

Comparison of Concentration of Halothane in Closed and Semiclosed Circuits During Controlled Ventilation

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ADEQUATE halothane anesthesia is maintained readily in semiclosed systems during spontaneous respirations. Under these conditions the patient may absorb halothane at a rate of 10 ml. of vapor per minute for prolonged periods without encountering excessive depths of anesthesia. In our experience with semiclosed halothane anesthesia, using controlled ventilation, it has been possible to maintain adequate anesthesia for prolonged periods where the apparent amounts of halothane delivered to the circle were less than 10 ml. of vapor per minute. Similarly during controlled ventilation in closed circuit halothane anesthesia, excessive depths of anesthesia are encountered under conditions in which the apparent rate at which halothane vapor is delivered into the circle is less than the rate of absorption by the patient. Because of these inconsistencies, an investigation of concentrations of halothane in closed and semiclosed circuits during positive pressure breathing was undertaken.

Methods

The ages of patients studied ranged from 22 to 82 years, and their weights varied from 40 to 84 kg. The time required for the surgical procedures ranged from one half to twelve hours, and included simple gynecological examinations and radical neck dissections. The studies included values obtained prior to, during, and following the surgical procedure. All anesthetics lasted at least one hour.

Patients were premedicated with 4 to 10

mg. of morphine sulphate and 0.1 to 0.4 mg. of atropine sulphate one hour prior to the induction of anesthesia. Induction of anesthesia was usually accomplished with 200 to 400 mg. of thiopental and tracheal intubation was usually facilitated with 40 to 60 mg. of succinylcholine injected intravenously. In three patients, tracheal intubation was accomplished with meperidine analgesia and topical lidocaine.

Additional 50 mg. doses of thiopental were administered as required to maintain anesthesia during the initial transition to closed circuit halothane anesthesia. Continuous electrocardiograms were monitored in most cases. Blood pressures were obtained periodically by auscultation.

A circle system consisting of a Ventimeter bellows assembly, Ohio Model 22 carbon dioxide absorber, and Y-piece with valves was attached to the endotracheal tube. Halothane vapor and oxygen were delivered into the circle at the absorber from a Fluotec Mark II vaporizer.

Ventilation was controlled by a Bird Respirator connected to the chamber surrounding the Ventimeter bellows. The minute volume was initially adjusted to permit the patient to trigger the ventilator during light anesthesia. The minute volume was subsequently adjusted to maintain respiration near the apneic threshold. Under these conditions the patient automatically alternated between periods of assisted and controlled ventilation.¹

A tuberculin syringe was used to obtain 1 ml. gas samples from the inspiratory, expiratory, and delivery hoses. The samples were withdrawn through a hypodermic needle attached to a three-way stopcock. Initially samples were obtained at one minute intervals. After the first thirty minutes of anes-

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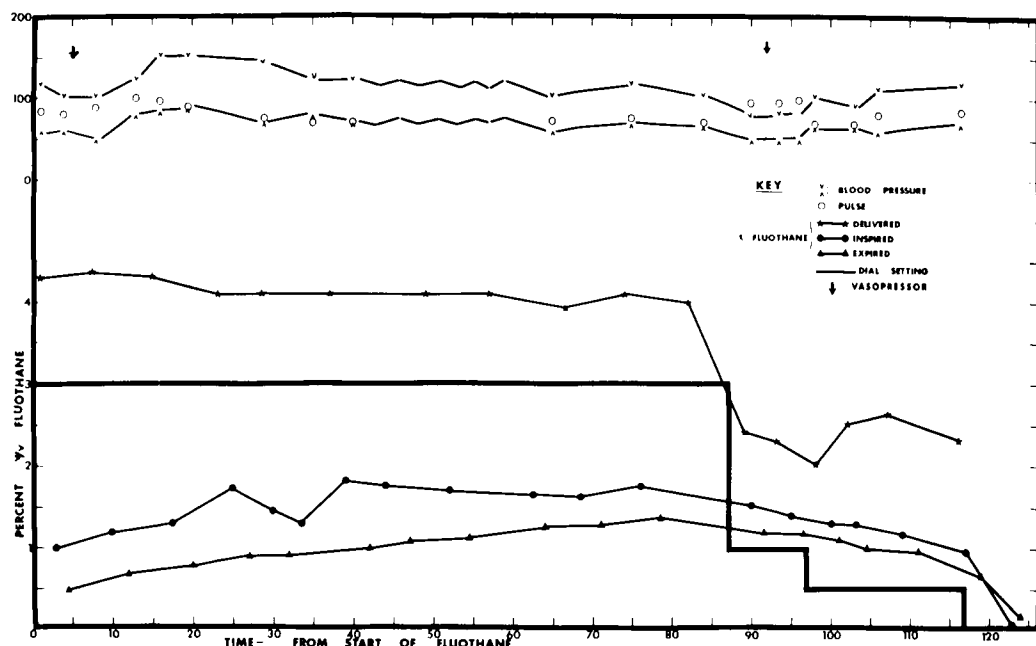


FIG. 1. Case 1.

thetia, samples were taken at five minute intervals.

An F and M Model 300 gas chromatograph was used to analyze the gas samples. A nine-foot long, one-quarter inch diameter column, packed with the domestic detergent, "Tide," (30-60 mesh) and maintained at 100° C. separated the expired gases from the halothane. The carrier gas consisted of helium at a flow rate of 75 ml. per minute. The height of the halothane peak on the chromatogram was found to be directly proportional to the concentration of halothane vapor. The gas chromatograph was calibrated for halothane using standard mixtures of halothane vapor in oxygen prepared in cylinders under pressure.² Gas chromatography has proved to be a versatile method for analyzing the gas and vapor mixtures encountered during anesthesia research.³

The milliliters of halothane vapor absorbed per minute was calculated from the difference in the mean inspiratory and expiratory concentrations based on the calculated alveolar ventilation. They are at best approximations.

Results

A series of 18 patients were anesthetized for periods of from one to twelve hours. In

four cases a semiclosed system was employed, for the rest a closed system was used. Two representative cases using each system will be discussed in detail.

Case 1 (Fig. 1). This 72 year old woman was operated on for an ovarian tumor. After induction of anesthesia with thiopental and intubation of the trachea with the aid of succinylcholine, the oxygen flow was set at 500 ml. per minute. The Fluotec dial was set at 3 per cent. The ventilation was held constant at 600 ml. twelve times per minute and required pressures of 20 cm. of water. The alveolar ventilation was estimated to be 3.6 liters/minute. After 87 minutes of anesthesia, the Fluotec dial setting was reduced to 1 per cent for 10 minutes, then maintained at a 0.5 per cent setting for the final 20 minutes of anesthesia. It should be noted that the delivered concentration at 0.5 per cent dial setting was higher than that obtained at the 1 per cent dial setting. Approximately 9 ml. of liquid halothane was used during two hours of anesthesia. The patient was absorbing approximately 17 and 14 ml. of halothane vapor per minute at 80 and 100 minutes, respectively.

Hypotension was observed during the initial administration of halothane and again after

87 minutes of anesthesia. Mephenteramine, 60 mg., administered intravenously resulted in an immediate blood pressure rise in both instances.

When the halothane was shut off at the end of operation and the oxygen flow increased to 4 liters per minute, the concentration of halothane in the circle fell below 0.2 per cent within six minutes and the expired concentration rose above the inspired concentration.

Case 2 (Fig. 2). A radical mastectomy was performed on this 48 year old woman. The patient's trachea was intubated with the aid of meperidine analgesia and 2 per cent lidocaine applied topically. The oxygen flow was set at 4 liters per minute. Halothane was administered at a dial setting of 2 per cent for seven minutes. Ventilation was held constant at 700 ml. twelve times per minute, and the alveolar ventilation was estimated to be 4.5 liters/minute. Pressures of 15 to 18 cm. of water were required. The patient's blood pressure fell from 140/80 to 80/50. The Fluotec was reset to 1 per cent and 45 mg. mephenteramine was administered. The blood pressure promptly rose to 120/80. Anesthesia was continued at a 1 per cent Fluotec setting for the next two hours. At this time the Fluotec was reset to 0.5 per cent for 50 minutes and the anesthesia completed at a dial setting of 0.1 per cent for the remaining 10 minutes. It should be noted that a significant difference in the delivered con-

centrations of halothane was not observed at dial settings of 0.5 and 0.1. The changes in the concentrations on changing from a dial setting of 1 to $\frac{1}{2}$ per cent are ascribed to the Fluotec having been inadvertently turned off for a few minutes. Little difference exists in the delivered concentration of halothane at dial settings of 0.5 and 1.0. Approximately 30 ml. of liquid halothane were used during three hours of anesthesia. The patient absorbed approximately 13 ml. of halothane vapor per minute during the first two hours and 5 to 7 ml. of halothane vapor per minute during the final hour of anesthesia.

Case 3 (Fig. 3). This 30 year old woman with metastatic carcinoma of the breast had a bilateral oophorectomy. Anesthesia was induced with thiopental and the trachea intubated with the aid of succinylcholine. The oxygen flow was set at 500 ml. per minute. The Fluotec dial was set and maintained at 3 per cent for the entire anesthetic. Ventilation was maintained constant at 750 ml. ten times per minute, pressures of 20 cm. of water were required. The alveolar ventilation was estimated to be 4 liters/minute. Although the patient's blood pressure remained within 20 mm. of mercury of preanesthetic values, the auscultory sounds and pulse became weak toward the end of anesthesia. This situation was not improved by administration of mephenteramine.

A total of 6 ml. of liquid halothane was used. The patient was absorbing approxi-

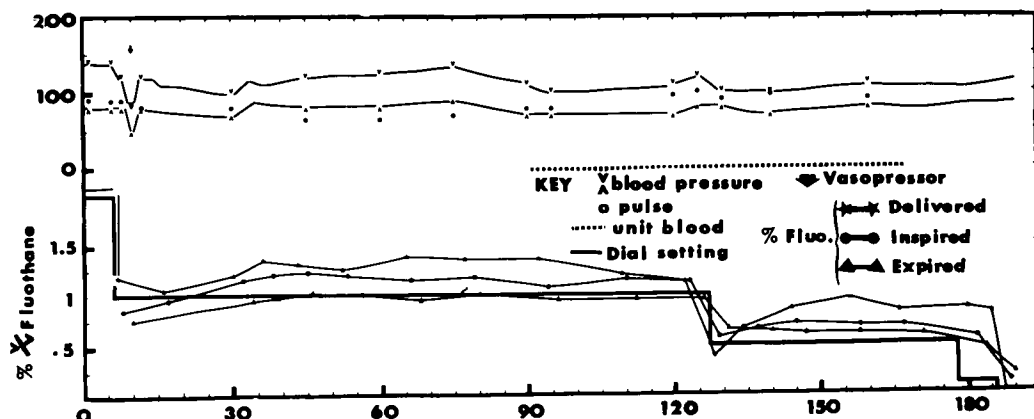


FIG. 2. Case 2.

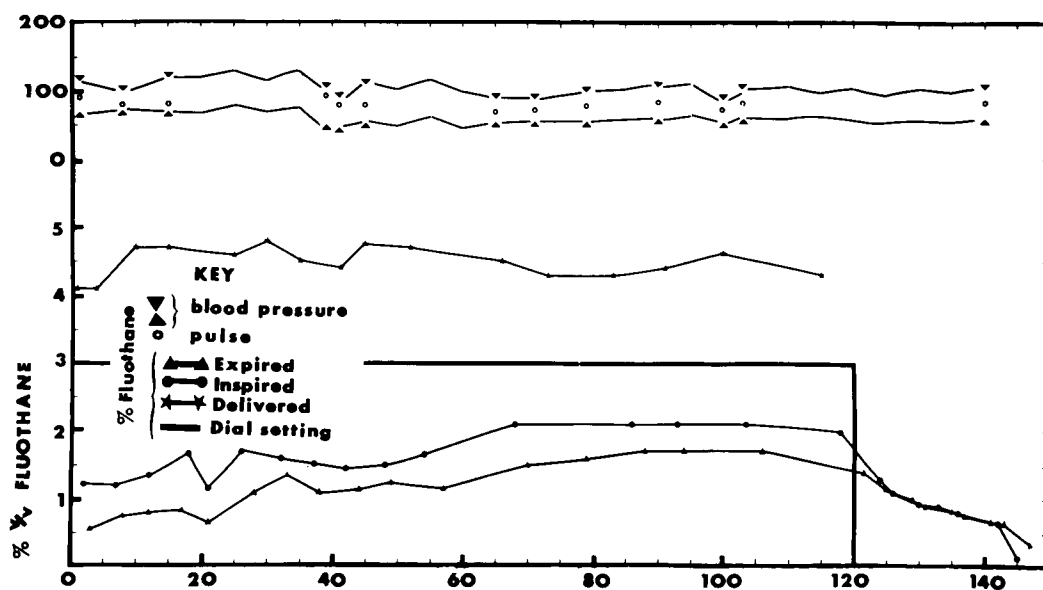


FIG. 3. Case 3.

mately 13 ml. of halothane vapor per minute after two hours. When the Fluotec was shut off and ventilation in the closed system maintained, the concentration of inspired halothane fell to one-half of its former value within ten minutes. Assuming the circuit volume plus residual lung volume to be 8 liters, the rate of elimination of halothane from the circle system approximates 8 ml. of vapor per minute.

Case 4 (Fig. 4). This 53 year old man with carcinoma of the left cheek had a left radical neck dissection, superficial parotidectomy, and resection of the left temporal and preauricular areas. Anesthesia was induced and with thiopental and the trachea intubated with the aid of succinylcholine. The oxygen flow was adjusted to 4 liters per minute. The Fluotec vaporizer was set at 3 per cent for three minutes and reduced to 2 per cent for 17 minutes. Maintenance was continued for approximately three hours at a dial setting of 1 per cent. Except for a 30-minute interval at a setting of 0.25, the Fluotec was left at a setting of 0.5 for the remainder of the procedure. Ventilation was held constant at 800 ml. twelve times per minute. Pressures of 25 cm. of water were required. The alveolar ventilation was estimated at 4.8 liters/

minute. Systolic blood pressures remained between 130 and 100 mm. of mercury throughout the anesthesia. Approximately 86 ml. of liquid halothane were required for eight hours of anesthesia. The patient absorbed about 10 ml. of halothane vapor per minute during the first four hours of anesthesia and less than 4 ml. of halothane vapor per minute during the remainder of the anesthetic. The percentage of halothane delivered at dial settings of 0.25, 0.5, and 1.0 is considerably higher than that indicated on the vaporizer calibration chart. When the Fluotec was shut off, the inspired and expired concentrations of halothane fell rapidly and the expired concentration of halothane exceeded the inspired concentration.

The Effect of Pressure on Vaporizer Performance. From the previous figures, it can be seen that, in the closed circle system, during controlled ventilation, the concentration of halothane vapor delivered by the Fluotec vaporizer is considerably higher than that indicated on the vaporizer dial or calibration graph. The Fluotec Mark II vaporizer was checked for steady gas flows by the manufacturer. The calibration obtained is shown in table 1.

The halothane concentrations were meas-

ured with a Rayleigh Refractometer as described by Hill.⁴ The Mark II Fluotec has, unlike the Mark I, been deliberately designed to give high concentrations at a steady flow rate of 500 ml./minute for use with circle systems. It is apparent that the vaporizer was giving the output concentration intended by its manufacturer. The fact that the concentrations are high at the 1/2 and 1 per cent settings when the Fluotec feeds into a closed circle system is due to the back pressure exerted on the vaporizer by the ventilator. This effect was investigated further by substituting a Pulmonator type rubber bag for the patient in the circle system. The pressure inside the Fluotec was measured by inserting a plastic tube into the drainage outlet, and observing the changes in the halothane levels. The manometer showed that the Fluotec attained an inside pressure equal to the circle pressure measured on an aneroid manometer connected to the carbon dioxide absorber. The effect of the circle system pressure on the vaporizer output is shown in table 2. An average flow rate of 500 ml. per minute of oxygen passed through the Fluotec.

The results show that the main effect has occurred when a mean circle pressure of 20

TABLE 1. Calibration of Mark II Fluotec by Rayleigh Refractometer*

Gas Flow Rate	Fluotec Dial Setting	Halothane (Per Cent v. v)
Air, 500 ml./minute	4.0	5.7
	3.0	3.3
	2.0	1.1
	1.0	0.5
	0.5	0.2
Air, 4 l./minute	4.0	3.96
	3.0	2.98
	2.0	2.03
	1.0	0.99
	0.5	0.49

* Figures supplied by manufacturer, Cyprane, Ltd., Buffalo, New York.

cm. of water is reached. Increasing the pressure to 30 cm. of water produces little further change in the Fluotec output concentrations. The time for which the pressure was applied was lengthened by increasing the inspiration time from one to two seconds. This did not alter the concentrations to any marked degree. A competent one-way valve was then inserted between the circle system and the outlet tube from the vaporizer. The vaporizer output concentration for various average oxygen flow rates through the vaporizer are shown in table 3.

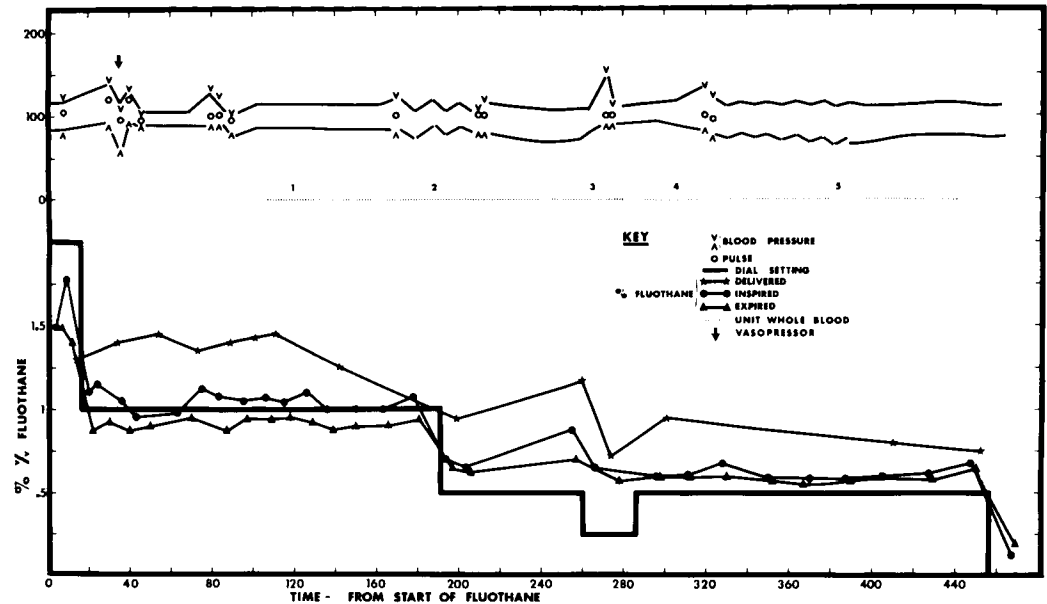


FIG. 4. Case 4.

TABLE 2. Effect of Circle Pressure and Inspiratory Time on the Fluotec Mark II Output. Oxygen flow equal to 500 ml. per minute.

Circle Pressure	Inspiratory Time	Respiratory Rate	Fluotec Dial Setting (v/v)	Halothane Concentration (v/v)
10 cm. H ₂ O	1 second	10/minute	0.5	0.9
			1.0	1.7
			2.0	2.4
			3.0	3.4
			4.0	5.7
20 cm. H ₂ O	1 second	10/minute	0.5	2.7
			1.0	2.5
			2.0	3.1
			3.0	4.1
			4.0	5.8
30 cm. H ₂ O	1 second	10/minute	0.5	3.2
			1.0	2.6
			2.0	3.1
			3.0	4.1
			4.0	6.0
30 cm. H ₂ O	2 seconds	10/minute	0.5	2.9
			1.0	2.9
			2.0	3.7
			3.0	4.4
			4.0	5.2

The action of the one-way valve is to slightly reduce the discrepancy between the dial setting and the measured concentrations. It is seen that the discrepancy is greatly reduced at an oxygen flow rate of 4 liters per minute. At a flow rate of 500 ml. per minute reducing the dial setting from 1 to $\frac{1}{2}$ per cent actually increases the output concentration. An increase in respiratory rate from 10 to 20 per minute produced little change in output concentration for any dial setting.

A second Fluotec vaporizer was tested and this produced results similar to the first.

A 'copper kettle' type vaporizer was connected to the circle system in place of the Fluotec. The mean circle pressure was 20 cm. of water and the respiratory frequency 10 per minute. With an oxygen flow through the 'kettle' of 75 ml. per minute and a bypass flow of one liter per minute, the output concentration was 3.5 per cent halothane. On disconnecting the 'kettle' from the circle system, the output concentration fell to 2.7 per cent. For use under semiclosed circle condi-

tions, the 'kettle' flow was increased to 120 ml. per minute of oxygen and the bypass flow to four liters per minute. The output concentration when the vaporizer was connected to the circle was 1.2 per cent and when it was disconnected 1.4 per cent. The effect of the pressure in a closed circuit is thus quite marked with this type of vaporizer.

Discussion

The potency of halothane increases the risk of employing this anesthetic in closed systems. Analytical methods for determining halothane concentrations are relatively recent. Robson *et al.*⁵ employed an infrared analyzer. Their results indicated that when 500 ml. of 3 per cent halothane vapor were delivered into the circuit, the inspired halothane concentration slowly increased during the first hour, became constant, and did not exceed 1.5 per cent (v/v). Fabian, *et al.*,⁶ showed that the inspired halothane concentration rose to one half of the apparent delivered concentration in approximately one hour. These investigations show that the inspired concentrations are predictable. Individual patients exhibit quite variable cardiovascular responses and may not tolerate a particular inspired concentration. In order to vary the circuit concentrations, it is essential to accurately know the delivered halothane concentration. It is apparent (tables 1 and 2) that the Fluotec calibrations for free flow are substantially different from those obtained in a closed circle employing controlled or assisted respirations. Further, reducing the dial setting fails to decrease the delivered concentration until the vaporizer is actually turned off. These peculiarities of vaporizers should be understood before attempting to employ them in closed circuits. It is quite possible that many of the difficulties encountered in the past, during closed circuit halothane anesthesia, are attributable to circle pressure effects on vaporizers.⁷⁻⁸ Closed circle halothane anesthesia should present no problems with respect to excessive depths of anesthesia if the vaporizer is turned completely off when clinically indicated. Reducing the dial setting to values lower than 2 per cent (0.1 to 2.0 per cent) can produce disastrous results

if one is under the impression that the halothane concentration is being reduced.

At dial settings of 0.5 and 1.0 per cent in semiclosed (4 l./minute) circuits, controlled ventilation increases the concentration of delivered halothane significantly (table 3). Thus at a Fluotec dial setting of 0.5 per cent the delivered concentration during controlled ventilation was 1.1 per cent, and at a dial setting of 1.0 the delivered concentration was increased to 1.4 per cent. Smith and Volpitta⁹ calibrated their Fluotec under conditions of free flow from the vaporizer and transposed these calibrations to past anesthetic records where assisted or controlled ventilation was used routinely. Under these conditions we have never observed delivered concentrations (table 3 and case 4) of less than one per cent at any dial setting (other than the off position).

The effect of circle pressure on the delivered halothane concentrations is ascribed to the pressure phase forcing additional oxygen into the vaporizing chamber of the Fluotec. Since the internal volume of the Fluotec is 600 ml., a Boyle's Law calculation shows that it is theoretically possible for the vaporizer to accept an additional 12 ml. of oxygen per breath when the circle pressure is 20 cm. of water (1/50 atmosphere) and pressure equilibrium throughout the system is achieved. In practice all this additional oxygen does not become saturated with halothane.

The additional oxygen forced through the vaporizer, whatever the mechanism, is greater at 4 l./minute than at 500 ml. per minute at a dial setting of 0.5 and 20 cm. of water intermittent circle pressure. Thus at 4 l./minute, 44 additional milliliters of O₂ pass through the vaporizer per minute; and at 500 ml. per minute, 26 additional milliliters of oxygen per minute pass through the vaporizer (calculated from tables 1 and 2). The actual increase in vapor pressure (or per cent) of halothane delivered was less at 4 l./minute than at 0.5 l./minute. Since the vapor pressure of the inspired halothane determines the depth of anesthesia, the closed circuit is potentially more dangerous. When signs of cardiac irregularity, hypotension, or depressed respirations are observed the Fluotec should be turned off, the circle system flushed with

TABLE 3. Vaporizer Output Concentration for Various Average Oxygen Flow Rates

Average Oxygen Flow Rate		Delivered Concentration (Per Cent)		
		0.5 l./minute	2 l./minute	4 l./minute
Fluotec Dial Setting	0.5	2.8	1.0	1.1
	1.0	2.5	1.0	1.4
	2.0	3.1	2.7	2.2
	3.0	3.8	3.6	3.1
	4.0	4.7	4.7	4.0

Respiratory rate, 10; inspiratory time, 2 seconds; mean circle pressure, 20 cm. of water; one-way valve connected.

oxygen and assisted ventilation continued. The dial setting should never be merely reduced because the delivered concentration is actually increased rather than lowered.

The effect of intermittent circle pressure on the vaporizer output was eliminated by the installation of a needle valve between the vaporizer and the circle.* An aneroid manometer was inserted between the needle valve and the vaporizer. At any selected oxygen flow rate the needle valve was adjusted to maintain the pressure within the vaporizer 30–40 cm. of water above the circle pressure. Under these conditions the Fluotec delivered halothane concentrations (v/v) in accordance with the calibration curves issued by the manufacturer. This pressurized vaporizer is currently being evaluated during closed circle halothane anesthesia.

Summary

The delivered, inspired, and expired concentrations of halothane in closed and semiclosed circuits during assisted and controlled ventilation were measured by means of gas chromatography. A Fluotec Mark II vaporizer was used outside the circle system. The halo-

* Cyprane, Ltd., Kieghtley, England, have recently designed a "lever" valve which maintains the pressure within the vaporizer at 30 cm. of water above circle pressures. The valve eliminates circle pressure effects on the vaporizer output.

thane concentrations delivered were significantly increased above the per cent indicated on the calibration curves and resulted from pressure fluctuations within the circle.

During closed circuit anesthesia, constant inspired and expired halothane concentrations were obtained within one hour. After two to three hours of stable anesthesia, the expiratory halothane concentration increased and gradually approached the constant inspiratory halothane concentration. Apparent absorption rates fell from 10-15 ml. of halothane vapor per minute to 4-8 ml. of vapor after three to four hours of anesthesia.

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