A High-humidity Circle System for Infants and Children

Jack Chalon, M.D.,* Ronald Simon, B.S.,† Sivam Ramanathan, M.D.,‡ Chandrakant Patel, M.D.,§ Glenda Klein, B.A.,† Peter Rand, B.S.,† Herman Turndorf, M.D.¶

A scaled-down version of a modified adult circle system capable of increasing normal humidity output 300 per cent was constructed for pediatric use. The moisture content of the gases leaving the system was tested and found to be superior to that of any pediatric circle system commercially available that does not incorporate an electrically heated water vaporizer. (Key words: Anesthesia, pediatric. Equipment: circuits; circle. Humidification.)

Existing pediatric circle-absorber systems (Bloomquist infant circle and Columbia valve mounted on adult circle systems) cannot supply infants weighing 5 kg or less with more than 10 mg H₂O/lt. This is 2 mg H₂O/lt below the minimum recommended inhaled moisture that will prevent damage to the ciliated cells of the tracheobronchial tree and these systems take two to three hours to achieve this level of humidification. Although the addition of electrically heated water vaporizers can produce adequate humidity, this can be done only through the use of high fresh gas inflows and high temperatures, and is associated with the dangers inherent with the use of electrical devices on anesthesia systems (tracheal burns due to overheating, electrocutions and explosions). To overcome these limitations, we have built a new pediatric circle-absorber system and tested it on a patient model.

Methods

A soda lime canister was made by closing the top and bottom ends of a polyvinylchloride (PVC) cylinder 15 cm long and 12 cm in diameter with appropriate PVC discs (fig. 1). Two snugly fitting fine-wire-mesh gauze sieves (WMG) with circular PVC outer frames and central PVC-coated circular apertures 18 mm in diameter had been inserted 1 cm below the lid and 3 cm above the bottom of the canister. A PVC tube 14 cm long and 18 mm in diameter was inserted through central holes in both the lid and the wire-mesh sieves. It protruded 1 cm above the lid and 1 cm below the lower sieve. A unidirectional inspiratory rubber flap valve (IV) was inserted between the top end of the central tube and the 90 cm long and 18 mm ID inspiratory limb of a coaxial corrugated breathing tube (CT). The 26-mm ID outer coaxial tube was connected to an expiratory rubber flap valve (EV) inserted into an 18-mm eccentric hole in the lid of the canister. Its patient end was tapered to accept a standard elbow connector or mask. Finally, a fresh gas inflow tube (FGI) was inserted into a 5-mm hole in the lid of the canister.

Two circular apertures were made into the lateral wall of the canister. The larger aperture, 5 cm in diameter, was made 6 cm below the upper rim and the smaller aperture, 2 cm in diameter, 1 cm above the lower rim. A snugly fitting short L-shaped PVC tube, 2 cm in diameter, bearing a pressure release valve (PO) and an anesthesia bag or ventilator (B/V) connector was fitted into the lower aperture. A threaded PVC tube 2 cm long and 5 cm in diameter was fitted into the upper aperture. All connections were glued tightly with Flexcraft** acrylic cement. The canister was filled with SodaSorb†† lime through the large aperture in its

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** Associate Professor.
† Research Assistant.
‡ Assistant Professor.
§ Instructor.
¶ Professor and Chairman.

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Address reprint requests to Dr. Chalon; 9 Tarryhill Road, Tarrytown, New York 10591.

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** Flexcraft Industries, Inc., Newark, New Jersey.
†† Dewey and Almy Chemical Division, W. R. Grace & Co., Cambridge, Massachusetts.
side wall, which was hermetically sealed by a screw-on lid (FC).

The model patient on which the system was tested is shown in figure 2. The patient end of the coaxial tube (CT), depicted in figure 1, is at the left of figure 2. A short corrugated tube contained a hygrosensor (HS) electrically connected to a Hygrodynamics** electric hygrometer indicator (EHI), was inserted between the inspiratory limb of the pediatric system and a Y piece (Y). A 1- or 2-l anesthesia bag (B), receiving carbon dioxide through its tail end from a calibrated metered source (CO₂) was attached to the vertical limb of the Y piece. The remaining free limb of the Y was connected by means of a second corrugated tube to the inlet port of a Cascade §§ humidifier (CH). 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 (MCTT) were inserted: in the inspiratory limb near the hygro-sensor (T₁), at the junction of the tube connecting the outlet of the humidifier to the expiratory limb of the circuit (T₂), and in ambient air (T₃). The thermostat of the Cascade was regulated to maintain the temperature of the gas reaching the expiratory limb at 32 ± 0.5°C. Ventilation was assured by an Ohio Anesthesia Ventilator™ (Series 300/DO) with infant bellows.

Four sets of experiments were conducted using fresh dry systems and CO₂ outputs of 15, 30, 45 and 60 ml/min, estimated to be equivalent to the CO₂ production per min of children weighing 5, 10, 15 and 20 kg (3 ml/kg body weight: Smith TC, University of Pennsylvania, Philadelphia, Pennsylvania, personal communications). Ventilator settings were adjusted as follows: 1) V₁ = 50 ml, f = 24; 2) V₁ = 100 ml, f = 22; 3) V₁ = 150 ml, f = 20; 4) V₁ = 200 ml, f = 18, for 5-, 10-, 15-, and 20-kg model children, respectively. All experiments were conducted at FGI values of 1, 3 and 5 l/min, repeated three times, and mean humidity and temperature measurements calculated for readings

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** Model 15-3001, Hygrodynamics Inc., Silverspring, Maryland.

 §§ Bennett Respiration Products, Santa Monica, California.

 †† Ohio Medical Products, Madison, Wisconsin.

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Fig. 3. Nomogram predicting the humidity output of the system after a period of stabilization that lasts approximately an hour. At the onset of anesthesia humidity values are approximately 25 per cent below indicated values. To calculate inspired humidity join an appropriate FGI value (fresh gas inflow expressed in liters per minute) on the curve on the right to an approximately estimated CO₂ production/min (VCO₂) on the line in the center and prolong to the vertical line on the left. Read absolute humidity in mg/L. To approximate relative humidity at room temperature (22.5°C), multiply by a factor of 5. The shaded area indicates the humidity range of the system.
made at 5-minute intervals. A 1-l bag (fig. 2) was used for CO₂ production of 10 l/min or less, and a 2-l bag for all other measurements. Finally, the resistance of the circuit was measured using gas flows of 20, 40, 60, 80 and 100 l/min.

**Results**

Humidity outputs of the system (fig. 3) ranged from 14 to 24 mg H₂O/l with an FGI of 5 l/min and CO₂ production of 15 ml/min and an FGI of 1 l/min and CO₂ production of 60 ml/min, respectively. These results were obtained after periods of stabilization that lasted 52 ± 24 min. Humidity values at the onset of experimentation were approximately 25 per cent lower than at stabilization. Finally, resistance of the system varied, being 0.05 cm H₂O/l for flows of 40 l/min or less, 0.1 cm H₂O/l for a flow of 60 l/min, 0.125 cm H₂O/l for a flow of 80 l/min, and 0.17 cm H₂O/l for a flow of 100 l/min. Room temperature was 22.5 ± 1.4 °C throughout experimentation.

Anesthetic gases delivered at the patient end of the system are humidified by both biologic and chemical heat. The reaction of neutralization of the soda lime by carbon dioxide produces heat and moisture. Expired gases rain out a certain amount of water after their passage through the soda lime (into the space of the canister below the lime and reservoir bag or ventilator). During inspiration, gases rich in water droplets (resulting from the raining out) join the fresh gas inflow, which has been humidified during its passage through the lime. Since the central tube in the canister is heated by the reaction of neutralization, it is reasonable to assume that vaporization of water droplets in that heated tube further enriches the inspired gas mixture with water vapor. Finally, the warm gases exhaled by the model child between the coaxial breathing tubes heat the inspired gas stream and thus decrease the rainout that can occur with conventional systems.

The humidity output of the system is adequate for all children weighing between 5 and 20 kg (fig. 3). Since the system has valves, virtually no reinpiration of carbon dioxide occurs during its use, so that it is possible to use it with both high and low fresh gas inflows. For instance, the absolute humidity of 14 mg H₂O/l inspired by children weighing approximately 5 kg can be safely increased to 18 mg H₂O/l by decreasing FGI to 1 l/min. Similar decreases in fresh gas inflows produce a much lower inspired humidity with existing conventional infant circle systems. The Columbia pediatric circle and the Bloomquist infant circle (even when modified as recommended by Berry et al.) cannot increase inspired humidity to more than 10 mg H₂O/l for small children weighing 5 kg or less. In addition, the period of stabilization of our circuit is much shorter when compared with those of the Columbia and Bloomquist systems (1, 2, and 3 hours, respectively). Finally, our initial humidity readings are only 25 per cent less than stabilized values, while those of the other two systems are 55 and 60 per cent less than these values.

We think that our circuit, therefore, is ideal for humidity output, particularly when used with small children. Its flow resistance characteristics are comparable to those of pediatric circuits in current use.

**References**

2. Berry FA Jr, Hughes-Davies DI: Methods of increasing the humidity and temperature of inspired gases in the infant circle. *Anesthesiology* 37:456–462, 1972