ANAESTHETIC EXPLOSIONS

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with apprehension by a large number of anaesthetists and surgeons. Indeed, because of these properties, such an excellent anaesthetic agent as di-ethyl ether may become surrounded by as many taboos as the wooden image worshipped by a savage African tribe. The drama of fire and explosion in the operating theatre is greater than that surrounding an atomic explosion, but the reason for this is that atomic explosions are more frequent and so less wondered at.

FREQUENCY

In 1930 the Committee on Anaesthesia Accidents of the American Medical Association[1] stated that 'explosion is statistically (today) the least of the hazards of anesthesia' and in 1955 the British Ministry of latter figure is for all types of anaesthetic agent, flammable and non-flammable. In 1939 Woodbridge[3] reported that of a total of $2\frac{1}{3}$ million anaesthetics in which ether, cyclopropane or ethylene were used (i.e. all flammable agents) 49 were accompanied by explosion or fire and these 49 accidents resulted in 2 deaths and in injuries to 7 other people. The risk of a fire or explosion during the use of one of these agents is therefore between 2 and 4 per 100,000 anaesthetics, and the chance of dying from an anaesthetic explosion is far less than 1 in 1,000,000. If these figures for flammable agents are equated with the figures of the British Ministry of Health for all agents, including non-flammable agents, then in every $7\frac{1}{2}$ million anaesthetics there will be one death from an anaesthetic explosion.

In contrast, in a review of a total of 1,050,422 anaesthetic administrations (Table I) it is found that 674 deaths were due directly or indirectly to the anaesthetic —an incidence of 1 death per 1,556 anaesthetics. Not one of these deaths was reported as due to an anaesthetic explosion. But from the same sources we find that in a series of 55,090 patients receiving an anaesthetic (Table II) 84 died as a result of hypoxia or anoxia due to the anaesthetic technique (i.e. deaths from haemorrhage or shock of *surgical* origin are excluded). Expressed in a slightly different form, in a highly selected series, including a very large (85%) proportion of patients receiving 'curare', there was one anoxic death per 656 anaesthetics. Thus we see that every year a completely negligible number of people are killed by anaesthetic explosions while a great number are being killed by oxygen deprivation. The first manner of death is loudly noisy and cannot be concealed, while the second is darkly secret. With the second, everybody is surprized at the patient's demise and ascribes it to enlarged thymus, myocardial infarction, shock, magic, or plain 'cussedness' on the part of the patient. The cause of death is frequently certified as being due to 'reflex cardiac asystole'—a mysteriously magical entity.

TABLE I

Source	*No. of Anaesthetics*	*No. of Deaths*
Beecher and Todd[4]	599,548	384
Meyer Saklad[5]	388,203	205
Wylie and Kee[6]	11,000	21
Groote Schuur Hospital[8,9,10] ..	51,671	64
	1,050,422	674

TABLE II

Source	*No. of Anaesthetics*	*No. of 'Anoxic' Deaths*
*Beecher and Todd[4]	44,090	74
Wylie and Kee[6]	11,000	10
	55,090	84

* All these anaesthetics included the use of muscle relaxants ('curare').

CAUSATION

An analysis of any series of anaesthetic explosions quickly reveals the fact that almost invariably the explosion is due to neglect of elementary precautions. This neglect, in turn, is usually born of ignorance and often sired by sloth. The anaesthetists who suffer these 'visitations of misfortune' are of the type who, while the petrol tanks of their motor cars are being filled, blithely light a cigarette and toss the match out of the car window without first extinguishing it. Lady Luck is not always with them.

An explosion is usually the result of a rapid chemical reaction which liberates large volumes of gas into a confined space. These volumes of gas rapidly increase the pressure in the confining vessel, which bursts. The sudden shock-waves, the flying splinters of the burst vessel, and the fire which is frequently started by the heat evolved in the chemical reaction, are responsible for whatever other damage may result.

Certain conditions must be satisfied before the chemical reaction can take place. Firstly the chemicals which are to take part in the reaction must be in physical contiguity. This requirement extends to the level of molecular existence. As an example, in mixtures of ether vapour and air, the ether molecules are widely separated from the oxygen molecules, with which they would unite, by interspersed nitrogen molecules, which are chemically inert. The ether and oxygen molecules in mixtures of ether vapour and oxygen are jostled together and are much more closely related than in ether-air mixtures. In either mixture, if the mixture is under increased pressure the molecules are more closely packed, while if the mixture is under decreased pressure they are more widely separated. The closer the physical contiguity of the potentially reactive molecules, the more likely is a reaction to occur if the remaining conditions are also satisfied.

The second condition which must be satisfied is the spark to fire the powder train. Energy, usually in the form of heat, must be supplied to initiate the chemical reaction and, as in the all-or-none law in physiology, the energy quantum must exceed a certain threshold value. Even given an energy quantum of sufficient value, reaction will not necessarily be initiated, because the nature of the molecules in the vicinity of the energy quantum, as well as their proximity to the energy quantum and to each other (see the first condition above) will influence the course of events.

Gases, like liquids and solids, have specific heat properties, and it is of course the molecule itself which absorbs the heat (or energy). If the molecules in the vicinity of the energy quantum have an increased capacity for absorbing heat they will absorb and dissipate the energy supplied, in addition to separating the reactive molecules, so that the chemical reaction will not be initiated.[7] Hence the nature of the mixture containing the reacting agents, and the physical conditions under which it exists, play an all-important part in the subsequent course of events when a quantum of energy (ignition source) is added to the mixture.

As an example of the importance of the physical conditions present during anaesthesia, consider the administration of ether by the open-drop method to a patient in a room which measures 15 feet long by 10 feet wide and 10 feet high. There will be 1,500 cubic feet of air in this room. To provide 1·5% of ether vapour in the air in this room (1·5% of ether in air is the weakest ether-air mixture which can be exploded) 22·5 cubic feet of ether vapour must be added. This volume of ether vapour will be provided by vaporizing 4·6 lb. of liquid ether. It is very rare to use much more than ½ lb. of liquid ether during an ordinary open-drop ether anaesthetic; moreover we are postulating in our example that there is no ventilation in the room to dilute and refresh the air.

In 1930 Yandall Henderson,[1] using mixtures of 80% ethylene (a highly explosive hydrocarbon anaesthetic gas) and 20% oxygen for clinical anaesthesia found that only minute amounts of ethylene could be detected a few feet away from the anaesthetic apparatus. Even in the neighbourhood of the anaesthetic facepiece, ignitable concentrations of ethylene were not found except within a distance of less than 12 inches in the direct line of the expiratory valve. Ether vapour, under the same conditions, diffused less readily, so that concentrations above the mask were negligible and concentrations below the level of the mask tended to be greater, at the same distances, than the corresponding relative concentrations of ethylene.

These examples show very well the value of diluting explosive gas-mixtures with inert gases, the handiest being air. They emphasize the value of adequate ventilation and remind us that before using the cautery or diathermy in any body-cavity it is an excellent principle to aspirate the air from that cavity. This will ventilate the cavity, removing old gas which may contain ignitable traces of anaesthetic, and drawing in fresh air.

CASE REPORT

An elderly male was receiving an anaesthetic for the excision of a malignant growth in the mouth. The anaesthetic was nitrous oxide, oxygen and ether, delivered through a plastic endotracheal tube directly into his trachea. The pharynx was packed with

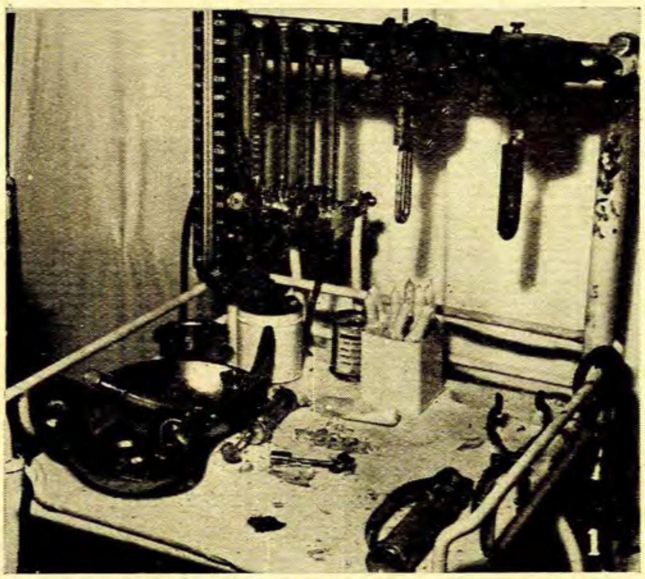

Fig. 1. The Boyle's anaesthetic machine immediately after the explosion.

moistened gauze. The surgeon unexpectedly announced that he would need to use the electric cautery; so the anaesthetist turned off the ether vapourizer *but did not remove the vapourizer from the anaesthetic machine*. After waiting for 3 minutes he announced that the cautery could now be safely used. As the surgeon began to cauterize within the mouth there was sharp explosion and the operating theatre was filled with flying glass and with flaming liquid ether from the shattered ether vapourizer. The corrugated rubber tubing was torn from its connections to the endotracheal tube and the anaesthetic machine and was hurled across the room. The reservoir gas bag was fragmented but the corrugated rubber tubing was undamaged (see Figs. 1 and 2). The patient was unharmed and so were surgeon and anaesthetist. The fire was rapidly extinguished (it is always a wise precaution to acquaint oneself with the siting of fire extinguishers in the places where

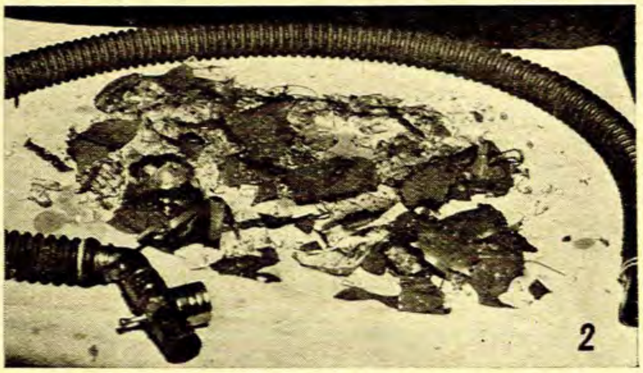

Fig. 2. The shattered remnants of the reservoir bag and the ether and trilene vaporizer bottles. The corrugated rubber tube is undamaged.

one works) and the anaesthetic was continued with a different anaesthetic machine. The operation was concluded successfully.

DISCUSSION

In reconstructing the event it was pointed out that the fact that an ether vapourizer is switched to the *Off* position is no guarantee that it is not still allowing small amounts of ether vapour to leak into the anaesthetic gases that are being delivered by the machine. It was apparent that the cautery had ignited the patient's inspiratory dead-space gas as he was about to exhale. The flame did not flash down into the patient's lungs because his tracheal and alveolar air contained a relatively high concentration of carbon dioxide and of water vapour, both inert diluent gases. But the flame did flash back along the anaesthetic gases in the corrugated rubber tubing, where there was relatively no water vapour or carbon dioxide but where there was sufficient ether vapour to propagate a flame. The fact that the ether vapourizer, although apparently isolated from the anaesthetic circuit, did explode, can only mean that it was not properly isolated. There was in fact a physical leak by means of which ether vapour could reach the anaesthetic gases and the flame could enter the vapourizer. In the confined space of the vapourizer the chemical reaction resulted in an explosion.

The accident could have been avoided by removing the ether vapourizer from the anaesthetic machine when it was known that the diathermy was to be used. As an additional precaution the mouth should have been ventilated by sucking out the air in that cavity and thus filling it with fresh air.

To prevent all deaths from anaesthetic explosions, it is necessary never to use a flammable anaesthetic agent. However by the very nature of the phenomenon of anaesthesia, there is *no* agent or method which does not carry a risk of permanent injury or of death, either from the inherent toxicity of the drugs used or from associated accidents. Accidents can never be completely eliminated in the practice of an art in which human judgment plays such a very large part.

By extension of the argument no anaesthetic should ever be administered to any patient because of the risk that the anaesthetic agent or the technique may be responsible for the death of the patient. This risk is 4,000 times greater than the risk of death from an anaesthetic explosion. A nicely calculated balancing of the risks involved in any anaesthetic should determine the choice of agent and technique, but the weight of available evidence suggests that those who will never use a flammable anaesthetic agent are deterred, not so much by the thought of what might happen to the patient, but by the thought of what might happen to themselves.

For those who feel that the elementary precautions to be observed in the use of flammable anaesthetic agents, which can be deduced from the discussion in this article, constitute insufficient protection, it is now possible to acquire a piece of apparatus known as an 'Explosimeter'.* This apparatus will indicate quickly and accurately whether a small gas-sample presented to it is capable of being ignited or exploded. With this apparatus it is possible, at any time, to monitor the anaesthetic atmosphere being inhaled by the patient.

* For example, that produced by Messrs. Mines Safety Appliances.

SUMMARY

The risk of death from an explosion during any anaesthetic is of the order of 1 in 7½ million while the risk of death from the anaesthetic itself is greater than 1 in 2,000.

The conditions required for explosion of anaesthetic atmospheres are discussed and a case is presented to emphasize that explosions are usually the result of failure to observe simple precautions.

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