Humidity Output of the Bloomquist Infant Circle

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Despite the well-known disadvantages associated with the use of rebreathing infant circles (inhalation of soda lime dust,1 channeling caused by poor packing, and high resistance), some anesthesiologists prefer them to high-flow semiclosed and nonrebreathing systems, on the assumption that they provide a higher inhaled humidity and because they can be used with reduced fresh gas inflows, which improve operating-room ecology. To verify the presumption of high inspired moisture we have studied the humidity output of the Bloomquist infant circle6 using a model patient6 and have constructed nomograms that predict inspired humidity after a period of stabilization for infants and children in relation to various fresh gas inflows. Recommendations as to the type of patient likely to receive adequate moisture from the system are made. Variations in humidity caused by structural alterations are also discussed.

MATERIALS AND METHODS

A model patient was constructed (fig. 1) by attaching a 1- or 2-liter anesthetic bag to the patient end of a Bloomquist infant circle, flowing CO2 from a calibrated metered source through the tail of the bag, and placing a Cascade Humidifier6 in the expiratory limb at the Y piece. Ventilation was provided by an Ohio Anesthesia Ventilator** (series 300/DO) with infant bellows. Thermometers were inserted: 1) at the Cascade outlet, 2) in the center of the soda-lime canister, and 3) in the inspiratory limb at the Y piece close to a hygrometer connected to a Hydrodynamics Electric Hygrometer Indicator.† The thermostat of the humidifier was regulated to maintain outlet temperature at 31 C (the mean temperature, measured in the endotracheal tube, of ten anesthetized children at the level of the incisor teeth). 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 VO2’s of children weighing 5, 10, 15, and 20 kg (3 ml/kg body weight). Ventilator settings were adjusted as follows: 1) VT = 50 ml, f = 24; 2) VT = 100 ml, f = 22; 3) VT = 150 ml, f = 20; 4) VT = 200 ml, f = 18, for the 5-, 10-, 15-, and 20-kg model children, respectively. All experiments were conducted with fresh gas inflows (FGI) of 1, 3, and 5 l/min, repeated five times, and humidity and temperature measurements recorded at 15-minute intervals. Fresh gas inflow and ventilator attachments were then reversed (fig. 2) and all measurements repeated. The canister was filled with 350 g barium hydroxide lime, USP. A 1-liter anesthetic bag was used at the patient attachment end of the system for the 5- and 10-kg model children and a 2-liter bag for the 15- and 20-kg models. Room temperature was recorded throughout the study. Results represent the means of five individual measurements recorded under identical conditions.

RESULTS

Humidity outputs of the Bloomquist system ranged from 1 mg H2O/l with a VCO2 of 15 ml/min and an FGI of 5 l/min (fig. 3) to 11 mg H2O/l with a VCO2 of 60 ml/min and an FGI of 1 l/min, after three hours of use. Humidity remained below 2 mg H2O/l in all experiments using VCO2 15 ml/min irrespective of the FGI used. When VCO2 was increased to

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§ Bennett Respiration Products, Inc. Santa Monica, California.
** Ohio Medical Products, Madison, Wisconsin.

† Hydrodynamics, Inc., Silver Spring, Maryland (model 15-3001).
30 and 45 ml/min using FGI 1 l/min, humidity gradually increased to 4 and 6 mg H₂O/l, respectively, over a three-hour period, and remained below 2 mg H₂O/l with higher FGI’s. When VCO₂ was increased to 60 ml/min with an FGI of 1 l/min, humidity gradually increased from an original 4 mg to 11 mg H₂O/l over a three-hour period, but it remained below 2 mg H₂O/l with higher FGI’s.

Reversing ventilator and fresh gas inflow attachments (fig. 2) resulted in much higher humidities (fig. 4). The amounts of moisture delivered by the system ranged from 5 mg H₂O/l with a VCO₂ of 15 ml/min and an FGI of 5 l/min to 25 mg H₂O/l with a VCO₂ of 60 ml/min and an FGI of 1 l/min, after three hours of use. Generally speaking, humidity measurements reached two thirds of final value after two hours of use and only one third after one hour of use. An exception to this rule was the

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**Fig. 1.** Model patient placed on the Bloomquist infant circle absorber system. The arrows indicate gas flow. V = ventilator, A = absorber canister, FGI = fresh gas inflow inlet port, PO = pop-off valve, IDV and EDV = inspiratory and expiratory dome valves, IL = inspiratory limb of the circle, M = manometer, B = bag attached at patient end, T₁, T₂, and T₃ are thermometers. HS = hygrosensor, and EHI = electric hygrometer indicator.

**Fig. 2.** Bloomquist infant circle absorber system with ventilator (or bag) and fresh gas inflow attachments switched. V = ventilator, FGI = fresh gas inflow, A = absorber canister, IDV and EDV = inspiratory and expiratory dome valves, IL and EL = inspiratory and expiratory limbs of circle, M = manometer, P = patient attachment. Arrows indicate direction of gas inflow.
humidity measured with a $\dot{V}_{CO_2}$ of 15 ml/min, with which the increase in humidity was much more gradual, and amounting to only 15 percent per hour of use.

Room temperature was $24 \pm 0.5$ C throughout the study.

The temperature of the soda lime in the absorber canister attained a maximum of 55 C after three hours with the usual system using an FGI of 1 l/min and a $\dot{V}_{CO_2}$ of 60 ml/min, and a minimum of 18 C when the ventilator and fresh gas inflow connections were reversed using an FGI of 5 l/min and a $\dot{V}_{CO_2}$ of 15 ml/min.

The nomograms were constructed from figures shown in table 1.

**DISCUSSION**

The humidity output of the Bloomquist infant circle (fig. 3) falls far below our minimum recommended standards. Only a child
TABLE 1. Humidity Output of the Bloomquist Infant Circle*

<table>
<thead>
<tr>
<th>FGI (l/min)</th>
<th>$V_{CO_2}$ (ml/min)</th>
<th>Humidity, mg/l gas</th>
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<td>Usual System</td>
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* At stabilization (after 3 hours of use), in relation to $V_{CO_2}$, both in the usual system and when ventilator (or bag) and FGI connections are switched. All figures are the means of five measurements.

with a $V_{CO_2}$ of 60 ml/min (i.e., weighing around 20 kg) can generate enough moisture through the reaction of neutralization of the soda lime, and this only when FGI is reduced to 1 l/min. Figure 3 is a nomogram summarizing the measured data. Figure 1 demonstrates that low humidity is caused by dilution of humidified gases emerging from the soda-lime canister by dry fresh anesthetic gases coming from the anesthesia machine. Humidity can be increased only by reducing the FGI or increasing the $V_{CO_2}$. As $V_{CO_2}$ plays an important role in this respect, it is obvious that only large children (20 kg or more) will derive sufficient inhaled humidity from this system, provided that their metabolic rates do not decrease appreciably during anesthesia. These children can safely be anesthetized on adult circuits. In addition, poor hygienic conditions obtain because the child may cough directly into the ventilator, which may be difficult to separate. Finally, during use in vivo, some CO$_2$ is lost through the ventilator or circuit pop-off valve (fig. 1), thus further reducing the extent of the exothermic reaction that raises inspired humidity.

As suggested by Berry and co-workers, humidity can be increased considerably by reversing the ventilator (or bag) attachment and the fresh gas inflow connection. Figure 4 summarizes data indicating that inspired moisture amounts to 5 to 25 mg H$_2$O/l with the reversed-flow pattern. This nomogram also shows that only children weighing more than 5 kg will receive adequate humidification from this modification.

The humidity values derived from this nomogram (fig. 4) are precise only after a three-hour period of stabilization. Correct values after one and two hours of use can be estimated by taking one third and two thirds of predicted values, respectively. In addition, the pop-off valve, because of its new relative position (fig. 2), will wash out fresh gases, which will be spilled into the operating room atmosphere. Moving this valve to a point between ventilator (or bag) mount and the absorber should improve efficiency.

A serious disadvantage of the Bloomquist infant circle is that it does not incorporate a drainage system to evacuate the water synthesized by the reaction of neutralization in the absorber. This water, mixed with dissolved soda lime, accumulates in the underlying channels, causing corrosion of metal and obstruction to gas flow, if it is not cleaned out at regular intervals.

In our opinion, a suitable humidified and vented Jackson Rees system is simpler and much more efficient for the conduct of pediatric anesthesia.

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