CYCLOPROPANE–AIR–OXYGEN ANESTHESIA

A Preliminary Report *

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The hazard of flammability and explosibility has existed with the use of some inhalation anesthetic drugs ever since their introduction. Ethyl ether presented the greatest potential danger until the last two decades. During this period, there was introduced the two gases: ethylene and cyclopropane, both of which were used with oxygen. Following the introduction of these gases, experiments were performed on the range of explosive concentrations for the several anesthetic drugs combined with air and with oxygen. The results of these experiments have been published. The information derived is of little assistance in preventing accidents when these drugs are used, because the anesthetic concentration of these drugs, when used clinically, is dependent upon the amount required to produce the indicated level of anesthesia. Therefore, they are seldom administered according to a pre-determined percentage. Precautions against static and other electrical potentials have been advocated, in the form of grounding and conditioned atmospheres. There has been no apparent decrease, however, in the number of explosions. Therefore, it was thought worthwhile to undertake an independent and careful study of the flammable and explosive tendencies of the various drugs mentioned above, in combination with one another when they were used with varying percentages of oxygen. If the information so derived would reveal any practical clinical application, the subject consequently could be pursued along these lines.

The Chemistry Department of Purdue University, under the direction of Henry B. Haas, Ph.D., with the sponsorship of the Purdue Research Foundation, has made detailed studies of the exact limits of flammability and explosibility of the commonly employed inhalation anesthetic drugs. Ether, ethylene, and cyclopropane were studied independently when combined with various concentrations of oxygen, as

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represented by the pure gas and also in the form of air. These drugs were studied, also, employing mixtures of the gases, nitrous oxide, carbon dioxide, and nitrogen, as diluents. The determinations provided by these experiments, when represented graphically, give the explosive range of the various agents in combination with the diluents, nitrogen, carbon dioxide and nitrous oxide. The complete data on this subject will be published at a later time, illustrated with pertinent graphs of numerous analyses.

Following a study of the graphs, test samples were obtained during various operative procedures on patients, employing different anesthetic combinations. The samples were analyzed and the findings were projected upon graphs to determine the actual flammability of the specific anesthetic mixtures used during clinical anesthesia. We believe that this is the first study made in this manner.

The study of the cyclopropane-nitrogen-oxygen graph for flammability gave scientific proof that there were conditions under which cyclopropane was not explosive. The question remained as to whether anesthesia could be produced safely, and at the same time, provide a non-flammable mixture. The graph (see Fig. 1) represents the range of flammable mixtures of cyclopropane-nitrogen-oxygen; all combinations which are flammable fall within the smaller feathered triangle.

All of the factors, including the analytical estimation which entered into the construction of the graph, were accomplished by careful laboratory research, and therefore, are accurate within the limit of a fraction of one per cent. To apply the graph, take the percentage individually of each component of the combination of nitrogen, cyclopropane, and oxygen, advance from that position on the component's base line to the point where all three lines intersect. If that point of intersection lies within the feathered triangle, then the mixture is flammable and may be explosive. If the point falls outside the feathered triangle, the mixture is both non-flammable and non-explosive. For example: Consider a theoretical mixture of 10 per cent. cyclopropane and 20 per cent. oxygen, the balance being nitrogen. Advance left and inward in a straight line from the proper point on the base line for cyclopropane to a point where that 10 per cent. line will intersect the 20 per cent. line similarly projected upward from the base line for oxygen. Now advance downward to the right from the nitrogen base line to its 70 per cent. line. The point of intersection of the three components will fall within the feathered triangle. The mixture is flammable and explosive.

Observe two facts depicted by the graph. First, irrespective of how great the percentage of oxygen in its mixture with nitrogen, one is always without the explosive range with 2 per cent. or less of cyclopropane. Secondly, one may note from the graph that irrespective of the percentage of cyclopropane in combination with nitrogen, at no time will the mixture be within the explosive range if the oxygen percentage is 11½ per cent. or lower. This latter fact is of greater importance.

No one would be so rash as to predict that we must, perforce, immediately change our technic of anesthetic procedure. Nevertheless, these studies definitely indicate the fact that, in inducing anesthesia with a

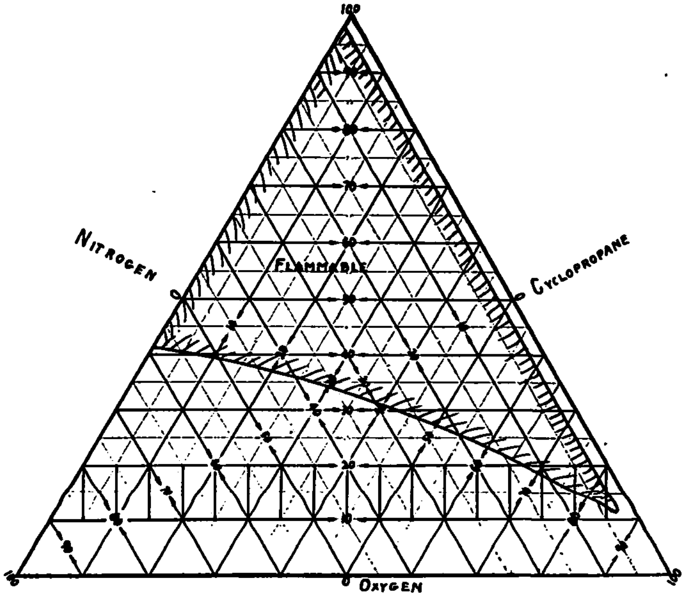

FIG. 1.

breathing bag containing oxygen 100 per cent., and then adding sufficient cyclopropane to establish anesthesia, at once an extremely hazardous explosive range is entered. Also, the practice of flooding or washing out the lungs with pure oxygen at the termination of the surgical procedure gives a similar effect. These two facts can be confirmed indisputably by a study of this graph. If meagre reports coming from centers where explosions have occurred are true, these two periods during anesthesia are the ones during which most of the explosions have occurred. This is what one might expect from the data given in the graph. This research suggests that a reasonable solution of this hazard can be obtained by using inert nitrogen as a diluent both for the induction and for the recovery, thus making it possible for each of these events to occur with reduced percentages of oxygen obtaining. We believe the hazard involved by such management is of less danger comparatively than the risk of flammability.

A further interesting point is shown in that a mixture of 25 per cent.

oxygen, 25 per cent. cyclopropane, and 50 per cent. nitrogen is nonflammable. However, with that percentage of cyclopropane in the mixture, it is quite probable that the patient might become too deeply anesthetized, and respiratory arrest may result. Respiratory arrest occurred with some patients with lesser percentages of cyclopropane, as determined by analyses.

Accordingly, with these facts and data before us, we determined to try cyclopropane-air-oxygen anesthesia. The problem of supplying air is solved in a simple way, as shown in Fig. 2. A bulb is attached to the

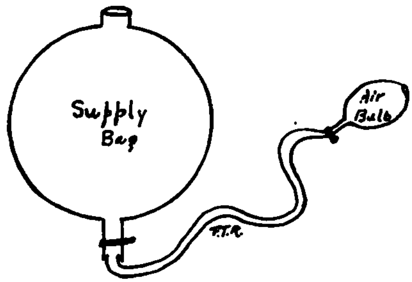

FIG. 2.

bottom of the breathing bag by means of a short length of rubber tubing. The breathing bag is filled first with air by compressions of the bulb. The patient breathes air, while cyclopropane and a metabolic supply of oxygen is added. Meanwhile, the signs of anesthesia are observed closely and constantly. Subsequently, should any of the contents of the bag become lost through leakage or by virtue of a poorly fitting facepiece, air is added by compressing the bulb. Of course, at any time, as it is indicated, air, cyclopropane, or oxygen is added.

A note of sternest warning must be given. To repeat, the physical signs of anesthesia are followed carefully. The signs are similar to those exhibited by other anesthetic agents, resembling more, perhaps, chloroform. The type of respiration and the patient's color, require particular observation, as do the reactions of pupils. It is wise to prognosticate the sequence of affairs by anticipating changes thirty seconds to a minute before they occur. The patient's ears are maintained a slightly pink color. Our analyses show that this can be done, in average cases, with a concentration of oxygen considerably less than 20 per cent. in the mixture. Denarcotization is produced by the addition of air alone. The above method can be used to produce smooth anesthesia and good relaxation.

A discussion of the difference between flammability and explosibility, necessitates a comparison of these terms. Any mixture of gases or vapors which is explosive is flammable also, but not every flammable mixture of vapors or gases is necessarily explosive, except under certain conditions.

We determined to use a color-index to differentiate clinically between the several degrees of tissue oxygenation. Dusky means slight suboxygenation. Pink (at ear lobes) denotes the normal.

The two cases illustrated will be treated in separate groups of three analyses, for, during each anesthesia, three test samples were obtained.

TABLE 1

Patient 1.
Ruth T. Surgical Procedure—Rectal
Anesthetic—Cyclopropane-Air-Oxygen—Circle Absorber
Sample Source—Supply bag
Stage—III, Plane 1 to 2—⊙
Color—Slightly dusky to pink

Analysis—Cyclopropane	13.8 per cent
Oxygen	15.7 per cent
Nitrogen	70.5 per cent
Carbon Dioxide	negligible

Result—Non-flammable

TABLE 2

Patient 1.
Ruth T. Surgical Procedure—Rectal
Anesthetic—Cyclopropane-Air-Oxygen—Circle Absorber
Sample Source—Supply bag
Stage—III, Plane 1 to 2—⊙
Color—Pink

Analysis—Cyclopropane	13.1 per cent
Oxygen	38.0 per cent
Nitrogen	48.9 per cent
Carbon Dioxide	negligible

Result—Flammable

TABLE 3

Patient 1.
Ruth T. Surgical Procedure—Rectal
Anesthetic—Cyclopropane-Air-Oxygen—Circle Absorber
Sample Source—Supply bag
Stage—III, Plane 1—←⊙→
Color—Pink

Analysis—Cyclopropane	8.3 per cent
Oxygen	64.9 per cent
Nitrogen	26.8 per cent
Carbon Dioxide	negligible

Result—Flammable

The first patient was a white female scheduled for a rectal procedure. We determined, before-hand, to start this patient on air only, induce and maintain the anesthesia with cyclopropane, then gradually add oxygen to produce extreme pinkness of the lobes of the ears. We wanted to ascertain the percentages of the gases and the degree of flammability. The breathing bag was filled with air, and the mask was applied to the face. A small flow of cyclopropane was started. All signs of anesthesia were watched carefully. The depth of anesthesia soon reached stage III, plane 2, with 200 cc. of oxygen flowing. Color—slightly dusky to pink; i.e., the patient was slightly suboxygenated. Then a sample (Table 1) was obtained from the breathing bag. The analysis demonstrated the mixture to be non-flammable, and safe as far as explosibility is concerned. Then air and plus oxygen were added to the mixture. The plane of anesthesia then changed to stage III, plane 1. The analysis is shown (Table 2). This concentration of cyclopropane is not only flammable but is definitely explosive. Further oxygen was added and the depth of anesthesia was allowed to become lighter. Sample three (Table 3) was taken, and the analysis is shown. This mixture is very dangerously explosive. This analysis parallels the many tests made during the ordinary cyclopropane-oxygen anesthesias previously taken.

The results obtained in Patient 1, encouraged further investigation. For the next patient, we determined to maintain a sufficiently low concentration of oxygen to stay outside the explosive limits throughout the anesthesia.

TABLE 4

Patient 2
Robert K. (Hawaiian) Surgical Procedure—Rectal
Anesthetic—Cyclopropane-Air-Oxygen—Circle Absorber
Sample Source—Supply bag
Stage—III, Plane 2—←⊙→
Color—Dusky

Analysis—	Cyclopropane	15.5 per cent
	Oxygen	6.1 per cent
	Nitrogen	78.4 per cent
	Carbon Dioxide	negligible

Result—Non-flammable
Respiratory arrest resulted.

TABLE 5

Patient 2
Robert K. (Hawaiian) Surgical Procedure—Rectal
Anesthetic—Cyclopropane-Air-Oxygen—Circle Absorber
Sample Source—Supply bag
Stage—III, Plane 1—←⊙→
Color—Pink

Analysis—	Cyclopropane	10.6 per cent
	Oxygen	7.0 per cent
	Nitrogen	82.4 per cent
	Carbon Dioxide	negligible

Result—Non-flammable

TABLE 6

Patient 2
Robert K. (Hawaiian) Surgical Procedure—Rectal
Anesthetic—Cyclopropane-Air-Oxygen—Circle Absorber
Sample Source—Supply bag
Stage—III, Plane 1—
Color—Pink

Analysis—	Cyclopropane	9.5 per cent
	Oxygen	6.0 per cent
	Nitrogen	84.5 per cent
	Carbon Dioxide	negligible

Result—Non-flammable
Awale in 3 minutes.

A young, vigorous Hawaiian, which characteristics constitute both an advantage and a disadvantage, was chosen. It was a disadvantage in that the color-index was more difficult to read; it was an advantage in that, if successful, it would be a severe test of the method. As soon as the anesthesia was levelled off at stage III, plane 2, the first sample was taken. The color was slightly dusky (Table 4). This mixture is non-flammable and non-explosive. With this percentage of cyclopropane, respiratory arrest was produced. As is well known, this is neither an unusual nor an embarrassing situation. With the mask off the face and by means of artificial respiration by simple pressure on the chest, the respiration was resumed and the anesthesia decreased to stage III, plane 1. In Table 5, the analysis of the second sample, then taken, is shown. Note that the color is normal. This sample, too, is non-flammable and non-explosive.

The anesthesia was maintained at this level for the remaining ten minutes of the operation. Toward the close, after no more air or cyclopropane had been added to the breathing bag, and only the required amount of oxygen had been flowing, the final sample was taken. The color was normal. The analysis (Table 6) was the same, essentially, as the one previously taken and was non-flammable and non-explosive. The patient was awake and thoroughly oriented mentally within three minutes. No nausea or vomiting was exhibited. We believe this is the first recorded case of cyclopropane anesthesia, during which an absolutely non-flammable mixture of cyclopropane was employed, as determined by analyses, throughout the entire procedure.

Upon examining the three analyses of patient 2 and plotting them upon the graph, it is interesting to observe that in the first sample, it would have been possible to have carried an oxygen percentage of 22 per cent., in the second an oxygen percentage of 18 per cent., and in the third an oxygen percentage of 17 per cent. and still have remained outside the explosive and flammable limits. These percentages of oxygen, in this particular patient, would have been ample to have carried him with a definitely pink-plus color-index.

No one knows at any one particular moment for any one particular patient exactly what the percentages contained in mixture are, except by rough approximation. It would not require a great deal of modification of existing instruments to provide equipment on present-day machines to serve as a device upon which constant readings of "danger" and "safe" would be indicated with regard to explosibility. Similar equipment is in use in the mining industry.

Final comment: In all the samples during which we used the closed circle, carbon dioxide absorption technic of anesthesia, not in a single instance did we find more than a mere trace of carbon dioxide. A fresh or relatively new supply of soda-lime was employed in the canister for each patient. This speaks well for the method.

In making this data at once available in a preliminary report, it is likely the results may arouse the interest of anesthetists. For generations, ether and chloroform have been administered with air. Why not employ cyclopropane with air? It seems reasonable and is based on sound physiologic principles. In fact, apart from the waste, in order to get sufficient oxygen, straight cyclopropane-air anesthesia with a partially open system should be feasible.

Normally, we breathe 80 per cent. nitrogen and 20 per cent. oxygen. Our physiological requirements are adjusted to these concentrations. The value of excess oxygen, under reasonably normal conditions, might be disputed, except in the presence of respiratory obstruction or definitely anoxic states. Authorities aver that, in normal concentrations of nitrogen and oxygen in the air and under ordinary atmospheric pressures, the blood stream is 98 per cent. saturated and that increasing the percentage of oxygen does not correspondingly increase this saturation. The residual air in the lung normally contains 13 to 14 per cent. oxygen plus 5.5 per cent. carbon dioxide when the individual is breathing air. Individuals ascending 6,000 to 8,000 feet above sea level in airplanes, or those living constantly at such altitudes are fairly comfortable in these atmospheres in spite of the reduced partial pressure of oxygen which is equivalent to reducing the oxygen percentage at sea level. In semi-closed, nitrous oxide-oxygen anesthesia little thought was given toward maintaining anesthesia with these patients definitely suboxygenated for protracted periods of time. We neither dare nor care to decry the obvious benefits of plentiful supplies of oxygen available to the tissues. We may be required, however, to change certain of our ideas because of the hazard of explosion.

We are happy to present the idea of cyclopropane-air-oxygen anesthesia because it appeals to us as an original and rational approach to a difficult problem. We are hopeful that anesthetists will experiment with it. Since the initial studies, it has been employed for major surgical procedures including thoracoplasty, during which the radio-knife was employed. The method is not fool-proof. It is neither a panacea nor a cure-all for hazards of flammability, nor is it offered as such. We make no claims of dogmatic absolutism. We merely suggest its clinical use as a possible application of the experiments conducted concerning the flammability of cyclopropane.

CONCLUSIONS

Excepting in nitrous oxide-oxygen anesthesia, without the addition of ether, ethylene, cyclopropane, or some like agents, the hazards of flammability and explosion are present in using the ordinary inhalation anesthetic agents under uncontrolled conditions. The only real solution for inhalation anesthesia would be the development of a non-flammable and non-explosive gas or volatile liquid possessing the required anesthetic properties. Research toward this end is being projected.

A method of administration of cyclopropane-air-oxygen anesthesia is described. Certain changes in technic which will tend to minimize or even abolish the hazard of explosion are suggested.

We believe it possible to develop an indicating device to attach to present-day anesthetic apparatus which would show instantly and perhaps constantly whether or not the mixture in use falls into or with the range of explosibility.

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The Board of Directors of the American Society of Regional Anesthesia, Inc., announce that a sum of money has been set aside to provide "The Labat Research Fellowship" in memory of Gaston Labat, M.D., founder of the society. The funds will be awarded to an anesthetist or surgeon for aid in pursuing original laboratory investigations in regional anesthesia. Inquiries and applications should be made to H. M. Wertheim, M.D., 1088 Park Avenue, New York, N. Y.