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TENSIONS OF OXYGEN AND ETHER VAPOR DURING USE OF THE SEMI-OPEN, AIR-ETHER METHOD OF ANESTHESIA *

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THE opinion is prevalent that drop ether anesthesia is as nearly safe and completely foolproof as any method of anesthesia at our command. The establishment of the truth or fallacy of this opinion on a firm scientific basis would be highly desirable and many authors have reported studies to this end.

Fuss and Darra (1), working with dogs, made various studies of the chemical constituents of the blood during ether anesthesia and discovered that the oxygen saturation of arterial blood was reduced consistently. Shaw, Steele and Lamb (2) made similar studies and reported similar findings. Courville (3) reviewed some cases of cerebral anoxia in human beings after ether anesthesia. Schnedorf, Lorhan and Orr (4), in discussing the problem of anoxia in surgery, pointed out that anoxic accidents can and do occur during ether anesthesia. Pisetsky (5) reported hemiplegia following "open ether" anesthesia which presumably was a result of anoxia. Such reports indicate that even the time-honored drop ether anesthesia is not without danger.

The purpose of the present study was to make a critical investigation of some of the reasons for the frequently observed reduction in the oxygen saturation of arterial blood during use of the semi-open, air-ether method of anesthesia, and, if possible, to determine by what measures this reduction might be obviated. A second purpose of this

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study was to make application of certain new physical methods to research in anesthesiology.

METHODS

Three instruments developed in recent years seemed to allow a fairly direct approach to the problems at hand in making possible observations on patients during surgical anesthesia. For the continuous determination of ether vapor tensions in mixtures of air and ether, an acoustic gas analyzer described in a previous publication (6) was used. The Pauling oxygen meter (7) provided a means for the continuous determination of oxygen tensions in the gas mixtures dealt with and a Millikan self-compensating oximeter (8) allowed the continuous estimation of oxygen saturation of arterial blood.

PROCEDURE AND RESULTS

By use of the instruments mentioned in the foregoing section, some of the relationships of gas and vapor tensions existing during administration of ether by the semi-open method were studied. These studies fall under two general parts: (a) studies using an artificial respirator and (b) clinical observations.

On Use of the Artificial Respirator.—The objective of these studies was to observe some of the physical phenomena associated with the evaporation of liquid ether on the gauze of an anesthesia mask through which an intermittent stream of air was passed to and fro at regular intervals. Particularly, a determination of the ether tension in the mixed air under the mask was desired under varying conditions of ventilation rate and rate of administration of ether. To this end an artificial respirator was used.

This device was a mechanically driven bellows with a single brass tube as an inlet and outlet providing for to-and-fro movement of air (fig. 1). The artificial respiration cycle could be varied in rate from 13 to 29 per minute and in "tidal volume" from 435 to 1,446 cc. The bellows itself was completely surrounded by water bath kept at 37 C. by thermostatic control. On the inlet and outlet tube was a T connection allowing for continuous sampling of the gas mixture passing through the system. An Esmarch mask was fitted to the inlet and outlet tube in such a manner that the entire volume of the respired gases passed through the gauze covering the mask. The active end of a thermocouple was placed between the layers of the gauze of the mask and a separatory funnel filled with ether and controlled by a glass stopcock was placed in position to allow a predetermined amount of ether to drop on the mask.

Studies were made when ether was applied to the mask at different rates recorded in drops per minute and when the ventilation rate was varied by changing the respiratory rate and by changing the respiratory depth. After substitution of a Pender-ball-shaped gauze-covered

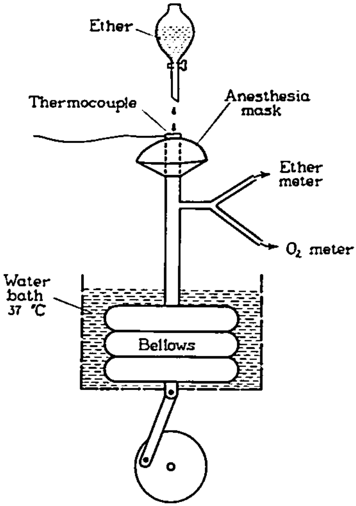


FIG. 1. Artificial respirator.

TABLE 1

ETHER TENSION RECORDED IN MILLIMETERS OF MERCURY

Drops of Liquid Ether per Minute	Inspiratory Minute Volume					
	5.3 liters	12.1 liters	12.6 liters	18.8 liters	27.7 liters	41.9 liters
Esmarch mask						
50	80.3			8.8	13.9	5.8
100	92.7			13.1		6.5
150	92.0		{70.8 78.0}	20.4		10.2
200	100.0	55.5	{86.1 92.7}	{20.4 24.8}	45.3	12.4
Pender mask						
8 layers of gauze						
50	52.6	18.7	37.6	4.4	7.9	
200	85.1	71.4	69.9	29.6	41.8	
12 layers of gauze						
50	67.8		82.2	2.9		
100	93.7		88.7			
200	117.5		98.1	27.4·		

mask for the Esmarch mask, studies were made first with 8 layers of gauze and then with 12 layers of gauze. The results of these experiments are summarized in table 1.

It was observed that the mask temperature taken at a point wet with ether stayed remarkably constant within fairly narrow limits, from − 2 to − 8 C. when the room temperature was 26 C. This temperature was reached and became steady within thirty seconds after the application of ether was begun. No significant or consistent variations in the temperature were found through wide ranges of ventilation rate and through wide ranges of rate of application of ether.

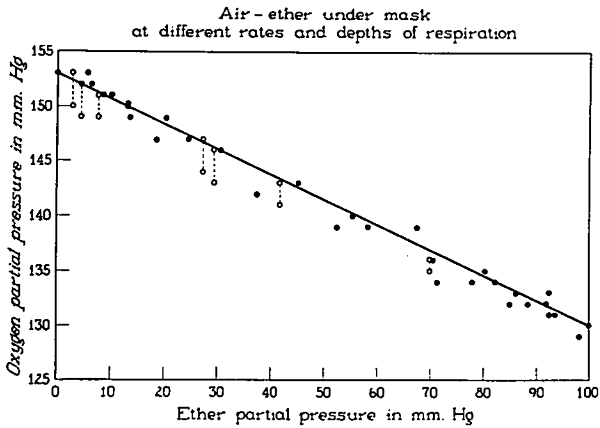


FIG. 2. Oxygen diluting effect of ether vapor. Solid black line represents calculated oxygen diluting effect of ether vapor. Dots are observations.

A definite tendency toward a decrease in the partial pressure of ether was found as the ventilation rate increased from 5.3 to 41.9 liters per minute. This tendency seemed to be independent of the rate of application of liquid ether to the mask and was independent of the type of mask used and the number of layers of gauze covering the mask. An increase in the partial pressure of ether occurred as the rate of application of liquid ether to the mask increased. This effect, too, was found to be independent of other factors, namely, minute volume and type of mask used. A comparison of the Esmarch mask with the Pender mask under similar conditions of ventilation rate and application of ether revealed no significant difference in concentration of ether in the mixed air under each. In the case of the Pender mask, a definitely higher concentration of ether vapor was found when 12 layers of gauze were used instead of 8. The highest partial pressure of ether found in the mixed air under the mask was 117.5 mm. of mercury. This was found when the Pender mask with 12 layers of gauze was used and ether was applied at the rate of 200 drops per minute and there was a ventilation rate of 5.3 liters per minute. The lowest ether concentration was found when an Esmarch mask was used and ether was applied at the rate of 50 drops per minute while the ventilation rate was 41.9 liters per minute.

Simultaneous determinations of the partial pressures of ether and oxygen were made. The partial pressures of ether, varying from 0 to 100 mm., are plotted as the abscissas in figure 2 and the partial pressures of oxygen, varying from 125 to 155 mm., on the ordinates. These observations were made on two different days. In one case the Esmarch mask was used, while in the other case the Pender mask was used.

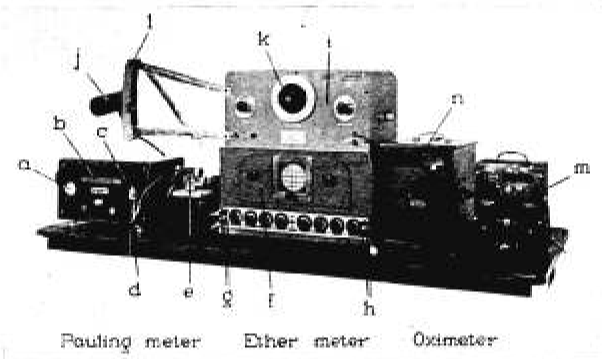
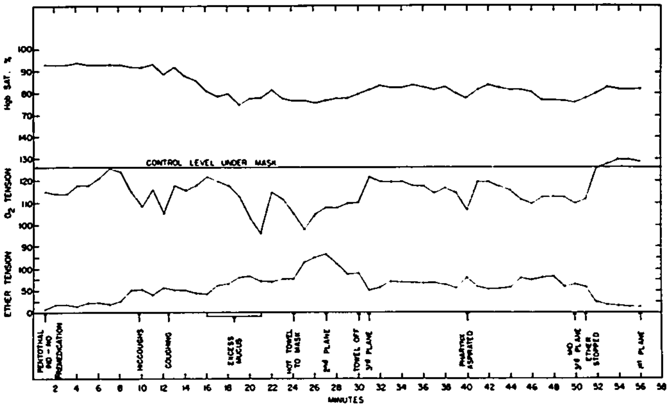


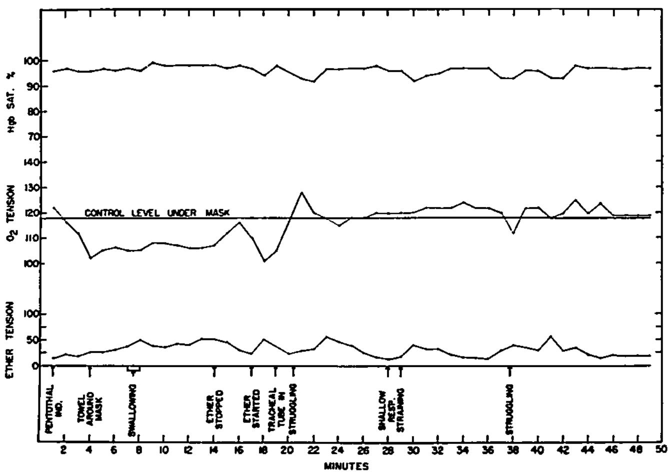
FIG. 3. Apparatus as assembled for clinical observations: *a*, thermometer on Pauling meter; *b*, Pauling meter scale; *c*, sample line flow meter; *d*, gas sample line to Pauling meter and ether meter; *e*, sound tube of ether meter; *f*, oscilloscope; *g*, x-axis leads from sound tube oscillator circuit; *h*, y-axis leads from variable oscillator; *i*, variable oscillator; *j*, light source; *k*, concave mirror; *l*, ether meter scale; *m*, control box of the Millikan oximeter; *n*, oximeter galvanometer scale.

Studies of the effect of ether vapor on the mixed air under the mask in relation to the partial pressure of oxygen revealed that there was an inverse relationship between the two; the partial pressure of oxygen was reduced in proportion to the increase in ether partial pressure. The decrease in partial pressure of oxygen may be calculated by multiplying the percentage volume of ether vapor by the partial pressure of oxygen prior to the addition of the ether vapor. The results thus calculated are found to be in very close agreement with the experimentally



HgB SAT. %
O2 TENSION
ETHER TENSION
CONTROL LEVEL UNDER MASK
PENTOTHAL IND - NO PREMEDICATION
HICCOUGHS
COUGHING
EXCESS MUCUS
HOT TOWEL TO MASK
2nd PLANE
TOWEL OFF
3rd PLANE
PHARYNX ASPIRATED
ETHER STOPPED
1st PLANE
MINUTES

FIG. 4



HgB SAT. %
O2 TENSION
ETHER TENSION
CONTROL LEVEL UNDER MASK
PENTOTHAL IND.
TOWEL AROUND MASK
SWALLOWING
ETHER STOPPED
ETHER STARTED
TRACHEAL TUBE IN
STRUGGLING
SHALLOW RESP.
STRAINING
STRUGGLING
MINUTES

FIG. 5

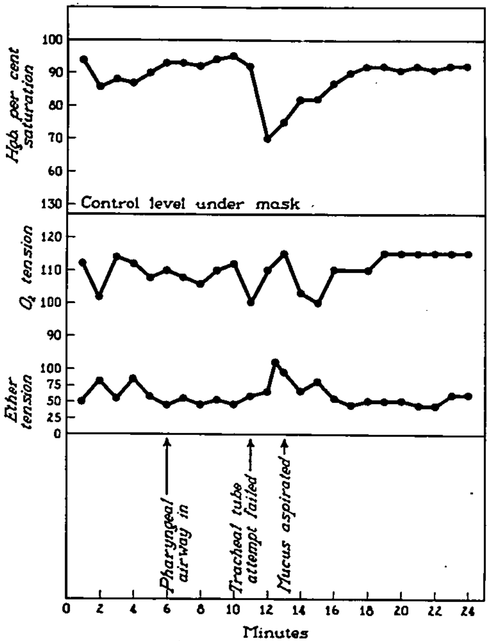


FIG. 6

FIGS. 4, 5 AND 6. Clinical observation of oxygen saturation of arterial blood as indicated on the Millikan oximeter, of oxygen tension as indicated on Pauling meter, and of ether tension as indicated on ether meter.

observed results. Thus, an increase in the partial pressure of ether to 100 mm. caused a reduction in the partial pressure of oxygen from a normal for room air of 153 to 130 mm. A proportionate and consistent reduction in the partial pressure of oxygen was found in every observation made.

Clinical Applications.—The apparatus illustrated in figure 3 was used in the operating rooms in making a study of the partial pressures of oxygen and ether in the mixed air under the mask and oxygen saturation of arterial blood during the use of the semi-open, air-ether method of anesthesia. Sixteen such cases have been investigated. The procedure was as follows:

When patients scheduled for operation were brought to the anesthesia room, the oximeter ear piece was applied and the instrument allowed to reach equilibrium; this was set arbitrarily to read 96 per cent saturation while the patient was breathing room air. The patient was asked to breathe normally for a period of two to three minutes through an ether mask of the type to be used for anesthesia, complete with occlusive towel, but with no ether applied to it. While the patient was breathing in this manner, the sampling tube leading to the oxygen meter and the ether meter was placed under the mask and the ether meter scale adjusted to 0. The partial pressure of oxygen indicated on the

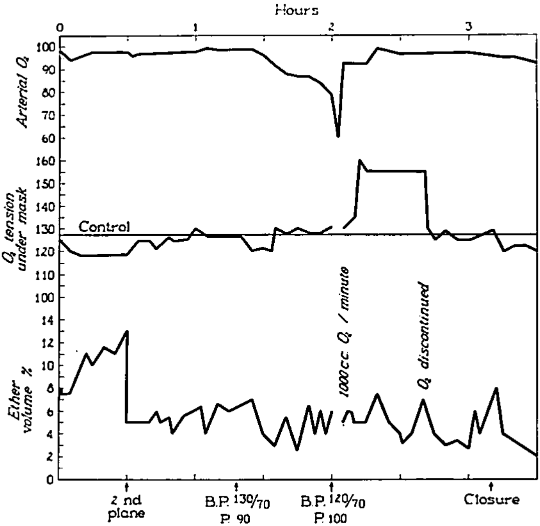


FIG. 7. Observations during ether anesthesia in a case of ventral hernia. Measurements were made as indicated in legend for figure 4.

oxygen meter was recorded as a control level. Anesthesia was induced in most cases by the intravenous injection of 6 to 10 cc. of 2.5 per cent solution of pentothal sodium, after which ether, administered by the semi-open drop method, was employed. In a few instances induction was started by administering nitrous oxide and oxygen, and shortly after the patient became unconscious, administration of ether by the semi-open drop method was substituted. The partial pressure of ether indicated on the ether meter, the partial pressure of oxygen and the oxygen saturation of hemoglobin in arterial blood indicated by the oximeter were all recorded graphically at intervals of less than half a minute (figs. 4 to 8).

It will be seen that the partial pressure of ether recorded in the mixed air under the mask seldom exceeded 90 mm. of mercury. On one occasion the maximal partial pressure of ether was 133 mm. (fig. 4).

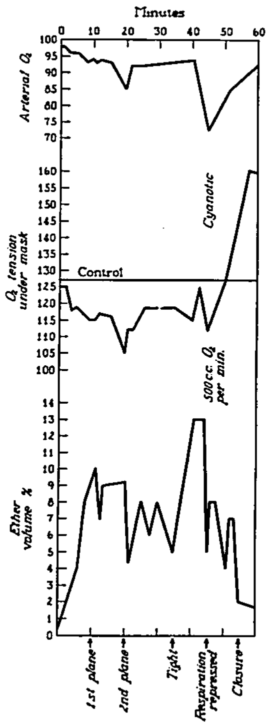


FIG. 8. Observations during ether anesthesia and performance of the Whipple operation. Measurements were made as indicated in the legend for figure 4.

However, this concentration was achieved purposely and only by the application of hot, wet towels to the mask during very rapid administration of liquid ether to the mask. The partial pressure of ether in one case (fig. 5) was maintained at an average of about 30 mm. throughout the induction, which probably accounts for the inadequacy and prolonging of the procedure. In this case, however, a significant fall in the oxygen saturation of arterial blood was not recorded; the lowest point was 92 per cent. In all other cases there was a significant and sometimes alarming drop in the oxygen saturation of arterial blood, on two occasions to 70 per cent (fig. 6). Although these excessive falls were commonly associated with simultaneous low partial pressures of oxygen, they were not always (figs. 7 and 8).

A significant decrease in the oxygen saturation of arterial blood unassociated with any similar depression of oxygen tension in the mixed air under the mask was observed after relatively long periods of anesthesia (figs. 7 and 8). The frequency of this observation in our series suggests that this phenomenon is worthy of further critical study. Analysis of our data does not indicate the cause. However, it was found that the addition of as little as 500 cc. of oxygen per minute under the mask quickly and completely restored the oxygen saturation of arterial blood to normal.

The average partial pressure of oxygen in the mixed air under the mask recorded during the control period and before the application of any ether was 123 mm. of mercury. This control level varied with the ventilation rate; it was higher (128 mm.) when the ventilation rate was greater and lower (118 mm.) when the ventilation rate was less. After application of ether to the mask was begun, the partial pressure of oxygen in the mixed air under the mask seldom again became as high as during the control test. In many instances it fell to less than 100 mm. and on one occasion reached a point as low as 80 mm. It averaged 105 mm.

COMMENT

Data Obtained by Use of Artificial Respirator.—The fact that the temperature of the masks was found to reach quickly and maintain steadily a level of from − 2 to − 8 C. was considered to be of some interest. It will be observed by reference to a standard vapor pressure curve for ether that this range of temperature will act as a limiting factor in governing the maximal tension of ether to be obtained with this form of ether anesthesia. The vapor pressures of ether in the extremes of this range of temperature are 170 and 125 mm. Ether tension in excess of these amounts would be impossible to achieve without some means of warming the ether mask. Although this observation was made in an admittedly artificial setup, our clinical experience has borne out the validity of the conclusion.

The data obtained from the study on the diluting effect of ether vapor on the normal oxygen content of the mixed air under the mask, while obvious on thoughtful analysis, are not widely recognized by anesthetists and may be a factor of major importance to patients for whom the risk is high and for whom semi-open, air-ether anesthesia is employed.

Clinical Data.—An interesting, and not widely recognized, observation became immediately apparent in these investigations, that is, the reduction in the partial pressure of oxygen in the mixed air under the ether mask while the patient is breathing normally. The oxygen tension as indicated by our Pauling meter for room air is constant at 153 mm. when the barometric pressure is an average normal of 730 mm. for an elevation of 1,000 feet. The partial pressures recorded from the mixed air under the masks of the 14 patients constituting this series vary from 118 to 128 mm. of mercury, the average tension being 123 mm. While this reduction alone was not, in most cases, sufficient to reduce the oxygen saturation of arterial blood significantly, as indicated by the oximeter, it reduces the margin of safety against anoxia. This effect added to the ether diluting effect already considered accounts for much of the reduction in the oxygen saturation of arterial blood which frequently was noted in these studies.

A rough inverse relationship between the ether tension and the oxygen tension will be found on studying the records of these observations; however, this is by no means universally true. It was immediately recognized that many other factors which were not controlled had a significant, and sometimes alarming, effect on the oxygen tension in the mixed air under the mask. Some of these factors were voluntary holding of breath, partially or completely obstructed airways, hiccups and respiratory depression owing to excessive premedication or deep anesthesia.

The partial pressures of ether used most commonly during the induction period varied markedly from minute to minute. The usual ether tension during induction ranged from 25 to 75 mm. Partial pressure of oxygen under the mask remained, with few exceptions, consistently lower than that during the control period and showed a usual variation from 100 to 120 mm.

The oxygen saturation of arterial blood recorded seemed roughly to follow the curves of oxygen tension, particularly when the partial pressure of oxygen was maintained at a low level for periods of more than two minutes. However, this was not always the case. Instances were found in which the arterial saturation curve was low despite an absence of significant reduction in the oxygen tension in the mixed air under the mask. Very often such a reduction in oxygen saturation could be accounted for on a basis of inefficient respiration. In other cases the reduction seemed to accompany deepening anesthesia and to be independent of the fact that there was no significant change in the partial pressure of oxygen. The data presented herein do not support a final explanation of the cause for this sometimes alarming state of anoxemia. However, our investigations indicate that the addition of as little as 500 cc. of oxygen per minute to the mixed air under the mask usually will prevent the development of an anoxemic state. On the basis of this finding it has been our practice to recommend the routine addition of small amounts of oxygen under the mask when the semi-open, air-ether method is used.

The experience gained in use of the instruments described shows clearly how difficult it is to judge, without exact measurement, the state of oxygenation of a patient during anesthesia. The instruments were of definite value in indicating danger points during anesthesia and should be of value to any anesthetist. They could be of particular value in the training of anesthetists. In addition, continued and further study with these devices should aid in a variety of studies on the physiologic mechanisms involved in anesthesia.

These findings indicate the value of a device such as the modern anesthesia machine in providing a means for oxygen control.

Summary and Conclusions

The partial pressures of oxygen and ether vapor and their relationship to oxygen saturation of arterial blood were studied during use of the semi-open, air-ether method of anesthesia.

With the aid of an acoustic gas analyzer and a Pauling oxygen meter a study of partial pressures of ether and oxygen under a mask for administration of ether by the semi-open method was made in the laboratories with the aid of an artificial respirator. Partial pressures of ether of from 0 to 117.5 mm. of mercury were obtained. Partial pressures in excess of 100 mm. were difficult to obtain. The greater the rate of ventilation the lower was the partial pressure of ether. Partial pressure of ether as high as 117.5 mm. was produced when the standard 8 layers of gauze covering the mask was replaced by 12 layers of gauze. The partial pressure of oxygen in the mixed air under the mask was found to bear an inverse relationship to that of the ether. An increase in the partial pressure of ether to 100 mm. reduced the partial pressure of oxygen 23 mm. The temperature was measured by means of a thermocouple between the layers of gauze on the mask at the site of evaporating ether. When ether was dropped onto the mask, the temperature dropped within thirty seconds to between − 2 and − 8 C. when the room temperature was 26 C.

Observations were made on 16 patients during ether anesthesia by the semi-open method, with the equipment mentioned previously and a Millikan self-compensating oximeter. Findings were as follows:

The application of a mask to the face of the patient before the administration of ether resulted in a reduction of the partial pressure of oxygen under the mask from that of the air in the room (153 mm.) to an average of 123 mm.

Application of ether to the mask produced a further reduction in the partial pressure of oxygen under the mask. The average value obtained was 105 mm. The lowest partial pressure of oxygen recorded under these circumstances was 80 mm.

The average range of partial pressures of ether under the mask during induction was 35 to 75 mm. The maximal partial pressure of ether observed was 133 mm. This pressure was attained by the application of hot wet towels to the mask.

Observations of 16 patients revealed frequent significant reductions in the oxygen saturation of arterial blood. These reductions in the oxygen saturation of blood could in most instances be related to the changes which were found in the oxygen tension under the mask.

The addition to the mixed air under the mask of as little as 500 cc. of oxygen per minute was found to restore the oxygen saturation of arterial blood to a normal level. This practice is recommended for routine use in all cases in which the semi-open, air-ether method of anesthesia is chosen.

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