Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
Pulsed xenon ultraviolet and non-thermal atmospheric plasma treatments are effective for the disinfection of air in hospital blood sampling rooms

Shan-Ni Wang, Jing-Jing Li, Ying-Xin Liu, Zhi Lin, Jiao-Jiao Qiao, Li-Hua Chen, Yu Li, Yong Wu, Mei-Mei Wang, Yun-Bo Liu, Chen Yan, Zhi-Heng Chen, Chang-Qing Gao

**Abstract**

**Background and objectives:** Non-thermal atmospheric plasma treatment and pulsed xenon ultraviolet (PX-UV) treatment are widely used in disinfection of hospital environments. However, their effectiveness has not been evaluated against a comparator. The objective of this study is to evaluate their effectiveness in the disinfection of pathogens in the air in hospital blood sampling rooms.

**Methods:** Samples were taken from the air before and after disinfection with PX-UV and non-thermal atmospheric plasma. We counted bacterial colonies and identified the types of bacteria.

**Results:** Non-thermal plasma treatment significantly reduced bacterial counts in the air, the median reduced from 1 before treatment to zero afterwards (p = 0.03). PX-UV treatment also significantly reduced bacterial counts in the air (p = 0.01), the median reduced from 1.5 before treatment to zero afterwards. Pathogens identified in the current study include nosocomial bacteria, such as *Staphylococcus aureus*, *Staphylococcus epidermidis*, and yeast.

**Conclusion:** Disinfection of blood sampling sites is essential in a health service department. The efficiency of PX-UV and non-thermal atmospheric plasma treatment is comparable in air disinfection.

1. Introduction

Hospitals are a source of cross infection [1,2]. This was demonstrated in 2003 by the epidemic of severe acute respiratory syndrome (SARS) in which 128 subjects were infected by a SARS patient who sat in the emergency department of a community hospital awaiting assignment to a hospital bed [1]. A simulated study showed that, due to the length of contact, the cross infection risk between health workers is greater than between patients or between patients and health workers [2]. To make matters worse, a hospital environment is widely contaminated by multidrug resistant organisms [3,4]. Therefore, it is critical to disinfect hospital environments to control cross infection.

The effect of manual cleaning is variable and cleaning is often incomplete even after an intervention to improve cleaning methods [5]. Medical devices used by multiple patients are often inadequately cleaned by manual measures [6]. Therefore automated cleaning systems, such as pulsed xenon ultraviolet (PX-UV), are innovations designed to disinfect hospital environments of different settings, such as wards [7–11], burns units [12], milk feed preparation rooms [13], operation rooms [14,15], surgical sites [16,17], nursing homes [18], long-term acute care facilities [19], isolation rooms [20], and community hospitals [21,22].

Non-thermal atmospheric plasma treatment is also used in prevention of nosocomial infections and other fields, including inactivation of dermatophyte infections in animal models, prevention of bacterial colonization on surgical sutures, and prevention of surgical site infection [23–26]. However, the effect is variable [24,27].

Health check-ups, disease prevention, and chronic disease management are an increasingly important subject. The health check-up clinic of the Third XiangYa Hospital sees more than 200 people each...
day. Blood sampling, an invasive procedure, is essential for the majority of people attending for evaluation. Disinfection of the blood sampling room is therefore important. However, no comparative study has yet compared the effectiveness of disinfection with PX-UV treatment and non-thermal atmospheric plasma treatment. Here, we compare these two automated methods of disinfecting a blood sampling room.

2. Materials and methods

2.1. Sampling

Sampling sites: This study was conducted in the blood sampling room of the Health Management Center of the Third XiangYa Hospital. The size of the room is 6 m x 6 m. Blood sampling tables are placed in the center of the room. We measured pathogens in the air of the room.

Five plates were used in the analysis of air study. We repeated the PX-UV experiment twice and the non-thermal atmospheric plasma treatment study three times. We did this because a parallel study of the evaluation of the disinfecting effect of PX-UV on a laboratory animal showed that PX-UV is effective in sterilizing and the results have been submitted for publication.

Due to errors in sampling, one sample using non-thermal atmospheric plasma treatment was missed. Therefore, the total number of samples analysed was 14 instead of 15.

Sampling time: Samples were taken in the afternoon of the working day at about 2:30 pm before automated disinfection, and then repeated immediately after disinfection.

Sampling methods: For the sampling, 64 cm² tryptic soy agar plates were left open for 30 min. While the control plates were open and covered immediately. Other procedures were the same for both sets of plates.

2.2. Culture count results

The bacterial colonies on each plate were counted and the types of bacteria were classified with matrix-assisted laser desorption/ionization time of flight mass spectrometry (MicroflexLT/SH. BRUKER, Germany). For the surface study, the colony form unit (CFU)/cm² is the number of colonies counted on each plate. For the air pathogen culture, results were reported as total CFU per plate. When CFU was over 100 per plate, results were reported as 100.

2.3. Device

The disinfectant efficacy of the PX-UV machine MX-3600 (Xi’An Fukang Air Purification Equipment and Engineering Co. Ltd, Xi’an, China) was initially assessed and we found that it was set at a wavelength of 100 nm–400 nm, a frequency at 3 Hz, and a duration of work of 6 min, its efficacy was 100% for Staphylococcus aureus and Escherichia coli. Thus, these parameters were used for this study. The machine was deployed on the floor in the center of the room. Hence, all the air in the room is exposed to UV light.

A non-thermal atmospheric plasma sterilization machine LK/JKF-Y100 (Chengdu Loakan Medical Technology Co., Ltd, Chengdu, China) is routinely used for disinfection each day by the center after blood sampling. During operation, plasma is formed inside the machine and air is sterilized as it passes through the plasma. With air circulating in the room for some time, all of the air in the room should be disinfected. During the study, the machine was placed in the same position as the PX-UV machine of the room, operated as usual, and turned on for 2 h.

Samples were collected as in the PX-UV disinfection study.

2.4. Statistical analysis

Data were pooled from the studies and analyzed by performing a Mann-Whitney rank sum test, using MedCalc (version 17) statistical analysis software (MedCalc Software, Ostend, Belgium), to compare the difference between the data before and after disinfection. Threshold statistical significance was set at $p < 0.05$.

3. Results

3.1. Disinfectant effect of two machines on the air

As shown in Table 1A, non-thermal atmospheric plasma treatment can significantly reduce bacterial colony counts (Mann-Whitney $U = 55.50, p = 0.03$), the median CFU/cm² of 1 before treatment reduced to 0 after treatment. PX-UV reduces bacterial colony counts ($U = 55.50, p = 0.03$), the median CFU/cm² of 1 before treatment reduced to 0 after treatment. PX-UV treatment and non-thermal atmospheric plasma treatment results have been submitted for publication.

Table 1

Comparison of colony counts before and after plasma treatment and after PX-UV disinfection on air.

|                   | Before plasma treatment on air |          | After plasma treatment on air |          |
|-------------------|-------------------------------|----------|------------------------------|----------|
|                   | no. samples        | Median (95% CV) | lowest - highest values | no. samples        | Median (95% CV) | lowest - highest values |
| A                 |                  |           |                        |                  |           |                        |
| Before plasma treatment on air |           |          |                        |                  |           |                        |
| no. samples       | 14               | 1 (0.89 – 1.00) | 0.00 - 6.00          | 14               | 0 (0.00 – 1.00) | 0.00 - 2.00            |
| B                 |                  |           |                        |                  |           |                        |
| Before PX-UV on air | 10               | 1.5 (1.00 – 3.5) | 0.00 - 9.00          | 10               | 0 (0.00 – 1.00) | 0.00 - 2.00            |

3.2. Pathogens identified in air disinfection study

As shown in Table 2, 30 types of bacteria were identified in the air disinfection study. Of these, 17 pathogens were identified in the non-thermal atmospheric plasma treatment study; 15 were found before treatment and two were found after treatment. In the PX-UV study, 15 pathogens were identified; 11 were identified before treatment and 4 after treatment. Two bacteria (Micrococcus luteus and Staphylococcus hominis, Table 2) were common to both studies.

4. Discussion

In our study, we found that both PX-UV treatment and non-thermal atmospheric plasma treatment can significantly reduce air pathogen counts and their effects are comparable. Some of the pathogens...
A study in a hospitalized neonatal inpatients [28] found that 10% of the patients suffered from nosocomial infection [29]. As so few bacteria were identified in each plate we decided to test them for resistance to antibiotics. Instead we used the published literature as a reference. Therefore, the percentage of drug resistant bacteria in the study is unknown.

The rates of bacterial resistance were the results of the effects of heat, ultraviolet radiation, reactive species, and that of charged particles [42].

The types of bacteria identified in the non-thermal atmospheric plasma treatment study in the air were greater than in the study of PX-UV treatment. This is probably caused by two factors. First, plasma treatment was repeated three times, while PX-UV treatment was repeated twice. Second, the total number of people visiting clinic on the days that plasma treatment was used was nearly double than that of the days PX-UV was used. Hence, more types of bacteria were probably brought into the clinic.

In both PX-UV and non-thermal plasma treatment studies, new bacterial species were identified after treatment. These were most likely brought into the room by the automatic ventilation system which was running throughout.

Taken together, our study shows that disinfection of blood sampling sites in a health management department is essential, and PX-UV and non-thermal atmospheric plasma treatment are comparable in killing airborne pathogens.

**Author contributions**

C.Q.G., Z.H.C., Y.C., and Y.B.L., conceptualized the study and wrote the manuscript. S.N.W., J.J.L., Y.X.L., Z.L., J.J.Q., L.H.C, Y.L., Y.W., and M.M.W conducted the experiments. All authors reviewed the manuscript.

**Ethics approval**

Not required.

**Competing interests**

The authors declare no competing interests.
Acknowledgements

The study was supported by grants from the National Key Research and Development Program of China (2017YFA0105201 to Y.B.L) and the Science and Technology Department of Hunan Province (2016DK2004 to CQG, 2019JJ00029 to YW, 2018SK20093 to ZHC) and a grant from the Municipal Science and Technology Bureau of Changsha (KQ1701086 to CQG). The sponsors have not played any role in the study design; in the collection, analysis and interpretation of data; in the writing of the report; and in the decision to submit the article for publication. We thank Dr. Paul Hones for reading and commenting on the manuscript.

References

[1] M. Varia, S. Wilson, S. Sarwal, et al., Investigation of a nosocomial outbreak of severe acute respiratory syndrome (SARS) in Toronto, Canada, Can. Med. Assoc. J. 169 (2003) 285–292.

[2] Vicki Stover Hertzberg, Yuke A. Wang, Lisa K. Elon, W. Douglas, Lowery–north. The risk of cross infection in the emergency department: a simulation study. Infect. Control Hosp. Epidemiol. 39 (June (6)) (2018) 688–693.

[3] Joshua S. Thaden, Vance G. Fowler Jr, Daniel J. Sexton, J. Deverick Anderson, Increasing incidence of extended-spectrum β-Lactamase-producing Escherichia coli in community hospitals throughout the Southeastern United States. Infect. Control Hosp. Epidemiol. 37 (January (1)) (2016) 49–54.

[4] Courtney R. Murphy, Samantha J. Jella, Victor Quan, Diane Kim, Ellena Peterson, Loren G. Miller, Susan H. Huang, Methicillin-resistant Staphylococcus aureus (MRSA) burden in nursing homes is associated with environmental contamination of common areas, J. Am. Geriatr. Soc. 60 (June (6)) (2012) 1012–1018.

[5] Britzany C. Eckstein, Daniel A. Adams, Elizabeth C. Eckstein, Agam Rao, Ajay K. Sethi, Gopala K. Yadavalli, Curtis J. Donsky, Reduction of Clostridium difficile and vancomycin-resistant Enterococcus contamination of environmental surfaces after an intervention to improve cleaning methods, BMC Infect. Dis. 7 (2007) 61.

[6] Chertan Jinadatha, Frank C. Villamaria, John D. Coppin, Charles R. Dale, Marjory D. Williams, Ryan Whitworth, Mark Stibich, Interaction of healthcare worker hands and portable medical equipment: a sequence analysis to show potential transmission opportunities, BMC Infect. Dis. 17 (2017) 800.

[7] M.M. Nerandzic, P. Thota, C.T. Sankar, A. Jenson, J.L. Cadmus, A.J. Ray, R.A. Salata, R.R. Watkins, C.J. Donsky, Evaluation of a pulsed xenon ultraviolet disinfection system for reduction of healthcare-associated pathogens in hospital rooms, Infect. Control Hosp. Epidemiol. 36 (February (2)) (2015) 192–197.

[8] C. Jinadatha, F.C. Villamaria, M.I. Restrepo, N. Ganasah-Mallappa, C.I. Liao, S.A. Ermolaeva, E.V. Sysolyatina, A.L. Gintsburg, Atmospheric pressure nonthermal plasma sources for microbial decontamination, J. Phys. D Appl. Phys. 44 (2010) 748–757.

[9] J.E. Zeber, J. Donskey, Cipluconate, Biomed. Res. Int. 2017 (2017) 6085741.

[10] C.M. Shen, Research on the significance of implementing chronic health management service in health physical examination, J. Clin. Med. Literature 6 (2019) 9–11.

[11] Y.L. Hang, Z.J. Chang, Social issues and cultural significance of chronic based on health management, Henan J. Prev. Med. 30 (2019) 248–250.

[12] V.B. Salvador, B. Chapagain, A. Joshi, D.J. Brennessel, Clinical risk factors for infection of pulsed-xenon light in the operating room, Am. J. Infect. Control 46 (September (9)) (2018) 1350–1353.

[13] S.S. Ghantoji, M. Stibich, J. Stachowiak, S. Cantu, J.A. Adachi, I.I. Raad, R.F. Chemaly, Utilization of a pulsed xenon ultraviolet room disinfection system and multidisciplinary care team on Clostridium difficile in a long-term acute care facility, Am. J. Infect. Control 43 (December (12)) (2015) 1350–1353.

[14] S.-N. Wang, et al. Photodiagnosis and Photodynamic Therapy 27 (2019) 137–140.