THE EFFECT OF VARIATIONS OF INTRATRACHEAL PRESSURE AND ANESTHETIC MIXTURES ON THE ARTERIAL BLOOD OXYGEN * †

(AN EXPERIMENTAL STUDY)

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Introduction

The maintenance of an adequate supply of oxygen for the body tissues during intrathoracic operations has always been a matter of prime concern to the thoracic surgeon and anesthetist. Failures in the early days of thoracic surgery were frequently due to anoxia. An appreciation of the factors tending to produce anoxia has led to methods to combat them (1). There is not, however, general agreement concerning the anesthetic agents and technics of administration most advantageous for intrathoracic surgery. Our clinical technic using ethylene-oxygen and ethylene-ether-oxygen mixtures has been described in previous communications (2–3). A clinical study of the arterial blood oxygen in these patients revealed that the level approximated the preoperative level during surgery, even though less than 20 per cent of oxygen was frequently being given. Some investigators have felt that agents other than ethylene-oxygen and nitrous-oxide oxygen should be employed in order to avoid administering a low percentage of oxygen (5–6). In an effort to obtain additional data on the subject we undertook further studies on experimental animals.

Method

In these studies two anesthetic agents were used, namely, ethylene-oxygen and nitrous oxide-oxygen. Two methods of administration were employed: a semiclosed partial rebreathing method with a positive pressure type of apparatus, and a to-and-fro absorption system with intermittent manual pressure on a breathing bag. The anesthetic mixtures were given at various pressures with the chest open and closed. The percentage of oxygen administered was also varied from time to time independent of the pressure variations.

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All experiments were conducted on adult mongrel dogs weighing from 6 to 14 Kg. The animals were used repeatedly at weekly intervals, therefore anemia often developed. They were prepared for the experiment by the hypodermic injection of 0.015 to 0.075 Gm. of morphine. One half hour later the dog was secured to the operating table. Before any anesthetic mixture was given a sample of arterial blood was drawn from a femoral artery into a mercury tenometer. This sample, and all subsequent blood samples, were analyzed for oxygen and carbon dioxide content. The first sample drawn from the unanesthetized animal was considered the basal arterial blood oxygen for that day. Hemoglobin, red cell count and hematocrit reading were also determined on the basal sample. The dog was then anesthetized with one of the agents and technics previously described, and further samples of arterial blood were drawn into mercury tenometers at intervals to test the effect on the arterial blood oxygen of variations in the intrabronchial pressure and percentage of oxygen administered. A hole was drilled in the face masks employed so that a Levin tube could be inserted through a metal airway into the trachea. This aperture was so constructed that it was readily sealed off around the Levin tube and thus kept the system air tight. A "Y" tube was attached to the Levin tube, one arm of the "Y" being connected to a water manometer to measure the intrabronchial pressure, and the other attached to an oxygen analyzer similar to that described by Pachman (8). This permitted us to check the percentage of oxygen delivered by the machine. When using the to-and-fro absorption technic with intermittent manual pressure on the breathing bag, the oxygen analyzer was also connected to the bag. All but one of these connections were clamped shut at any given moment. Each experiment was completed in two to three hours. Five or six arterial blood samples were drawn in the course of each experiment; they were refrigerated and the blood oxygen and carbon dioxide determined by the method of Van Slyke (7) at the conclusion of the experiment. All determinations were made in duplicate (see Protocol No. 1).

RESULTS

Twenty-one experiments were carried out with the chest closed. They were fairly evenly divided both as to anesthetic technic and agent employed. No significant variations in the arterial blood oxygen could be determined for either agent or technic of administration providing the percentage of oxygen administered was constant. The intrabronchial pressure was not an important consideration since the pressure needed to force the anesthetic mixture into the lungs was sufficient to maintain alveolar exchange of gases. Obviously, the variation of the percentage of oxygen in the anesthetic mixture caused considerable variation in the arterial blood oxygen. We were anxious, however, to study this feature extensively so that we would have a basis for comparison in the later experiments when the chest was opened.

The amount of oxygen administered ranged from 10 to 20 per cent according to anesthetic machine readings. It was found necessary to express the arterial blood oxygen in percentage of the basal for that day as well as in absolute readings. Since many of the animals became anemic, the arterial blood oxygen in the resting state when breathing warm air was often as low as 15 volumes per cent. Naturally, one could not expect the oxygen content of the arterial blood to be higher than 15 volumes per cent in such an animal even though the anesthetic mixture contained 20 per cent of oxygen. Twenty arterial blood samples were drawn in animals receiving 20 per cent of oxygen in the anesthetic mixture. The oxygen contents of these samples averaged 17.86 volumes per cent, and ranged from 15.27 volumes per cent to 21.93 volumes per cent. Expressed in terms of percentage of the basal reading for the dogs on the day the experiments were run, 17.86 volumes per cent was 102 per cent of the basal readings. If each of the twenty determinations was compared with the basal reading, the range was found to be 94 to 111 per cent. It is fair to assume, then, that a healthy animal will maintain his arterial blood oxygen at approximately the same level whether the 20 per cent oxygen inhaled is in room air or an anesthetic mixture.

Sixteen arterial blood samples were drawn from animals receiving 15 per cent oxygen in the anesthetic mixture. These samples contained an average of 13.99 volumes per cent of oxygen, and ranged from 9.98 volumes per cent to 16.69 volumes per cent of oxygen. These figures averaged 78.6 per cent of the basal for that day. In the animal carrying only 9.98 volumes per cent of arterial blood oxygen, the basal reading for that day was 12.55 volumes per cent, so this animal had an oxygen content of approximately 75 per cent for that day. In the absence of anemia, when 15 per cent oxygen is administered in the anesthetic mixture, the arterial blood oxygen will average about 15 volumes per cent or 75 per cent of normal.

Eight samples of arterial blood from animals receiving 10 per cent oxygen in the anesthetic mixture were analyzed. The arterial blood oxygen in these animals averaged 8.62 volumes per cent and ranged from 7.59 volumes per cent to 11.70 volumes per cent. This represented an average figure of 45 per cent of the basal blood oxygen for that day. Therefore, a simple rule of thumb can be established; i.e. in the absence of anemia or bronchial obstruction the arterial blood oxygen will approximate the percentage of oxygen in the inspired mixture. In some animals the percentage of oxygen in the anesthetic mixture was as high as 40. This failed to cause an increase of more than 10 per cent in the oxygenation of the blood over that seen when 20 per cent oxygen was being given. This is to be expected since the arterial blood normally is over 90 per cent saturated with oxygen.

Nineteen experiments were performed with the chest open. As in the former experiments, a basal blood sample was drawn before the anesthetic was begun and further samples were drawn with the chest closed and open. Nitrous oxide-oxygen was used in 11 experiments and ethylene-oxygen in 8 instances. No significant difference was found between the two agents. No attempt was made to test relaxation, and since all animals received 0.015 to 0.075 Gm. of morphine preoperatively no difficulty was encountered in obtaining anesthesia.

PROTOCOL—DOG NO. 123

DOG NO. 123, ANESTHETIZED WITH THE TO-AND-FRO ABSORPTION TECHNIC WITH INTERMITTENT PRESSURE ON THE BREATHING BAG

Time, a.m.	Procedure	Intratracheal O_2, per cent	Bag O_2, per cent	I.T. Pressure		Blood CO_2	Blood O_2	Remarks
				Insp.	Exp.			
7:20	0.075 Gm. morphine							
7:45	0.06 Gm. nembutal							
7:46	Blood sample					15.98	16.69	Basal blood
7:47	Anesthesia started $N_2O + O_2$							
7:52	I.T. catheter in							
7:54	N_2O—3 L O_2—700 cc.							
8:34	Blood sample	22	21	+3	+8	19.64	17.41	
8:42	Chest opened							Lung falls away on inspiration
8:48	Blood sample	22	21	+3	+7	21.06	16.05	
8:58	Blood sample	22	21	+5	+12	20.72	18.23	Lung well expanded
9:09	Chest wall closed							
9:25	Blood sample	22	21	+9	+15	21.24	18.07	
9:30	Experiment concluded							

Eight experiments were performed using the to-and-fro absorption technic with intermittent pressure on the breathing bag, and 11 with the semiclosed, positive pressure method with partial rebreathing. Difficulties were occasionally encountered with both methods, partially due to the lability of the dog's mediastinum, but all were overcome with experience. In the former method some practice was necessary to determine the proper tension to be maintained in the bag. In the latter, the type of spring valve used to estimate pressure at the inhaling and exhaling valves was prone to become inaccurate. Careful attention to the condition of the lung and the reading on the attached water manometer aided in maintaining the proper aeration of the lungs.

The effect of anemia was again demonstrated. Table 1 represents an experiment performed on Dog No. 181 when the hemoglobin was only 80 per cent and the hematocrit reading 40. In this instance a combination of factors resulted in very low arterial blood oxygen in an animal with the chest open. Adequate intratracheal pressure was not maintained and a low percentage of oxygen was given.

TABLE 1

DOG NO. 181 ANESTHETIZED WITH NITROUS-OXIDE PLUS OXYGEN USING THE SEMICLOSED, POSITIVE PRESSURE METHOD WITH PARTIAL REBREATHING

Note that the initial or basal arterial blood oxygen was very low. The inadequate intratracheal pressure and low percentage of oxygen in the anesthetic mixture resulted in a very low arterial blood oxygen. A similar fall in arterial blood oxygen would have been less dangerous in an animal with a basal oxygen of 19 to 20 volumes per cent.

% O_2	Blood O_2	Basal O_2	I.T. Pressure	Chest
20	14.40	14.42	0 +8	closed
15	7.63		−4 +9	closed
14	8.45		+6 +11	open
13	5.43		0 +7	open

% O_2—per cent of oxygen in anesthesia mixture.
Blood O_2—Arterial blood oxygen (volume %).
Basal O_2—Arterial blood oxygen before start of experiment (volume %).
I.T. Pressure—Recording on water manometer (in centimeters) attached to Levin tube in trachea. The first figure represents inspiration, the second expiration.
Chest—Refers to the state of the incision in the chest wall.

The use of mixtures rich in oxygen did not compensate for a low intrabronchial pressure if the chest was open (table 2). In this regard it must be borne in mind that the dog's mediastinum is much more labile than that of man and the effect shown in this table is exaggerated for human material.

TABLE 2

DOG NO. 137 ANESTHETIZED WITH NITROUS OXIDE PLUS OXYGEN USING TO-AND-FRO ABSORPTION TECHNIC WITH INTERMITTENT PRESSURE ON THE BREATHING BAG

This animal was not anemic and the basal arterial blood oxygen was in the normal range. When the intratracheal pressure was adequate the arterial blood oxygen was maintained, even though the chest was open and the percentage of oxygen being administered was constant. However, when the inhalation pressure was inadequate, the arterial blood oxygen fell to 4.42 volumes per cent despite the increased percentage of oxygen in the anesthetic mixture.

% O_2	Blood O_2	Basal O_2	I.T. Pressure	Chest
21	19.45	19.09	−2 +7	closed
20	17.84		+6 +10	open
24	4.42		+2 +3	open

% O_2—per cent of oxygen in anesthesia mixture.
Blood O_2—Arterial blood oxygen (volume %).
Basal O_2—Arterial blood oxygen before start of experiment (volume %).
I.T. Pressure—Recording on water manometer (in centimeters) attached to Levin tube in trachea. The first figure represents inspiration, the second expiration.
Chest—Refers to the state of the incision in the chest wall.

If the intratracheal pressure was maintained at a higher level, the arterial blood oxygen was maintained when the chest was opened even though the percentage of oxygen in the anesthetic mixture was not varied (table 3). It soon became evident that it was necessary to maintain the intrabronchial pressure at about plus 6 cm. of water inspiration and plus 12 cm. of water expiration when the chest was open in order to get the maximum alveolar exchange. These readings were obtained through the Levin tube which was inserted into the trachea down to the level of the bifurcation. With these pressures the arterial blood oxygen could be maintained at the same level when the chest was open or closed even though the percentage of oxygen in the anesthetic mixture remained constant. The intratracheal pressure was prone to fall on inspiration unless the exhaling valve was partially closed, or the bag maintained fairly tense. It was therefore necessary to maintain an intratracheal pressure of 8 to 9 cm. of water at all times, except during inspiration. This was demonstrated by observing the pressure

TABLE 3

DOG NO. 214 ANESTHETIZED WITH NITROUS OXIDE PLUS OXYGEN, USING THE SEMICLOSED, POSITIVE PRESSURE METHOD WITH PARTIAL REBREATHING

The percentage of oxygen in the anesthetic mixture was not varied and the arterial blood oxygen remained constant when the pleural cavity was open because the intratracheal pressure was adequate.

% O_2	Blood O_2	Basal O_2	I.T. Pressure	Chest
18	18.74	17.32	+7 +12	closed
20	18.05		+1 +7	closed
18	16.55		+4 +9	open
18	18.38		+8 +13	open

% O_2—per cent of oxygen in anesthesia mixture.
Blood O_2—Arterial blood oxygen (volume %).
Basal O_2—Arterial blood oxygen before start of experiment (volume %).
I.T. Pressure—Recording on water manometer (in centimeters) attached to Levin tube in trachea. The first figure represents inspiration, the second expiration.
Chest—Refers to the state of the incision in the chest wall.

on the manometer at the conclusion of expiration before the next inspiratory effort began. This basal pressure was independent of respiratory efforts and represented the pressure at which the anesthetic mixture was delivered.

In this study we dealt with healthy animals. The only complicating factor was the presence of anemia after several experiments had been run. In some respects the material studied was not comparable to clinical practice. The mediastinum is very labile in the dog, and any changes that occurred when the chest was opened were more marked than those seen in clinical surgery. For this reason the pressure readings were peculiar to dogs. In addition, we did not have to deal with pulmonary suppuration and bronchial obstruction. The vital capacity of these animals was not diminished by cardiac or pulmonary disease. Therefore the data obtained are not applicable in all respects to disturbed human physiology.

SUMMARY AND CONCLUSIONS

1. Forty experiments were carried out in dogs to test the effect of variations in anesthetic pressures and mixtures of nitrous oxide-oxygen or ethylene-oxygen on the arterial blood oxygen.

2. The arterial blood oxygen was found to approximate the percentage of oxygen administered with the chest closed. Under proper conditions, opening the pleural cavity did not alter the arterial blood oxygen.

3. The biggest single factor in maintaining an adequate arterial blood oxygen in a dog with an open chest is the regulation of the intrabronchial pressure. It is particularly important to maintain a constant intrabronchial pressure of about 8 cm. of water. This should be done by maintaining an adequate inhalation pressure to ensure oxygen reaching the blood.

4. The presence of anemia is a real hazard in that it markedly reduces the oxygen carrying capacity of the blood. The resulting anoxia cannot be corrected by the use of anesthetic mixtures rich in oxygen.

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