Precision Anesthesia Using Two Volatile Anesthetic Agents—Apparatus and Method

By

Takao Saito, Mitsuo Sato and Kenichi Iwatsuki

*Department of Anesthesiology, Tohoku University School of Medicine,
Sendai*

(Received for publication, June 21, 1961)

Although it is still a matter of controversy, a combined use of various anesthetic agents with different pharmacological properties, so-called balanced anesthesia, has become more popular during the last decade. A reduction of dosis or concentration of the drugs required for the maintenance of surgical anesthesia and a low incidence of undesirable side effects may be highly advantageous. On the other hand, however, a less simplicity in anesthesia and a relatively low controllability may be disadvantages in this type of anesthesia.

A simultaneous administration of two or more different volatile anesthetic agents, like fluothane-ether or chloroform-ether might offer quite interesting problems to anesthesiologists if these are given under precise and dynamic control of vapor concentration and mixing ratio of each agent. However, such a method has never been reported yet in clinical practice, probably because of technical difficulties.

Special devices have been on trial in our laboratory and some of them are going to be commercialized in this country. The methods and devices are described and discussed in details in the present paper.

The principle is a use of two or more copper kettle vaporizers, each filled with different volatile anesthetic agents which are vaporized by oxygen inflow separately and the vapors are conducted to a mixing chamber in parallel through a selector with a piping system.

*A new anesthetic apparatus designed forso-called precision
anesthesia using two volatile anesthetic agents— a new
double copper kettle machine*

1. Structure

The apparatus designed by the authors is shown in Photo 1 and is illustrated schematically in Fig. 1. The apparatus is provided with two copper kettle

Photo. 1.

Fig. 1.

vaporizers (K_1 and K_2), each equipped with a flowmeter for oxygen inflow to the vaporizer (A and B), a selector (G), a mixing chamber (F), flowmeters for bypass-oxygen, -nitrous oxide and -cyclopropane (C, D and E) and a respiratory circle (patent pending 35-45089).

If one puts different volatile anesthetics into each vaporizer, for instance fluothane to the first vaporizer (K_1) and ether to the second one (K_2), the respective concentrations of fluothane and ether and the mixing ratio of fluothane/ether in a gas mixture supplied to the inhaler can be regulated easily, accurately

and expediently by simply controlling the diluent or bypass flow (F_d) and the oxygen inflow to the copper kettle 1 and 2 (F_{k_1} and F_{k_2}).

If only one agent is desired to be administered, the selector should be switched to such a direction as the anesthetic vapor desired can pass through the selector towards the mixing chamber.

In our first trial product one vaporizer was made a little larger than the other. Basis for this difference in size is discussed later in this paper.

2. Performance characteristics (theoretical)

As previously described by Morris¹⁾ and Feldman and Morris²⁾ oxygen which flows through a liquid anesthetic is finely dispersed by passing through a sintered bronze disk (porex), and the magnitude of tiny bubbles leads to maximal vaporization efficiency by providing a greatly increased surface for the liquid-gas interface. In other words, the oxygen passed through the copper kettle vaporizer containing a volatile anesthetic agent is to be saturated instantaneously by the anesthetic vapor at the particular working temperature.

Therefore, the performance characteristics of the new double copper kettle machine are well expressed with the formulas described below.

$$A = \frac{F_{k_1} \times P_1}{(760 - P_1) \left\{ F_d + F_{k_1} \left(1 + \frac{P_1}{760 - P_1} \right) + F_{k_2} \left(1 + \frac{P_2}{760 - P_2} \right) \right\}} \times 100\% \quad (1)$$

$$B = \frac{F_{k_2} \times P_2}{(760 - P_2) \left\{ F_d + F_{k_1} \left(1 + \frac{P_1}{760 - P_1} \right) + F_{k_2} \left(1 + \frac{P_2}{760 - P_2} \right) \right\}} \times 100\% \quad (2)$$

$$F_{k_1} = \frac{A}{B} F_{k_2} \times \frac{P_2(760 - P_1)}{P_1(760 - P_2)} \quad (3)$$

$$F_{k_2} = \frac{B}{A} F_{k_1} \times \frac{P_1(760 - P_2)}{P_2(760 - P_1)} \quad (4)$$

The marks used in these functions are defined as follows:

F_d (cc./min.): Diluent or bypass flow. Sum of gas flows which directly go to the mixing chamber.

F_{k_1} (cc./min.): Kettle flow 1.

F_{k_2} (cc./min.): Kettle flow 2.

Both are oxygen inflow to the vaporizer K_1 and K_2 .

P_1 (mmHg): Vapor pressure of the volatile anesthetic agent (a) contained in the copper kettle 1.

P_2 (mmHg): Vapor pressure of the volatile anesthetic agent (b) contained in the

copper kettle 2.

$A(\% \text{ v/v})$: Vapor concentration of the anesthetic agent (a) in the whole gas mixture supplied to the inhaler.

$B(\% \text{ v/v})$: Vapor concentration of the anesthetic agent (b) in the whole gas mixture supplied to the inhaler.

When only one vaporizer is to be used the relationship between these variables could be given in simpler equations:

$$A = \frac{F_{k_1} \times P_1}{(760 - P_1) \left\{ F_d + F_{k_1} \left(1 + \frac{P_1}{760 - P_1} \right) \right\}} \times 100\% \quad (5)$$

$$B = \frac{F_{k_2} \times P_2}{(760 - P_2) \left\{ F_d + F_{k_2} \left(1 + \frac{P_2}{760 - P_2} \right) \right\}} \times 100\% \quad (6)$$

As P_1 and P_2 are constant with each agent at the particular temperature, A and B are dependent upon F_d , F_{k_1} and F_{k_2} in the formulas (1) and (2). On the contrary, if the desired concentrations of each drug (A, B) mixing ratio (A/B), and diluent flow (F_d) are given F_{k_1} and F_{k_2} are obtained from the equations (1), (2), (3) and (4).

As a direct calculation of desired values from these equations are somewhat complex and time-consuming, it seems to be necessary to provide a simple flow-temperature-concentration nomogram or a calculator for the convenience of practical use of this machine.

Table I.

Flow Temperature °C		1% Fluothane-Ether Mixture											
		0/100	10/90	20/80	30/70	40/60	50/50	60/40	70/30	80/20	90/10	100/0	
15	0	58	15	30	45	60	74	89	104	119	135	150	0
	1	54	14	28	43	58	72	87	102	117	132	147	0
	2	50	13	26	41	56	70	85	100	115	130	145	0
	3	46	12	24	39	54	68	83	98	113	128	143	0
	4	42	11	22	37	52	66	81	96	111	126	141	0
	5	38	10	20	35	50	64	79	94	109	124	139	0
	6	34	9	18	33	48	62	77	92	107	122	137	0
	7	30	8	16	31	46	60	75	90	105	120	135	0
	8	26	7	14	29	44	58	73	88	103	118	133	0
	9	22	6	12	27	42	56	71	86	101	116	131	0
	10	18	5	10	25	40	54	69	84	99	114	129	0
	11	14	4	8	23	38	52	67	82	97	112	127	0
	12	10	3	6	21	36	50	65	80	95	110	125	0
	13	6	2	4	19	34	48	63	78	93	108	123	0
	14	2	1	2	17	32	46	61	76	91	106	121	0
	15	0	0	0	15	30	44	59	74	89	104	119	0
	16	0	0	0	13	28	42	57	72	87	102	117	0
	17	0	0	0	11	26	40	55	70	85	100	115	0
	18	0	0	0	9	24	38	53	68	83	98	113	0
	19	0	0	0	7	22	36	51	66	81	96	111	0
	20	0	0	0	5	20	34	49	64	79	94	109	0
	21	0	0	0	3	18	32	47	62	77	92	107	0
	22	0	0	0	1	16	30	45	60	75	90	105	0
	23	0	0	0	0	14	28	43	58	73	88	103	0
	24	0	0	0	0	12	26	41	56	71	86	101	0
	25	0	0	0	0	10	24	39	54	69	84	99	0
	26	0	0	0	0	8	22	37	52	67	82	97	0
	27	0	0	0	0	6	20	35	50	65	80	95	0
	28	0	0	0	0	4	18	33	48	63	78	93	0
	29	0	0	0	0	2	16	31	46	61	76	91	0
	30	0	0	0	0	0	14	29	44	59	74	89	0

Table I is a flow-temperature-concentration nomogram prepared for fluothane-ether anesthesia. Since it is impossible to summarize many factors such as E_d ,

F_{k_1} , F_{k_2} , P_1 , P_2 , A and B, etc. into a single chart, F_{k_1} and F_{k_2} (cc./min.) required to produce 1% fluothane-ether mixture of various mixing ratio at the temperature range of 15–30° C when F_d is set to 5000 cc./min., are shown in Table I.

On the practical application of Table I, a few simple calculations are necessary as the nomogram is prepared for the case in which F_d and the sum of concentration of fluothane and ether are fixed to 5000 cc./min. and 1% v/v respectively.

(1) In a case in which F_d other than 5000 cc./min. is desired, for example $m \times 5000$ cc./min., then multiply the F_{k_1} and F_{k_2} by m .

(2) When the concentration of fluothane-ether mixture other than 1% is desired, for example $n\%$ FEM, then multiply the F_{k_1} and F_{k_2} by n . Errors produced by this calculation are negligible, provided that F_d is large enough in comparison with F_{k_1} and F_{k_2} .

(3) When temperature of fluothane and ether are different from each other, pick up the F_{k_1} and F_{k_2} at the respective working temperature from Table I. Errors are quite small with this calculation, as the temperature difference remains usually within a few degrees centigrade. (refer to the formulas (1) and (2)).

The descriptions of concentration and mixing ratio are somehow complex and need to be explained.

The following expressions are commonly used in our laboratory. For example:

Ex. 1. 2% FEM 50/50 Ex. 2. 3% CEM 33/67

Ex. 1 represents a gaseous mixture containing 1% fluothane and 1% ether in volume percent and the total concentration of the anesthetic vapors is 2%.

Fig. 2. Flow-Temperature-Concentration calculator for copper kettle vaporizer (Example of calculation 1.)

Fig. 3. Flow-Temperature-Concentration calculator for copper kettle vaporizer (Example of calculation 2.)

Ex. 2 represents a gaseous mixture containing 1% chloroform and 2% ether and the total concentration of the anesthetic vapors is 3%. The mixing ratio of chloroform and ether in the latter is 33/67.

More recently, a simple and accurate calculator for copper kettle vaporizers was developed in our laboratory (Patent pending 36-16813).

The basic scales are calibrated for kettle flow (F_k cc./min.) and anesthetic vapor concentration ($C\%$ v/v). The sliding scale is calibrated for total gas flow (F_t cc./min.) and temperature ($^{\circ}\text{C}$) of various anesthetic agents (chloroform, ether, fluothane and trichlorethylene) as seen in Figs. 2 and 3. In a standard position of the calculator, F_t/F_k is calibrated in a proportion of 10/1.

Examples of calculation are presented.

Ex. 1

Fig. 2 illustrates how to calculate the vapor concentration when the temperature of the anesthetic, total gas flow and oxygen inflow to the copper kettle are given.

If F_k is set to 500 cc./min., F_t to 5000 cc./min. and the temperature of chloroform is 20°C , the vapor concentration of chloroform supplied to the inhaler is about 2.6%(v/v).

This corresponds very well to the theoretically calculated value, 2.62%. It is not necessary to shift the sliding scale in this example of calculation.

Ex. 2

Fig. 3 illustrates an example in which 2.3% (v/v) of ether vapor is desired to be delivered from the anesthetic machine to the inhaler. Temperature of ether is supposed to be 25°C .

Firstly move the cursor and correspond the cursor line to 2.3% on the C scale.

Secondly, shift the sliding scale towards left and correspond the line of 25°C of ether to the cursor line.

Then, $F_k/F_t=1/100$ is obtained on the F_k and F_t scale. When total flow of 51. /min. is desired, oxygen inflow to the vaporizer should be 50 cc./min. in this case.

On the combined use of two volatile anesthetic agents, calculation is made in the same way with respective anesthetic agents separately as described in Exs. 1 and 2.

Instead of "diluent flow." total gas flow was used in this scale in order to make the calculator as compact as possible.

The relationship between total gas flow (F_t) and diluent flow (F_d) is well described in the following formula.

(1) A use of single copper kettle vaporizer

$$F_d = F_t \left(1 - \frac{A}{100} \right) - F_{k_1} \quad (7)$$

(2) Combined use of two copper kettle vaporizers

$$F_d = F_t \left(1 - \frac{A+B}{100} \right) - (F_{k_1} + F_{k_2}) \quad (8)$$

In these formulas marks are used as follows :

F_d (cc./min.): Diluent or bypass flow.

F_t (cc./min.): Total gas flow from the anesthetic machine to the inhaler.

F_{k_1} (cc./min.): Oxygen inflow to the copper kettle vaporizer 1.

F_{k_2} (cc./min.): Oxygen inflow to the copper kettle vaporizer 2.

A (% v/v): Vapor concentration of the anesthetic contained in the vaporizer 1 in the whole gas mixture supplied to the inhaler.

B (%(v/v): Vapor concentration of the anesthetic contained in the vaporizer 2 in the whole gas mixture supplied to the inhaler.

Fig. 4. Performance of copper kettle vaporizers.

Also, when F_{k_1} and a (cc./min. : volume of an anesthetic vapor taken up by the oxygen flow through the vaporizer $1 = F_i \times A/100$ in the formula (7)) are small enough as compared with F_i , F_i could be dealt as F_d without making any significant discrepancies in calculation.

We are using this calculator with great satisfaction in clinical anesthesia and laboratory investigations.

3. Performance characteristics (measured)

Actual vaporization performance of our first machine was described in Figs. 4 and 5. Performance of individual vaporizer in a single use and that of two vaporizers in combined use were tested with dry gas meter and further confirmed with an ultraviolet absorption technique previously described by Kalow³⁾ and MacKay and Kalow⁴⁾ and modified by us.

Fig. 4 illustrates the vernier increments of fluothane vapor concentration in correlation with an increase in oxygen inflow to each copper kettle vaporizer. Bypass flow and temperature of the anesthetic were set to 5 l./min. and 20° C

Fig. 5. Combined use of two copper kettle vaporizers

respectively in these measurements.

Actual vaporization of fluothane from two copper kettle vaporizers in combined use was shown in Fig. 5.

Both with a use of single vaporizer and a combined use of two vaporizers, the new double copper kettle machine we tested has a good vaporization performance which is in very close correspondence with that of theoretically calculated.

Both fall in temperature and difference in temperatures of two anesthetic agents in the vaporizers have been almost negligible with our machine when vapor concentration of fluothane-ether mixture or chloroform-ether mixture remained within 2% v/v and the time of administration did not exceed two hours.

However, if higher anesthetic concentrations were used for a long period of time, a fall in liquid temperature and temperature difference between two anesthetic agents might become considerably larger.

Since the latent heat of vaporization of various volatile anesthetic agents are, ether : 87.0 Cal./gm., fluothane : 35.2 Cal./gm., chloroform : 64.0 Cal./gm. at 20°C and the specific volume of vapors of these agents at 20°C are, ether : 324.3cc./gm., fluothane : 121.6 cc./gm., chloroform : 201.6cc./gm., heat for vaporization required for production of 1l. of anesthetic vapor are, ether : 267.9 Cal., fluothane : 369.3 Cal. and chloroform : 317.4 Cal.

If the equal vapor concentration is used, a degree of fall in temperature due to vaporization must be in the following order :

Fluothane > Chloroform > Ether

In our first trial model, one vaporizer was made a little larger than the other in order to minimize the discrepancy in temperature of two volatile anesthetic agents during practical application.

SUMMARY AND CONCLUSION

A method and an apparatus for simultaneous administration of two or more volatile anesthetic agents under precise and expedient control of vapor concentration and mixing ratio were described in details and problems on performance characteristics of the newly designed double copper kettle machine were discussed in the present paper.

An anesthetic apparatus equipped with two copper kettle vaporizers was introduced by the Foregger Company a few years ago⁵⁾. This is, however, designed for a single use of different volatile anesthetic agents and it is impossible to deliver vapors of two volatile anesthetic agents simultaneously under precise and expedient control of concentration and mixing ratio. This is essentially a different apparatus from the new double copper kettle machine.

It is now possible to do a "precision anesthesia" using two volatile anesthetic agents with this apparatus.

References

- 1) Morris, L. E., A new vaporizer for liquid anesthetic agents, *Anesthesiology*, 1952, **13**, 587.
 - 2) Feldman, S. A. & Morris, L. E., Vaporization of halothane and ether in the copper kettle, *Anesthesiology*, 1958, **19**, 650.
 - 3) Kalow, W., Spectrophotometric determination of fluothane vapour, *Can. Anaes. Soc. J.*, 1957, **4**, 384.
 - 4) MacKay, I. M. & Kalow, W., A clinical and laboratory evaluation of four fluothane vaporizers, *Can. Anaes. Soc. J.*, 1958, **5**, 248.
 - 5) Catalog 16, The Foregger Company, Inc., New York, 1960.
-