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Pilot study of aerosols visualized and evaluated in a radiotherapy room

Atsushi Musha[1,2,*], Nobuteru Kubo[1], Hidemasa Kawamura[1], Naoko Okano[1], Kunio Yanagisawa[3], Kazuaki Sugawara[4], Ryuta Okamoto[4], Kozo Takahashi[4], Hideki Kawabata[4] and Tatsuya Ohno[1]

[1]Gunma University Heavy Ion Medical Center, Maebashi, Gunma, 371-8511, Japan
[2]Department of Oral and Maxillofacial Surgery and Plastic Surgery, Gunma University Graduate School of Medicine, Maebashi, Gunma, 371-8511, Japan
[3]Infection Control and Prevention Center, Gunma University Hospital, Maebashi, Gunma, 371-8511, Japan
[4]Solution Division, Shin Nippon Air Technologies Co., Ltd., Chuo-ku, Tokyo, 103-0007, Japan

*Corresponding author. Gunma University Heavy Ion Medical Center, 339-22, Showa-machi, Maebashi, Gunma, 371-8511, Japan. Tel: +81-27-220-8383; Fax: +81-27-220-8397; E-mail: musha@gunma-u.ac.jp
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ABSTRACT

Health care institutions provide prevention strategies for coronavirus disease 2019 and non-infectious disease care. We investigated the characteristics of patient contamination in a radiotherapy room by examining the trajectory and number of airborne particles in the air when talking and coughing occurred and clarified the actual state of contamination in this closed space. Aerosols were visualized and evaluated in the vertical height and head-to-tail width directions when the participant was lying on the radiotherapy tabletop. Aerosol reach was significantly greater for loud voice and coughing both at vertical height and the head-to-tail width direction. The size and number of particles around the radiotherapy tabletop were also visualized and evaluated in the radiotherapy room. The radiotherapy staff who were in the presence of the participant sometimes had many particles adhering to their facial area; particle adhesion to the staff was dominated by small size particles. Particle adherence to the irradiation device surface near the ceiling had particles larger than 1 mm. Tabletop particles tended to have a wider size range, including bigger sizes and a larger count compared to the surrounding floor. The 0.7-m radius distance from the participant's mouth tended to be highly contaminated, and the smaller the particle size, the farther it reached. The capacity to estimate areas prone to contamination can be used to predict infection of other patients and medical staff in a radiotherapy room.

Keywords: coronavirus disease 2019 (COVID-19); aerosol; radiotherapy; head and neck cancer

INTRODUCTION

The transmission of coronavirus disease 2019 (COVID-19) infection has caused a pandemic, and the number of infected people has been increasing worldwide since 2019. Infection occurs when susceptible individuals are exposed to particles containing the infectious virus released from the nose or mouth of an infected person. There are three main routes of transmission: inhalation of aerosols containing the virus floating in the air (aerosol infection); adhesion of droplets containing the virus to exposed mucous membranes such as the mouth, nose and eyes (droplet infection); and direct contact with droplets containing the virus or touching exposed mucous membranes with fingers that have touched surfaces with the virus (contact infection) [1, 2].

Due to the continuing presence of COVID-19 worldwide, these three routes of infection have implemented standard precaution protocols for the prevention of spreading COVID-19. In health care institutions, infection prevention is enforced while non-infectious disease care is also provided daily. Among medical care, cancer treatment is the one of those that cannot be stopped even when infectious diseases are spreading, and procedures such as surgery and radiotherapy, must continue. Since radiotherapy is a treatment that must be continued, long-term infection prevention measures are desirable. What can we do to ensure radiotherapy provided to patients with cancer is conducted in a safe environment for the patients and health care workers?

Among the infection routes, aerosol generation may be caused by physiological events such as the cough reflex. Due to the specificity of the disease, patients with head and neck cancer may induce a cough reflex and generate many aerosols during an examination, treatment and oral care, and health care professionals are easily exposed [3]. These aerosols may mix with patient blood, saliva and dental plaque, increasing the potential for contamination of the air and equipment around the patient and risk of infection. Aerosols from the cough reflex can easily expose staff preparing for treatment around the radiotherapy equipment, especially when the patient in radiotherapy is not wearing a surgical mask. Although the aerosol is likely to be heavy and will not travel far because of the saliva component, radiotherapy rooms are generally small, enclosed spaces. Past study observations have confirmed there is a substantial probability that even normal speaking causes airborne virus transmission in confined environments [4]. Furthermore, if virus particles are aerosolized, they can potentially travel distances of up to 6 meters [5], which could be enough to spread throughout the radiotherapy room and cause secondary infection. The survival time of severe acute respiratory syndrome coronavirus–2 (SARS-CoV-2) is also a problem, as it is reported to be 72 hours for plastics and stainless steel after surface deposition and 3 hours in suspended aerosols [6]. There is an urgent need to investigate the actual state of contamination in radiotherapy rooms to measure against infection among medical staff involved in cancer treatments. To date, there are no reports specifically on the risk of contamination in radiotherapy rooms.

This study aimed to determine the characteristics of contamination in radiotherapy rooms of patients with head and neck cancer, examine the number of airborne particles in the air when the cough reflex develops, and clarify the actual state of contamination in closed spaces due to the cough reflex and other causes.

MATERIALS AND METHODS

In this study, a laser beam and a highly sensitive camera were used to visualize participant-generated aerosols in a super-clean laboratory (SCL) that simulated a radiotherapy room and a real radiotherapy room. We used the fine particle visualization system of atmospheric particles as previously reported [7, 8]. Corresponding qualitative and quantitative assessments were performed to measure the quantity of microparticles using particle counters. The same healthy 63-year-old man voluntarily enrolled as the participant in this experiment for both the SCL and the radiotherapy room.

The SCL simulated radiotherapy room (specifically, an ISO14644-1 Class 3 clean booth) was used for visualization (Shin Nippon Air Technologies Co., Ltd., Chuo-ku, Tokyo, Japan) in the experiment. Twenty fans filter unit were present in the SCL, which made it possible to reduce the number of particles drifting through the air to nearly zero. All the particles measured were aerosols specifically created for this study by talking (normal and loud voice) and coughing. A 'normal' talking volume was defined as talking that can be heard within a few meters indoors; whilst a 'loud' talking volume was defined as the loudest voice in the supine position for this participant. Both of normal and loud talking were assessed by making the participant to say the same sentence, 'DAIJOUBUDESU' in Japanese, which means 'It is OK' or 'No problem.' The dimensions of the SCL were 2.3 × 5.9 × 2.0 m. At the center of this area, a linear accelerator (LINAC) tabletop was placed to simulate radiotherapy. The tabletop had a height of 0.65 m, which was assumed to correspond to the natural posture of a patient during radiotherapy. To analyze only aerosol particles emitted by a patient, the clean booth was switched on prior to the experiment to remove most micro particles in the room air. The visualized image confirmed the particles disappeared. The clean booth was then stopped after approximately 10 seconds and the experiment started.

In the radiotherapy room experiment was conducted with the Elekta Synergy LINAC (Elekta AB, Stockholm, Sweden) tabletop in a radiotherapy room at the Gunma University hospital, Maebashi, Gunma, Japan. All the particles measured were aerosols specifically created for this study by talking and coughing while the participant was in a supine position. The dimensions of the radiotherapy room used for the experiment were 5.1 × 6.3 × 3.0 m. At the center of this area was the LINAC tabletop. The tabletop was set at a height of 0.65 m.

Aerosol particle scattering experiment

Table 1 lists the materials that were used for the measurements. The participant was placed in a supine position to observe how aerosols develop from the mouth of a supine position. First, the procedure was performed in a clean booth so that the airflow and particle background were as close to zero as possible. Aerosols were visualized and evaluated in the vertical height and head-to-tail width directions while the participant was placed in a supine position in the middle of the booth (Fig. 1A), and in the horizontal and head-to-tail width directions at a vertical height of 0.7 m from the participant's mouth (Fig. 1B). Normal talking, loud voice and coughing were performed three times each. The particle trajectories were photographed with a high-sensitivity camera (Table 1), and the vertical height and horizontal and head-to-tail width directions of the trajectory were measured.

Second, in the radiotherapy room, the airflow and particle background were natural. The actual area where the particles dispersed was photographed with a high-sensitivity camera and evaluated (Table 1). The participant was placed in a supine position on a LINAC tabletop and administered 1 ml of an aqueous solution containing a coloring agent (acid red 106) in the mouth and performed the cough reflex 20 times; this was were performed three times. The medical staff wear personal protective equipment, such as face shield, surgical mask and gown, and were placed near the participant (Fig. 2A). The areas and staff where contamination was evaluated are shown in the Fig. 2. At each area (Fig. 2), a 0.05 × 0.05 m piece of black aluminum tape was attached, and after every experiment, the dye on the tape surface was photographed with a dedicated camera for measurement and analysis.

Statistical analyses

The differences between groups were assessed using t-tests. The differences were considered statistically significant at $P < 0.05$. Statistical analyses were performed using IBM SPSS (version 28.0; IBM Corp., Armonk, NY, USA).

Ethical statements

This single-institution interventional study was approved by the institutional review board of Gunma University Hospital (approved number: IRB2021-020, registration number: UMIN000047845),

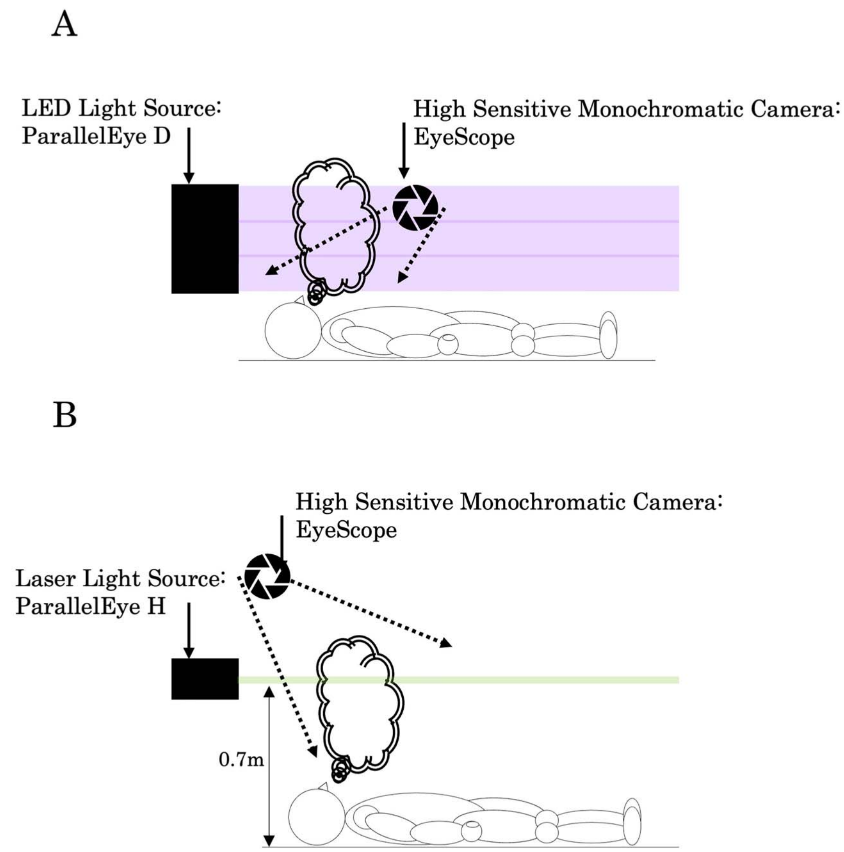

Fig. 1. Schematic illustration of experimental design. (A) Aerosols were visualized and evaluated in the vertical height and head-to-tail width directions while the participant was placed in a supine position in the middle of the booth. (B) Aerosols were visualized and evaluated in the horizontal and head-to-tail width directions at a vertical height of 0.7 m from the participant's mouth.

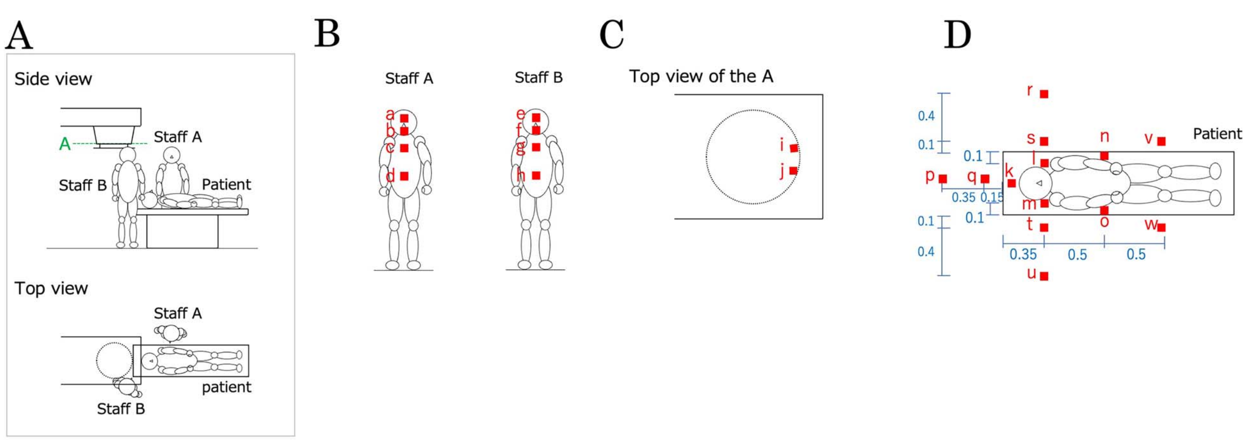

Fig. 2. Schematic illustration of the areas and staff. (A) Side and top view of the experimental area, (B), (C) and (D) at each area. A 0.05 × 0.05 m piece of black aluminum tape was attached for analysis. Black aluminum tape was attached at staff eye level (a, e), mouth level (b, f), chest level (c, g) and waist level (d, h), respectively. In C, the tape was attached to the bottom surface of the irradiation device (i, j). In D, the taped areas were on the radiotherapy tabletop by the patient (k, l, m, n, o) and on the floor (p, q, r, s, t, u, v, w).

Table 1. Aerosol particle scattering experiment measurements and materials list

Objects	Equipment	Industry	Specifications
Clean booth			
Vertical height and head-to-tail width directions			
camera	High-sensitivity Monochromatic Camera EyeScope	Shin Nippon Air Technologies Co., Ltd. Tokyo	
light source	LED Light Source ParallelEye D		wavelength: 400 nm
software	Movie Recording Software ParticleEye V&A		software version: 1.8
	Moving Image Processing Software ParticleEye Viewer		software version: 3.7
Visualizable particle size when using this equipment: 0.001 mm or larger			
Horizontal and head-to-tail width directions at a vertical height of 0.7 m from the patient's mouth			
camera	High-sensitivity Monochromatic Camera EyeScope	Shin Nippon Air Technologies Co., Ltd. Tokyo	
light source	Laser Light Source ParallelEye H		wavelength: 532 nm
software	Movie Recording Software ParticleEye V&A		software version: 1.8
	Moving Image Processing Software ParticleEye Viewer		software version: 3.7
Visualizable particle size when using this equipment: 0.001 mm or larger			
Radiotherapy room			
camera	High-sensitivity Color Camera D-Scope	Shin Nippon Air Technologies Co., Ltd. Tokyo	
light source	LED Light Source D-Light Type-F		wavelength: 395 nm
software	Image Recording Software D-SHOT		software version: 1.2
	Image Processing Software D-POST		software version: 1.2
Visualizable particle size when using this equipment: 0.03 mm or larger			

and carried out in accordance with the Declaration of Helsinki. The participant provided informed written consent.

RESULTS

In the clean booth, aerosols were visualized and evaluated in the vertical height and head-to-tail width directions. Figure 3A–C shows a representative cumulative image of aerosol trajectories. The maximum vertical height and head-to-tail maximum width directions measured from the mouth measured are shown in Fig. 3. Normal talking had 0.17 ± 0.05 m for vertical height, and 0.18 ± 0.02 m for head-to-tail width. Loud voice had 0.4 ± 0.16 m for vertical height, and 0.43 ± 0.13 m for head-to-tail width. Coughing had 0.7 ± 0.06 m for vertical height, and 0.35 ± 0.13 m for head-to-tail width (Fig. 4A–B). Compared to normal talking, the aerosol reach difference was significantly greater for loud voice and coughing both at vertical height and for the head-to-tail width direction. At a vertical height of 0.7 m from the mouth, coughing had 0.46 ± 0.1 m for width directions, and 0.46 ± 0.1 m for head-to-tail width (Figs 3D and 4C).

The size and number of particles around the radiotherapy tabletop were visualized and evaluated in the actual radiotherapy room. Table 2 shows the number of each measurement, and Fig. 5 graphs the number of particles dispersed to the locations in Fig. 2. Staff B, who was on the head side of the participant, sometimes had more than 100 particles adhering to the facial area, depending on the number of experiments (Table 2). They also reached the surface of the irradiation device (Figs 2C and 5C) (0.6 m from the treatment table). Both the top and surroundings of the radiotherapy tabletop generally had particle adherence (Figs 2D, 5D–E).

The analysis for each size of adhered particles is presented in Fig. 6. The tendency of particles to spray was similar in all experiments. Particles adhesion to the staff was dominated by small size particles (Fig. 6A). Particle adherence to the irradiation device surface was not limited to small particles, but also included particles larger than

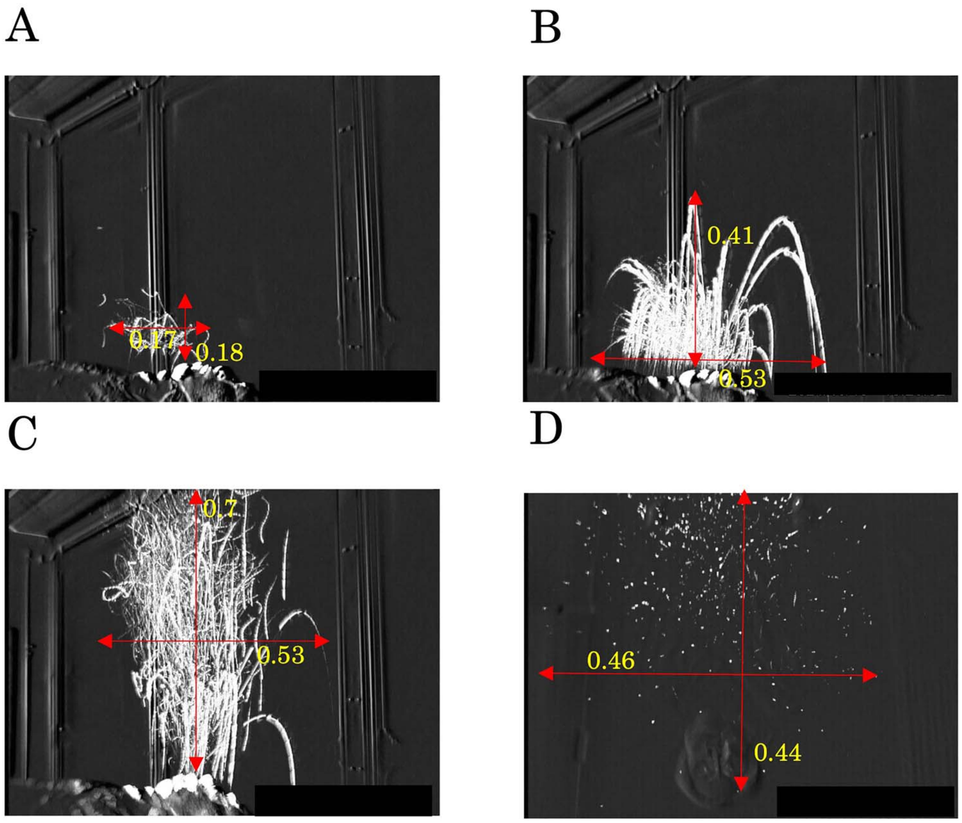

Fig. 3. A representative cumulative image of aerosol trajectories. The maximum vertical height and head-to-tail maximum width directions from the mouth were measured. (A) Normal talking, (B) loud voice, (C) coughing and (D) coughing at a vertical height of 0.7 m from the mouth. Only in (D) was coughing analyzed for width directions and head-to-tail width.

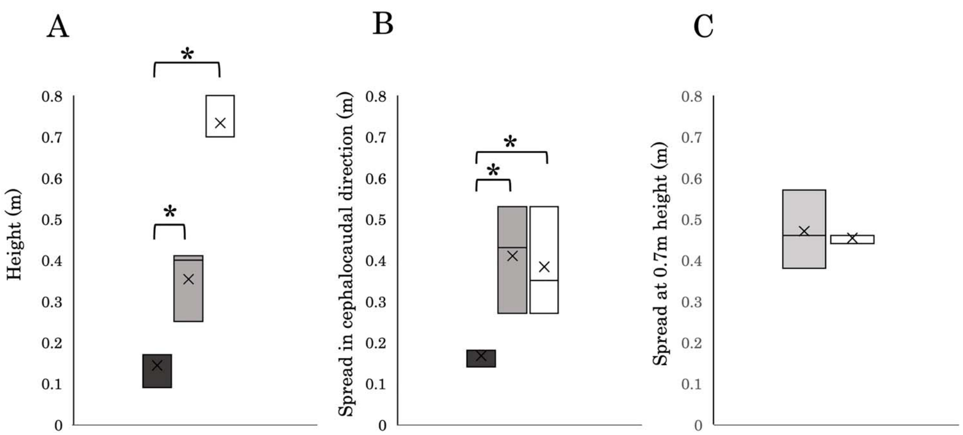

Fig. 4. Aerosol reach differences. (A) Vertical height, (B) spread in cephalocaudal direction, and (C) spread at 0.7 m height. Dark gray is normal talking, gray is loud voice, and white is coughing.

1 mm (Fig. 6B). Compared to the floor surrounding the radiotherapy tabletop, the particles on the radiotherapy tabletop tended to have a wider range of size range, include larger sizes, and a greater count (Fig. 6C–D).

DISCUSSION

In this study, we investigated the contamination characteristics in radiotherapy rooms by the participant, examined the trajectory and number of particles in the air when the talking and coughing develops, and

Table 2. Number of each measurement for the number of particles

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	*p*	q	r	s	t	u	v	w
1st	6	1	1	8	0	1	3	1	1	4	72	90	29	11	2	4	18	65	5	22	19	1	6
2nd	7	4	7	23	121	1	2	2	1	7	32	120	34	3	21	4	57	64	7	5	34	3	23
3rd	2	0	2	2	37	4	0	6	10	1	23	43	12	22	3	72	4	3	5	3	17	1	76

1st, 2nd and 3rd indicate the three times the experiment was conducted. The letters indicate the tape location (Fig. 2) for the number of particle adherence.

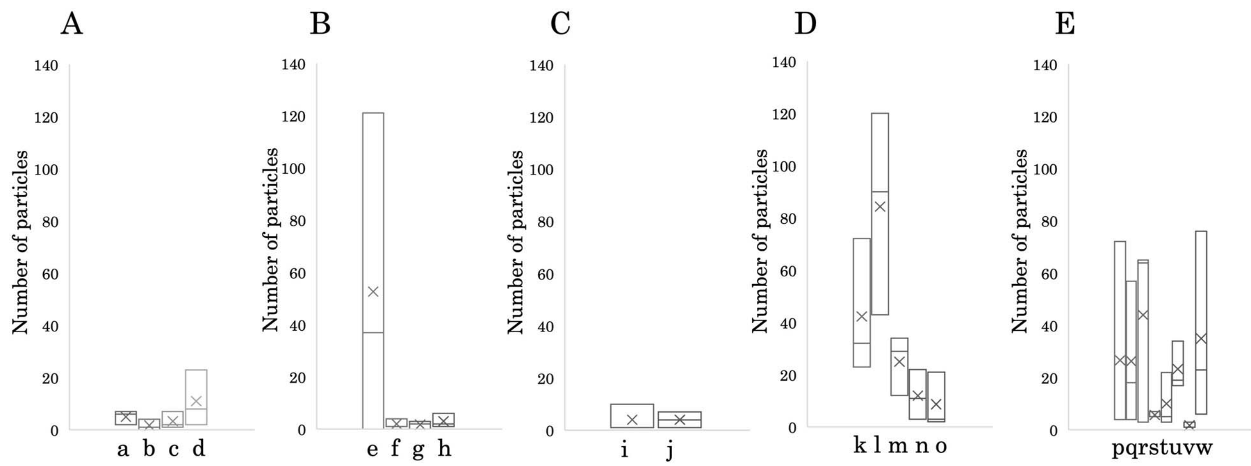

Fig. 5. Number of particles dispersed to the locations in Fig. 2. (A) staff A, (B) staff B, (C) irradiation device, (D) radiotherapy tabletop, and (E) floor.

clarified the actual state of contamination in a closed space. Compared to normal talking, aerosol reach was significantly greater for loud voice and coughing both at the vertical height and head-to-tail width directions. The radiotherapy staff who were around the participant sometimes had a lot of particle adherence in the facial area. Compared to the floor surrounding the radiotherapy tabletop, the particles on the radiotherapy tabletop tended to have a wider size range, include larger sizes, and a greater count. The 0.7 m radius from the participant's mouth tended to be highly contaminated, and the smaller the particle size the farther it reached. This area was within the range where staff move around to position patients, confirming the ease of exposure for staff.

Particle size and reach are reported to be within 2 m for particles $> 5\ \mu$m, within 6 m for particles $< 5\ \mu$m and all share space at 1-0 and 1 μm [1, 2, 9]. Radiotherapy rooms are generally small, and it is difficult for staff to be at a distance more than 6 m away from a patient. In addition, preparation for radiotherapy may require contact with a patient, therefore, it is important to implement standard precautions and prevent contact infection. Staff should wear surgical masks, as recommended for all health professionals and patients according to World Health Organization indications [1, 10]. The results of this study can support the use of infection prevention devices, such as face shields, surgical masks and gowns, are sufficient for protecting staff from contamination.

It is also necessary to decontaminate contaminated areas because it is difficult to completely block the route of infection through contact with patients. Hand and finger sanitizing is a basic infection control measure for individual staff members; since SARS-CoV-2 has an envelope, hand disinfection with alcohol (60–90% ethanol concentration, 70% isopropanol recommended) and hand washing with soap and running water are both effective [2]. Therefore, thorough use of hand alcohol in each radiation treatment by each patient is important. Alcohol wiping of areas where viruses have dispersed or adhered to the area around the LINAC is also recommended. The survival time of SARS-CoV-2 on respective materials (surface properties) should also be considered [6]. The area most likely to be contaminated is the area around the radiation therapy tabletop. A previous study demonstrated that in open spaces, airborne droplet carriers can travel significantly further than the 2 m recommended safe distance due to the wind speed [5]. Without the surrounding wind speed, the droplets will fall to the ground in a shorter distance from the person exhaling or coughing, therefore, the range may not exceed 1 m [5]. In general radiotherapy rooms are tiny spaces with no strong wind, thus areas wiped by alcohol for should range of 1 m from a patient's mouth. The 0.7 m range is particularly important based on the results of this study. It is important to wipe around LINAC tabletop with alcohol after every patient's radiation treatment.

Ideally, the entire treatment room should be wiped down, but this is not practical because contamination can extend near the ceiling area. Some reports recommend ultraviolet disinfection of the radiotherapy rooms [11], and a conclusion regarding decontamination of the entire radiotherapy room is awaited. Furthermore, UV irradiation cannot decontaminate areas in the shadows and the UV rays may influence the equipment. Since the COVID-19 pandemic, most patients undergoing radiotherapy in Japan have been required to wear surgical masks. Therefore, patients with head and neck cancer are only allowed

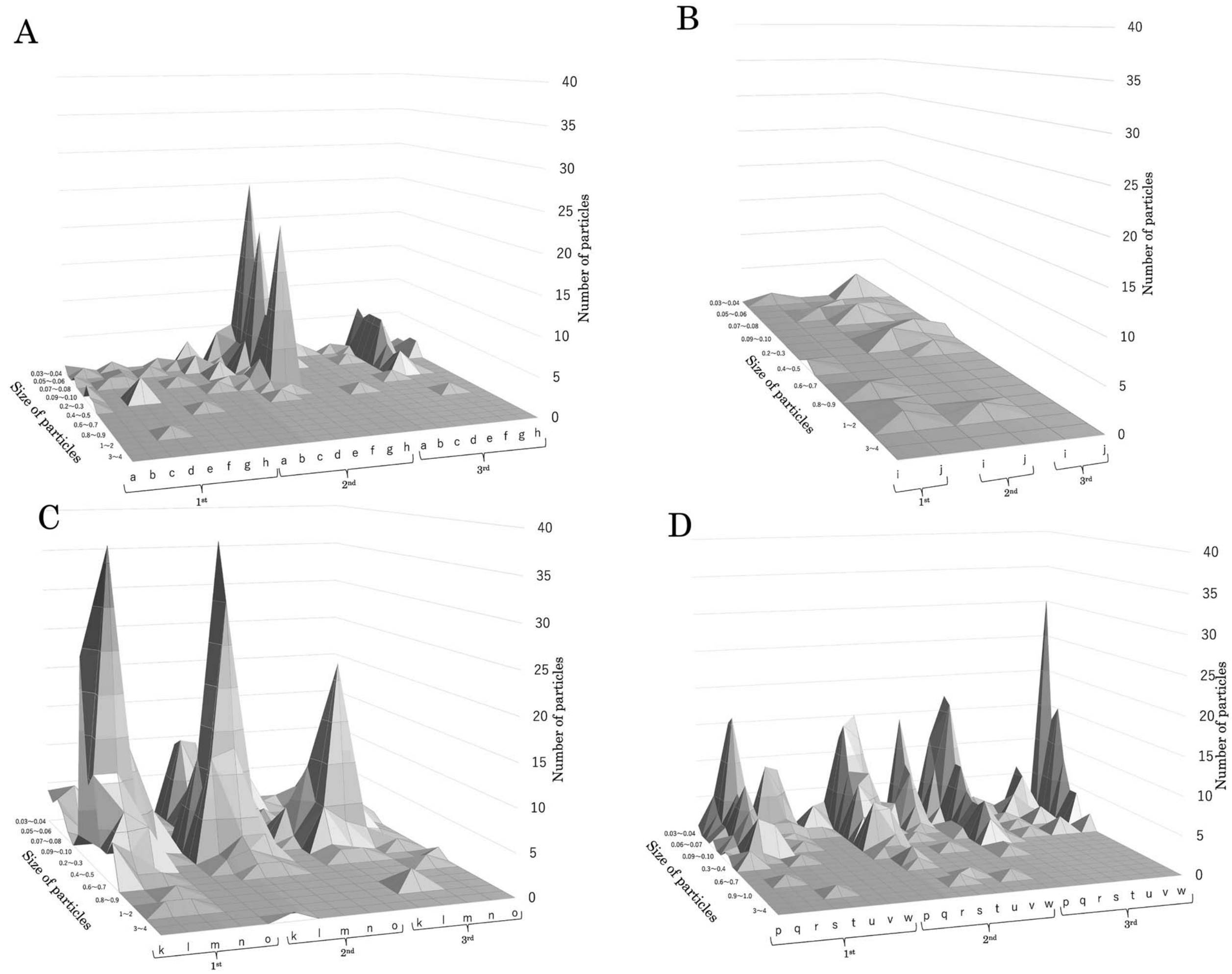

Fig. 6. Analysis of the number of attached particles per size for the three times the experiment the experiment was conducted. (A) Particles adhesion to the staff. (B) Particle adherence to the irradiation device surface. (C, D) Particle adherence to the radiotherapy tabletop and the floor surrounding it.

to remove the mask for a very short period of time before and after the shell is put on. However, this still presents a risk of cough reflex; therefore, we would like to emphasize the importance of wearing personal infection prevention devices when approaching the 0.7 m radius around the patient's mouth. However, efforts can be made to reduce the source of droplets itself, such as face shields over the shell [11] and surgical masks under the shell [12], which can reduce exposure in the surrounding environment.

To reduce the risk of COVID-19 transmission, the amount of virus from the oral cavity must be reduced. One of the most efficient actions is the use of antiviral mouthwashes [13, 14]. A review of the literature concluded that mouthwashes containing cetylpyridinium chloride or povidone-iodine can reduce the oral viral load of SARS-CoV-2. Since it is difficult to completely control the development of aerosol outbreaks in a radiotherapy room, a pre-treatment mouthwash for each patient is recommended and can be a relatively simple method of infection prevention.

This study has a few limitations. This was a pilot study in which one participant was analyzed to obtain the degree of contamination in a specific radiotherapy room during aerosol generation because the degree and the risk of contamination were unknown. Many patients with head and neck tumors are men over the age of 60, with our patient being in the younger range of this age group [15]. Future studies should include women and patients in different age groups to evaluate the varying degrees of cough reflex among the participants. In addition, when considering the fluid airways, fluid trajectories are likely to vary in different facilities and radiotherapy rooms.

To the best of our knowledge, there have been no environmental measurements in radiotherapy rooms, and we believe that the results of this study can at least serve as a reference for standard precautions in radiotherapy rooms. This simulation study was conducted in a radiotherapy room, but the same could be determined for other tiny rooms such as medical examination, computed tomography, angiography and operating rooms. In the future, experiments using similar procedures should be conducted in multiple types of radiation therapy rooms and with multiple participants.

In conclusion the results from this study provide evidence for areas prone to contamination by patients in a radiotherapy room and to the staff. These findings can assist in implementing protocols for preventing the spread of COVID-19 as well as other infectious diseases such as tuberculosis and flu.

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CONFLICT OF INTEREST

The authors declare they have no conflicts of interest.

DATA AVAILABILITY

The data set generated and/or analyzed during the current study is not publicly available because it contains personal information, but anonymized data are available from the corresponding author on reasonable request.

CLINICAL TRIAL REGISTRATION NUMBER

UMIN000047845.

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