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Original Article

Evaluation of an Automatic Fogging Disinfection Unit

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Abstract

A new fogging disinfection method was evaluated as a means of disinfecting ward rooms and operating theaters. A temporary room was established where the disinfection effect of fogging was examined. Based on the results, an automatic fogging disinfection unit was developed. This unit was then used in the disinfection of operating theaters, where its safety and effectiveness were examined.

To evaluate the results of disinfection, bacterial culture tests were performed on the floor, walls and other areas of the operating theater, and the number of colony forming units was used as an index of effectiveness. Benzalkonium chloride, alkyldiaminoethylglycine, sodium hypochlorite, glutaral and acidic electrolytic water were used for the operating theaters. The average disinfection effect was 90% or better for all disinfectants, except acidic electrolytic water.

The newly developed automatic fogging disinfection unit enables safe and effective disinfection, and may be suitable for disinfecting ward rooms and operating theaters.

Key words: disinfection, fogging, disinfectant, operation, bacteria

Introduction

The method of room cleaning used in ward rooms and operating theaters usually involves cleaning and/or disinfecting using a mop[1–4]. In some facilities, however, spraying of disinfectant onto floors and walls is also done. Such spraying is generally performed while wearing protective masks, goggles and/or protective clothing. However, the Centers for Disease Control and Prevention (CDC) does not recommend this practice because disinfection by spraying or fogging carries the risk of harmful side effects[5–7].

Therefore, to re-evaluate this fogging disinfection method we established a temporary laboratory and examined the effectiveness of disinfectant on a variety of bacteria. The results of this study showed a good disinfection effect, so an automatic fogging disinfection unit (AFDU) capable of filling the room with fog was developed. The features of the AFDU were as follows: the particles were very fine and almost uniform at 10 μm or less; it could spray evenly throughout the room; after setting the disinfectant, fogging could be carried out completely automatically. In this study, the AFDU was used to disinfect an operating theater, and its effectiveness was examined.

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Materials and Methods

A) Basic experiment in the test booth

A test booth covered with a sheet 1.2×2.0×2.0 m was constructed as a temporary laboratory. Three shelves were put in the test booth at the heights of 0, 0.9 and 1.6 m, and 80 petri dishes containing culture medium with 10^8 bacteria were put on each shelf. *Staphylococcus aureus* (ATCC 25923) and *Pseudomonas aeruginosa* (ATCC 27853) were selected as standard bacteria, and eight other bacteria (*Staphylococcus aureus* [MRSA], *Pseudomonas aeruginosa*, *Enterococcus faecalis*, *Escherichia coli*, *Serratia marcescens*, *Burkholderia cepacia*, *Acinetobacter anitratus*, *Candida albicans*), which had been stored in the Research Institute for Microbial Diseases, were chosen for the evaluation of disinfection in the test booth. Four disinfectants (0.2% benzalkonium chloride, 0.05% chlorhexidine gluconate, 0.2% alkyldiaminoethylglycine, 1.0% povidone iodine) were used for fogging disinfection. Benzalkonium chloride was purchased from Nihon Pharmaceutical Co., Ltd., chlorhexidine gluconate from Sumitomo Pharmaceuticals Co., Ltd., alkyldiaminoethylglycine Inui Trading Co., Ltd., and povidone iodine from Meiji Seika Kaisha, Ltd.. They were diluted to the appropriate concentrations with distilled water. Spraying was performed for 3, 5, or 8 minutes via two nozzles from a height of 1.8 m. Colony forming units (CFU) were counted after 48 hours of culturing at 37°C.

B) Disinfection of operating theaters

1) Operating theaters

The rooms subjected to fogging disinfection were five operating theaters (108–217 m^3) which were not in use on a Saturday. These operating theaters had vertical laminar flow-type ventilation systems with high-efficiency particular air filters; operating theaters are generally designed with ventilation frequencies of 50 times or more per hour. These theaters were usually for thoracic, abdominal, otolaryngological or ophthalmic surgery. The ventilation frequency in bioclean operating theaters is more than 200 times per hour, and these rooms were mainly used for orthopedic or cardiovascular surgery. The air conditioning systems of the various theaters enables the independent commencement of operation and stopping of exhaust discharge, and due to the air-tight doors, the exhaust gas is taken out only from the exhaust outlets located in the four corners of the room. Furthermore, 20% of the ventilation volume is usually from outside air in order to remove medical gases and odors, but the system is also designed to obtain 100% of the ventilation air from outside. Consequently, after stopping the air conditioning temporarily and cleaning and disinfecting the operating theater, any odorous air and disinfectant remaining in the air can be removed by the exhaust system alone.

2) Automatic fogging disinfection unit

The AFDU used here (Figure 1) was manufactured by Ikeuchi Co., Ltd., The Mist Engineers. After the disinfectant was loaded, this fogging unit was capable of carrying out the entire spraying process automatically. The spray generated was an even fog with an average particle size of approximately 10 μm, and the pair of spray nozzles capable of vertical (+90°) and side-to-side (+185°) movement facilitated even distribution of the spray in the operating theater. A powerful fan was installed to ensure that the spray spread over a sufficient distance.

3) Disinfectants

The two chemicals chosen as fogging disinfectants in this case were 0.5% alkyldiaminoethylglycine and 0.2% benzalkonium chloride[8]. In addition, 0.2% sodium hypochlorite (Nippon Shinyaku Co., Ltd.) and 0.5% glutaral (Maruishi Pharmaceutical Co., Ltd.) were included due to their powerful disinfecting/bactericidal effects[9,10], along with acidic electrolytic water (Bio Japan Co., Ltd.), the disinfecting/bactericidal effects of which have been the subject of much discussion recently.

4) Fogging method

First, a bacterial culture test was carried out inside the operating theater, then fire alarms as well as all computers and precision instruments inside the theater with a danger of damage from the spray, were covered with plastic bags. After turning off the ventilation, two AFDUs in which disinfectant had been loaded were set up in the center of the operating theater and switched on. After 30 or 40 seconds the units started spraying, performing the designated disinfecting process. The volume of disinfectant for fogging (Table 1) was set in the range of 35–50 ml/m^3, taking the size of each operating theater into account.

After completion of fogging, distilled water was sprayed through the nozzles for 2 minutes followed by spraying with air for 5 minutes to prevent nozzle occlusion. To further precipitate the fog, the theaters were left as they were for 15 minutes before restarting ventilation. The samples for the culture test following disinfection were taken approximately 30 minutes after restarting the air-conditioning.

Fig. 1 Automatic fogging disinfection unit

Table 1 Operating theaters subject to fogging disinfection

Operating Theater Number	Capacity (m^3)	Disinfectant	Spray Volume (ml)	Spray Time (min)	Measurement Points		
					Floor	Wall	Other**
4	108	0.2% sodium hypochlorite	3,930	16	20	4	17
9	116	acidic electrolytic water	5,500	18	20	5	14
11	122	0.5% alkyldiaminoethylglycine	5,500	19	20	1	19
12	122	0.2% benzalkonium chloride	5,360	19	20	4	15
13*	217	0.5% glutaral	7,950	30	30	6	19

13*: Bioclean operating theater.

Other**: operating table, surgical lights, doorknob, power-outlet socket, shelf and ceiling.

5) Bacterial culture test

The media used were Trypticase Soy Agar Medium (Nikken Biomedical Co., Ltd.) for general bacilli, and Baird-Parker-Medium Egg Yolk-Tellurite Emulsion (Nikken Biomedical Co., Ltd.) for *Staphylococcus aureus*.

The sampling locations for the bacterial tests were the floor, walls and other locations easily touched at a height of about 1.5 m from the floor including the operating table, surgical lights and ceiling. A section of the floor was marked with a rubber ring 20 cm in diameter, and samples were taken from within each semicircle before and after fogging disinfection. In addition, while the surface area of the medium used was about 8 cm^2, in this instance sampling was carried out using the stamp method from a surface area of approximately 100 cm^2. After 48 hours of culturing at 37°C, CFU were counted and the reduction in CFU at each point was calculated. The effectiveness of disinfection was determined by calculating the average CFU reduction rate for the floor, walls and other locations.

Results

The experiment carried out at the temporary laboratory used the following disinfectants: 0.2% benzalkonium chloride, 0.05% chlorhexidine gluconate, 0.2% alkyldiaminoethylglycine, and 1.0% povidone iodine. The effectiveness of disinfection depended on the types of bacteria and disinfectants. By spraying the disinfectants for 3, 5 or 8 minutes the reduction in bacteria and the effectiveness of disinfection could be easily observed. The optimal disinfection effectiveness was obtained with 1.0% povidone iodine. All bacteria were killed by povidone iodine spraying for 8 minutes. 0.2% Benzalkonium chloride (Figure 2) had the next best disinfection and bactericidal effect, exhibiting an effectiveness of 100% on *Staphylococcus aureus*, *Enterococcus faecalis*, *Acinetobacter anitratus* and *Candida albicans* with 5 minute spraying, and on *Serratia marcescens* and *Burkholderia cepacia* with 8 minute spraying. However, it did not show adequate effectiveness against two kinds of *Pseudomonas aeruginosa* even with 8 minute spraying. 0.2% Alkyldiaminoethylglycine showed weak effectiveness, and 0.05% chlorhexidine gluconate spraying for 8 minutes was not effective enough, with 6 species of bacteria still surviving. The effectiveness of disinfection was higher on the lower shelf than on the middle and upper shelves. However, the difference was minimal and it is suggested that this system was effective for the uniform disinfection of a room in a short time. After fogging, 0.05% chlorhexidine gluconate and 1.0% povidone iodine remained adhered to the surfaces and problems relating to their odor and color led to the judgment that they were not suitable for the subsequent experiments.

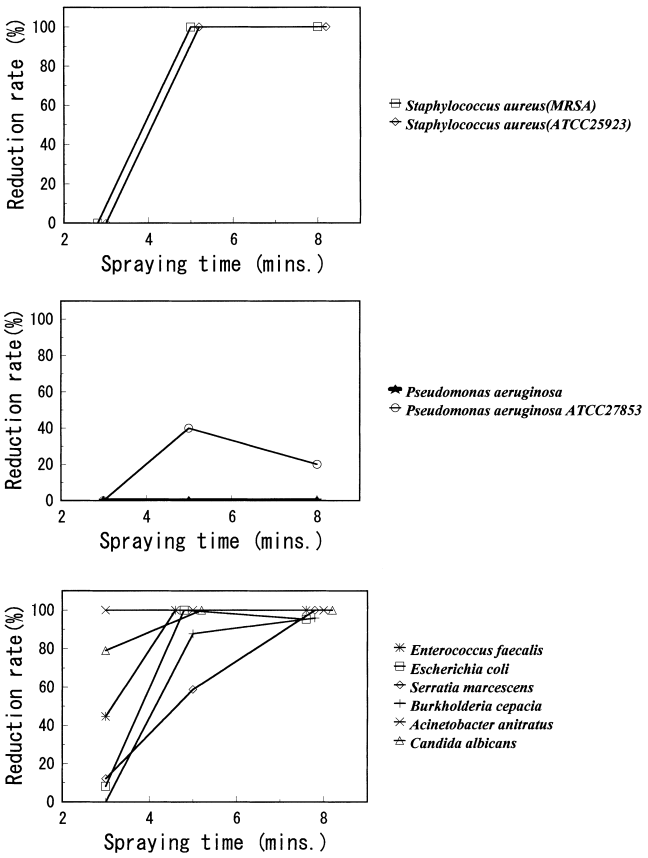

Fig. 2 Reduction rate after disinfection by 0.2% benzalkonium chloride in the test booth. Benzalkonium chloride exhibited no effectiveness on two kinds of *Pseudomonas aeruginosa*, and an effectiveness of 100% on the other bacteria after 3, 5 or 8 minute-spraying.

For disinfection of the operating theater, anesthetic equipment and computers on the walls were covered with plastic bags before disinfection. Immediately after spraying, the field of view inside the operating theater was totally obscured by fog, but 5 minutes after commencing ventilation the fog had completely disappeared, and the floor was uniformly wet.

In terms of the bactericidal effect against general bacilli on the floor, 0.2% benzalkonium chloride was the most effective (Table 2). This was followed in order by 0.5% alkyldiaminoethylglycine, 0.2% sodium hypochlorite and 0.5% glutaral, while acidic electrolytic water yielded the lowest value of 74.2%. The overall average effectiveness of disinfection, including the walls and other locations, was low for acidic electrolytic water, which showed a reduction rate for general bacilli of 76.8%, while the remaining disinfectants all showed 90% or higher.

Table 2 Effectiveness of fogging disinfection for general bacilli and *Staphylococcus aureus*

Disinfectant	Reduction Rate (%) of CFU							
	General Bacilli				*Staphylococcus aureus*			
	Floor	Wall	Other	All	Floor	Wall	Other	All
sodium hypochlorite	96.8±4.3	100±0.0	85.6±32.3	92.5±21.8	90.8±24.4	100±0.0	98.8±4.7	95.0±17.8
acidic electrolytic water	74.2±32.6	95.0±10.0	73.8±41.2	76.8±34.8	93.8±22.2	100±0.0	77.9±40.8	88.9±30.3
alkyldiaminoethylglycine	98.6±5.5	100±0.0	81.0±31.8	90.2±23.9	94.0±21.8	100±0.0	82.3±32.9	88.6±28.0
benzalkonium chloride	100±0.0	75.0±25.0	87.8±26.1	92.8±19.9	90.0±30.0	100±0.0	99.5±1.8	94.7±22.0
glutaral	86.4±17.8	100±0.0	93.9±22.3	90.5±19.2	97.0±10.2	83.3±37.3	100±0.0	96.5±15.2

Other: operating table, surgical lights, doorknob, power-outlet socket, shelf and ceiling.

Glutaral recorded the highest reduction rate for *Staphylococcus aureus* on the floor with 97.0%, but the other chemicals also recorded 90% or higher on the floor. All chemicals used for Staphylococcus aureus scored 88% or above in the overall average, taking walls and other locations into account.

For 0.2% benzalkonium chloride and 0.2% sodium hypochlorite, there was a general tendency for the reduction rate for general bacilli to be greater when the CFU prior to disinfection was larger.

Discussion

It is important to perform routine cleaning of surfaces to re-establish a clean environment after each operation[11–14]. It is recommended that wet-vacuuming of the floor with a disinfectant is performed after the last operation of the day or night. Mops are used as the main method for disinfecting ward rooms and operating theaters to clean all equipment and environmental surfaces, and the CDC recommends that spraying be avoided for environmental disinfection, including operating theaters[6]. The reasons are as follows: spraying carries an inherent risk of inhalation of chemicals or contact disturbance on the body surface; depending on the particle size, an even spray may not be obtained on the subject area, leading to sprays with irregular patches; the corrosive effect of sprays on medical instruments. Here, using a newly developed AFDU, we reviewed whether any of these problems were resolved and whether satisfactory results could be achieved in an actual operating theater.

Firstly, the complete automation of the fogging process eliminated the danger of harm through contact or inhalation of the disinfectant because the particle size of the remaining spray becomes rough and precipitates with time as the particles adhere to each other. Five minutes after ventilation is recommenced, discharge of air can be performed and almost all of the disinfectant's odor disappears. In addition, to do this simply requires loading the disinfectant and replacing the two filters. After setting up the unit, approximately 15–30 minutes of disinfection can be achieved by simply pushing buttons.

To prevent the fogging disinfectant from damaging sensitive medical instruments, they were first wiped with 80% ethyl alcohol and covered with nylon bags. In addition, in previous preliminary experiments involving the disinfection of operating theaters, fire alarms were accidentally or inadvertently activated. To avoid this they were also covered during the present trial. While the time needed for pre-fogging preparations is not negligible, the operating table, surgical lights and walls can be disinfected with this new device once disinfection has commenced. Another advantage of this system is that the spray can reach comparatively narrow gaps, resulting in an even disinfection of the whole floor. Of the five agents used, benzalkonium chloride was found to have the least adverse effect on the medical instruments, but in some cases there was a cloudiness brought about by the adherence of the disinfectant onto the surface of the surgical lights.

The particle sizes of 50–100 μm used were previously suggested to be impossible to obtain as an even fog because of irregular surface patches. However, this unit was modified to make it capable of creating a virtually even fog with a particle size of 10 μm or below. A fan was also added to ensure dispersion over an adequate distance, and as shown in Figure 1, an even fog was obtained over the whole operating theater after spraying for 6 minutes.

The effectiveness of disinfection against general bacilli using this unit, expressed in terms of the reduction rate for the whole area (including the floor, walls and other areas), was low for acidic electrolytic water (76.8%). However, the average reduction rate for the other disinfectants was good (greater than 90.0%). In particular, the effectiveness of disinfection with 0.2% benzalkonium chloride showed a reduction rate of 100% for the floor. 0.2% Sodium hypochlorite and 0.5% alkyldiaminoethylglycine also rated well, at 96% or higher for the floor. The reduction rate of 0.5% Glutaral, which by nature possesses a powerful disinfection effect[10], scored low (86.4%) compared with the other disinfectants. However, this may be attributed to the presence of threads and/or dust at the places of measurement on the floor. Although the reduction rate of walls sprayed by benzalkonium chloride was low, measurement points were small and may show some discrepancies. That is to say, when fogging with this unit, there is a problem that areas in slight shadow cannot be disinfected adequately. Consequently, although the fogging disinfection was carried out in operating theaters on a Saturday following normal cleaning, there may be a need to remove all the dust from the floor before performing fogging disinfection with this unit. The results obtained for the effectiveness against *Staphylococcus aureus* were almost identical to those obtained for general bacilli.

Regarding cleaning with mops, it was suggested that it would be impossible to obtain an adequate disinfection if it is performed in a rough manner, because some knowledge of techniques pertaining to bactericide is required[15–18]. However, disinfection with this unit does not need such consideration. Furthermore, it is important to disinfect each mop after use. If the mop is not dried, it becomes an ideal environment for the growth of bacteria and mold, so appropriate care is called for in their management. Therefore, disinfection using this unit appears to be both simpler and more effective.

The fogging disinfection method was found to have the following advantages: the average reduction rate for general bacilli on the floor was very effective; the disinfection time was short and all areas of the rooms, including walls, could be disinfected; the financial benefit of the unit stems from a reduction in labor costs due to its simple operation. Taking preparations for fogging disinfection into account, the system may be suitable for periodic disinfection. However, it may not be good for operating theaters, because of its effect on certain sensitive medical instruments. Finally, the unit is also considered suitable for use in general-use rooms, in addition to ward rooms.

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