dial settings: least “on” position, 0.5 per cent setting, an intermediate point, and the “off” notch. Duplicate samples were obtained after 5 minutes of a 6 l/min gas flow (4 l/min N₂O and 2 l/min O₂) through the vaporizer at each dial adjustment.

RESULTS

The average measured concentrations of halothane output from four Fluotec vaporizers are shown in figure 1. The output did not decrease linearly to zero; at the least “on” position the lowest delivered concentration was 0.44 per cent.

Vaporizer performance was also tested in the “off” position after the dials of two Fluotec had been completely drawn back without rotation. Both vaporizers delivered a halothane concentration of 0.46 per cent.

COMMENT

Anesthetists should be aware that the lowest concentration of halothane delivered by the Fluotec Mark 2 vaporizer at any dial setting with a gas flow of 6 l/min is little different from the first engraved setting, i.e., 0.5 per cent.

REFERENCES


Volume-controlled Relative Humidity Using a Constant-temperature Water Vaporizer

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It has been suggested 1–3 that humidification of anesthetic gases is advantageous in the protection of the airways and maintenance of body temperature, especially when nonrebreathing and high-flow systems are used for prolonged periods. Attempts to obtain saturated humidification have been described by Weeks et al.4 They introduced a Cascade Humidifier § in the inhalation side of the circle absorber system and, by regulating the thermostat of the vaporizer, managed to control the temperature at the Y piece, thus assuring saturated humidity at the desired temperature, including body temperature.

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5 Cascade Humidifier, Bennett Respiration Products, Inc., Santa Monica, California.

In a study of the effects of dry and partly and fully humidified gases on the cells of the tracheobronchial tree, we were unable to find a clinical water vaporizer which could deliver the selected relative humidities to a nonrebreathing system with precision; ultimately, we had to build our own. In our cytologic studies we have observed that dry gases damage ciliated tracheobronchial epithelium when used clinically for more than an hour. Cases with a relative humidity of 60 per cent at room temperature (22–26 C) and gases saturated at body temperature did not cause evident cytologic changes three hours after the onset of anesthesia.

Overhydration as well as dryness can represent a risk to the patient; it can decrease the heat loss from evaporation of water through the lungs.5 There is also the theoretical possibility of pulmonary surfactant washout. We feel that provision for precise humidification at desired levels eventually will be mandatory in anesthetic systems.
The present study offers details in the construction and evaluation of a constant-temperature water humidifier capable of delivering selected relative humidities to a nonrebreathing anesthetic system. We offer it as an early experimental model which could become a prototype of future humidifiers.

**MATERIALS AND METHODS**

A constant-temperature water vaporizer (fig. 1) was built by inserting a half-liter flask into a McGaw Blood Warmer. The flask contained sterile distilled water 6 cm deep heated to 36 C, leaving 14 cm between the water level and the rubber stopper. The stopper was perforated to admit a thermometer (T₁) which reached below water level, a short tube connected to a manometer, P_V, and pipes for the delivery and collection of gases. The collecting pipe was short, whereas the delivery pipe

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|Fig. 1. System capable of delivering various controlled humidities at room temperature using a constant-temperature water vaporizer. McG B.W., McGaw Blood Warmer; AS, fish-tank air stones; Pr, manometer indicating internal pressure of vaporizer; P_b, barometric pressure; S₁ and S₂, metered sources of gases; T₁, temperature of vaporization; T₂, end water trap temperature; T₃, room temperature. |

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|Fig. 2. Measurement of premixed relative humidity as set by flowmeter adjustments. A, Carbon dioxide absorber with empty canister; IPMG, incoming premixed gases; S, hygrometer sensor; EHI: Electric Hygrometer-Indicator. A thermometer (not shown) records gas temperature at S. |

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†McGaw Blood Warmer, Catalogue number V-5420, McGaw Laboratories, Glendale, California.
Fig. 3. Estimation of relative humidity by Electric Hygrometer-Indicator readings. The gases were relatively humidified by adjusting flowmeter settings. Each point represents the mean of ten readings between ± one standard deviation. AB, line of identity. Range of sensors is in right column.

was long, reaching the water level in the flask, where it joined a small Y piece. Below the water's surface each free limb of the Y piece was connected to a fish-tank air stone designed to break the incoming gases into small bubbles. The vaporizer received metered gases through the calibrated flowmeters of a Foregger anesthesia machine and led them to a water trap made from three half-liter saline-infusion bottles connected in series. The last bottle of the water trap contained a thermometer (T₂) inserted through its stopper. This thermometer was used to ensure that the gases entering the last bottle had cooled to room temperature and thus rained out the water surplus caused by vaporization at a higher temperature.

The humidified gases emerging from the water trap were joined at a Y piece by dry gases which had flowed through an independent calibrated metered source (we removed the flowmeters from another Foregger anesthesia machine and clamped them on the one in use). We could thus regulate the relative humidity of the mixture by adjusting the flows of the dry and humidified gases arriving at the Y piece.

Gases leaving the Y piece joined the inlet tube of a circle absorber system with an empty canister. Sensors from a Hydrodynamics Electric Hygrometer-Indicator ** were inserted distal to the inhalation dome valve, between the canister and the corrugated conductive breathing tube (fig. 2). For ranges of relative humidity between 50 and 70 per cent, a “first sensor” (Hydrodynamics number 15-1219) was used, and for ranges of relative humidity between 25 and 40 per cent a “second sensor” (Hydrodynamics number 15-1215) was employed. All readings were repeated ten times. Gases reaching the flowmeters had passed through regulators. A total flow of 10 l/min was used in every instance. Vaporizer and water-trap connections were sealed with Perma-slip †† and after drying were found to be airtight to pressures reaching 100 torr. Barometric pressure and room temperature were recorded at the onset and at the end of the experiment.

In addition to the measurements on the Electric Hygrometer-Indicator, gravimetric estimations of water content were obtained for gases with a preset relative humidity of 60 per cent (the setting used in our cytology studies). Measurements obtained from readings on the Electric Hygrometer-Indicator were plotted against relative humidities estimated from flowmeter readings (fig. 3).

The system can be used clinically by inserting a Frumin nonrebreathing valve distal to the Y piece of the circle absorber system.

** Electric Hygrometer-Indicator (model 15-3001), Hydrodynamics, Inc., Silver Spring, Md.

†† Permaslip (a synthetic mounting medium), Alban Scientific, St. Louis, Mo.
RESULTS

All measurements were very close to the line of identity, AB (fig. 3). Standard deviations were small, indicating a very narrow scatter of all readings. At no time did they exceed 1.02 per cent. The largest deviation from the line of identity was that of preset flowmeter readings aimed at producing 50 per cent relative humidity. In this case mean hygrometer readings indicated an excess of 1.7 ± 0.63 per cent relative humidity.

The 60 per cent preset humidity, as mentioned above, was measured both on the Electric Hygrometer Indicator and gravimetrically. Electrical readings indicated a mean of 61.2 ± 0.94 per cent relative humidity, and gravimetric estimation a mean of 61.48 ± 1.60 per cent for five experiments.

DISCUSSION

The results demonstrate a high degree of accuracy of the system. The factors we found most responsible for this precision were the bubbling device, the height of the water level in the vaporizer, and the number of 500-ml bottles composing the water trap. For instance, one air stone at the inlet tube of the vaporizer gave accurate results for flow rates through the apparatus not exceeding 5 l/min, but two stones mounted in parallel were necessary for accurate vaporization for flows not exceeding 7 l/min. The height of the water level in the vaporizer was fixed at 6 cm; above that height particulate water was washed out into the gas stream with flow rates exceeding 6 l/min. This could be detected both by measuring the weight of water accumulated in the trap and by Hygrometer-Indicator readings. The number of bottles composing the water trap was fixed at three. Equilibration at room temperature is essential before mixing humidified gases with dry gases in order to allow maximal raining out of surplus water extracted by vaporization at a higher temperature. Three trap bottles ensured this for flows not exceeding 7.5 l/min. Another point that required special attention was, of course, the elimination of leaks, especially before mixing humidified with dry gases when the Electric Hygrometer-Indicator was used, and at all points when gravimetric measurements were made.

Pressure measurements in the vaporizer were constant, ranging from 12 ± 0.5 torr with a 2.5-l/min flow to 48 ± 1 torr with a 7-l/min flow. (All pressure measurements were used in this study for gravimetric estimation and for detection of leaks.) Temperature of vaporization was constant, remaining 36 C for all vaporizing flows up to 10 l/min, thus assuring very uniform vaporization. We feel that vaporization at a temperature higher than that of the system to be humidified affords a great degree of precision, for if during their rapid passage through the humidifier the gases do not have time to reach absolute humidity at 36 C, they are later saturated at room temperature just before they are mixed with dry gases.

The device is presented here as a useful home-made experimental prototype. It is constructed of normally available components and is capable of delivering, very accurately, relative humidities ranging from 25 to 70 per cent at room temperature.

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