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BRIEF REPORT

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Visualization of aerosol spread using a smoke tester during tracheal intubation performed in an operating room

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Abstract: Tracheal intubation is an essential procedure in the induction of general anesthesia; however, it is also a main source of infectious aerosols such as severe acute respiratory virus 2 (SARS-CoV-2). For protection from infectious aerosols, an air conditioning system which provides continuous laminar air flow from the ceiling and a local isolating device are widely used in typical operating rooms. However, how aerosols spread in an actual operating room has not been visualized, especially during tracheal intubation. In this study, we observed the spread of aerosols under several circumstances. To recreate the scenario of general anesthesia induction, we substituted aerosol spray with smoke from a smoke tester device in the mouth of a human body model placed on the operating table. Then we measured the maximum height of aerosol spread every second for 9 seconds. To verify the contribution of air conditioning and an isolating device, we compared four situations based on their presence or absence. The maximum height of aerosol spread was significantly lower in the presence of laminar air flow from the ceiling. An isolating device contributed to initially enclosing the aerosol; however, some aerosol leaked and diffused depending on the air flow outside the device. During tracheal intubation in typical operating room, air-conditioned laminar air flow can contribute to prevent infectious aerosol spread, and an isolating device can provide supplementary protection.

***Keywords*:** aerosol infection, tracheal intubation, laminar air flow, smoke tester, operating room

Introduction

Tracheal intubation is an essential procedure in general anesthesia; however, it exposes medical staff to infectious aerosols derived from the patient's exhalation, which can be a potential risk of respiratory infections, such as that caused by SARS-CoV-2 (*1*). Therefore, to protect staff from aerosol infection, it is very important to elucidate how aerosols spread across an operating room.

The most fundamental prevention from infection of coronavirus infectious disease, emerged in 2019 (COVID-19) is hand hygiene (*2*), however, in some cases such as tracheal intubation, isolation of aerosol is attempted (*3*). In fact, plenty of cluster cases of COVID-19 infection occurred not only in restaurants but also in medical settings, the main cause of which might be from aerosol droplets. Hence, the most basic characteristics of aerosol infection, in other words, how the actual aerosol spread has not been fully visualized and reported.

Several previous studies have reported simulations with moving images of aerosol spread from coughing patients calculated using supercomputers; however, these reports were based upon several presuppositions, so the results might not necessarily describe actual aerosol spread and may overlook unexpected factors. In the occupational health field, air flow is commonly checked using a smoke tester, which can provide visible white smoke. This approach can elucidate the general condition of aerosol spread instantly with all surrounding factors considered.

In our central operating department, aerosol infection of COVID-19 has been a great threat (*4*), because operating room activities cannot be suspended and the room itself can be an epicenter of an infectious outbreak. In a modern operating room, purified laminar air flow is constantly provided from the ceiling to the floor. Additionally, to protect from droplet infection, medical staff undertake standard precautions and occasionally use an isolating device. However, whether such protective gadgets can actually control aerosol spread is not fully understood.

Therefore, we duplicated the scenario of performing tracheal intubation in an air-conditioned operating room with an isolating device, and visualized how exhalation can spread by substituting the aerosol for test smoke.

Materials and Methods

Experiment conditions

We performed this study in the operating room in the Central Operation Center in the Center Hospital of National Center of Global Health and Medicine from July 2020 to February 2021. The cleanliness of the operating room was equivalent to class 2 of healthcare engineering. association of Japan standard-02-2013 (HEAS-02-2013), and air was circulated 15 times per hour with laminar air flow from the ceiling to the floor.

We replicated aerosol release from tracheal intubation as follows; first, we set a human body model (Laerdal® Airway Management Trainer, Laderal, Stavanger, Norway) on the operating table; second, we substituted test smoke for the patient's exhalation during manual ventilation using a smoke tester (Smoke tester kit 500, Gastec Co., Ayase, Kanagawa, Japan), which can provide constant amounts of white smoke (and is usually used for air conditioning management in occupational health); third, we setup an isolating device, shown in Figure 1 (available elsewhere), which was originally used in our hospital. The device was placed between the human body model and a member of the medical staff, so as to cover the patient's face except for two small holes positioned on both sides caudally for arm access to perform tracheal intubation.

We recorded aerosol spread using a high-resolution video camera (RX-100M5A, SONY, Japan) from the left side of the operating table.

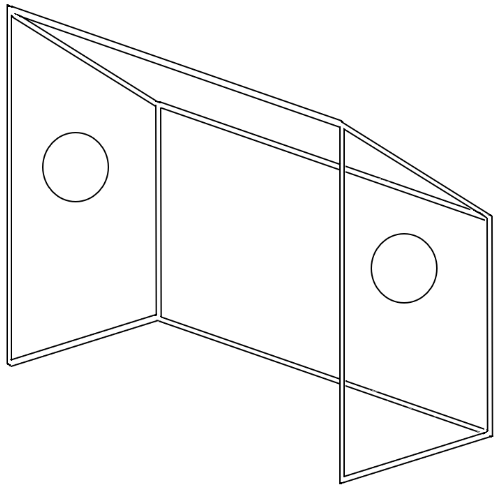

Figure 1. An isolating device originally used in the National Center Hospital of Global Health and Medicine (height, 50 cm × length, 30 cm × width, 45 cm).

Experimental protocol and analysis

We observed the air flow in four different conditions based upon whether air conditioning and an isolating device were provided:

Condition 1: laminar air flow (+), isolating device (−)

Condition 2: laminar air flow (−), isolating device (−)

Condition 3: laminar air flow (+), isolating device (+)

Condition 4: laminar air flow (−), isolating device (+)

All experiments were performed after the air conditioning system had worked sufficiently or was completely stopped. We sprayed a constant amount of smoke from the right corner of the model's mouth duplicating a patient's exhalation, and recorded, from the side of the operating table, how the smoke spread across the operating room for 9 seconds. Each measurement was performed 5 times per condition. Next, we extracted still images for every second from the recorded moving images and 2 independent reviewers performed evaluations of the maximum height of the smoke with all images randomized to avoid bias based on the conditions and reviewers.

We evaluated the spread of smoke by its maximum height because we especially wanted to monitor how the spread of aerosols can be suppressed by laminar air flow, from the ceiling of the operating room, in conjunction with an isolating device. The obtained data are expressed as average ± standard deviation with one way ANOVA for every condition using the R project for statistical computing.

Results and Discussion

The change over time of the highest point of aerosol diffusion in each condition is shown in Figure 2 and Table 1. The characteristic diffusion of aerosol in each condition is shown in Figure 3.

The presence of laminar air flow significantly contributed to suppress the diffusion of aerosol throughout the experiment. In addition, under laminar air flow circumstances, no additional effect was observed regardless of the presence of the isolation device. On the other hand, without laminar air flow, the isolation device significantly suppressed the diffusion of aerosol at first, however, over time, the aerosols leaked outside the device and diffused.

We visualized the distribution of aerosol in an operating room effectively and conveniently using our test smoke model. It strongly suggests that continuous laminar air flow from the ceiling plays a major role in the evacuation of aerosol.

In contrast, use of an isolating device provided mixed effects. It completely enclosed the aerosol derived from the cough reflex at an early phase regardless of the presence of laminar air flow. However, the leaked aerosol diffused depending on the presence

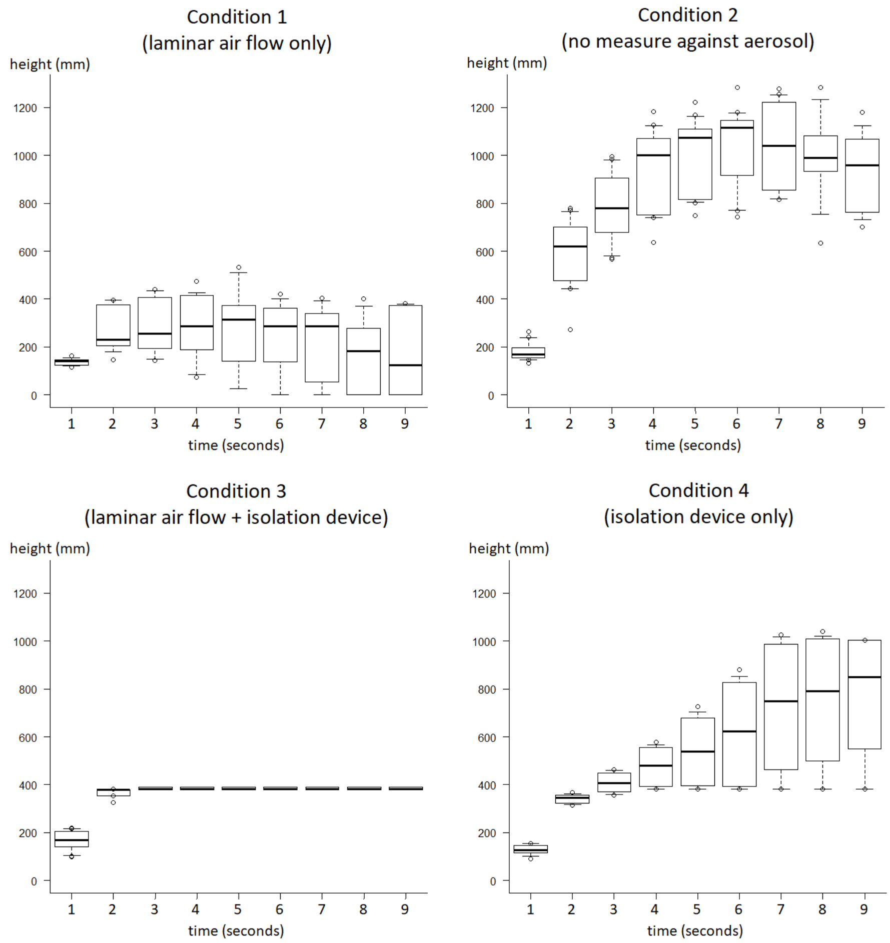

Figure 2. Distribution of aerosol in each condition. Condition 1: laminar air flow (+), isolating device (−); Condition 2: laminar air flow (−), isolating device (−); Condition 3: laminar air flow (+), isolating device (+); Condition 4: laminar air flow (−), isolating device (+).

of air flow outside the device, and by contrast, contaminated aerosol inside the device was trapped for a long time.

The risk of aerosol infection is widely known from previous studies (*4*). However, with the use of visualized smoke, our study shows that there is no exhaust route for the isolated aerosols, which leak from the edge of the isolating box at the very early stage of inhalation.

These findings suggest that an air-conditioned operating room is suitable for infection-safe tracheal intubation, with recommended addition of an isolating device in the case of a risk of convulsive exhalation, such as during a cough reflex and mask ventilation. Tracheal intubation performed without an air conditioning system or solely using an isolating device might place medical staff at potential risk of exposure to patient-derived aerosols.

In our study, we used a smoke tester, which is widely used in industrial hygiene departments, to visualize aerosol spread from a patient. The smoke tester can provide a constant amount of smoke containing particles with similar size and characteristics to exhaled aerosols. Moreover, it has excellent visual recognizability and low toxicity. Thus, this smoke tester model is suitable for visually evaluating the distribution of aerosols in other areas outside of the operating room.

The effectiveness of air conditioning in the operating room depends on several factors, including the size of the room and arrangement of equipment for surgery, which might unexpectedly interrupt air conditioning. Therefore, this practical air flow simulation system may contribute to preventing aerosol-based infection at clinical sites. Conversely, an isolation device blocked laminar air flow completely on the patient, resulting in aerosol drifting in the isolated area during measurement. This result suggests that we should pay special attention to aerosol infection "inside" the isolated area and "recurrence" of aerosol diffusion when removing the device. Nevertheless, isolating devices can be effective in suppressing the early phase of aerosol diffusion derived from aerosol spouting, such as that due to the cough reflex; however, our result showed that for subsequent control of aerosol

Table 1. Qualitative description and maximum height of aerosol spread in conditions 1 to 4

Seconds	1	2	3	4	5	6	7	8	9
Average ± SD (Condition 1)	138.7 ± 14.9	273.9 ± 96.6	290.1 ± 118.9	283.9 ± 140.5	277.4 ± 181.7	236.2 ± 156.2	213.6 ± 162.4	162.4 ± 156.8	167.7 ± 172.7
Average ± SD (Condition 2)	181.0 ± 39.0	591.9 ± 151.3	787.0 ± 146.9	940.6 ± 177.1	1003.5 ± 162.8	1044.0 ± 177.7	1046.0 ± 183.7	992.6 ± 188.2	938.0 ± 184.4
Average ± SD (Condition 3)	165.9 ± 41.7	368.2 ± 17.3	383.7 ± 5.48	383.7 ± 5.5	383.7 ± 5.5	383.7 ± 5.5	383.7 ± 5.5	383.7 ± 5.5	384.2 ± 5.9
Average ± SD (Condition 4)	128.1 ± 21.8	341.5 ± 20.1	408.9 ± 44.0	476.3 ± 86.8	542.1 ± 156.4	618.0 ± 234.6	725.3 ± 288.1	751.6 ± 283.2	773.9 ± 271.2
p value (ANOVA)	0.0031	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
p value (Bonferroni test)									
Condition 1 *vs.* 2 (air-condition on/off without isolation device)	0.029	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Condition 1 *vs.* 3 (isolation device on/off with air-condition)	0.367	0.15	0.208	0.396	0.524	0.215	0.184	0.033	0.163
Condition 1 *vs.* 4 (air-condition *vs* isolation device)	1	0.85	0.099	0.013	0.002	< 0.001	< 0.001	< 0.001	< 0.001
Condition 2 *vs.* 3 (both on/off)	1	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Condition 2 *vs.* 4 (isolation device on/off without air-condition)	0.007	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.002	0.032	0.611
Condition 3 *vs.* 4 (air-condition on/off with isolation device)	0.098	1	1	0.646	0.113	0.015	< 0.001	< 0.001	< 0.001

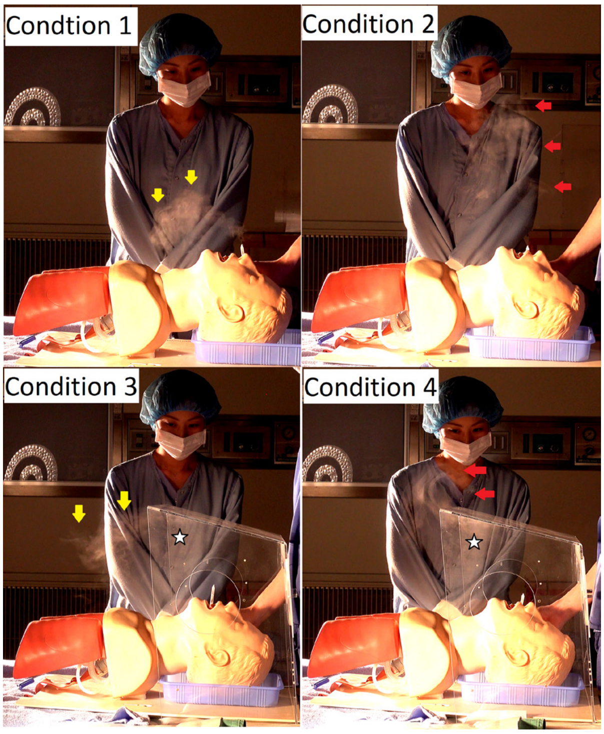

Figure 3. Characteristic diffusion of aerosol in each condition. Condition 1: laminar air flow (+), isolating device (−); Condition 2: laminar air flow (−), isolating device (−); Condition 3: laminar air flow (+), isolating device (+); Condition 4: laminar air flow (−), isolating device (+). The aerosol is confined by laminar air flow (yellow arrows), and diffuses without the presence of laminar air flow (red arrows). Inside the isolated area, the aerosol drifts with/without the presence of laminar air flow (white stars).

diffusion, laminar air flow is an essential factor and the role of the isolating device remains limited.

Computer simulation is another effective method of elucidating aerosol behavior. It has superior reproducibility and can provide quantitative evaluations. However, these simulations require a supercomputer, the availability of which is often limited. Additionally, it also requires all preconditions to be converted to numerical parameters, some of which might not be quantized properly or remain unintentionally overlooked. By contrast, observing air flow using a smoker tester is relatively easy and inexpensive, which can help manage prevention of aerosol-based infection.

In conclusion, our smoke tester model is a simple and practical tool for visualizing actual air flow in an operating room with a potential risk of aerosol infection. Based upon our results, we recommend that infection-safe tracheal intubation should be performed in facilities with a laminar air flow system installed, such as in an operating room.

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Conflict of Interest: The authors have no conflicts of interest to disclose.

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