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A NEWLY DEVELOPED CLEAN HOOD FOR ISOLATION OF PATIENTS THOUGHT TO HAVE AIRBORNE INFECTIOUS DISEASES

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Abstract
A new medical clean hood was developed for isolation of patients thought to have airborne diseases, such as pandemic influenza and the like. The hood is intended to be used in a ward where many patients are treated simultaneously in the same closed airspace such as a dialysis facility, in order to prevent cross infection of other patients by the potentially infected patient. The hood consists of foldaway framework, a fan High Efficiency Particulate Air Filter (HEPA) unit, and transparent polypropylene curtains. The patient is treated inside the hood, and airborne microbes from coughing or sneezing by the patient are contained inside the hood, and the air containing microbes finally passes through the fan HEPA unit to be released outside the hood as clean air.

1. Introduction
The Sendai Medical Center and Takasago Thermal Engineering Co., Ltd. jointly developed the Barrihood clean booth for protecting patients in a room from infection by other patients in the same room who are thought to be infected with a new strain of influenza during an epidemic. This booth can be used to isolate individual patients. This paper presents an outline of the technology.

2. Purpose of Development
In winter, hospitals are often required to accommodate influenza patients, even if only temporarily. However, if for example a patient is urgently hospitalized with influenza during the night or a holiday and must be accommodated in a general ward because a private room is not available, or in a dialysis treatment facility with several beds, there is a high risk of infecting surrounding patients.
In this research, we developed a simple negative pressure hood with the aim of preventing the spread of influenza by airborne particles from coughing and so on by influenza patients who are accommodated in a ward with other uninfected patients. (Figures 1 and 2)

3. The Behavior of Human Cough Particles
The particles generated when humans cough are a few microns in size, and their behavior is exactly the same as the air current resulting from exhaled breath. However, visualizing and analyzing these behaviors is very difficult. Therefore we substituted these particles with the sub micron particles of cigarette smoke

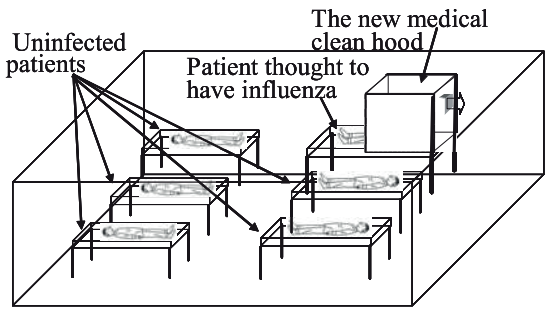


Figure 1 The new medical clean hood Barrihood for isolation of patients thought to have an airborne infectious disease.

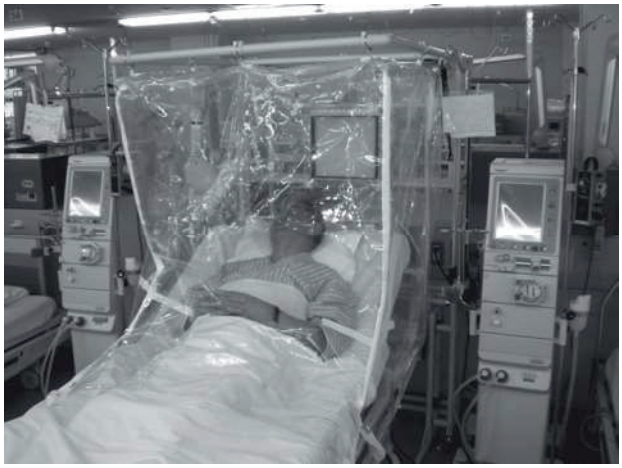
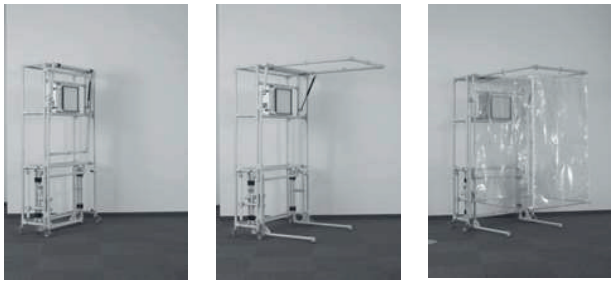


Figure 2 The Barrihood, used for isolation of a dialysis patient thought to have influenza (provided courtesy of Sendai Shakai Hoken Hospital)

which we used as a tracer to investigate the dispersal of breath exhaled when coughing. We analyzed 5 seconds of video from the moment of a cough, captured with a high-speed camera. We found that the sub micron sized particles leave the mouth at a speed of 10 m/s, but within 0.5 m of the mouth, they largely stop moving before they are dispersed.

4. Basic Configuration

The hood consists of an approximately 0.75 m^3 hood formed of plastic curtains, a fan filter unit (FFU) for maintaining negative pressure inside the hood by sending clean air filtered with a HEPA filter outside the hood, and a pipe framework for supporting the hood and FFU. As shown in Figure 3, the part of the pipe framework corresponding to the ceiling can be folded up for storage. As shown in Figures 2 and 4, the hood covers the upper body of a patient lying in bed, and apart from the front curtain which drapes over the bedcover, the other 3 curtains are fixed to the sides of the bed. The FFU attached to the hood draws ambient air from the room through the gap between the front curtain and the bed. After ventilating the inside of the hood, the air is cleaned by the HEPA filter and returned to the room.



(a) (b) (c)

Figure 3 The Barrihood, consisting of a foldaway framework, a fan HEPA unit, and transparent polypropylene curtains. (a) Folded framework with fan HEPA unit; (b) Expanded framework with fan HEPA unit; (c) Expanded framework with fan HEPA unit and transparent polypropylene curtains.

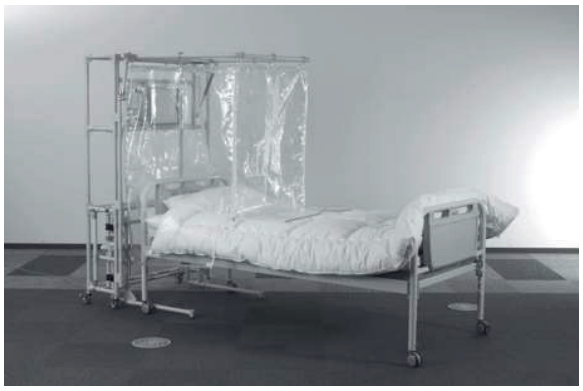


Figure 4 A bed equipped with the Barrihood for isolation of patients thought to have an airborne disease, such as pandemic influenza.

5. Examination of the Effectiveness of a Simple Hood

Experiments were performed in a strict, bio-safety facility and under bio-safety-conscious operation protocols, and were approved by the ethic committee of Sendai National Hospital. We used the double enclosure system: a 14.4 m^3 chamber formed of a sealed hood provided with fan HEPA-units inside as the first enclosure system, placed in a clean room as the 2nd enclosure system provided with several fan HEPA-units and UV-lights set surrounding the 1st enclosure system. The influenza virus strain used in

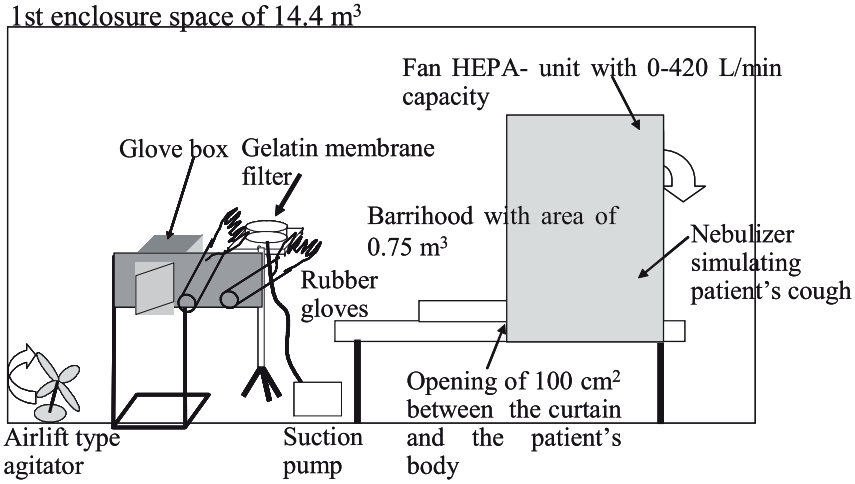


Figure 5 Experiment to check for leakage of airborne virus from inside the hood to outside.

this study was one of laboratory strains thought to be almost non-pathogenic in humans. Experimenters were always wearing N95 respirator while operations using the virus in the facility, and they were allowed to step in the 1st enclosure area only after running the fan HEPA-units set inside it and physiological cleanliness of the air was confirmed by monitoring laser particle counters set inside it.
Approximately 25 million live influenza viruses were sprayed as air-borne particles inside the Barrihood set in the 1st enclosure, using a nebulizer, as a simulation of coughing particles released by an influenza patient (Figure 5). The nebulizer was run for 4 minutes, then stopped. After intervals of 20 seconds and 17 minutes, airborne particles floating in the air were sampled inside and outside the hood for 1 minute using a gelatin filter with an airflow of 80 L/min, and the filter was collected and melted in the medium for titration of the trapped virus with the plaque assay technique. Collection of the gelatin filter was done through a glove box built into the 1st enclosure system.

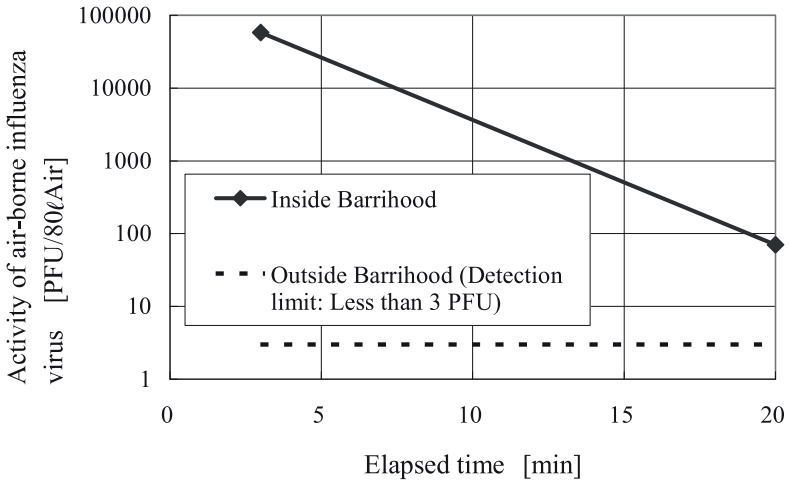


Fig.6 Results of leakage experiment shown in Fig. 5.
Minimum detection limit: 3 PFU.

6. Performance

At room temperature of 25°C with relative humidity (RH) of 30%, the FFU ventilated the Barrihood at a rate of 0-420 L/min, and the amount of virus contained in 80 L of air inside and outside the hood was collected with the gelatin-membrane filtration system and measured.
As was shown in Figure 6, when the air volume of the FFU was maintained at the minimum volume of ventilation, 133 L/min, the amount of virus outside the hood, i.e. virus leakage from inside to out side, was less than the limit of the detection system, and the virus number collected inside the hood decreased drastically to less than one thousandth in 20 minutes, by the FFU filtration.

7. Verification of Performance Using Air Current Simulation

As Figure 7 shows, the Barrihood covers the upper body of an influenza patient lying on a bed. The size of the hood is approximately 0.75 m^3. Assuming a fan HEPA unit of 0.09 m^2 near the patient's head, and gaps of 50 cm^2 between the bottom of the hood and the top of the bed on either side of the patient's hips, the airborne microorganisms released inside the hood when the patient coughs are contained within the hood and their concentration declines with the passage of time, according to analysis using the computational fluid dynamics software FlowDesigner Ver. 5 from Advanced Knowledge Laboratory Co. Ltd.
Figure 8 shows the results of a simulation of the temporal change in the concentration of airborne microorganisms dispersed inside the hood when the fan HEPA unit is run at the rated air volume of 0.4 m^3/min. We set the index of 76.5 for the contamination level (concentration) at the outer edges of the air contaminated by a cough 2 seconds after it occurs, and color coded the concentration level with 10 levels.
In other words, we set a total of 10 colors to represent parts with contamination of 76.5 or more, parts with no contamination as level 0, and parts with levels of up to 76.5 in 9 equal divisions. While negative pressure is maintained inside the hood, the contaminated air inside the hood is cleaned by the HEPA filter at a rate of 0.4 m^3/min and released into the air in the ward outside the hood, while the concentration of

airborne microorganisms inside the hood declines. Figure 9 shows frames from digital video (at 30 fps) of a man in his late twenties coughing naturally inside the hood after inhaling cigarette smoke. The frames are from within 0.1 seconds of the cough and after 2 and 4 seconds. The images closely match the results of the simulation of dispersal of the air contaminated by the cough after 2 and 4 seconds shown in Figure 8.
However, Figure 10 shows the situation when the airflow of the fan HEPA unit is stopped completely. The airborne microorganisms dispersed inside the hood leak out through the 50 cm^2 gaps on either side of the patient's hips into the air in the ward, while the number of airborne microorganisms inside the hood declines. Figure 11 compares the temporal change in the average concentration of airborne microorganisms inside the hood when the fan HEPA unit is run at the rated air volume and when the airflow is stopped completely.

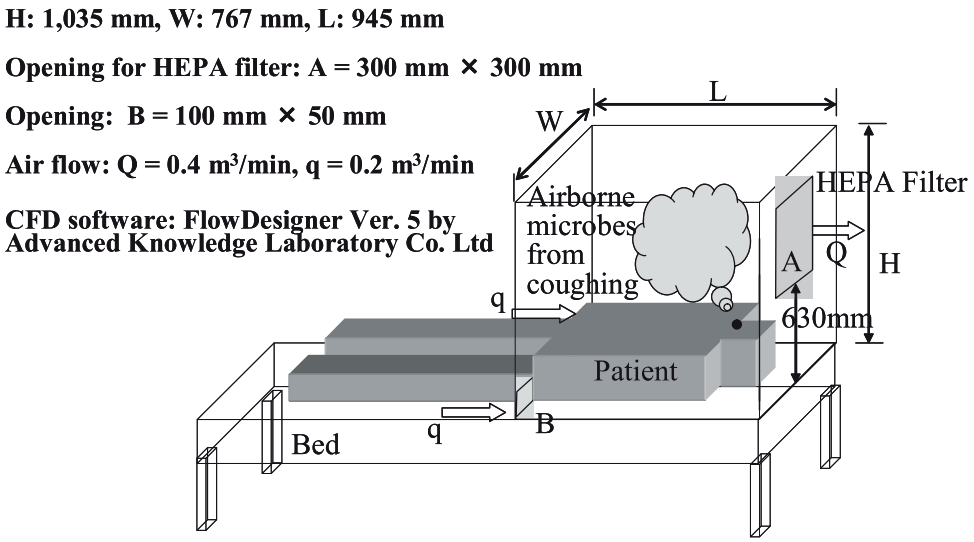


Figure 7 Simulation of airflow and virus leakage

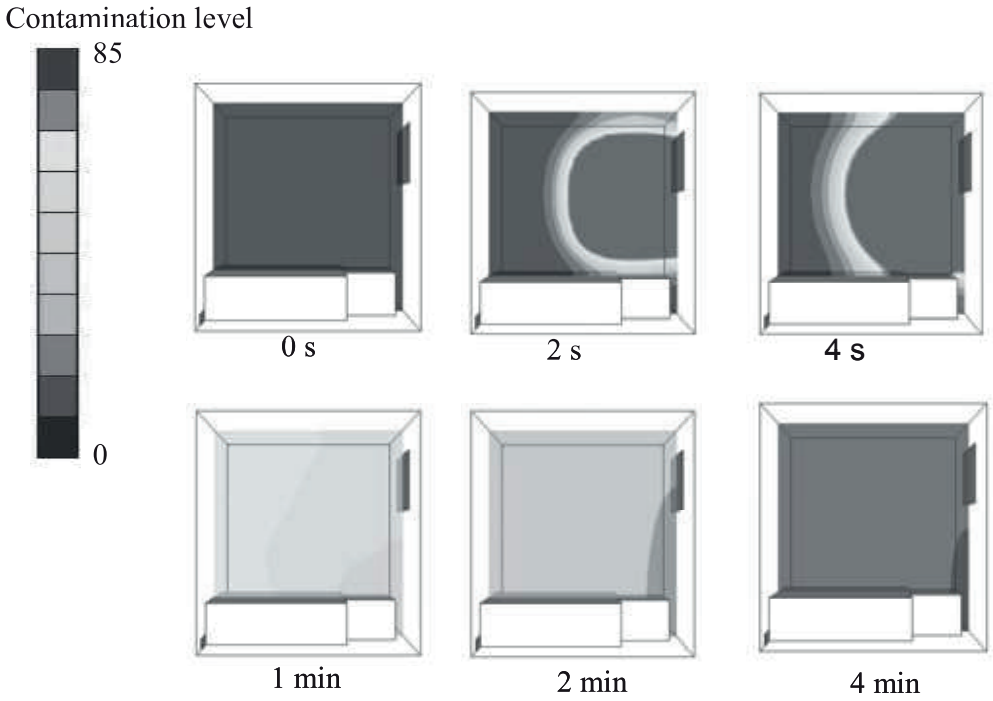


Figure 8 Result of simulation of the time-dependent airborne microbe concentration inside the Barrihood when the FFU is run at 0.4 m^3/min.

(a) <0.1 s (b) 2.0 s (c) 4.0 s

Figure 9 Dynamics of cough traced using tobacco smoke in the Barrihood. (a) less than 0.1 s after coughing; (b) 2.0 s; (c) 4.0 s

8. Potential Clinical Applications of the Hood

1) The Barrihood should be extremely useful in preventing the spread of infection when influenza patients must be accommodated temporarily in large rooms such as dialysis facilities and so on. (Figure 1) The Barrihood is sufficiently spacious that the patient does not feel confined. It allows for a reasonable standard of quality of life, enabling the patient to watch a TV installed inside the hood when used for up to 4 hours with a dialysis treatment bed.

2) Besides influenza, the Barrihood can be used with a wide range of infectious diseases of the respiratory system, including multi-drug-resistant tuberculosis and SARS which have a high risk of infection. It can also be used for temporary isolation of patients arriving at the hospital with suspected infections.

3) In addition, the direction of the FFU can easily be reversed making a positive pressure hood that can be used to prevent exposure to allergens and reduce allergic symptoms to prevent the exposure to allergens and reduce allergetic symptoms such as seasonal hay fever.

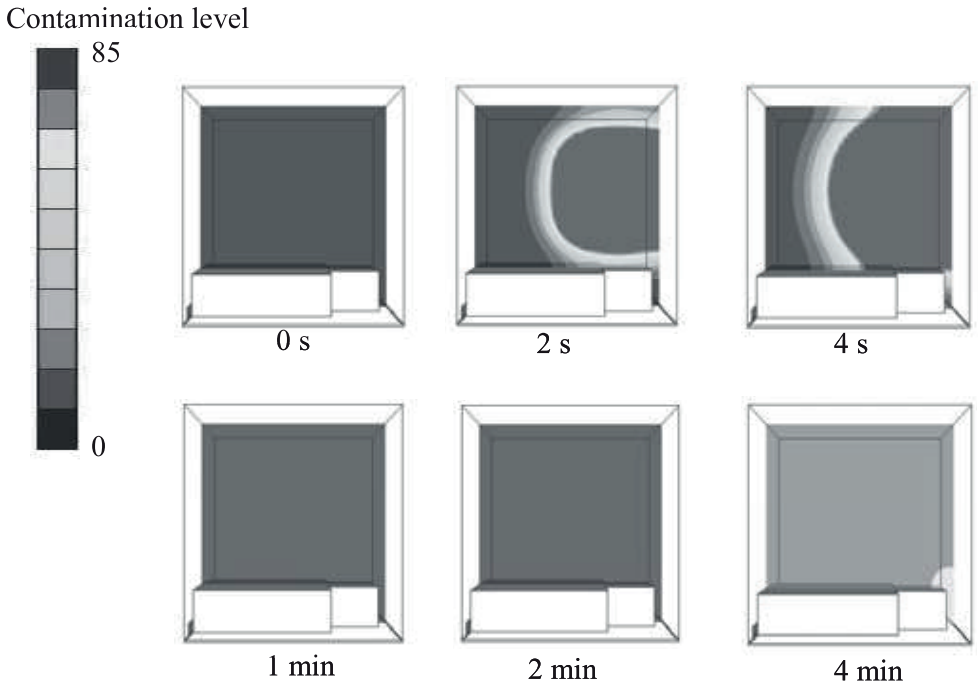


Figure 10 Simulation of the time-dependent airborne microbe concentration inside the Barrihood with the FFU shut down

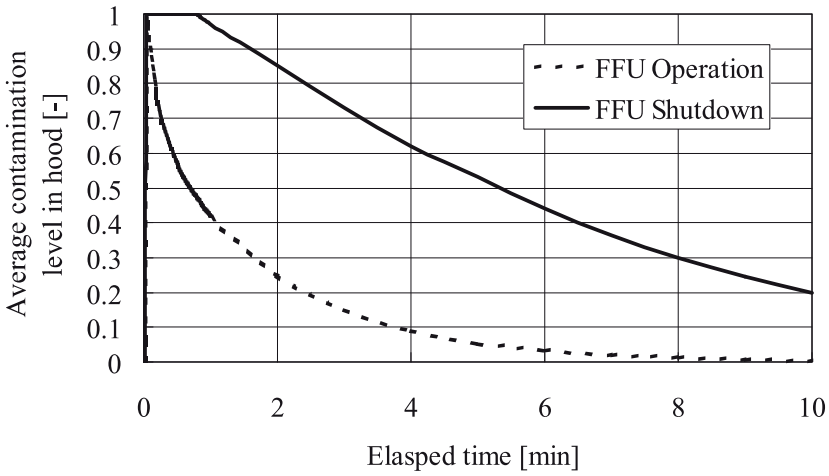


Fig.11 Comparison of the time-dependent average air-borne microbe concentration inside the Barrihood with the FFU running ar 0.4m^3/min and with the FFU shutdown.