THE PREVENTION OF ACCIDENTS ASSOCIATED WITH ANAESTHETIC APPARATUS

BY

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It is difficult to assess how many deaths have occurred as a result of faulty design or improper use of anaesthetic equipment. Although cases have been reported where the oxygen supply has failed unobserved by the anaesthetist, and where the wrong cylinder was attached to an anaesthetic machine, there are probably several types of accident which have not been publicized.

In a series of 162 cases of death associated with anaesthesia reported in Australia (Clifton and Hotten, 1963) two were due to the failure of the oxygen supply. In 1956, Edwards and his associates reported on 1,000 cases of death associated with anaesthesia; in two of these cases the oxygen flowmeters were found to be leaking, and in another the circle absorber had fallen off the apparatus, and control of respiration in a poor-risk paralyzed patient could not be restored in time. One death was due to an explosion caused by static electricity, and another was due to the attachment of a nitrous oxide cylinder in the place of an oxygen cylinder on an anaesthetic machine.

In 1964, Dinnick discussed 600 deaths associated with anaesthesia. Of these deaths there were approximately 400 in which anaesthesia was partly or entirely responsible. Three of these cases were due to the misuse of anaesthetic apparatus. In one the soda-lime canister was not in place during closed circuit cyclopropane anaesthesia. In another, the carbon dioxide had been turned fully on but the bobbin in the flowmeter was not observed; and in the last case the nitrous oxide bypass was turned on instead of the oxygen bypass.

It is well known that accidents, some of them fatal, have occurred as a result of the unobserved exhaustion of an oxygen cylinder. Many anaesthetists can recall occasions when their attention was attracted elsewhere as oxygen supply failed, and it was noticed only when the patient became cyanosed. It is a human failing that anaesthetists working in hospitals where piped supplies of oxygen and nitrous oxide have been installed may lose the habit of checking frequently a contents or pressure gauge. This habit may never be acquired by trainees. Thus, when these anaesthetists are working where piped supplies are not installed, they may fail to keep a constant check on the cylinder contents.

Accidents also occur where the patient suffers permanent damage to the brain or other organs, although a fatality may be avoided. Anaesthetic mishaps can result in a modification or postponement of operation (Bishop, Levick and Hodgson, 1967).

CAUSES OF ACCIDENTS

Mechanical fault or breakdown of apparatus.

Although mechanical faults or breakdown of apparatus are seldom the result of the activities of the anaesthetist, and rarely follow from the design of the anaesthetic apparatus itself, a knowledge of the more common instances makes it possible for the anaesthetist to prevent the outcome from becoming serious or fatal.

Confusion of the pipelines.

There has been at least one fatal mistake where an oxygen outlet was connected to the nitrous oxide pipeline. As more and more pipelines are installed, and alterations and maintenance increase, this type of accident could become more frequent. The code of practice for commissioning piped services (approved by the Ministry of Health), is so strict that mistakes are unlikely to occur in the hands of competent engineers. It is still possible that during the course of building alterations and so forth other people may tamper with the supply lines. The use of different-sized pipes and fittings for different gases in such installations would seem desirable.

The outlet (self-closing) sockets of the pipeline and the plugs on the hoses attached to anaesthetic machines and other equipment are colour coded. Each socket will accept only the appropriate plug,
Schrader plugs and sockets for the pipeline. The skirts are of different size and coloured white for oxygen, blue for nitrous oxide, and yellow for medical suction.

since the skirt on the plug is of a different size for each gas and for vacuum. Provided that the correct plugs are fitted, confusion cannot occur at this point.

Fractured Rotameters.
Several accidents have occurred in which the cyclopropane or carbon dioxide Rotameter tubes were broken or leaking (Bishop, Levick and Hodgson, 1967). The usual sequence in which the Rotameters are fitted results in all or part of the oxygen being expelled through the leak, whilst nitrous oxide, alone or with a reduced percentage of oxygen, is delivered to the reservoir bag. It would obviously be most unwise to alter the physical order of the oxygen and other Rotameters, but it would seem desirable that the manufacturers should redesign the Rotameter block so that the oxygen is the last gas to enter the mixed gas flow (Eger and Epstein, 1964).

Sticking of Rotameters.
The bobbin in a Rotameter may stick to the side of the tube in any position. This may be due either to static electricity, or less commonly dust, grease or oil which has entered the system. Sticking is more troublesome if the tube is not absolutely vertical. The bobbin can become impaled upon the spiral stop at the top of the tube. It may stick in this position even if no gas is flowing, there being no indication of failure.

Leaks.
If a glass vaporizer bottle is chipped, or if the cork washer is damaged or missing, gases will leak from the vaporizer and therefore the mixed gas flow to the reservoir bag is reduced. This may result in rebreathing and loss of the volatile agent. If no cylinder or block is fitted to a cyclopropane yoke, air may be drawn through it, especially when certain ventilators are used.

Sticking of unidirectional valves.
As the design of circle absorbers has improved to give a lower resistance to gas flow, so the unidirectional valve discs have been made lighter. The valve on the expiratory side soon becomes moistened with condensed water vapour, and there is a tendency for these light valve discs, as
a result of surface tension, to stick in the “open” position. This allows rebreathing without carbon dioxide absorption, and even loss of the fresh gas flow. Hypoxia and hypercarbia ensue.

**Obstruction of gas flow.**

When the oxygen flush control of one modern Boyle anaesthetic machine was turned nearly full “on”, not only was there no oxygen flow but also it obstructed the mixed gases from the Rotameters. When the same machine was used with its circle absorber, a complete obstruction to gas flow occurred. The latter obstruction was due to kinking of the tube supplying the fresh gases from the swivel outlet to the absorber. The manufacturer had failed to provide unkinkable tubing for this purpose.

Many other causes of failure in anaesthetic equipment have occurred, and space does not permit their enumeration here. However, it cannot be stressed too often that whereas these faults may occur, accidents arising from them can be prevented by

1. the thorough checking of anaesthetic equipment by the anaesthetist immediately before use;
2. constant observation during anaesthesia;
3. an adequate knowledge of the mechanical construction and function of anaesthetic machines.

**IMPROPER USE OF APPARATUS**

As anaesthetic machines and ventilators have become more complicated, so it has become increasingly important that the anaesthetist should be familiar with the intricacies of those types of apparatus which he uses. At the same time it may fairly be said that colour coding of fine adjustment valves, Rotameters and their bobbins, as well as bypass controls, could be made more striking.

**Bypass (flush) controls.**

The position in the circuit of the oxygen bypass control varies in different anaesthetic machines; in some it is so placed that the extra supply of oxygen will pass through the Rotameter and thus be indicated—but it will also flow through the vaporizers, so that if these are turned on the patient will receive the volatile anaesthetic agent as well as oxygen. This could prove dangerous. In other machines the bypass controls are situated in the same position but the extra gases do not pass through the Rotameter. Thus if they are accidentally left “on” there is no indication of the fact. This is particularly important in the case of nitrous oxide bypass. Where the bypass valve is fitted to the Rotameter block it may become loose, and the lever fall into the “on” position.

The most common position for the oxygen bypass is on the end of the back bar after the last vaporizer. Pure oxygen is added to the mixed gas flow. It can be left on by mistake, and this has resulted in patients remaining awake during operations when relaxant and IPPR are used.

**Accidental wrong setting of Rotameters.**

The carbon dioxide may be inadvertently turned on (Prys-Roberts, Smith and Nunn, 1967; Ross, 1968; Dinnick, 1968). In one case the bobbin was at the top of the Rotameter tube but hidden from view by part of the unit. Severe hypercarbia resulted. Better design of the Rotameter unit with a bobbin visible in all positions might have prevented such accidents. The fine adjustment valve may turn too easily if the gland nut behind it has become loose. In anaesthetic machines where rubber low-pressure tubing is used, cyclopropane is controlled by a handle on the cylinder valve. When the machine is being taken into the theatre this handle may be used by assistants to pull it along, or it may be knocked against the doorpost by accident, resulting in a high flow rate of cyclopropane. Since the bobbin is so small, it is not easily noticed at the top of the Rotameter tube.

**Incorrect choice of circuits.**

On some anaesthetic machines a tap is fitted to direct the mixed gas flow, either to a Magill attachment or to a circle absorber and in some cases to an anaesthetic ventilator. It may escape the anaesthetist’s notice that this tap is not turned to the circuit in use. This may happen when a patient is anaesthetized with a technique involving controlled ventilation but no nitrous oxide and oxygen are fed to the ventilator. At the best the patient is ventilated with air drawn into the ventilator, and at worst there is complete rebreathing or the ventilator will stop (Waters, 1968).
In anaesthetic machines where circle absorbers or ventilators are supplied from a feedmount attached to the common gas outlet this type of accident is still possible.

When ventilators are used, especially with a negative phase, air leaks, or the use of a fresh gas flow less than the minute volume of the ventilator, may cause the admission of atmospheric air to the circuit. This can lead to the awareness of a patient during surgery (Waters, 1968).

**High pressure.**

Excessive pressure can be developed either when the expiratory valve is fully closed and there is a steady build-up resulting in unrelieved inflation of the lungs, or when there is a sudden surge as a result of opening a bypass control, and overinflation or even lung damage can result. Dinnick (1964) reports a case in which the stomach was ruptured when a catheter intended to administer nasal oxygen was passed into the oesophagus. Some anaesthetic machines now give regulated (“reduced”) gas pressures as high as 60 Lb./sq.in. (4.2 kg/cm²), i.e. the pressure of the piped supply, rather than 5 to 12 Lb./sq.in. (0.35–0.84 kg/cm²) hitherto regarded as the standard setting for reducing valves operating from cylinders. The danger of pressure surges is obviously greater. To avoid accidents, flow restrictors are fitted proximal to the Rotameters, and pressure relief valves are usually fitted on the common gas flow. It should be noted that the recently introduced so-called “Pressure Limiting Bag” primarily designed for use on ventilators such as the Cyclator is in fact not a pressure-limiting but a volume-limiting bag. If it should accidentally be used in place of an ordinary reservoir bag in the Magill attachment the valve tends to open more readily than the expiratory valve, resulting in a serious degree of rebreathing (Waters, 1967). A warning should be fixed to this type of bag.

**CONFUSION OF AGENTS OR GASES**

Where rubber or other demountable tubing is used to connect the reducing valves to the Rotameters non-interchangeable connections are used to prevent confusion. The introduction of the pin-index system for anaesthetic gas cylinders should now prevent any cylinders being accidentally interchanged.

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**Pin-index yoke.**

**Fig. 3**

The pin-index system to prevent the wrong cylinder being fitted. A different spacing arrangement of the holes and pins is used for each gas so that it is impossible to fit cylinders incorrectly.
CONFUSION OF VOLATILE ANAESTHETIC AGENTS

The practice of adding to each anaesthetic agent, other than ether, a distinctive colouring matter has been discontinued for some of the newer agents. Further, one brand of chloroform is not coloured pink, and is supplied in a bottle and wrapper very similar to ether. This has led to the accidental administration of chloroform at a very high concentration.

In America concern is growing on account of the mistaken recharging of vaporizers calibrated for methoxyflurane with halothane. This error can give rise to delivery of halothane at a dangerously high concentration. One manufacturer in this country is now considering the introduction of non-interchangeable containers for charging vaporizers with volatile agents.

FAILURE OF THE OXYGEN SUPPLY

Oxygen failure (particularly from cylinders) has been the cause of several tragic accidents. Anaesthetists of experience know that, however conscientious they may be, their attention can be distracted at the time of the exhaustion of a cylinder. Many fear lest they might be the next to be involved in such an apparently inexcusable misadventure. This risk has recently been exaggerated by the fact that piped medical gas supplies are installed in some but not in all hospitals. Some consider that oxygen failure warning devices may lead to a lesser standard of vigilance. Others agree that any reliable device which prevents oxygen failure must be a safeguard. It is not within the scope of this paper to judge between these two opinions. Sufficient may it be stated that any such device should prevent oxygen failure rather than give a warning that it has happened.

The "Bosun" warning device gives an audible and visible warning of oxygen failure. The audible warning depends upon the supply of nitrous oxide while the visible warning depends upon a bulb lit by a battery. These may fail and, what is more, both can be switched off. It may therefore give rise to a false sense of security.

The Wantage oxygen failure alarm (Cooke and Waine, 1967) also depends on a battery which can fail or be switched off.

The Coote warning device (Hill, 1956) requires a supply of nitrous oxide to give warning of the failure of oxygen, and of oxygen to give warning of the failure of nitrous oxide. A simultaneous failure of both gases would result in no warning being given.

The Adler and Burn device (Adler and Burn, 1967) gives a warning when the supply pressure falls below 25 Lb./sq.in. (1.75 kg/cm²). It is designed for use with machines having regulated pressures of 60 Lb./sq.in. (4.2 kg/cm²), and can be applied to others only if they can be modified to work on 60 Lb./sq.in. instead of lower pressures. It incorporates a plunger which if depressed stops the device functioning. This plunger could be kept depressed by the use of a piece of sticking-plaster.

The "Fail-Safe" oxygen device described by Lucas and Fisher (1967) depends upon the pressure of the oxygen supply to maintain engagement between the delivery tube of the Magill attachment and the bag mount. On failure of the oxygen supply the delivery tube is allowed to drop away from the bag mount. The patient, if breathing spontaneously, will now rebreathe through the delivery tube. Again a little sticking-plaster will render the device inoperative.

The E.G.C. gas failure alarm (Murray Wilson, 1965) consists of a spring-loaded bell with an arm. Upon the failure of the oxygen supply, the bell will ring and the arm will rise to cover the fine adjustment valves on the Rotameter block. The same alarm may be applied to the nitrous oxide supply. This too can be prevented from operating.

On the Walton Five, the A.E. and some McKesson dental anaesthetic machines the nitrous oxide is interrupted if the oxygen fails. The anaesthetist's attention is immediately attracted. This may not fulfil the criteria suggested by the Ministry of Health; nevertheless it increases the safety of dental anaesthesia.

A new automatic failure warning device incorporating a safety cut-out is now being developed by the British Oxygen Company. It is designed to operate on low pressure circuits at 60 Lb./sq.in. (4.2 kg/cm²). Relying simply on a magnet and the oxygen pressure, it gives an audible warning as the oxygen begins to fail and cuts off the common gas flow when the oxygen is exhausted. Air may be drawn into the circuit by the opening of a valve which also gives an audible warning.
Epstein and others (1962) describes a system of pressure regulators which requires the pressure of oxygen to permit the flow of other gases. This arrangement requires the precise adjustment of several regulators, which may prove difficult to maintain in proper balance. Its addition to existing anaesthetic equipment is presumably expensive.

All warning devices depending on oxygen pressure may fail due to back pressure when used in conjunction with some ventilators such as the Manley.

If an oxygen warning device is desirable, then it must not only give an audible warning of the exhaustion of an oxygen cylinder but, more important, should also turn on an alternative supply. None of the above do so. Merely to allow the access of atmospheric air into the circuit is insufficient, since when it is admitted to the proximal end of the Magill's attachment rebreathing occurs up and down the delivery tube. If a ventilator powered by the pressure of the supply gases is in use, then it will fail to operate. A committee of anaesthetists and other advisors to the Ministry of Health made recommendations regarding oxygen failure warning devices in 1965 (Hospital Equipment Information, No. 5, December 1965, para. 59/65) (see Appendix).

A device described elsewhere (Ward, 1968) provides a warning of the failure of an oxygen cylinder and at the same time turns on a second source of oxygen should this be available.

There are other and more unexpected causes of an inadequate oxygen supply.

If an oxygen cylinder valve has not been opened sufficiently, the initial adequate flow rate is not maintained, but falls to a dangerously low level or may even fail altogether. Thus a cylinder tested and found to be full under static conditions may not deliver oxygen at the rate required.

Again, an oxygen cylinder may be tested by turning it on and the contents gauge observed to show "full". The cylinder is then turned off and because the reducing valve delivers a lower pressure than that connected to the other cylinder, the gauge remains at "full". The anaesthetist may gain the impression that the cylinder is both full and turned on. When the other cylinder fails the small quantity of oxygen under pressure in the reducing valve and pressure gauge of the first is rapidly exhausted and the oxygen supply fails.

Piped oxygen supply systems seldom fail. In most types even if the electric mains fail the flow continues, and change-over from the running bank of cylinders to the reserve still operates. (Warning lights and bells are, however, out of action and failure of the reserve bank may go unnoticed.) In the latest system devised by the British Oxygen Company, electrical failure is also indicated.

In larger installations there are isolating valves on the branches to different parts of the hospital. One of these may be mistakenly closed, resulting in sudden failure. Mains-operated lights and bells can be installed in the theatre block to give warning of this event.

As already described, anaesthetic machines are connected to the piped supply system by flexible hoses fitted with non-interchangeable plugs and sockets. If these are not completely engaged they may hold together but fail to pass an adequate gas flow.

When oxygen failure results from some form of sudden disconnection, most devices depending solely on the oxygen pressure to give an audible warning will fail to operate properly.

Following installation or repair, pipelines may remain full of air rather than oxygen. The use of nitrogen for testing has been discontinued following its accidental administration to a patient. Oxygen pipelines are sometimes flooded with nitrogen before welding a fault. This too has led to a near-fatality.

**DESIGN FEATURES WHICH MIGHT PROMOTE ACCIDENTS**

1. On many anaesthetic machines the cylinder contents gauges are not conspicuous, and items of equipment placed on the table top may obscure them.

2. There is frequently a lack of clear indication of controls which switch the supply of gases to ventilators or circle absorbers. Sometimes both the movement of a tap and the alteration of connections is required to change from one circuit to another. One may be forgotten.

3. Some Rotameters are insufficiently protected, and may be fractured.

4. The corks on some ether vaporizers have a central core of metal, connecting the metal top
to the retaining chain. If the chain is broken or
missing the cork will act as a sparking-plug if a
person charged with static electricity touches it;
an explosion might occur.

SOME DESIGN FEATURES PREVENTING
ACCIDENTS

(1) All rubber parts including tubing are made of
conducting rubber, thus preventing explosions
due to static electricity. Conducting ("antistatic")
rubber carries a yellow mark; sterilizing may
affect its antistatic properties. The castors on
anaesthetic machines should have conducting rub-
ber tyres which leach away static electricity.
Where these are not fitted, two earthing chains
hang from the frame of the machine and at least
three links of each chain should be in contact
with the floor. (If the floor is not constructed of a
conducting material the machine should be con-
nected via a suitable resistance to an earthed
point.)

(2) On some new machines giving a regulated
pressure of 60 Lb./sq.in. (42 kg/cm²), i.e. that
of the pipeline, a pressure relief valve operating at
5 Lb./sq.in. (0.35 kg/cm²) is fitted to protect the
vaporizers, and another opening at 70 mm Hg
may be fitted to protect the patient. These are in
addition to flow restrictors.

(3) Soda-lime canisters are now constructed of
transparent plastic material so that the soda-lime
can be readily inspected at any time.

(4) Some anaesthetic machines are so con-
structed that all parts are immediately visible and
accessible. In the case of any mechanical failure
quick diagnosis and repairs may be made. Rubber
low-pressure tubing between the reducing valves
and the Rotameters is now mainly replaced by
metal, but when rubber is used it may be kinked,
especially where out of sight.

(5) In many machines it is impossible to use
the circle absorber if the Trilene vaporizer is in
circuit, thus preventing its interaction with soda-
lime.

(6) The position of the bypass control for oxy-
gen should be standardized. It should be so
designed that if it becomes loose, the action of
gravity should turn it off rather than on. Nitrous oxide bypasses should not be fitted.

(7) Rotameter blocks should be constructed so
that in the case of fracture of, for example, the
cyclopropane flowmeter there will be no reduction
of oxygen percentage in the mixed gas flow.
Finally it cannot be over-stressed that the pre-
vention of accidents associated with anaesthetic
equipment depends upon the familiarity of the
anaesthetist with the machines he uses, and the
care with which he examines and tests them and
the cylinders before he embarks upon a anaes-
thetic. The thoroughness of the aeroplane pilot's
"cockpit drill" should be taken as an example.
Warning devices and the like should be regarded
merely as aids to the anaesthetist, and should in
no way replace his constant vigilance. It should,
too, be appreciated that nearly every item of
equipment used in anaesthesia has, through
mechanical fault or misuse, resulted in some form
of accident. Many of these accidents are com-
pletely unforeseeable.

APPENDIX

(Extract from paragraph 59/65 of
Hospital Equipment Information No. 15,
December 1965)

WARNING DEVICES AND CONTENTS GAUGES
FOR ANAESTHETIC MACHINES

As the result of the death of a child under anaesthesia
in April 1964, the Ministry appointed a committee of
consultant anaesthetists and its own advisers to discuss
the value of warning devices to indicate failure of gas
supplies to anaesthetic machines.
The committee made the following recommenda-
tions:

(a) Cylinder oxygen supplies used in anaesthesia.

No warning device can be a hundred per cent effec-
tive at all times and the use of such a device should
not excuse the anaesthetist from the responsibility of
maintaining constant vigilance.
The use of a suitable warning device should be re-
garded as a valuable additional precaution which was
desirable but not essential.
Such a warning device could be regarded as suitable
only:

(i) if it was operated by and dependent solely on
the pressure of oxygen in the supply line; and
(ii) if it had been rigorously tested before bring-
ing into use.
The warning device should not be dependent on the
mains supply, on batteries or on the pressure of
nitrous oxide, and once a satisfactory model has been
devised, it should be fitted by the manufacturers in
the interest of uniformity.
The warning device should be on the "reduced"
side of the oxygen supply line and should be additional
to the existing contents gauge which would remain
proximal to the reducing valve.
The Bosun oxygen warning device manufactured by the British Oxygen Company.

The Wantage oxygen failure alarm manufactured by Longworth Scientific Instrument Co. Ltd.

A prototype of the Adler and Burn warning device.

The "fail safe" oxygen warning device manufactured by Vickers Medical Division.
A cut-out device which would stop gas flow in the event of oxygen failure would not increase the safety factor and would be undesirable.

The cylinder contents gauge was a valuable aid which already existed, but which required improvement. Gauges should be as rugged as possible to resist damage. They should be large enough for easy reading, positioned so as to be easily visible to the sitting anaesthetist and also visible in darkened operating theatres and X-ray rooms. Gauges must be accurate and regular maintenance was necessary.

(These recommendations were agreed as not relevant to the use of oxygen in Intensive Care and Special Baby Care Units—where special other considerations apply.)

(b) Piped oxygen supplies used in anaesthesia.

Maintenance was an engineering problem outside the immediate control of the anaesthetist. Built-in precautions were, on the whole, satisfactory, and no additional warning device was required.

(c) Anaesthetic agents.

The main anaesthetic concerned was nitrous oxide. No warning devices in the event of failure were considered necessary for this or other gaseous anaesthetic agent.

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I am most grateful to the British Oxygen Company for the use of their library service, a great deal of information, the photograph of their new warning device, and for the blocks for figures 3 and 4.

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REFERENCES


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**CORRESPONDENCE**

**TRILENE INTERLOCK UNIT**

Sir,—The Trilene Interlock Unit (Model C) has the obvious and notable advantage of making it impossible to administer trichloroethylene to a patient via the closed circuit. The formation of dichloroethylene from trichloroethylene and hot soda-lime is a well-known hazard, in spite of the purity of modern soda-lime.

The Unit does, however, have the dangerous disadvantage that it is possible to attempt to supply anaesthetic gases through the Magill “top” circuit, when in fact the tap is in the “closed circuit” position. This hazard produces very blue patients, and has caused considerable concern to myself on one occasion and also to two of my colleagues on others.

This danger can be removed if a small guard, as depicted, is fitted to the tap, which prevents the fitting of the “top circuit” unless the tap is fully open, while the advantage of the Trilene interlock is retained.

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Open circuit: showing the guard free of the top circuit opening, and the Trilene lever unlocked.

Closed circuit: showing the guard blocking the top circuit opening, and the Trilene lever locked.

The guard can be any shape as long as it begins to impinge on the top circuit opening as soon as the tap is moved. It can easily be fixed to the screw on the top of the tap.