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Methods and devices

Efficacy of a heat and moisture exchange device during high-frequency jet ventilation

D. F. Zandstra, C. P. Stoutenbeek and D. R. Miranda

Institute of Anaesthesiology and Intensive Care, University Hospital Groningen, Groningen, The Netherlands

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Abstract. A hygroscopic condensor humidifier has been tested during high-frequency jet ventilation, in an experimental set up. The influence of various ventilator settings on relative humidity, temperature and water content of the inspiratory and expiratory gases was investigated. The device provides adequate conditioning of the inspired gases with regard to relative humidity, temperature and water content at various ventilator settings.

Key words: High-frequency jet ventilation – Humidification – Heat and moisture exchange device

Efficient humidification during artificial ventilation may be obtained in several ways [1]. Also for high-frequency jet ventilation (HFJV) several methods have been described to provide humidification [5, 7, 9, 10]. The demands made on the humidifier can be summarized as follows: (a) the inspired gas should have a water content of at least 32 g/m^3 corresponding to a relative humidity (RH) of 70% at 37 °C to maintain adequat mucus flow [6], (b) the inspired gas should have a RH of at least 60% at 22–26 °C to prevent histological evidence of damage to the tracheobronchial mucosa [3], (c) the system should protect against overhydration and overheating of the inspiratory gases also when ventilator settings are changed, (d) it should have a low compressible volume, dead space and flow resistance during HFJV. The hygroscopic condensor humidifier (Servo 150, Siemens, Elema, Solna, Sweden) is a heat and moisture exchange device (HME) with a hygroscopic sponge to reduce water loss from the breathing system. This device has proved to be very effective and superior to other HME in several studies [8, 11, 12]. The aim of the present study was to examine the performance of the device during HFJV at various ventilator settings in an experimental set up.

Materials and methods

An experimental set up was as depicted in Figure 1. A high-frequency jet ventilator (Acutronic MK 800, Medical Systems AG Switzerland) using a 14 G insufflation catheter with sideholes and its tip 15 cm distal of the HME Servo 150 (Siemens Elema, Solna, Sweden) was connected via an endotracheal tube no 8 to a rubber bag that emptied over a waterbath kept at 37 °C. Temperature, relative humidity (RH) and water content (g/m^3) were measured simultaneously on spot 1 (Fig. 1) for the inspiratory gases and on spot 2 for the expiratory gases using a thermohygrometer (EP 400 Wallac 04). Various ventilator settings (i.e. frequencies 100, 200, 300 and 500 c/min) and driving pressures (1, 1.5 and 2 bar) were tested. I/E ratio was 1:2 with a F_IO_2 of 0.5. Readings were made after achieving steady state values, approximately after 15 min. The whole series were repeated and the average of the two values taken. The procedure was repeated without the HME in the circuit. The environmental temperature was kept at 24 °C with a relative humidity of 40%. Additional specifications of the tested HME were: deadspace 90 ml, compliance 0.01 ml/cm H_2O and a pressure drop at 50 l/min of 0.4 cmH_2O.

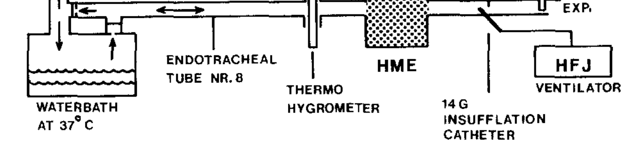

Fig. 1. Experimental set up

Results

Influence of the HME in the system on the RH and watercontent is shown in Figure 2a. Without the HME in the system the RH never exceeds 70%. With the HME in the system RH remains greater than 75% at all the ventilator settings. There is a tendency to a decrease of RH and watercontent with increasing frequencies and decreasing driving pressures. Inspired gas temperatures varied at all ventilator settings between 28.2 °C for the lowest driving pressure with the highest frequency without the HME in the system and 29.6 °C with the HME in the system on the highest driving pressure with the lowest frequency. Expired gas temperature varied between 23–24 °C with and without the HME in the system at all ventilator settings. Watercontent in the inspiratory gas with and without the HME is shown in Figure 2b. Water content in the expiratory gas varied between 3–7 g/m^3 without the HME in the system. With the HME in the ventilator circuit expiratory gas contained less than 3 g H_2O/m^3 at all ventilator settings (detection limit of the thermohygrometer).

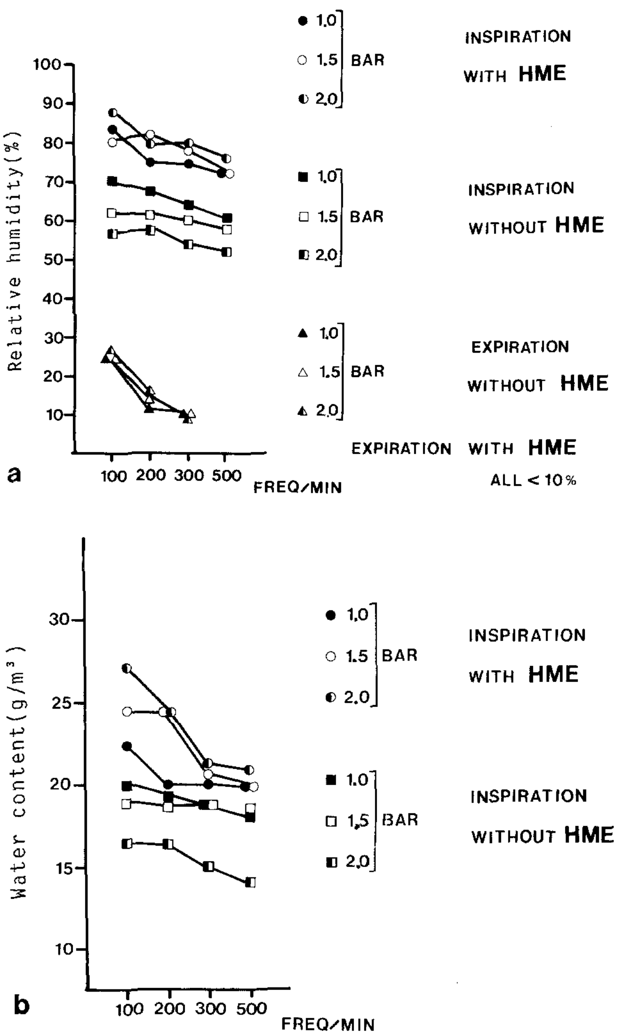

Fig. 2. a Influence of various ventilator settings on relative humidity with and without HME in the circuit. **b** Influence of various ventilator settings on water content (g/m^3) in inspiratory limb with and without HME in the circuit

Discussion

Adequate humidification during HFJV is of utmost importance. Insufficient humidification leads to rapid drying of the respiratory tract resulting in impairment of the mucociliary transport mechanisms, increased viscosity of mucous secretion, impairment of mucous flow with obstruction of airways and structural damage of the mucosal architecture [3, 5, 6, 10]. Overhydration after inhaling 100% saturated air at 35 °C can also lead to structural damage of the bronchial tree [12]. Also impairment of the mucociliary transport mechanism during HFJV can result from overhydration [10]. Several methods are used to replace watervapour loss from the respiratory tract when using HFJV. They are mainly based on substitution of calculated water loss by infusion of water through the jet itself or just distal of the jet, thereby resulting in nebulisation with or without additional heating of the inspiratory gases and with or without humidification and or heating of entrained gases [5, 7, 9, 10]. Histological studies on these various ways of conditioning gases during HFJV revealed no pathological changes [5]. During CMV no histological evidence of damage of the tracheobronchial mucosa can be observed when inhaled gases have a RH of 60% at 22–26 °C [3]. Mucus flow rates remain unaffected when inspiratory gases have a RH 70% at 37 °C. Exposure of 40 min to RH 75% at 32 °C seemed to be without harm [6]. Slowing of the mucous flow during HFJV has been shown when the aerosolation is provided by jet stream without entrained humidity [10]. In the present study the tested HME fullfills the criteria of Chalon [3] to prevent histological evidence of tracheobronchial mucosal damage. The HME effectively dries the expiratory gases during HFJV. Results on temperature, RH and watercontent are comparable to previous studies using this device during CMV [8, 11, 13]. Effects on the inspiratory temperature are limited, indicating that the endotracheal tube functions as the principal heat exchanging device. This phenomenon has also been noticed during CMV [4, 11]. The efficiency of the HFJV could be impaired by the insertion of the HME in the inspiratory line, due mainly to increased deadspace ventilation (90 ml). The additional increase in airway resistance can be neglected, although positioning of the jetcatheter too close to the device (15 cm) can result in a rebound of the jet gas stream. The small decrease in the RH and watercontent at increasing frequency and decreasing driving pressure probably reflects increased dead space ventilation and reduced "alveolar ventilation". This might be comparable to carbondioxide retention as noticed with HFJV in practise and should be considered as a ventilation technique problem and not related to the HME. Additional dead space of the device (90 ml) could be compensated for with increased driving pressure but might also be compensated for by combining HFV techniques with conventional tidal volumes. The need to increase driving pressure is also necessary in other systems for humidification during HFJV [7]. At the higher frequencies and lower driving pressures slowing of the mucus flow according to the criteria of Forbes [6] cannot be excluded. At these ventilator settings, however, ineffective alveolar ventilation can be expected, which can lead to insufficient humidification. This can also be expected in other systems that provide humidification of inspired gases [2]. In conclusion: use of this device during HFJV with a range of ventilator settings enabled adequate levels of temperature, watercontent and RH to be obtained. Clinical application of the device can be considered during HFJ ventilation if CO_2 retention can be controlled.

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Dr. D. F. Zandstra
Institute of Anesthesiology and Intensive Care
University Hospital Groningen
Oostersingel 59
Groningen
The Netherlands