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Prevention of COVID-19 infection in the delivery room by assessing smoke test visualization of exhaled air

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ABSTRACT

The principal route of the coronavirus disease 2019 (COVID-19) infection is through the inhalation of respiratory droplets and aerosols. To date, there are no reports on the control of aerosol-mediated infections during vaginal delivery. This study aimed to visualize the airflow in a delivery room and use this information to develop infection control measures. A tracheal intubation practice manikin was used for the experiment. Smoke was generated using fog liquid and a fog machine. Smoke was collected in a plastic bag connected to the lower pharynx of the manikin via a conduit. Exhaled airflow was visualized by irradiating exhaled smoke with a laser beam. We visualized the aerosol flow from the mouth and nose of the manikin by compressing a plastic bag filled with smoke. We performed a smoke test to check the expiratory flow and accordingly modified the delivery room in two ways: the head side of the delivery table was surrounded with a plastic sheet, and the exhaust pipe was passed through the vinyl sheet to the exhaust port. After these modifications, we managed 18 vaginal deliveries in parturient women with COVID-19, with no related infections among the babies or staff. With emerging infectious diseases, such as COVID-19, the route of infection may be unclear and determining appropriate infection control measures can be difficult. By considering the characteristics of the virus and implementing appropriate infection control measures, we can safely manage high-risk vaginal deliveries.

Key words: *COVID-19*, *Delivery room*, *Respiratory aerosols and droplets*, *Smoke test*

INTRODUCTION

The Coronavirus disease 2019 (COVID-19) is an infectious disease caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). This virus has caused a worldwide pandemic since the end of 2019 and has been designated as a Category 2 infectious disease under the Infectious Disease Law in Japan. The infection period is approximately between two days before onset to seven–ten days after onset[7,13], and the principal route of infection is through the inhalation of respiratory droplets and aerosols.

Aerosol is not a clearly defined term, but rather a general term for substance particles suspended in air. Aerosol infections have characteristics intermediate between those of conventional and droplet infections. To date, there are no reports on the control of aerosol-mediated infections during vaginal delivery. However, aerosols and droplets may be generated during vaginal delivery because parturient women may cry out or remove the surgical mask. Although vaginal delivery is not typically considered an aerosol-generating procedure, Mok et al.[8] characterized respiratory products during labor and vaginal delivery and stated that both labor and vaginal delivery may increase the rate of transmission of respiratory discharge. Therefore, obstetricians and midwives are at high risk of SARS-CoV-2 infection because they are exposed to droplets and aerosols throughout the vaginal delivery process, which can be of substantial durations. A nationwide survey conducted by the Japan Association of Obstetricians and Gynecologists reported that 3–4% of medical staff were infected while attending deliveries[3]. In Japan, although cesarean section has become a socially accepted delivery method during the COVID-19 pandemic[7], the surge in COVID-19 infections among pregnant women has led to particular considerations regarding vaginal delivery.

Infection control measures were administered at our hospital. Because of the longer exposure to aerosols during delivery compared to other aerosol-generating procedures, such as tracheal intubation[14], it was necessary to implement in-hospital infection control measures to ensure safe vaginal deliveries. As our hospital has no negative-pressure delivery room, we retrofitted a previously unused room and installed a delivery table and

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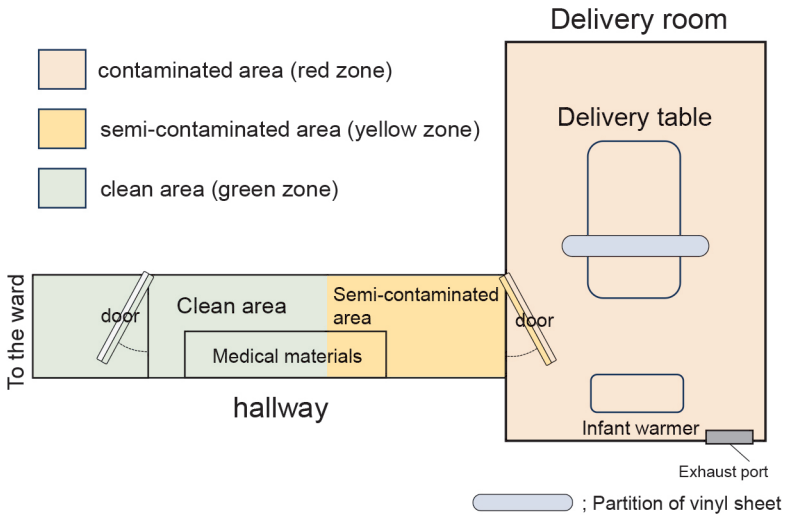

Fig. 1 The layout of the delivery room before the smoke test. The delivery room is separated from the ward by two doors. The hallway between the two doors is used as an antechamber with a clean area (green zone) and a semi-contaminated area (yellow zone). When the door is opened and closed, contaminated air flows into the antechamber.

an infant warmer. We sought to visualize the airflow in the room and use this information to develop infection control measures.

MATERIAL AND METHODS

i) Delivery room and infection control measures

We cleaned a room that had not been used before and set up a delivery table and an infant warmer. The delivery room was separated from the ward by two doors. The hallway between the two doors was used as an antechamber with a clean area (green zone) and a semi-contaminated area (yellow zone). There was no pressure difference because the delivery room was not a negative-pressure room; therefore, air from the room flowed out into the corridor used as an antechamber every time the door opened (Fig. 1). The room was equipped with mechanical ventilation and the air that entered from the air supply port on the ceiling was exhausted from a single exhaust port in the corner of the room. Mechanical ventilation was performed at a rate of three times/h, and the ventilation volume was 250 m^3/h.

As an infection control measure, a partition made of vinyl sheets was placed between the parturient woman and the medical staff. Therefore, direct exposure to the droplets was avoided (Fig. 2a). However, any aerosol from parturient women could reach the obstetricians, midwives, and babies along the airflow toward the exhaust port.

ii) Smoke test

A tracheal intubation practice manikin was used for the experiments. Smoke was generated using a fog liquid (FLG-5 Fog Liquid, Antari, Taiwan) and a fog machine (400 W portable fog machine, Tomshine, China). Smoke was collected in a plastic bag (70 L) connected to a conventional ventilator horse (30 cm in length) as a conduit. The other end of the conduit was connected to the distal end of the pharynx of the manikin to simulate the actual aerosol flow via the oral, nasal, and pharyngeal cavities. The exhaled airflow was visualized by irradiating the exhaled smoke with a laser beam (VH-30G, Danpon™, China) (Fig. 2b). By compressing the plastic bag with smoke, we visualized the aerosol flow from the mouth and nose of the manikin. We called this the “smoke test.”

The smoke test was conducted to answer the following two questions. First, whether the partitioning between parturient women and medical staff was effective. Second, whether the placement of the delivery table and infant warmer were appropriate.

RESULTS

The smoke test results are shown in Fig. 3. The manikin used for tracheal intubation was placed on a horizontal table (Fig. 3a). When no surgical mask was worn by the manikin, the exhaled air rose upward (Fig. 3a-i). However, when the surgical mask was worn correctly, the exhaled air did not rise but flowed through the gaps in the surgical mask (Fig. 3a-ii).

The delivery table was placed in a semi-sitting position, which is an angle commonly used during delivery. When the surgical mask was not worn and there was no partition, the exhaled air flowed toward the medical staff at the foot of the table (Fig. 3b-i). When there was a partition, the exhaled air hit the partition and flowed back toward the head of the manikin (Fig. 3b-ii), after which it spread to the surroundings.

When the surgical mask was worn correctly, the exhaled air flowed around the head of the manikin through the gaps in the mask (Fig. 3c-i). During delivery, a parturient woman is often unable to wear a surgical mask properly; therefore, we had the manikin wear a surgical mask with the nose exposed. Fig. 3c-ii shows how the exhaled air flowed over the surgical mask and toward the foot of the table.

As shown in Fig. 3c-i, when the manikin wore the surgical mask correctly, the exhaled air diffused toward the head, and the medical staff were not directly exposed to aerosols. However, the aerosols may remain suspended

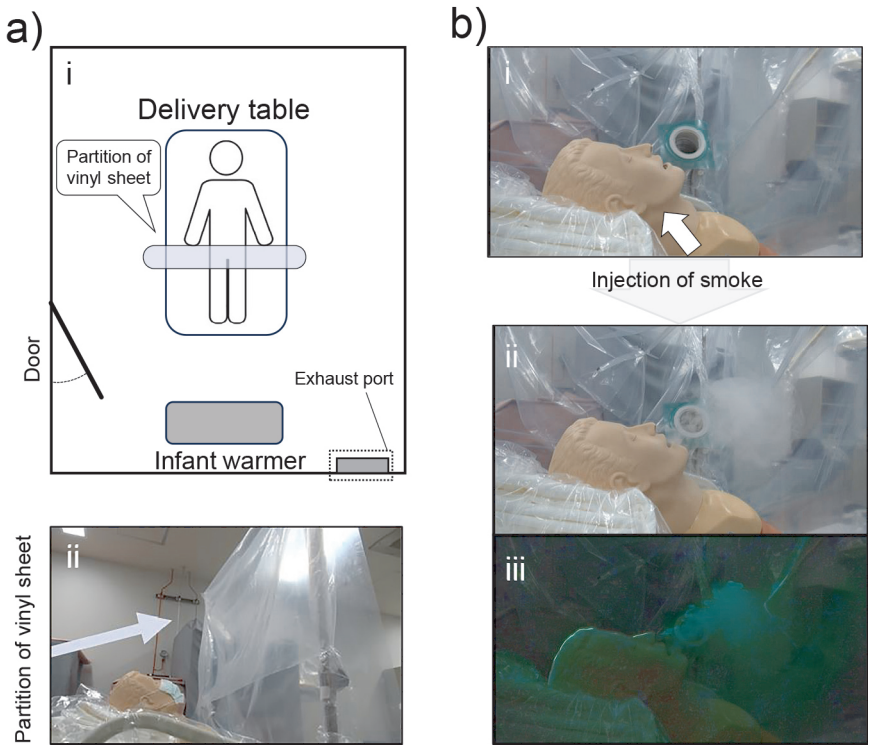

Fig. 2 Smoke test. (a) Delivery room before modification. The air entering the ceiling from the air supply port s exhausted from a single exhaust port at the corner of the room. A partition made of vinyl sheets is placed between the parturient woman and medical staff. (b) A plastic bag filled with smoke is connected to the pharynx of the manikin used for endotracheal intubation (b-i). All the smoke is expelled from the mouth and nose of the manikin by compressing it with a plastic bag (b-ii). A laser beam is used to visualize the flow of expired air (b-iii).

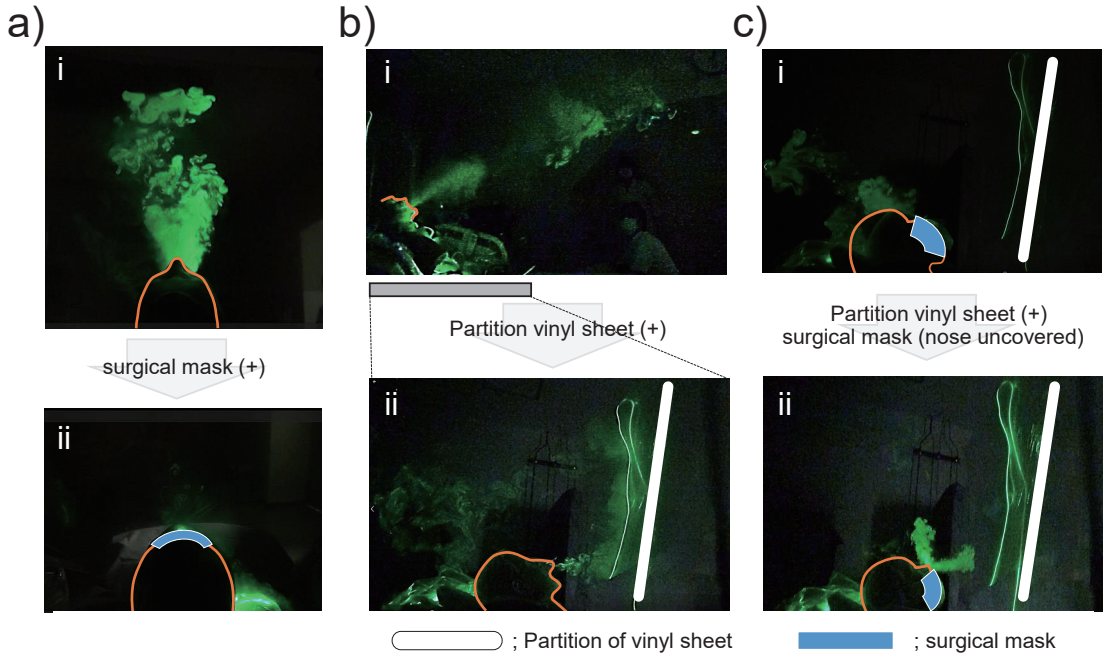

Fig. 3 Smoke test results. (a) The smoke test is performed on a horizontal table (a-i) without a surgical mask; and (a-ii) with the surgical mask worn correctly. (b) Simulating the delivery, the head is elevated in a semi-sitting position. The manikin is not wearing any surgical mask. (b-i) No partition; (b-ii) With partition. (c) Simulating the delivery, the head is elevated in a semi-sitting position. (c-i) The mannequin wears the surgical mask correctly; (c-ii) A surgical mask is worn with the nose exposed.

in the room. Prolonged labor exposes medical staff to the aerosol-laden air because the air in the delivery room flows from the parturient women toward the staff who stand near the exhaust port.

Altering the position of the exhaust port may reduce the risk of aerosol exposure to medical staff by changing the direction of the airflow and evacuating aerosols before they spread. Therefore, a plastic sheet was used to surround the head of the delivery table, and an exhaust pipe directed the air inside this space to the exhaust port.

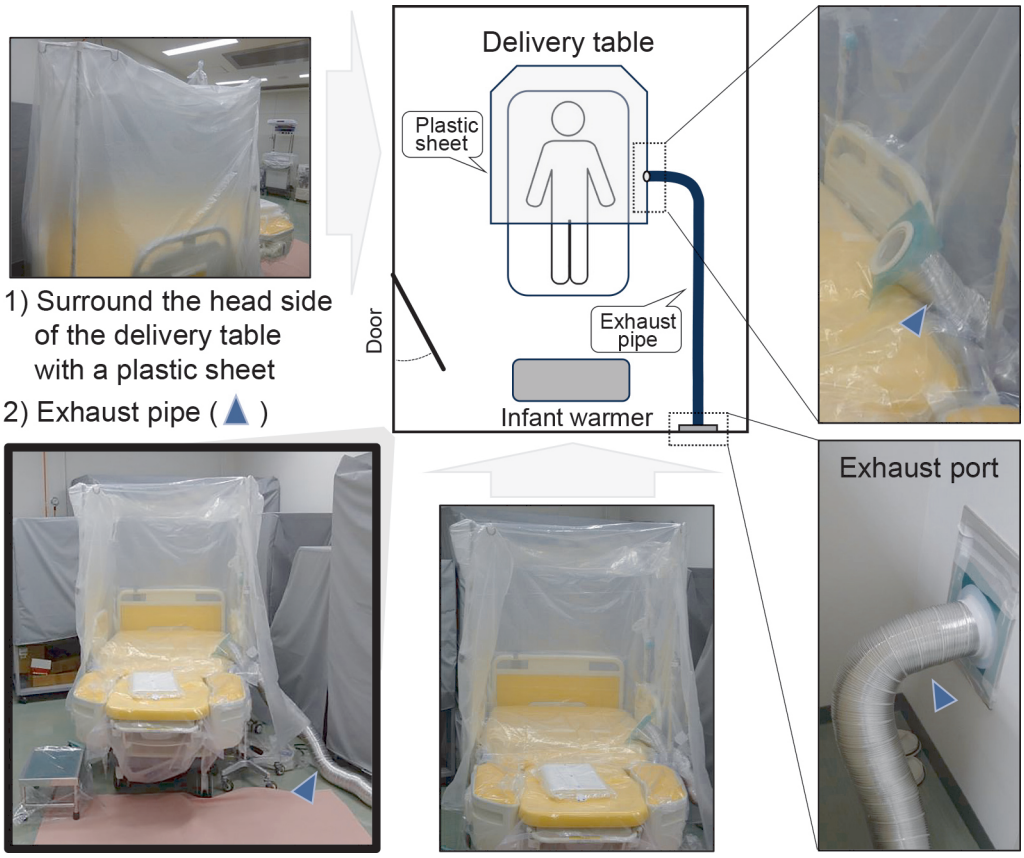

Fig. 4 Modified delivery room. This figure shows the delivery table, infant warmer, exhaust port, and exhaust pipe arrangements in the modified delivery room. The exhaust pipe is indicated by the blue triangle.

By exhausting aerosols through the exhaust pipe, the infant warmer installed near the exhaust port was not at a risk of aerosol exposure.

Fig. 4 shows the modified delivery room. Two improvements were made: the head side of the delivery table was surrounded by a plastic sheet and the exhaust pipe (blue arrow) was passed through the vinyl sheet to the exhaust port. We conducted the smoke test again (Fig. 5). The manikin did not wear a surgical mask. The exhaust pipe extend very close to the manikin's head. Most of the exhaled air was drawn into the exhaust pipe and did not spread within the vinyl sheet area (Fig. 5b). By evacuating the air before it could spread into the room the medical staff and the baby on the foot side of the partition could avoid direct exposure to the exhaled air conditioning aerosols. With these modifications, we managed 18 vaginal deliveries in parturient women with COVID-19, and there were no related infections.

DISCUSSION

The outbreaks of severe acute respiratory syndrome (SARS) in China in 2002 and the Middle East respiratory syndrome (MERS) epidemic in 2012 were similar to the SARS-CoV-2 outbreak; however, in those epidemics, it was not well understood whether coronaviruses were transmitted via aerosols. Fenizia et al.[2] concluded that there is a low likelihood of a baby getting infected with coronavirus during vaginal delivery. SARS-CoV-2 has rarely been detected in vaginal discharge; therefore, the possibility of the baby being infected in the birth canal during vaginal delivery is low. However, the study did not consider that coronaviruses are transmitted via aerosols. There have been many reports[2,9] of viral transmission during vaginal delivery by parturient women infected with SARS-CoV, MERS-CoV, and SARS-CoV-2. However, there have been no reports discussing the infection of babies or medical staff via aerosols.

The coronavirus disease (COVID-19) pandemic has continued since the first case was reported in Japan in early 2020. In response, the Japanese Ministry of Health, Labour, and Welfare (MHLW) COVID-19 guideline version 4.1[7] provides its recommendations for the mode of delivery as follows: "Depending on the state of infection, cesarean section is allowed as a primary mode of delivery; however, in some multipara, vaginal delivery is rapid, and thus the mode of delivery is determined at the discretion of the attending obstetrician." In other countries, cesarean sections are not commonly recommended[1,11]. In Japan, the number of deliveries per hospital is small, and the number of staff is also often small; therefore, local general hospitals are often responsible for the deliveries of parturient women with COVID-19. Our hospital originally intended to treat pregnant women with severe symptoms; however, owing to the spread of the infection, it took on the role of a regional perinatal maternal and child medical center to protect local obstetricians and gynecologists. Initially, our hospital recommended cesarean delivery as the common delivery mode; however, partly because of the rapid

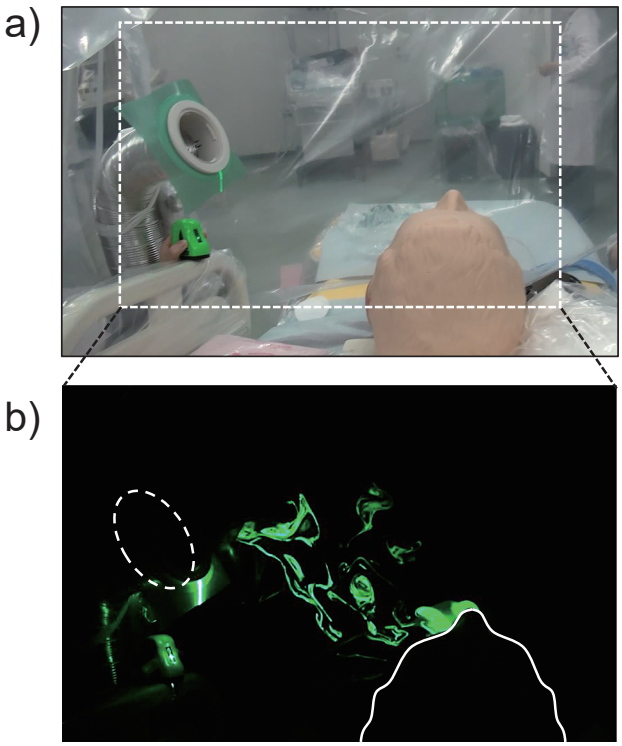

Fig. 5 Smoke test conducted on the modified delivery table. (a) Setting up the protective system. A plastic sheet surrounds the head side of the delivery table. The exhaust pipe is extended very close to the head of the manikin and passed through the vinyl sheet to the exhaust port. Simulating delivery, the head is elevated to a semi-sitting position. The manikin is not wearing a surgical mask. (b) Smoke test. The outline of the manikin's head is indicated with a white line, and the intake of the exhaust pipe is indicated with a white dot line.

increase in the number of infected people during the seventh COVID-19 wave, we began to permit vaginal delivery. Revised MHLW guidelines (ver. 7.2) state that, "The mode of delivery is determined individually by the attending obstetrician, giving due consideration to the safety of the parturient women and baby and medical staff, and the maintenance of the medical system."[10)]

Aerosols are intermediate-sized liquid particles of approximately 5 μm that have properties that are intermediate between those of droplets and droplet nuclei. Aerosols do not drop to the ground immediately, but gradually settle after drifting for 1–2 h. As surgical masks do not prevent the inhalation of aerosols, medical staff should wear high-performance masks such as N95 masks[14)]. Ueki et al.[12)] investigated the appropriate use of masks and their protective effects against the airborne transmission of SARS-CoV-2. The authors found that N95 masks are less protective if the mask is not in close contact with the face and that a certain number of SARS-CoV-2 particles will penetrate the mask even if the gaps are completely sealed. For individuals with normal immunity, the establishment of an infection depends on the amount and virulence of the virus entering the body. To prevent infection, it is important to reduce the concentration of SARS-CoV-2 in the air. An air ventilation rate of 12 times/h or greater is required to effectively prevent airborne infections, but this rate should be 2–12 times/h to protect against aerosol infections[4)]. The greater the air turnover, the faster the air in the room is replaced and airborne aerosols are removed.

During vaginal delivery, parturient women may cry, generating aerosols. The mask is often removed owing to heat, and the generated aerosols float in the air, eventually becoming droplet nuclei and spreading. The average duration of labor s 12–16 h for primiparous women and 5–8 h for parous women[6)]. The involvement of a medical professional is essential from the latter half of the first stage of labor to the second stage of labor. Therefore, it is important for medical personnel to protect themselves from infection. Because of the longer exposure to aerosols during delivery compared with other aerosol-generating procedures, such as tracheal intubation[14)], it is necessary to implement in-hospital infection control measures to ensure safe vaginal deliveries.

The Japan Association of Obstetricians and Gynecologists recommends that medical staff wear an N95 mask, face shield or goggles, cap, gown, and disposable gloves to protect against infection, because parturient women generate aerosols through heavy breathing and bearing-down efforts that are necessary during delivery. The association recommends ventilation as an important countermeasure against aerosol infection, and that air be transported outside the facility via mechanical ventilation and open windows[5)]. Our hospital does not have a negative-pressure delivery room; therefore, we used a spare room for the vaginal delivery of parturient women with COVID-19. The room was mechanically ventilated to exhaust air from outside the hospital. Air entering from the air supply port on the ceiling of the room flows toward the sole exhaust port located in a corner of the room where the obstetricians stand. The ventilation frequency was 3 times/h, which is not particularly high.

We conducted a smoke test and used the results to implement infection control measures in a delivery room. We thought that having a parturient woman wear a surgical mask would weaken and control the direction of exhaled air. Ueki et al.[12)] found that placing a mask on a manikin that ejected aerosols significantly reduced the volume of the aerosols inhaled by the manikin. These results indicated that when an infected person wears a mask, the exposure for others is effectively reduced. These findings are consistent with our smoke test results, and one of the infection control measures we implemented at our center was to ensure that parturient women wore surgical masks as correctly as possible.

To reduce the risk to medical staff's exposure to air-containing aerosols, we surrounded the head side of the delivery table with a vinyl sheet and guided the air inside this space through an exhaust pipe to the exhaust port. By visualizing the flow of exhaled air in an actual delivery room, we determined practical infection control measures. During labor, parturient women are often not stationary on the delivery table, and most of their exhaled air is not sucked into the exhaust pipe, as in the smoke test. Although there is a vinyl barrier, it is not sealed; therefore, it is possible that parturient women's exhaled breath containing aerosols could spread to the

surroundings through gaps in the vinyl sheet and be inhaled by medical personnel.

After implementing these modifications, we treated 18 parturient women with COVID-19 who underwent vaginal delivery. The average time from delivery room entry to delivery was 3 h, with a midwife present for up to 10 h. There were no cases of SARS-CoV-2 transmission to the babies or medical staff, which could be attributed to vaginal deliveries. A nationwide survey conducted by the Japan Association of Obstetricians and Gynecologists reported that 3–4% of medical staff were infected while attending deliveries[3], suggesting that the measures we took may have been effective. For this emergency, we installed a duct to efficiently reduce the exposure of staff to aerosols, and the delivery room did not have negative pressure; therefore, we could not prevent aerosols from spreading outside the room. Planned ventilation systems should be installed in the future.

CONCLUSION

Based on the knowledge obtained from our smoke test, we modified our center's delivery room to safely handle vaginal delivery. Although vaginal delivery carries an increased risk of aerosol infection, we observed no cases of SARS-CoV-2 transmission to babies or medical staff after the implementation of these modifications. In the future, novel infectious diseases such as COVID-19 may continue to emerge. Therefore, it is necessary to implement infection control measures in accordance with the characteristics of the virus.

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Disclosure statement

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