ANESTHETIC EXPLOSION HAZARDS AND PRECAUTIONS

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While certain anesthetic explosions have achieved spectacular prominence, it must not be assumed that the problem presented is a sudden new creation. As a matter of fact the fundamental equation per se has faced our field in one degree or another for certainly thirty-eight years, since Murray in 1903 reported the ignition of ether, which was being administered by open drop method when an electric light was turned on.¹

The drama and its motif are old, but new players introduced to the scene have brought with them modern complications which demand new understandings to identify them, and new skills to combat them.

To me, the subject of anesthesia explosion accidents is divided into two separate aspects, each of which must be considered as an entity. These aspects are first, the inflammable anesthetic compounds themselves and the techniques by which they are administered, and second, the sources of possible ignition, and the integrated methods inaugurated to combat them.

Considering first the anesthetic agents themselves; reference to suitable textbooks will establish the fact that nitrous oxide gas is non-inflammable at ordinary temperatures. I do not overlook the fact that at very high temperatures nitrous oxide decomposes into its component elements, nitrogen and oxygen, and that in such circumstance the oxygen set free will support and intensify any combustion that has already been initiated—but at the temperatures with which we come in contact clinically, nitrous oxide acts as a stable com-

Read at the seventh annual convention of the Mid-South Post Graduate Nurse Anesthetists' Assembly held in Memphis, Tenn., February 12-13, 1941.

ound, of itself non-inflammable. To demonstrate this fact, I have more than once experimentally passed a stream of nitrous oxide over a red-hot cautery—always without untoward effect.

When nitrous oxide plus oxygen is administered in anesthesia, the mixture still merits the designation of "non-inflammable," as demonstrated by the experimental work of Hornor and Gardenier.² The accidents which in our literature have been attributed to ignition of mere nitrous oxide-oxygen, so far as I know have never been cleared from suspicion that they were in reality explosions of nitrous oxide-oxygen plus ether vapor—the ether possibly being present in the apparatus from earlier administration, in either that or some preceding case. Nor have those particular accidents been divorced from the possible accidental presence of oxidizable oil or grease in the equipment—highly dangerous components when high pressure oxygen is valved.

As we proceed to the consideration of ether vapor, which is so regularly administered as a part of nitrous oxide-oxygen anesthesia, we enter a field wherein all three of the potent agents generally used (ether, ethylene and cyclopropane) are inflammable and explosive—the differences between them being principally in the speed of propagation of flame when they are ignited, and the amplitude of
destructive expansive pressure which they exert as a result thereof.

Illustrative of these characteristics is the fact that as a result of the relatively slow velocity of propagation of the flame of ignited ether-air mixtures, accidents involving that combination have been known to result in merely local burns; but that fact must not lead to a false sense of security, as many fatalities have resulted from ignition of mere ether-air anesthetic mixtures. In fact, as far back as ten years ago, Pinson estimated that at that time in England alone, there were occurring probably one hundred ether anesthetic explosions every year.

And when we turn from ether-air mixtures to ether-oxygen, or to ether-nitrous oxide-oxygen mixtures, we find wide testimony to many fatal terminations to ignition of such ether combinations.

Obviously, all ether combinations must be catalogued as inflammable mixtures, and appropriate safety precautions observed during their administration.

The higher percentage of fatal terminations to ethylene and cyclopropane explosion accidents, is due to the higher velocity of their flame propagation. As a consequence of this characteristic, the combustion is rapidly communicated to all parts of the mixture, causing thereby the violently expansive force that ruptures respiratory areas which are pneumatically coupled to that distensive force through the breathing tube and mask. As a defense against that now recognized mechanistic aspect of past accidents, research is under way to devise means of mechanically preventing communication of those destructive pressure forces to a patient.

At this juncture the question might almost be asked, "When non-inflammable nitrous oxide-oxygen is available, why use inflammable agents such as ethylene and cyclopropane?"—but the superiority of these more modern potent gases for many patients has been established so definitely that such a question loses most of its point. As Morrill and others have pointed out, the dramatic nature and emotional news value of these anesthesia ignition accidents have given them a prominence quite out of proportion to the relative infrequency of their occurrence, and to the low anesthetic mortality rate consequent to them. The earlier editorial statement of the Journal of the American Medical Association seems to still hold true, that "regrettable as is any case of death from explosion of anesthetic gases, explosion is still statistically one of the least of the hazards of anesthesia."

To reduce that hazard, however, to a still lower percentage of incidence, the dangers must be realistically recognized and defended against by the inauguration of specific appropriate precautionary safeguards. Obviously, neither ether, ethylene nor cyclopropane should be administered in the presence of a live cauter.

**INDUCTION**

*Ethylene* should not be used to induce an anesthesia because of the amount of inflammable gas that would thereby be discharged into the room through the open exhaline valve, during the period necessary for establishment of unconsciousness. Instead, anesthesia should be induced by nitrous oxide-oxygen, replacing the nitrous oxide by ethylene only after unconsciousness has been established. After beginning administration of the ethylene, the exhaline valve should be permitted open only long enough to actually displace the nitrous oxide, and to establish anesthetic tension of ethylene in the blood. The anesthesia
itself should always be conducted by closed soda lime filtration method.

Cyclopropane anesthesia should be inaugurated by a brief closed circuit administration of nitrous oxide-oxygen, until the leak-free integrity of all connections can be verified (including that between the mask and face) before admitting any cyclopropane to the circuit.

MAINTENANCE

During the conduct of cyclopropane anesthesia, completely leak-proof contact between the patient's face and the mask must be maintained inviolably—and every connection and joint of the administrative mechanism must be scrutinized, to identify and remedy promptly any leakage. If a leak develops during administration, the flow of cyclopropane should be discontinued until a mechanically tight circuit can be demonstrated. No compromise in this regard could ever be justified if an accident should result. However irksome at the moment, a voluntarily imposed delay to the procedure is infinitely preferable to a preventable fatality.

If, during the administration of cyclopropane, necessity supervenes for removal of the mask, to insert an airway or an endotracheal catheter, the obturator valve at the mask should be first closed, to limit the amount of gas spilled into the room, to that which is within the mask at the time of its removal and that which the patient exhales. As an added minor precaution, the mask should be turned "face upward" for the period of time during which it stands removed. (Cyclopropane is heavier than air.)

SURGICAL CLOSURE

At the conclusion of either ethylene or cyclopropane anesthesia, the gases should be watchfully spilled through the exhaling valve at the soda lime cannister, and that spillway area specifically defended from intrusion by persons who are not electrically inter-coupled with the machine and with the anesthesia group. Also, diffusion of the spilled gas to a concentration lower than its inflammable limit should be facilitated by purposely created air currents.

As the ethylene or cyclopropane is in that manner displaced from the anesthetic circuit when the surgeon begins his closure, nitrous oxide-oxygen should be administered with open exhaling valve to replace the ethylene or cyclopropane for the period of closure. The exhaling valve area should be protected against ignition, during this open exhaling valve "displacement" period.

DEANESTHETIZATION

After closure has been completed, brief deanesthetization with helium, oxygen and carbon dioxide should be effected, so that when the protective leak-free mask-to-face contact is discontinued, and the patient's respiratory tract thereby exposed to or directly connected with the room and its ignition hazards, those vital respiratory areas will be not charged with ethylene or cyclopropane, but instead with a non-inflammable gas mixture composed chiefly of helium and oxygen, with some carbon dioxide. If there is individual or institutional prejudice against carbon dioxide, the deanesthetization should be accomplished with helium and oxygen alone.

GENERAL

The greatest danger area during ethylene or cyclopropane administration exists within a radius of about a foot in any direction from a simple leak. This distance extends to about two feet when the gases are discharged into the atmosphere through an open exhaling valve. This latter
distance naturally varies with the amount or velocity of flow of the diffusible gas mixture so discharged through the open exhaling valve into the room. Obviously, the smaller the amount of such explosive gas spilled into the room, the less will be the area of the danger zone to which the gas extends before its diffusion reduces it to a concentration that is below its explosion limit.

But whatever the dimension, and wherever it may lie, there does exist within the room when inflammable anesthetic gases are administered, a danger area whose precise extent and location cannot with certainty be predicted. It is clearly necessary, therefore, that the safety precautions inaugurated must encompass within them all areas presenting ignition hazards to which the explosive mixture might extend. What are these ignition hazards, and how may they be safeguarded?

CURRENT ELECTRICITY

The literature is replete with explicit statements cataloguing the danger of ignition by sparks which originate from “current” or “live” electricity. The defense against spark ignition from that source lies in eliminating from electrical circuits any but approved lighting switches; and especially keeping all wiring and electrical equipment within the room in a state of complete repair, verifying all electric bulbs to be screwed tightly into their sockets, whether they be in lighting fixtures, in laryngoscopes or in head lamps. Head lamps should be lighted by a current whose potential is not higher than 6 volts.\textsuperscript{12} The glaring ignition danger which is presented when personnel either inserts into a wall socket, or pulls from a wall socket, the plug of a lamp or other electrical device while it is lighted or while its switch is in the “turned on” position, is clearly recognized. Such a practice should be strictly prohibited.

STATIC ELECTRICITY

Sparks from electrostatic sources (and these have been the principal causes of recent ignition accidents) call for quite different defensive precautions. These have been so widely and clearly stated in the literature, that to do more than mention them here would be mere repetition. But some phases still invite elaboration.

As an introduction to that aspect, let me remind you that when two or more objects (including persons), carry electrostatic charges that exist at different potentials in one than in the others, they may cause an igniting electric spark if brought into contact with each other.

Therefore, stated simply, the elimination of dangerous sparks from this source resolves itself into either preventing all such unequally charged objects from coming into contact with each other (a manifestly impractical thing to do) or else bringing to a common electrical potential, all such objects that are disposed within the area which is to be protected—and then keeping them at a balanced potential with each other for the duration of the procedure. This maintenance of electrical balance implies “equalization” or “dissipation” among those objects, of such electrostatic charges as may be generated by frictional activities of personnel within the room or who enter the room, during the procedure.

This continuous electrical bonding may be accomplished effectively for the direct anesthesia group by means of the Horton intercoupler, which embraces within one balanced intercouple, anesthetist, anesthetizing machine, operating table and one other person or thing (usually anesthetist’s
assistant, or the ground). It is urged that no ethylene or cyclopropane anesthesia be undertaken without the protection of either this safeguard or its full equivalent. The recently proposed conductive rubber breathing bags, tubes, and connections for anesthetizing machine, will add to the completeness of the electrical bonding of this group (which embodies the focal point of the danger zone,) when they are perfected to a satisfactorily low resistance value throughout their entire dimension.

The ultimate desideratum, of electrical bonding of all objects within the room, is contributed to by the maintenance of a very high relative humidity (55 to 60 per cent) when the atmosphere of the room has not been depleted of normal carbon dioxide, or of some other electrically conductive component, by "washing" during air conditioning. In this connection it is to be remembered that experiment has indicated that the air's moisture or humidification must carry carbon dioxide or some other essential substance, if it is to conduct or dissipate electrostatic charges satisfactorily. This factor seems to have escaped recognition during earlier years, when the successful avoidance of explosions in certain industries was credited to merely the humidity, rather than to the association of some electrically conductive component with that moisture.

At this point I call attention to some pitfalls which, if not recognized and avoided, might result in appreciable errors in appraising the true humidity of an operating room that is relying on high humidity for electrostatic protection. The stationary wet and dry bulb hygrometers frequently employed to indicate prevailing conditions of relative humidity may introduce errors up to 15 per cent, if not fanned vigorously imme-

diately before reading, and if not "read" quickly and accurately immediately the fanning ceases. It is important that relative humidity safeguards should not be based upon the indication of these instruments, unless such vigorous air movement is maintained for a sufficient period of time to bring the reading of the wet bulb thermometer to a stationary level.

A stationary instrument whose indicating mechanism is actuated by a hygroscopic element, such as human hair, does not require air circulation for accuracy of indication, but does require calibration at regular intervals with a correctly operated wet and dry bulb apparatus. When regularly serviced and calibrated, however, such instruments yield results of satisfactory accuracy.

While we at Barnes use both hygroscopic and dry and wet bulb instruments, I prefer for routine use an air aspirated psychrometer, equipped with red liquid thermometers that have been matched for accuracy, and carrying a manually operated aspirating mechanism. Such instruments are simple to operate, yet yield the accuracy of sling psychrometers without their awkwardness of manipulation.

In addition to high humidity for electrically bonding all objects within the operating room, two "positive" methods are available. The first of these is the long established system of brass floor grids installed as a part of the terrazzo flooring. The second is the more recently proposed flooring made of special composition "electrically conductive" rubber. Both the brass grid and the conductive rubber flooring imply directly bonding to them all equipment within the area, by means of fine meshed drag chains or other conductive materials; but both systems exhibit the same shortcoming, namely, they do not actually include within them the circulating

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personnel (either staff or visiting) when such persons are insulated from those conductive floorings through the interposition of electrically non-conductive shoes.

Until early last year, conventional leather soled shoes were felt to be "satisfactorily conductive" when worn on a conductive rubber flooring but preliminary tests made for our department, and later tests made by our department, developed the fact that different pairs of leather soled shoes yielded great differences in their degree of conductance; and that a given pair of shoes which presented one conductance value at one time, exhibited quite a different conductance value at another time. These findings were communicated to Professor Horton, in charge of investigations at the Massachusetts Institute of Technology.18

It is now recognized that conventional leather-soled shoes present such variations in their properties of electrical conductance under different conditions of usage (related chiefly to variations in moisture content), that until some dependable shoe of permanent conductivity is devised, the only assurance that personnel is actually intercoupled through the medium of a flooring, lies in electrically testing each pair of shoes at the time it is being worn for service.19 Ordinary "composition" soled shoes and conventional rubber-soled shoes, are definitely non-conductive and should be excluded from use. In this connection I may mention that our department of anesthetia at Barnes has been experimenting for some time with several designs of electrically conductive shoes, and expects to have something of interest to announce in the near future.

Summary:

During the administration of inflammable anesthetic combinations of ethylene, cyclopropane, or ether plus nitrous oxide, there exist at times and at places within the operating room, explosive mixtures which may be fired if subjected to sources of ignition.

The hazard of such accident is reduced by (a) restricting to a minimum the frequency and amount of spillage or discharge of such mixtures into the room, (b) excluding from the room during such administration, the use of cautery or other known source of ignition, (c) inhibiting the production of "current sparks" or "static sparks" within the area.

The hazard from sparks of current electricity origin, may be controlled by maintaining in a state of complete repair, all electric wiring, sockets, connections and ignition-proof switches; by preventing the "opening" or "closing" of live electric lighting circuits or power circuits during the administration; by limiting the voltage used for head lamps.

The hazard from sparks of electrostatic origin may be combated by electrically bonding with each other all objects (including persons) within the area to be safeguarded. The missing link to such a general intercouple system is a suitable shoe for duty service by the personnel (including surgical, anesthesia, circulating and visiting) that will exhibit permanent conductivity of electrostatic charges of the order met with clinically. Experiments with service shoes that are electrically conductive, are now under way.

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THE PROGRESS OF THE NURSE ANESTHETIST

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There is a word in the dictionary, the definition of which is "persistent," "to urge with frequent application." This word is "importune" and it may be applied to much of what I am going to say. I am convinced that there are many problems which concern us as nurse anesthetists that should be brought before our groups repeatedly. Excellent articles along these lines have already been published in our Bulletin, such as Mr. Hamilton's "Building Esprit de Corps," Mr. Flash's "Organizational Activity," and several papers on the organization of an anesthesia department.

The nurse anesthetist today has a twofold obligation: first — to the hospital, the surgeons, and the public she serves; and second — to all other nurse anesthetists, or in other words, to the organization of which she is a member. She cannot function any more merely as an isolated individual — the organization of the group has changed that.

Whenever I hear criticism of a nurse anesthetist, either from a professional or personal standpoint, it is always my reaction to take this rather personally. I am vitally interested in each anesthetist's success or failure in her post, even though she may be unknown to me. The percentage of the individuals in our group who are, or are not filling

Read at a meeting of the Michigan Association of Nurse Anesthetists, on February 22, 1941, Detroit, Mich.