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Letter

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Potential effects of aerosol generation and transmission during bedside endoscope cleaning

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Airborne transmission is among the most frequent types of nosocomial infection. Recent years have witnessed frequent outbreaks of airborne diseases, such as severe acute respiratory syndrome (SARS) in 2002, Middle East respiratory syndrome (MERS) in 2012, and coronavirus disease 2019 (COVID-19), with the latter being on the rampage since the end of 2019 and bringing the effect of aerosols on health back to the fore (Gralton et al., 2011; Wang et al., 2021). An increasing number of studies have shown that certain highly transmissible pathogens can maintain long-term stability and efficiently spread through aerosols (Leung, 2021; Lv et al., 2021). As reported previously, influenza viruses that can spread efficiently through aerosols remain stable for a longer period compared to those that cannot. The World Health Organization (WHO) has stated that aerosol-generating procedures (AGPs) play an important role in aerosol transmission in hospitals (Calderwood et al., 2021). AGPs, referring to medical procedures that produce aerosols, including dental procedures, endotracheal intubation, sputum aspiration, and laparoscopic surgeries, have been reported to be significantly associated with an increased risk of nosocomial infection among medical personnel (Hamilton, 2021).

Flexible endoscopes are long and thin with narrow lumens. Blood, mucus, or gastrointestinal secretions may adhere to the internal cavity or external surface of endoscopes and dry if not processed in a timely manner, making cleaning more difficult (Murdani et al., 2017; Roca et al., 2023; Yan et al., 2023). Such problems loom larger with regard to emerging techniques, such as the transnasal gastroscope that has even narrower lumens. Guidelines suggest that precleaning should take place at the point of use immediately following endoscopy procedures. According to Section 6.2.1 of "Regulation for cleaning and disinfection technique of flexible endoscope" (National Health and Family Planning Commission of PRC, 2017), endoscopes should be subject to bedside endoscope cleaning in a container filled with cleaning solution immediately after use. Bedside endoscope cleaning immediately after use comprises the following main steps: wipe the external surface of the endoscope with a cloth soaked with cleaning solution, place the front end under the liquid surface of a bucket containing cleaning solution, install the cleaning connector for air and water channels, inject and repeatedly suction air and water, disconnect and disassemble the endoscope components, coil the endoscope in large loops, and perform safe transport. Contaminated endoscopes are usually placed in a bucket immediately after use, followed by air and water injection, which may spatter the dirt in the bucket to become aerosolized and into the air. In this process, aerosols already formed in endoscope lumens may also be released into the surrounding environment, posing an increased risk of aerosol exposure to medical personnel and patients. While bedside endoscope cleaning is not explicitly classified as an AGP, it carries a significant risk of aerosol generation.

In recent years, various methods and tools have been developed to reduce harm from bioaerosols in

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the air, including thermal energy, ultraviolet light, filtration, and utilizing filters with anti-components, each with its pros and cons. Most of these methods, however, can only be implemented under certain conditions for a limited period of time, restricting their wide application in clinical practice.

Transmission route blocking is an important means of controlling AGP. Therefore, in an attempt to reduce the risk of occupational infection and nosocomial infection in endoscopic diagnosis and treatment, we devised an effective tool, which comprises resealable bags to block the route of aerosol transmission, and assessed its safety and effectiveness. In addition to targeting the challenge of aerosol transmission brought about by the ongoing COVID-19 pandemic, we performed simulation experiments to measure the counts of aerosols in the gastrointestinal endoscopy room at different distances from the source of aerosol generation. These tests turned out to be simple, rapid, sensitive, and repeatable. Then, we established a three-dimensional (3D) space (high-risk aerosol exposure area) around the endoscope precleaning bucket.

In order to standardize the procedures, we randomly chose one endoscopy room (47 m^2×2.5 m) from our hospital's endoscopy center that was free of diagnostic or therapeutic procedures for 12 h, and made sure that the room ventilation was set at 35 air changes per hour. For aerosol collection, we minimized unnecessary airflow by not allowing the room doors to be opened during the procedures and used enhanced personal protective equipment that minimized additional human aerosol sources. All medical personnel present in the room wore personal protective equipment (garments, caps, masks, and gloves) in accordance with the test method specified for the YY0569-2005 Biological Safety Cabinet. Prior to the experiment, the endoscopy room was disinfected with a mobile air sterilization station (MKJ4000-S4, Jiaxing Heyu Purification Technology Co., Ltd., China) for approximately 30 min until the air cleanliness reached class 10000. We used a portable particle counter (DT-9880 M, Shenzhen Huashengchang Machinery Industry Co., Ltd., China) for particle size measurement. Background aerosol count was measured before the bedside endoscope cleaning procedures. The experimental parameters were set as follows: particle channel, 0.5 μm; flow rate, 0.1 ft^3/min (cubic feet per minute; equal to 2.83 L/min); sampling time, 22 s (1.0384 L). The aerosol count was available on the counter screen (particles/L).

A total of 16 endoscopes were processed by four certain operators following the steps specified in the "Regulation for cleaning and disinfection technique of flexible endoscope, WS 507-2016" (National Health and Family Planning Commission of PRC, 2017): (1) wipe the external surface of the flexible endoscope with a cloth presaturated with cleaning solution immediately after use, and wipe the lens in the direction of water flow; (2) immerse the distal end of the endoscope into the cleaning solution placed in the precleaning bucket; (3) install the cleaning connector for the air and water channels; (4) turn on the air pump, set the air flow on the light source to the highest, repeatedly inject air and water for at least 10 s, and end with air injection; (5) repeatedly suction the cleaning solution through the endoscope until the liquid in the suction tube is clear (or for at least 30 s), remove the distal end from the cleaning solution, and suction the air for at least 10 s; (6) proceed from cleaner to dirtier areas, that is, turn off the image processing device, remove the cable connector, cover the waterproof cap, remove the water injection bottle connector, remove the suction tube, and finally, detach the endoscope from the light source.

Data analysis was performed using SPSS 25.0 statistical software (IBM Corp., Armonk, New York, USA) and Prism V.8 (GraphPad, San Diego, California, USA). The continuous variables were presented as mean±standard deviation or median (quartile). Student's *t*-test or nonparametric comparison was used for comparisons between groups, where a bilateral P value of <0.05 was considered statistically significant.

For the assessment of aerosol dissemination in the horizontal direction, while one operator was performing the endoscope precleaning procedures, another operator held a particle counter 10 cm horizontally away from the liquid surface of the cleaning bucket to record the aerosol counts, a third operator held two particle counters 55 and 100 cm away, and a fourth one 145 and 175 cm away. A large number of aerosols could be detected at the position of 10 cm horizontally away from the liquid surface of the precleaning bucket (Fig. 1a; Table 1), that is, a count of (6403.0±791.7) particles/L. As the distance increased in this direction, the number of aerosols decreased significantly, with (2328.0±585.3) particles/L at 55 cm,

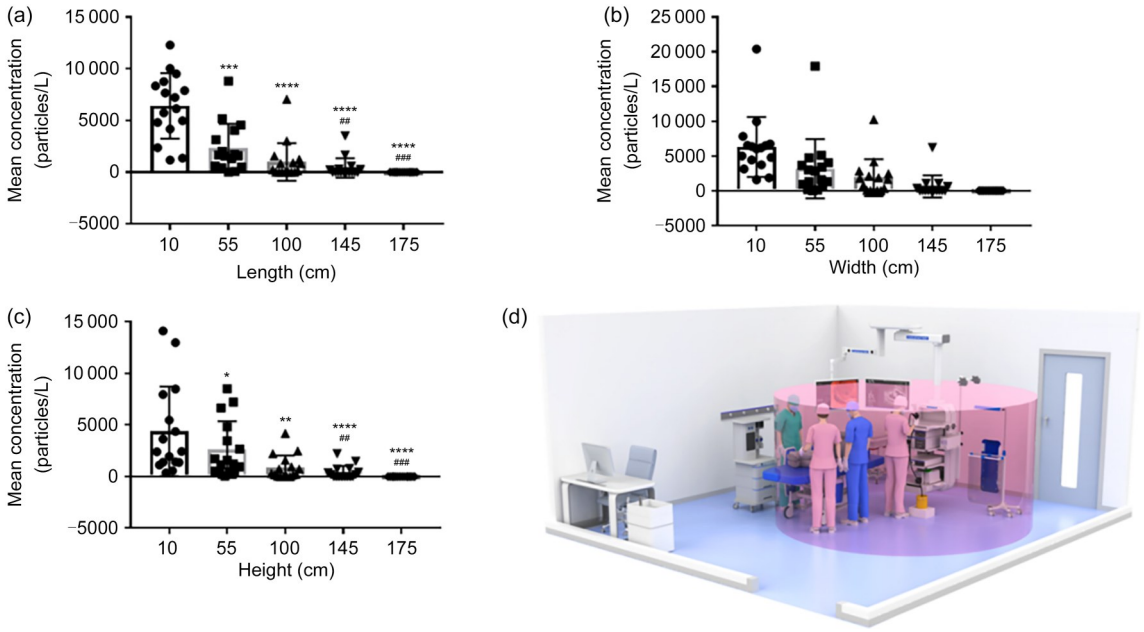

Fig. 1 Aerosol dissemination in three dimensions during bedside precleaning procedures. (a, b) Aerosol dissemination at different horizontal distances (10, 55, 100, 145, and 175 cm) from the precleaning bucket liquid surface. (c) Aerosol dissemination at different vertical distances (10, 55, 100, 145, and 175 cm) from the precleaning bucket liquid surface. (d) Schematic diagram of aerosol dissemination during bedside precleaning procedures. Aerosol could be detected in the cylindrical three-dimensional space, up to 175 cm both along the horizontal and height radius, with the precleaning bucket liquid surface at the bottom center. Data are presented as mean±standard deviation (n=16). $^{*}P$<0.05, $^{**}P$<0.01, $^{***}P$<0.001, $^{****}P$<0.000, compared with the 10 cm group; $^{\#\#}P$<0.01, $^{\#\#\#}P$<0.001, compared with the 55 cm group.

Table 1 Scope of aerosol transmission measured in three dimensions during endoscope precleaning procedures

Distance (cm)	Aerosol counts (particles/L)			
	In length	In width	In height	In height with resealable bags
10	6403.0±791.7	6321.0±1082.0	4381.0±1084.0	99.9±57.4
55	2328.0±585.3	3162.0±1072.0	2627.0±682.1	76.1±44.1
100	991.8±454.3	1886.0±682.8	864.0±299.3	43.0±32.5
145	413.1±233.3	620.1±413.2	407.5±159.5	32.3±23.3
175	0	0	0	0

Data are presented as mean±standard deviation (n=16).

(991.8±454.3) particles/L at 100 cm, and (413.1±233.3) particles/L at 145 cm. At 175 cm from the liquid surface, the number of detectable aerosols was 0 particles/L. These data indicated that bioaerosol transmission significantly decreases with distance.

The aerosol dissemination in different horizontal widths was assessed (Fig. 1b; Table 1). Consistent with the results measured for length, a large number of aerosols could be detected at 10 cm, that is, up to (6321.0±1082.0) particles/L. With increasing distance in this direction, the number of aerosols decreased significantly, but they could still be detected at 55 and 100 cm, with counts of (3162.0±1072.0) and (1886.0±682.8) particles/L, respectively. At 175 cm from the liquid surface, aerosols could hardly be detected.

We further assessed aerosol dissemination at different heights (Fig. 1c; Table 1). Large aerosol particle counts could be detected at 10 cm vertically away from the precleaning bucket liquid surface, at up to (4381.0±1084.0) particles/L. With increasing height, the aerosol count decreased, and no aerosols could be detected at the vertical distance of 175 cm.

Based on the above data, we established a 3D aerosol dissemination model (Fig. 1d), which indicated

that the cylindrical 3D space, with the precleaning bucket at the bottom center, measuring 175 cm both in horizontal radius and height, could be considered a high-risk aerosol exposure area. The distance from the precleaning bucket, both horizontally and vertically, largely decided the aerosol counts; that is, the longer the distance, the lower the count. In China, the average standing height of males and females aged 18–44 years is 169.7 and 158.0 cm, respectively, and the distance from the nasal/oral plane to the liquid surface is approximately 155 and 145 cm, respectively, all of which are within the range of 175 cm. According to our data, aerosols can present a problem at such distances ((407.5±159.5) particles/L at 145 cm). While undergoing endoscopy, the patient lies on the bed with his nose and mouth approximately 100 cm away from the liquid surface, exposing them to a higher risk of aerosol contact. These data indicated that both medical personnel and patients are subject to a high risk of bioaerosol exposure during the endoscope precleaning procedures. Therefore, personal protection is necessary for both groups, especially for medical personnel dealing with patients at a high risk of airborne diseases, such as tuberculosis and COVID-19.

For the efficacy and safety assessment of the precleaning bucket, the scope of aerosol dissemination was decided by measuring aerosol counts at different distances (10, 55, 100, 145, and 175 cm) away from the precleaning bucket in three dimensions at the same time, with or without the use of resealable bags. Immediately after use, the endoscopes were placed into the bag prefilled with cleaning solution and underwent due precleaning procedures with the bag well sealed. Aerosols could still be detected around the bag, but the counts were significantly lower at (99.9±57.4) particles/L at 10 cm, (76.1±44.1) particles/L at 55 cm, (43.0±32.5) particles/L at 100 cm, and (32.3±23.3) particles/L at 145 cm (Table 1). No aerosols could be detected beyond a distance of 175 cm. These data indicated that the use of resealable bags significantly reduces the transmission of aerosols from the source.

In conclusion, we demonstrated through simulation experiments that in the bedside endoscope cleaning process, a large number of aerosols could be produced around the precleaning bucket. Therefore, the layout design of the endoscopy center, such as the locations of the patient reception desk and the report station, should take into consideration the risk of aerosol exposure. In addition, based on the actual conditions, a mobile air sterilization station is preferred in the diagnosis and treatment room to filter out and sterilize aerosols or other media in the air that can transmit infectious pathogens (Corrêa et al., 2021). We also suggested that patients should put on masks and leave the at-risk area as soon as possible after endoscopy.

Although the source of AGP cannot be completely eradicated, blocking the route of aerosol transmission with resealable bags may prove effective. Performing precleaning inside a well-sealed bag largely prevents the aerosols from spreading from the source, remarkably reducing the bioburden imposed on medical personnel and patients. The scope of applying resealable bags may be expanded, such as to the reprocessing procedures of other medical devices, including tracheoscopes, cystoscopes, and surgical appliances. We believed that reducing the risk of bioaerosol exposure will largely improve the safety of the work environment of medical personnel and lower the risk of occupational infection, further contributing to a reduction in nosocomial infections.

Data availability statement

All data generated and analyzed during this study are available from the corresponding author upon reasonable request.

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Author contributions

Conceptualization and Writing – original draft: Tingting SHENG and Qing GU; Data curation: Li CEN; Methodology: Ye LU; Writing – review & editing: Xin WU, Chenying ZHOU, and Qing GU; Project administration: Qing GU. All authors have read and approved the final manuscript, and therefore, have full access to all the data in the study and take responsibility for the integrity and security of the data.

Compliance with ethics guidelines

Tingting SHENG, Xin WU, Li CEN, Ye LU, Chenying ZHOU, and Qing GU declare that they have no conflict of interest.

This article does not contain any studies with human or animal subjects performed by any of the authors.

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