THE HAZARD OF FIRE AND EXPLOSION IN ANESTHESIA: *

Report of a Clinical Investigation of 230 Cases

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In 1937 the American Society of Anesthetists, Inc. appointed a committee for the study of the hazard of fire and explosion. This is the first comprehensive report of the case findings of this committee. We wish to emphasize here the fact that the American Society of Anesthetists, Inc., by its official action in giving great publicity to the hazard of explosion and by fostering a nationwide inquiry among its members, is to be credited with providing the inspiration and incentive which have led to the recent advances in our knowledge. Furthermore, I wish to secure your recognition of the great encouragement given by Dr. Paul M. Wood and the very helpful advice and cooperation of the many members of our society, especially Drs. Everett A. Tyler and Huberta M. Livingstone.

We have secured information concerning 230 fires and explosions involving anesthetic agents. The distribution of the occurrences is shown in Table 1.

TABLE 1

Fires and Explosions Grouped as to Etiology

1. X-ray apparatus	10	cases
2. Cautery apparatus	57	"
3. Diathermy apparatus	20	"
4. Suction-pressure machines	59	"
5. Endoscopic apparatus	5	"
6. High pressure explosions	10	"
7. Static electricity	63	"
8. Miscellaneous	6	"
	230	

The distribution of injuries is shown in Table 2. It is apparent from this tabulation that at least 152 (or 70 per cent.) of the explosions and 23 (or 60 per cent.) of the deaths were due to those causes about which effective prophylactic information has long been available and repeated cautions have been urged. For example, despite the authoritative advice issued by the National Board of Fire Underwriters in 1929, against the use of combustible mixtures in the presence of x-ray, cautery and diathermy, we find that more than half of such ignitions

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TABLE 2

ANESTHETIC FIRES AND EXPLOSIONS (EXCL. O_2 THERAPY AND HIGH PRESS.)

Agent	Due to All Causes			Due to Static		
	Total	Deaths	Injuries	Total	Deaths	Injuries
Ether-air	81	1	19	2	0	0
Ether-O_2 (c̄ or s̄ N_2O)	52	12	31	21	4	15
Ethylene-air	0			0		
Ethylene-N_2O	1	1	1			
Ethylene-O_2 (c̄ or s̄ ether)	37	9	16	25	3	8
Cyclopropane-air	1	0	0			
Cyclopropane-O_2 (c̄ or s̄ N_2O or ether)	21	8	13	15	7	12
Ethyl chloride-O_2	1	0	1			
Ether-air or O_2	8	2	1			
Ethyl chloride-air	3	0	2			
Acetylene-O_2	3	0	2			
Alcohol	4	1	2			
Ether or ethylene	1	1	0			
N_2O-O_2 plus unknown	1	0	1			
Field ether	1	1	0			
Total	215	36	89	63	14	35

have occurred since 1930. We will consider separately each category in the etiology of anesthetic fires and explosions.

X-RAY APPARATUS

In 1929 the National Board of Fire Underwriters stated that "safe practice dictates the absence of such apparatus (x-ray fluoroscopic equipment) in the presence of combustible anesthetics." The International X-ray and Radium Protection Commission in 1937 unequivocally stated "Low flash-point anesthetics should never be used in conjunction with x-rays."

TABLE 3

X-RAY APPARATUS

10 explosions and fires are known.
(8—ether, 1—ethyl chloride, 1—cyclopropane)
The 3 ether-air accidents caused no injuries.
2 patients died and 2 more were seriously injured in those cases involving ether-nitrous-oxide-oxygen.
1 cyclopropane-oxygen explosion caused a slight burn to the patient's cheek and a serious injury to the anesthetist.

In spite of these warnings, explosions and fires due to x-ray equipment are still recurring, and hazardous technics are still widely recommended and used, even in some of our largest hospitals.

It is apropos to point out here that static electricity probably is a greater hazard in the x-ray room than in the operating room because of the greater frequency of movement of the patient, staff and anesthesia equipment over the insulated flooring material in the x-ray room.

The possible sources of a spark in the x-ray rooms are so many that the mere listing of them should be impressive. (See Table 4.)

TABLE 4

POSSIBLE SOURCES OF SPARKS IN X-RAY DEPARTMENTS

A. Under normal operating conditions:

1. Arcing switches, if not sealed or removed from the x-ray room.
    - Main switch
    - X-ray switch
        - Hand switch; foot switch; magnetic contactor; timer contacts
    - Overload circuit breaker
    - Auto-transformer control
    - Rotary rectifier switch
    - Open interrupter
    - Auxiliary equipment control switches
        - Bucky, plate changer and stereo tube shift—if electrically operated and controlled
        - Room light switches
2. Charged conductor (which may spark to a person or another conductor).
    - Any unshielded part of the high tension system, e.g., reel cord, tube terminal
    - Any ungrounded or poorly grounded metallic part of the equipment or metal utensil or metal furniture near the equipment charged by induction. Sometimes a person may be charged sufficiently to cause a spark to ground. Induced charges may be retained even after the equipment has been shut off.
3. High tension arcs.
    - Any point in the high tension system where there is a poor contact or friction contact. Because of the nature of the high voltages and low currents used, it is common practice to have such conditions in any x-ray machine, e.g., anode tube connection by means of a ring and hook.

B. Under abnormal operating conditions:

1. Any defect causing arcs.
    - Insulation breakdown
    - Insufficient clearance between high tension conductors and ground
2. Application of excessive voltage on high tension circuit causing corona or arcing, e.g., by error in setting controls, by excessively gassy tube, by failure of x-ray tube filament or of valve tube.

Some physicians feel safe in using a combustible anesthetic mixture if the x-ray equipment is of the modern shockproof type. For example, Dr. Warren P. Morrill of the American Hospital Association has recently stated that "the manufacturers of the modern self-contained shockproof x-ray machines feel that they carry no hazard of ignition." Shockproof apparatus in general use today diminishes the hazard but does not completely eliminate all sources of igniting sparks. To determine whether further technical improvement of x-ray equipment could entirely eliminate the hazard created by sparking, we solicited the written opinions of the engineering departments of the leading manufacturers of x-ray apparatus. Five companies displayed an excellent comprehension of the hazard and their reports came to approximately the same conclusions, namely,

1. It is possible to develop equipment that would be spark-proof under all circumstances.

2. Very few, if any, of the modern shockproof diagnostic x-ray outfits used today are completely spark-proof.

3. The cost of manufacturing and servicing of completely spark-

proof apparatus would be significantly higher than that of the conventional shockproof apparatus.

4. A completely spark-proof equipment could be secured by following the recommendations in Table 5.

TABLE 5

a. The x-ray tube should be oil-immersed and in a grounded metal container.

b. The transformer and rectifying tube, if any is used, should be oil-immersed or be located outside the x-ray room.

c. The connecting cables and cable sockets should be of shockproof construction.

d. The control panel should be located outside the x-ray room.

e. The foot switch should be vaporproof or enclosed in a bag.

f. The filament control switch should be spark-proof.

g. No part of the high tension wires in the x-ray room should be exposed or ungrounded.

h. All low-voltage connecting wires in the x-ray room should be specially treated, regularly inspected and replaced as they deteriorate.

i. Electric light switches in the x-ray room should be vaporproof.

We know of no institution in which the x-ray equipment, even when of the most modern type, conforms to the outline of necessary safeguards for the complete elimination of sparks. (See Table 5.) This is confirmed by the very wide experience of Mr. I. H. Blatz, x-ray physicist with the Department of Hospitals of New York City and consulting physicist to many private hospitals and roentgenologists.

None of the known explosions and fires has occurred in the presence of shockproof equipment. The use of the conventional shockproof x-ray apparatus only decreases but does not eliminate the hazard of combustion.

The closed method of administration of a combustible anesthetic agent does not make the anesthesia completely safe from ignition by sparks generated during the use of x-ray equipment.

CAUTERY APPARATUS

We report here, in one group, those anesthetic fires and explosions started by the cautery, gas flame, match light or cigarette because they all present obvious and identical features determining the occurrence of an explosion. We also present here, because it is most appropriate, the group of fires caused by the application of the cautery to surgical fields prepared with a spray containing ethyl chloride or with skin cleansers such as ether and alcohol or with skin antiseptics such as the various tinctures.

We have recorded 57 cases ignited by a cautery, flame or similar hot object. This group includes many concrete and forceful examples of ignorance, carelessness and indifference.

In at least 28 cases the cautery or flame was present in or near the head, neck, chest and respiratory tract; in all of the other 29 cases the cautery or flame was incorrectly or inadequately protected from contact with a combustible agent. The general belief exists that there is

TABLE 6

Agent	Total No. of Cases	Cautery or Flame Used Near Head, Neck, Chest, Etc.			Cautery or Flame Used in Abdomen or Elsewhere		
		Cases*	Deaths†	Injuries†	Cases*	Deaths†	Injuries†
Ether-air	14	5	1	3	2	0	0
Ether-O_2 ($\bar{c}$ or $\bar{s}$ N_2O)	17	7	4	5	5	0	2
Ether-air or O_2	6	(one patient died—classification not possible for want of details of explosion.)					
Ethylene	9	6	5	4	2	0	3
Ether or Ethylene or both	1	1	1				
Ethyl chloride	3				3	0	2
Acetylene	3				2	0	2
Cyclopropane	2	(one patient died—classification not possible for want of details of explosion.)					
Alcohol	2	1	0	1	1	0	1
	57						

* The cases counted in this group are only those in which the presence or absence of injury is known.

† The total number of persons injured or killed is stated; some cases had more than one person injured. In no case was more than one person killed.

no danger from combustion of ethylene, cyclopropane or ether beyond a 12 inch zone about the mask or expiratory valve during a partial or complete rebreathing administration. While this is generally true we have found at least 10 cases in which all three of these agents have been ignited at points more distant than 12 inches from the mask or spill valve or point of possible leakage during partial or supposedly closed circuit administrations.

In no instance was there a true closed method of administration, although in several instances there were attempts to secure complete rebreathing for cauterization about the head, and the anesthetists involved believed the circuits to be tightly closed.

Tabulation of the 55 cases presented in this report clearly shows the truth of the following statements:

a) Explosions and fires of all combustible anesthetic agents and mixtures, even ether-air, are capable of causing death.

b) Ether-air mixtures, however, have a relatively small tendency toward propagating a wave of flame or pressure into and down the respiratory tract.

c) Ether-O_2, with or without nitrous oxide, has the same great tendency toward propagating a wave of flame or pressure through the respiratory tract, as have ethylene-oxygen and cyclopropane-oxygen when compared under similar clinical circumstances; i.e., the location of the point of ignition with reference to the respiratory tract of the patient.

d) In no case has anyone been killed when the cautery or flame was present beyond a 12 inch zone surrounding the upper respiratory tract. This is just as true of ethylene as it is of ether. The large admixture of air (79 per cent. nitrogen) which is inevitable when the inhalant anesthetic is ignited at a distance of 12 inches or more greatly diminishes the explosive force and propagation tendency of combustible mixtures containing high percentages of oxygen.

e) All deaths—and all were patients—have been the result of a flame or cautery employed within a 12 inch danger zone surrounding the upper respiratory tract.

Every tyro of the operating room staff knows that a cautery, flame or hot object should not be permitted to come into contact with any inflammable mixture. Yet there have been at least 57 known and wholly preventable anesthetic fires and explosions ignited by a cautery, flame or other hot object. We think the explanation is to be found in the following reasons:

1. Ignorance of an elementary knowledge of anesthetic combustion. Our personal survey has found an astonishingly large number of surgeons and anesthetists who lack basic and even rudimentary information on this subject.

2. Indifference toward the hazard because of past good fortune while using set-ups which we consider dangerous in the operating room.

3. A paucity and inflexibility of anesthetic methods available to many surgeons who must use the cautery. This is the usual reason for the use of hazardous technics.

In short, the cause is almost always ignorance. The cure must be education, and elevation of the standards of anesthetic training and practice.

DIATHERMY APPARATUS

The hazard of using diathermy in the operating room is discussed separately here because there are many features of the behavior of high frequency electricity which are not seen in the use of the cautery. Nevertheless, it is advisable to recall now that the active electrode of the surgical diathermy machine presents the very same hazard as the hot cautery tip.

We have found published warnings against the use of diathermy apparatus in the presence of inflammable agents as early as 1924. Nevertheless, explosions and deaths have been caused recently by this hazardous practice. We have recorded 19 cases of fires and explosions ignited by diathermy apparatus, as shown in Table 7.

In our detailed written report we have carefully considered the electrical basis of all sparking or arcing during the use of high frequency apparatus. The prevention of all sparks is impossible. No matter how far from the mask the electrodes are placed, there is serious danger of ignition of spark of a combustible inhalation anesthetic mixture. Because of the relatively narrow field of use of surgical diathermy and

TABLE 7

Agent	No. of Cases	Injuries
Ether-air	3	No injuries
Ether-O_2 (c̄ or s̄ N_2O)	9	2 patients died.
		1 patient and 3 bystanders seriously injured.
		1 patient and 2 bystanders slightly injured.
Nitrous oxide-oxygen mixed with an unknown combustible agent seriously injured a patient.		
Ethylene-oxygen	2	1 patient died.
		1 patient suffered a ruptured bladder but recovered.
Cyclopropane-oxygen	2	1 patient died.
Surgical field fires:		
alcohol	2	1 patient died.
ether	1	Patient died.
	20	6 patients died

because of the practical impossibility of the prevention of sparks during diathermy, we have reached the conclusion that combustible anesthesia is contraindicated by the need for diathermy in any part of the head, body or extremities.

In our extended report we have also recorded many instances of the other hazards of surgical diathermy in the operating room, namely, surgical field fires, explosions of hydrogen produced by fulguration in the urinary bladder, and electric shock and sparking resulting from short circuits in defective apparatus.

We have found that there is a marked variation and lack of uniformity in anesthetic practices with regard to diathermy. Our study forces us to conclude with the bold statement: anesthetic fires and explosions ignited by diathermy, like those due to x-ray apparatus, are completely preventable only by the use of non-combustible anesthetic methods.

SUCTION-PRESSURE APPARATUS

We have learned of 59 cases ignited by an electrical spark produced by the use of a suction or vaporizing machine. Forty-eight of these instances were personally reported to us by members of the Society. All manufacturers have denied knowledge of any report involving their machines. Yet oddly enough, a large number of the companies have with effort and expense made some of their models explosion-proof.

Our records show that there have been explosions or fires (more often the latter) ignited by suction and vaporizing machines in the cities shown in Table 8.

This record is a striking tribute, not to the safety of ether but to the retarding influence of air on the force and propagation of the pressure and flame waves of ether combustions with air, as compared with ether-oxygen and ether-nitrous-oxide-oxygen mixtures. The long period of toleration of the hazard has been due largely to this feature of relative harmlessness which is associated with the combustion of any anesthetic mixed with air.

TABLE 8

Brooklyn, N. Y.	3	Philadelphia, Pa.	1
Chicago, Ill.	3	Providence, R. I.	2
London, Eng.	3	Reading, Pa.	1
Harrisburg, Pa.	2	San Antonio, Texas	1
Louisville, Ky.	1	Santiago, Chile	1
Madison, Wis.	3	St. Johns, N. B.	1
Minneapolis, Minn.	2	Syracuse, N. Y.	1
Montreal, Quebec	6	Toronto, Ont.	5
New Rochelle, N. Y.	3	Washington, D. C.	4
New York, N. Y.	13	Winnipeg	3

TOTAL NUMBER—59 cases

Ether-air—58 cases.
Cyclopropane-air—1 case.
No injuries in 47 of the cases (46 ether-air and 1 cyclopropane-air).
1 patient slightly burned and 1 patient seriously burned about the head.
2 surgeons, 1 nurse and 4 anesthetists were seriously burned.
5 surgeons, 1 nurse and 1 anesthetist were slightly burned.

The use of mercury switches, a sealed motor, grounding of the metal cabinet, locking wall sockets placed 4 feet above the floor—all these safety devices have long been available to anesthetists and hospital authorities. Ignorance of the hazards and lack of demand by anesthetists and surgeons have permitted the growth of the presene dangerous situation wherein most anesthesias by insufflation today are still being administered in the presence of serious, obvious and preventable sources of ignition.

ENDOSCOPIC APPARATUS

The use of electrically lighted instruments in the body cavities during anesthesia, especially in the mouth and larynx, has caused five anesthetic combustions and the death of one patient and a serious injury to another. (See Table 9.)

TABLE 9

1—ether-air—bronchoscope—patient's pharynx burned but he recovered.
1—ether with air or oxygen—pencil light—patient died of lung injury and surgeon's face was burned.
1—ether-oxygen—laryngoscope—no injuries.
1—cyclopropane-oxygen—laryngoscope—no injuries.
1—ethylene-oxygen—no details obtainable.

Such accidents have been started by:

a) Accidental short-circuiting of exposed terminals.
b) Unsuspected failure of insulation.
c) Faulty contacts in the endoscope proper or at the various switches or rheostats.
d) Accidental exposure of a hot filament by the breaking of a bulb.

There are other types of hazard associated with endoscopic instruments and of special interest to the anesthetist, namely, electric shock and electric burn. One patient was fatally electrocuted during cystoscopy; another was severely shocked as the result of faulty insulation in an examination light, and a third patient had his urethra severely burned during cystoscopy as the result of a faulty rheostat. Those conditions which permit the patient to be electrically shocked or burned present serious potential hazards of explosion in the presence of inflammable anesthetics.

The desirable features of endoscopic apparatus from the point of view of prophylaxis of accidents are:

1. Solid glass, rather than thin bulbs should be used.
2. Lamp bulb contact should be so arranged in the socket that no sparking can occur between the bulb and socket.
3. The bulb should not become excessively hot during prolonged use.
4. The lamps should be supplied with low voltage currents in the range of 3–4½ volts.
5. The insulation, rheostats and switches should be free of short circuiting faults and non-sparking.
6. The lamp circuit, if fed by a house current, should conform to those types demonstrated by electrical engineers to be entirely free of the hazard of electrical burn and shock.

MISCELLANEOUS CATEGORY

A. High Pressure Explosions and Fires

The fact that anesthetic gases are under high pressure introduces hazards which are entirely absent in the handling of liquid anesthetics. Consequently we have found, as would be expected, several instances where the presence of highly compressed agents have caused explosions of two types. The first is that due to the sudden release of a highly compressed gas into portions of the anesthetic apparatus inadequately protected against a high pressure wave of oxygen, carbon dioxide, or nitrous oxide.

TABLE 10

EXPLOSIONS FROM PRESSURE

Agent	No. of Cases	Injuries
Oxygen	5	1 patient possibly killed. 1 anesthetist 1 patient 1 bystander
Nitrous oxide	1	None
Carbogen	1	Anesthetist

All of these explosions from pressure, with the exception of one, occurred during the use of a single type of apparatus which, until recently, was without a safety valve. This is now present on the newer models of this make of machine. One explosion occurred during the use of an emergency oxygen valve on a McKesson machine with endotracheal anesthesia and may have contributed to the patient's death.

The second type of high pressure accident resulted from the passage of oxygen at high speed over combustible material, such as oil or a leather washer, in the anesthetic circuit. Two such accidents have been recorded.

A third type of anesthetic combustion due to high pressure resulted from the inadvertent intermixing of nitrous oxide and ethylene under high pressure. One such case is known and the anesthetist was killed and an orderly seriously injured.

The prevention of explosions under high pressure is easy if the anesthetic apparatus is properly constructed and maintained so that a safety release valve is present on the low pressure side of the apparatus: intermingling of anesthetic gases under high pressure is made impossible and oily contamination and oil-containing leather washers are avoided.

B. Fires in Oxygen Therapy Equipment

There have been five serious or fatal fires due to the violation by the patient of the rule that flames are to be avoided in the presence of high concentrations of oxygen, as in an oxygen tent. While in each case the patient violated the rule, we should realize that the responsibility for the strict observance of this rule should be repeatedly impressed upon those supervising the patient under oxygen therapy.

C. Miscellaneous Types

We have no record of any anesthetic fire or explosion ignited by electrical sparks originating in overhead lighting fixtures in the operating room. We mention this negative fact because two manufacturers of such lighting equipment have recently developed and secured the approval of the Underwriters Laboratories for explosion-proof overhead surgical lamps.

There have been anesthetic explosions caused by igniting agents not classified under any of the groups listed above. For instance, one ether-air or oxygen anesthetic mixture was ignited by a short circuit spark in an electrical apparatus used to heat the ether. The patient died in a few hours.

STATIC ELECTRICITY

This final category of causes of anesthetic explosions and fires has received more attention than any other group because of the supposed mystery surrounding the occurrence of an anesthetic explosion in the absence of any apparent or obvious electrical hazard. Furthermore, the controversy of humidification versus grounding has served to confuse many anesthetists and hospital executives with a consequent delay in the application of known prophylactic measures. Finally, the high incidence of fatalities among electrostatically ignited combustions has led to a great deal of unfavorable publicity.

We have secured knowledge of the occurrence of 63 static explosions and fires. (See Table 11.)

TABLE 11

Agent	No. of Cases
Ether-air	2
Ether-O_2 (c̄ or s̄ N_2O)	21
Ethylene-O_2 (ether also present in 4 cases)	25
Cyclopropane-O_2 (ether also present in 4 cases)	15
TOTAL	63

As a result of these explosions and fires the injuries shown in Table 12 have occurred.

TABLE 12

Agent	No. of Cases	Injuries	Deaths
Ether-air	2	None	None
Ether-O_2 (c̄ or s̄ N_2O)	21	1 patient—ruptured lung with recovery 7 patients injured 7 other persons	3 patients 1 anesthetist
Ethylene-O_2	25	2 patients 6 other persons	3 patients
Cyclopropane-O_2	15	4 patients—2 recovered from ruptured lungs 7 other persons	7 patients

From Table 12 we may reasonably conclude that any combustible anesthetic agent, when mixed with a high concentration of oxygen or nitrous oxide, may explode to produce the injury typical of a violent blast, namely, rupture of the lung. The fact that 9 of the 11 patients injured in the 15 explosions from cyclopropane experienced rupture of the lung might indicate that explosions from cyclopropane are more likely seriously or fatally to injure the patient than are explosions from ethylene or ether. This may be true, but we have only 15 cases on which to base such a conclusion, and this is too small a number. Furthermore, we should remember that this table shows that explosions of ether-oxygen also injured 11 patients out of 21 cases although only 4 suffered ruptured lungs. This difference in incidence of the fatality may be entirely accidental and may be found to be absent with an increased number of static explosions. Animal experiments are needed to settle the question.

If we consider showing the number of cases of static explosions with each agent, in which the explosion occurred at a time when the anesthesia was not in progress and the patient was not in the anesthetic circuit, we come to a very interesting conclusion. (See Table 13.)

TABLE 13

PATIENT NOT IN ANESTHETIC CIRCUIT AT TIME OF EXPLOSION

Agent	No. of Cases
Ether-air	2
Ether-O_2	10
Ethylene-O_2	17
Cyclopropane	2
	31

If we subtract these cases from the totals presented in Table 12 we find that the incidence of fatality and injury to the patient will be as shown in Table 14.

TABLE 14

INCIDENCE OF PATIENT MORTALITY AND MORBIDITY WITH PATIENT IN ANESTHETIC CIRCUIT AT TIME OF EXPLOSION

Agent	No. of Cases	Deaths	Injuries
Ether-air	0	0	0
Ether-O_2 ($\bar{c}$ or $\bar{s}$ N_2O)	11	3 patients (27%)	1 patient recovered from ruptured lung 7 other patients injured (100%)
Ethylene-O_2	8	3 patients (37%)	2 patients (62%)
Cyclopropane-O_2	13	7 patients (54%)	4 patients—2 recovered from ruptured lung (83%)
	32		

From Table 14 we may reasonably conclude that if a patient is in the anesthetic circuit at the time of a static explosion with ether, ethylene or cyclopropane mixed with oxygen, he is almost sure to be injured irrespective of the type of anesthetic agent. The likelihood of the patient's death appears to be greater with ethylene and cyclopropane than with ether, but such a conclusion is not supported by a sufficient number of cases to be accepted as a proved fact. We must await the accumulation of more data on this point to be able to make a clinical comparison of the lethal tendencies of these three anesthetics. Table 14 does prove, however, that static explosions of ether-O_2, with or without N_2O, with the patient in the circuit, are almost always injurious and often fatal to the patient. This fact will disturb the complacency of many hospital administrators and surgeons.

An explosion in the lung is not necessarily fatal. There have been three instances of ruptured lungs with recovery.

A significant fact is that we have found no explosion of cyclopropane-air ignited by static electricity. This may be an important clue to the future use of cyclopropane. For every type of cyclopropane explosion we have an exact duplicate involving ethylene or ether. The addition of helium to cyclopropane-O_2 failed to prevent explosions of cyclopropane in 2 cases.

Table 15 shows that most types of anesthetic apparatus have been involved in static explosions, including several whose manufacturers have claimed an immunity which we have found to be non-existent.

TABLE 15

(Reported in 34 cases)

Open Wire Ether Mask	1	McKesson Models	[illegible]
Heidbrink Models	12	Shipway Model	[illegible]
Foregger Models	8	S. S. White	[illegible]
Connell Models	4	Ohio Monovalve	[illegible]

We do not believe that there is any machine on the market today which can claim a real superiority with respect to the hazard of static production within the apparatus. Of course this does not apply to the most recent machines equipped with conductive rubber throughout and thereby maintaining the anesthetic apparatus as a single electrical unit from the face piece through to the gas channels and tanks and down to the conductive rubber wheels.

There have been three explosions of cyclopropane with the to-and-fro-canister method of closed circuit administration but in no case did it appear that the absorber or the act of manipulating the absorber caused the static spark that ignited the mixture of cyclopropane.

Table 16 shows that static explosions have occurred under the administration of physician-anesthetists as well as nurse-technicians; in complete rebreathing circuits as well as in partially closed and completely open circuits. It may seem surprising to find the high proportion of physician-anesthetists involved, but this is easily understood when we note that many of these physician-anesthetists were internes who, in most hospitals today, we must admit, possess less knowledge of anesthesia usually than do nurse-anesthetists. Also, physician-anesthetists have been more thoroughly canvassed by our inquiry than technician-anesthetists. Furthermore, we have found that a very large percentage of specialists in anesthesiology have long neglected the practical application of the most elementary methods of static prevention.

TABLE 16

Nurse Anesthetists	13	Complete Rebreathing	18
Physician Anesthetists	25	Partial Rebreathing	27
Insufflation	2		

Complete rebreathing failed to prevent the occurrence of static explosions in 18 cases. This finding was unexpected because most anesthetists have felt that this type of administration would go a long way toward preventing static explosions. Nevertheless, complete rebreathing circuits were frequently broken at a time when a combustible mixture was in the circuit. Simultaneously, the method of breaking the circuit favored the production and discharge of spark of static electricity produced on the outer surfaces of the rebreathing circuit.

The 63 case reports clearly show that the greatest single hazard of explosion has been in the anesthesia machine together with the rebreathing tubes, bags and masks. During the past twenty years we have seen many inadequate and incomplete attempts to remove or circumvent this source of static electricity. Our case reports show that all of these recommended measures, when applied singly or combined to only a small degree, have signally failed in many instances. The use of internal intercoupling wires, "personal" intercoupling, external wire intercoupling, wet flow-meters, wet rebreathing apparatus, grounded floors, artificial maintenance of relative humidities greater than 55 per cent —all of these have been steps in the right direction but only small steps —steps much smaller than their advocates had hoped—steps that most anesthetists did not take.

To show how little protection is usually to be found in the operating rooms, we have tabulated the efforts at grounding and humidification as reflected in the case reports. (See Tables 17 and 18.)

TABLE 17

DATA ON GROUNDING

No complete system present in any case	
Partial grounding, confined to the machine	5 cases
Broken ground wires in rebreathing tubes	2 "
Anesthetic apparatus disconnected from ground at time of explosion	2 "
No grounding	42 "
Grounding data not reported	12 "

TABLE 18

DATA ON RELATIVE HUMIDITY

Humidity 60% or more	2 cases
Humidity 54–55%	3 "
Humidity lower than 50%	32 "
Humidity data not reported	26 "

We have tabulated the seasonal incidence of static combustions and it confirms the general impression that such accidents are more common in the seasons of the year in which the operating room relative humidity is usually below the desired range of 60–65 per cent. (See Table 19.)

Further confirmation of the influence of humidity on the frequency of static explosions is the fact that there has never been a static explosion in Australia; and there has been, as far as we know, only 1 static explosion in England. This occurred in an air-conditioned oper-

TABLE 19

SEASONAL INCIDENCE OF STATIC CASES

Agent	Winter	Fall	Summer	Spring	Season Not Known
Ether	5	6	1	3	8
Ethylene	6	2	1	7	9
Cyclopropane	7	2	0	6	
	18	10	2	16	17

ating room in which the relative humidity was artificially maintained too low and many serious static hazards were present.

The two explosions which occurred in the presence of a relative humidity of 60 per cent. or more, and the three cases in the presence of 55 per cent. humidity were caused by very potent static generators (such as a woolen blanket, rubber soled shoes, a rubber cushion) which have long been known—certainly since 1930—to be impossible of prevention by humidification up to even 80 per cent. Such cases do not warrant the discarding of humidification as a generally valuable prophylactic measure.

Artificial air-conditioning has been criticized as dangerous by Drs. Newcomer and Horton. The only explosions, in our records, which have occurred in air-conditioned operating rooms do not warrant this assertion because in all four instances there were glaring faults in static prevention technics, e.g., low relative humidity, the use of a rubber cushion or woolen blanket.

Ethylene and cyclopropane should not be used for intermittent obstetrical analgesia except under the complete set of safeguards feasible only in the operating room. There have been 3 explosions of ethylene-oxygen; one fatal to the patient, during intermittent obstetrical analgesia.

The only combustible anesthetic mixture which is safe for the patient to receive in an operating room unprotected by static precautions is ether-air.

Today, we who have been educated by the sad experiences revealed in these 63 static explosions and fires, find that our perspective is much clearer and broader. We believe that there is no longer any basis for a controversy between the advocates of grounding and the proponents of humidification. We know now that no single measure is sufficient to prevent all static sparking and that all means of prevention should be simultaneously applied in a comprehensive system.

Within the period of the existence of this investigation by the American Society of Anesthetists, Inc. there have appeared two real advances in our knowledge of the prophylaxis of static sparking in the operating room. First, Prof. Horton has determined the optimum degree of electrical resistance needed in intercoupling grounding devices to protect against electrical shock and increased capacity for static sparking; the two disadvantages which forced many anesthetists to avoid this means of prophylaxis. Secondly, in England and in the United States, various engineers and rubber manufacturers have simultaneously announced the perfection of conductive rubber—a feature long known to be desirable and recommended by Dr. Horatio Williams in his report of 1930. Many ideas, e.g., conductive rubber, conductive machines, calcium chloride, and humidification, were first advocated by Prof. Horatio B. Williams in 1930, but remained unused because of the lack of an intelligent and sustained interest in anesthetic explosions.

At last there is available today a safe, comprehensive and probably completely effective system for the prevention of static sparking in the operating room. None of the 63 static fires and explosions occurred under a set-up which we now regard as offering the maximum protection against static sparking in the operating room. In fact, in none of these 63 cases was there present even such safeguards as were being recommended at the time these explosions occurred.

The first and most important phase of the scheme of prevention is the education of the medical profession, especially the anesthetist and hospital superintendents, in the basic principles of anesthesiology as it is related to the physics and chemistry of anesthetic combustions. Our records clearly demonstrate the deplorable lack of knowledge and low standard of practice of the current means of prevention in the great majority of operating rooms.

Second, all anesthetic apparatus should be made completely conductive by the use of all of the safe and effective measures known to date.

Third, humidification of the internal and external atmospheres above a minimum of 60 per cent. should be attained and maintained by the use of all methods appropriate to the weather, the operating room and the type of anesthetic circuit.

Fourth, measures should be taken for the elimination of all static production in the operating room outside of the anesthetic apparatus by the use of flooring of proper resistance and conductivity, with which conductive contact is maintained by all persons and apparatus in an operating room.

Fifth, there should be eliminated from anesthesia and operating rooms all especially potent generators of static electricity, such as those objects covered by wool, silk, rayon and rubber.

SUMMARY

We have collected and analyzed 230 fires and explosions involving all anesthetic substances. Seventy per cent. of these explosions and 60 per cent. of the deaths of patients were caused by igniting agents

other than static, and were completely preventable by measures known at the time of their occurrence.

Sixty-three combustions were ignited by static electricity. In no case were there in use *all* of the safeguards which were known and recommended by competent authorities at the time of the explosion.

The findings reported in the 230 cases do not contradict the assertion with which we conclude—that our present day knowledge of the etiology and prophylaxis of all anesthetic fires and explosions is sufficient to prevent all further anesthetic combustions.

OF INTEREST TO ANESTHESIOLOGISTS

SECTIONAL MEETINGS OF THE AMERICAN COLLEGE OF SURGEONS

Three such meetings will be held in March, one in Minneapolis on March 10, 11 and 12, one in Pittsburgh on March 17, 18 and 19, and one in Salt Lake City on March 26, 27 and 28. At these meetings there will be a panel discussion in each city on the subject of the "Choice of Anesthesia with Indications and Contraindications." These panel discussions last one and one half hours.

The meeting in Minneapolis will be held at the Nicollet Hotel at 3:30 o'clock on Monday, March 10, and will be led by Dr. John S. Lundy, Rochester, Minnesota, with Dr. Ralph T. Knight, Minneapolis, and Dr. I. Mims Gage, New Orleans, as collaborators.

The discussion in Pittsburgh will be held at the William Penn Hotel and is scheduled for 3:30 o'clock on Monday, March 17. Dr. Paul M. Wood, New York, will be the leader, and the collaborators will be Dr. J. L. Atlee, Jr., Lancaster, Pennsylvania, and Dr. George J. Thomas, of Pittsburgh.

The meeting in Salt Lake City will be held at the Utah Hotel. The exact hour of the panel has not yet been determined.

The College will welcome the attendance of anesthesiologists at these panels and at such other sessions of the meetings as they may care to attend.

COMING MEETING

The American Medical Association will hold its Scientific Assembly and Exhibit in Cleveland from June 2–6, 1941, inclusive. The new Section on Anesthesiology will consist of three half-day sessions. The Secretary of the Section has received many offers of papers; consequently, those who are interested in applying for a place on the program should not delay in writing to the Secretary. It is hoped that there will be as many exhibits on Anesthesiology as possible in the Scientific Exhibit. Application for space for exhibits should be sent to Dr. Thomas G. Hull, Director, Scientific Exhibit of the American Medical Association. The titles for papers for the Scientific Assembly should be submitted to Dr. John S. Lundy, Secretary of the Section on Anesthesiology, Rochester, Minnesota.