Laboratory Evaluation of Heat-and-moisture Exchangers

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We conducted a laboratory study on six commercially available heat and moisture exchangers in order to determine and compare their water retaining efficiency and their contribution to airway resistance.

The Gambro-Engström Edith Flex device was the most desirable of the six devices we evaluated in terms of its water retaining efficiency. The NMI Pneumoist 1 and the Siemens Servo Humidifier 153 units had good water retaining capacity but their higher airflow resistance need close monitoring, especially after prolonged clinical use. The Pall HME 15–22 and the Portex Humid-Vent 1 devices were also efficient in water retaining capacity. The Pall also demonstrated low airflow resistance and the minimum increase in airflow resistance after water immersion. The pathogen filtering capacity of the Pall should also be considered an additional advantage, especially in infected patients. The Terumo Breathaid device performed worst of all six devices, but it was still better than no HME at all. (Key words: heat and moisture exchanger, humidification, bacterial filter)

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Humidification of gases during mechanical ventilation and, recently, during endotracheal general anesthesia is widely accepted and practiced[1]. The benefits of humidification include the preservation of mucociliary function, the maintenance of pulmonary mechanics, and the conservation of body temperature[1–5]. Failure to humidify inspiratory gases may incur alteration of pulmonary mechanics and body temperature, and may lead to increases in pulmonary arteriovenous shunting, with systemic arterial oxygen desaturation[2,28], and decreases in compliance[29], surfactant[2,28], and ciliary transport[2,28].

Many devices have been manufactured to supply heat and humidity to inspired gases[6]. Of these, heated humidifiers are the most widely used because of their effectiveness. But they are not without some disadvantages and complications, which are listed in table 1[6–10]. Heat and moisture exchangers (HME) have been used since the early 1960s to warm and humidify gases in patients with tracheostomies[11]. The HME is used during mechanical ventilation and general anesthesia by placing it between the endotracheal tube and the ventilator or anesthesia circuit.

Table 1. Problems associated with Heated Humidifiers

Immobile
Electricity required
Electrical shock
"Rain out" in respiratory circuit
Temperature monitoring required
Bacterial contamination
Overhydration
Hyperthermia
Tracheal burns
Incorrect connection

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Table 2. Six Heat-and-Moisture Exchangers evaluated and their weight (gm), volume (ml) and insert materials

		wt	vol	insert material
Pall:	HME 15–22	42.5	90	Hydrophobic ceramic fiber
Portex:	Humid-Vent 1	10.5	10	Hygroscopic paper roll
Siemens:	Servo Humidifier 153	40.5	92	Cellulose sponge & synthetic felt
NMI:	Pneumoist 1	10.2	35	Hygroscopic synthetic felt
Gambro-Engström:	Edith Flex	18.4	92	Hygroscopic polypropylene filter
Terumo:	Breathaid	14.4	9	Alminum & cellulose fibers

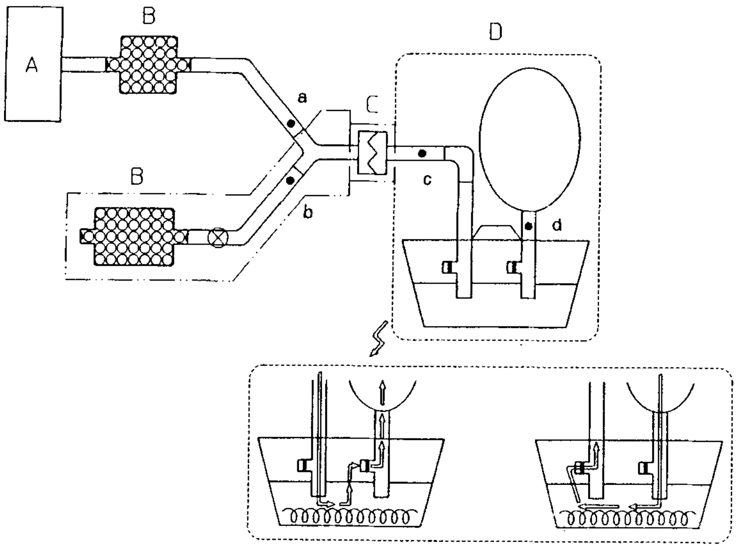

Fig. 1. Schematic diagram of the test rig.
A : Ventilator
B : Drying agent in inspiratory limb (upper) and expiratory limb (lower; enclosed in the double-dotted line)
C : Heat and moisture exchanger tested.
D : Artificial lung (enclosed in the dotted line). Gas flow during inspiratory (left) and expiratory (right) phase is illustrated in the lower insert enclosed also in the dotted line.
● : Temperature probes (a–d)
⊗ : Expiratory valve
I : One-way valve

The HME captures heat and moisture from the patient's respiratory tract carried in the expiratory gases and returns collected heat and moisture to the cool, dry gases subsequently inspired by the patient. Thus, the HME is also called the "artificial nose".

Although there have been many studies comparing the effectiveness of HME in different clinical and laboratory settings[12–26], we conducted our laboratory study on six commercially available heat and moisture exchangers in order to determine and compare, first, their efficiency to retain humidity from the respiratory tract and, second, their contribution to airway resistance.

Materials and Methods

The six different heat and moisture exchangers we evaluated are listed in table 2 with their physical characteristics. Four were hygroscopic condenser humidifiers but Pall HME 15–22 and Terumo Breathaid did not incorporate that principle. To evaluate the efficiency of each HME, we constructed the test rig shown in figure 1. The humidity of the inspiratory gas was reduced to zero by passing the gas through an inspiratory limb drying agent chamber. The dried gas then passed through the HME being tested and entered an artificial lung consisting of a 5-liter anesthesia bag and water bath (Bennett Cascade Humidifier).

The temperature of the water bath was maintained at a heat level necessary to keep the temperature at 31°C immediately proximal to the HME (at temperature point "c"). In this way, we controlled the "humidity load" presented to the HME. This humidity load was identical for each HME and can be calculated as the arithmetic product of

Table 3. Results of the water retaining efficiency test

(Mean ± S.D.)

	Insp Gas Temp* (°C)	Exp Gas Temp** (°C)	Water Loss (g/h)	Water Loss (mg/L)	Moisture Output (mg/L)	Water Retention Efficiency (%)
Pall	23.9±1.1	31.1±0.2	3.11±0.18	7.8±0.4	24.4±0.2	76.1±1.6
Portex	25.3±0.2	31.3±0.1	3.20±0.13	8.0±0.3	24.6±0.3	75.5±0.9
Siemens	23.4±0.2	31.5±0.1	2.92±0.08	7.3±0.2	25.7±0.3	77.9±0.3
NMI	25.0±0.4	31.3±0.4	2.50±0.22	6.2±0.5	26.2±0.8	80.8±1.5
Gambro-Engström	23.1±1.0	31.5±0.2	2.31±0.08	5.8±0.1	27.2±0.2	82.6±0.2
Terumo	23.7±0.2	30.9±0.1	7.10±0.30	17.8±0.8	14.1±1.0	44.2±1.7
No HME	25.5±0.4	31.2±0.5	9.20±0.10	23.0±0.3	9.5±0.8	29.3±1.8

*Temperature point "a", **temperature point "c" in figure 1.

Table 4. Pressure drop across HME at the flowrate of 50 L/min and 60 L/min. Pressure drop expressed in cmH_2O (Mean ± S.D.)

	FLOWRATE 50 L/min		FLOWRATE 60 L/min	
	DRY	WET	DRY	WET
Pall	1.3 ± 0	1.5 ± 0	1.7 ± 0	1.9 ± 0
Portex	2.0 ± 0.1	3.4 ± 0.2	2.6 ± 0.2	4.0 ± 0.2
Siemens	1.6 ± 0.1	5.7 ± 0.8	2.2 ± 0.2	6.4 ± 1.1
NMI	3.2 ± 0.9	6.4 ± 1.6	4.0 ± 1.1	7.0 ± 2.0
Gambro-Engström	1.3 ± 0.1	1.9 ± 0.1	1.8 ± 0.1	2.4 ± 0.1
Terumo	2.2 ± 0	2.2 ± 0	2.9 ± 0	2.9 ± 0

the water content of the saturated gas at the prevailing temperature of 31°C (33mg/L) and the total flow (400L/hr). Thus, the humidity load was identical for each HME (13.2g/hr).

Copper wire mesh was incorporated in the water bath and anesthesia bag to stabilize temperature and humidity. Expired gases passed through each HME where heat and humidity could be reclaimed before these gases entered the distal expiratory limb. Moisture that the HME failed to reclaim was captured within an expiratory limb drying agent chamber (labeled "B" in figure 1 and enclosed by a double-dotted line). Each HME was tested at a tidal volume of 666 ml at a ventilation rate of 10 per minute (hourly ventilation = 400 L/hr). Peak inspiratory flow rate was adjusted to 40 L/min. The amount of water lost from the artificial lung (that portion of the test rig labeled "D" in figure 1 and enclosed by the dotted line) was determined as the difference in the weight of the artificial lung before and after each experiment run (△wt1 = initial weight of artificial lung minus final weight of artificial lung).

Water loss was also calculated by recording the changes in the weights of the HME ("C" in figure 1) and expiratory drying agent chamber (enclosed in the double-dotted line in figure 1 and labeled "B"): △wt2 = △wt of HME plus △wt of expiratory drying agent chamber. We difined the "water discrepancy" as the arithmetic difference between these two figures: water discrepancy = △wt1 munus △wt2. The calculated water discrepancy was less than 10% of the numerical value of △wt1 for each experimental run. The observed hourly water loss during each test run was divided by hourly flow (400 L/hr) to generate a figure for water loss per liter. The "moisture output" of each HME can be calculated as the difference between its "humidity load" and its "water loss" (moisture output = humidity load minus water loss). "Efficiency" was calculated as the ratio of moisture output to humidity load (%efficiency = [moisture output / humidity load] × 100). Water content figures were derived from a standard water vapor content table.

Water loss and efficiency figures were also generated in the absence of any HME under the test conditions described earlier.

An electronic balance (ALSEP model EX-8000A) was used to determine weights of various test rig components. Three samples of each HME were evaluated. Resistances to airflow were measured by recording the pressure drop across each HME in a dry and a wet state at a flowrate of 50 L/min and 60 L/min. Wet testing was performed by immersing each HME in water at 31°C for 10 min. Wet testing was performed in order to simulate prolonged use of each HME under actual clinical conditions.

Results

Table 3 shows the inspiratory gas temperature, the expiratory gas temperature, the water loss from the artificial lung in gH_2O per hour, the water loss from the artificial lung in mgH_2O per liter of ventilatory gas, the moisture output of the HME in mgH_2O per liter of gas at the expiratory gas temperature and the water retention efficiency in %. All parameters are expressed in Mean ± Standard Deviations. The Pall and all the hygroscopic HME showed satisfactory results with respect to their water retaining efficiency. The Terumo device functioned very poorly and its water retaining capacity was only half as much as the other HME. Table 4 shows the pressure drop through each HME. The NMI device showed higher resistance even under dry conditions. The resistance of NMI increased greatly after immersing them in the water for 10 min, showing the highest resistance of all HME tested. The Siemens device also showed an appreciable increase after water immersion. In fact, its absolute increase was even larger than the NMI device. The Portex device also showed some increase in resistance after water immersion. Both the Pall and the Gambro-Engström devices showed a small increase in resistance after water immersion. The Terumo device did not show any increase in resistance. Because we had noted that the NMI device showed wide variances in initial resistance, we measured a total of five samples to ascertain this variance which is reflected in the greater standard deviations. We found that the color of the insert affected resistance. The deeper the color, the higher the resistance. Quality control problems seem to exist in the manufacturing processes for the NMI.

Discussion

Chalon et al.[14] found that the minimum humidity level necessary to prevent ciliary cellular morphologic changes during anesthesia was 14 mg/L. However, it has been shown that physiologic value of 25–28 mg/L of humidity is desirable to prevent alteration in pulmonary mechanics and body temperature as the larynx is normally exposed to this level of moisture[27]. Another study showed a minimum level of 23 mg/L (100% RH at 25°C) to be acceptable[28]. Recently, ECRI set a minimum requirement for the output of HME to be 21–24 mgH_2O at 27–29°C to provide humidity for long term ventilation needs of patients[12].

Our aim in this study was to evaluate the water retaining capacity of each HME by loading them with the same level of absolute humidity at an identical temperature. Thus, we were able to avoid the measurement of humidity with a hygrometer, the response time of which is not fast enough to suit our purposes. The average water output and water retaining efficiency was derived from the water loss from the artificial lung and the moisture contet was read from the table. We believe our test methods enabled us to obtain an objective assessment of HME.

Our results confirmed that the Pall, Portex, Siemens, NMI and Gambro-Engström devices were acceptable for clinical use. Of these, the NMI and Gambro-Engström devices were the most efficient in moisture retaining capacity. However, the NMI device had a high resistance, especially after water immersion simulating prolonged clinical use. The NMI device also showed a great variance in resistance among samples, making prediction of airway resistance very difficult. The Pall device has the ability to filter pathologic organisms, in addition to being an effective heat and moisture exchanger in our test. The Terumo device is not made of hygroscopic material and this contributed to low resistance even after water immersion. But it showed the poorest efficiency in water retention.

In summary, the Gambro-Engström Edith Flex device was the most desirable of the six devices we evaluated in terms of its water retaining efficiency. The NMI Pneumoist 1 and the Siemens Servo Humidifier 153 units had good water retaining capacity but their higher airflow resistance need close monitoring, especially after prolonged clinical use. The Pall HME 15–22 and the Portex Humid-Vent 1 devices were also efficient in water retaining capacity. The Pall also demonstrated low airflow resistance and the minimum increase in airflow resistance after water immersion. The pathogen filtering capacity of the Pall should also be considered an additional advantage, especially in infected patients. The Terumo Breathaid device performed worst of all six devices, but it was still better than no HME at all.

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