REFRESHER COURSE FOR GENERAL PRACTITIONERS

ANAESTHETIC EXPLOSIONS

BY

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For many years the danger of ignition and explosion of anaesthetic vapours has been recognized in countries like the United States, where the humidity of the air is apt to be greatly reduced by high atmospheric temperatures. It is perhaps not so generally appreciated that the same effect may be produced by very cold conditions which, owing to the freezing and precipitation of moisture, also make the air very dry. As neither of these conditions is common in this country, the danger is correspondingly less. However, during the past twenty years or so, in spite of no observable improvement in the British climate, anaesthetic explosions have become more frequent.

There seems to be no single and, indeed, no entirely satisfactory explanation why this should have happened. Hospital architects have placed sterilizing rooms at a distance from the actual operating area and so possibly reduced the humidity there by preventing the entry of steam. Air-conditioning may have reduced the humidity of the air to a dangerous degree. Possibly a leading factor may be found in the increasing use by surgeons of cautery, diathermy, and endoscopes of various kinds.

Explosive Properties of Anaesthetics

It is unnecessary to describe in detail the explosive properties of the various gases and vapours used for anaesthesia. Ethyl chloride is inflammable and possibly explosive in certain circumstances, but, probably owing to the methods by which it is used, there seems to be no record of a fire or explosion being caused by it. Chloroform vapour is free from risk of explosion, but it is well to remember that in a flame it will decompose into products which are highly irritating to the respiratory system.

The really dangerous agents are ethers of all kinds, cyclopropane, and ethylene. Explosions due to any of these are violent enough to be lethal, and therefore slight differences of degree are of little practical importance. Ethylene, which incidentally detonates more violently than the others, is now so infrequently used as to call for little further comment. However, should it be employed it may be well to remember that it is a very light gas and that consequently any source of ignition placed high enough to escape risk from heavy ether vapour might prove dangerous.

With nitrous oxide the story is very different. It is so generally and correctly regarded as an inert chemical compound that one is surprised to find that it has dangers of its own. It was the late Professor H. B. Dixon who pointed out that nitrous oxide, although non-ignitable itself, will under suitable conditions greatly enhance the ignitability and explosibility of other gases. In the special apparatus which he devised for the investigation of this and other similar problems he found that a jet of, say, hydrogen burning in air could be increased in size and heat by replacing the air by oxygen. But he found to his surprise that the flame could be still further increased by partly replacing the oxygen by nitrous oxide. The explanation is said to be that the heat generated by the flame is sufficient to split up the nitrous oxide into nitrogen and oxygen ions, and that these support combustion better than oxygen itself. Whether this explanation is correct or not, the practical

lesson to be learnt from the experiment is that a mixture of, say, ether vapour with oxygen and nitrous oxide is more ignitable and explosive than one with air or oxygen alone.

The degree of ignitability and explosibility of ether and other ignitable gases varies with the strength of the vapour. A very weak mixture with air or oxygen will not ignite. Pure ether vapour will not ignite. For a similar reason it is said to be safe to drop a lighted match into the petrol tank of a car, but on the one occasion that I have heard of when this was tried the experimenter was killed. Varying mixtures of ether vapour with air or oxygen will therefore, according to the proportions, refuse to ignite, burn quietly or with a "cold flame," go off with a pop, or explode violently. So, in theory at least, if we could be sure of using a vapour either too weak or too strong to ignite, all danger would be averted. However, in practice this is quite impossible, especially with a strong vapour, as this might easily become diluted to a dangerous degree by admixture with surrounding air. The same general considerations apply to vinyl and other ethers and to cyclopropane.

None of these gases will ignite spontaneously, so their use is quite safe in the absence of any spark or flame or of any body hot enough to cause ignition. But it must be realized that a piece of metal which is not red hot, even at a temperature as much as 200-300° C. below visible red heat is still hot enough to ignite a vapour of suitable strength. As an example may be given the rubber and metal syringes sometimes used by dentists for drying cavities with hot air.

Sources of Sparks and Flames

The various sources of flames and sparks for which one must be ever on the watch may for convenience be divided into two groups—the "dynamic" and the "static." In the dynamic group can be included any source of ignition which is actually in existence or is due to the breakdown of some piece of apparatus. For instance, a coal or gas fire or an open electric stove provides such obvious sources that no discussion of them is required. Other sources of this kind are due to the breakage of electric lamps, either those connected with the main installation, or the small ones used in head-lamps, endoscopes, and similar surgical appliances. In some of these the current is reduced to the necessary low voltage by the use of a variable resistance. During his examination the surgeon often demands more light, and the adjusting button gets pushed further and further until much more than the correct two or three volts are passing to the lamp. This may cause only an inconvenient but harmless burning out of the lamp, but it may result in a fracture of the lamp or a failure in the insulation of the flexible lead; either may cause the explosion of any dangerous vapour present. In general, the use of the main electric installation, with a resistance, for endoscopic examinations is to be discouraged. It is safer to employ a low-voltage accumulator or dry battery with which dangerous overloading is impossible. Even if the correct voltage is not exceeded, there is some risk with these delicate lamps. The current is usually led to the bulb through a thin flexible insulated wire, commonly composed of a number of fine metal strands. In the course of ordinary use, such leads are frequently bent and restraughtened, and it may be that first one or two and then more of the

constituent strands get broken until only a few remain intact. The danger arises from the fact that the lamp may continue to function, if not normally at least adequately. This would mean that the full or only slightly reduced current is passing through, let us suppose, not the full 20 strands of the flexible wire but a much smaller number. This must involve increased resistance, and so increased heat, which in turn may be sufficient to destroy the insulation and lead to disaster. Such a possibility can best be avoided by frequent examination and, if necessary, replacement of the flexible wire.

There are, of course, innumerable other ways in which explosive vapours may be ignited. If people will insist on investigating escapes of coal-gas with a lighted match it seems useless to exhort them. Similarly, if an anaesthetist will administer ignitable vapour near a possible source of flame he is asking for trouble. The pity of it is that his fault will involve others, and more particularly the patient. It may seem unnecessary to stress such an obvious point, but experience has demonstrated that it cannot be emphasized too often. In the Ministry of Health's memorandum entitled "Precautions Against Anaesthetic Explosions in Operating Theatres" (see *British Medical Journal*, 1951, 1, 1324) one of the accidents reported is a case in point. It reads as follows:

"A diathermy operation was in progress for carcinoma of the epiglottis. Anaesthesia was induced by chloroform (intra-tracheal), but during the course of the operation the anaesthetist thought it desirable to change to ether. An explosion occurred when the diathermy electrode was within the patient's mouth. Some of those present were injured by flying glass, and the patient subsequently died."

Electric switches of all kinds are specially dangerous. The ordinary electric-light switch often emits a spark, as may be confirmed by removing the cover and operating one in the dark. All such switches should be outside the theatre or, if this is impossible, should be placed as high up as may be, so as to be out of reach of any ether vapour that may be accumulating along the floor. A more serious danger is associated with the foot switches used by surgeons to control diathermy apparatus, electric saws, and the like. If operated by the foot these are of necessity on the floor, and so in the most dangerous position possible. Such switches, and so far as possible all switches near the patient, should be of the mercury "non-sparking" type in which the make and break occur in a closed tube. Electrically operated suction pumps are another source of danger. An electric motor may emit sparks, and if, as in many of the older forms of pump, the mixture of blood and explosive anaesthetic vapour is drawn directly into it an accident is almost sure to happen. Even with the safer modern types the electric motor should be outside the theatre.

Static Electricity

Explosions due to static electricity are very different from those due to exposed flames or electrical failures. Such accidents are often so unexpected that it is difficult, but nevertheless necessary, to be continuously on guard against them. When two bodies differing in electrical potential are brought into close proximity with each other a spark is apt to jump across the intervening gap. Instances of such static sparks are common, such as the slight ones obtained in frosty weather when we comb our hair or stroke the domestic cat. In some dry climates it is possible, and I believe customary, to light the gas by shuffling along the carpet, so charging oneself with electricity, and then approximating a knuckle to the metal of the gas jet. The resulting spark will light the gas just as well as that from the flint in a modern gas fire. It is in fact of great importance to realize the ease with which persons and things can become electrically charged if the circumstances are favourable. It may only be necessary to rub a cloth lightly over the rubber covering of a rubber-tyred theatre trolley to charge it sufficiently to give a spark upwards of $\frac{1}{4}$ in. (1.3 cm.) in length.

The usual type of rubber-tyred anaesthetic table may become similarly charged, though it is usually very difficult to discover where the charge has come from. A possible cause may be suggested by consideration of the unpleasant experiences sometimes suffered by drivers of light steam-traction engines with rubber tyres. On a warm dry day the driver may stop for his lunch, leaving the engine standing idle. As the pressure of the unused steam rises in the stationary vehicle the safety valve will come into operation and a flow of steam escape through it at high pressure. On returning to his cab the driver may receive a shock sufficient to throw him into the road. The blast of the steam can generate a static charge which, being unable to escape because of the rubber tyres, may attain a sufficient potential to cause a disturbing shock when earthed by the driver's foot; the fitting of a trailing chain easily disposes of this trouble. The same plan is adopted for anaesthetic tables. For this purpose a looped chain is found to be more reliable than a single one, as it is less likely to be tucked away by a tidy-minded but uninstructed nurse. On the analogy of the steam-engine it seems possible that an anaesthetic table might receive a charge from the passage of gases through its metal and rubber tubes, especially should any dust be present. Experts at the National Physical Laboratory, however, have passed gases through a Boyle machine under working conditions for long periods without producing a static charge.

Some explosions seem to have been due to the charging of the anaesthetists themselves or of other persons in the theatre. Just as one may get a sufficient charge to light a gas-jet by shuffling across the floor, so an anaesthetist may by his own necessary movements charge himself to a dangerous potential if, as is usually the case, he is not earthed. In one case that was reported to me the lady anaesthetist was wearing a silk garment, and this may have been contributory. The fact that theatre personnel are generally required to wear rubber footwear naturally increased this danger, especially on a non-conducting floor. In munition factories it used to be obligatory for workers to wear rubber or felt shoes to avoid the risk of striking a spark on the floor. Such a precaution increased rather than diminished the danger. Apart from persons themselves becoming electrically charged, small pieces of apparatus, such as facepieces, metal unions, bags, and the like, may also become statically charged or perhaps obtain a charge by being handled by the anaesthetist. I know of several cases where a flame has appeared, with or without an explosion, when some metal union on the apparatus has been separated or reassembled. So real is this danger that, if such a manipulation is necessary, it is wise to discontinue the flow of ignitable gas until it is completed.

Many of the dangers from static sparks are due to the non-conductibility of the rubber of which much anaesthetic apparatus is composed. It is this that makes it so difficult for any electric potential, however generated, to leak away. During the last war one of the rubber companies succeeded in producing a conducting rubber; the general use of this for anaesthetic apparatus, wheels of trolleys, and soles of footwear would eliminate many sources of danger. Even with ordinary rubber the risk can be somewhat lessened by running a little water through the bags and tubes before use and so slightly increasing their conductivity.

Other Hazards

A special warning must be given about the handling of the ether bottle on any kind of Boyle machine. After using ether it is not enough just to turn off the ether tap before exposing the patient to any possible source of ignition. Such a tap may be entirely gas-proof, but it is difficult to be sure of this, and to be quite secure the ether bottle should be removed to a safe distance. Should it be necessary, for any reason, to leave the ether bottle in position, it is not enough to empty and replace it. This may be more dangerous than simply turning off the tap. The

"empty" bottle will probably retain a few drops of ether. A small quantity like this is far more easily vaporized than 8-10 oz. (0.25 litre) of liquid ether, and in consequence may set up a greater vapour pressure than the latter, with the attendant greater risk of leakage through a faulty tap. If the bottle is required in position it should be emptied and rinsed out with water before replacement.

Two other hazards deserve brief mention. The first concerns oxygen cylinders. It is, or should be, well known that it is dangerous to apply oil to the valves of cylinders containing compressed gases, particularly to those of oxygen cylinders. In anaesthetic apparatus the oxygen usually comes through two valves: one, the main one, on the cylinder head, and the second, a fine-adjustment valve, which controls the actual flow. If, when this second valve is closed, the main valve is *suddenly* turned on fully, the rush of released gas impinging on the second valve may generate enough heat to detonate the vulcanite of the main valve, with disastrous consequences. The presence of dust and oil will render this all the more probable. It should not be difficult to remember that the main valve (often very stiff) of an oxygen cylinder should be turned on quite gradually, and that any second valve beyond should be at least partially opened. Once the gas is flowing the valves may be operated at will without risk.

The second hazard is unconnected with anaesthesia except in so far as the anaesthetist is well situated to hold a watching brief. Surgeons sometimes make use of strong spirit lotions or actual spirit for skin sterilization and other purposes. If this is freely applied any excess may be absorbed by surrounding towels, which thus become highly inflammable. Should diathermy or other cautery be later used in the vicinity a conflagration may result.

Conclusions

When records of the actual damage done by anaesthetic explosions are examined it will be observed how variable are the resulting injuries. They are reminiscent of the vagaries of bomb damage. While many, and probably most, of these explosions have caused the immediate or delayed death of the patient, in others he has escaped unharmed. Such escapes are rare. It would almost certainly be correct to say that such an escape will never occur if the explosive gas is being administered through an endotracheal tube. In such a case there must be an open passage filled with explosible vapour extending from the site of the explosion to the trachea and bronchi, and the flash must pass along it. In this way the lung tissue will be disintegrated by the explosion or so burnt that fatal bronchopneumonia must follow.

Recent developments in anaesthetic technique make it easier than formerly to avoid risk of explosion. Non-ignitable trichlorethylene ("trilene") is of the greatest service, as it will maintain an adequate plane of anaesthesia during a dangerous period. The use of local, regional, spinal, and intravenous methods needs no more than mention. Perhaps the greatest help of all is to be found in the employment of curare and other similar muscle relaxants. With their help a satisfactory degree of muscular relaxation can be obtained without the use, or with only very limited use, of the explosible vapours.

However, in spite of all these advances, and in spite of the frequent warnings that have been published, these distressing and fatal accidents continue to occur. One short sentence sums up all that has been or can be said on this subject—namely, Never administer an ignitable anaesthetic unless the absence of any flame, spark, or other source of ignition can be assured.

Next Refresher Course Article.—"The Surgical Relief of Pain," by Professor Lambert Rogers.

CHIEF CHARACTERISTICS OF NERVE GAS

NOTES ON FIRST-AID TREATMENT

(This article has been prepared at the request of the Chemical Defence Advisory Board, and is here published by permission of the Chief Scientist, Ministry of Supply.)

"Nerve gases" are liquids with boiling points varying from 150 to 250° C. (approximately). They are therefore roughly comparable in volatility to kerosene. They are fairly soluble in water, and are slowly destroyed by hydrolysis. Alkalis, such as solutions of caustic soda or washing-soda, will decompose them more quickly. They are almost odourless and the vapour is invisible. They have no immediate irritant properties either to the eyes, skin, or respiratory tract. No warning of their presence is therefore given to the subject exposed to them.

Mode of Action

Their very dangerous and insidious qualities are primarily due to the fact that their action is that of cholinesterase inhibition—that is, they prevent the action of the enzyme which, under normal conditions, continuously destroys acetylcholine in the body as it is produced. This leads to the accumulation of acetylcholine, and hence all neuromuscular mechanisms are upset. Voluntary muscle, including the muscles of respiration, ultimately becomes paralysed and smooth muscle passes into a state of spasm. In effect there is a generalized parasympathetic stimulant action.

The total amount of cholinesterase in the body is small, and nerve gases inhibit this enzyme for a prolonged period. Therefore these gases are highly toxic and may be lethal in minute concentrations. They are rapidly absorbed by inhalation of the vapour, absorption of the liquid through the skin and mucous membrane, or by the ingestion of contaminated food or water. A drop of liquid in the eye or the inhalation of a high concentration of vapour for a few seconds may cause incapacity or death within a few minutes. Liquid on the bare skin penetrates somewhat less rapidly, but two or three drops may kill within half an hour. Ordinary clothing cannot be relied on for protection, as it is quickly penetrated.

The inhibition of cholinesterase activity may persist for many weeks, so that repeated exposures to very low concentrations may have a cumulative effect.

Signs and Symptoms of Poisoning

These can be divided into primary and secondary.

Primary, Due to Direct Action of the Nerve Gas.—There is copious salivation, slowing of the heart, constriction of the pupils, headache, nausea, diarrhoea, vomiting, muscular weakness, and sometimes generalized muscular fibrillation. The muscles of respiration are weakened or paralysed, the diaphragm being affected most. The bronchial musculature may be in spasm.

Secondary, Due to the Anoxia Brought About by Respiratory Paralysis.—This will produce cyanosis, venous congestion, low blood pressure, convulsions, and possibly pulmonary oedema. Death occurs suddenly from the effects of the anoxia.

Clinical Features.—Since comparatively few cases of poisoning have occurred, the clinical picture is as yet imperfectly known. The following summarizes the features which have been recognized.

A severe case of nerve-gas poisoning will present itself as one of acute asphyxia. The subject may be unconscious from anoxia, with cyanosis, sweating, and pallor. Breathing will be laboured and wheezing in character, similar to that of an acute asthmatic attack. While conscious, the subject will be anxious and suffering from air-hunger; there may be restlessness and lack of co-operation owing to the effects of the anoxia.