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Humidification of the Circle Absorber System

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The circle absorber system is a commonly used anesthesia circuit capable of functioning efficiently with both high and low fresh gas inflows (10 to 0.5 l/min). However, when one reviews its constructional characteristics, it becomes obvious that the primary intent of the designer was to prevent reinspiration of carbon dioxide, and that the moisture content of inspired gas is left to chance. Several investigators have tried to increase the humidity output of the system through the addition of electrically or chemically heated vaporizers,[1,2] by introducing fresh gas inflow (FGI) directly into the soda lime canister,[3] or by using coaxial inspiratory and expiratory limbs.[4] While each of these methods has proved successful in increasing the humidity of inspired gas, none has eliminated the wasteful loss of heat and moisture that takes place in the channels connecting the soda lime canister to the inspiratory dome valve. A circle system (patent pending) was designed to minimize this loss of warmth and humidity. The circuit, and the methods employed to regulate its humidity output, are described.

METHODOLOGY

A modified circle absorber system (MCS) was constructed by introducing a 25-cm copper pipe (18 mm ID) through the center of the lid of a North American Dräger circle absorber canister (fig. 1). The pipe passed through the center of the canister and ended in the compartment immediately below the soda lime. A short L-shaped pipe bearing a pressure-release valve and an anesthesia bag connector was introduced through the side wall of the canister at its bottom end. An inspiratory dome valve was inserted on the top of the pipe passing through the center of the canister. A coaxial breathing circuit,[4] 90 cm long, was then connected to the canister. The inner inspiratory tube conveyed gas emerging from the inspiratory dome valve to the patient end of the circuit. The outer expiratory tube was connected at its machine end to the expiratory dome valve of the system by means of a short corrugated tube. Fresh gas inflow was introduced into the circle by either of two inflow ports: one in the lid of the canister (high-humidity port), and the other in the inspiratory dome valve (low-humidity port). Anesthetic gas delivered to the patient was humidified by two distinct processes: 1) *biologically* since the warm gas exhaled by the patients between the coaxial tubes heated the inspired stream, thus preventing rainout from warm humid inspired gas and causing vaporization of droplets nebulized at the inspiratory dome valve,[4] and 2) *chemically* through the reaction of neutralization of the soda lime by carbon dioxide. During expiration, condensation of water occurs in the compartment of the canister situated below the soda lime, but during inspiration, gas rich in water vapor and water droplets is rehumidified during its passage through the central tube, which is heated by the reaction of neutralization.

The system was tested on a model patient[5] and on eight anesthetized patients.

Laboratory Study

The model patient used is depicted in figure 2. The patient end of the coaxial tubing described in figure 1 is at the left in figure 2. A short corrugated tube containing a hygrosensor, electrically connected to a Hygrodynamics¶ electric hygrometer indicator, was inserted between the inspiratory limb of the MCS and a Y-piece. A 5-liter anesthesia bag, receiving carbon dioxide through its tail from a calibrated metered source, was attached to the vertical limb of the Y-piece. The remaining limb of the Y-piece was connected by means of a second corrugated tube to the inlet port of a Cascade** humidifier. The outlet port of the humidifier was connected to the expiratory tube of the circuit by means of a third corrugated tube attached at its patient end. Thermistor probes connected to a multichannel telethermometer were inserted: 1) in the inspiratory limb of the circuit near the hygrosensor, 2) at the junction of the tube connecting the outlet of the humidifier to the expiratory limb of the circuit, and 3) in

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¶ Model 15-3001. Hygrodynamics, Inc. Silversprings, Maryland.
** Bennett Respiration Products, Inc., Santa Monica, California.

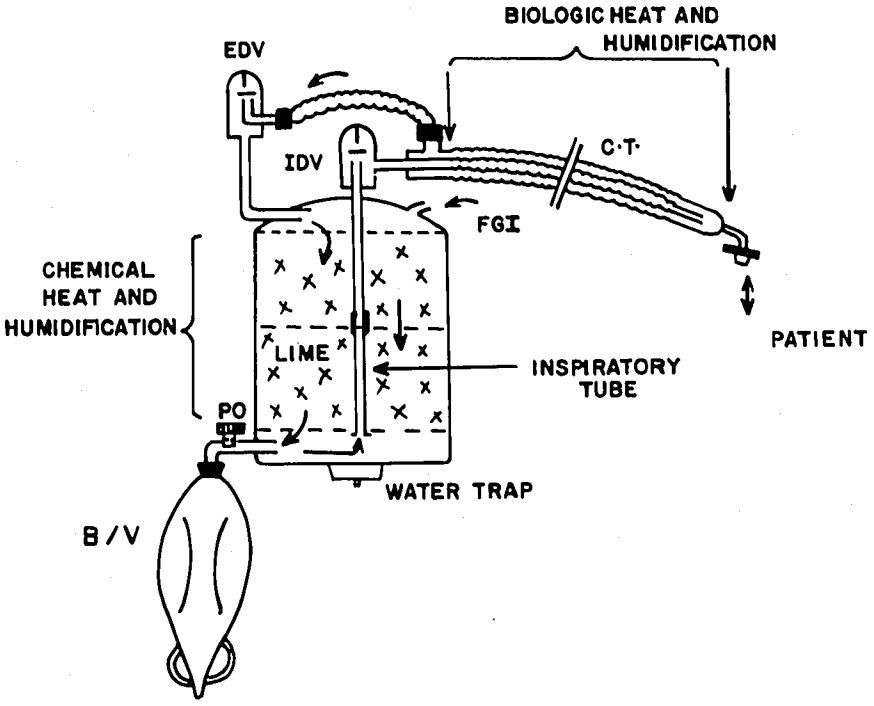

FIG. 1. Modified circle absorber system (MCS): B/V = anesthesia bag or ventilator; P.O. = pressure-release valve on L-shaped tube; EDV = expiratory dome valve; IDV = inspiratory dome valve; FGI = fresh gas inflow port in the lid of the canister (a fresh gas inflow port inserted into the inspiratory dome valve is not shown); CT = coaxial breathing tubes.

ambient air. Ventilation was ensured by an Airshields Ventimeter ventilator. The thermostat of the Cascade was regulated to maintain the temperature of the gas reaching the expiratory limb at 32 ± 0.6 C (mean temperature measured in the endotracheal tubes of ten anesthetized patients at the level of the incisor teeth). The anesthesia bag of the model was its lung, the CO_2 blown into the tail of the bag represented metabolic production, and the humidifier introduced exhaled water vapor into the circuitry.

Three sets of experiments were conducted to study the humidity output of the MCS in relation to time: 1) with fresh gas inflow (FGI) introduced into the inspiratory dome valve at a rate of 5 l/min, V_{CO_2} 200 ml/min, V_t of 500 ml, and f 12/min; 2) with FGI introduced directly into the lid of the canister, using the same V_{CO_2}, FGI and ventilatory settings; 3) using settings similar to those in experiment 2, but reducing FGI to 1.5 l/min. In addition, the humidity output of the MCS was compared with that of a regular Dräger circle system and assessed

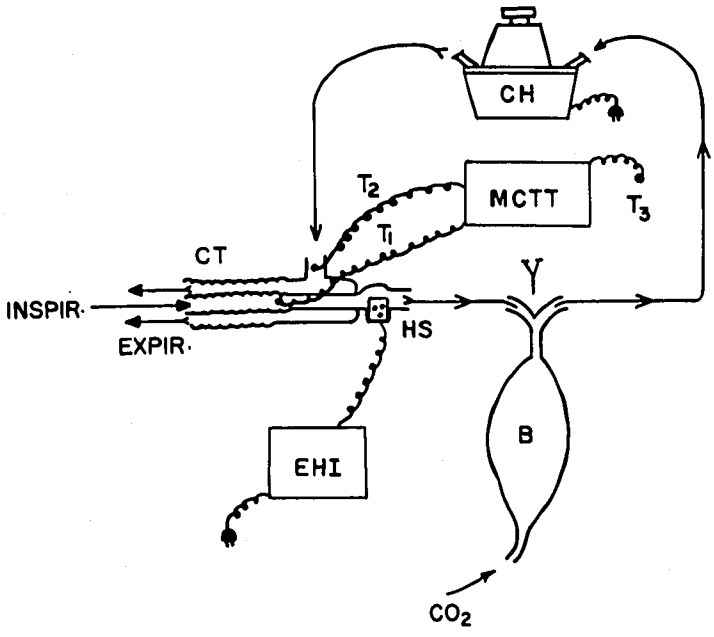

FIG. 2. Model patients used in the laboratory: CT = patient end of coaxial tubing; HS = hygrosensor; EHI = electric hygrometer indicator; B = 5-liter anesthesia bag; Y = Y piece; CH = Cascade humidifier; MCTT = multichannel telethermometer; T_1, T_2, T_3 = thermistor probes.

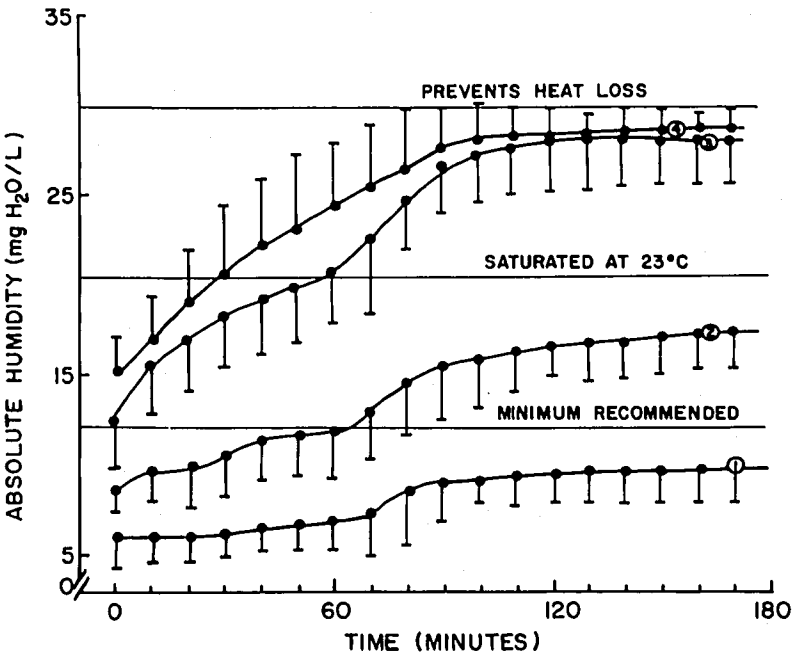

FIG. 3. Humidity output of the regular circle system compared with that of the modified circle absorber system (MCS) in relation to time. *Curve 1* = regular circle system (FGI = 5 l/min, V_t = 500 ml, f = 12/min, $\dot{V}_{CO_2}$ = 200 ml/min); *Curve 2* = modified circle system (MCS) using same gas inflows and ventilatory rates with FGI introduced at the inspiratory dome valve; *Curve 3* = MCS using same gas flows and ventilatory settings but with FGI introduced at the lid of the canister; *Curve 4* = MCS using same ventilatory settings and $\dot{V}_{CO_2}$ as for Curve 3 but with FGI reduced to 1.5 l/min. Brackets indicate mean ± 1 SD, n = 5.

by the method of Chalon *et al.*,[5] using FGI 5 l/min, V_t 500 ml, $\dot{V}_{CO_2}$ 200 ml/min, and f 12/min. The resistance of the MCS was also compared with that of the regular circle system at flow rates of 10, 20, 40, 60, 80 and 100 l/min. Finally, the temperature in the inspiratory limb of the circuit was measured at various distances from the patient end, at the termination of experiment 2. All experiments were repeated five times and results expressed as mean (± 1 SD) of individual measurements. Statistical significance was assessed by Student's t test for values obtained with the MCS and the regular circle system.

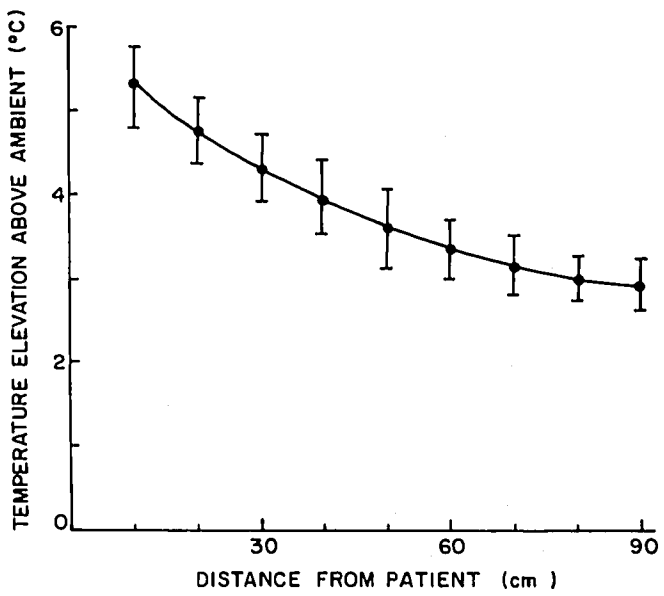

FIG. 4. Temperature elevation above ambient in the inspiratory tube of the modified circle absorber system (MCS) at various distances from the patient end, at stabilization with the fresh gas inflow introduced into the lid of the canister. Brackets indicate mean values ± 1 SD, n = 5.

Clinical Study

Eight consenting patients underwent general endotrachael anesthesia utilizing the MCS. They included two men and six women, ranging in age from 34 to 74 years, and weighing 42 to 84 kg. The mean duration of operation was 275 ± 77 minutes. Anesthesia was induced with thiopental (3 mg/kg) and succinylcholine (1.5 mg/kg) intravenously, and maintained with nitrous oxide in oxygen supplemented with 0.5 to 1 per cent halothane or *d*-tubocurarine and a narcotic. Arterial blood-gas tensions were measured 15, 45, 90, 135, and (when relevant) 180 minutes after onset of anesthesia. Inhaled gas humidity and temperature were measured on an electric hygrometer indicator and telethermometer connected to a hygrosensor and thermistor probe inserted at the patient end of the inspiratory limb of the system. FGI was directed into the circuit through the high-humidity inflow port, at flows of 4.5 ± 0.5 l/min. Ventilation was maintained automatically with tidal volumes of 10 ml/kg, 10 times per minute. The esophageal temperatures of all subjects were continuously recorded.

RESULTS

Laboratory Study

The humidity output of the MCS (fig. 3) was consistently higher than that of the regular circle system

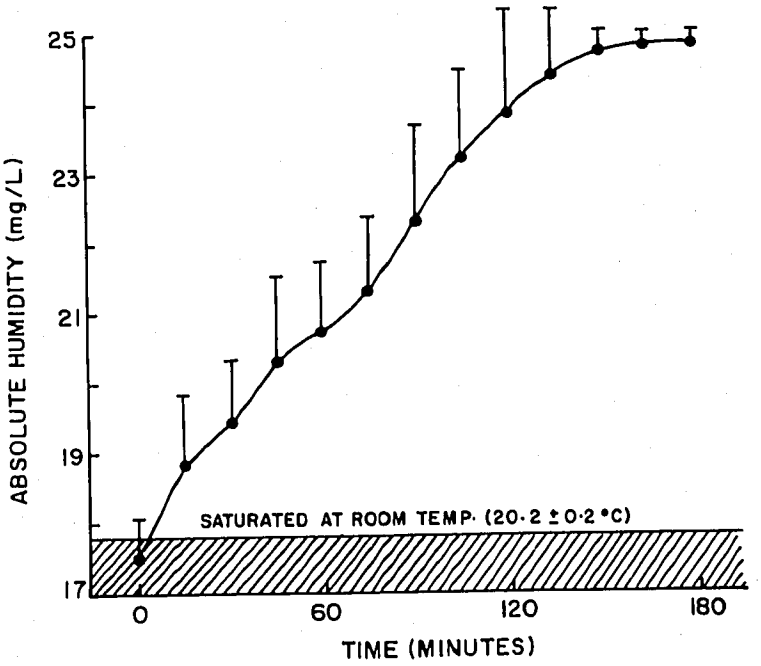

FIG. 5. Humidity output of the modified circle absorber system during clinical use on eight patients. The brackets indicate mean values ± 1 SD.

when similar FGI's and respiratory settings were used with the FGI introduced into the inspiratory dome valve. At the onset of experimentation absolute inspired humidities were 9 ± 0.7 mg H_2O/l and 6 ± 0.8 mg H_2O/l, respectively. Humidity output increased gradually in both circuits, reaching 17 ± 2 mg H_2O/l for the MCS and 10.1 ± 1.6 mg H_2O/l for the regular circle system. When FGI was introduced directly through the soda lime of the MCS, its humidity output was much higher. It started at 12.2 ± 2.5 mg H_2O/l and reached and stabilized at 27 ± 2.5 mg H_2O/l after 120 minutes of use. Reducing FGI to 1.5 l/min produced a higher original humidity (15 ± 1 mg H_2O/1), but at stabilization after 90 minutes of use, the humidity output was very similar to that obtained with a higher FGI (28 ± 1.5 mg H_2O/l). Measurement of inspiratory limb temperatures at various distances from the patient end of the system at the termination of experiment 2 (fig. 4) showed 5.25 ± 1 C above ambient temperature 10 cm from the patient, with temperatures diminishing exponentially as the distance from the patient increased, reaching 3 ± 1 C at 90 cm.

The resistances of the MCS and regular circle system were almost identical. Both were of the order of 0.05 cm H_2O/l/min at flows of 10, 20, 40, and 60 l/min, and 0.1 cm H_2O/l-min at a flow rate of 100 l/min.

Clinical Study

The humidity output of the MCS during anesthesia was very similar to that seen in the laboratory when one takes into account differences in ambient temperatures (mean ambient temperatures were 23.2 ± 3.9 C in the laboratory and 20.2 ± 0.2 C in the operating room). At the onset of anesthesia (fig. 5), inspired gas contained 17.6 ± 0.5 mg H_2O/l. Humidity increased steadily, reaching 24.75 ± 0.6 mg H_2O/l after 150 minutes.

The arterial blood-gas tensions of all patients remained within acceptable limits. The mean reduction in temperature sustained by patients anesthetized using the MCS was 0.3 ± 0.15 C, which was significantly lower than the temperature reduction sustained by eight patients anesthetized with the regular circle system and undergoing similar operations (1.5 ± 0.5 C), $P < 0.0005$.

DISCUSSION

The high inspired moisture content of gas delivered by the MCS was confirmed by the fact that fogging of the inspiratory dome valve was noticed both during anesthesia and in the laboratory after approximately an hour of use. Fogging of the expiratory dome valve during anesthesia with the regular circle system is common, but fogging of both valves is never seen with that system unless a water vaporizer is introduced in the gas delivery line. The minor reduction in body temperature sustained by patients placed on the MCS also attests to its ability to prevent heat loss from the lung because of its high humidity output.

The higher humidity output of the MCS in the laboratory was due to the fact that ambient tempera-

ture was higher than that in the operating room by approximately 3 C. However, the increases above saturated humidity at room temperature were very similar in the two settings (7.5 mg H_2O/l in the laboratory and 7.25 mg H_2O/l in the operating room).

The soda lime used in all our experiments was Soda-Sorb,††, which probably accounts for the low stabilized humidity output of the regular circle system compared with values obtained in a previous study conducted with barium hydroxide lime USP.[5] In fact, temperatures in the center of the canister did not exceed 34 C in the present study, whereas they were of the order of 42 C when barium hydroxide lime was used. This no doubt indicates that we could have obtained even higher humidities in the present study had we used a different type of lime.

A loss of humidity still occurs in the unheated portion of the MCS, which includes the part of the tube in the center of the canister that emerges above the lime (fig. 1), the inspiratory dome valve, and its connection with the circuit. It is obvious that water of condensation occurs in this area, since we noticed fogging of the inspiratory dome valve in all our experiments. Thermally insulating that section would no doubt increase the humidity of inspired gas.

†† Dewey and Almy Chemical Division, W. R. Grace & Co., Cambridge, Massachusetts.

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Anesthesia-induced Rhabdomyolysis in a Patient with Duchenne's Muscular Dystrophy

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Tachycardia during general anesthesia is a nonspecific response of the body to a variety of stimuli. Pain, hypercarbia, hypoxia and pyrexia are important differential diagnoses that must be considered when tachycardia occurs. We report a case in which a young child in whom severe tachycardia with multifocal premature ventricular contractions developed was subsequently found to have acidosis, hypercarbia, myoglobinuria, and markedly elevated creatinine phosphokinase, without an elevation in body temperature or evidence of increased heat production. Subsequent clinical investigation and muscle biopsy revealed that the patient had Duchenne's muscular dystrophy.

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Report of a Case

A 4-year-old boy, an only child (20 kg), was scheduled for elective calcaneal osteotomy to repair "flat feet." Halothane anesthesia given without the use of succinylcholine for tonsillectomy at another hospital four months previously had been uneventful. The child was brought to the operating room without premedication. Rectal temperature prior to operation was reported to be 36 C. Induction of anesthesia by mask through a circle system with CO_2 absorber with halothane, N_2O and oxygen was accomplished without difficulty in this cooperative child. A #20 intravenous line was established. The heart rate was 120/min, with normal sinus rhythm. Succinylcholine, 20 mg, was administered. Rigidity was not seen, and ventilation was controlled briefly with 1.5 per cent halothane (Dräger Vapor vaporizer) and oxygen. Insertion of the laryngoscope resulted in a transient slowing of the heart rate to 70/min, and 0.1 mg atropine was given. The heart rate then returned to 120/min. The larynx was difficult to visualize but muscular relaxation seemed adequate. After two attempts at intubation, the succinylcholine effect had worn off, and the child breathed spontaneously. Heart rate was 120/min. A second dose of succinylcholine (20 mg) was administered after an additional 0.2 mg atropine, and a #5 orotracheal tube was inserted. The breath sounds were equal over each hemithorax.

The surgical preparation of the patient began approximately 20 minutes after induction of anesthesia. Manual ventilation with 50 per cent N_2O and 2 per cent halothane did not slow the pulse rate of 140/min. Oropharyngeal temperature was 36.6 C.

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