of halothane on the Bohr shift has not been studied. Enflurane does not affect the Bohr shift.[2]

It is unlikely that anesthetic agents contribute directly to the low $Pa_{O_2}$'s often found during anesthesia.

The Forane used for this study was supplied by Ohio Medical Products, a division of Airco, Inc.

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# Methods of Increasing the Humidity and Temperature of the Inspired Gases in the Infant Circle System

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One of the main drawbacks of current pediatric anesthesia apparatus is the almost complete lack of humidification and warming of the inspired gases. Adverse effects on the tracheobronchial tree occur when the normal humidifying and warming apparatus of the upper airway is bypassed by an endotracheal tube. These include: 1) arrest of ciliary activity and mucous flow; 2) hyperemia of the tracheobronchial tree; 3) increased viscosity of the mucus, with crust formation leading to obstruction of the endotracheal tube and the tracheobronchial tree.[1] These complications can cause serious intraoperative and postoperative problems, including obstruction of airways, atelectasis, and shunting.[2]

In addition to the water loss, a second major problem in the management of the critically-ill child exposed to dry gases is the possibility of hypothermia, with the associated cardiorespiratory depression and prolongation of recovery from anesthesia.[3,4]

The objects of this study were to ascertain the effects of varying the rate of fresh-gas flow and minute ventilation on the humidity supplied to the patient using the infant circle system, and to evaluate a relatively simple, inexpensive method for increasing the humidity and temperature of inspired gases delivered through the system.

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## METHODS

Three factors and their effects on the humidity and temperature of the inspired gases were evaluated: 1) the introduction of the fresh-gas flow at two different ports in the infant circle system; 2) the flow rates of the gas (air) compared with minute ventilation; 3) heating the soda-lime canister.

The Ohio infant circle system ‡ used is designed so that the normal fresh-gas-flow port is on the patient's side of the canister. All the fresh gas, with its low moisture content and low temperature, goes directly to the patient.[5] There is another port on the Ohio infant circle system that is an optional bag mount. Using this alternative port to introduce fresh gas requires all fresh gas to go through the canister before going to the patient (fig. 1). This system allows the fresh gas to equilibrate with the moisture and temperature of the gas in the canister. There are two sizes of canisters for the Ohio infant circle system. The larger canister, 240 g, was used exclusively in our studies.

The second factor studied was the ratio of fresh-gas flow to minute ventilation. This is important only when the fresh gas enters at the normal inspiratory port, and not when all gases pass through the canister. If the flow rate is low and minute ventilation high, then most of the gas in the circuit will pass through the canister before going to the patient. If the ratio is such that fresh-gas flow is higher than minute ventilation, then the patient will be exposed to more of the dry, cool, fresh gas.

The third factor was heating of the canister. Three methods of heating were studied: 1) the tubing of a water-filled recirculating-type infant heating blanket,§ with the thermostat set at 40 C, was wrapped around the canister; 2) the tubing of an infant heating blanket was wrapped around the canister as in 1), and the canister assembly was placed on the top of the mattress, the temperature of which was 40 C; 3) an electric heating tape ¶ was wrapped around the canister and the inspiratory limb of the circle system. The temperature of the tape was controlled with a rheostat to maintain the temperature of the gases in the inspiratory limb between 36 and 38 C.

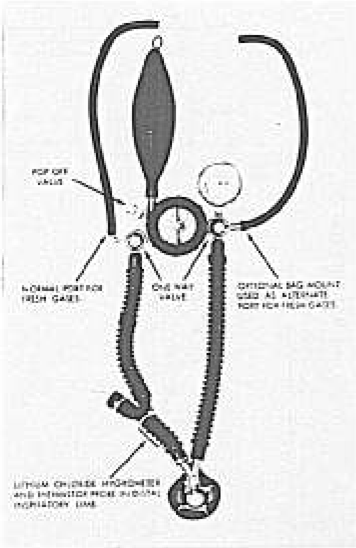


FIG. 1. Ohio infant circle system, showing the normal port, the alternative port for fresh-gas flow, the location of the hygrometer and thermistor probe, the one-way valves, and the pop-off valve.

Humidity and temperature were measured in the distal inspiratory limb of the circle just proximal to the Y connector. Humidity was measured using a lithium chloride hygrometer °° [6,7,8] calibrated at various humidities against a sling psychrometer. It was accurate to within ±1 mg $H_2O$. A thermistor probe °° placed at the same site as the hygrometer was used to measure temperature. The thermistor probe was calibrated against a mercury thermometer and found accurate to within ±0.5 C.

The three methods of heating the canister were studied as follows: The fresh-gas flow was changed from the normal port on the infant circle system to the alternative port (optional bag mount) (fig. 1). Observations were

‡ The Ohio Circle Absorber, Model No. 60, Infant.

§ Therm X Change Model ET-100, Gorman-Rupp Ind., Inc., Belville, Ohio.

¶ Climate Control Division, The Singer Co., Auburn, New York.

°° Dewpoint and Temperature Indicator, Model 32H64-Atkins Technical Inc., Gainesville, Florida.

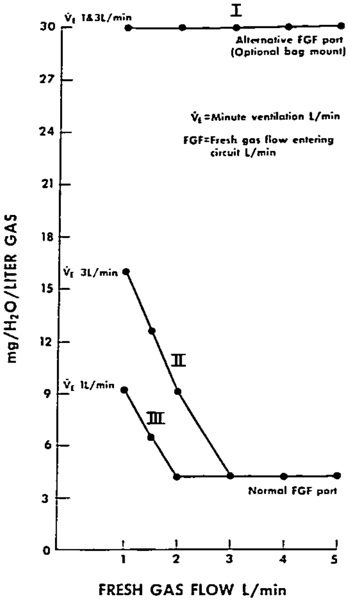


FIG. 2. The effects on humidity of increasing fresh-gas flow and $V_E$. The heating-tape method was used to warm the canister. Curve I represents the use of the alternative fresh-gas-flow port and shows that within the limits studied humidity remains constant. Curves II and III, illustrating the use of the usual fresh-gas-flow port, show the decrease in humidity that occurs as fresh-gas flow exceeds $V_E$, thereby reducing the amount of gas recycled through the canister.

made using flow rates of 1 to 5 l/min and minute ventilations ($V_E$) of 1 and 3 l/min. The minute ventilations were used to simulate two infants of different sizes. The lower $V_E$, 1 l/min, was obtained using a tidal volume of 33 ml and a rate of 30/min. The higher $V_E$, 3 l/min, was obtained using a tidal volume of 100 ml and a rate of 30/min. These minute volumes and flows were measured using a Pediatric Minute Volume Meter.††

A 3-liter anesthetic bag was fitted to the mask mount of the Y connector of the infant circle system to mimic the patient's lungs. To ventilate the circuit an Air Shields Roswell Park ventimeter ‡‡ was driven by an Emerson ventilator,§§ producing a "bag in the bottle" [9] arrangement so that no gas other than the fresh gas entered the circuit.

The final study was done to determine how long it would take to significantly deplete the water content of the soda lime.¶¶ Fresh-gas flow rates of 1, 3 and 5 l/min were studied at a minute ventilation of 3 l/min.

In this study the amount of moisture in the inspired gases was expressed as absolute humidity in mg $H_2O$ per liter of gas rather than as relative humidity. For comparison of this humidification system with others, the use of absolute humidity appeared simpler.[1]

## RESULTS

Anesthetic gases delivered from tanks contain no water. Figure 2 shows the effects of increasing the rate of fresh-gas flow and varying $V_E$ on the humidity in the distal inspiratory limb using the heating-tape method of warming the canister and inspiratory limb. In addition, this figure shows the increased humidity that can be obtained by cycling all fresh gas through the canister before it goes to the inspiratory limb. Curve I, determined in this fashion, shows that within the limits studied humidity is not only increased by the use of the alternative port but is unaffected by normal flow rates and $V_E$. The amount of water delivered with this system is 30 mg per liter of gas. Normally the inspired air in the lower respiratory tract is fully saturated with water at 37 C, and this represents a water content of 44 mg/l. Curves II and III, obtained using the normal fresh-gas-flow port, show the decreased humidity in the system that results from introducing the fresh gas at the inspiratory limb, as well as the decreased humidity that results when flow rate exceeds $V_E$. This is owing to the fact that less of the inspired gas has been recycled through the soda lime, where it can equilibrate with the

†† Pediatric Minute Volume Meter, Donti Research, Monsey, New York.

‡‡ Model No. V2, Air Shields, Inc., Anarco Co., Hatboro, Pa.

§§ Emerson Volume-controlled Ventilator, Model 3-PV, J. H. Emerson & Co., Cambridge 40, Mass.

¶¶ Sodasorb (USP), Ohio Medical Products.

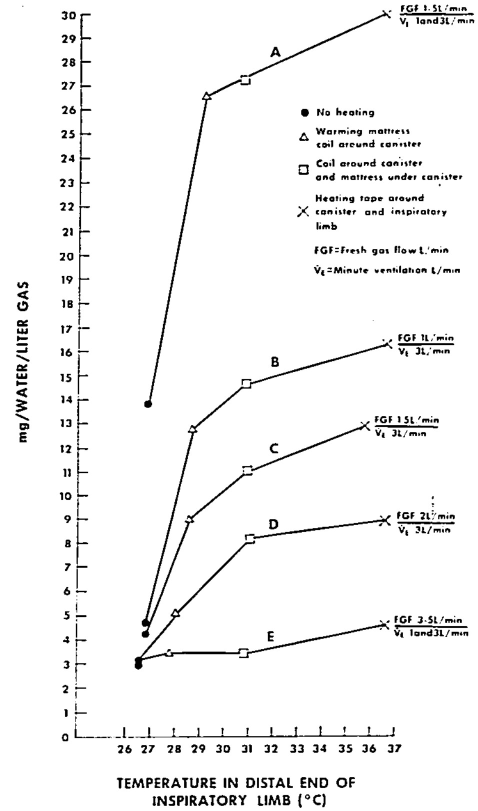


FIG. 3. The effects on humidity and temperature of the inspired gas using the alternative fresh-gas-flow port and varying the fresh-gas flow and $V_E$ of unheated and heated systems. Curve *A* illustrates the use of the alternate port (optional bag mount) for fresh-gas flow. Curves *B*, *C*, *D*, and *E* were obtained using the normal port for fresh-gas flow.

moisture of the soda lime. The humidity and temperature readings stabilized 5 to 10 minutes after changes in the rate of fresh-gas flow or $V_E$.

A high flow rate and a low $V_E$ provide, in effect, a nonrebreathing system, with minimal recirculation of gas through the soda-lime canister. This results in a very low moisture content of the inspired gases. As fresh-gas-flow rate decreases or $V_E$ increases, there is more dilution of the dry fresh gas by the gases which have passed through the soda lime, equilibrating with the moisture and temperature of the gas in the canister.

The effects on the humidity and temperature of the inspired gas of heating the canister are shown in figure 3. In addition, the previously-described effects of using the alternative fresh-gas-flow port, as well as those of varying the flow rate and $V_E$, are demonstrated. Curve *A*, figure 3, was obtained using the alternative port for fresh-gas flow. With the three meth-

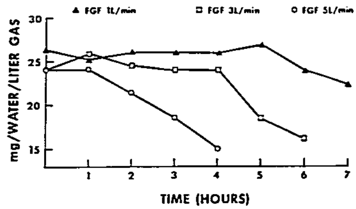


FIG. 4. The effect of varying fresh-gas flow using the alternative port on the time until the moisture of the soda lime begins to be depleted, as measured in the distal inspiratory limb. Observations were made at 1, 3, and 5 l/m.

ods of heating there was not much variation in humidity, but there was more variation in the temperatures of the inspired gases. This combination increases the quantity of heat supplied to the patient. The only factor affecting the moisture content was the temperature of the soda-lime canister: the higher the temperature, the more moisture was supplied to gas in the inspiratory limb.

The remaining curves in figure 3 were obtained with the fresh-gas flow connected to the normal port, whereby the fresh gas does not pass immediately through the canister. These curves show the effects on temperature and humidity of: 1) changing $\dot{V}_E$ in relation to the flow to the circuit; 2) changing the temperature of the canister and, in one study, warming the canister and inspiratory limb of the circuit.

At high flow rates, comparing curve *A* with curve *B*, the effect of using the alternative port for introducing the fresh gas is immediately apparent. The use of the alternative port increases the humidity in the unheated circuit from less than 5 mg to more than 13 mg/$H_2O$/l inspired gas. Curves *B* through *E* show the effects of the ratio of flow to $\dot{V}_E$ on the humidity of the inspired gases; as is shown in figure 2, when the ratio of flow to $\dot{V}_E$ increases, humidity decreases.

Therefore, using the normal port of fresh-gas flow, the ratio flow/$\dot{V}_E$ must be kept low to obtain the highest humidity from this circuit, as it is normally used clinically, so that more of the recycled gas can be delivered to the patient. This problem is overcome and the humidity increased considerably by using the alternative port.

Introducing the fresh gas through the alternative port and using the heated-tape method of warming the canister and inspiratory limb, it became evident that there was a limit to the amount of moisture in the soda lime of the 240-g canister. The usual water content of soda lime is 14 to 19 per cent, which is 33.6 to 45.6 g in 240-g of soda lime. Figure 4 depicts the changes in the humidity of the gases in the distal end of the inspiratory limb with time. At a 5-liter flow, the moisture content began to decrease significantly after 2 hours. At a 3-liter flow, it decreased after 4 hours, and at a 1-liter flow, after 6 hours. These values were obtained without the additional moisture which would be present under clinical conditions, when the patient's expired moisture and the moisture that would result from the reaction of expired $CO_2$ with soda lime are added to the circuit. Both of these would maintain the water content of the canister for a longer time.

## DISCUSSION

Many devices to increase the humidity of inspired gases in pediatric anesthetic circuits and to maintain the patient's temperature are available. Most involve bulky, expensive apparatus and must be placed in the circuit.[10] The results of this study show that with anesthesia apparatus presently in use and with relatively simple heating units both moisture and heat can be supplied to the patient.

Cycling all gas flow through the soda-lime canister increases the water content of the inspired gases significantly, from less than 4 mg/l to 13 mg/l. In addition, if heating devices are applied to the canister and inspiratory line, additional moisture and heat can be added to the system. By heating the canister, as well as directing all fresh gas through it, 27 to 30 mg $H_2O$/liter of gas can be delivered to the patient. This compares favorably with other humidification systems,[11] which range from the unheated water-bath humidifier that delivers 20–22 mg $H_2O$/liter of gas[1] to the heated modified Mapleson A-type T-piece system, which delivers 30–35 mg $H_2O$/liter of gas.[8] The use of nebulizers designed on the

Venturi principle leads to back-pressure [8] and increased resistance [12] in the circuit, and possible contamination of the circuit. Furthermore, use of this system should not entail the risk of causing supersaturation,[13] overhydration,[14] or hyperthermia [15] in the infant.

Under physiologic conditions, inspired air in the lower respiratory tract is fully saturated with water at 37 C; this represents a water content of 44 mg/l. The contribution of the upper respiratory tract to humidifying inspired air is approximately two thirds of this, which is a water content of 30 mg/l. As shown in figure 3, curve *A*, this water content was achieved by our apparatus. Chase *et al.*[16] demonstrated that a nonrebreathing technique may result in the loss of 28 mg of water per liter of inspired gas from the respiratory tract. These findings were confirmed by Han and Lowe,[17] who found that the respiratory water loss of adults during oral breathing was 27.7 mg/l of expired air. Therefore, additions of this amount of water to the inspired gases would minimize water loss from the respiratory tract, minimize the adverse effects of drying the airway, and eliminate the loss of heat by vaporization of this amount of water.

Introducing the fresh gas into the system at the normal port is barely adequate, since under optimum conditions (fig. 3, curve *B*) the system will deliver only 16 mg of water per liter of air when fully heated.

Studies are currently being extended to the clinical evaluation of these methods of humidifying inspired gases. While the alternative gas port, as used in this study, could be used with all anesthetic techniques, the use of the heating tape will have to be avoided in the presence of explosive agents, and commercially available heating tapes may well present shock hazards. Furthermore, caution will be necessary in the use of the heating tape, to prevent possible burns of the patient. The other two methods of warming the soda-lime canister with the infant heating blanket allow the use of explosive anesthestics, since the blanket's reservoir can be placed at a safe height.

## Conclusion

This study shows the effects of varying the rate of fresh-gas flow and $\dot{V}_E$ on the humidity supplied to the patient by the infant circle system, and describes a simple, inexpensive method of augmenting moisture and heat in the system by cycling all gas through the canister before it reaches the patient and by heating the canister and the inspiratory limb.

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# Jaundice Following Fluroxene Anesthesia

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There have been no published reports of hepatic damage secondary to fluroxene anesthesia in healthy human beings since its introduction into clinical anesthesia in 1953, and we are aware of only one report of such damage in a chronically ill and elderly patient, who had abnormal liver function tests and blood transfusions prior to operation.[1]

## REPORT OF A CASE

The patient, a 39-year-old Caucasian man in perfect health, was scheduled for elective thoracotomy for biopsy of an asymptomatic mediastinal mass discovered on routine chest x-ray. He had no history of prior surgical operations, anesthesia, blood transfusion, allergies, recent tattoos, foreign travel, exposure to hepatitis, or use of parenteral materials possibly contaminated with hepatitis virus. On admission, all blood studies (including CBC, electrolytes, bilirubin, alkaline phosphatase, CPK, and LDH) and urinalysis were normal.

Anesthesia was induced with thiopental prior to intubation facilitated by succinylcholine and maintained with $N_2O$–$O_2$ (3 and 2 l/min) and concentrations of fluroxene (approximately 2 per cent) necessary to keep the systolic blood pressure between 110 and 140 torr. During the 1½-hour procedure, a benign neurofibroma was easily excised. Blood transfusion was not necessary. The immediate postoperative course was uneventful except for a slight temperature elevation (100.2–100.4 F) until the fourth postoperative day, when serosanguineous wound drainage was noted. Prostaphlin therapy was instituted at this time. On the fifth day a pulmonary infiltrate had developed in the right lower lobe, and the patient had a spiking fever, with temperatures of 101–103 F, and was visibly jaundiced. The next day he was afebrile, but laboratory studies revealed the following abnormal values: bilirubin 4 mg/100 ml, alkaline phosphatase 260 mU/ml, CPK 425 mU/ml, LDH 250 mU/ml, SGOT 445 mU/ml. The surgical wound was clearly infected, but responded to routine care and continuation of prostaphlin therapy. Prostaphlin was discontinued on the tenth postoperative day, but was reinstituted for a four-day period two weeks later without further jaundice. By the twelfth day, bilirubin, CPK, LDH, and SGOT had returned to normal. The remainder of the postoperative course was unremarkable. The patient refused to submit to a fluroxene challenge.

## DISCUSSION

One advantage proposed for fluroxene is its lack of hepatotoxicity, and there is no evidence that it alters liver function tests, even in the presence of severe hypercarbia and prolonged or severe hypotension.

It is presently accepted that most inhalation agents are metabolized in the body.[2-5] Currently the question has been raised as to whether the agents themselves or their metabolites cause tissue reactions and damage. Trifluoroacetic acid and trifluoroethanol are compounds demonstrated in the metabolism of both fluroxene[3,6] and halothane.[3,7,8] Although the toxicity of these metabolites in man remains to be determined, there is evidence of hepatotoxicity in experimental ani-

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The opinions expressed in this article are those of the authors and do not necessarily reflect those of the Department of the Navy.