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Methods and Devices

A New Hygroscopic Condenser Humidifier

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Abstract. A new hygroscopic condenser humidifier for the mechanically ventilated patient has been tested. It functions as a heat and moisture exchange device (HME) with an additional hygroscopic sponge to minimize the water loss from the breathing circuit. A comparative in vitro study was undertaken with a conventional HME. The influence of tidal volume, inspiratory flow rate and minute volume on the relative humidity of the inspiratory gas and on the water loss was investigated. The new device provides adequate humidification within a broad scale of ventilatory settings. In a subsequent clinical test the hygroscopic condenser humidifier proved to be a simple and reliable way of humidification.

Key words: Humidifier – Hygroscopic

Introduction

Efficient humidification of the mechanically ventilated patient may be obtained in several ways [1], but not all of them are satisfactory. The demands made on a humidifier can be summarized as follows:

a) The inspired gas should have a water content of at least 32 gm/m^3 corresponding to a relative humidity of 70% at 37 °C [2].
b) The patient should be protected against overheating or overhydration of the inspiratory gas, also when the ventilator settings are being changed.
c) The humidifier should have a low compressible volume.

Recently a new device has been introduced – the hygroscopic condenser humidifier – Servo 150® (Siemens Elema, Solna, Sweden), which is in principle a heat and moisture exchange device with a hygroscopic sponge to reduce the water loss from the breathing circuit (Fig. 1). The purpose of the present study [2] was to examine the performance of this humidifier under different ventilation settings in an experimental set-up and in clinical practice.

We compared the device with another heat and moisture exchanger without hygroscopic sponge (Portex Humid Vent®).

Material and Methods

An experimental set-up was made as depicted in Fig. 2.

A ventilator (Servo 900 B, Siemens Elema) with a humidifier in place, is connected through a PVC endotracheal tube (no. 8) with a rubber bag (Artificial lung) that empties over a water bath kept at 37 °C. The inspiratory gas is separated from the expiratory gas at the measuring points by a short bypass with two one-way valves. The temperature, the relative humidity and the water content are measured simultaneously with a thermo-hygrometer (EP-400 Wallac 04) at the following points:

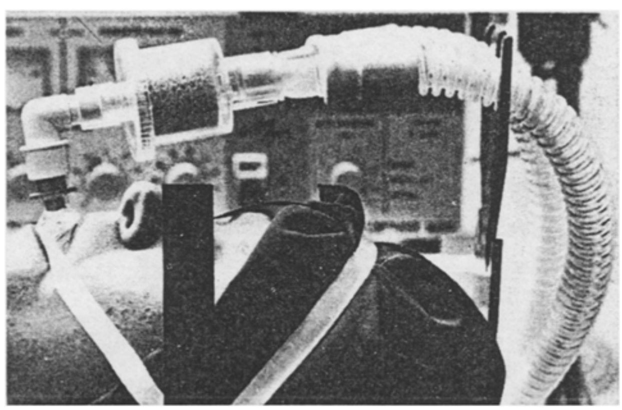

Fig. 1. The Servo hygroscopic condensor Humidifier®

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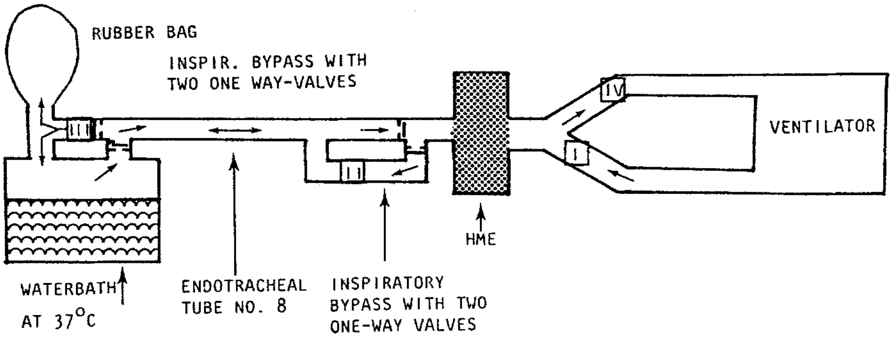

Fig. 2. An experimental system to study the performance of the two humidifiers at different ventilator settings. The measuring points are indicated by roman numerals

I The inspiratory gas, before humidification (ambient temperature; dry)
II The inspiratory gas, after passing through the humidifier
III The inspiratory gas, at the distal end of the endotracheal tube
IV The expiratory gas, after cooling and drying out in the humidifier

In the first series of experiments the effect of the inspiratory flow rate on the performance of the humidifier was studied.

At a constant tidal volume (400 ml), the flow rate was increased step-wise (4 – 80 l/min) by increasing the pre-set minute volume and adjusting the inspiratory time percentage.

In the second series of experiments the tidal volume was increased step-wise (200 – 1000 ml) at a constant inspiratory flow rate (0.6 l/s) and a pre-set minute volume (10 l/min).

The hygroscopic condenser humidifier (Servo 150) and the Portex Humid-Vent® were independently studied at each ventilator setting. The readings were done after achieving steady-state values (average 30 min). The whole series was then repeated and the average of the two values was taken.

Finally the hygroscopic condenser humidifier was tested in ten patients ventilated after open-heart surgery (average 15 h). To study the inspired and expired gas separately, the same bypass as in the experimental set up was fitted to the endotracheal tube. The temperature, relative humidity and water content were simultaneously measured in the corresponding points II and IV (Fig. 2) at 3-h intervals.

Results

In the first series of experiments the water content of the inspiratory gas after humidification with the

Table 1. See text

		Portex Humid-Vent®				Servo humidifier®			
		II			III	II			III
V_E	$\dot{V}$	Temp.[a] °C	RH %[b]	Water content[c]	Temp.[d] °C	Temp.[a] °C	RH %[b]	Water content[c]	Temp.[d] °C
2	4	22.5	70	12	26.0	24.5	90	20	28.5
2	8	22.5	70	13	26.5	24.5	90	20	28.5
4	12	22.5	67	13	27.0	24.5	90	20	28.5
4	16	22.5	67	13	27.0	25.0	90	20	29.0
4	20	22.5	65	13	27.0	26.0	90	21	29.5
10	30	23.5	65	13	28.0	27.0	85	20	30.0
10	40	23.5	65	13	29.0	27.0	85	20	30.5
10	50	24.0	62	13	29.0	27.0	85	20	30.5
20	60	24.0	60	13	29.5	28.5	80	22	31.5
20	80	24.5	60	13	30.0	29.0	78	22	32.0

V_E = inspiratory minute volume (l/min); $\dot{V}$ = inspiratory flow rate (l/min); tidal volume = 400 ml; the respiratory frequency and inspiratory time % were so chosen as to give the desired inspiratory flow rate (room temp = 21 °C RH% = 70%)
[a] temperature (°C) at the proximal end of the tube
[b] relative humidity at the proximal end of the tube
[c] absolute humidity (g/m^3) at the corresponding temperature and relative humidity, at the proximal end of the tube
[d] temperature (°C) at the distal end of the tube

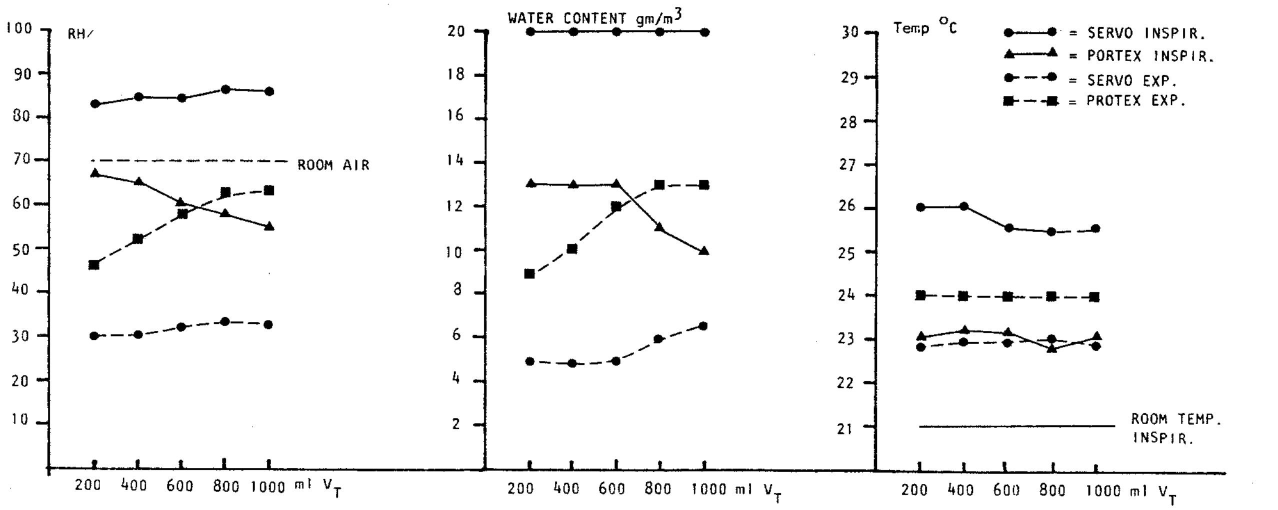

Fig. 3. The effect of Tidal Volume (V_E = 10 l/min; $\dot{V}$ = 0.6 l/s) on the humidifier performance. The temperature, relative and absolute humidity have been measured at the proximal end of the tube (II) and at the expiratory side of the humidifier (IV)

hygroscopic condenser humidifier is much higher than with the conventional heat and moisture exchanger (Table 1) at every ventilation setting. Table 1 shows that the water loss from the breathing circuit with the Portex Humid Vent® increases proportionately with the minute volume (water content up to 14 g/m^3), while the Servo humidifier 150® presented substantially lower and constant values (water content 5 g/m^3).

Figure 3 shows that the Servo humidifier 150® has an almost constant performance in the tested range of tidal volume. The effectivity of the Portex Humid Vent® decreases with an increase in tidal volume, while it is noteworthy that the temperature of the expiratory gas is higher than that of the inspiratory gas with this device.

The clinical study with the hygroscopic condenser humidifier confirmed to a great extent the experimental findings, although the water loss from the breathing circuit appeared to be higher than in the experimental situation. Increased viscosity of mucous secretions and accumulation of secretions were not found. During the observation period (up to 24 h) the performance of the humidifier did not decrease.

Discussion

The humidification of inspired gases during prolonged controlled mechanical ventilation, IMV or CPAP, still presents some practical problems. Many devices are used in clinical practice, but most of them present

Table 2. See text

		Portex Humid-Vent®			Servo humidifier®		
		IV			IV		
V_E l/min	V l/min	Temp. °C	RH %	Content g/m^3	Temp. °C	RH %	Content g/m^3
2	4	22.0	35	6.0	24.5	35	7.0
2	8	22.5	40	7.5	24.5	33	6.5
4	12	23.0	40	7.5	24.0	30	5.5
4	16	23.5	42	8.5	24.0	28	5.0
4	20	23.5	45	9.0	24.0	27	5.0
10	30	23.5	50	10.0	24.0	27	5.0
10	40	24.5	52	10.5	24.0	26	4.5
10	50	24.5	55	11.5	24.0	27	4.5
20	60	24.5	65	14.0	23.0	30	5.0
20	80	24.5	65	14.0	23.0	32	5.0

For explanation of symbols see Table 1. Temp., RH and water content measured at the expiratory limb (point IV in fig. 2) and representing the water loss from the breathing circuit

Table 3. Measurements on 10 patients with the Servo humidifier

Patient	V_E l/min	f/min	Room temp. °C	Inspiratory II Temp. °C	RH %	Water content	Expiratory IV Temp. °C	RH %	Water content
1	6.5	12	23.5	26.0	80	20	28	40	10
2	7.0	12	23.0	28.5	87	22	24	35	7
3	7.0	15	23.4	27.5	85	22	24	39	8
4	7.5	13	23.5	27.5	87	22	25	40	8
5	7.5	12	24.0	27.5	78	22	27	50	10
6	8.0	12	23.0	28.0	90	23	27	38	8.5
7	9.0	12	23.0	28.0	90	23	25	40	8
8	10.0	20	23.5	29.5	90	24	26	38	8
9	10.0	15	22.8	28.5	90	24	26	40	8
10	10.0	12	23.0	28.5	90	24	25	40	8

Temperature, RH% and water content (g/m^3) were measured at the proximal end of the endotracheal tube (II) and at the expiratory limb of the breathing circuit (representing the water loss)

one or more disadvantages, such as inconstant performance, overheating, overhydration, accumulation of condensing water in the circuit, large compressible volume etc. [1, 2, 4, 5].

Many studies have demonstrated that the heat and moisture exchangers have a poor performance [1, 2, 5] and are therefore unsuitable for long-term ventilation.

The recently introduced hygroscopic condenser humidifier (Servo 150®) utilizes a hygroscopic sponge to dry out the wasted gases to minimize the water loss from the breathing circuit and to increase the humidity of the inspiratory gas [3, 6].

In this study we compared this device under experimental conditions with a conventional heat and moisture exchanger (Portex Humid Vent®). The water loss from the breathing system is effectively reduced by the addition of the hygroscopic sponge (Table 2). The higher water loss in the in vivo study has to be explained by the higher ambient temperature.

The hygroscopic condenser humidifier is also more effective in retaining and exchanging heat, as is apparent from Fig. 3.

The inspiratory gas is ± 3 °C warmer than the expired gas while with the Portex Humid Vent the expired gas is warmer than the inspired gas. The experimental and clinical results with the hygroscopic condenser humidifier show that the inspired gas after humidification, at the proximal end of the tube is 4° – 5 °C warmer than the ambient temperature, has a relative humidity of 80% – 90% and a water content of 20 – 22 g/m^3, not affected by the tested ventilator settings. From the experimental study it is clear that the endotracheal tube itself functions as a heat and moisture exchanger (Table 1). At the distal end of the tube the temperature increased to 30° – 32 °C, the relative humidity to 100% and the water content 32 gm/m^3. This meets the criteria proposed by Forbes [2] to prevent mucosal and ciliary damage.

The increase in dead space (90 ml) introduced in the breathing circuit with this device can be easily compensated. The resistance to gas flow is comparable to the heated humidifiers (2 – 3 cm H_2O/l/s).

Obstruction of this device is virtually impossible. In our Intensive Care ward we use the hygroscopic condenser humidifier as a routine method for postoperative ventilation. It proves to be a very simple, reliable and safe method of humidification.

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