Intensive Care Med (1992) 18:97–100

Intensive Care Medicine

Comparison of hydrophobic heat and moisture exchangers with heated humidifier during prolonged mechanical ventilation

J. P. Roustan[1], J. Kienlen[1], P. Aubas[2], S. Aubas[1] and J. du Cailar[1]

[1] Département d'Anesthésie Réanimation A and [2] Département de l'Information Médicale, Hôpital Lapeyronie, Montpellier, France

Received: 28 July 1991; accepted: 15 January 1992

Abstract. Inspired gases must be warmed and humidified during mechanical ventilation. In a prospective randomized study we compared the performance of a heated humidifier (HH) (Draegger Aquaport) and a heat and moisture exchanger (HME) (Pall Filter BB 2215). A total of 116 patients requiring mechanical ventilation (Servo 900C Siemens) were enrolled into the study and were randomly assigned to 2 groups. Patients in group I were ventilated with a traditional breathing circuit with HH and patients in group II using a simplified circuit with HME. Pre-existing and hospital acquired atelectasis and pneumonia, occurrence of endotracheal tube (ET) occlusion and ventilatory parameters (respiratory rate, tidal volume) were studied. No statistical difference was found between groups for each parameter except the greater frequency of ET occlusions in the II group (0/61 vs 9/55) ($p = 0.0008$). Pall Filter (PF), a hydrophobic filter, humidifies the dry gases from the condensed water which is put down on the HME surfaces during cooling of saturated expired gases. This purely physical property is linked to the magnitude of the thermic gradient between the expired gases and the ambiant temperature. Performance impairment of PF in our study might be due to high ambiant temperature in the intensive care unit (usually around 28 °C) which reduces thermic gradient and water exchanges. We conclude that efficiency of PF may be weak in some conditions of ambiant temperature.

Key words: Equipment – Mechanical ventilation – Heat and bacterial filter

It is imperative that inspired gases during prolonged mechanical ventilation (MV) be warmed and humidified. Heated humidifiers (HH), the present gold standard, provide adequate warming and humidification over a wide range of minute ventilation. Their efficiency, however, is countered by various drawbacks linked to the accumulation of water in the circuit and to its possible bacterial colonization [1]. Heat and moisture exchangers (HME) would therefore appear to be a simple alternative. The PALL BB 2215, an antiviral and antibacterial filter used in mechanical ventilators, has also been used for its thermohygrometric properties. The aim of this study was to compare on clinical grounds the HME PALL BB 2215 with a HH (Draegger Aquaport) in ventiled patients in an intensive care unit (ICU).

Methods

A prospective randomized study was designed to assess patients over a 3-month period in an ICU at the University Hospital, Montpellier. All patients requiring MV (Servo 900C Siemens), were enrolled in this study. Exclusion criteria consisted of weight less than 35 kg and patients requiring high frequency jet ventilation. All patients were initially intubated via the nose with an endotracheal tube (ET) size 7.5, 8 or 8.5 (Mallinckrodt HiLo). When MV was judged to continue more than 8 days, tracheostomy was performed (9 mm i.d. Vygon tracheostomy tube). The patients were randomly assigned to 2 groups.

Patients in group I were ventilated with a traditional breathing circuit [2] with HH (Draegger Aquaport). Patients in group II were ventilated utilizing a simplified circuit (without HH, water trap and thermometer) with an HME (PALL BB 2215) positioned between the ET and the Y piece. Sterile water was used to maintain adequate levels in the HH of group I, the circuit was decontaminated on a daily basis and the temperature was controlled to be between 31 and 32 °C at the Y piece. The only intervention in the group II circuit was a daily change of the HME. Tracheal suction was performed every 2 h on all patients using a sterile technique. As recommended by the PALL manufacturer, in group II, 4 ml of sterile isotonic saline were instilled prior to suctioning.

Data collection for each patient included age, sex, Simplified Acute Physiologic Score (SAPS) [3] as well as durations of MV, weaning, ICU stay and outcome. Pre-existing and hospital acquired lung atelectasis and pneumonia were noted. Moreover, the occurence of ET occlusion was recorded. Ventilatory parameters including respiratory rate (RR) and tidal volume (V_T) were checked every 4 h. Three pathophysiological groups were identified; A: institution of MV not resulting from acute respiratory pathology, B: MV for acute parenchymal or parietal respiratory pathology, and C: acute phase of chronic obstructive pulmonary disease requiring MV. Pneumonic processes were diagnosed according to Johanson's criteria [4]. The diagnosis of atelectasis included chest radiograph criteria and the necessity to perform bronchial suction with a fiberscope. The diagnosis of ET occlusion was defined as the inability to pass a suction catheter (10 gauges of external diameter). Longitudinal sections of the ET were then examined to confirm the diagnosis.

Both groups were compared using Student's t-test and the Mann-Whithney test for differences between means. χ^2 analysis and Fisher's exact test were used for differences in frequencies. The search for predictive factors for the incidence of nosocomial pneumonia, atelectasis and ET occlusion was performed using stepwise regression analysis. Statistical significance was assumed when $p<0.05$.

Results

A total of 116 patients entered into this study: 61 in group I and 55 in group II. No difference was found between groups with respect to age, sex, SAPS, pathophysiological group distribution, frequency of pre-existing pneumonia and atelectasis (Table 1).

No difference could be demonstrated between groups for durations of MV, weaning, ICU stay and outcome (Table 2). Incidence of nosocomial pneumonia did not significantly differ between groups I and II (9/61 vs 5/55, $\chi^2 = 0.876$, $p>0.25$). This incidence was correlated with pre-existing pneumonia (F = 7.99, $p<0.001$). No difference could be observed in the incidence of atelectasis between groups I and II (9/61 vs 10/55, $\chi^2 = 0.294$, $p = 0.587$). Incidence of atelectasis was correlated with duration of ventilation (F = 12.54, $p<0.001$). ET obstruction was more frequent in the II group (9/55 vs 0/61, $p = 0.0008$) occurring after the 6th day of MV (6 to 37 days, median 10 days). ET were totally occluded inducing acute asphyxia in 3 cases. In the other cases wheezing was associated with the inability to pass a suction catheter. These 6 partially occluded tubes were also changed. ET occlusions were correlated with HME utilization (F = 11.98, $p<0.001$) and pre-existing atelectasis (F = 10.89, $p<0.001$). The cases of ET occlusions are characterized in Table 3.

No difference existed between groups with respect to ventilatory parameters. Furthermore, in group II ventilatory parameters for patients who experienced ET obstruction did not differ from those of other patients: RR = 19.7±0.72 vs 19.1±0.86 breaths/min and V_T = 0.665±0.053 vs 0.625±0.046 L. Ex vivo examination of obstructed ET demonstrated adherent solidified secretions forming circular deposits which spanned several centimeters and which could not be dislodged using classical aspiration techniques.

Table 1. Clinical data of studied patients

	Group I	Group II	
Patients	n = 61	n = 55	
Sex (M/F)	35/26	33/22	NS
Age (yr)[a]	49.3±18.7	52.7±18.5	NS
SAPS[a]	11.5± 4.8	11.5± 4.9	NS
Pathophysiological group distribution[b]	A = 38	A = 26	NS
	B = 19	B = 24	
	C = 4	C = 5	
Pre-existing atelectasis	n = 10	n = 7	NS
Pre-existing pneumonia	n = 11	n = 10	NS

[a] Values are expressed as mean±1 standard deviation
[b] Pathophysiological groups: A, Institution of MV not resulting from acute respiratory pathology; B, MV secondary to acute parenchymal or parietal respiratory pathology; C, acute phase of chronic obstructive pulmonary disease
NS, no significance

Table 2. Clinical variables collected during ICU stay

	Group I	Group II	p Value
Stay duration (day)[a]	9.3±10.2	13.9±16.6	NS
Duration of MV (day)[a]	8.2±11.9	10.9±14.5	NS
Duration of weaning (day)[a]	1.0± 2.9	2.4±6.6	NS
Outcome	15 death	10 death	NS
Nosocomial pneumonia	n = 9	n = 5	NS
Atelectasis	n = 9	n = 10	NS
ET occlusions	n = 0	n = 9	p = 0.0008

[a] Values are expressed as mean±1 standard deviation

Table 3. Clinical characteristics of patients developing endotracheal tube (ET) occlusion

Case	Diagnosis	V_T (L)	RR (b/min)	Occlusion[a]	i.d. ET[b] (mm)	Day[c]
1	SURG+SEPS	0.65	20	Complete	7.5	7
2	TRAU	0.72	20	Partial	9	7
3	PANC	0.60	19	Partial	9	37
4	SURG+CODE	0.73	21	Partial	9	13
5	TRAU	0.62	15	Complete	7.5	9
6	SURG+COPD	0.72	20	Complete	9	22
7	INTO+ASPR	0.65	20	Partial	9	10
8	SEPS	0.70	21	Partial	8.5	6
9	SURG+COPD	0.60	19	Partial	9	19

Abbreviations: SURG, postoperative; SEPS, sepsis syndrome; TRAU, multitrauma; PANC, pancreatitis; CODE, cardiorespiratory arrest; COPD, chronic obstructive lung disease; INTO, intoxication; ASPR, aspiration
[a] Type of ET occlusion: complete with asphyxia or partially
[b] Internal diameter of ET 7.5 mm and 8.5 mm are nasotracheal tubes, 9 mm are tracheostomy tubes
[c] Day of HME use before ET occlusion

Discussion

This study clearly demonstrates the increased risk of ET occlusion in ICU patients submitted to prolonged MV with a PALL filter (PF) (9/55: 16%). Some authors also report ET occlusion with this device, sometimes leading to life-threatening accident [5, 6]. Furthermore, when ET were removed, cement-like casts lining the entire inner portion of the lumen were observed.

Therefore, it was obvious that airway humidification was inadequate in group II. Such ET occlusion did not occur during this study in group I and clinical reports on the complications of MV report ET occlusion as a rare event when adequate humidification is used [7]. Inspired gas can be at a wide range of temperatures and humidity but alveolar gas is fully saturated with vapour at body temperature. A thermohydric gradient therefore exists between the nose and the point where gas reaches 37 °C and 100% relative humidity [8, 9]: this isothermic saturation boundary under physiological conditions is just below the carina. Above this point, natural and artificial airways act as a counter current heat and moisture exchanging system allowing fresh gas to pick up water while being heated. Secretions deposited on the inert walls of the ET also interact with the inspired gases, and when these are not sufficiently heated and humidified, the secretions dry out progressively. This can then result in ET occlusion with tenacious deposit. So airway occlusion depends on 2 factors: 1) thermic gradient between inspired gases and body temperature and 2) presence of secretions which will themselves provide additional water. Plugs will appear where the gradient is maximal: in the ET. Tracheal instillations may facilitate the cleaning of the tracheal tube before the occurence of dry thick incrustations which become unremovable [10]. In our study the bolus saline instillations through ET failed to prevent such occlusions. The interest of this technique is subject to controversy [11, 12].

No difference in the incidence of atelectasis could be demonstrated between both groups. Onset of atelectasis could only be correlated to the duration of MV. Inadequate humidification provokes changes in bronchial epithelium, but this harmful effect does not spread to secondary bronchi or more peripherally [13, 14]. So atelectasis may depend more on many others factors than on humidification only [15].

ET obstructions have not been described in most studies. But these studies included only intraoperative or stable postoperative patients and they have not evaluated HME use over prolonged period of time [16, 17, 18]. In our study, the occlusions appeared to be delayed and constantly occurred after the sixth day of MV. In recent studies focused on ICU patients, the results are divergent: some reports emphasize dramatic increase in ET occlusion with the use of PF [5, 6]; but Tenaillon et al. do not report any ET occlusions [19].

The optimal inspired humidity, during long term MV, in ICU patients is not well established. Most authors suggest that inhaled gas should be warmed to between 25 and 30 °C and be saturated with water to 100%, i.e. 23 – 30 mg water per litre of gas [20 – 22]. The performance of PF is in the lower part of the range. Furthermore, efficiency of the filters is impaired by high tidal volume [23, 24]. Therefore several factors could explain these differences between HME assessment in long term ventilation. On one hand ICU patients are heterogenous: the series may differ, as well as their ventilatory requirements and metabolic rates. Let us point out that in this study V_T were high: above 0.6 L. However ventilatory parameters do not differ within the II group, between the patients presenting ET occlusions and those who didn't. On the other hand, the role of ambiant temperature is not mentioned in any of the studies. The PF, known as "hydrophobic", is made from a chemically inert material (ceramic fibers) which turn back to the patient water vapour breathed out in expiration. Water retention in the filter is due to a purely physical phenomenon: whilst passing through the filter, saturated expired gases cool down, which provokes a reduction of saturating vapour pressure and a condensation on the HME surfaces. At the following inspiration, evaporation of this condensed water humidifies the dry gases coming from the ventilator and cools the filter (latent vaporization heat) [25]. This cooling of the HME is essential to allow continuation of the cycle. Furthermore low thermal conductivity of ceramic fibers maintains a temperature gradient between the patient-end and the ventilator-end of the filter. The importance of this thermic gradient determines the amount of water exchanged [26]. This gradient is developed between a maximum determined, on the patient-end, by the temperature of expired gas, and a minimum, on the ventilator-end, slightly below ambiant temperature (because energy is consumed in the formation of humidity: latent vaporization heat) [27, 28]. Performance impairment of PF in our study might be due to high ambiant temperature in the ICU (around 28 °C), which reduces the thermic gradient between both sides of the HME. Only a measure of hygrometric levels in ventilatory gas flows could confirm this hypothesis: this measure was not done in this study, because of lack of available fast response-time hygrometers [29].

The rate of nosocomial pneumonia was not significantly lessened by the use of PF (5/55 vs 9/61 in group I). These filters provide adequate protection of the circuit [30, 31] but their influence on the incidence of pneumonia has to be confirmed. Effectively the ventilation circuit is not the only pathway for pulmonary contamination [32].

Based on our experience, we conclude that some caution in the use of PF must be stressed. Performance of this device depends on ambiant temperature. In high ambiant temperature conditions (Burn center, Air fluidized bed unit...) and when high V_T are used, the risk of ET obstruction increases over the time period. So these devices are not adequate for replacement of HH in all circumstances.

References

1. Craven DE, Goulbate TA, Make BJ (1984) Contaminated condensate in mechanical ventilator circuits. A risk factor for nosocomial pneumoniae. Am Rev Respir Dis 129:625 – 628
2. Siemens-Elema (1982) Reglages cliniques. In: Servo Ventilator 900C Siemens-Elema AV Ventilator division. Solna Sweden, p 4:4
3. Le Gall JR, Loirat Ph, Alperovitch A, Glaser P, Granthil C, Mathieu D, Mercier P, Thomas R, Villers D (1984) A simplified acute physiology score for ICU patients. Crit Care Med 12: 975 – 977
4. Johanson WG, Pierce AK, Sanford JP, Thomas GD (1972) Nosocomial respiratory infections with gram negative bacilli. Ann Intern Med 77:701 – 706
5. Cohen IL, Weinberg PF, Fein IA, Rowinski GS (1988) Endotracheal tube occlusion associated with the use of heat and moisture exchangers in the intensive care unit. Crit Care Med 16:277 – 279
6. Martin C, Perrin G, Gevaudan MJ, Saux P, Gouin F (1990) Heat and moisture exchangers and vaporizing humidifers in the intensive care unit. Chest 97:144 – 149
7. Swillich CW, Pierson DJ, Creagh CE (1974) Complications of assisted ventilation: a prospective study. Am J Med 57:161 – 169
8. Shelly MP, Lloyd GH, Park GR (1988) A review of the mechanisms and methods of humidification of inspired gases. Intensive Care Med:14:1 – 9
9. Hayes B, Robinson JS (1970) An assessment of methods of humidification of inspired gas. Br J Anaesth 42:94 – 104

10. Tenaillon A, Boiteau R, Humbert M, Brailowsky A, Burdin M, Perrin-Gachadoat D (1990-S) Effect of periodical instillation of isotonic salt solute on tracheal tubes permeability. Am Rev Respir Dis A 569
11. Michael H, Ackerman RN (1985) The use of bolus normal saline instillations in artificial airways: is it useful or necessary. Heart Lung 14:505–506
12. Hantey MV, Rudd T, Butler J (1978) What happens to intratracheal saline instillations. Am Rev Respir Dis 117:124–129
13. Boiteau R, Gosgnach ML, Tenaillon A, Perrin-Gachadoat D, Burdin M (1990) Effets de deux niveaux de température des gaz insufflés sur l'humidification des voies aériennes et les sécrétions bronchiques en ventilation mécanique prolongée. Réan Soins Intens Méd Urg 5:357–361
14. Tsuda T, Noguchi H, Takumi Y, Aochi O (1977) Optimum humidification of air administered to a tracheostomy in dogs. Br J Anaesth 49:965–977
15. Gaussorgues Ph, Bachmann P, Jaboulay JM, Piperno D, Boyer F, Leger P, Gerard M, Robert D (1984) Etiologies des atelectases lobaires aigues sous ventilation mécanique. Etude prospective de 112 patients. Rean Soins Intens Méd Urg 5:213–216
16. Chalon J, Markham JP, Ali MM, Ramanathan S, Turndorf H (1984) The Pall Ultipor breathing circuit filter. An efficient heat and moisture exchanger. Anesth Analg 63:566–570
17. Eckerbom B, Lindholm CE (1990) Heat and moisture exchangers and the body temperature: a peroperative study. Acta Anaesthesiol Scand 34:538–542
18. Golberg ME, Jan R, Gregg CE, Berko R, Marr AT, Larijani GE (1988) The heat and moisture exchanger does not preserve body temperature or reduce recovery time in outpatients undergoing surgery and anesthesia. Anesthesiology 68:122–123
19. Tenaillon A, Cholley G, Boiteau R, Perrin-Gachadoat D, Burdin M (1989) Filtre échangeur de chaleur et d'humidité versus humidificateur chauffant en ventilation mécanique prolongée. Rean Soins Intens Méd Urg 5:5–10
20. Chalon J, Ali M, Ramanathan S, Turndorf M (1979) The humidification of anaesthesic gases: its importance and control. Can Anaesth Soc J 26:361–366
21. D'Athis F, De La Coussaye JE (1988) Humidification des voies aériennes en anesthésie. Ann Fr Anesth Reanim 7:393–400
22. Mebius C (1983) A comparative evaluation of disposable humidifiers. Acta Anaesthesiol Scand 27:403–409
23. Eckerbom B, Lindholm CE (1990) Performance evaluation of six heat and moisture exchangers according to the Draft International Standart (ISO/DIS 9360). Acta Anaesthesiol Scand 34:404–409
24. Ogino M, Kopotic R, Mannino L (1985) Moisture conserving efficiency of condenser humidifiers. Anaesthesia 40:990–995
25. Mapleson WW, Morgan JG, Millard EK (1963) Assessment of condenser humidifiers with special reference to a multiple gauze model. Br Med J 1:300–305
26. Chalon J et al. (1981) Physics of water vaporization. In: Thomas CC (ed) Humidification of anesthesic gases. Bannetstone House, Springfield, Illinois, USA, pp 5–11
27. Ravenas B, Lindholm CE (1979) The foam nose. A new disposable heat and moisture exchanger. Acta Anaesthesiol Scand 23:34–39
28. Ravenas B, Lindholm CE (1980) Temperature variations in disposable heat and moisture exchangers. Acta Anaesthesiol Scand 24:237–240
29. Tilling SE, Hancox AJ, Hayes B (1983) An accurate method of measuring medical humidifier output. Clin Phys Physiol Meas 4:197–209
30. Gallagher J, Strangeways JEM, Allt-Graham J (1987) Contamination control in long-term ventilation. A clinical study using a heat and moisture exchanging filter. Anaesthesia 42:476–481
31. Shelly MP, Bethune DW, Latimer RD (1986) A comparison of five heat and moisture exchangers. Anaesthesia 41:527–532
32. Woods DE (1988) Bacterial colonization of the respiratory tract: clinical significance. In: Pennington JE (ed) Respiratory infections: diagnosis and management, 2nd ed. Raven Press, New York, pp 34–40

Dr. J. P. Roustan
Département d'Anesthésie Réanimation A
Hôpital Lapeyronie
555 Route de Ganges
F-34059 Montpellier Cedex
France