Design and Development of Ultraviolet Germicidal Irradiation Device for Controlling Airborne Bacteria in the Workplace

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Objective: *To design and develop an ultraviolet germicidal irradiation (UVGI) device for controlling airborne bacteria in the workplace of hospitals.*
Material and Method: *The constructed UVGI device was a chamber, consisting of a return air grille, an air supply grille, two 30-watt ultraviolet lamps and a cross flow fan inside the chamber. The efficiency of the UVGI device was tested at three different flow rates of 15.7, 31.6 and 46.1 m^3/min, respectively by collecting bacteria samples before and after operating the device for 30, 60, 90 and 120 minutes.*
Results: *The efficiency of the UVGI device at flow rates of 15.7, 31.6 and 46.1 m^3/min was 60.6, 92.8 and 80.8%, respectively and the bacteria concentration was reduced to less than 100 cfu/m^3, except at the flow rate of 15.7 m^3/min. The application of the UVGI device in the specimen-received room showed that the concentration of bacteria was reduced to less than 100 cfu/m^3 after 180 minutes.*
Conclusion: *The constructed UVGI device was effective to reduce airborne bacteria in workplace of hospital.*

Keywords: *Ultraviolet germicidal irradiation device, Bacteria, Workplace of hospital*

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Hospitals are workplaces where patients, visitors and hospital employees can acquire variety of infections caused by bioaerosol agents. The prevention and control of infection in hospital are good practice, personal protection, cleaning, sterilization and isolated room for high-risk patients[1].

Generally, the ultraviolet wavelength of 253.7 nanometers is the best kinetics of killing bacteria by induction of pyrimidine dimers which stop the process of DNA synthesis[2]. As a consequence, the bacteria lose the ability for cell division. The effectiveness of ultraviolet irradiation depends upon several factors, dose of ultraviolet radiation, duration of exposure and types of microorganism[3]. The application of ultraviolet lamps to the ventilation systems of three schools could reduce measles infection of students[4]. The upper room of ultraviolet germicidal irradiation reduced 14-19% of culturable airborne bacteria in outpatient waiting room[5]. The addition of ultraviolet lamps to the ventilation system reduces the available viable infectious droplets nuclei[6] and does not seem to result in any adverse effects[7]. Jenkins[8] designed a portable UV chamber consisting of an ultraviolet germicidal bulb of 15 watts and a cooling fan. He found that the UV chamber had 90-100% effective in killing *E.Coli* and *E. aerogens* but it was only 51% effective against the bacteria in the fish culture room[8]. The purpose of this research was to design and construct the ultraviolet germicidal irradiation (UVGI) device by placing two ultraviolet radiation lamps in a closed chamber to prevent irradiation of people.

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Material and Method

Germicidal ultraviolet lamp device

An ultraviolet germicidal irradiation (UVGI) device had a characteristic of chamber (50 x 25 x 95 cm,

118,750 cm^3) made of zinc (Fig. 1). The chamber consisted of a returned air grille (14 x 82 cm, 1,148 cm^2) beside it and a supplied air grille (4 x 68 cm) on the top of it. Two 30-watt Philip ultraviolet germicidal lamps, 92-cm long, were placed perpendicular to the flow of air in the chamber. Each bulb produced current of 0.415 amps, ultraviolet power of 13.4 watt and ultraviolet irradiation intensity of 130 microwatts per square centimeter at a distance of 1 meter. An aluminum foil was lined with an aluminum tape inside the chamber to reflect the ultraviolet radiation back towards the flow of air. An extremely quiet cross flow fan was driven directly by the 10-watt motor, mounted inside the chamber to control the velocity of airflow into it.

Study site

The selected room, an office in the hospital, was 4 x 6.5 x 3 m, 78 m^3 having one door and two windows. The room had an air conditioning system having two supplied air diffusers and a returned air grille on the ceiling. A propeller fan was installed on the wall of the room. The room was illuminated with 12, 36-watt fluorescent bulbs during the working day. Prior to placing the UVGI device, the direction of airflow within a test room was checked as shown in Fig. 2. The UVGI device was placed on the floor 1.3-m high on the stand beside the wall near the returned air grille of the air conditioning system. It helped mix the air extremely well within the test room.

Germicidal lamp operation

The bacteria contaminated air was pulled from the test room through the returned air grille by the quiet fan and passed through the ultraviolet lamp at a distant of 50-cm maximum. The bacteria or germs were finally destroyed by ultraviolet irradiation. The treated air was expelled and dispersed back into the room environment. The airborne germs or bacteria in the test room were therefore progressively eliminated due to the continuous flow of the air inside the device. The UVGI device could supplement the generation ventilation into the room expressed in number of air changes per hour (ACH) by setting the flow rate of air flow into the device and measuring the airflow rate at the supplied air by a vane anemometer.

Air sampling for airborne bacteria

An andersen N-6 single stage sampler (Anderson Instruments, Inc, USA) was used to collect airborne bacteria in the test room. The sampler was placed at a height of 1 m in the middle of the room (Fig. 2). Before samples, the impactor was cleaned with 70% isopropyl alcohol. Three-minute air samples were collected at a flow rate of 28.3 *l*/min on a plate count agar and incubated at 35-37°C for 72 hours. The colonies of viable bacteria were counted and recorded as colony forming unit per cubic meter of air (cfu/m^3)[9].

Efficiency of the constructed UVGI device

The fan of UVGI device was turned on at a flow rate of 15.7 m^3/min but the ultraviolet germicidal lamps were still in off position. After a bacteria sample was collected, and at the same time temperature and relative humidity were also recorded. The ultraviolet germicidal lamps were simultaneously turned on. Bacteria samples were collected after the ultraviolet germicidal lamps were turned on for 30, 60, 90 and 120 minutes. The experiment was performed for 5 replications on different days. The efficiency of the UVGI device was determined by dividing the concentration of bacteria before and after operation of the ultraviolet germicidal lamps by concentration of bacteria before operation. The experiment was also carried out at flow rates of 31.6 and 46.1 m^3/min of the UVGI device. The efficiency comparison of the UVGI device in reducing airborne bacteria in the test room was determined at three different flow rates of 15.7, 31.6 and 46.1 m^3/min to represent approximately equivalent ventilation rates of 12, 24 and 36 air changes per hour of the test room, respectively.

Other measurements

During collection of each air samples, relative humidity and temperature were also recorded. The concentration of ozone in the test room was collected using a KI-method[10]. The ozone sampler was placed at the height of 1 meter in the same position as bacteria sampler. The ozone sample was collected before operating the ultraviolet lamps and after operation for 60, 120, 180, 300 minutes.

Application of the UVGI device in the specimen-received room

The specimen-receiving room is 3 x 4 x 3m, 36 m^3 having two doors that were always opened and had an air conditioning system, a supplied air diffuser and a returned air grille located on the ceiling. The room was illuminated by 4, 36-watt fluorescent bulbs operated during working hours. Three to five occupants were working in the room during operating the UVGI device (Fig. 3).

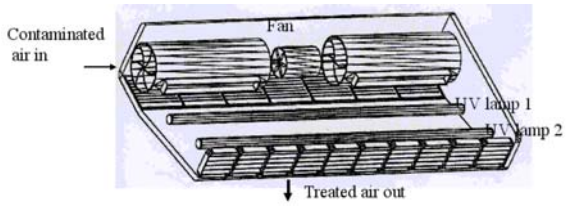

Fig. 1 Ultraviolet germicidal irradiation (UVGI) device

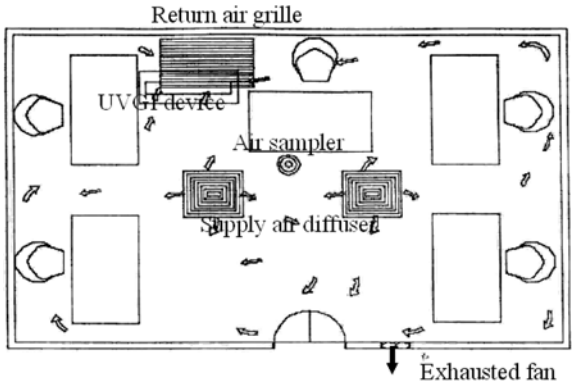

Fig. 2 An airflow diagram within the test room

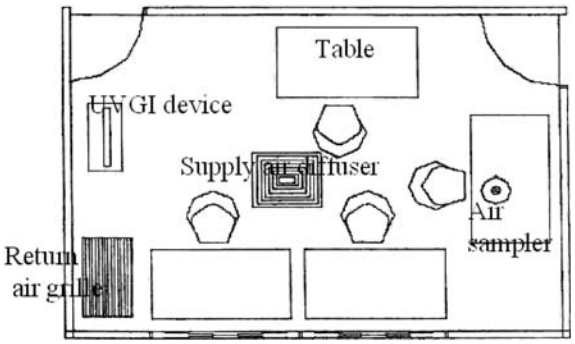

Fig. 3 The specimen-received room

Experiments were divided into two parts; the first part was to determine background of airborne bacteria in the room. The UVGI device was placed on the floor at the height of 1.3 meters on the stand beside the wall, near the returned air grille of the air conditioning system as shown in Fig. 3. The fan of UVGI device was turned on at a flow rate of 31.6 m^3/min but the ultraviolet germicidal lamps were still in off position. Bacteria sample was collected after 30, 60, 90, 120 minutes. The second part was to determine effectiveness of the UVGI device in reducing bacteria by routine activities of occupants. The ultraviolet germicidal lamps of the UVGI device were turned on and the bacteria sample was collected at 30, 60, 90, 120, 150 and 180 minutes.

Results

Efficiency test of the UVGI device

Results revealed that after operating the UVGI device at a flow rate of 15.7 m^3/min for 30 minutes, concentrations of bacteria (n = 5) were reduced from 507, 365, 318, 330 and 283 cfu/m^3 to 377, 200, 153, 295 and 141 cfu/m^3, respectively (Fig. 4a). When continuously operating UVGI device for 120 minutes, the bacteria concentrations were in the range of 59-187 cfu/m^3. Regarding operating the UVGI device at 31.6 m^3/min, the concentrations of bacteria before operating the ultraviolet lamps ranged from 318 to 931 CFU/m^3 (n = 5). The concentrations of bacteria were reduced to 24-59 cfu/m^3 after turning on the ultraviolet germicidal lamps for 120 minutes (Fig.4b). When the flow rate of UVGI device was adjusted to 46.1 m^3/min with the ultraviolet germicidal lamps off, concentrations of bacteria ranged from 342 to 1,237 cfu/m^3 (Fig.4c). After operating the ultraviolet germicidal lamps for 120 minutes, bacteria concentrations were in the range of 47-226 cfu/m^3. Results indicated that bacteria

Table 1. Average efficiency comparison in reducing airborne bacteria of UVGI device operating at three different flow rates of 15.7, 31.6 and 46.1 m^3/min

Duration of operating the UVGI device (min)	Efficiency of airborne bacteria reduction (%), (n = 5)						p-value
	15.7 m^3/min		31.6 m^3/min		46.1 m^3/min		
	Mean	SD	Mean	SD	Mean	SD	
30	36.40	19.63	70.60	12.22	38.00	24.18	0.026
60	61.40	6.50	79.80	5.89	53.00	18.93	0.010
90	52.60	12.78	83.60	6.77	67.00	10.74	0.009
120	60.60	11.55	92.80	2.59	80.80	4.55	0.003

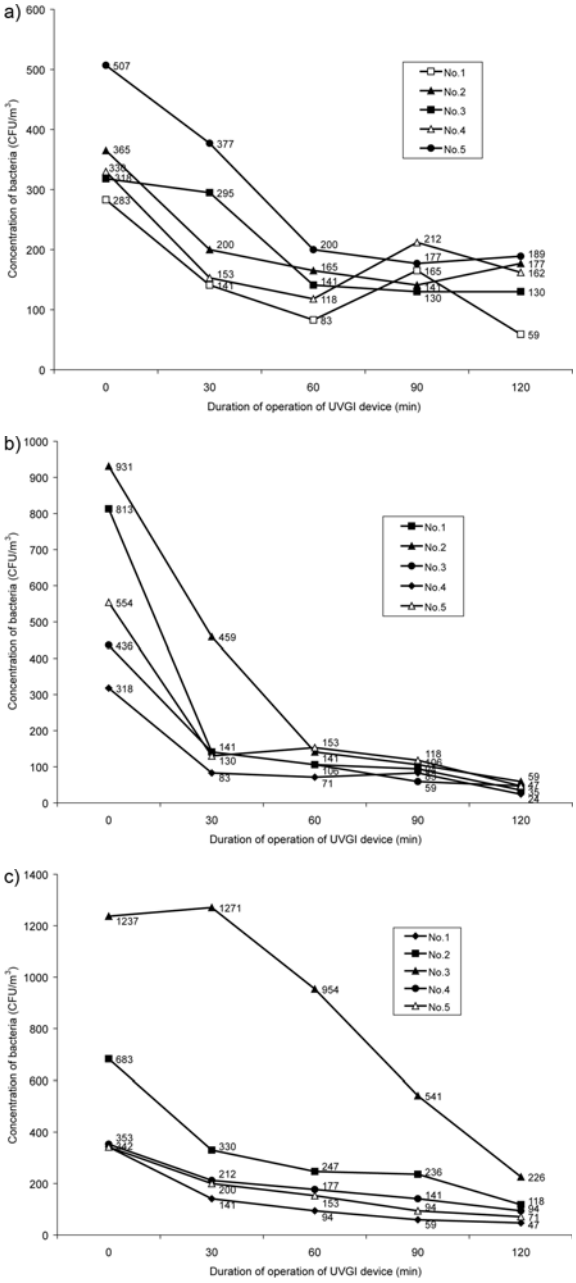

Fig. 4 Concentrations of bacteria after operating the UVGI device at a flow rate of a) 15.7 m^3/min, b) 31.6 m^3/min and c) 46.1 m^3/min for 30 to 120 minutes

concentrations were reduced as the duration of operating the ultraviolet germicidal lamps increased. Table 1 shows that the efficiency in reducing bacteria concentration was increased as duration of operating the ultraviolet germicidal lamps increased at all three flow rates used.

From Kruskal-Wallis test, the efficiency of the UVGI device operating at 15.7, 31.6 and 46.1 m^3/min for reduction of bacteria at 30, 60, 90 and 120 minutes were significantly different at 95% confident limit ($p < 0.05$). The result clearly showed that operating the UVGI device at 31.6 m^3/min provided the highest average efficiency of 92.8% after operating the UV lamps for 120 minutes.

Ozone concentrations generated from the UVGI device

During the operation of the UVGI device at 0, 60, 120, 180, 240 and 300 minutes, the concentration of ozone in the test room ranged from undetectable to 0.011 ppm which was below the occupational standard of 0.08 ppm recommended by the American Conference of Governmental Industrial Hygienists[11]. The result confirmed that the operation of UVGI device would not produce ozone into the working environment.

Application of the UVGI device in the specimen-receiving room

Background concentration of bacteria in the specimen-receiving room ranged from 318 to 435 cfu/m^3. After the operation of the ultraviolet germicidal lamps for 30, 60, 90, 120, 150 and 180 minutes, concentration of bacteria was 189, 200, 212, 130, 212, 94 cfu/m^3, respectively. This result indicated that the UVGI device was effective in reducing airborne bacteria during occupant activities to less than 100 cfu/m^3.

Discussion

The CDC guidelines recommend the air changes per hour (ACH) of upper room irradiation in the range of 6 to 37 ACH. This study selected three ventilation levels at equivalent ventilation rates of 12, 24 and 36 ACH of the test room by adjusting the flow rate of UVGI device approximately at 15.7, 31.6 and 46.1 m^3/min corresponding to the contact time at 0.50, 0.23 and 0.16 seconds, respectively. The contact time in this study was slightly wider than the study of Jenkins[8] using the contact time of UV chamber at 0.267, 0.272, 0.291, 0.332 and 0.415 seconds. He also indicated that the contact time at 0.332 seconds provided the highest efficiency (92%)[8]. However, Jenkins[8] measured bacteria concentration before entering and after leaving the UV chamber. Concerning the design of the UVGI device, this study placed 2, 30-watt UV bulbs perpendicular to the airflow exhausted, whereas Jenkins[8] placed a 15-watt UV bulb along the direction of airflow exhausted. In addition, the constructed UVGI device in this study also consisted of supply air

grille and a returned air grille in order to increase the distribution of air which was not used in the design of Jenkins[8].

Ideally, the test room selected to test efficiency of the UVGI device should be completely isolated to prevent the change of bacteria concentration occurring from occupants during experiments. Since the test room selected was an office in the hospital, the number of occupants could not be controlled. However, condition of the test room was controlled under similar conditions for all experiments; the temperature and relative humidity in the test room ranged from 22 to 24.5°C and 47-76%, respectively. At typical indoor temperatures, relative humility above 70% reduced the bactericidal efficiency of ultraviolet germicidal irradiation[1].

The flow rate of UVGI device at 15.7 m^3/min may have an advantage of higher contact time of 0.5 second; however, it may not be capable of better mixing air in the test room resulting in low efficiency in reducing the number of bacteria. The flow rate of 31.6 m^3/min or equivalent ventilation rate of 24 ACH showed the highest efficiency of the UVGI device. The result obtained agreed with previous reports suggesting that ACH at 20 destroy surrogate bacteria[12,13]. When operating the UVGI device at 46.1 m^3/min, it would help increase the distribution of air extremely well in the test room. Therefore, contaminated air in the test room was circulated to pass through the germicidal ultraviolet lamps rapidly leading to a shorter contact time of 0.16 second. If the number of lamps were to increase to three or more, the efficiency of the UVGI device in reducing airborne bacteria would probably be better.

With reference to the manufacturer of ultraviolet lamps, the UV lamp made from mercury vapor does not produce ozone. In fact, low pressure mercury vapor lamp produces negligible ozone but high pressure lamp produces some ozone. However, this study was concerned with the problem associated with the generation of ozone during operation of the UVGI device. The results obtained were consistent with that of Menzies D, et al[7]. They found that the concentration of ozone was in the range of 0 to 0.01 ppm, which varied depending on level of ozone in outdoor air environment. Therefore, installation and operation of the constructed UVGI device in the workplace do not result in any adverse health effects of occupants from ozone.

The application of UVGI device to reduce bacteria concentration in the specimen-received room (volume of 36 m^3) was carried out at the flow rate of 31.6 m^3/min corresponding to equivalent ventilation rate of 53 ACH. The result showed that the UVGI device could reduce bacteria concentration to less than 100 CFU/m^3 after 180 minutes.

In conclusion, the constructed UVGI device was effective in reducing airborne bacteria in workplace of hospital and could be operated continuously during the working days. Workers were protected from ultraviolet irradiation because the device was a close chamber. Therefore, the UVGI device would help reduce the risk of hospital personnel from exposure to airborne bacteria.

References

1. Conroy LM, Franke JE. An industrial hygiene approach to tuberculosis control. In: Charney W, editor. Handbook of modern hospital safety. Florida: *CRC* Press; 1999: 122-49.
2. Salle AJ. Effect of environment upon bacteria. In: Salle AJ, editor. Fundamental principles of bacteriology. New York: McGraw-Hill; 1967: 232-69.
3. Klunklin P. Prevention and control of tuberculosis infection in personnel of community hospital [thesis]. Chiang Mai: Chiang Mai University; 1994.
4. Perkins JE, Bahlke AM, Silverman HF. Effect of ultra-violet irradiation of classrooms on spread of measles in large rural central schools. Am J Public Health Nations Health 1947; 37: 529-37.
5. Macher JM, Alevantis LE, Chang YL, Liu KS. Effect of ultraviolet germicidal lamps on airborne microorganisms in an outpatient waiting room. Appl Occup Environ Hyg 1992; 7: 505-13.
6. Barnhart S, Sheppard L, Beaudet N, Stover B, Balmes J. Tuberculosis in health care settings and the estimated benefits of engineering controls and respiratory protection. J Occup Environ Med 1997; 39: 849-54.
7. Menzies D, Pasztor J, Rand T, Bourbeau J. Germicidal ultraviolet irradiation in air conditioning systems: effect on office worker health and wellbeing: a pilot study. Occup Environ Med 1999; 56: 397-402.
8. Jenkins PR. Design and evaluation of a portable ultra-violet microbial disinfection chamber, Virginia [thesis]. Virginia: Virginia Polytechnic Institute and State University; 1999.
9. Jensen PA, Schafer MP. Sampling and characterization of bioaerosols. In: NIOSH manual of analytical methods. Cincinati, OH: National Institute for Occupational Safety and Health; 1998: 82-112.
10. American Public Health Association Intersociety

Committee. Tentative method for the manual analysis of oxidizing substances in the atmosphere. In: Morris K, editor. Methods of air sampling and analysis. 2nd ed. Washington, DC: American Public Health Association; 1977: 556-9.
11. American Conference of Governmental of Industrial Hygienists (ACGIH). TLVs and BEIs. Threshold limit values for chemical substances and physical agents and biological indices. Cincinnati, OH: ACGIH; 2007: 45.
12. Centers for Disease Control and Prevention. Guidelines for preventing the transmission of Mycobacterium tuberculosis in health-care facilities. MMWR Recomm Rep 1994; 43(RR-13): 1-132.
13. Dooley SW Jr, Castro KG, Hutton MD, Mullan RJ, Polder JA, Snider DE Jr. Guidelines for preventing the transmission of tuberculosis in health care setting with special focus on HIV- relate Issues. MMWR Recomm Rep 1990; 39(RR-17): 1-29.

การออกแบบและพัฒนาเครื่องรังสีอัลตราไวโอเลตในการควบคุมเชื้อจุลินทรีย์ในสถานที่ทำงาน

วิทยา อยู่สุข, พรพิมล กองทิพย์, สุทธินันท์ ฉันท์ธนกุล

วัตถุประสงค์*: เพื่อออกแบบและพัฒนาเครื่องรังสีอัลตราไวโอเลตสำหรับควบคุมเชื้อแบคทีเรียในอากาศในสถานที่ทำงานของโรงพยาบาล*

วัสดุและวิธีการ*: เครื่องรังสีอัลตราไวโอเลตมีลักษณะเป็นกล่อง มีทางดูดอากาศเข้าและทางจ่ายอากาศออก ประกอบด้วยหลอดรังสีอัลตราไวโอเลต ขนาด 30 วัตต์ 2 หลอดและพัดลมดูดอากาศ ทำการทดสอบประสิทธิภาพของเครื่องโดยใช้อัตราการดูดอากาศ 3 ค่าและเก็บตัวอย่างแบคทีเรียก่อนและหลังการเดินเครื่องที่ระยะเวลา 30, 60, 90 และ 120 นาที*

ผลการศึกษา*: ประสิทธิภาพของเครื่องรังสีอัลตราไวโอเลตที่อัตราการดูดอากาศ 15.7, 31.6 และ 46.1 ลบ.ม. ต่อวินาที เท่ากับร้อยละ 60.6, 92.8 และ 80.8 ตามลำดับ และความเข้มข้นของแบคทีเรียจะลดลงต่ำกว่ามาตรฐาน 100 cfu/m^3 ยกเว้นที่อัตราการดูดอากาศ 15.7 ลบ.ม.ต่อวินาที การใช้เครื่องรังสีอัลตราไวโอเลตในห้องรับตัวอย่าง พบว่าความเข้มข้นของแบคทีเรียลดลงต่ำกว่า 100 cfu/m^3 หลังการเดินเครื่องเป็นระยะเวลา 180 นาที*

สรุป*: เครื่องรังสีอัลตราไวโอเลตมีประสิทธภาพในการลดแบคทีเรียในอากาศในสถานที่ทำงานในโรงพยาบาล*