PROVISION OF ENDOGENOUS AND EXOGENOUS HUMIDITY FOR THE BAIN BREATHING CIRCUIT

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INTRODUCTION

THE BAIN BREATHING CIRCUIT, a streamlined anaesthetic system of the Mapleson D classification, is purported to have several desirable clinical features, including convenience for the anaesthetist, proper scavenging of waste anaesthetic gases, and adequate CO₂ elimination.¹ The manufacturer's advertisement states that adequate humidity is provided by partial rebreathing. This paper reports our laboratory and clinical study of the humidification actually provided by the Bain Breathing Circuit, and of the effectiveness of certain humidifiers when they were added to the circuit.

METHOD

Clinical

The humidity endogenously produced by the Bain Breathing Circuit was measured in the operating room in seven young adult patients free of overt pulmonary disease and selected for this study because their operation would require endotracheal anaesthesia lasting for at least two hours. All patients understood the nature of the study. Their weights ranged from 47 to 81 kilograms.

Premedication, including belladonna alkaloids, was allowed. Halothane or nitrous oxide, or both, and oxygen with intravenous anaesthetics were used as indicated. Fresh gas flow rate (FGF) was maintained at 70 ml/kg/min or 5 litres per minute (l/min) whichever was greater.¹ The anaesthetist manually controlled minute volume by monitoring a Wright spirometer, and establishing a tidal volume of 10 ml/kg at a rate of 12 to 14 ventilations per minute to maintain normal arterial CO₂ tensions.¹ These minute ventilation values generally agreed with those suggested by the Adelaide Ventilation Guide.² Inspired humidity was measured with a previously described³ experimental circle modified by the addition of the Wright spirometer in the expiratory limb. This circle divided inspiration from expiration and was interposed between the tracheal tube and the Bain "to-and-fro" partial rebreathing system (Figure 1). Endotracheal anaesthesia was first established with the conventional semiclosed circle to prevent contamination of the experimental circle with oronasal breathing; then the experimental circle and the Bain Breathing Circuit were connected as recommended.¹ Measurements of inspired temperature and humidity were recorded at five-minute intervals. Ambient temperatures were noted throughout the experiment.

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FIGURE 1. Composite of experimental systems: 1, Wide-range HygrosensorTM and Yellow Springs Thermistor.® 2, 3, Sierra valves in series to prevent humidity sensor chamber contamination. 4, Patient. 5, Wright Spirometer.® 6, Exhalation side heated to 32° C. 7, Mirror to reflect radiant heat from humidity sensor. 8, Columbia paediatric valve. 9, Heat and moisture exchanger. 10, Bain Breathing Circuit. 11, Bain reservoir-bag support. 12, Yellow Springs thermistor. 13, Bennett Cascade humidifier. Components 9, 12, 13 were used for research; 12 and 13 were used in the laboratory study, while 9 (HME) was used clinically as described in the text. In one clinical trial 12 and 13, omitting 9, were used.

After a plateau of humidity had been established, additional humidity was given to five of the patients by interposing a Garthur Vapor Condenser (HME) between the experimental circle and the Bain Breathing Circuit. Inspired temperatures and humidity were again measured at five-minute intervals until a plateau was established. Arterial blood gases were measured at 30 minutes.

In one additional patient, humidification was added with a Bennett Cascade heated humidifier to confirm the findings of the experimental study described next.

Experimental

Three studies of humidification of the fresh gas supply were done using three different Bain Breathing Circuits and three different Bennett Cascade heated humidifiers. In each, the humidifier was interposed between the Bain Breathing Circuit and the fresh gas source as in the clinical study (Figure 1).

After time was allowed for the reservoir water in the humidifier to reach maximum temperatures, humidity and temperatures were measured at the patient end of the Bain system at FGF of 5, 6, 8, and 12 l/min. Temperature was also measured between the Cascade humidifier and the Bain system to establish the amount of heat loss in transit. Condensed water in the inner fresh gas tube was quickly suctioned every ten minutes by disconnecting the patient end and applying suction at the fresh gas port.

RESULTS

With the Bain Breathing Circuit, endogenous humidity from rebreathing varied widely, depending on the ventilatory pattern. Mean humidity ranged from 12 to

FIGURE 2. Inspired humidity with time are reported as mean and range. [●] Humidity produced by partial rebreathing alone. [×] Humidity conserved by addition of HME. The difference between the two populations of observations is statistically significant ($p < 0.05$).

13.5 milligrams of water per litre ventilation (mg/l) (Figure 2). Addition of the HME raised the mean humidity range to 18 to 19.4 mg/l (Figure 2).

Temperatures without the HME were similar to ambient temperatures ($22.8 \pm 0.8^\circ \text{C}$). The HME raised the inspired temperatures 0.5° to 1°C above ambient temperatures.

Arterial carbon dioxide tension ranged from 34 to 46 torr, and substantiated previously suggested ventilatory indices.¹

Laboratory findings with the Bennett Cascade humidifier demonstrated 100 per cent relative humidity (R.H.) at ambient temperature with reservoir water at room temperature. Subsequent trials with reservoir water at maximum heat capacity (effluent gases at 42°C) at FGF of 5, 6, and 8 l/min revealed a large temperature loss across the Bain Breathing Circuit, although the R.H. remained saturated. Temperatures at the patient end of the circuit seldom rose above 28.5°C , representing a moisture content of 28 mg/l. At a FGF of 12 l/min, the transit time was such that temperatures as high as 40°C were obtained at the patient end of the circuit (51 mg/l). At all FGFs, water condensation in the inner fresh gas tube was marked, causing noise and rapid accumulation that required suctioning. The

results from one clinical test of the Bennett Cascade humidifier with the Bain Breathing Circuit so closely matched the results from this laboratory test that no further clinical trials were made.

DISCUSSION

Numerous investigators have demonstrated pathological alteration in the morphology⁴ and function⁵ of pulmonary ciliated epithelium and in pulmonary mechanics⁶ when anhydrous gases are respired through a tracheal tube. Chalon, Loew and Malebranche have suggested that as little as 60 to 70 per cent R.H. at ambient temperatures of 22 to 26° C (13 to 15 mg/l) protects ciliated epithelium.⁴ It has also been shown that a minimum of 100 per cent R.H. at 25° C (23 mg/l) protects ciliary function,⁷ and protects the lung from atelectasis, increases in alveolar-arterial oxygen differences and changes in compliance.⁶

The endogenous humidity supplied by rebreathing at acceptable ventilatory rates with the Bain Breathing Circuit is marginally adequate to protect ciliary morphological integrity and function, but is not adequate to prevent the heat loss that can occur in infants and children⁸ or changes in pulmonary mechanics.⁶ Addition of the Garthur HME increases humidity toward the minimum recommended levels, thus placing the system's humidification slightly above that supplied by the conventional semiclosed circle at a FGF of 4 l/min.⁹ The size and convenience of the HME make it an attractive adjunct to the Bain system;^{10,11} however, its deadspace is 17 ml and its use in patients weighing less than 10 kg is not advisable.

At room temperature, the Cascade humidifier supplied adequate humidity for ciliary protection as would probably a similar device such as the Critical Care Humidifier¹² and, in fact, fully satisfied minimal requirements that have been suggested for neonatal surgery¹³ when used in ambient temperatures of 26° C. At flow rates for patients weighing 80 kg or less (less than 6 l/min), the use of the heated Cascade netted 100 per cent R.H. at approximately 28° C (27 mg/l). This approaches normal laryngeal inspired humidity;⁹ however, the nuisance caused by condensation in the fresh gas line is formidable. The need for frequent removal of condensation from the circuit completely offsets the advantage of additional humidity added by heating the Bennett Cascade humidifier for use with the Bain Breathing Circuit.

The Bain Breathing Circuit is frequently used in infants and children. Although no paediatric data were obtained in this study, several points regarding paediatric anaesthesia can be made. First, it is recommended that FGF through the Bain Breathing Circuit be not less than 3.5 l/min.¹ On the basis of this value and the suggestion by Harrison¹⁴ that FGF be 2.5 times minute ventilation, it would appear that children weighing less than 10 kg would receive poorly humidified gases because rebreathing would be minimal. That is, a 10 kg child with a tidal volume of 100 cc and breathing 15 times a minute¹ would require a fresh gas flow rate of 3.7 l/min, a value approximating the FGF of the Bain Breathing Circuit. Secondly, the 17 ml deadspace of the HME while contributing humidity, might allow carbon dioxide accumulation in the child whose anatomical deadspace is of similar size.

Finally, the use of a heated humidifier or nebulizer to satisfy humidity requirements causes rather heavy condensation in the inner fresh gas hose of the Bain Breathing Circuit. Until a method is devised to warm the Bain Breathing Circuit safely¹⁵ or to shorten the inner hose to prevent condensation*, the Bennett Cascade Humidifier should probably be used with the Bain Breathing Circuit in children only with reservoir water at ambient temperatures of 24–26° C.

SUMMARY

The endogenous humidity produced by a partial rebreathing system, the Bain Breathing Circuit, was measured clinically and experimentally. The addition of humidification by interposing a Garthur Vapor Condenser (HME) or a Bennett Cascade heated humidifier into the system was also studied.

Without supplemental humidity, the Bain Breathing Circuit probably meets marginal requirements for preservation of ciliary morphology and function during endotracheal anaesthesia. However, additional humidity is needed to prevent alteration in pulmonary mechanics. The HME is a beneficial adjunct to the Bain Breathing Circuit, raising humidity to near acceptable levels, especially if ambient temperatures range from 24° to 26° C. However, the deadspace of the HME is 17 ml, which might limit its use in children. The Bennett Cascade humidifier plus the Bain Breathing Circuit satisfies minimal suggested humidity requirements at ambient reservoir water temperatures of 24° to 26° C. Heating the reservoir water to maximum heat capacity increased humidity but caused marked water condensation along the inner fresh gas tube of the Bain Breathing Circuit.

RÉSUMÉ

Nous avons fait la mesure en laboratoire et en clinique de l'humidité endogène produite par la réinspiration partielle dans un circuit de Bain. On a également étudié les effets produits par l'addition au système d'un condensateur de vapeur Garthur (HME) ou d'un humidificateur Bennet.

L'humidité d'origine endogène lorsque le circuit de Bain est utilisé seul, se situe en moyenne à 13 mg/l ou 64 pour cent d'humidité relative à température de la pièce, ceci après dix minutes de fonctionnement. L'addition du condensateur HME élève en 15 minutes le taux d'humidité à une moyenne de 19.4 mg/l ou 92 pour cent d'humidité relative à température de la pièce. L'interposition d'un humidificateur Cascade à température de la pièce, élève le taux moyen à 21 mg/l ou 100 pour cent d'humidité relative. Si maintenant l'on fait chauffer le Cascade à son maximum, l'on retrouve un taux de 28 mg/l (100 pour cent d'humidité relative à 28.5° C); et il y a production de condensation dans le circuit de Bain avec effets bronchiques nocifs possibles.

Utilisé seul, le circuit Bain répond probablement à la limite aux exigences

*The Bain circuit is easily shortened, but once it is, the ventilation guides recommended by Bain and Spoerel¹ would probably have to be altered. The use of Harrison's guide,¹⁴ which prevents rebreathing, would solve the problem of carbon dioxide accumulation, while a shorter system might allow less condensation from a heated humidifier because of shorter transit times. This idea is presently in the protocol stage.

d'humidité permettant une conservation de la morphologie et de la fonction ciliaire durant l'anesthésie endotrachéale. Il faut cependant fournir davantage pour conserver la mécanique pulmonaire. Lorsque la température de la pièce varie entre 24–26° C, l'interposition d'un condensateur peut élever l'humidité relative à des taux acceptables. Cependant, cet appareil ajoute 17 ml à l'espacement, inconvénient possible chez l'enfant.

L'addition d'un vaporisateur Bennett avec eau chauffée entre 24 et 26° répond probablement aux besoins d'humidité suggérés. Si par ailleurs on élève la température de l'eau au maximum, le Bennett fournit probablement une humidification comparable à celle fournie par la muqueuse nasale, mais l'on assiste alors à de la condensation dans le circuit de Bain, ce qui contrebalance les avantages obtenus.

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