only focus on whether the irradiance of the UV lamp is qualified, but should also regularly use dose indicator cards to verify the actual dose on high-touch surfaces.

Theoretically, prolonging the UV lamp irradiation time linearly increases the cumulative dose. However, this study found that after extending the irradiation time from 30 min to 60 min, the proportion of surfaces with a dose < 25 mJ/cm² decreased from 45% to 5%. More notably, the proportion of surfaces reaching > 100 mJ/cm² (high-level disinfection) increased only from 0% to 15%. This indicates that for some sites that are severely shadowed or too distant, simply extending the time cannot effectively compensate for the defect of an extremely low initial irradiance. In actual clinical workflows, excessively prolonging the irradiation time encroaches on other work in the room and has poor feasibility. A more reasonable strategy should be: (1) use indicator cards to identify "disinfection blind spot" sites; (2) adjust the position of the UV lamp or add auxiliary mobile devices [11]; and (3) wipe and disinfect high-touch object surfaces first, then combine this with UV irradiation [12, 13].

Traditional monitoring of UV disinfection efficacy mainly relies on UV radiometers to periodically detect the output intensity of the lamp (e.g. whether the irradiance at 1 m from the lamp is > 70 µW/cm²), but this only proves that the lamp itself is qualified and cannot reflect the final dose actually irradiated onto object surfaces. In this study, the irradiance at 1 m of all lamps met the national standard, but the actual dose on object surfaces was generally insufficient. In contrast, the dose indicator card can be placed on any object surface to be disinfected and directly reflects the cumulative UV dose at that point, achieving a shift from monitoring the "UV device" to monitoring the "UV disinfection endpoint". In addition, the indicator card is single-use, requires no power supply or calibration, and is suitable for large-scale multi-point deployment, especially for rapid spot-checking of the effectiveness of terminal disinfection in hospital environments.

This study has some limitations: it was conducted in only one healthcare facility, with one ward selected for each of the four environmental categories, so the representativeness of the sample is limited; although colour interpretation of the indicator card was supplemented by CIELAB quantification, routine clinical use relies on visual comparison, which is subject to inter-individual variation; and no simultaneous microbiological sampling was performed, so the quantitative correspondence between the indicator card reading and the bacterial/viral inactivation rate was not directly verified. Future studies should carry out multi-centre, large-sample validation and combine microbiological testing to analyse the dose–colour–inactivation rate relationship.

Conclusion

In summary, the UVC dosimeter can intuitively and reliably reflect the cumulative UV dose received on object surfaces and effectively identify areas of insufficient dose in clinical disinfection practice; it is a powerful supplement to traditional irradiance monitoring. It is recommended that healthcare facilities incorporate UVC dosimeters into the routine quality control process for UV disinfection, especially in high-risk areas such as ICUs and fever clinics where UV is used to disinfect object surfaces, and regularly verify the dose on high-touch surfaces (bed rails, monitor buttons, call buttons, door handles, etc.). For sites where dose insufficiency occurs repeatedly, the UV lamp layout should be optimized or a

combined disinfection approach adopted to ensure that the killing requirements for target micro-organisms are met.

Declarations

Author contributions

Youjian Zhang and Li Tan conceived and designed the study. Youjian Zhang and Cong Shi performed the experiments and collected the data. Youjian Zhang and Li Tan analysed and interpreted the data. Youjian Zhang drafted the manuscript. Li Tan and Cong Shi critically revised the manuscript for important intellectual content. All authors read and approved the final manuscript and agree to be accountable for all aspects of the work.

Funding

This work was supported by the China Health Inspection Association project "Monitoring and Evaluation of Ultraviolet Indicators" (No. ZWJX2026009). The funding body had no role in the study design, data collection, analysis, interpretation, or writing of the manuscript.

Data availability

The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

This study did not involve human participants, human tissue or identifiable personal data. Ethical approval was therefore not required. The study was conducted in accordance with institutional guidelines for environmental disinfection quality monitoring.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

References

1. Poster DL, Miller CC, Martinello RA, et al. Ultraviolet radiation technologies and healthcare-associated infections: standards and metrology needs. J Res Natl Inst Stand Technol. 2021;126:126014.

2. LightSources, Team. UV-C disinfection explained: how germicidal light destroys bacteria, viruses, and fungi. 2025. Available at: <https://www.light-sources.com/blog/uv-c-disinfection-explained-how-germicidal-light-destroys-bacteria-viruses-and-fungi/>
3. Ramos CCR, Roque JLA, Sarmiento DB, et al. Use of ultraviolet-C in environmental sterilization in hospitals: a systematic review on efficacy and safety. *Int J Health Sci (Qassim)*. 2020;14:52–65.
4. Ethington T, Newsome S, Waugh J, Lee LD. Cleaning the air with ultraviolet germicidal irradiation lessened contact infections in a long-term acute care hospital. *Am J Infect Control*. 2018;46:482–6.
5. Doka T, Horák P. Fluence and dose distribution modeling of an ultraviolet light disinfection process for pathogen inactivation efficiency evaluation. *ACS Omega*. 2025;10:4291–302.
6. Masjoudi M, Mohseni M, Bolton JR. Sensitivity of bacteria, protozoa, viruses, and other microorganisms to ultraviolet radiation. *J Res Natl Inst Stand Technol*. 2021;126:126021.
7. Xu FF, Dai LL, Chen XH, Qu XH, Zhao Q. [Study on irradiance intensity and action range of different ultraviolet germicidal lamps]. *Chin Nurs Res*. 2020;34:4122–4. [In Chinese].
8. Lindblad M, Tano E, Lindahl C, Huss F. Ultraviolet-C decontamination of a hospital room: amount of UV light needed. *Burns*. 2020;46:842–9.
9. Masse V, Hartley MJ, Edmond MB, Diekema DJ. Comparing and optimizing ultraviolet germicidal irradiation systems use for patient room terminal disinfection: an exploratory study using radiometry and commercial test cards. *Antimicrob Resist Infect Control*. 2018;7:29.
10. Casini B, Tuvo B, Cristina ML, et al. Evaluation of an ultraviolet C (UVC) light-emitting device for disinfection of high touch surfaces in hospital critical areas. *Int J Environ Res Public Health*. 2019;16:3572.
11. Cadnum JL, Pearlmutt BS, Redmond SN, Jencson AL, Benner KJ, Donskey CJ. Ultraviolet-C (UV-C) monitoring made simple: colorimetric indicators to assess delivery of UV-C light by room decontamination devices. *Infect Control Hosp Epidemiol*. 2021;43:306–11.
12. Casini B, Tuvo B, Scarpaci M, et al. Implementation of an environmental cleaning protocol in hospital critical areas using a UV-C disinfection robot. *Int J Environ Res Public Health*. 2023;20:4284.
13. Scott R, Joshi LT, McGinn C. Hospital surface disinfection using ultraviolet germicidal irradiation technology: a review. *Healthc Technol Lett*. 2022;9:25–33.

Figures

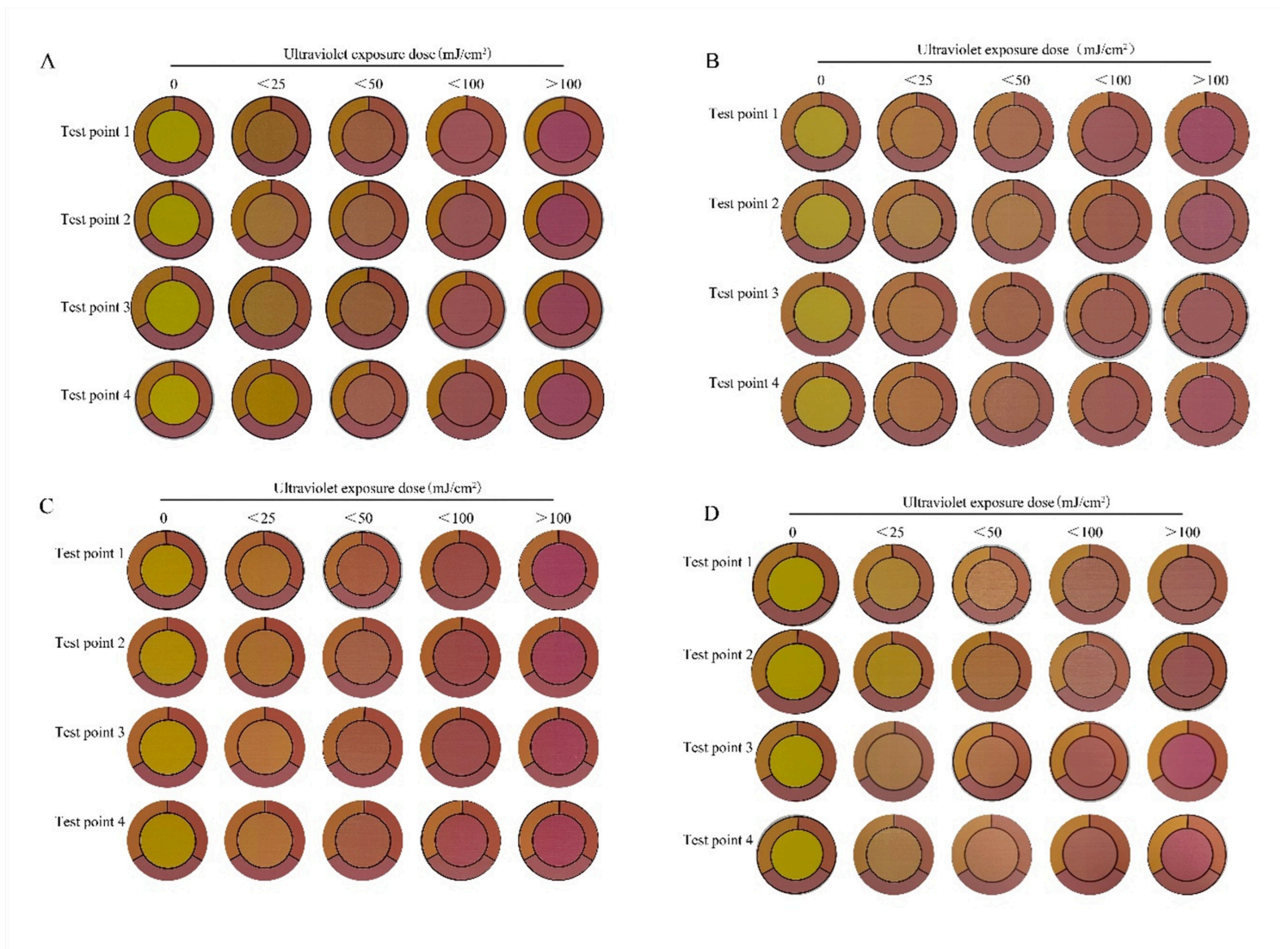


Figure 1

Figure 3 Dosimeters after exposure to different doses of UV. A: Class I environment; B: Class II environment; C: Class III environment; D: Class IV environment.

Image not available with this version

Figure 2

Legend not included with this version



Figure 3

Figure 5 Placement sites of the UVC dosimeters.

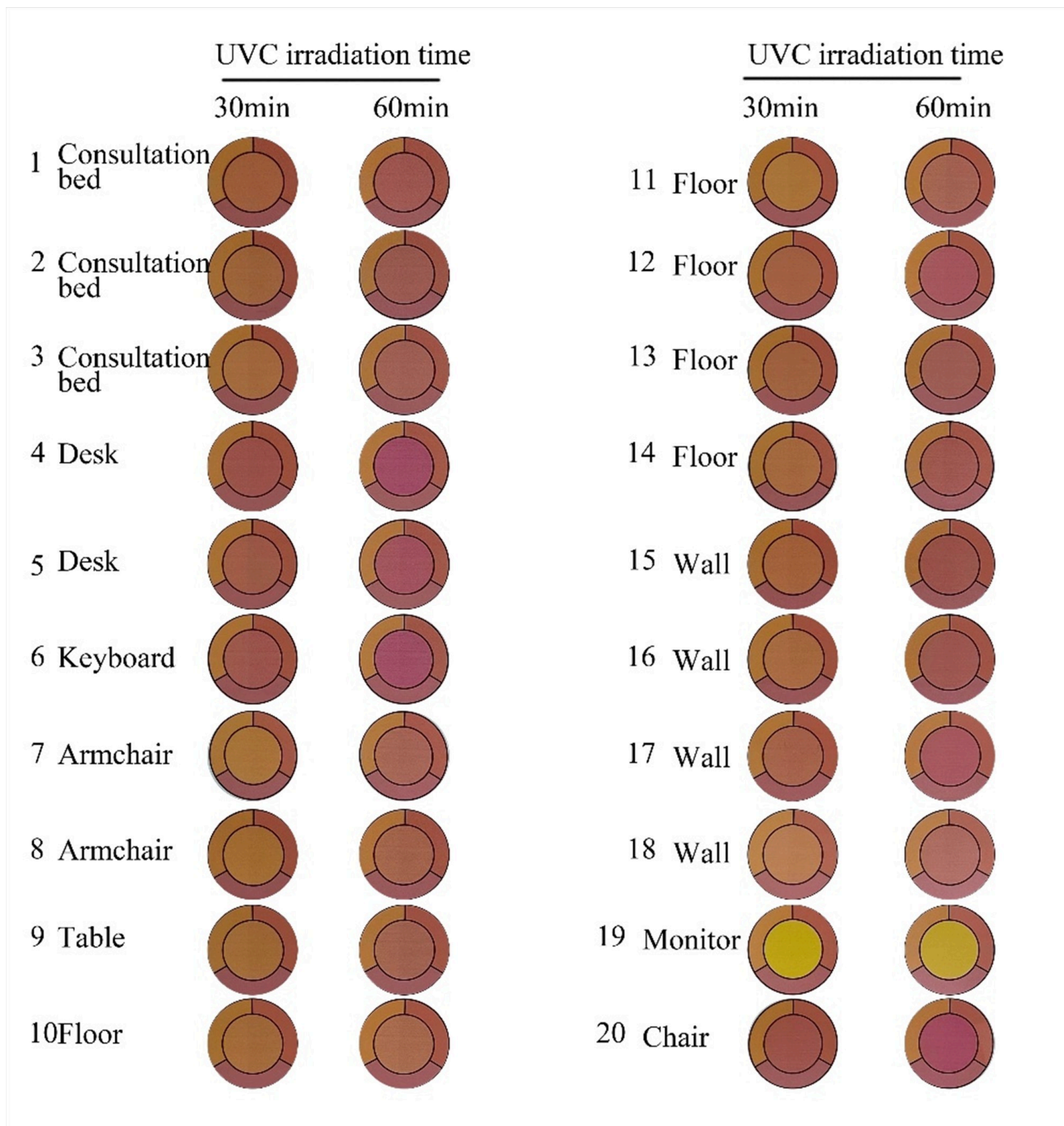


Figure 4

Figure 6 UVC dosimeters after 30 min and 60 min of irradiation.