Research Article

Development of a Pulsed Xenon Ultraviolet Disinfection Device for Real-Time Air Disinfection in Ambulances

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Objectives. We have developed a pulsed xenon ultraviolet light-based real-time air disinfection system with rapid and effective disinfection by using high-intensity pulse germicidal UV. Disinfection of the ambulance’s environment is critical in the prevention of infectious cross contamination. Methods. In this study, a pulsed xenon ultraviolet light-based air disinfection system was established for real-time air disinfection in ambulances. In this system, a pulsed xenon ultraviolet (PX-UV) was used to generate broad-spectrum (200–320 nm), high-intensity ultraviolet light to deactivate and kill bacteria and viruses. The results showed that the use of PX-UV could be effective in reducing E. coli, Staphylococcus albus, and environmental pathogens level in ambulances (>90% reduction in 30 mins). Results. This device was relatively simple and easy to use and does not leave chemical residues or risk exposing patients and workers to toxic chemicals. Conclusions. This appears to be a practical alternative technology to achieve automated air disinfection in ambulances.

1. Introduction

Hundreds of millions of patients around the world are affected by health care-associated infections (HCAI) each year, and despite the presence of many disinfection methods, microbial contamination remains a significant health concern throughout the world [1, 2]. The ambulance is one of the most common and important types of medical transport in the hospital emergency system. It is responsible for transferring individuals that are severely injured or ill. Because of the special construction and the narrow space inside, ambulances are frequently contaminated with pathogenic microorganisms shed by patients during prehospital transport, which would be transferred to subsequent patients and emergency medical service workers. Previous studies have demonstrated that ambulances operating in the emergency medical services (EMS) system may have a significant degree of MRSA contamination [3, 4]. These results demonstrated that ambulances represent an important reservoir for infectious microorganisms during an infectious disease pandemic, when large numbers of highly contagious patients would be transported. Disinfection of the ambulance’s environment is critical in the prevention of infectious cross contamination. Chemicals such as chlorine dioxide and hydrogen peroxide disinfectant have traditionally been used for ambulance disinfection after used by infectious patients. However, manual chemical disinfection is tedious, time-
UV lamp was placed in the center of a reflective, aluminum-covered chamber to continuously purify the air. The air flows through the processing chamber with an internal cross-flow fan with a flow rate of 5.4 m³/min. In this case, the cross-flow fan has two functions: (1) driving the air into the device and (2) cooling the pulsed xenon UV lamp. The reflectivity of the aluminum is proposed to enhance the light reflection efficiency and increase the time that the pulsed light is in contact with the air, thereby improving the germicidal activity of the apparatus. The air outlet was made in the form of shutters to block UV radiation.

2.2. Preparation of Bacterial Suspension. *E. coli* (ATCC 8099) and *Staphylococcus albus* (ATCC 8799) were used as the model bacteria to evaluate the sterilization effect. *E. coli* (ATCC 8099) and *Staphylococcus albus* (ATCC 8799) were obtained from Beijing Beina Chuanglian Biotechnology Institute and grown in the nutrient broth and nutrient agar at 36°C ± 1°C for 24 hours, followed by centrifugation at 3,300 × g for 30 min. The bacteria were resuspended in 0.1 M phosphate buffer. A turbidimeter was used to prepare a bacterial suspension with a concentration of 1.5 × 10⁸ CFU/mL to 3.0 × 10⁹ CFU/mL. The prepared bacterial suspension will be ready for use.

2.3. Bacterial Suspension. The bacterial suspension was diluted with PBS buffer solution (the concentration of *E. coli* and *Staphylococcus* suspension was 1.20 × 10⁶ CFU/mL and 1.40 × 10⁶ CFU/mL, respectively). The diluted bacterial suspension was loaded in an aerosol generator (atomization effect >90%, particle size <5 μm). This quasiexperimental study was conducted in two biosafety cabinets. The microbial aerosol generator was placed in biosafety cabinets (NUAIRE NU 437 600S). Air spray was carried out under the following conditions: the room temperature is 20°C to 25°C, and the relative humidity is 50% to 70%. The spraying time was 5 min and stationary for 1 min. The airborne bacterial populations were sampled by impaction directly onto nutrient agar plates, using a Merck MAS-100 air
In this study, we used E. coli and Staphylococcus albus as models to test the disinfection effect of PX-UV. Tables 1 and 2 show the E. coli and Staphylococcus albus concentration levels before and after the PX-UV treatment, respectively. It can be seen that the 30-min PX-UV treatment reduces the E. coli concentration which is lower than the detection level, while the PX-UV treatment results in 99.91% Staphylococcus albus disinfection. UV can kill bacteria, viruses, fungi, and spores, but different types of microorganisms have different sensitivity to UV. Gram-negative bacteria are the most sensitive, followed by Staphylococcus albus [16]. The available reason for this case is that E. coli is more sensitive to UV light than Staphylococcus albus. Therefore, it is seen that PX-UV treatment for more than 30 mins has an apparent effect in reducing the bacteria concentration levels to a value compatible with the guidelines.

The disinfection efficiency of the real-time PX-UV disinfection device was evaluated by measuring the bioaerosol levels of natural bacteria before and after disinfection. The experimental results found that the average disinfection rate of natural bacterial aerosols was found to be more than 90% after 60 mins of disinfection, which was lower than that of the laboratory simulation test (see Table 3). Because of the harsh living conditions in the natural environment, the survival ability of the living microorganisms and the ability to resist external interference are stronger than those used in the experimental group, and Kt is the disinfection rate of bacteria in air.

2.4. Field Air Disinfection Test. To test the ability of the PX-UV system to disinfect pathogens in ambulances, we choose the ambulances that just returned to the hospital for their reasoned propensity to yield a large spectrum of bacteria. According to the ambulance instruction manual, the volume of the ambulance therapeutic cabin is approximately 10 m³. Before starting the disinfection device, a Merck MAS-100 air sampler was used to influence 1 L air onto blood agar plates before and after the pulsed xenon ultraviolet (PX-UV) disinfection for 60 minutes. All the plates incubated at 36°C ± 1°C for 24 h. All bacteria and fungi colony forming units were counted, and the airborne bacterial count and killing rate were calculated:

\[
\text{Killing rate} = \frac{\text{Bacterial count before disinfection} - \text{bacterial count after disinfection}}{\text{Bacterial count before disinfection}} \times 100\%.
\]

### Table 1: Effectiveness of the real-time air disinfection device against E. coli in the air.

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>No.</th>
<th>(V_0) (Cfu/m³)</th>
<th>(V_t) (Cfu/m³)</th>
<th>(N_t) (%)</th>
<th>(V_0') (Cfu/m³)</th>
<th>(V_t') (Cfu/m³)</th>
<th>(K_t) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>1</td>
<td>2.70 × 10⁵</td>
<td>1.76 × 10⁵</td>
<td>34.81</td>
<td>2.64 × 10⁵</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2.54 × 10⁵</td>
<td>1.66 × 10⁵</td>
<td>34.65</td>
<td>2.40 × 10⁵</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2.10 × 10⁵</td>
<td>1.40 × 10⁵</td>
<td>33.33</td>
<td>2.10 × 10⁵</td>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>

\(N_t\): the natural extinction rate of bacteria in the air; \(V_0\) and \(V_t\): the amount of bacteria in the air at different times before and during the disinfection process of the experimental group; \(K_t\): the disinfection rate of bacteria in air.

### Table 2: Effectiveness of the real-time air disinfection device against Staphylococcus albus in the air.

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>No.</th>
<th>(V_0) (Cfu/m³)</th>
<th>(V_t) (Cfu/m³)</th>
<th>(N_t) (%)</th>
<th>(V_0') (Cfu/m³)</th>
<th>(V_t') (Cfu/m³)</th>
<th>(K_t) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>1</td>
<td>2.64 × 10⁵</td>
<td>1.76 × 10⁵</td>
<td>33.33</td>
<td>2.64 × 10⁵</td>
<td>160</td>
<td>99.91</td>
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<tr>
<td></td>
<td>2</td>
<td>2.44 × 10⁵</td>
<td>1.51 × 10⁵</td>
<td>38.11</td>
<td>2.52 × 10⁵</td>
<td>150</td>
<td>99.90</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2.31 × 10⁵</td>
<td>1.40 × 10⁵</td>
<td>39.39</td>
<td>2.40 × 10⁵</td>
<td>130</td>
<td>99.91</td>
</tr>
</tbody>
</table>

\(N_t\): the natural extinction rate of bacteria in the air; \(V_0\) and \(V_t\): the amount of bacteria in the air at different times before and during the experiment was conducted; \(V_0'\) and \(V_t'\): the amount of bacteria in the air at different times before and during the disinfection process of the experimental group; \(K_t\): the disinfection rate of bacteria in air.
laboratory. Thus, using a real-time PX-UV disinfectant to maintain the air quality is of great importance to reduce cross infection in ambulances.

4. Conclusions

In conclusion, we have developed a pulsed xenon ultraviolet light-based real-time air disinfection system with rapid and effective disinfection by using high-intensity pulse germicidal UV. Our design is an enclosed air disinfection device, which can be operated in the presence of people. The device is powered by an ambulance and can be operated automatically as the ambulance starts.

In our study, we found that the real-time air disinfection device reduced the number of *E. coli* and *Staphylococcus aureus* on the biological safety cabinet with a 30-minute exposed time and foresaw a positive effect. Similarly, because of the complex environment of the actual site, only 90% of the bactericidal results have been achieved. Although the disinfection effect has not reached more than 99%, the efficacy of the real-time air disinfection device could get the desired results in real-world settings. The results of this study suggest that the home-made PX-UV disinfection device can provide real-time and effective disinfection for ambulance application.

In actual use, some problems with the real-time air disinfection device have been discovered. The first is the ventilation problem. The space for an ambulance is approximately 10 m³. Does the air in the ten cubic meters of ventilation problem. k_ the space for an ambulance is a...


