An Evaluation of Heat and Moisture Exchangers Used in Pediatric Patients

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要　約

新生児、小児人工気道患者での人工鼻の使用は一般的になったものの、まだいくつかの問題が残されている。これらの問題を要約すると、1）どのようにして臨床での人工鼻の加湿効果を評価するか、2）小児特有のカフなしチューブ使用に際し、ガスリークにより吸入ガスの加湿が不充分になりうるか、3）人工鼻自身が湿度を持つと、呼吸抵抗が増す可能性があるか、などがあげられる。

そこで、われわれが改良した酸素投与用人工鼻を含めたポーテックスーサーモベント人工鼻の死腔量、抵抗および加湿効果を実験的および臨床的に検討した。また、当研究室で開発した自発呼吸をシミュレートできるモデル肺を使用し、酸素投与用人工鼻の吸入濃度に影響するパラメータについても検討した。

人工鼻の加湿効果は小児患者での人工鼻使用前と使用後の重さの変化を測定することによって評価した。臨床ではコネクターの緩みやPEEPにより、ガスリークが増加し人工鼻の加湿効果に影響を与えることが示唆された。

以上の結果より、改良した酸素投与用人工鼻を含めたポーテックスーサーモベント人工鼻は使用法に配慮すれば充分な加湿効果があり、小児患者に有用であることが認められた。

Introduction

Many studies have demonstrated that delivery of dry, cool gases directly to the trachea and lungs can result in reduced ciliary activity, diminished ability to clear mucus and debris, and thickened secretions, which leads to atelectasis or obstruction of the airway[1)2)]. The importance of humidification during the use of artifical airways has thus been recognized and stressed, especially in pediatric patients. Heat and Moisture Exchangers (HME) have gained wide acceptance in humidifying the inspired air in intubated or tracheostomized patients.

The use and efficiency of the HME in infants and children is, however, associated with some problems that have not been assessed in detail. The problems include how to estimate the humidifying capacity of the HMEs clinically, inadequate humidification of inspired gas caused by gas leakage for various reasons including the use of uncuffed tubes in children[3)], the possibility of potential increase in resistance to breathing because of humidified HME or clogging of secretions[4)]. These issues, special to pediatric patients, were tested both in a laboratory setting and clinical trial.

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Methods

1) The Use of HME in a Laboratory Setting

Three types of Portex-ThermoVent HMEs were used in our experiments: vertical, horizontal and oxygen-delivery (**Fig. 1**). The vertical HME was used for mechanical ventilatory support, and the horizontal and the oxygen-delivery types for spontaneous breathing[5)6)]. Three of each type HME were selected, and the results were expressed as a Mean±SD.

The weights of the HMEs were measured by using an electronic balance (ISHIDA CB-300) and their dead space was determined by estimating the volume of water that filled it (the connector mount was included). The resistance to airflow across the HME was investigated at a gas flow rate of 30 *l*/min with a Flow-Pressure Meter (METRAN) at 0 hours when the HMEs were dry and after 4, 6, 8, 10 and 12 hours of use at 37°C, 100% humidified air.

Because the reservoir space of oxygen-delivery type HME is very small, inspired oxygen concentrations were easily affected by respiratory patterns and other factors. The relationships between inspired oxygen concentrations, oxygen flow rates, minute volume and respiratory patterns were thus investigated with a computer-controlled respiration simulator developed by us[7)]. The testing system consists of a respiratory simulator, pneumatachograph (HEWLETT-PACKARD) and O_2 analyzer (TELEDYNE 60), a tracheal tube and the HME. Oxygen flow rates were regulated from 0.5 to 3.0 *l*/min and from 3.0 to 0.5 *l*/min stepwise and oxygen concentrations were measured four times after stabilization. $\dot{V}e$ was made 0.6, 1.5, 1.9, 2.4, 3.0 *l*/min corresponding to ages of pediatric patients. Respiratory rates were divided into fast, normal, and slow frequencies.

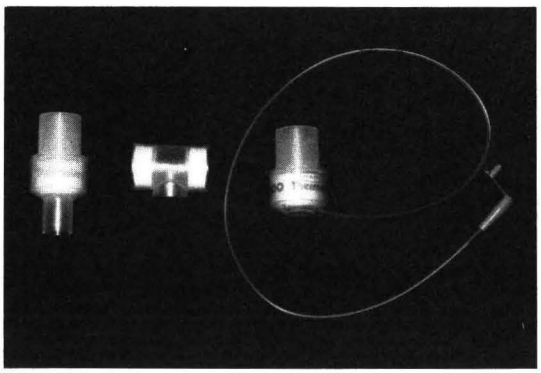

Fig. 1 Three types of Portex-Thermovent HMEs

2) The Use of the HME in Clinical Trials

In order to estimate the humidifying capacity of the HMEs and to reduce the effect of humidifying efficiency, the weight of the HME before and after use was measured and compared to the variations of weight in pediatric practice. At the same time, clinical symptoms including the condition of airway secretions were observed. 20 hospitalized patients who were managed with an oral or nasal tracheal tube or a tracheostomy tube were investigated. Three types of the HMEs were used on these patients. The patients ranged in age from 10 months to 19 years. The weights of the HMEs were recorded in 20 patients before use and after 6 to 72 hours of use.

Our investigation focused on three patients (A, B, C) who used the vertical type HME and who were mechanically ventilated. The weights of the HMEs were measured before use and after 6, 12, 24, 48 and 72 hours of use.

The factors resulting in gas leakage were

Table 1. The weight and dead space of HME

	Weight (g) (n=3)	Dead Space (ml) (n=3)
Vertical type	10.26±0.07	14.00±0.00
Horizontal type	4.98±0.05	11.50±0.00
Oxygen-delivery type	11.65±0.05	12.00±0.00

(Mean±SD)

Table 2. The resistance to airflow at a flow rate of 30 *l*/min

Resistance (cmH_2O/l/min. n=3)	22°C. 20% RH. Dry Air	37°C.100% RH. Humidified Air				
	0h	4h	6h	8h	10h	12h
Vertical type	0.024± 0.001	0.024± 0.001	0.026± 0.003	0.028± 0.005	0.029± 0.003	0.031± 0.004
Horizontal type	0.006± 0.000	0.006± 0.000	0.006± 0.000	0.006± 0.000	0.006± 0.000	0.006± 0.000
Oxygen-delivery type	0.034± 0.004	0.036± 0.005	0.036± 0.005	0.036± 0.004	0.036± 0.003	0.036± 0.002

(Mean±SD)

investigated by measuring the volume differences of inspiration and expiration using a pneumotachograph system.

Results

1) The Use of the HME in a Laboratory Setting

The weight and dead space of each type of HME are shown in **Table 1**. The lightest weight and the smallest dead space was found in the horizontal HME.

There was no clinically significant increase of resistance to airflow at a gas flow rate of 30 *l*/min with 100% humidified air after 4, 6, 8,and 12 hours, compared with dry air (0 h) (**Table 2**).

The relationships of inspired oxygen concentrations, oxygen flow rates and minute volume with respiratory patterns were investigated on the oxygen-administering type of HME (**Fig. 2**). This type of HME achieved higher inspired oxygen concentrations at a faster respiratory frequency and a smaller tidal volume, with the same minute volume and oxygen flow. The oxygen flow rates of less than 3 *l*/min were adequate for pediatric patients to achieve F_{IO_2} above 0.8.

2) The Use of the HME in the Clinical Trial

The relation of weight change with time of the vertical HME is shown in **Figure 3**. The weights of the HMEs became heavier with time in patients A and B, but not in patient C. Patient C caught cold easily and had thick secretions which were difficult to

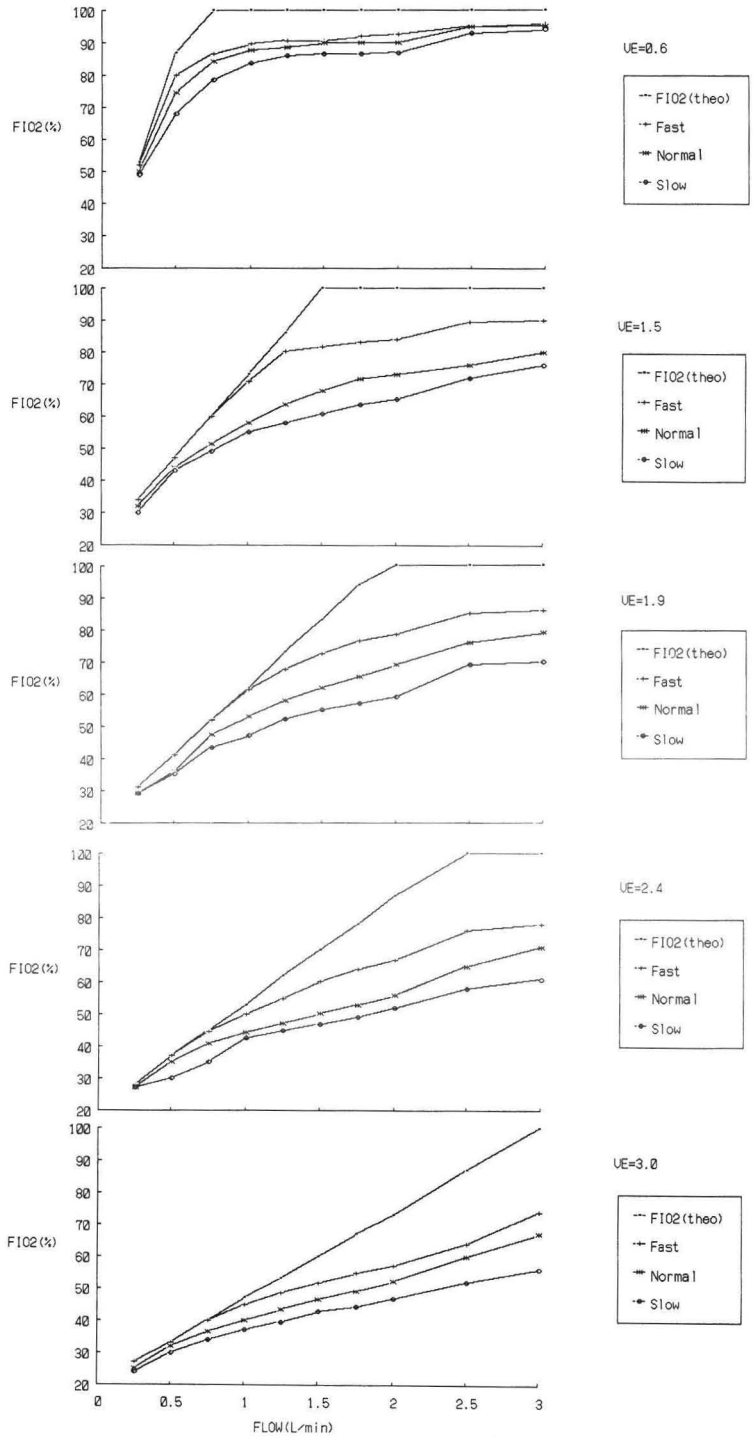

Fig. 2 The relation of F_{IO_2}, exygen flow rates, $\dot{V}_E$ with respiratory patterns.

Oxygen-delivery HME achieved higher inspired oxygen concentrations at a faster respiratory freguency and a smaller tidal volume with the same minute and oxygen flow. The oxygen flow rates of less than 3 *l*/min were adequate for pediatric patients to achieve F_{IO_2} above 0.8.

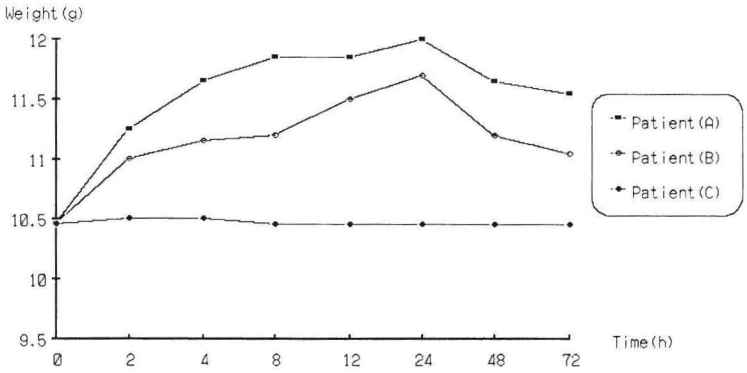

Fig. 3 The relation of HME weight change with time in patients A, B and C.

HME weight did not increase in patient C who suffered lack of humidification. Although HME weight increased in patients A and B, indicating adequate HME function, a peculiar phenomenon of weight decrease after 24 hours was observed.

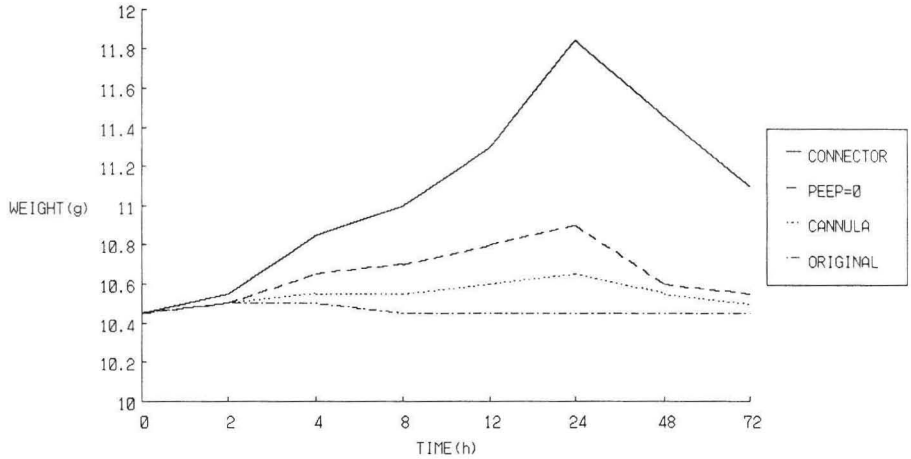

Fig. 4 Factors influencing the humidifying efficiency of the HME in patient C.

Weight of HME increased with time after stepwise corrective measures to decrease gas leakage in patient C. At first, a larger size tracheostomy cannula was used to replace the original smaller one. Then PEEP levels were reduced from 5 cmH_2O to 0 cmH_2O stepwise. Finally an old L type swivel connector, which was the main reason for the large gas leakage was replaced with a new one and HME weight started to increase.

aspirate. That is to say, the HME in patient C did not play an adequate role in humidification.

The weight of the HME started to increase progressively with time after adjustments were made (**Fig. 4**).

The main reason the weight of the HME did not change was initially considered due to gas leakage. Several measures were adopted to eliminate the gas leakage. At first, a larger size endotracheal cannula was used to replace the original smaller one. Unfortunately, the weight of the HME did not increase significantly. The PEEP level was then reduced from 5 cmH_2O to 0 cmH_2O to decrease air leak. The weight of the HME showed only a slight increase.

Other causes of the gas leakage besides the size of the endotracheal tube and PEEP level were investigated. Finally, it was found that the main cause of a lack of increase of weight in the HME was due to a large gas leakage through an old L type swivel connector. A new L type swivel connector to connect the endotracheal tube was then introduced.

During the course of this experiment, a peculiar phenomenon that the weight of HMEs decreased after 24 hours of use was observed both clinically and experimentally.

An increase of resistance to breathing caused by HME use was not found in clinical patients.

Discussion

HMEs, developed in the 1930's, have recently been rediscovered for clinical use[8)9)]. HMEs have become increasingly popular and acceptable in clinical practice. Some studies even suggested that HME may be an alternative to Hot Water Humidifiers (HWH) in some applications[10)11)]. HME offers freedom of activity for patients at home.

An oxygen-delivery type HME was developed and used in our hospital since 1985. The parameters associated with inspired oxygen concentrations of an O_2-delivery HME were investigated using a spontaneous respiration simulator in the laboratory. We found that when minute ventilation is the same, the smaller the tidal volume and the faster the respiratory frequency, the higher the actual value of the inspired oxygen concentrations was. This is because larger tidal volume increases the chances of ambient air entrainment in pediatric patients whose reservoir volume is very small.

We felt that the use of the HME may add resistance to breathing because of humidification or clogging of secretions in the HME, which could be significant in critically ill and weak patients. Our laboratory results indicated that there was no significant increase in resistance to airflow when the HMEs were humidifed after 4 to 12 hours of use in our laboratory setting. But we found that a part of the horizontal type of HME blew off the endotracheal tube when secretions were clogged in the HME in some patients. Perhaps this is due to a sudden rise in expired resistance when thick secretions stick to the inside of the HME. Therefore, it is important to emphasize that inadequate airway humidification may occur in patients who have abnormal secretions. If this happens, the HME should be immediately replaced, or other methods should be employed to augment humidification.

Portex HMEs have been used in clinical patients since 1981 in our hospital. The measurement of humidifying capacity of the HME has successfully been studied in the laboratory setting, however, it has not

been investigated thoroughly and systematically in clinical practice, especially in pediatric patients[12)13)]. This may be due to the fact that the response time of currently available hygrometers is not fast enough to measure humidity breath-by-breath, and the obviously large dead space of the hygrometer connector would be inappropriate for measuring HME moisture output at low tidal volume in pediatric practice[12)].

Therefore, we adopted an indirect method, that is, measuring the HME's weight before and after use to estimate its humidifying capacity. An increase of weight means that the HME captured water and heat from the expired gases of the patient. The heat and moisture was transferred into the subsequent inspired gas. Thus, it may be assumed that the increase of the weight of the HME has a positive relation with its humidifying capacity. If the weight of the HME did not change after use, or in dry conditions, inspired air was probably not humidified. The peculiar phenomenon that the weight of HMEs decreased after 24 hours of use both clinically and experimentally has to be investigated further.

Excessive gas leakage can result in poor performance of the HME. Leakage from uncuffed endotracheal tubes has already been recognized in pediatric patients, but leakage from connectors also can not be neglected. The weight of the HME was found to increase with time, when leakage from various factors was eliminated and secretions became thinner and easier to aspirate. We suggest that avoiding large gas leakage is very important in obtaining adequate humidity when PEEP and swivel connectors are used with HME.

Satisfactory humidification was observed in the majority of our patients. Secondary bacterial contamination in the HME was rare after long-term ventilation in our cases.

Conclusions

We carried out an investigation of dead space, resistance to airflow and humidifying capacity of Portex-ThermoVent HMEs in both laboratory and clinical settings. Also, the relation of F_{IO_2} to respiratory patterns in the oxygen-delivery type of HME were undertaken.

The humidifying capacity of HME was estimated in a different way, that is, by measuring change in the HME's weight before and after use in pediatric patients.

Effects of gas leakage and PEEP were studied in the clinical setting as factors influencing humidification of the HME. We found the elimination of gas leakage is important to obtain adequate humidification.

The results of this study indicate that the HMEs of Portex-ThermoVent modified for oxygen-delivery produced satisfactory humidification and that oxygen-delivery types of HMEs are useful for pediatric patients.

(1990. 1. 20 受)

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