diagnosis of mild congestive heart failure was made, and the patient responded well to digoxin. The patient was asymptomatic upon discharge, 14 days postoperatively.

Discussion

Although intraoperative catecholamines were not measured, the occurrence of hypertension during gland manipulation suggests that increased blood levels of catecholamines were present during at least part of the enflurane anesthesia. Since only an occasional atrial premature beat occurred during this period, it appears that enflurane did not increase the ventricular sensitivity to endogenous catecholamine challenge. Further use of enflurane for operations for this disease may be warranted.

References

1. Perry LB, Gould AB: The anesthetic management of pheochromocytoma: Effect of preoperative adrenergic blocking drugs. Anesth Analg (Cleve) 51:36–40, 1972
2. Joas TA, Craig D: Fluroxene anesthesia for pheochromocytoma removal. JAMA 208: 927–929, 1969
3. Crout JR, Brown BR Jr: Anesthetic management of pheochromocytoma: The value of phenoxybenzamine and methoxyflurane. ANESTHESIOLOGY 30:29–36, 1969
4. Cooperman LH, Engleman K, Mann P: Anesthetic management of pheochromocytoma employing halothane and beta-adrenergic blockade: A report of fourteen cases. ANESTHESIOLOGY 28:575–582, 1967
5. Mazze RI, Trudell JR, Cousins, MJ: Methoxyflurane metabolism and renal dysfunction: Clinical correlation in man. ANESTHESIOLOGY 35:247–252, 1971

Water Vaporizer Heated by the Reaction of Neutralization by Carbon Dioxide

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The moisture output of unheated humidifiers diminishes with time because vaporization cools the water in the humidifier, thereby reducing its vapor tension. To obviate this, manufacturers have constructed electrically heated, thermostatically controlled humidifiers. This introduces the danger of potential explosions and electroshock in the operating room or the costly incorporation of protective devices.

In an attempt to produce a safely heated humidifier, capable of delivering accurately controlled inspired humidity, we have built a vaporizer‡ that utilizes the heat of the reaction of neutralization of barium hydroxide lime by carbon dioxide within the canister of a circle system. By placing the vaporizer in the absorber, but flowing humidified gases through the fresh gas inflow port of the inhalational dome valve and introducing a controllable bypass system, we have been able to deliver very accurately regulated inspired humidities ranging from 8 to 23 mg H_2O/l gas (40 to 116 per cent relative humidity at 23 C).

Materials, Methods and Patients

An experimental vaporizer (fig. 1) was constructed by drilling three holes in the metal lid of a cylindrical glass jar (external diameter 7.5 cm, depth 6.5 cm). Two pieces of conductive tubing, 30 and 60 cm long, respectively, were inserted through two of the holes in the lid and a thermistor probe through the third one. The longer piece of tubing reached the bottom of the vaporizer, where it was connected to a gas diffusion stone§ (vaporizing line). The shorter piece of tubing only just protruded through the lid (collecting line). The thermistor probe was placed at the bottom of the vaporizer, filled with water to a depth of

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Received from the Albert Einstein College of Medicine of Yeshiva University, Bronx, New York 10461. Accepted for publication May 1, 1974.

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‡ Patent pending.

§ Fisher Scientific, Springfield, N.J., Catalog number 11-139B.

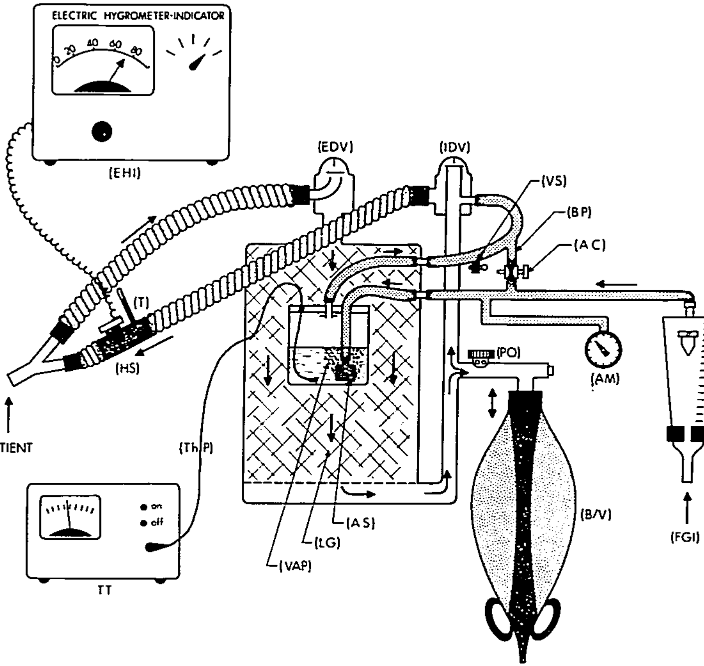

FIG. 1. Diagram showing the experimental vaporizer in the canister but outside the circle system. FGI, fresh gas supply to the vaporizing line; IDV, inspiratory dome valve, connected to the collecting line; VAP, vaporizer; AS, gas diffusion stone; LG, lime granules; EDV, expiratory dome valve; VS, voiding system; BP, bypass; AC, adjustable clamp on bypass; PO, pop-off valve; AM, aneroid manometer; Th.P, thermistor probe; TT, telethermometer; HS, hygrosensor; EHI, electric hygrometer indicator; T, thermometer; B/V, anesthetic bag or ventilator.

3 cm. The vaporizer was then introduced into the cylinder of a Foregger Jumbo Absorber with corresponding holes for the tubings and the thermistor probe. The cylinder was filled with barium hydroxide lime, U.S.P., taking care to ensure that the vaporizer remained horizontal, 6 cm above the bottom of the lime container. The vaporizing line was connected to the common outlet of an anesthesia machine, the collecting line to the fresh gas inflow port of the inhalational dome valve of the canister, and the thermistor probe to a telethermometer. All connections in the vaporizer and canister were made airtight with acrylic cement.

An adjustable bypass system was built to divert selectively the gas supply of the vaporizer towards the inhalational dome valve. To achieve this, a 15-cm length of tubing bearing an adjustable clamp, linking the collecting and vaporizing lines outside the canister, was inserted on these lines by means of two small T pieces. To drain water condensing in the collecting line, a voiding system made of a clamped 5-cm length of tubing was placed on that line between the bypass and the

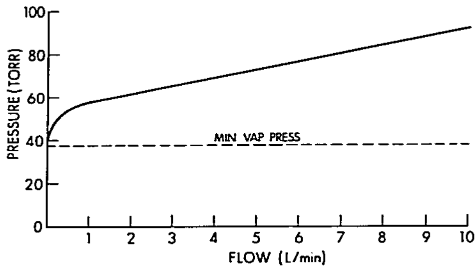

FIG. 2. Pressure measurements in the vaporizing line (bypass closed off) in relation to variations in gas flow through the vaporizer. Min. vap. press. = minimum vaporizing pressure.

canister by means of a small T piece. A calibrated aneroid manometer was inserted on the vaporizing line between the bypass and the canister.

Pressure/flow relationships in the vaporizing line were measured for fresh gas inflows ranging from 0.1 to 10 l/min by connecting the vaporizer to a pressure-compensated flowmeter and reading pressures in the vaporizing line at different flow settings with the bypass closed. The humidity output of the vaporizer, measured in the inhalational limb of the circle at the Y piece, was studied in both the laboratory and the operating room. All results are the means of three readings.

Studies were conducted on a model patient described by Chalon *et al.*[1] A hygrosensor connected to a Hygrodynamics Electric Hygrometer Indicator¶ was inserted in the inspiratory limb at the Y piece (fig. 1). Ventilation was provided by an Airshields Ventimeter ventilator. All temperatures, including ambient temperature, were monitored at 10-minute intervals, and humidity was recorded simultaneously. The thermostat of the Cascade humidifier was regulated to keep outlet temperature at 37 C. Absolute humidity in the inspiratory limb at the Y piece (mg H_2O/l gas) was measured with the bypass closed and with a fresh gas inflow from the anesthesia machine of 5 l/min, in three experiments in which $\dot{V}_{CO_2}$ and ventilatory settings were varied as follows:

¶ Model 15-3001, Hydrodynamics, Inc., Silver Springs, Md.

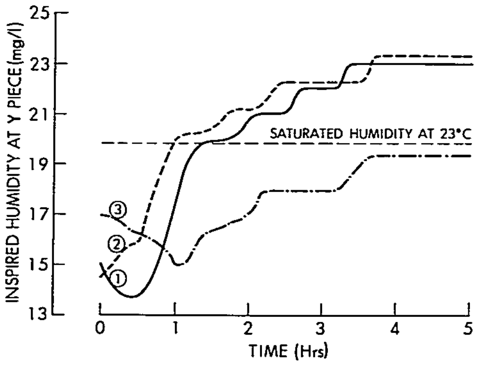

FIG. 3. Humidity in the inspiratory limb at the Y piece expressed in mg/l, as time progresses, using a fresh gas inflow of 5 l/min. Curve 1 (standard adult): $\dot{V}_{CO_2}$ = 200 ml/min, V_t = 600 ml, f = 12. Curve 2 (large adult): $\dot{V}_{CO_2}$ = 300 ml/min, same ventilation. Curve 3 (pediatric): $\dot{V}_{CO_2}$ = 100 ml/min, V_t = 200 ml, f = 20.

1) *Standard-adult experiment:* $\dot{V}_{CO_2}$ = 200 ml/min, V_t = 600 ml, f = 12.
2) *Large-adult experiment:* as above, but $\dot{V}_{CO_2}$ = 300 ml/min.
3) *Pediatric experiment:* $\dot{V}_{CO_2}$ = 100 ml/min, V_t = 200 ml, f = 20.

In addition, a fourth experiment was conducted to assess the controllability of the humidity of the system by endeavoring to keep the humidity reading on the hygrometer at 60 per cent at ambient temperature (22–26 C) by adjusting the clamp on the bypass and regulating fresh gas inflow. Presence of carbon dioxide in the inspiratory limb was tested with a Severinghaus electrode after five hours of use with large-adult settings. The pattern of neturalization of the lime in the canister was examined after each experiment.

Studies were performed in six adult patients (four male and two female) who were undergoing general endotracheal anesthesia for surgery. Informed consent was obtained in all cases. The humidity and temperature of gases in the inspiratory limb at the Y piece were read at 10-minute intervals. Pressure variations in the inspiratory and expiratory limbs of the circle were measured during all laboratory and clinical tests with the vaporizer in and out of the canister. We also tested the circuit on ourselves, with the vaporizer in the canister, for subjective feeling of resistance to breathing.

Results

The relationship between flow through the vaporizer and vaporizing line pressure is shown in figure 2. Pressure ranges from 40 to 90 torr for variations in flow from 0.1 to 10 l/min. The relationship is linear for flow ranges of 1 l/min to 10 l/min (at pressures of 59 to 90 torr). The manometer on the vaporizing line was, therefore, calibrated in litres per minute.

With the *standard-adult* environment, humidity in the inspiratory limb at the Y piece (fig. 3) was 15 mg H_2O/l (76 per cent relative humidity at 23 C). It decreased to 13.6 mg H_2O/l (69 per cent relative humidity at 23 C) after 30 minutes, then gradually rose and stabilized at 23 mg/l after 3 hours and 20 minutes (116 per cent relative humidity at 23 C). With the *large-adult* environment, humidity followed

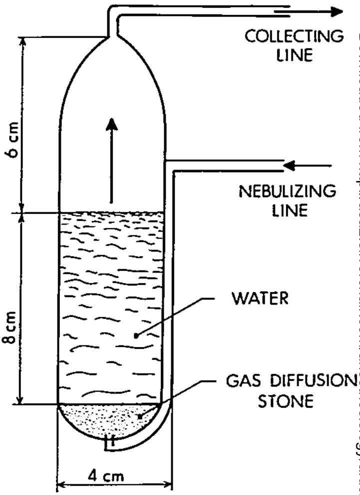

FIG. 4. Streamlined disposable vaporizer.

very closely the pattern seen with the standard-adult environment. It was, generally speaking, approximately 1 mg H_2O/l higher than in that experiment, but at stabilization it reached the same value. However, the decrease in humidity, seen at the onset of the standard-adult experiment, was not found. With the *pediatric environment*, the original humidity was higher than in the two adult environments (17 mg H_2O/l or 86 per cent relative humidity at 23 C), decreased to 15 mg H_2O/l (76 per cent at 23 C) and then gradually increased and stabilized at 19.4 mg H_2O after three and a half hours (98 per cent at 23 C).

When attempts were made to control inspired moisture at 60 per cent at ambient temperature (12.95 to 14.4 mg H_2O/l at 22 to 26 C), humidity in the inspiratory limb remained within that range (13.8 ± 0.85 mg H_2O/l) over a five-hour period.

There was no trace of carbon dioxide in the inspiratory limb after five hours of use with large-adult settings. The lime granules above the base of the vaporizer were invariably seen to have turned blue, with the exception of those in a conical area over the lid (apex upwards) which remained uniformly pink, as did the lime below the base of the vaporizer. Pressures (during the expiratory and inspiratory phases) in the inspiratory and expiratory limbs of the circle were 4/21 and 4/18 cm H_2O during the clinical study and 4/32 and 4/28 cm H_2O during the laboratory study, irrespective of the presence or absence of the vaporizer in the canister. There was no subjective feeling of resistance to breathing when we tested the circuit on ourselves, with the vaporizer in the canister. The humidity of anesthetic gases measured in the inspiratory limb at the Y piece during the clinical study was very close to that predicted by laboratory tests. All errors noted were slightly in excess of expected humidity.

The temperature of the water of the vaporizer in the canister was generally higher than was gas temperature by a few degrees, except during the early period of vaporization when the reverse obtained. In all cases, Y-piece temperature reached water temperature after three hours. In no instance did any of these temperatures increase to above 29 C. Room temperature for all experiments was 23 ± 0.7 C.

Discussion

The humidity in the inspiratory limb at the Y piece is derived from the mixture of two gas streams that are deliver by: 1) the vaporizer at the inlet port of the inspiratory dome valve, 2) that exhaled by the patient after passage through the lime. As time progresses, the reaction of neutralization by CO_2 warms both the lime granules and the water in the vaporizer and synthesizes water, thus raising the humidity of both streams. The transient initial decreases in temperature and humidity in the inspiratory gas stream for CO_2 production of less than 300 ml/l are due to cooling of water in the vaporizer caused by the latent heat of vaporization, before enough heat is generated by the reaction of neutralization. A larger CO_2 production (300 ml/min) liberates sufficient initial heat to mask this effect.

When the bypass is fully opened, humidity in the inspiratory limb is derived from 1) moisture and heat evolved from the patient's breath, 2) heat and moisture generated by the reaction of neutralization of the lime in the absorber, and 3) water incorporated in the lime granules by the manufacturer (15 per cent weight for weight for barium hydroxide lime, U.S.P.). Humidity can then be predicted and controlled by adjustments in fresh gas inflow and ventilatory settings.[1] When the bypass is fully closed, the dilutional effect of fresh dry gases arriving at the inspiratory dome valve from the anesthesia machine is lost, and humidity is dependent only on CO_2 inflow, room temperature, and duration of use (fig. 3). When the bypass is partially opened, inspired humidity depends on the relative mixture of humidified gases coming from the absorber and the vaporizer and on the fraction of dry fresh gas inflow which bypasses the vaporizer (fresh gas inflow minus vaporizing line flow shown on the manometer), less the loss of moisture caused by water condensation in the collecting line and in the channels between the canister and the Y piece (T piece, bag or ventilator, inspiratory dome valve, and inspiratory limb).

When it is desired to control inspired humidity for experimental reasons, with a thermometer and hydrosensor in the inspiratory limb at the Y piece, it is necessary at the onset of the experiment to dilute the original high humidity by adjustments of the clamp on the bypass. When the bypass is fully opened and humidity still increases above the required value, it can be further controlled by increasing fresh gas inflow.

The pattern of neutralization of the lime in the canister suggests the use of a more streamlined vaporizer, such as that shown in fig. 4. A plastic disposable instrument of similar design would make an ideal humidifier.

Reference

1. Chalon J, Kao ZL, Dolorico VN, et al: Humidity output of the circle absorber system. ANESTHESIOLOGY 38:458–465, 1973