DECONTAMINATION OF ANAESTHETIC EQUIPMENT AND VENTILATORS

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For some years there has been concern over the role of anaesthetic and ventilatory equipment in the transmission of infection. It is known that those pieces of anaesthetic apparatus which come in direct contact with the skin and mucous membranes of the patient (face mask, airway, endotracheal tube, catheter mounts, suction catheters) are all liable to become contaminated with micro-organisms (Stark, Green and Pask, 1962).

Jenkins and Edgar (1964) found all the corrugated tubing in one hospital to be contaminated with Pseudomonas pyocyanea, and showed experimentally that a small proportion of these organisms could be caught up in the inspiratory gas. They showed further that coughing into anaesthetic apparatus caused heavy contamination of masks and Y-pieces, and that soda-lime in a Waters' canister was ineffective as a bacterial filter. However, as a result of experimental work, Stark, Green and Pask (1962) concluded that it was unlikely that infection would be transmitted from patient to patient via anaesthetic machines, but did state that if a patient was known to be infected with virulent organisms, then readily sterilizable apparatus should be used.

Virtually every organism has been isolated from anaesthetic equipment, and transmission of infection from such apparatus to patient has been confirmed in a number of instances (Joseph, 1952; Wyant and Nanson, 1957; Tinne et al., 1967; Old et al., 1972). Cross-infection from self-inflating breathing bags (Cartwright and Hargrave, 1969), humidifiers (Grieble et al., 1970), and ventilators (Phillips and Spencer, 1965) is now well documented. Furthermore, Babington, Baker and Johnston (1971) have even demonstrated the upstream spread of bacteria along the expiratory tubing of a simulated patient-ventilator circuit. Apart from the obvious risk of direct contamination of the patient from a ventilator circuit, the expired gas may carry micro-organisms into the room air.

There is no doubt, therefore, that cross-infection can occur via anaesthetic equipment (Roberts, 1973a) and ventilators, and it is the responsibility of the anaesthetist to ensure that such equipment is decontaminated before use.

METHODS OF DECONTAMINATION

In the context of this paper, decontamination is defined as any process which destroys micro-organisms present on anaesthetic equipment, and may be divided broadly into two parts:

1. Sterilization, which is the destruction of all forms of micro-organisms.
2. Disinfection, which is the destruction of organisms in the vegetative state, and does not usually include spores.

Although sterilization of all anaesthetic equipment is the ideal, this is not always practicable and possibly not always necessary. The object of decontamination of such apparatus is to remove Gram-positive, Gram-negative and acid-fast organisms. The role played by viruses and spores in the transmission of infection in the anaesthetic environment has yet to be fully established.

Ziegler and Jacoby (1956) have stressed the importance of cleaning anaesthetic equipment before definitive decontamination. The objectives are:

1. To reduce the number of organisms to be destroyed.
2. To remove pyrogens, tissue fragments and organic deposits which may be toxic to the patient and interfere with the decontamination process.
3. To prevent the cumulative deterioration of equipment.
4. To meet anaesthetic and hygienic standards.

The methods of cleaning commonly used are:

manual, that is soaking in cold detergent and then cleaning under running water;
mechanical, for example washing machines; and ultrasonic vibrations, a technique used more commonly by central sterile supply departments.

Sterilization

For the sake of simplicity, methods of sterilization of anaesthetic equipment may be classified as thermal, gaseous or physical.
(1) **Thermal methods**

In destroying micro-organisms, there is an inverse relationship between temperature and time, whether the heat employed is in the dry or the moist form. In general, the higher the temperature the shorter is the time required to achieve sterilization.

(a) **Dry heat.** This kills by causing oxidative destruction of bacterial protoplasm, a temperature of 150–180 °C being required to destroy spores. It can be achieved by flaming small items or by using hot-air ovens, but is generally unsuitable for anaesthetic equipment.

(b) **Moist heat.** This kills by coagulation of bacterial protoplasm, the temperature of coagulation being dependent on the amount of water vapour present. The low content of free water in bacterial spores has been suggested as one explanation for their high degree of heat resistance (Ross and Billing, 1957). In practice, moist heat can be applied in the following ways:

(i) **Autoclaving,** that is, steam under pressure. Air in a pressurized chamber is completely displaced by steam brought to a temperature usually of 121 °C and a pressure of 15 lbf/in² (103.5 kPa) for 20 min (the temperature may range from 110 to 132 °C). The pressure in the sterilization chamber should be increased 0.5 lbf/in² (3.45 kPa) for every 1000 ft above sea level (Schneierson, 1972).

This exposure will suffice for all metal and rubber items and heat-resistant plastics, although frequent autoclaving will affect the durability of the article (Stark and Pask, 1962; Bosomworth and Hamelberg, 1965). Particular attention should be paid to the cuffs on tracheal tubes. Latex cuffs are prone to damage by autoclaving, and can lead to insidious forms of respiratory obstruction. Inadequate sterilization may occur if the item is too loosely packaged or the chamber is improperly packed so that air is trapped and not completely displaced.

(ii) **Low temperature steam.** There would be few problems in sterilization of medical equipment in hospitals if all materials were able to withstand a temperature of 121 °C without damage. However, plastics in particular are usually heat sensitive. Sterilization by low-temperature steam is achieved by using a high pre-vacuum autoclave to maintain a sub-atmospheric pressure, so that the temperature of the steam does not increase above 80 °C. This process is not normally hot enough to sterilize, but with the addition of formaldehyde from a generator, a load may be sterilized in 2 hr.

(2) **Gaseous methods**

Ethylene oxide is a highly effective sterilizing gas, but is toxic to human tissues, and is explosive. It is used, therefore, in an atmosphere of 88% freon or 90% carbon dioxide to obviate the explosion risk (Ernst, 1972). If temperature and humidity are controlled, as in a large automatic chamber, the sterilization process takes about 4 hr, but will take 18 hr at ambient temperature and humidity. Ethylene oxide has excellent powers of penetration so that the item can be packaged in polythene (but not polyvinylchloride, p.v.c.), paper or cardboard before sterilizing. However, dried organisms on plastic surfaces occasionally survive gassing.

Because of its toxic nature, it is essential that all ethylene oxide is removed from an item before use. Rubber and plastic (especially p.v.c.) absorb large quantities of ethylene oxide, and inadequate aeration can lead to burns (Marx et al., 1969), tracheal stenosis (Lipton et al., 1971) and vocal cord paralysis (Holley et al., 1967). Sterilization with ethylene oxide requires large stocks of equipment because of the need for aeration and the slow deterioration of some delicate rubber items. The subject of aeration has been reviewed recently by Roberts and Rendell-Baker (1972).

Ethylene oxide is highly effective for use with items which are too bulky or cannot withstand autoclaving. P.v.c. items previously sterilized by gamma irradiation should not be resterilized with ethylene oxide as the irradiation loosens chlorine atoms in the p.v.c., which then combine with the ethylene oxide to form ethylene chlorohydrin which is highly toxic and difficult to elute. Bubble formation blocking the lumen of a latex armoured endotracheal tube has been reported after ethylene oxide sterilization (Bosomworth and Hamelberg, 1965).

(3) **Physical methods**

Gamma irradiation is a highly effective method of sterilization. It is used extensively to sterilize disposable syringes, needles, cannulae, endotracheal tubes and such things as extradural and spinal packs (Artandi, 1972; Rainey, 1974).
Disinfection

The methods of disinfecting anaesthetic equipment can be grouped into thermal and chemical, which can be further subdivided into liquid or gaseous.

(1) Thermal methods

It is not always appreciated that heat is a simple, cheap and reliable disinfectant. The process known as pasteurization employs heat at a minimum temperature of 65 °C continued for 10 min in the presence of moisture. This can be achieved conveniently in a water bath, and these conditions will destroy most organisms in the vegetative state. This method of disinfection has been recommended for all anaesthetic face masks, tubing, rebreathing bags, etc. (Jenkins and Edgar, 1964; Bennett, Cope and Thompson, 1968; Craig et al., 1975). It is essential, however, that the equipment be completely immersed in the water.

(2) Chemical methods

Any chemical disinfectant used on anaesthetic equipment must be effective, simple to use, and not leave any toxic residues. It should be bactericidal rather than bacteriostatic. In spite of this statement, no disinfectant can be depended upon to kill all bacteria present. A kill of 99.99% means that 100 in every 1 000 000 bacteria survive, and thus in the practical situation where organisms are counted in millions, conditions are far from germ-free.

In general, Gram-positive organisms are more readily killed by chemical disinfectants than are Gram-negative. Tubercle and other acid-fast bacilli are still more resistant, and spores even more so.

Many variables can affect disinfectant behaviour (Maurer, 1974). Organisms must be easily accessible to the agent and not dried on a surface or embedded in semi-solid material. All disinfectants are more active at higher temperatures, while some are pH-dependent. Greater volumes are more effective than smaller volumes, at the same concentration. The longer the immersion, the more effective is a disinfectant for up to 24 hr; thereafter, the solution is said to deteriorate. All chemical disinfectants are inactivated by certain materials, for example hard water, soaps, detergents and organic and man-made materials.

With these points in mind, several disinfectants have been used in anaesthetic practice.

(a) Liquid

Glutaraldehyde. The use of aqueous buffered glutaraldehyde (Cidex) as a disinfectant for anaesthetic equipment has been described by Haselhuhn, Brasson and Borick (1967), and Meeks, Pemberton and Hench (1967). A 2% solution is said to kill all bacteria and viruses within 10 min (10 hr being required for spores). The disadvantages of rinsing, residual wetness and air (George, 1975), and the need for packaging after the process to maintain cleanliness, remain. The manufacturers state that glutaraldehyde will retain its effectiveness for up to 14 days after initial use, but this statement has not been confirmed by Kelsey, Mackinnon and Maurer (1974). Furthermore, Varpela, Otterström and Hackman (1971) have shown that rubber and plastics absorb varying but detectable amounts of glutaraldehyde during immersion. As yet, the amount absorbed does not appear to constitute a hazard to patients, but this aspect requires further study.

Chlorhexidine (Hibitane). This is a diguanide disinfectant. It should be used as an alcoholic solution, as otherwise the solution itself might support such Gram-negative organisms as *Pseudomonas aeruginosa*. It is also seriously inactivated by many materials, including some plastics and organic matter.

Hypochlorites. These are useful, rapid and inexpensive disinfectants, but suffer from the disadvantage that they are seriously inactivated by organic materials and that they corrode metals. Some brands, for example Domestos, effectively incorporate detergents in order to clean and wet the item to be disinfected. Hypochlorites are the agents of choice where the presence of viruses is suspected. They are recommended for the disinfection of equipment soiled with blood, particularly where there is a risk of viral hepatitis. A concentration of 10 000 parts per million (p.p.m.) of available chlorine is recommended owing to the inactivation of hypochlorite by blood, whereas, normally, 1000 p.p.m. is adequate in the presence of organic material other than blood. In the absence of organic matter the effective concentration is 100–200 p.p.m.

Benzalkonium chloride and picloxydine (Resiguard) has been used for disinfecting ventilators (Meadows et al., 1968; Nancekievill and Gaya, 1969). However, it is seriously inactivated by hard water, organic matter and a wide range of other materials.

(b) Gaseous

Formaldehyde. The bactericidal properties of formaldehyde depend on the presence of a relative humidity of greater than 75%. The vapour has little penetrating power and tends to polymerize on
surfaces. As a disinfectant it has been used for decontamination of ventilators. It can be used for any machine in which a closed circuit can be made, and it can also be used for gas-driven ventilators if the formaldehyde can be drawn in through a venturi air-mix and due allowance made for the dilution. The formaldehyde method of decontamination of ventilators is documented by Sykes (1972), who states that the process takes 2 hr with warm, moist vapour. Bacterial spores are said to be sensitive to this method at temperatures above 40 °C. After circulation, the formaldehyde is neutralized with ammonia and the ventilator cycled on a “non-rebreathing” circuit in a well-ventilated room for at least 24 hr, in order to remove all the remaining formaldehyde and ammonia from the circuit. However, this method is time-consuming and results in a lot of wear and tear and time out of service. Cartwright and Hargrave (1970) have shown that pseudomonas can survive in the scales of humidifiers during this process. The efficiency of a modified technique has been described by Benn, Dutton and Tully (1972).

**GENERAL CONSIDERATIONS**

Apart from apparatus making up the anaesthetic circuit, attempts should be made to decontaminate such items as laryngoscope blades, Magill forceps, airways, catheter mounts, etc. Roberts (1973b) has shown that washing laryngoscope blades with water or wiping with iodophor or isopropyl alcohol will not guarantee their sterility. They can be autoclaved, however, without damage to the bulb or wiring. After previous washing, pasteurization is a possible method of disinfecting this type of item.

Anaesthetic machines should be washed down daily with a disinfectant such as alcoholic chlorhexidine or 70% isopropyl alcohol. This also applies to the outside of other large anaesthetic equipment such as drug trolleys and ventilators, which should be treated in the same way as any other piece of operating room furniture.

**Decontamination of ventilators**

Patients in Intensive Care Units are usually seriously ill and have a reduced resistance to infection. It is in such circumstances that decontamination of ventilatory equipment is mandatory. Sykes (1972) has suggested that the problem of decontaminating ventilators can be approached in three ways:

(1) Decontamination of the complete respiratory circuit before use, and filtering of all the gas admitted to the circuit (Bishop, Roper and Williams, 1963). Where possible, the entire respiratory circuit should be autoclaved (for example, as in the Cape-Bristol and Engstrom 300 series); failing that, formaldehyde vapour, ethylene oxide or Resiguard is an acceptable method of decontamination.

(2) Separation of the ventilator from the patient by bacterial filters, with sterilization of only the tubing and humidifier on the patient side of the filters (Helliwell et al., 1967; Bryan-Brown, 1972; Leading article, 1973). Expiratory filters with a low resistance to airflow have been designed (Holdcroft, Lumley and Gaya, 1973; Mitchell and Gamble, 1973), and heated filters have been used clinically for over a year without loss of this characteristic or blockage by moisture or impairment of bacterial filtration efficiency (Holdcroft et al., 1974). With this method, the filters effectively bacteriologically isolate the patient from the ventilator and the environment, and thus the costly and time-consuming practice of decontaminating ventilators can be abandoned.

(3) Filtration of all gas entering the circuit, and the use of presterilized disposable circuits. Such equipment is now becoming available, but it will be some time before it replaces that at present in use.

**Maintenance of cleanliness during use**

At Hammersmith Hospital we have found that, with the use of appropriate bacterial filters, ventilator tubing can be changed daily without contamination occurring, although other workers recommend more frequent changing to reduce bacterial challenge from multiplying pathogens. Humidifiers should be capable of being autoclaved. Bacterial growth can be prevented in hot-water humidifiers by keeping the temperature at 50 °C or above. The use of 0.2% aqueous chlorhexidine in the humidifier will prevent bacterial growth during use (Phillips, 1967), but since chlorhexidine is virtually non-volatile, all losses should be made up with sterile water.

Nebulizers are more likely to be a source of infection than humidifiers. If the reservoir of fluid becomes contaminated, then nebulizers produce quantitatively more highly contaminated aerosols more frequently than humidifiers, presumably because viable bacteria become suspended in water droplets (Moffet, Allan and Williams, 1967; Schulze et al., 1967). Small-volume nebulizers used for specific medications rarely generate bacterial aerosols (Pierce et al., 1970), but large-volume nebulizers constitute a greater hazard because of the size of the reservoir and hence the larger volume to be contaminated. Such
equipment often becomes contaminated within 24 hr (Reinartz et al., 1965), as do ultrasonic nebulizers. The only answer to this problem is to provide a fresh nebulizer, water traps and tubing, daily.

Disposable equipment
A satisfactory alternative to the sterilization of anaesthetic equipment is the use of presterilized, disposable items. This is particularly useful for patients known to be infected with virulent organisms. Roberts (1972) has defined a disposable medical item as one which can be more economically replaced than sterilized. In evaluating the comparative cost of disposable and re-usable items, many factors are often forgotten. To the costs of storage, delivery and collection of re-usable items must be added those of cleaning and sterilizing, which in turn must include the expense of labour, depreciation of equipment such as washers and sterilizers, and sterilants, indicators and packaging.

Disposable items improve patient safety by protecting against inadequate sterilization and the hazards of residual toxic substances following the sterilization process. The problem of uptake of volatile anaesthetic agents into tubing is eliminated, so that subsequent patients are not exposed unintentionally to the agents which elute out of rubber anaesthetic circuits (Samulska, Ramaiah and Noble, 1972; Murray and Fleming, 1973). The environmental problems involved in the disposal of these items are largely being overcome as much work is now in progress on the recycling of plastics.

SUMMARY AND CONCLUSION
All anaesthetists would ensure the use of sterilized equipment when performing local anaesthetic procedures such as an extradural or spinal block, as the causal relationship between infection and serious sequelae is obvious. This relationship is not so obvious when considering transmission of infection from general anaesthetic equipment and ventilators, but from all the available evidence this sort of equipment must be regarded as a potential source of infection. It is interesting to note that Dryden (1973), on repeating a questionnaire study of the sterility of anaesthetic apparatus, found that there was a marked increase in the percentage of departments making an effort to clean or sterilize, or both, the easily accessible parts of the anaesthetic system.

In general terms, equipment should be autoclaved where possible, ethylene oxide sterilization being a costly alternative. Chemical disinfection should be used when other methods are impracticable or disposable items unavailable. As there is no room for complacency in the management of this problem, it is suggested that the concept of “balanced sterility” proposed by Roberts (1972) should be observed, in which each item in anaesthetic use should be considered separately and the most appropriate decontamination technique used. These policies should be formulated by consultation with a bacteriologist and they should be strictly adhered to and closely monitored.

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REFERENCES


