The accumulation of a number of acutely ill patients within a relatively small area, such as we see in the Intensive Care Unit (ICU), increases the potential for the development of infections, both endogenous and acquired. Infection has been a problem in ICUs for as long as these units have existed, especially in those undisciplined units where policies for antibiotic usage and infection control are conspicuous by their absence.

The availability and use of complex and sophisticated machinery for maintaining life in moribund patients increase the proportion of patients in ICU who are unusually susceptible to infection, and who become potent sources for its spread. The large-scale and often indiscriminate use of broad-spectrum antibiotics is an infallible environmental influence for selecting a largely antibiotic-resistant endemic bacterial flora in the ICU.

Many ICUs also suffer from inadequate numbers of trained nursing and medical staff, a rapid turnover of untrained (and "agency") staff, all working in overcrowded conditions with a surprising lack of support from the hospital and nursing administrators. This can lead only to poor morale and the consequent maintenance of a level of infection which would be intolerable elsewhere in hospital.

EPIDEMIOLOGY
An understanding of the mode of spread of microbes is essential for the development and maintenance of policies for the prevention and control of infection, and the prevention of infection is surely preferable even to its successful treatment.

Any infection may be endogenous or exogenous in origin. The patient's own endogenous flora may change profoundly following admission to the hospital environment, and he may be colonized by endemic hospital strains of pathogen which may subsequently cause infection. Thus, many apparently endogenous infections are really exogenous in origin; the alimentary tract, the nose or the skin being the final common pathway for the infection.

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Bacteria spread in the following ways:
1. By airborne dissemination.
2. By direct personal contact.
3. Via fomites: (a) ingested food, drink and medicaments;
   (b) contaminated creams, lotions and solutions;
   (c) instruments and equipment.

The airborne route of dissemination of bacteria is now clearly documented, classically in the spread of Staphylococcus aureus, Streptococcus pyogenes and Mycobacterium tuberculosis. The last of these is dispersed in small droplet nuclei of sputum, each containing one tubercle bacillus (Riley et al., 1962), whilst the others become airborne on particles such as desquamated skin scales, with a diameter of about 13 μm (Noble, Lidwell and Kingston, 1963), and may remain airborne for long periods. They may colonize the upper respiratory tract directly or settle on bedding or horizontal surfaces, to be acquired by contact.

Transmission by direct contact has been more difficult to document than by the other routes, probably because the antibacterial activity of healthy skin shortens the survival time of non-resident, or transient, organisms. However, the hands of nurses and other personnel have been shown to become contaminated with Pseudomonas aeruginosa and to be responsible for its transmission (Lowbury et al., 1970; Kominos, Copeland and Grosiak, 1972). We have also demonstrated that nurses' uniforms rapidly become contaminated with S. aureus, leading to its spread from patient to patient (Speers et al., 1969).

Fomites have been implicated in many common-source outbreaks of hospital infection, especially with P. aeruginosa and Klebsiella aerogenes. Foods and drinks, previously contaminated in hospital kitchens, and contaminated medicaments, are known to produce colonization of patients with P. aeruginosa, and sometimes cause infection (Shooter et al., 1969). Contaminated lignocaine jelly (Phillips, 1966), steroid cream (Noble and Savin, 1966), eye irrigation fluids (Ayliffe et al., 1966), and intravenous fluids (Phillips,
Pseudomonas colonization, infection and even death. Shaving equipment used before operation was the source of a severe outbreak of pseudomonas meningitis (Ayliffe et al., 1965), and other equipment such as ventilators, neonatal incubators, nebulizers and humidifiers have been implicated in many outbreaks of infection with *P. aeruginosa*.

The importance, however, of inanimate environmental sources of infection is over-emphasized. Strains of *P. aeruginosa* (and other Gram-negative bacilli) are regularly found with consummate ease in environmental sites such as ventilators or sinks, but only rarely are they found in the environmental site before they are found in the patient. Organisms thus pass easily from patient to environment (where they appear to lose some of their infectivity), but, fortunately, only rarely are they transmitted in the opposite direction.

Our most recent observations (in collaboration with Mr T. Pitt and Dr M. T. Parker, Cross-Infection Reference Laboratory, Central Public Health Laboratories, London N.W.9) lead me to suspect that a not insignificant proportion of *P. aeruginosa* infections are in fact endogenous in origin. Although we can detect the organism in only about 5% of the population outside hospital, the variety of strains isolated inside hospital suggests that the pressure of antibiotic usage and alterations to normal physiology such as tracheostomy, lead to the selection and proliferation of small, usually undetectable, numbers of endogenous pseudomonas, to apparent “colonization” of the patient, and perhaps to subsequent infection.

The spectrum of bacteria causing infections in any hospital varies from time to time, from country to country, and even from ward to ward within the same hospital. The incidence of *S. aureus* infection continues to decline, and its resistance to antibiotics other than penicillin (and ampicillin) is also declining. The major pathogens now in the ICU are *P. aeruginosa* and *K. aerogenes*. The predominant organism is determined by local conditions, especially antibiotic use and prophylaxis, which may account for 50% or more of the infections caused by Gram-negative bacilli. *Serratia marcescens* and *Enterobacter* are still rarely encountered in this country, and fungal and exotic infections are also relatively uncommon.

**CONTROL OF INFECTION**

**Architecture and ventilation**

No one design is adequate for all requirements. Every ICU is a compromise making the best use of available space to suit local requirements. There are, however, certain general principles which should be adhered to.

An open ward design should be avoided and the unit subdivided into two- or three-bedded cubicles together with some single-bedded cubicles for containment (infectious) isolation and protective isolation. Each bed must have adequate space for the large volume of bulky equipment required for ICU patients, as well as space for easy and rapid access to the bed in an emergency. The nursing station should be positioned centrally within the unit and must be easily accessible to all beds. Separate clean and dirty utility rooms are required, as is a generous space for a CSSD (sterile supply) store, an equipment store and a staff rest/sitting/seminar room. Handwashing facilities and an area for changing outer clothing are required at the entrance to the unit, and wash basins, perhaps with heated sink-traps, must be provided within easy reach of each bed. A waiting room for visitors is desirable.

The ventilation system is required to keep the ICU at a positive pressure with respect to the rest of the hospital and it should incorporate temperature (heating and cooling) and humidity controls. Isolation cubicles, unless provided with a vestibule, should be single-purpose ones. Containment isolation should be exhaust-ventilated (negative pressure), and protective isolation plenum-ventilated (positive pressure).

The use of dual-purpose isolation cubicles with reversible ventilation is to be discouraged because of the danger of choosing the wrong ventilation option for a particular patient, and because changes in the ventilation of one part of the unit can lead to unwanted changes in airflow in other parts. The ideal isolation room (for containment or protection) is plenum-ventilated and separated from a plenum-ventilated corridor by an exhaust-ventilated vestibule which acts as an air-lock.

Non-isolation areas should be maintained at a neutral or slightly positive pressure. Clean areas, such as the CSSD store and clean utility room, should be plenum-ventilated, and dirty areas such as the sluice and WCs should be exhaust-ventilated.

**General policies**

Any members of staff or visitors who enter the ICU should remove their outer clothing, wash their hands and put on protective clothing such as plastic disposable aprons which are somewhat cheaper in the long run than cotton gowns. Any patients, with the exception of those in isolation, may then be visited,
but hands must be washed between patients. Aprons which are obviously contaminated (with blood, for example) should be changed immediately. Protective isolation cubicles, containing patients at special risk from infection, are entered only after the full aseptic ritual, as practised in the operating theatre, has been carried out. Containment isolation cubicles require no special precautions for entry, but if the infected patient or his bedding has been touched, the apron should be discarded and the hands thoroughly washed before leaving the cubicle. A fresh apron should then be put on.

As I have written elsewhere (Gaya, 1974), probably even more important than the foregoing is restriction of entry to the patient areas. Only personnel essential for the immediate treatment of the patients should be allowed entry, and large ward rounds consisting of the “sterile professor” and his entourage, whose “dirtiness” is in inverse proportion to seniority, should be prohibited.

Isolation policy

Patients who are immunosuppressed or who for other reasons may be unusually susceptible to infection should be nursed in protective isolation.

Patients who are obviously infected or heavily colonized with a potentially epidemic organism should be barrier-nursed in containment isolation.

Where any doubt exists about the best nursing of a patient from the microbiological point of view, the hospital infection control officer should be consulted.

Disinfection and sterilization policy

Only physical methods of sterilization, such as heat or ionizing radiation, can be relied upon to kill all micro-organisms with certainty. Few, if any, liquid disinfectants kill spores within a reasonable time or kill viruses with certainty. Their efficiency is reduced by the presence of organic material. Disinfectants should, therefore, be used only when physical methods are not possible, or where disposable items are unavailable.

In general, the choice of equipment for the ICU should be made on the basis of availability of disposables or ease of sterilization. In other words, my first choice would be for disposable equipment, followed by autoclavable equipment and, last, by that which would only be disinfected.

Having said that, it would appear wise for economic and other reasons to minimize disinfectant usage by having available only a small number of preparations at “in-use” dilution from the hospital pharmacy. Staff can thus become familiar with their correct use, and dilution errors are avoided. Three or four agents are probably sufficient for any disinfectant policy. Suitable agents would be a phenolic disinfectant (for example, Cleargel) for general disinfection, hypochlorite-plus-detergent for surface disinfection and for viruses, and a skin-cleansing antiseptic in aqueous and alcoholic solution (for example, chlorhexidine).

A choice of disinfectants and procedures for their use should be drawn up only after consultation between bacteriologists, pharmacist and nursing staff.

Special equipment

It is regrettable that bulky equipment, which is often impossible to sterilize, tends to dominate the modern ICU. Disinfection and sterilization of such equipment is dealt with elsewhere in this issue (Lurnley, 1976). Suffice it only to say that it would seem reasonable to consider ease of sterilization before buying new equipment, thus encouraging manufacturers to design machines that are easily dismantled, cleaned and autoclaved.

Tracheostomy and endotracheal tubes

The patient with a recently performed tracheostomy, or who has been recently intubated and ventilated, is particularly susceptible to hospital-acquired respiratory infection, especially with P. aeruginosa or K. aerogenes. Several mechanisms are involved, as nasopharyngeal defences are bypassed, pulmonary abnormalities predisposing to infection are often present, and inhalation therapy and tracheal suction are common methods of introducing pathogens. Furthermore, the therapeutic or prophylactic systemic use of broad-spectrum antibiotics, predisposes to infection with opportunistic organisms.

I have enumerated previously the important points in the microbiological management of patients with tracheostomy or with endotracheal tubes in situ (Gaya, 1974), and will not enlarge upon the subject here.

Bacteriological monitoring

For most patients the examination of specimens without clinical indication is a waste of time both for the patient and for the staff involved in their collection and processing. In the ICU, however, a few monitoring specimens may be helpful in the early detection of microbial colonization by potential pathogens, and thus prevent subsequent infection by the colonizing organisms. Of particular importance in this respect
are the daily examination of endotracheal aspirates from ventilated patients, and of dialysis fluid from patients on peritoneal dialysis. These examinations are a useful indicator which aids the choice of initial blind antibiotic therapy, should a severe infection suddenly develop. Environmental sampling is valueless except in epidemiological research.

**Antibiotics**

Much has been written about antibiotic therapy and prophylaxis, and it is clear from the divergent views expressed that a policy must be agreed between surgeon, physician and bacteriologist. This subject is covered elsewhere in this issue (Darrell and Uttley, 1976), and I shall restrict myself to a very few observations relating to the control of infection.

Antibiotic prophylaxis must be restricted to patients who require it, and when used, narrow-spectrum agents should be chosen in preference to broad-spectrum agents such as the cephalosporins. The indiscriminate use of broad-spectrum antibiotics can lead only to the spread of resistant microorganisms. This is well documented by Price and Sleigh (1970) in the cautionary tale of epidemic klebsiella infection, including fatal meningitis, in a neurosurgical ICU, where ampicillin was the principal prophylactic antibiotic used. Only by stopping all antibiotic therapy and prophylaxis was the epidemic halted.

Where initial blind therapy has been commenced for a severe infection, specific therapy should be substituted, on the basis of antibiotic susceptibility test results, as soon as these become available. Failure to do this leads to colonization with and super-infection by highly resistant microbes.

Only by obsessional attention to detail and strict adherence to agreed protocols for control of infection and antibiotic use, together with first-class teamwork, can the problem of infection in intensive care be minimized. In this respect the clinical microbiologist can be of immense help if he can be persuaded to venture outside his laboratory into the wider world of the hospital, and participate in the management of the patients who are our professional **raisons d'être**.

**REFERENCES**

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