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Membrane Humidifier That Does Not Require Addition of Water

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We developed a new device called "a membrane humidifier" which does not require an external water supply. Fifteen patients inhaled humidified-oxygen from the membrane humidifier and were asked about their subjective impression. The relative humidity of room air and that of humidified-oxygen from the membrane humidifier or a conventional bubble water humidifier were measured with a digital hygrometer. The relative humidity of the oxygen humidified by humidifiers was measured after the gas was flowed into a partially opened 500-mL container for 30 min. None of the patients experienced dryness of the nose or throat. All patients answered that there was no difference in their subjective impression between breathing oxygen from the membrane humidifier and from the conventional bubble water humidifier. A significant regression was observed between the relative humidity of room air and that of the oxygen humidified from the membrane humidifier. The membrane humidifier was able to produce humidification very well. This new compact device can be used not only in hospitals, but can also be incorporated in home oxygen concentrators. This new device also saves the procedure of changing water.

Key words: humidifier; humidity; membrane humidifier

Bubble water humidifiers have conventionally been used to humidify dry gas (Hayes and Robinson, 1970; Mercke, 1975; Chalon, 1980). It is troublesome to clean the humidifier container and change the water. To reduce the risk of infection, the water reservoir must be cleaned periodically and the water must be changed frequently. We have developed a new device called "a membrane humidifier" whose function does not require the addition of external water for humidification. This new system obtains moisture from room air. It can be used not only in hospitals, but can also be incorporated in home oxygen concentrators (Burioka et al., 1997a,1997b). This technical study evaluated the membrane humidifier to determine its efficiency in humidifying dry oxygen.

Subjects and Methods

Structure of the membrane humidifier

The membrane humidifier is composed of a compressor and a steel cylinder containing several hundred hollow fibers made from polyimide resin (Fig. 1). The different permeation rate of gases is used to separate water molecules from the air (Mulder, 1996). Water vapor can permeate the polyimide membrane of a hollow fiber (UBE membrane, UBE Industries, Ltd., Tokyo, Japan) hundreds of times more readily than either nitrogen or oxygen (Nishimura, 1986). Compressed air with water vapor is passed outside the hollow fibers. As the room air is passed under high pressure through the space around the hollow fibers (outside passage), the water molecules in the air permeate the membrane of the hollow fibers. Dry oxygen from the hospital's oxygen supply is passed through the hollow fibers (inside passage) within the membrane humidifier, and is humidified with water vapor (Fig. 2). One unit of hollow fibers is highly durable. The polyimide membrane of a hollow fiber can be sterilized with alcohol or disinfecting gases. The pressure of the compressed air was 196 kPa (2 kgf/cm^2) in this study although it was 98 kPa (1 kgf/cm^2) in our previous study (Burioka et al., 1997a, 1997b).

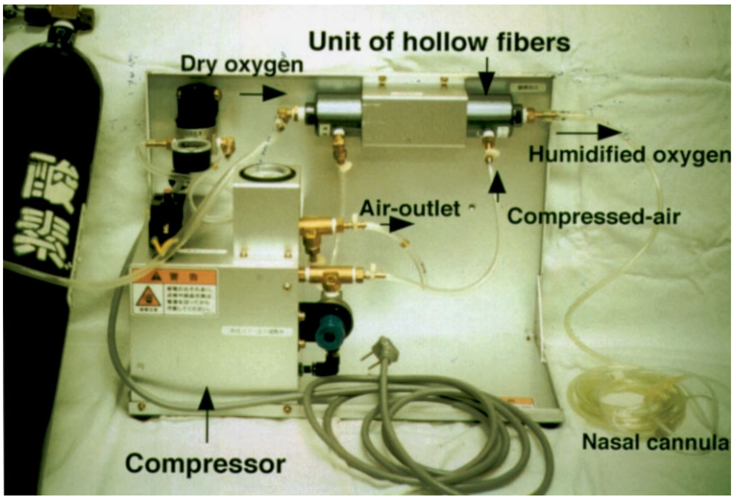

Fig. 1. Membrane humidifier. The membrane humidifier is composed of a compressor and a steel cylinder containing several hundred hollow fibers.

Patients

We examined 15 patients (8 males and 7 females, mean age; 67.3 years old) who were hospitalized for chronic pulmonary disease (emphysema: 5 patients, interstitial pneumonia with collagen disease: 2 patients, sequelae of tuberculosis: 4 patients, idiopathic interstitial pneumonia: 2 patients, diffuse panbronchiolitis: 2 patients). Their clinical condition was stable. They were receiving oxygen therapy in the hospital. The study was explained and informed consent was obtained from patients before their participation.

Measurement

After inhaling humidified-oxygen from both the membrane humidifier and conventional bubble water humidifier (Koike Medical Co., Tokyo) for 5 h, all patients were asked to fill out a questionnaire. We asked the patients whether their throat or nose was dried by the oxygen inhalation from the 2 humidifiers, and we also asked whether they felt some difference in their impression of inhalation between breathing oxygen from the new device and breathing oxygen from the conventional bubble water humidifier.

We measured the relative humidity of the room air, that of the dry oxygen from the hos-

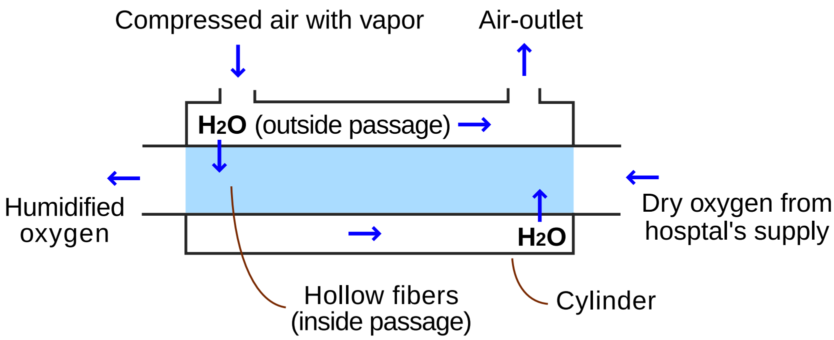

Fig. 2. Principle of humidification in one unit of hollow fibers. Compressed air with water vapor passes through the outside passage. Water vapor only permeates the hollow fibers. Dry oxygen from the hospital's supply passes inside the hollow fibers, and is humidified with water vapor.

pital's oxygen supply and that of the oxygen humidified by the membrane humidifier or the bubble water humidifier. The relative humidity was measured with a digital hygrometer (TRH-CA, Shin-ei Co., Tokyo, Japan), after the gases (1 L/min) had flowed into a partially opened container (500 mL) for 30 min. The pressure of the compressed air in the membrane humidifier was 196 kPa (2 kgf/cm^2). The temperatures in the laboratory room were maintained from 20 to 22°C during the study.

Data analysis

Data are reported as mean ± SD. The significance of the results of multiple comparisons was calculated with a one-way analysis of variance by Turkey's test. Correlation between the relative humidity of room air and that of the oxygen flow humidified by the membrane humidifier was calculated using a regression curve with the software StatView-J 4.11 (Abacus Concepts Inc, Berkeley, CA). A level of $P < 0.05$ was considered statistically significant.

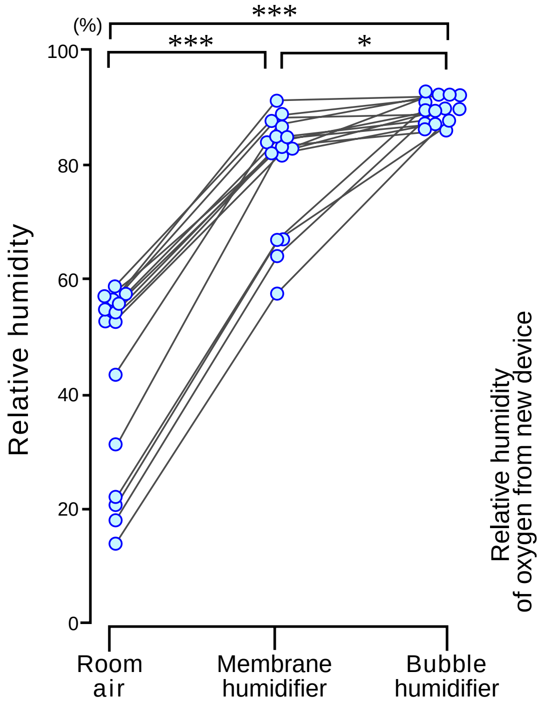

Fig. 3. Relative humidity of room air, oxygen humidified by the membrane humidifier, and oxygen humidified by the bubble water humidifier. $***P < 0.001$, $*P < 0.05$ (Turkey's test).

Results

None of the patients experienced dryness of their nose or throat while breathing oxygen from the new device or the conventional bubble water humidifier. All subjects also answered that there was no difference in their subjective impression between while breathing oxygen from the new machine and while breathing oxygen from the conventional bubble water humidifier.

The relative humidity of the air in the laboratory room was 43.8 ± 14.9%. The relative humidity of the dry oxygen flow delivered by hospital's oxygen supply was 7.0 ± 1.0% after it had flowed into a partially opened 500-mL container for 30 min. A significant difference was observed between the relative humidity of the oxygen from the membrane humidifier (81.4 ± 8.2 %) and that from the conventional bubbling humidifier (88.9 ± 2.6%) ($P < 0.05$) (Fig. 3). A significant regression was observed between the relative humidity of the room air and that of the oxygen humidified by the membrane device (Fig. 4).

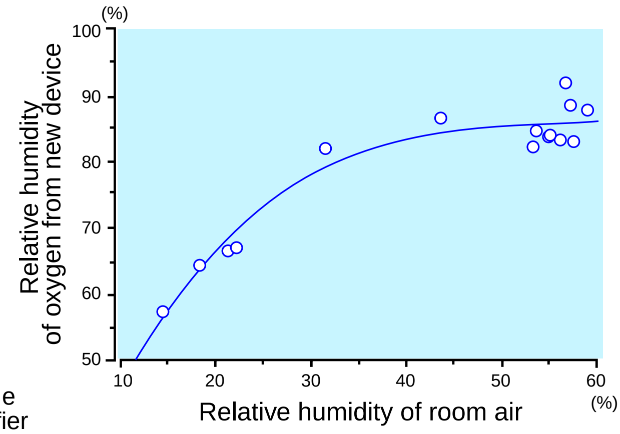

Fig. 4. There is a strong positive regression between the relative humidity of room air and that of the oxygen humidified by the membrane humidifier ($Y = 14.1X - 3.96X^2 + 0.0005X^3$ ($r^2 = 0.93$).

Discussion

Dry oxygen is generally humidified by sterile distilled water when a supplement of oxygen is provided by nasal cannula in Japan. However, sterile distilled water is expensive, and it is troublesome to change the water in the reservoir. We developed a new humidifier that can humidify dry oxygen without the use of water.

A strong positive regression was observed between the relative humidity of room air and that of the oxygen humidified by the membrane humidifier. A significant difference was observed between the relative humidity of the oxygen humidified by the membrane humidifier and that humidified by the conventional bubble water humidifier (Fig. 3), because the relative humidity of the oxygen humidified by the new device was low when the relative humidity of room air was low (about 14–22%). Since this system obtains its water vapor from room air, it appears that its efficiency is diminished when the relative humidity of room air is low (Burioka et al., 1997a,1997b). However, even if the relative humidity of room air is about 14%, the membrane humidifier could humidify the dry oxygen to 55%. When the relative humidity of room was above 30 %, the relative humidity obtained from the membrane humidifier was almost the same as that of the conventional bubble water humidifier.

None of the patients experienced dryness of their nose or throat while breathing oxygen from the new device or the conventional bubble water humidifier. The membrane humidifier supplied well-moistured nasal oxygen without the need of water. This new device can be also incorporated in a PSA type oxygen concentrator (Burioka et al., 1997a,1997b) used in home oxygen therapy. The membrane humidifier will be beneficial in both hospitals and the home because it eliminates the laborious cleaning of the reservoir and changing of the water.

The polyimide membrane using hollow fibers has a dense layer pinhole-free surface. Its pore size is less than 10^{-3} μm (Nishimura, 1986; Mulder, 1996). Water vapor in the air dissolves and diffuses into a membrane wall. Since bacteria and mycetes can't permeate the membrane, this new device may be more hygienic than conventional humidifiers that use water. A more detailed study will be needed to investigate whether bacterial contamination can be completely preventable.

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