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RESEARCH

Inactivation Effects of Hypochlorous Acid, Chlorine Dioxide, and Ozone on Airborne SARS-CoV-2 and Influenza A Virus

Yasuo Imoto[1] · Hidehito Matsui[2] · Chihiro Ueda[1] · Eri Nakajima[1] · Hideaki Hanaki[2]

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Abstract

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and influenza A virus are primarily transmitted through droplets or aerosols from patients. The inactivation effects of existing virus control techniques may vary depending on the environmental factors. Therefore, it is important to establish a suitable evaluation system for assessing virus control techniques against airborne viruses for further real-world implementation. This study aimed to assess the inactivating effects of chemical substances on SARS-CoV-2 and influenza A virus in the air using an established evaluation system. A mixture containing SARS-CoV-2 and influenza A virus in diluted saliva was nebulized into the designed 1 m^3 chamber, and the virucidal effects of hypochlorous acid, chlorine dioxide, and ozone in the air samples at 23 ± 1 °C with 50 ± 5% relative humidity were determined using the plaque assay. Both viral infectivity titers decreased depending on chemical substance concentration and exposure time. The concentrations of hypochlorous acid, chlorine dioxide, and ozone in the air reached an approximately 2-log reduction of SARS-CoV-2 infectivity titer within 10 min at 0.02, 1.0, and 1.0 ppm, respectively. SARS-CoV-2 persisted in the air even under conditions where the influenza A virus was inactivated below the detection limits. These findings demonstrate that hypochlorous acid, chlorine dioxide, and ozone are effective in inactivating SARS-CoV-2 and influenza A virus in the air.

Keywords SARS-CoV-2 · Influenza A virus · Hypochlorous acid · Chlorine dioxide · Ozone · Air

Introduction

The World Health Organization declared the coronavirus disease 2019 (COVID-19) pandemic on March 11, 2020 (World Health Organization, 2020). Since then, the emergence of mutant strains of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) has been continuously reported (Chavda et al., 2022; Hill et al., 2022; Viana et al., 2022). The modes of SARS-CoV-2 transmission include contact, droplet, and aerosol transmission (Short & Cowling, 2023; Zhang et al., 2020); the corresponding virus control measures have been implemented for each transmission route. To prevent further increases in the number of COVID-19 cases, virus control technologies, which physically reduce or biochemically inactivate infectious viruses in the environment, have been extensively examined (Garg et al., 2023; Hu et al., 2021; Xiling et al., 2021). One of these infection control measures is the inactivation of airborne viruses, which spread from patients with COVID-19 by coughing and sneezing, to address aerosol transmission. The stability of viruses in the air or on the surface is influenced not only by the virus species but also by various environmental factors, such as temperature, humidity, and the suspension medium of the virus particles (van Doremalen et al., 2020; Kwon et al., 2021; Bushmaker et al. 2023; Haddrell et al., 2024). Accordingly, the inactivation effect of virus control techniques, such as chemical treatment, UV irradiation, and physical removal, may vary depending on the environmental factors in which the virus exists. Therefore, it is important to evaluate virus control techniques against airborne viruses using a suitable evaluation system to implement appropriate

Yasuo Imoto and Hidehito Matsui have equally contributed to this work.

✉ Hideaki Hanaki
hanaki@insti.kitasato-u.ac.jp

[1] Kobe Testing Center, The Japan Textile Products Quality and Technology Center, 5-7-3 Yamate-Dori, Chuo-Ku, Kobe, Hyogo 650-0011, Japan

[2] Ōmura Satoshi Memorial Institute, Kitasato University, 5-9-1 Shirokane, Minato-Ku, Tokyo 108-8641, Japan

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strategies in real-world situations. Previous studies have reported the virucidal effects of chemical substances on viral suspensions or virus-contaminated surfaces for SARS-CoV-2 and other viruses (Hakim et al., 2023; Kubo et al., 2024; Urushidani et al., 2022; Yano et al., 2020). However, the inactivating effects of these chemical substances on viruses existing in the air remain unclear. To establish effective infection control measures against aerosol-transmitted infections, it is essential to verify the effectiveness of these substances against airborne viruses.

This study aimed to investigate the inactivating effect of chemicals, such as hypochlorous acid, chlorine dioxide, and ozone, on viruses in the air. Using the developed evaluation system, the inactivation effects of these chemicals were simultaneously evaluated for SARS-CoV-2 and influenza A virus in the air under completely identical environmental conditions of temperature and relative humidity (RH) (23 ± 1 °C, 50 ± 5% RH), to simulate the real-world environment.

Materials and Methods

Preparation of Viral Samples

The SARS-CoV-2 strain 2019-nCoV/Japan/TY/WK-521/2020 was provided by the National Institute of Infectious Disease, Japan. Monolayer cell plates of VeroE6/TEMPRESS2 cells (JCRB1819) (JCRB Cell Bank, Osaka, Japan) were incubated with approximately 10^3 plaque-forming units (PFU)/mL of SARS-CoV-2 suspension (0.1 mL/well) at 37 °C under 5% CO_2 for 1.5 h for viral adsorption onto the cells. Further, 1 mL/well of Eagle's minimum essential medium (EMEM; Sigma-Aldrich, St. Louis, MO) was added to the plate and incubated at 37 °C under 5% CO_2 for 40 h. After crude purification by centrifugation at 1000×*g* for 15 min at 4 °C, the SARS-CoV-2 was collected by ultracentrifugation at 1,00,000×*g* for 1 h at 4 °C and resuspended in human saliva from pooled normal donors (Lee BioSolutions, Inc., Maryland Heights, MO) that had been previously diluted tenfold with sterile ultrapure water to reduce the viscosity for particle formation by spraying. The SARS-CoV-2 salivary suspension was adjusted to $1–5 \times 10^8$ PFU/mL.

For influenza A virus proliferation, Madin–Darby canine kidney (MDCK) cells (ATCC CCL-34; American Type Culture Collection, Manassas, VA, USA) were cultured to a monolayer in a 75 mL flask at 37 °C under 5% CO_2 for 3 days in EMEM containing 10% fetal bovine serum (FBS), and 0.06 mg/mL kanamycin sulfate (FUJIFILM Wako Pure Chemical Corp., Osaka, Japan). The cells were inoculated with a 1.0-mL suspension of influenza virus (ATCC VR-1678 strain; A/Hong Kong/8/68, H3N2), adjusted to approximately 10^3 PFU/mL, and incubated at 34 °C under 5% CO_2 for 1 h, for viral adsorption onto the cells. Subsequently, 20 mL of EMEM containing 1.5 ppm trypsin was added to the flask and incubated at 34 °C under 5% CO_2 for 2 days for influenza A virus multiplication. After crude purification by centrifugation at 1000×*g* for 15 min at 4 °C, the influenza A virus was collected by ultracentrifugation at 1,00,000×*g* for 1 h at 4 °C and resuspended in human saliva from pooled normal donors that had been previously diluted tenfold with sterile ultrapure water to reduce the viscosity for particle formation by spraying. The salivary suspension of the influenza A virus was adjusted to $1–5 \times 10^8$ PFU/mL. Finally, equal amounts of SARS-CoV-2 and influenza A virus suspensions were mixed to prepare the mixed test virus suspension.

Antiviral Test for Airborne Viruses

The evaluation system was a 1 m^3 chamber made of stainless steel with dimensions of 79 cm (length) × 113 cm (width) × 113 cm (height) and was equipped with a thermo-hygrometer, pass box, and grooves (Fig. 1). The BioSampler (SKC, Inc., Eighty Four, PA) as an impinger used for collecting air containing the virus was installed in the exhaust unit with a high-efficiency particulate air (HEPA) filter adjacent to the chamber. Additionally, for internal sterilization after the test, the chamber was equipped with ultraviolet lamps, an ozone generator, a chamber air recirculation unit through a HEPA filter, and a chemical removal unit with a HEPA filter and activated carbon. The evaluation system was located in a biosafety Level 3 facility.

The test procedure is illustrated in Fig. 2. First, 2 mL of the test virus mixed suspension containing SARS-CoV-2 and influenza A virus was nebulized using NE-C28 (OMRON Corporation, Kyoto, Japan) into the chamber with a stirring fan for 5 min at 23 ± 1 °C with 30 ± 5% RH. Next, 20 L of air inside the chamber was collected using a BioSampler into 20 mL phosphate-buffered saline (PBS) with 20 µM sodium thiosulfate at 12.5 L/min for 96 s as initial samples. Subsequently, aqueous solutions of the chemical substances were loaded into the ultrasonic humidifier and sprayed for 100 s at a rate of approximately 130 mL/h. The RH in the chamber was increased to 50 ± 5% RH, owing to spraying of the virus suspension and chemical substance solution, and was maintained throughout the test period. Immediately after spraying the chemical substances, 20 L of air was collected using the same method as that for the initial sample. After 5 and 10 min of stirring using a fan, 20 L of the air samples were collected. For the control test, purified water was sprayed instead of the chemical substances.

The chemical substances used in the tests included hypochlorous acid, chlorine dioxide, and ozone gas.

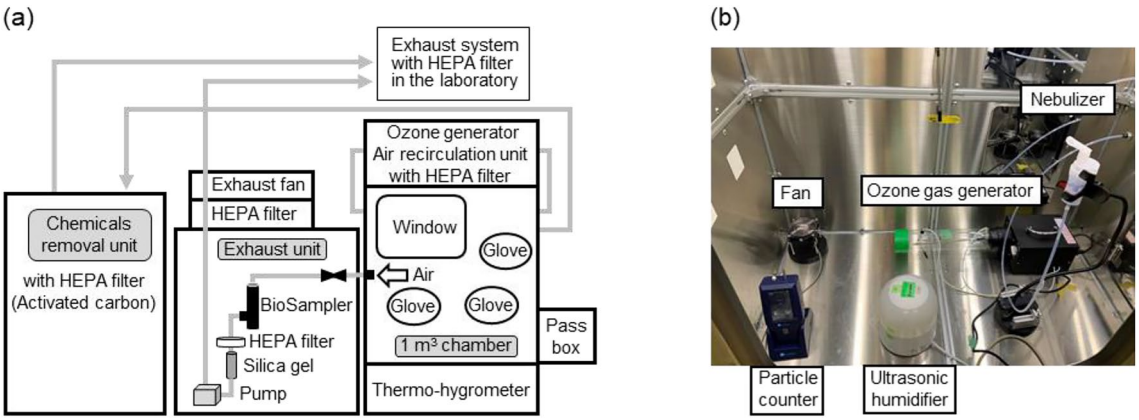

Fig. 1 System for evaluation of the inactivating effects of airborne viruses. The evaluation system was constructed with a 1 m^3 chamber, exhaust unit, and chemicals removal unit (**a**). The 1 m^3 chamber contained a nebulizer for spraying viruses, a fan, an ultrasonic humidifier for chemical substances, an ozone gas generator, and a particle counter (**b**)

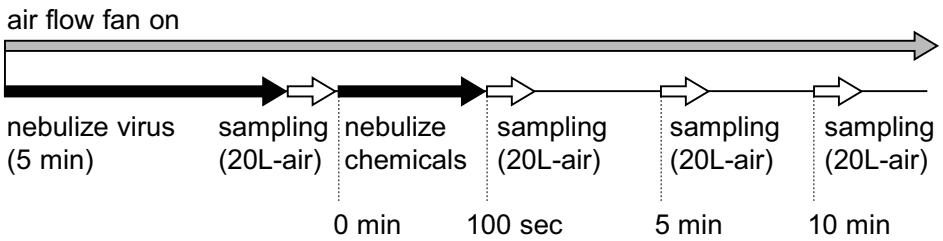

Fig. 2 Evaluation procedure for airborne virus inactivating effects. The test virus was nebulized for 5 min in the chamber, and the initial sampling of air was performed at 0 min. The evaluation chemicals were generated in a chamber maintained at 23 ± 1 °C and 50 ± 5% RH. Subsequently, 20 L of air was sampled at 100 s, 5 min, and 10 min

Spraying of hypochlorous acid water (Nipro Co., Ltd., Osaka Prefecture) at concentrations of 3 and 30 ppm into the chamber resulted in their concentrations of 0.002 ppm and 0.02 ppm, respectively, inside the chamber. Chlorine dioxide water (Taiko Pharmaceutical Co., Ltd., Osaka, Japan) was sprayed into the chamber, and its concentration was adjusted to achieve chlorine dioxide gas concentrations of 0.02, 0.1, and 1.0 ppm, respectively. The chlorine dioxide gas concentration was determined using a GD-70D instrument (RIKEN KEIKI Co., Ltd., Tokyo, Japan). Ozone gas was produced in the chamber using an ozone gas generator (Mitsubishi Heavy Industries, Ltd., Tokyo, Japan). The operating time of the ozone gas generator was adjusted to achieve ozone gas concentrations of 0.1, 0.3, and 1.0 ppm in the chamber, as confirmed using an ozone gas monitor OZG-EM-011 K (Applics Co., Ltd., Tokyo, Japan). Purified water was sprayed for 100 s to match the humidity in the chamber with the test conditions. Each assay was performed twice independently.

Measurement of Virus Infectivity Titer using a Plaque Assay

To accurately determine the infectivity titers of the viral mixture sample, we confirmed that in MDCK and VeroE6/TMPREE2, no interference was detected in plaque formation by both viruses, respectively. In the SARS-CoV-2 infectivity titer assay, the collected 20 L air samples in PBS with 20 μM sodium thiosulfate were diluted with 2% FBS-containing Dulbecco's modified Eagle medium. The diluted samples were inoculated into 10 wells of 6-well plates (0.1 mL each), and the viral infectivity titer per 1.0 mL of the test mixture was measured. The plate was incubated at 37 °C with 5% CO_2 for 1.5 h to adsorb the virus onto the cells. After washing the cells with EMEM, 3.0 mL of overlay medium containing 0.75% agar, 2% FBS, and 0.01% DEAE-dextran in EMEM was added to each well and incubated for 2 days. The cells in the wells were fixed with 1% glutaraldehyde for 1 h and then stained with 0.0375% methylene blue for plaque quantification. For

the influenza A virus infectivity titer assay, MDCK cells were cultured in 6-well plates in EMEM containing 10% FBS, 0.06 mg/mL kanamycin sulfate at 37 °C with 5% CO_2 for 3–5 days. After washing the cells with EMEM, 0.1 mL of the diluted samples were added. The plate was incubated at 34 °C with 5% CO_2 for 1 h to adsorb the virus onto the cells. The surface of the cultured cells was washed with EMEM once, and 3.0 mL of the overlay medium containing 0.75% agar, 1.5 ppm trypsin, and 0.01% DEAE-Dextran in EMEM was added and incubated at 34 °C with 5% CO_2 for 2 days. The cells were fixed with 1% glutaraldehyde for 1 h and stained with 0.0375% methylene blue for plaque quantification.

The virus inactivation effect was calculated using the following formula:

$$Virusinactivationeffect = (T_0 - T_t) - (C_0 - C_t)$$

where, T_0: Average infectivity titer ($\log_{10}$ PFU/20 L-air) at 0 min evaluating the chemical substances.

T_t: Average infectivity titer ($\log_{10}$ PFU/20 L-air) at sampling time for evaluating the chemical substances.

C_0: Average infectivity titer ($\log_{10}$ PFU/20 L air) at 0 min in the control test.

C_t: Average infectivity titer ($\log_{10}$ PFU/20 L air) at sampling time in the control test.

Measurement of SARS-CoV-2 RNA Using Quantitative Reverse Transcription Polymerase Chain Reaction

Each viral suspension was directly subjected to quantitative reverse transcription polymerase chain reaction (RT-qPCR) using the SARS-CoV-2 N1 gene detection kit (TOYOBO Co., Ltd., Osaka, Japan), according to the manufacturer's protocol. For the standard curve, a tenfold dilution series from 10^4 to 10^6 copies/mL of SARS-CoV-2 positive control RNA (Nihon Gene Research Laboratories, Inc., Miyagi, Japan) was used, and the copy number of SARS-CoV-2 RNA in each sample was calculated.

Results

A mixed sample of SARS-CoV-2 and influenza A virus in diluted saliva was nebulized in the chamber of the evaluation system, and the inactivating effects of hypochlorous acid, chlorine dioxide, and ozone on both the viruses in the air were evaluated over time using a plaque assay. In addition, the number of SARS-CoV-2 RNA copies in the collected air samples was measured using RT-qPCR. The virus inactivation effect of hypochlorous acid for SARS-CoV-2 at 0.002 ppm for 10 min was 0.72, and the effects at 0.02 ppm for 5 and 10 min were 2.22 and 2.17, respectively (Fig. 3a). For influenza A virus, the inactivation effect of hypochlorous acid at 0.002 ppm for 10 min was

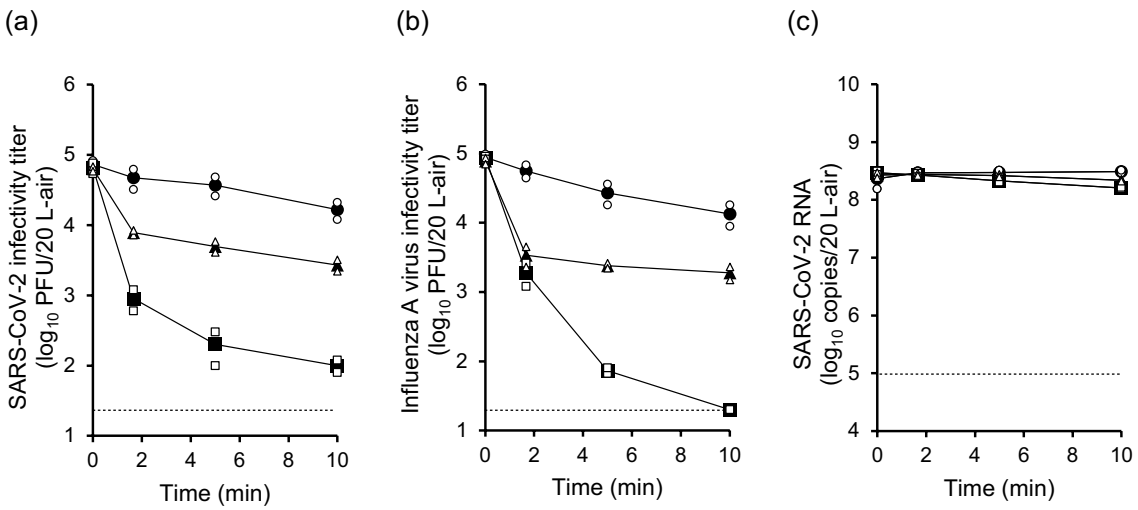

Fig. 3 Inactivating effect of hypochlorous acid on airborne severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and influenza A virus. Hypochlorous acid water was sprayed in the chamber at 0.002 ppm (△, ▲) and 0.02 ppm (□, ■). Purified water was used as the control (○, ●). The infectivity titers of SARS-CoV-2 and influenza A virus in air samples at 0 min, 100 s, 5 min, and 10 min were measured using a plaque assay (**a**, **b**). SARS-CoV-2 RNA in the air samples was quantified using quantitative reverse transcription polymerase chain reaction (RT-qPCR) (**c**). The experiments were performed independently twice; each data point is represented by open symbols, and the average data are represented by closed symbols. The dashed line indicates the detection limits of the plaque assay and RT-qPCR

0.80, and the effects at 0.02 ppm for 5 and 10 min were 2.56 and 2.82, respectively (Fig. 3b). The infectivity titer of influenza A virus at 0.02 ppm of hypochlorous acid for 10 min was lower than the detection limit of the plaque assay. Reduction in both the viral infectivity titers was observed within approximately one order of magnitude at 0.002 ppm of hypochlorous acid and two orders of magnitude at 0.02 ppm after more than 5 min of contact. In contrast, the viral RNA assay for SARS-CoV-2 using RT-qPCR showed no reduction in viral RNA in the air samples under all conditions (Fig. 3c).

Further, the inactivating effect of chlorine dioxide at 0.02, 0.1, and 1.0 ppm on viruses in air was evaluated. For SARS-CoV-2, the virus inactivation effects at chlorine dioxide concentrations of 0.02 and 0.1 ppm for 10 min were 0.20 and 0.21, respectively. The virus inactivation effect of 1.0 ppm chlorine dioxide on SARS-CoV-2 was 1.15 after 100 s contact and the infectivity titer of SARS-CoV-2 decreased over time, with the virus inactivation effects reaching 1.49 and 1.93 for 5 and 10 min, respectively (Fig. 4a). For influenza A virus, the virus inactivation effects at chlorine dioxide concentrations of 0.02 and 0.1 ppm were 0.77 and 1.43, respectively, at 10 min. The virus inactivation effects of 1.0 ppm chlorine dioxide for influenza A virus were 1.66, 2.11, and 2.84 for 100 s, 5 min, and 10 min, respectively (Fig. 4b). Chlorine dioxide at 1.0 ppm for 10 min reduced both viral infectivity titers by two orders of magnitude, and the infectivity titer of the influenza A virus was particularly low. In contrast, the assay results of SARS-CoV-2 RNA detection from air samples showed no reduction in viral RNA in any of the collected samples (Fig. 4c).

Furthermore, the inactivating effect of ozone gas at 0.1, 0.3, and 1.0 ppm on the airborne viruses was evaluated. For SARS-CoV-2, the inactivation effects at ozone gas concentrations of 0.1 and 0.3 ppm for 10 min were 0.42 and 0.89, respectively. The virus inactivation effects of 1.0 ppm ozone gas on SARS-CoV-2 were 2.11, 2.26, and 2.14 after 100 s, 5 min, and 10 min, respectively (Fig. 5a). For influenza A virus, the inactivation effect of ozone gas concentrations at 0.1 and 0.3 ppm for 10 min were 0.56 and 1.76, respectively. The virus inactivation effects of 1.0 ppm ozone gas for the influenza A virus were 1.78, 3.25, and 2.76 for 100 s, 5 min, and 10 min, respectively (Fig. 5b). Ozone gas at 1.0 ppm for more than 5 min reduced both viral infectivity titers by two orders of magnitude, with particularly low titers for the influenza A virus. Similar to the results for the tested hypochlorous acid and chlorine dioxide, the assay results for SARS-CoV-2 RNA detection from the air samples showed no reduction in viral RNA in any of the collected samples (Fig. 5c).

Discussion

To prevent the aerosol-based transmission of respiratory viruses, it is necessary to establish an effective method to inactivate the airborne viruses. Although the virucidal effects of chemical substances on viral suspensions or virus-attached surfaces have been evaluated, the inactivation effect for the airborne viruses, particularly for SARS-CoV-2 in the air, is limited. In this study, hypochlorous acid, chlorine dioxide, and ozone showed an inactivation effect on both

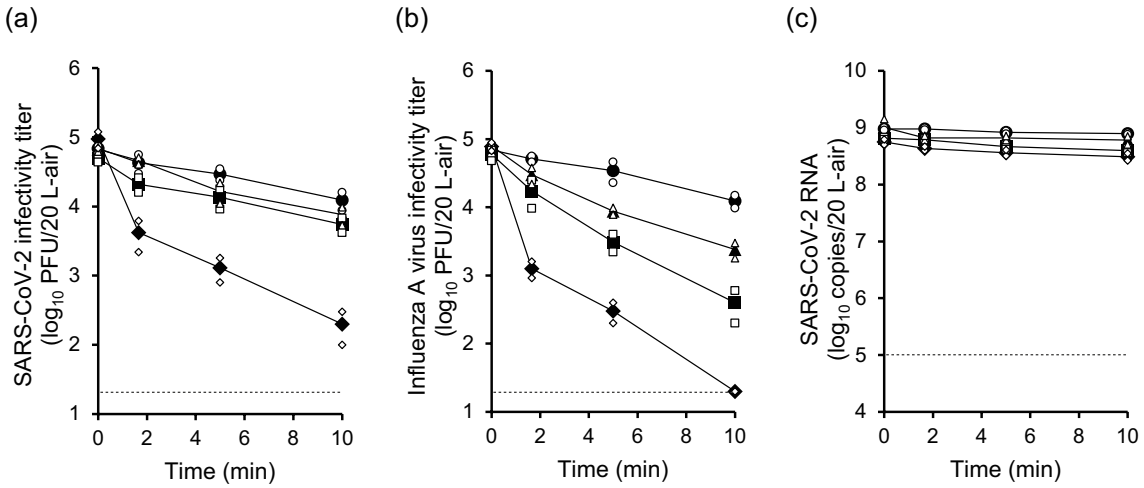

Fig. 4 Inactivating effect of chlorine dioxide on airborne SARS-CoV-2 and influenza A virus. Chlorine dioxide water was sprayed in the chamber at 0.02 ppm (△, ▲), 0.1 ppm (□, ■), and 1.0 ppm (◇, ◆). Purified water was used as the control (○, ●). The infectivity titers of SARS-CoV-2 and influenza A virus in air samples collected at 0 min, 100 s, 5 min, and 10 min were measured using a plaque assay (**a**, **b**). SARS-CoV-2 RNA in the air samples was quantified using RT-qPCR (**c**). The experiments were performed independently twice; each data point is represented by open symbols, and the average data are represented by closed symbols. The dashed line indicates the detection limits of the plaque assay and RT-qPCR

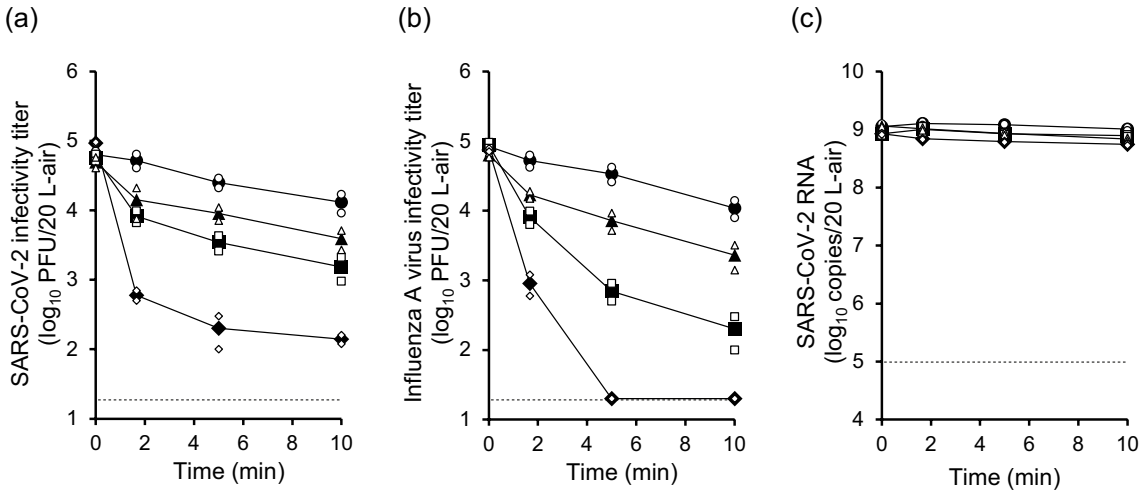

Fig. 5 Inactivating effect of ozone gas on airborne SARS-CoV-2 and influenza A virus. Ozone gas was produced in the chamber using an ozone gas generator at 0.1 ppm (△, ▲), 0.3 ppm (□, ■), and 1.0 ppm (◇, ◆). Purified water was used as the control (○, ●). The infectivity titers of SARS-CoV-2 and influenza A virus in air samples at 0 min, 100 s, 5 min, and 10 min were measured using a plaque assay (**a**, **b**). SARS-CoV-2 RNA in the air samples was quantified using RT-qPCR (**c**). The experiments were performed independently twice; each data point is represented by open symbols, and the average data are represented by closed symbols. The dashed line indicates the detection limits of the plaque assay and RT-qPCR

airborne SARS-CoV-2 and influenza A virus, depending on the concentration and exposure time, although the effective concentrations varied depending on the chemical substances. To achieve more than a 2-log reduction in viral infectivities, exposures of 0.02 ppm hypochlorous acid for more than 5 min, 1.0 ppm chlorine dioxide for 5 to over 10 min, and 1.0 ppm ozone for 100 s to 5 min were required. In a previous study on the inactivation of SARS-CoV-2 suspensions using aqueous ozone, viral titers decreased by over 1.8 $\log_{10}$ FFU/mL after 5 min of contact at 0.75 mg/L (Albert et al., 2021). Additionally, the inactivation effect of chlorine dioxide at 8 ppm for 10 s to 3 min achieved a 3 to 4 $\log_{10}$ $TCID_{50}$/mL reduction in viral suspensions (Hatanaka et al., 2021). These results from viral suspensions were comparable to the findings in the air samples of the present study. In contrast, hypochlorous acid water containing 0.02% FBS exhibited a virucidal effect, achieving a 5.3 $\log_{10}$ $TCID_{50}$/mL reduction at 10 ppm within 5 min, whereas a 1 ppm solution had no virucidal effect on SARS-CoV-2 (Kubo et al., 2024). The virucidal effect of hypochlorous acid differed significantly between suspension and air samples. The findings of this study revealed that although the stability of the tested SARS-CoV-2 and influenza A virus strains in the air under control conditions showed no significant difference, the infectivity titer of influenza A virus was reduced by the tested chemical substances to less than 20 PFU/20 L air of the detection limit within 10 min at the tested maximum concentration, and viable SARS-CoV-2 persisted under the same conditions. A previous study reported a higher stability of SARS-CoV-2 than that of the influenza A virus on plastic surfaces with fogging hypochlorous acid or hydrogen peroxide (Urushidani et al., 2022). In the air, SARS-CoV-2 may be more resistant to disinfectants than the influenza A virus.

In this study, the virucidal effect of chemical substances on SARS-CoV-2 was evaluated using the viral infectivity titer and viral RNA copy number. A reduction in the infectivity of their titer was observed when exposed to chemical substances, whereas the RNA copy number remained constant, and there was no reduction during the tested incubation time. This implies that there was no reduction due to the natural settling or physical adsorption of the nebulized virus particles on the chamber walls; rather, the tested viruses in the air were inactivated by the various chemical substances. Furthermore, it is speculated that viral inactivation within the concentration range used in this study may not be due to damage to the viral RNA but rather to denaturation of the viral envelope. Previous reports have shown that the main inactivation mechanisms of hypochlorous acid, chlorine dioxide, and ozone are based on viral lipid peroxidation and the subsequent lipid envelope and protein shell disruption (Ataei-Pirkooh et al., 2021; Block & Rowan, 2020; Ge et al., 2021).

The chemical substances evaluated in this study—ozone gas, chlorine dioxide, and hypochlorous acid—are well known to have harmful effects on humans when they exceed certain levels. They also have corrosive effects on materials such as iron, natural rubber, and nylon. The permissible exposure limits for ozone gas and chlorine dioxide are defined as 0.1 ppm each for 8 h/day (40 h/week) by the Occupational Safety and Health Administration

(OSHA) in the United States (The Occupational Safety & Health Administration, 2024). The data from this study indicate that achieving a 2-log reduction in virus inactivation within a short period (less than 10 min) would exceed the permissible exposure limits for ozone gas and chlorine dioxide. Therefore, the application of these chemicals may be limited in environmental spaces where humans are present. Although no permissible exposure limit has been defined for hypochlorous acid, the standard for chlorine gas was applied, as chlorine rapidly converts to hypochlorous acid on mucous membranes (Fukuzaki, 2023). The permissible exposure limit for chlorine gas is defined as 1 ppm for 8 h/day (40 h/week) by OSHA (The Occupational Safety & Health Administration, 2024). Consequently, the condition at 0.02 ppm, which showed a 2-log reduction in airborne SARS-CoV-2 and influenza virus A within 10 min, is considered an adaptable concentration for real-world settings where humans are present.

This study has some limitations. First, we evaluated the virucidal activities of hypochlorous acid, chlorine dioxide, and ozone against one strain each of SARS-CoV-2 and influenza A virus. There may be differences in susceptibility to virucidal agents among viral strains, particularly the emerging strains of SARS-CoV-2. Second, although the experiment was performed at 23 ± 1 °C and 50 ± 5% RH, which are typical ambient conditions, temperature and humidity influence the stability of the virus particles, and SARS-CoV-2 is more stable at lower temperatures and humidity levels on aerosol and nonporous surface (Biryukov et al., 2020; Haddrell et al., 2023). Furthermore, the virucidal activity of the evaluated chemical agents is dependent on humidity, and the inactivation effect is reduced, particularly under low-humidity conditions (Murata et al., 2021; Nishimura et al., 2017). Therefore, to validate the airborne virus inactivation effects of these chemical agents, further experiments at low and high humidity levels, along with the moderate humidity levels set in this study, are necessary.

In conclusion, the evaluated chemical agents fogging indicated concentration and time-dependent airborne virus inactivation effects on both viruses under ambient temperature and moderate humidity conditions. In actual living environments, the virus inactivation effects caused by the dispersion of chemical substances on airborne viruses are likely to vary depending on environmental factors such as the presence of humans, air circulation, degree of ventilation, and presence of household items such as wallpaper and sofas. However, we believe that the basic data obtained from this study will contribute to further investigations into infection control measures using chemical fogging for airborne viruses.

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Data Availability No datasets were generated or analysed during the current study.

Declarations

Conflict of interest The authors declare no competing interests.

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