Original Article

New applications of a portable isolation hood for use in several settings and as a clean hood

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Background: We previously reported that we developed a compact and portable isolation hood that covers the top half of a patient sitting or lying in bed. The negative pressure inside the hood is generated by a fan-filter-unit (FFU) through which infectious aerosols from a patient are filtered. The outside area is kept clean which decreases the risk of nosocomial infections in hospital wards. We tried new applications of the hood.

Methods: The negative pressure hood was newly applied in an intensive care unit (ICU) as a place where a staff performs the practice of suctioning that generates much aerosol from the patient, as well as a waiting space for patients. Furthermore, the possibility that the hood can be converted to a positive pressure hood as a clean hood by switching the airflow direction of FFU was assessed. The cleaning efficacy of the inside of the hood was tested using an aerosolized cultured influenza virus tracer and an optimal airflow rate was determined according to the test results.

Results: The hood, named Barrihood, was found to be competent to be used (I) for tracheal suctioning in ICU, (II) as a waiting space for a child in a nursery who suddenly showed symptoms of the disease and waiting to be picked-up by the guardian, and (III) as a waiting space in a special outpatient clinic in a hospital for COVID-19 suspected cases to prevent dissemination of airborne pathogens. The positive pressure hood was also competent in keeping clean air quality that meets the standard class 100 of NASA's bio-clean room category.

Conclusions: The proposed new applications will broaden the range of the hood's usage. The isolation hood could be useful in many settings to protect people outside the hood from a patient inside, or to protect an individual inside from air particles outside the hood, such as airborne pathogens, allergens, or hazardous particulate matter like PM2.5.

Keywords: Infection control; airborne transmission; isolation hood; negative pressure; positive pressure

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Introduction

In every winter in the temperate zone as well as in a pandemic situation, hospitals are often overflowed with influenza patients and beds in wards are occupied by these patients. Such situations are inevitably associated with a risk of nosocomial airborne infections (1-4). It is the same with the epidemic of exotic contagious respiratory illness like SARS, MERS, and COVID-19 (5-7).

Such a risk increases in a place like a ward room with multiple numbers of beds or a renal dialysis facility, where many patients are cared for simultaneously in a narrow, closed space, since the virus is usually spread through airborne mists from sneezing, coughing and even from

breathing of the patient (8-12).

Physical interventions such as isolation and/or cohort nursing can help to reduce nosocomial transmission (13), although few hospitals have sufficient individual patient isolation rooms available—even fewer with negative pressure ventilation capability (14). Personal protective equipment (PPE) such as face masks (15,16), and increasing ventilation rates (i.e., air-exchanges per hour, ACH) (17-19), with or without stand-alone room air filtration units or air-cleaners (electronic fan-HEPA-filter units, FFUs) can also be employed (20).

However, these methodologies have their own disadvantages. Long-time mask wearing leads to poor quality of life (QoL) for both influenza and non-influenza patients; frequent ventilation of the room air in the winter season is not practical in the temperate area; high-performance is required for air cleaners to filter enough amount of room air compared with the total room air volume, which leads to frequent ventilation to be practically competent for prevention of airborne transmissions.

To resolve those issues, several products that put a patient in a closed space were manufactured for efficient isolation: e.g., a large and heavy, negative-pressure chamber with an FFU, which looked almost the same as a small room, or products with a simple, large FFU panel placed at the head side of a patient's bed. However, they have disadvantages in portability and more importantly, did not provide scientific validity for controlling airborne viruses that are supported by experimental data.

Thus, we proposed a personal, easily portable hood system that included a small fan-filter air-extraction system that covers the top half a patient sitting or lying in bed (21).

It provides good QoL for the patient with low cost, is compact and light enough for high portability for practical use in clinical settings, and above all, is supported with scientific data on the containment or removal of airborne pathogens based on experimental data.

After completing development of the hood with the original idea, we tried other new applications of the hood to cope with the following issues: whether the hood could be applicable for (I) use in ICU where a nurse to perform tracheal suctioning that generates much aerosol from the patient, a risky procedure among clinical practice (22); (II) use in the special outpatient clinic in a hospital for COVID-19 suspected cases without good ventilation, to prevent dissemination of airborne pathogen in its crowded waiting room and (III) isolation of a child in a nursery who suddenly showed influenza-like symptoms and waiting for pick-up by the guardian.

In addition, we explored the possibility that the hood could be easily changed to the positive pressure hood by using its basic structure to convert it to a clean booth by changing the direction of the airflow of the FFU. This is done by reversing its setting, which brings clean air to the inside through the FFU.

Methods

The hood

The details of the structure of the hood named Barrihood, were described in the previous paper (21) In short, it had dimensions height 172 cm, width 97 cm, length 38 cm, constructed out of lightweight pipes, transparent plastic curtains, and an FFU which was easily assembled on the pipe frame by a single person. It is operated on AC power and is warranted to run for at least 1,000 cumulative hours.

Physical analyses

The air speed was measured using an air flow meter, model 6141, KANOMAX Japan Inc. (Osaka, Japan). The air flow rate was obtained from the formula, "air speed x opening area". The positive pressure inside the hood was measured with a fine differential pressure gauge, DPC-500N12, Okano Works. Ltd. (Osaka, Japan).

Airborne particle experiments for positive pressure hood

Saline (1 wt%) was atomized for 2 s with a nebulizer (NE-C28, Omron Healthcare Co., Ltd., Kyoto, Japan) set outside the hood in 25 m^3 chamber. Thereafter, particle concentration in the air was measured for five particle size-ranges from 0.3 to 5.0 μm with a Laser particle counter (KR-12A, Rion, Tokyo) both inside and outside the hood.

Experiments using airborne virus

Details of the chamber, virus and airborne experiments using atomized influenza virus fluid were described in the previous report (21). In short, the double enclosure system of a sealed chamber of 14.4 m^3 equipped with FFUs to remove the airborne virus in a short time was placed in a secondary negative-pressure clean room with a larger space-size. The temperature and relative humidity in the chamber were controlled at 21–22 ℃ and about 30%, respectively.

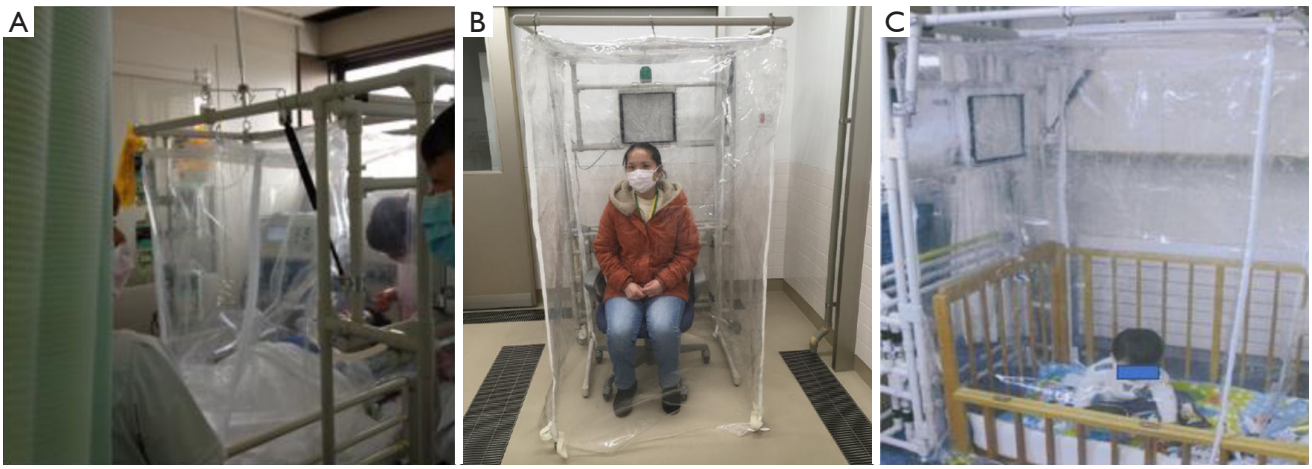

Figure 1 Proposed new applications. (A) Use in ICU. The hood was set on the lateral side of the bed. The hood contained a respiratory tubing system, and a nurse was performing the suctioning from a patient through a window of two-way zipper in the side curtain; (B) use as an isolation hood for a COVID-19 suspected patient waiting for medical check in the special out-patient clinic for respiratory infectious diseases; (C) isolation hood for a small child in a nursery facility. ICU, intensive care unit.

The difference in viral concentration between the inside and the outside the hood was measured using influenza virus A/Aichi/2/68 (H3N2) grown in the allantoic cavity of fertilized chicken eggs as described previously (21). Collection of the airborne virus was done using an air sampler and a gelatin membrane filter (MD8 AirScan Sartorius AG, Göttingen, Germany) followed by dissolving the membrane in 10 mL of culture medium. The medium was subjected to a conventional plaque assay using Madin-Darby canine kidney cells (23).

Ethics approval

The experiments were approved by the Ethics Committee of Sendai National Hospital (IRB NO.: 17-2). The study conformed to the provisions of the Declaration of Helsinki (as revised in 2013), and conducted in a strict biosafety facility, with safety procedures of frequent monitoring of the airborne particle counts of the working environment followed by air cleaning using FFUs.

Results

New applications of the original, negative pressure hood

The hood had been used in the general ward for isolation of seasonal influenza patients (21), and several requests came from the ICU to be used for an influenza patient because several beds were occupied by patients with illnesses other than influenza. The main concern then was whether or not the setting of the mechanical ventilator and practice of tracheal suctioning was possible while setting the hood to the bed without difficulty. It was resolved by using the revised hood with side curtains having two-way zippers, which can create an opening. The hood was set on the lateral side of the bed over the head, and tubes from the ventilator were extended to be able to reach the patient through the window, and the nurse can do suctioning also through the window (*Figure 1A*).

Second, we tried to apply our hood to prevent dissemination of airborne pathogen in a crowded waiting room. Due to the shortage of isolation facilities during the SARS epidemic in 2003, fast-track ventilation strategies for dealing with patient surges was tried in affected countries (24). The same situation was expected in the special outpatient clinic in our hospital for COVID-19 suspected cases.

We used the negative pressure hood set without bed to isolate a suspected case sitting on a chair inside the hood with curtains that reached the floor (*Figure 1B*).

Physical and biophysical experiments for validation of the hood to be used as a waiting hood

Containment of the virus inside the hood was experimentally confirmed in two ways: physically, the air pressures inside and outside of the waiting hood were measured and air pressure inside was calculated as −0.37 Pa. Experiments

Table 1 Amount of active virus collected from the air (pfu)

Hood	Time after virus atomization (min)	
	0*	20
Without hood	8.0×10^5	4.3×10^4
With hood		
Inside	1.7×10^5	3.0×10^3
Outside	**	**

*, collection for 1 min after atomization of the viral fluid for 3 min while the fan-filter-unit (FFU) was active; **, less than detection limit of 33 pfu.

using active influenza virus were the same as previously done with the original negative pressure Barrihood (21).

Aerosol containment experiments for the waiting hood use was performed as follows: the virus fluid of about 10^{8-9} plaque forming unit was atomized in the hood in the presence of an active FFU of rated airflow rate 0.42 m^3/min. At 0 and 20 min after switching on the FFU, the mists inside and outside the hood were sampled with air for 3 min, followed by titration of the active virus. The virus atomized in the hood did not leak outside the hood using the rated flow of the negative pressure-use (0.42 m^3/min) in the FFU (*Table 1*).

Third, two nursery schools consulted us whether the hood could be applied to children for their temporary isolation when any of them suddenly showed influenza-like symptom(s) while attending the school and waiting to be picked-up by their guardian. The hood has enough space for a small child to stay inside. A concern was whether children could sit there without problem. We just tried and, consequently, a child in a nursery could stay for at least one hour playing by himself with toys, without any trouble. (*Figure 1C*).

Physical and biophysical experiments for validation of the hood to be used as a positive-pressure hood

The hood was converted to be used as a positive-pressure hood, as well. It is for use as a clean hood to protect an immunologically incompetent person like a patient after chemotherapy or an individual with respiratory susceptibility to environmental hazardous airborne particles like PM2.5 or allergens like pollen. Theoretically, the hood is easily converted between negative and positive pressure uses because the FFU airflow is reversible. By changing the direction of the setting, the positive pressure use brings clean air to the inside through the FFU, from the contaminated outside air. The conversion can be done by a single non-professional person in 10 minutes.

The inside pressure, airflow velocity at the entrance, and airflow rate of the positive pressure use was 0.26 Pa, 0.1 m/s, 0.39 m^3/min, respectively.

Analyses using airborne fine particles generated from saline and viral fluid

The laser particle counters were set outside and inside and experiments using FFU with various airflow rates to monitor the particle counts were conducted after atomization of the saline. As a result, the particle count of size-level more than 0.3 μm decreased drastically to 4–21/cf^3 (140–700/m^3) with airflow rate at least 0.19 m^3/min within 15 min after switching on the FFU (*Figure 2*), which physiologically qualified for the standards of a bio-clean room class 100 of NHB-5340-2, NASA and the class 4 for particles sized over 0.5 μm of ISO.

The experiment using atomized saline or active virus fluid with the hood running with a flowrate of 0.39 m^3/min showed that concentrations of saline aerosol particles of every size were reduced to the minimum levels (*Figure 3*) and viral concentration was also confirmed to be reduced to less than the detection-limit level (*Figure 4*).

Thus, we suggest that the positive-pressure hood could be applied for individuals to be protected from contaminated air as a portable semi-clean space.

Discussion

We suggested applications of the Barrihood other than as a simple isolation hood that covers the upper body of a patient on a bed that we reported previously. Firstly, it will

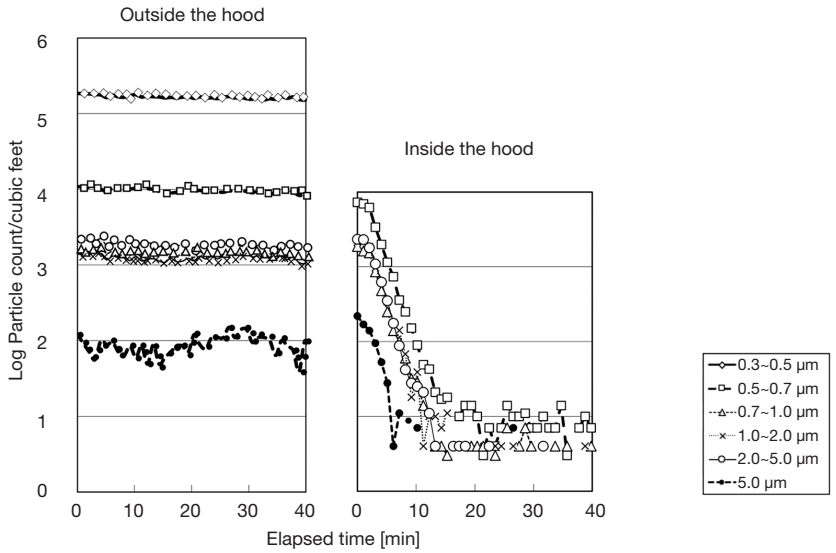

Figure 2 Concentration of airborne particles with size greater than 0.3 μm, inside and outside the positive-pressure hood with the FFU switched on with airflow rate 0.19 m^3/min. Saline was atomized outside the hood and airborne particle concentrations of the air inside and outside the hood were measured at several time intervals after the atomization.

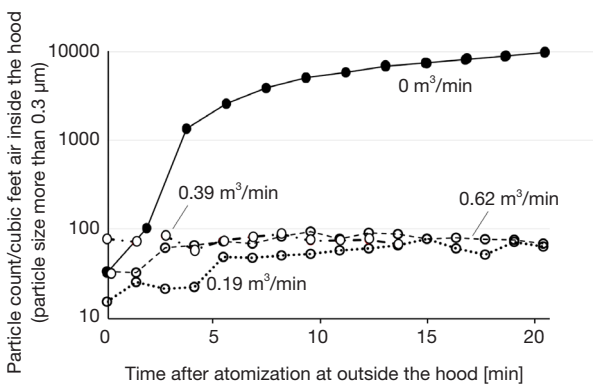

Figure 3 Time course of concentration of airborne particles of various sizes of saline mist inside the hood after atomization at the outside under active fan-filter-unit (FFU) with various airflow rates, 0.42 m^3/min.

be useful for isolation of a patient with COVID-19, as well as those with respiratory distress who requires respirator in a bed in ICU without negative pressure function, as has been introduced in our case with influenza. Secondly, it will be also useful for temporary isolation of a COVID-19 suspected out-patient at the waiting area of a special out-patient clinic, with only its curtains rolled-down to the floor and a chair inside. Thirdly, for isolation of a younger child without becoming uneasy in it; the hood size is adequate for children, not so broad but not so narrow and the curtain is transparent. The child feels no fear inside the space, while teachers are working near. These varying applications might be possible because the hood is lightweight, portable, and quick and easy to set-up.

Lastly, another application of the hood is the positive-pressure use. This way of usage would be applicable to many settings: for immunocompromised patients with leukemia or other cancers who return from a heavy-duty clean room after completing chemotherapy, or after receiving immunosuppressing agents for organ transplantation to avoid airborne microbes that cause opportunistic infections. For such high-risk patients in general, the heavy-duty clean room is used even after completing therapy, but such facilities are not available for many patients at once in most settings. The hood would be useful as a second-line clean environment after patients successfully passed the dangerous phase of their illness. In addition, the hood can be applied for individuals susceptible to PM2.5 particles or airborne allergens. It will be a sanctuary for them to avoid pollens or house dusts. They can stay safe inside the hood with better QoL without wearing a stifling, high performance face mask.

Conclusions

The Barrihood is applicable not only in the general hospital ward but also in ICU and a special out-patient clinic for

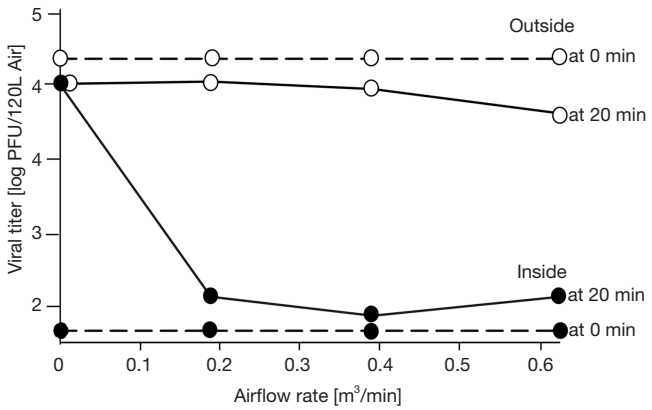

Figure 4 Viral titers in the sampled air collected inside and outside the positive-pressure hood at 0 and 20 min after atomization of the viral fluid outside the hood under active FFU with various airflow rates. Open circle, outside the hood; solid circle, inside the hood. Solid line, 20 min; broken line 0 min. FFU, fan-filter-unit.

isolation of respiratory contagious disease, as well as in a nursery or daycare facility settings. It can be used as a clean hood for an individual to be protected from microbes or other airborne particles. All of these applications are possible because of its mobile feature. The utility of the hood is supported by laboratory evidence and it will be strengthened by more clinical experience.

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Footnote

Data Sharing Statement: Available at http://dx.doi.org/10.21037/jtd-20-1211

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at http://dx.doi.org/10.21037/jtd-20-1211). SS is a retired ex-employee of Takasago Thermal Engineering Co. LTD. Japan worked as a technical expert. SS was retired three years ago and he has no right of the intellectual property on the Barrihood and does not get any reward from the company on it. The other authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The experiments were approved by the Ethics Committee of Sendai National Hospital (IRB NO.: 17-2). The study conformed to the provisions of the Declaration of Helsinki (as revised in 2013). Informed consent was waived due to the nature of the study.

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