A NEW VAPORIZER FOR LIQUID ANESTHETIC AGENTS

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Throughout the years many types of vaporizers and inhalers for liquid anesthetic agents have been devised, each with its own peculiar merits, idiosyncrasies and disadvantages. Few have stood the test of time and the continuous procession of various modifications indicates incomplete satisfaction with the way they perform. Some of these devices have been based on the "draw-over" principle, dependent for proper function upon the active respiration of the patient. Others, including most modern anesthesia machines, have been of the "ad plenum" variety in which gases are added from a pressure tank. Both systems provide for variable vapor concentration of volatile anesthetic agents, such as ether, by diverting a varying portion of the total flow of gases over or through the liquid to be vaporized. The vaporizer in such a system lacks vernier control, the changes in concentration are quite likely to be sudden, gross and irritant, and contribute to difficulty in providing smooth anesthesia.

In order to make an improved vaporizer it would be desirable to provide a simple vernier control of concentration and efficiency of vaporization such that a fully potent and predictable concentration is always available, regardless of the type of system by which the anesthetic agent is to be administered. Such a method for vaporization of volatile anesthetics has been devised. This new vaporizer involves important modifications of circuit design, liquid container and vaporizing surface (figs. 1 and 2).

The Circuit

The distinguishing feature of the circuit is the additional and completely separate flow of oxygen which is bubbled through the liquid anesthetic agent. This oxygen is metered through a rotameter provided with a by-pass so that the entire required range of both fine and coarse flow may be read on the same tube. This separate stream of oxygen containing anesthetic vapor is then joined with the main stream of gases from all the other meters in a special small mixing chamber situated just before the point of delivery of the gases from the machine. The value of such a circuit lies in the fact that the increase in vapor concentration delivered to the patient may be gradual and steadily progres-

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Fig. 1.  a. Photograph of table model of new vaporizer for liquid anesthetic agents.
   b. Schematic diagram of circuit design of apparatus.
sive in proportion to the amount of oxygen metered through the liquid and in inverse relationship to the total flow of other gases.

Lyons described a circuit which in some respects is similar to this (1). Although a separate oxygen flow was led through the ether bottles in his machine, the underlying concept appears to have been different from that described in this paper since he did not discuss the use of a variable flow through the ether as a means of metering the increase in

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**Fig. 2.** a. Diagrammatic representation of vaporization chamber. b. Alternate small cup porex unit to hold small amounts (30 cc.) of chloroform or trilene when it is desired to use them in the circuit.
ether concentration. He apparently continued to use the variable key on top of the ether bottles for this purpose.

The by-pass arrangement so that both fine and coarse flows can be read on the same rotameter is similar in principle to the additional capillary by-pass described by Pask for water depression meters (2). The lever which turns the by-pass into parallel with the rotameter is so arranged that it also changes the scale readings to conform to the different calibration.

THE CONTAINER

Copper, because of its high specific heat, is the material from which the container is made. It is well known that heat is required to vaporize any liquid. If vaporization takes place without addition of heat from an outside source, then the heat necessary to vaporize the liquid is taken from the liquid itself. As the temperature of the liquid goes down, the efficiency of vaporization is reduced because of the fall in partial pressure of the vapor above the liquid. The copper container, therefore, plays an important role as a source of heat and in the transfer of heat from the room air and all the metal parts of the machine to the liquid to be vaporized. The temperature of the liquid anesthetic agent in this vaporizer has been observed during use with ether to be never lower than 15°C, less than the room temperature.

THE VAPORIZING SURFACE

The gas flowing through the liquid anesthetic is finely dispersed by passing through a sintered bronze disk (porex). The multitude of tiny bubbles leads to maximal vaporization efficiency by providing a greatly increased surface for the liquid-gas interface. In addition, this disk conducts directly to the liquid the heat required for vaporization.

An alternate porex unit can be inserted in the vaporizer when it is desired to use chloroform or trichloroethylene in the circuit (fig. 2b).

USE OF THE VAPORIZER

The vernier control over increments in vapor concentration which is provided by the new circuit is of great advantage. Because of this increased delicacy and sureness of control, the danger of inadvertent relative overdosage of chloroform is reduced and the irritant effects of sudden exposure to high concentrations of ether may be avoided. Actually, an induction with ether-oxygen becomes nearly as pleasant as one with nitrous oxide-oxygen and very nearly as rapid. The metered flow of oxygen through liquid anesthetic in effect reflects the addition of increments of anesthetic vapor as though it were itself being metered as a separate gas.

The vaporizer is adaptable to use in any of the usual anesthetic technics, including insufflation, and appears to provide a fully potent
concentration of ether in all circumstances in which it has yet been tried.

In a closed absorption system only the lower part of the fine scale of the oxygen-through-ether meter need be used to add adequate ether to the system. Additional oxygen for metabolic requirements should be added from the fine flow of the "oxygen only" meter as needed. Potentially, a lethal concentration of ether can be easily introduced into the bag of a closed system, since concentrations more than ten times the amount required for maintenance anesthesia are provided by the vapor-

![Ethyl Ether Concentrations in an Oxygen Atmosphere as Measured with the Aid of a Beckman Oxygen Analyzer](image)

**Fig. 3.** Concentration of ether in an oxygen atmosphere produced by various flows through the vaporizer, as determined by difference with the aid of a Beckman Oxygen Analyzer.

izer. *Caution equal to that used when adding cyclopropane to a closed system is indicated.*

Near the outlet of the machine a cut-out valve is provided so that the vaporizer unit can be instantly excluded if desired in an emergency or during use of the machine for other purposes.

It is in partial rebreathing, nonrebreathing or insufflation technics that the vaporizer is particularly useful. Nitrous oxide can be used for induction if desired. However, in a semiclosed system with the oxygen or air meters or both set at a total flow of 8 liters, induction with ether alone is accomplished rapidly by increasing the oxygen-through-ether
flow rate by 25 to 50 cc. increments. Usually three or four breaths by the patient between each addition is well tolerated. Concentrations of ether which are produced at various flow rates are presented in the accompanying graph (fig. 3). The observed ether values in oxygen-ether mixtures as estimated by reduction of oxygen partial pressure revealed by the Pauling Meter closely approximate the theoretical concentrations of saturated ether vapor at the particular working temperature.

The provision for the use of compressed air as a diluent in the system is believed to be physiologically desirable as well as economical. The addition of an excess of oxygen to every anesthetic mixture is very important, but if oxygen is the only diluent for the anesthetic, hyperventilation may be overlooked and, as a consequence, hypercarbia may develop.

**Genesis**

Many forces contributed to the development of this new vaporizer. The oft repeated desire of Ralph Waters for meticulous vernier control over increments in chloroform concentration was most important. Three ideas were explored in an attempt to improve existing systems and devices for controlling the concentrations of anesthetic vapors offered to the patient. The simplest and potentially most useful of these proved to be the change in circuit design which permitted separate metering of a variable flow of gas through liquid anesthetic, and thus provide delicate control over the resultant vapor concentration almost as though the vapor itself were being metered. Two laboratory models of this vaporizer were made, in the second of which important technical assistance was given by Fred McConkey and Evan Fredericksen. Six weeks of laboratory trial was followed by clinical usage in the spring of 1948. Animated discussions with Carlos Parsloe, Darwin Waters, Willard Bennett and others strengthened the impression that the circuit designed for control of vapor concentrations of chloroform might also be useful in the clinical administration of ether.

In the first models, the vaporizer bottle was surrounded by a water bath to keep the temperature of the liquid constant by providing heat for vaporization and thus make conditions more constant and reproducible. Following a suggestion of Warren Gilson and Ralph Waters, the supply of heat for vaporization was provided in more finished models by using copper to make the container for liquid anesthetic. Copper had also been used in an early vaporizer described by John Snow in 1847 (3).

There was a need for a more suitable and efficient bubbling device in the vaporizer, one which would provide fine bubbles with no serious in-

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† Throughout the development of this apparatus much stimulation and encouragement were received from O. Sidney Orth and Ralph Waters. I am indebted also to Edward Wylie and Richard v. Foregger for their interest, cooperation, and assistance in the making of the later models of this apparatus.
crease in resistance to gas flow. Sintered glass disks made by Evan Frederickeon were first tried for this purpose. The trials were satisfactory except for the moderate difficulty of glass to metal sealing, and it seemed that a real improvement had been made over other types of bubblers. At that time, a contact with Charles Boyd of the Naval Research Laboratory revealed that he was using a sintered bronze substance (porex) in his studies of flame propagation. Porex had two obvious advantages over glass in increased durability and heat conduction to the vaporizing surface. After suitable trials, a porex disk, therefore, was made an integral part of the vaporizer.

SUMMARY

Because of the recognition that certain deficiencies have been present in existing devices for the vaporization of liquid anesthetic agents, a new machine has been designed to provide reproducible conditions for efficient vaporization and vernier control over small increments in concentration. The important modifications for achieving this are in the circuit design, the liquid container and the vaporizing surface. No brief is made for resurgence of the use of liquid anesthetic agents. However, since there remain many occasions in which liquid agents such as ether or chloroform are being used as the agent of choice it seems desirable to have a device that provides the physician with discrete control over these agents.

REFERENCES