The Effectiveness of Commercial Household Ultraviolet C Germicidal Devices in Thailand

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Research Article

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Abstract

Ultraviolet C (UVC), also called ultraviolet germicidal irradiation (UVGI), is known for its effective air, water, and surface disinfectant properties. With the rise of global awareness about public sanitation and personal hygiene due to the emergence of the current coronavirus disease 2019 pandemic, several applications of UVC were developed and introduced to the commercial market. The present experimental study was conducted to evaluate the effectiveness of commercial household ultraviolet C germicidal devices for severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) inactivation. UVC dosages (mJ/cm^2) of 10 UVC devices were determined at the recommended settings and compared to a UVC dosage benchmark for SARS-CoV-2 inactivated UVC dosage (3.7 mJ/cm^2). Of the 10 devices, 3 were handheld UVGI surface disinfection equipment, 4 were UVGI disinfection chambers, and 3 were movable UVGI air and surface purifiers. Three UVGI disinfection chambers and all movable UVGI air and surface purifiers provided sufficient UVC dosages for SARS-CoV-2 inactivation. None of the studied handheld UVGI surface disinfection equipment achieved the UVC dosage for SARS-CoV-2 inactivation. A lack of standardization in the distance and cycle duration for each UVC application was observed. Standard usage guidelines for UVC devices are required to improve the effectiveness of UVC irradiance for SARS-CoV-2 inactivation as well as to minimize the potential side effects of UVC.

Introduction

The emergence of the current coronavirus disease 2019 (COVID-19) pandemic has raised global awareness about public sanitation and personal hygiene. COVID-19, caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), was first reported in Wuhan, China, on December 31, 2019, and was identified as a pandemic disease by the World Health Organization on March 11, 2020 (Acuti Martellucci et al. 2020). The transmission of SARS-CoV-2 primarily occurs through direct contact, indirect contact (fomite transmission), and respiratory droplets (Anonymous 2020a). Recent studies have shown potential airborne transmission of SARS-CoV-2. The studies generated aerosols of SARS-CoV-2 from nebulizers under experimental conditions. One study showed that SARS-CoV-2 remains viable within aerosols for 3 hours (van Doremalen et al. 2020). Another study suggested that the infectivity and virion integrity of SARS-CoV-2 persisted for up to 16 hours in respirable-sized aerosols (Fears et al. 2020).

To control the pandemic, several modalities have been adopted to reduce transmission, including social distancing, use of masks, hand hygiene, surface cleaning and disinfection. (Anonymous 2020c). Regarding disinfection methods, ultraviolet germicidal irradiation (UVGI) systems are gaining popularity due to their effective disinfectant properties for air, liquids, and surfaces (Buonanno et al. 2020, Heilingloh et al. 2020, Reed 2010, Welch et al. 2018).

Ultraviolet radiation is electromagnetic radiation that is classified into UVA (315–400 nm), UVB (280–315 nm), UVC (200–280 nm), and vacuum UV (100–200 nm). UVC is primarily used in UVGI because it has strong germicidal effects, and its wavelength (particularly 250–270 nm) is strongly absorbed by the nucleic acids of microorganisms. UVC inactivates microorganisms by interrupting deoxyribonucleic acid or ribonucleic acid replication through the formation of pyrimidine dimers (Yin et al. 2013).

There are several types of UVC light sources that have different peak UVC emissions and different applications. Low-pressure mercury lamps, with a peak emission of 254 nm, are the most common type of UVC light source. Other types include excimer lamps (or far-UVC lamps), pulsed xenon lamps, and light-emitting diodes (LEDs) (Anonymous 2020b).

Although the germicidal effect of UVC radiation was documented over many decades, the applications of UVC have been limited since overexposure to UVC radiation can potentially cause adverse effects on human health, including corneal irritation, conjunctival irritation, and skin irritation (Ploydaeng et al. 2020). Therefore, the UVGI system has mainly been used in healthcare settings and research. Recently, the demand for household UVC germicidal devices has been increasing in response to the current COVID-19 pandemic. Several applications of UVC were developed and introduced to the commercial market. To the best of our knowledge, no study has evaluated the effectiveness of commercial household UVC devices for SARS-CoV-2 inactivation. Therefore, the present study aimed to measure the dose of available commercial UVC devices to reach the UVC dosage that can inactivate SARS-CoV-2.

Materials And Methods

Study design

A prospective experimental study was conducted from February to March 2021. The study protocol was reviewed by the Institutional Review Board at Mahidol University and was considered a value-adding study (COA. MURA2021/82).

Commercial UVC devices

Ten UVC devices were included in the study. The devices had a household-use purpose and availability in the market. The studied devices were categorized based on UVC light source and application (Fig. 1). Types of UVC light sources were divided into low-pressure mercury lamps and light-emitting diodes (LEDs). Applications were divided into handheld UVGI surface disinfection equipment, UVGI disinfection chambers, and movable UVGI air and surface purifiers. Regarding confidentiality, labels were assigned to each device and were used throughout the study. For ease of communication, the label comprised letters (M or L) followed by a number. M was used for devices with a low-pressure mercury source, while L was used for devices with an LED source. The label and specification of UVC devices are provided in Table 1.

Table 1
The label and specification of 10 studied ultraviolet C germicidal devices.

UVC light source	Application	Label	UVC wave range (nm)	UV light power (W)
Low-pressure mercury lamps	Handheld UVGI surface disinfection equipment	M1	N/A	2.5
		M2	253.7	2
	UVGI disinfection chamber	M3	253.7	24
		M4	253.7	8
	Movable UVGI air and surface purifier	M5	N/A	38
		M6	253.7	24
		M7	253.7	8
Light-emitting diodes	Handheld UVGI surface disinfection equipment	L1	265–280	4.5
	UVGI disinfection chamber	L2	265	8
		L3	270–285	5–8

UVC, ultraviolet C; UVGI, ultraviolet germicidal irradiation; N/A, not applicable

UVC light measurement

A Lutron UVC-254SD meter equipped with a cosine correction filter UV photosensor was used to measure UVC irradiance. The sensor covered 220 nm to 280 nm UVC wavelengths.

Measurement procedure

To evaluate the effectiveness of UVC devices in practice, UVC irradiance was determined at short and long distances. First, we placed the sensor at a distance of 2 cm for all devices. Long distances for each device varied depending on the manufacturers' usage instructions. The duration of the cycle for each device was determined based on instructions given by the manufacturers. In the case of no given instructions, the distance and duration of the cycle were determined by dermatologists based on the application and power of the device.

The UV photosensor was pointed directly toward UVC devices. UVC measurement was repeated three times in each position. UVC irradiance (mW/cm^2) was subsequently converted to UVC dosage (mJ/cm^2) by summing all irradiance values obtained every second during a cycle.

Determination of SARS-CoV-2 inactivation

A UVC dosage of 3.7 mJ/cm^2 was applied as a benchmark for SARS-CoV-2-inactivating UVC dosage. The value was the UVC radiation dose required for a 90% SARS-CoV-2 reduction, as reported in a recent review study (Heßling et al. 2020). The recommended settings were the maximum distance and minimum cycle duration for achieving a SARS-CoV-2-inactivating UVC dosage for the studied devices.

Results

Ten commercial household UVC devices were included. Of the 10 devices, 7 devices were low-pressure mercury lamps, while the others were LEDs. The power of devices with a low-pressure mercury source ranged from 2 to 38 W, while that of devices with an LED source ranged from 4.5 to 8 W. With regard to application, there were 3 handheld UVGI surface disinfection equipment, 4 UVGI disinfection chambers, and 3 movable UVGI air and surface purifiers. For standardization purposes, UVC dosages were compared across devices with similar applications.

There were 3 handheld UVGI surface disinfection equipment (M1, M2, and L1). The long distances of M1, M2, and L1 were 1.4 m, 5 cm, and 3 cm, respectively, according to the manufacturers' instructions.

According to the usage instructions, none of the studied handheld UVGI surface disinfection equipment achieved the SARS-CoV-2-inactivating UVC dosage.

At 1.4 m, no UVC irradiance was detected from M1. The maximum distance at which UVC irradiance could be detected was 10 cm. Considering the duration, 2 minutes of M1 usage provided a sufficient UVC dosage for SARS-CoV-2 inactivation.

At the recommended distances of M2 and L1, UVC irradiances were detected for both devices; however, the SARS-CoV-2-inactivating UVC dosage was not achieved despite the use of the recommended duration. Recommended settings from the authors for M1, M2, and L1 are shown in Table 2. The distances ranged from 1 to 10 cm, while the durations of the cycles varied from 35 sec to 2 min.

Table 2
Ultraviolet C dosage and recommended settings of the 3 studied handheld UVGI surface disinfection equipment.

	Handheld UVGI surface disinfection equipment		
	Low-pressure mercury lamps		Light-emitting diodes
Label	**M1**	**M2**	**L1**
Power (W)	2.5	2	4.5
Short distance	*2 cm*	*2 cm*	*2 cm*
Cycle duration	*15/30 min*	*30 sec*	*2 sec*
UVC dosage (mJ/cm^2)	260.60/436.54	4.52	**0.29**
Long distance	*1.4 m*	*5 cm*	*3 cm*
Cycle duration	*15/30 min*	*30 sec*	*2 sec*
UVC dosage (mJ/cm^2)	**Undetectable**	**2.46**	**0.22**
Recommend settings			
Manufacturer			
Distance	No more than 1.4 m	3–5 cm	1–3 cm
Cycle duration	15/30 min	30 sec	2 sec
Author			
Distance	No more than 10 cm	3–5 cm	1–3 cm
Cycle duration	2 min	45 sec	35 sec

UVC, ultraviolet C; UVGI, ultraviolet germicidal irradiation

Four UVGI disinfection chambers labeled M3, M4, L2, and L3 were included in the experiment. Since the UVC light sources of the studied chambers were located in the lid, 2 cm and 10 cm from the light source could be defined as the top and bottom of the chambers, respectively. M3, M4, and L2 showed favorable results. As shown in Table 3, these devices provided sufficient UVC dosage for SARS-CoV-2 inactivation when following the usage instructions from the manufacturers. In contrast, L3 could not deliver a sufficient UVC dosage measured at the bottom of the chamber with the recommended duration.

Table 3
Ultraviolet C dosage and recommended settings of the 4 studied UVGI disinfection chambers.

	UVGI disinfection chambers			
	Low-pressure mercury lamps		Light-emitting diodes	
Label	**M3**	**M4**	**L2**	**L3**
Power (W)	24	8	8	5–8
Short distance	*2 cm*	*2 cm*	*2 cm*	*2 cm*
Cycle duration	*35 sec*	*11/16/21 min*	*5 min*	*3 min*
UVC dosage (mJ/cm^2)	86.14	790.22/1115.19/ 1423.00	19.40	7.58
Long distance	*10 cm*	*10 cm*	*10 cm*	*10 cm*
Cycle duration	*35 sec*	*11/16/21 min*	*5 min*	*3 min*
UVC dosage (mJ/cm^2)	22.62	411.14/587.35/ 755.75	6.80	**2.05**
Recommend setting				
Manufacturer				
Distance	In chamber	In chamber	In chamber	In chamber
Cycle duration	35 sec	11/16/21 min	5 min	3 min
Author				
Distance	In chamber	In chamber	In chamber	In chamber
Cycle duration	6 sec	8 sec	3 min	6 min

UVC, ultraviolet C; UVGI, ultraviolet germicidal irradiation

All 3 studied movable UVGI air and surface purifiers were low-pressure mercury lamps with powers of 8 to 38 W. No usage instructions were given for M7; therefore, we measured UVC irradiance under the same settings as M5 and M6. These 3 devices were effective for inactivation at the recommended settings, as shown in Table 4.

Table 4
Ultraviolet C dosage and recommended settings of the 3 studied movable UVGI air and surface purifiers.

	Movable UVGI air and surface purifiers		
	Low-pressure mercury lamps		
Label	**M5**	**M6**	**M7**
Power (W)	38	24	8
Short distance	*2 cm*	*2 cm*	*2 cm*
Cycle duration	*15 min*	*15 min*	*15 min*
UVC dosage (mJ/cm^2)	9622.97	9137.52	2794.49
Long distance	*2 m*	*2 m*	*2 m*
Cycle duration	*15 min*	*15 min*	*15 min*
UVC dosage (mJ/cm^2)	36.55	21.61	5.37
Recommend setting			
Manufacturer			
Distance	*2 m*	*2 m*	N/A
Cycle duration	*15 min*	*15 min*	N/A
Author			
Distance	*2 m*	*2 m*	2 m
Cycle duration	2 min	3 min	11 min

UVC, ultraviolet C; UVGI, ultraviolet germicidal irradiation

Discussion

UVC devices with different specifications were included in this study to represent the variety of UVC devices available on the market. SARS-CoV-2 inactivation performance was examined and categorized by device application to provide ease of use in practice.

Different applications of UVC devices possess certain characteristics that make them useful for different purposes. Specifically, handheld UVGI surface disinfection equipment is characterized as a small portable UVC device providing a minimum sufficient level of UVC irradiance for SARS-CoV-2 inactivation. Therefore, this application is appropriate for disinfecting small surface areas, such as cell phones, keyboards, and door handles. The effective range is a short distance ranging from 1 to 10 cm. A practical misleading point for this application is the overestimation of the application range, as evidently seen in the M1 device. A longer duration of UVC irradiance could not compensate for a longer effective range.

UVGI disinfection chambers are another common UVC application suitable for surface disinfection. Importantly, the values of UVC irradiance at the top and bottom of the chamber were different. The UVC dosage at the bottom of the chamber in 3 devices (M3, M4, and L2) was more than the dosage required for SARS-CoV-2 inactivation; therefore, the recommended duration could be shortened. However, the design of the chambers can prevent potential UVC side effects in humans; thus, the authors the support manufacturers' usage instructions to gain the benefit of inactivation of bacteria and other viruses without increasing the risk of side effects(Hijnen et al. 2006).

Comparing the 3 studied applications, the UVC dosages of the movable UVGI air and surface purifiers at the recommended settings were the highest, which can be explained by their usage purpose. These applications are effective not only for surface disinfection but also proper for air disinfection. Therefore, the expected range of the applications is longer than that of the other 2 applications. Unlike UVGI disinfection chambers, UVC irradiance from movable UVGI air and surface purifiers disperses, so potential side effects to humans should be taken into consideration. Accordingly, the authors suggest a shorter irradiance duration for movable UVGI air and surface purifiers in SARS-CoV-2 inactivation.

In addition to distance and duration, the direction of UVC irradiance is another crucial factor determining the disinfectant property of UVC. Boyce et al.(Boyce et al. 2016) conducted an experimental study to evaluate the impact of room location on UVC irradiance and UVC dosage. The results revealed that the orientation of the UVC sensor relative to the UVC device affected UVC irradiance. The UVC sensor pointed directly at UVC light yielded the highest UVC irradiance.

Another key concern in selecting UVC devices is the type of UVC light source. A low-pressure mercury lamp is a traditional UVC source mainly emitting at 254 mm(Anonymous 2020b). Although a low-pressure mercury lamp effectively generates UVC irradiance for disinfectant purposes, it has a major disadvantage that should not be overlooked. The main component (mercury) is known for its toxicity to humans and the environment(Bernhoft 2012, Clarkson &Magos 2006). As the accessibility of UVC devices expands, the public should be aware of mercury toxicity, and the safety of commercial mercury lamps must be ensured by manufacturers. LEDs are another UVC light source that were recently introduced to commercial markets. The use of LEDs is rising because they contain no mercury; thus, UVC LED devices are safe for human use and environmentally friendly. However, the limitations of LEDs are their small surface and directionality; hence, the use of UVC is limited for UVGI disinfection chambers and handheld UVGI surface disinfection equipment applications.

The authors are aware of the limitations of this study. First, a benchmark for the SARS-CoV-2-inactivating UVC dosage was used instead of examining SARS-CoV-2 inactivation with UVC. The second limitation is the generalizability of the results. The specifications of the studied UVC devices varied in the type of light source, application, and usage (distance and cycle duration), which could be inferred from the variety of UVC devices available in the commercial market. Consequently, the results from the present study will help guide the effectiveness of commercial household UVC devices for SARS-CoV-2 inactivation, but further adjustments are necessary depending on the specifications of the UVC device.

Conclusion

All movable UVGI air and surface purifiers and 3 out of 4 UVGI disinfection chambers achieved an adequate UVC dose for SARS-CoV-2 inactivation, but handheld UVGI surface disinfection equipment provided a minimum sufficient level of UVC irradiance for SARS-CoV-2 inactivation. There was no standardization of the distance and cycle duration for each UVC application in achieving SARS-CoV-2 inactivation in the present study. Standard usage guidelines for UVC devices are required to improve the effectiveness of UVC irradiance for SARS-CoV-2 inactivation as well as to minimize the potential side effects of UVC.

Declarations

Ethics approval and consent to participate.

The study protocol was approved by Institutional Review Boards in Mahidol University (COA. MURA2021/82).

Consent for publication

Not applicable

Availability of data and materials

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

Competing interests

The authors declared no competing interest.

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Authors' contributions

PP (Pasita Palakornkitti) and PR analyzed and interpreted the data regarding and were the major contributor in writing the manuscript. PP (Prinpat Pinyowiwat), NR and ST were the minor contributor in writing the manuscript. All authors read and approved the final manuscript.

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Figures

Figure 1

Handheld UVGI surface disinfection equipment

Figure 2

UVGI disinfection chambers

Figure 3

Supplementary Files

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- UVCdevicetable.docx