Hospital-acquired infections: guidelines to laboratory methods
HOSPITAL-ACQUIRED INFECTIONS: guidelines to laboratory methods

Edited by

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WORLD HEALTH ORGANIZATION
REGIONAL OFFICE FOR EUROPE
COPENHAGEN
1978
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FOREWORD

Hospital-acquired infections are one of the main causes of morbidity and mortality in hospitalized patients at the present time, leading directly or indirectly to an enormous increase in the cost of hospital care and to the emergence of new health hazards for the community. Although some success has been achieved in controlling infections spreading in hospitals, recent advances in biomedical technology and therapeutics are producing greater numbers of highly susceptible patients, and this is aggravated by the occurrence of transferable resistance to antibiotics in pathogenic organisms.

WHO views this situation with much concern, and the Regional Office for Europe, aware that the laboratory plays a key role in the prevention and control of hospital-acquired infections and that in recent years a number of special techniques have been developed for the recognition and typing of potential pathogens, convened a meeting in Copenhagen in April 1975 to review the application of laboratory methods in this field and prepare guidelines for hospital microbiologists and infection control teams. Four working papers presented and examined at the review meeting formed the background for these guidelines. In May 1976 the Regional Office convened a Working Group in Bucharest to discuss the draft guidelines; this meeting made many valuable suggestions for amendments and additions. The Regional Office is grateful to all those who generously shared their wide experience and knowledge in this endeavour to overcome the long-standing problem of infections acquired in hospitals. Lists of participants in the two meetings are given in Annexes 1 and 2.

These guidelines are offered in the firm belief that hospital infections, if tackled systematically and energetically, can be controlled and largely prevented, thereby helping to make hospitals safer and more effective.
The prevention of hospital-acquired infection depends on the continuous and concerted efforts of all those who design, administer, and work in hospitals. Microbiologists — whose training and experience should have made them familiar with the causes of communicable disease and the sources and routes of transmission of pathogenic micro-organisms — should play a leading part in these activities. Their traditional role in hospitals has been to examine specimens from individual patients for the purpose of identifying the microbial cause of diseases and to give advice about appropriate chemotherapy in the light of their findings. To function effectively in the preventive field, however, their activities must be extended in several directions.

They must accumulate information from routine diagnostic work and from other sources about the frequency of clinical infection and the current importance of individual pathogens and their sensitivity to antimicrobial agents. They should engage in investigations into the sources and routes of spread of the infections prevalent in the hospital, whether or not these form part of clearly defined outbreaks. They should act promptly to investigate suspected outbreaks and be prepared to give advice about appropriate control measures. They should take a leading part in planning the hospital’s infection control programme, educating all grades of staff in correct hygienic procedures, and monitoring the performance of these.

The object of this publication is not to provide detailed technical schedules for the performance of individual tests but to discuss the use of the more important procedures, indicate when and by whom they should be applied, and show how the work of the laboratory should be integrated with the rest of the hospital’s infection control activities. These activities should include the following:

(1) performing tests on specimens from patients to establish a diagnosis and to assist in choosing appropriate antimicrobial treatment;

(2) compiling information from routine diagnostic work and from other sources about the frequency of clinical infection, the importance of individual pathogens, and their resistance, if any, to antimicrobial agents;

(3) initiating epidemiological investigations of hospital-acquired infections to determine their sources and routes of spread;
(4) giving advice on the control of current outbreaks in the light of this information; and

(5) taking a leading part in planning the hospital's programme for the prevention of infection and in educating all grades of hospital staff in correct hygienic procedures.
CHAPTER 1

THE NATURE OF THE PROBLEM

A hospital-acquired infection may be defined as "any clinically recognizable microbiological disease that affects the patient as a consequence of his being admitted to hospital or attending for treatment, or the hospital staff as a consequence of their work, whether or not the symptoms of the disease appear while the affected person is in the hospital."

Such infections may be caused by micro-organisms acquired from another person in the hospital (cross-infection), acquired from an inanimate object or substance that had not been recently contaminated from a human source (environmental infection), or carried by the patient before the appearance of the hospital-acquired disease (self-infection). It is reasonable to regard the self-infection of a patient, whether the causative organism was carried by the patient before admission to hospital or acquired subsequently, as hospital-acquired if the development of disease can be attributed to a procedure performed in hospital.

The microbial diseases acquired in hospital are extremely varied, but most of them fall into one of three groups: (1) septic infection ("sepsis") is usually characterized by local acute inflammation, with or without the presence of pus, and includes infections of wounds and of the respiratory and urinary tracts; the infection may become generalized ("septicaemia") and metastatic septic lesions may appear elsewhere in the body; less often, septicaemia or a metastatic lesion may appear without an initial septic lesion at the point of entry of the microbe; (2) diarrhoeal disease; and (3) "conventional" infectious fevers such as measles or influenza. The pattern of hospital-acquired infection depends on a number of factors in the structure, organization, and activities of the hospital.

THE HOSPITAL AS AN INSTITUTION

Some outbreaks of infectious disease in hospitals do not differ epidemiologically from outbreaks in other comparable institutions such as nurseries, schools, or even hotels. The hospital population usually shares a common supply of water and food, and members of this population come into close proximity to one another. Thus, outbreaks of enteric, diarrhoeal, and foodborne
diseases, a variety of respiratory-tract infections, and the infectious fevers of childhood may occur from time to time. The consequences of these diseases may be more serious for some categories of hospital patients than for healthy persons.

**SPECIFIC HOSPITAL FACTORS THAT INFLUENCE THE PATTERN OF INFECTION**

The situation in a hospital differs from that in other types of institution in a number of ways. Most infections acquired in hospital are caused by microbes that are commonly present in the general population, in whom they cause disease less often and usually in a milder form than in hospital patients. Thus, contact with the micro-organism is seldom the main circumstance determining the appearance of clinical disease. Various combinations of four main factors influence the frequency and nature of infections.

**Low resistance of patients to infection**

Many hospital patients have decreased resistance to infection because of the pre-existing disease for which they were hospitalized, the medical or surgical treatment given them in hospital, or their age.

(a) General resistance to infection may be lowered by underlying disease or drug treatment or irradiation, or may be naturally low, as in newborn infants. When this is the case micro-organisms from the body surface may invade the tissues.

(b) The natural defence mechanisms of the body surface may be bypassed by injury to skin or mucous membranes, either sustained before admission or inflicted in hospital, or microbially contaminated objects or substances may be introduced directly into the tissues or into normally sterile areas such as the urinary tract and the lower respiratory tract (e.g., indwelling catheters, tracheotomy tubes).

**Contact with infectious persons**

Hospitals both accumulate and generate infectious persons.

(a) Patients suffering from infectious diseases and carriers of pathogenic microbes are sent to hospital for treatment or isolation, and are potential sources of infection for others.

(b) Patients who have become infected in hospital form an important additional source of infection. Hospitals are so organized that patients with a uniform type of increased susceptibility to infection tend to be concentrated in the same area, e.g., newborn infants, burned patients, patients with urological diseases. Nursing procedures for these groups tend to be standardized and repetitive, and there are numerous opportunities for the spread of microbes from an infected patient to others by direct contact.
Contaminated environmental sites

Certain objects and materials often become contaminated with microbes, which may subsequently be transferred to susceptible body sites on patients.

(a) Gram-positive cocci are found in air and dust and on surfaces. The pathogenic members of this group are of human origin; they may survive for a number of days in dry situations but do not multiply. Epidemiological evidence suggests that most infections deriving from these sources are caused by organisms that contaminated them fairly recently. These sites may therefore be looked upon as temporary reservoirs, and infection from them is in reality cross-infection.

(b) Gram-positive spore-bearing anaerobes may be introduced into hospital from outside in air or on unsterilized objects, or they may be released into the hospital environment from dried faeces or wound exudate. Their spores may survive for very long periods of time in dry situations. Nevertheless, in gas gangrene after “clean” surgical operations infection comes rarely from extraneous environmental sources and much more commonly from the body flora of the patient; post-operative tetanus, on the other hand, appears to arise mainly from materials contaminated outside the hospital and inadequately sterilized before being brought into contact with the patient.

(c) Gram-negative aerobic bacilli are common in moist situations and in fluids, where they often survive for very long periods of time (months or years). Many of them have the additional ability to multiply at these sites in the presence of minimal nutrients.

Thus, micro-organisms found in the environment include (1) some derived from the body flora of the hospital population (e.g., staphylococci and streptococci) and (2) others that appear to be independent of recent contamination by man. These “independent” environmental sources of infection are probably responsible for most hospital-acquired tetanus and a considerable proportion of sepsis due to Gram-negative bacilli.

Drug resistance of endemic microbes

A large proportion of hospital patients receive antimicrobial drugs; microorganisms in the normal body flora that are sensitive to the drug given tend to be suppressed, and resistant strains are selected and become endemically established in the hospital population. In addition to restricting the range of agents available for the treatment of clinical infections, and even causing this treatment to fail, there are other consequences of this.

(a) Removal of sensitive bacterial flora may reduce the minimal dose for infection and the colonization dose of potential pathogens by the oral or cutaneous routes, and may prolong faecal excretion.

(b) If a patient becomes a carrier of a resistant pathogen he may become a source of infection for others; if he receives an antibiotic to which the organism is resistant uncontrolled growth of the organism may enhance infectivity for other patients.
(c) Multiplication of the organism at the carrier site may lead to illness, either from the effects of locally produced toxin or, if resistance to infection is low, by favouring invasion of the tissues.
CHAPTER 2

MICROBIAL CAUSES, SOURCES, AND ROUTES OF INFECTION

CAUSATIVE AGENTS

The more important of the microbes responsible for hospital infection are listed in Table 1, where they are classified broadly into the following categories:

P: “conventional” pathogens that cause disease in healthy persons in the absence of specific immunity to them.

C: “conditional” pathogens that cause disease, other than trivial local infections, only in persons with reduced resistance to infection (including newborn infants) or when implanted directly into tissue or a normally sterile body area.

O: “opportunist” pathogens that cause generalized disease, but only in patients with profoundly diminished resistance to infection.

The symbol (C) indicates that a pathogen that may cause disease in normal persons does so much more often and in more severe form in certain classes of patient; (O) has a corresponding meaning.

These distinctions are by no means clear cut, and the grading accorded to individual pathogens could be challenged. Nevertheless, this classification gives some indication of the circumstances under which particular microorganisms may be expected to cause infection in hospitals. Thus “conventional” pathogens are often responsible for “institutional” outbreaks in hospital, “conditional” pathogens are responsible for the bulk of the infections that are attributable to specific procedures performed on hospital patients, and “opportunist” pathogens cause disease almost exclusively in patients with severe underlying diseases.

SOURCES OF INFECTION

Table 2 summarizes information about the sources and environmental reservoirs of the more important pathogens responsible for septic diseases in hospitals. (For the intestinal pathogens, sources and reservoirs in hospitals are similar to those in other institutions; knowledge of these is assumed.) The entries in the table indicate merely that an organism is commonly found in a stated place, or is known to have been acquired from a particular source;
Table 1. Major microbial causes of hospital-acquired infections

<table>
<thead>
<tr>
<th>Class of micro-organism</th>
<th>Organism</th>
<th>Pathogenicity in hospital patients&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gram-positive cocci</td>
<td><em>Staphylococcus aureus</em></td>
<td>P (C)</td>
</tr>
<tr>
<td></td>
<td>Other staphylococci and micrococci</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td><em>Streptococci</em> group A</td>
<td>P</td>
</tr>
<tr>
<td></td>
<td><em>Streptococci</em> group B</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td><em>Streptococci</em> groups C &amp; G</td>
<td>P (C)</td>
</tr>
<tr>
<td></td>
<td>Enterococci</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>Other nonhaemolytic streptococci</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>Anaerobic cocci</td>
<td>C</td>
</tr>
<tr>
<td>Anaerobic bacilli</td>
<td><em>Histotoxic clostridia</em></td>
<td>C</td>
</tr>
<tr>
<td></td>
<td><em>Clostridium tetani</em></td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>Nonsporing Gram-negative bacilli</td>
<td>C</td>
</tr>
<tr>
<td>Gram-negative aerobic bacilli</td>
<td>Enterobacteria: <em>Salmonella, Shigella</em>, enteropathogenic <em>Escherichia coli</em></td>
<td>P</td>
</tr>
<tr>
<td></td>
<td>Other <em>Escherichia coli</em>, <em>Proteus</em>, <em>Klebsiella-Serratia-Enterobacter</em></td>
<td>C</td>
</tr>
<tr>
<td></td>
<td><em>Pseudomonas aeruginosa</em>, other pseudomonads</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td><em>Flavobacterium meningosepticum</em></td>
<td>C</td>
</tr>
<tr>
<td></td>
<td><em>Acinetobacter</em></td>
<td>C</td>
</tr>
<tr>
<td>Other bacteria</td>
<td><em>Corynebacterium diphtheriae</em></td>
<td>P</td>
</tr>
<tr>
<td></td>
<td><em>Listeria</em></td>
<td>C (O)</td>
</tr>
<tr>
<td></td>
<td><em>Mycobacterium tuberculosis</em></td>
<td>P</td>
</tr>
<tr>
<td></td>
<td>Anonymous mycobacteria</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td><em>Bordetella pertussis</em></td>
<td>P</td>
</tr>
<tr>
<td>Viruses</td>
<td>Hepatitis</td>
<td>P</td>
</tr>
<tr>
<td></td>
<td>Smallpox, vaccinia</td>
<td>P</td>
</tr>
<tr>
<td></td>
<td>Chickenpox</td>
<td>P</td>
</tr>
<tr>
<td></td>
<td>Influenza and other respiratory viruses</td>
<td>P</td>
</tr>
<tr>
<td></td>
<td>Herpes simplex</td>
<td>P (C) (O)</td>
</tr>
<tr>
<td></td>
<td>Cytomegalovirus</td>
<td>P (C) (O)</td>
</tr>
<tr>
<td></td>
<td>Measles</td>
<td>P</td>
</tr>
<tr>
<td></td>
<td>Rubella</td>
<td>P</td>
</tr>
<tr>
<td></td>
<td>Rotavirus</td>
<td>P</td>
</tr>
<tr>
<td>Fungi</td>
<td><em>Candida</em></td>
<td>C (O)</td>
</tr>
<tr>
<td></td>
<td><em>Nocardia</em></td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>Moulds</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td><em>Histoplasma, Coccidioides, Cryptococcus</em></td>
<td>P (O)</td>
</tr>
<tr>
<td>Other</td>
<td><em>Pneumocystis</em></td>
<td>O</td>
</tr>
<tr>
<td></td>
<td><em>Toxoplasma</em></td>
<td>P (O)</td>
</tr>
</tbody>
</table>

<sup>a</sup> P = "conventional" pathogen; causes clinical disease in healthy persons.

C = "conditional" pathogen; causes significant disease only in presence of specific predisposing factor.

O = "opportunistic" pathogen; causes generalized disease, but only in patients with profoundly diminished resistance to infection.

(C) = chance or severity of infection greatly increased in predisposed persons.

(O) = gives generalized infection rarely except in patients with profoundly diminished resistance.
they carry few implications about the relative importance of individual sources and reservoirs, which may vary widely according to the situation in the hospital. Nevertheless, some generalizations are possible. Thus, newborn infants in most hospitals tend to acquire Staphylococcus aureus less often from their mothers than from other persons, and particularly from other babies. They are, however, known often to acquire group B streptococci from their mothers; the frequency of acquisition of group B streptococci from other hospital sources is uncertain. Gas gangrene is most often the result of self-infection from the bowel, and infection from other persons is uncommon; tetanus is acquired almost exclusively from external environmental sources. The Gram-negative bacilli shown as "present in normal flora" include Escherichia coli, which is almost invariably present in large numbers, and other enterobacteria and Pseudomonas aeruginosa, which are found in a smaller proportion of persons and usually in lesser numbers. Among hospital patients, however, and particularly in those receiving certain antibiotics, carrier rates of the latter organisms may rise considerably, and some of the Gram-negative bacilli listed as "not present in normal flora" may also colonize the bowel in some hospital patients.

In general, however, we may conclude that most infections caused by enterococci and other nonhaemolytic streptococci, anaerobic cocci, histotoxic clostridia, Bacteroides, and Acinetobacter are self-infections; that S. aureus, group B streptococcal, enterobacterial, and P. aeruginosa infections may be acquired either from other persons or by self-infection, and that most group A streptococcal infections are from other persons. Infections with Clostridium tetani, Pseudomonas cepacia, Flavobacterium meningosepticum are nearly always, and infections with P. aeruginosa and members of the Klebsiella-Serratia-Enterobacter group are often, acquired from "independent" environmental sources. Patients and hospital personnel may acquire hepatitis through contact with blood positive for hepatitis B antigen from patients and blood donors.

ROUTES OF TRANSMISSION OF INFECTION

Table 3 gives broad generalizations about the routes of spread of representative pathogenic agents. These are based partly on the observed dispersion of the agents from sources and partly on what is known about the conditions under which infections occur.

In aerial spread, the infective agent is liberated from its source and reaches the recipient on an airborne particle. Such particles are expelled directly from the mouth during talking, coughing, and sneezing, and even in the absence of these actions. The length of time a particle remains suspended in the air and the distance it is likely to travel are related inversely to the size of the particle. The range of infectivity is thus influenced by the frequency with which very small particles contain the infectious agent and the ability of the agent to maintain its infectivity when dessicated in the air.

Some micro-organisms, e.g., tubercle bacilli, may cause infection by the aerial route in rooms at a considerable distance from that occupied by the
<table>
<thead>
<tr>
<th>Organism</th>
<th>Source of infection</th>
<th>Other animal</th>
<th>Environmental reservoirs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Present in normal</td>
<td></td>
<td>&quot;Dry&quot; (dust, surfaces,</td>
</tr>
<tr>
<td></td>
<td>flora</td>
<td></td>
<td>etc.); &quot;Wet&quot; survival</td>
</tr>
<tr>
<td></td>
<td>Self-infection</td>
<td></td>
<td>of micro-organism</td>
</tr>
<tr>
<td></td>
<td>Mother to baby at</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>infection</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Infection from</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>other persons</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Staphylococcus aureus</td>
<td>Yes</td>
<td>+</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Group A streptococci</td>
<td>Yes</td>
<td>+</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+</td>
<td></td>
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<td></td>
<td></td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>No</td>
<td></td>
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<tr>
<td>Group B streptococci</td>
<td>Yes</td>
<td>+</td>
<td>Good</td>
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<td></td>
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<td>+</td>
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<tr>
<td></td>
<td></td>
<td>No</td>
<td></td>
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<tr>
<td>Enterococci</td>
<td>Yes</td>
<td>+</td>
<td>Good</td>
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<td></td>
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<td>?</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>?</td>
<td></td>
</tr>
<tr>
<td>Coagulase-negative staphylococci &amp; micrococci</td>
<td>Yes</td>
<td>+</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td></td>
<td>?</td>
<td></td>
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<td></td>
<td></td>
<td>?</td>
<td></td>
</tr>
<tr>
<td>Anaerobic cocci &amp; other non-haemolytic streptococci</td>
<td>Yes</td>
<td>+</td>
<td>?Good</td>
</tr>
<tr>
<td></td>
<td></td>
<td>?</td>
<td></td>
</tr>
<tr>
<td>Group 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clostridium</td>
<td>Yes</td>
<td>+</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>–</td>
<td>Good</td>
</tr>
<tr>
<td>Listeria</td>
<td>Yes</td>
<td>?</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+</td>
<td>Good</td>
</tr>
<tr>
<td>Group 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Escherichia</td>
<td>Yes</td>
<td>+</td>
<td>Poor</td>
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<td></td>
<td></td>
<td>+</td>
<td>S</td>
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<tr>
<td></td>
<td></td>
<td>+</td>
<td>?No</td>
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<tr>
<td>Proteus</td>
<td>Yes</td>
<td>+</td>
<td>Poor</td>
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<td>S</td>
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<td></td>
<td></td>
<td>+</td>
<td>?No</td>
</tr>
<tr>
<td>Klebsiella (&quot;respiratory&quot; biotypes)</td>
<td>Yes</td>
<td>+</td>
<td>Poor</td>
</tr>
<tr>
<td></td>
<td></td>
<td>–</td>
<td>?S only</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+</td>
<td>?No</td>
</tr>
<tr>
<td>Group 3–4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Klebsiella-Serratia-Enterobacter</td>
<td>Yes</td>
<td>+</td>
<td>Poor</td>
</tr>
<tr>
<td></td>
<td></td>
<td>–</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+</td>
<td>Yes</td>
</tr>
<tr>
<td>Pseudomonas aeruginosa</td>
<td>Yes</td>
<td>+</td>
<td>Poor</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+</td>
<td>M</td>
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<tr>
<td></td>
<td></td>
<td>+</td>
<td>Yes</td>
</tr>
<tr>
<td>Organism</td>
<td>Source of infection</td>
<td>Environmental reservoirs&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>--------------------------------</td>
<td>------------------------------------------</td>
<td>-------------------------------------</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Man&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Other animal&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Hospital</td>
</tr>
<tr>
<td></td>
<td>Present in normal flora</td>
<td>Self-infection</td>
<td>Mother to baby at birth</td>
</tr>
<tr>
<td>Group 4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other fluorescent pseudomonads</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Pseudomonas cepacia</em></td>
<td>No</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><em>Flavobacterium meningosepticum</em></td>
<td>No</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Ungrouped</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Bacteroides</em></td>
<td>Yes</td>
<td>+</td>
<td>?</td>
</tr>
<tr>
<td><em>Acinetobacter</em></td>
<td>Yes</td>
<td>+</td>
<td>—</td>
</tr>
</tbody>
</table>

<sup>a</sup> +, occurs; —, does not occur; ?, occurrence doubtful.

<sup>b</sup> M, multiplication; S, survival; —, absent; ?, doubtful.
Table 3. Common routes of infection

<table>
<thead>
<tr>
<th>Route</th>
<th>Source</th>
<th>Examples of diseases</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Aerial (from persons)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(a) Small particles (c. 5 µm); long range (room to room)</td>
<td>(i) Droplet; short duration (&lt; 2 min)</td>
<td>Mouth</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(ii) Dry particulate; long duration (hours or days)</td>
</tr>
<tr>
<td>(b) Medium-sized particles (c. 15—25 µm); intermediate range (same room) — skin scales, dried exudate on fabric particles</td>
<td>Dry particulate; long duration (hours or days)</td>
<td>Nose, skin exudate, infected lesion</td>
</tr>
<tr>
<td>(c) Large particles (&gt; 100 µm); short range (&lt; 3 m)</td>
<td>Droplets; short duration (&lt; 2 min)</td>
<td>Mouth</td>
</tr>
<tr>
<td>2. Aerial (from inanimate sources)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(a) Wide range of particle size spread within breathing circuit</td>
<td></td>
<td>Respiratory apparatus</td>
</tr>
<tr>
<td>(b) Small particles (&lt; 5 µm) spread over long distances</td>
<td></td>
<td>Air conditioning plants</td>
</tr>
</tbody>
</table>
### Table 3 (contd)

<table>
<thead>
<tr>
<th>Route</th>
<th>Source</th>
<th>Examples of diseases</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>3. Contact (from persons)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(a) Direct: patient → patient; nurse → patient</td>
<td>Respiratory secretions</td>
<td>Staphylococcal and streptococcal sepsis, enterobacterial sepsis, enterobacterial diarrhoea, <em>Pseudomonas aeruginosa</em> sepsis, viral diseases (?)</td>
</tr>
<tr>
<td>(b) Indirect: patient or nurse → nurse’s hands or equipment → patient</td>
<td>Faeces &amp; urine, Skin &amp; wound exudate</td>
<td></td>
</tr>
<tr>
<td><strong>4. Contact with “independent” environmental source</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(a) Into tissues or normally sterile sites</td>
<td>Apparatus, instruments, fluids, food and medicaments</td>
<td>Enterobacterial sepsis (mainly <em>Klebsiella-Serratia-Enterobacter</em>, <em>Pseudomonas aeruginosa</em> sepsis, sepsis due to other pseudomonads (route 1(a) only), tetanus (route 1(a) only)</td>
</tr>
<tr>
<td>(b) Contamination of body surface (in very susceptible persons)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(c) Oral → carriage → self infection</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>5. Direct contact</strong></td>
<td>Blood products</td>
<td>Hepatitis</td>
</tr>
<tr>
<td>Into tissues or wounds. Mucous membranes (?)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
source patient, and complete aerial isolation of the infectious person is necessary to prevent this. On the other hand, in diseases such as streptococcal tonsillitis infectivity is progressively reduced at distances over 5 m, presumably because large particles play an important part in the transmission of infection; in these diseases, prevention of overcrowding might be expected to reduce infection rates. It should be noted, however, that distance between patients has not been observed to influence the infection rate in septic infections caused by streptococci.

Infectious particles are rarely expelled into the air from the nose. Staphylococci from the nose reach the air indirectly from the contaminated skin by the desquamation of epidermal scales. These are of such a size that they remain suspended in the air for a long enough time to reach distant parts of a large hospital ward. Particles of dried pus and exudate of a similar size may be similarly dispersed. Airborne particles that have sedimented onto surfaces may subsequently be redispersed into the air. Many pathogens remain viable in dust for long periods of time (days and weeks) but there is evidence that some of them undergo a considerable loss of infectivity. In practice, aerial transmission of staphylococcal and streptococcal infections can usually be traced to a source that is still present in the hospital or has left it very recently.

Infection with Gram-negative bacilli appears very seldom to be spread by the aerial route in hospital rooms although it may occur under conditions of high humidity when the particles do not undergo desiccation, notably within respiratory machines.

Infections that are spread by contact between persons include several (e.g., staphylococcal and streptococcal sepsis) that are also spread aerially. There is no general agreement about the relative importance of the two routes, which undoubtedly varies considerably according to the situation in the hospital and is influenced by the efficacy of the precautions being taken to prevent infection by either route. However, some recent research has shown that contact spread is of growing importance; this type of transmission is simpler and less expensive to counteract.\footnote{Hambraeus, A. Spread of Staphylococcus aureus in a burns unit. Acta Universitatis Uppsaliensis; Abstracts of Uppsala Dissertations from the Faculty of Medicine, 158 (1973).}
CHAPTER 3

ORGANIZATION FOR THE CONTROL OF INFECTIONS

The microbiologist will find it possible to take an active part in preventive work only if an infection-control organization exists in the hospital. This organization will normally have two parts: (1) a committee to formulate policy for the whole hospital on matters having implications for infection control, and (2) a team of workers, headed by an infection control officer, to take day-to-day responsibility for the implementation of this policy. The constitution of these bodies, the role of specific persons in them, and the amount of time each person should devote to infection-control work will depend on the size and nature of the hospital and on local or national organizational practice. The functions that need to be performed can, however, be specified.

(a) The committee should include members of the medical, nursing, and administrative staff who have authority to determine policy and make the necessary decisions. The infection control officer and the senior microbiologist must both be members though the posts may be combined. The field worker (see below) may be a member. If a question is under consideration that affects engineering, housekeeping, pharmacy, sterilization services, or a special nursing unit the appropriate people may join the committee. The committee should meet regularly, though not necessarily often, and should take decisions on relevant principles that are binding on all hospital departments.

(b) The team should comprise, as a minimum, a senior (preferably medical) member who acts as infection control officer, a field worker (in all but the smallest hospitals), and a microbiologist (if the infection control officer is not a microbiologist). When a laboratory technician is employed full-time on infection-control work he should be a member of the team.

In small hospitals the microbiologist may act as infection control officer; in large hospitals a specially trained member of his staff may do so. Experience shows that a microbiologist with major laboratory commitments cannot act effectively as field worker. In some countries it is usual for a medically qualified epidemiologist having relevant postgraduate training in microbiology to be appointed as full-time infection control officer in the larger hospitals. In other countries the infection control officer is usually a microbiologist or clinician who acts part-time in this capacity; in this situation the contribution made by a
full-time field worker is even more important. Field workers are usually nurses of either sex who have received special training. Whatever their formal position in the hospital, they must be permitted to develop close working links with the laboratory staff.

The functions of the infection control team include day-to-day surveillance and control of infection and monitoring of hygienic practices, advising the infection control committee on matters of policy in relation to the prevention of infection, and continuous participation in the education — both formal and in-service — of all categories of staff in the microbiologically safe performance of procedures.
CHAPTER 4

SURVEILLANCE OF INFECTIONS

The detection and characterization of microbial diseases in the hospital will be impossible unless information from various sources is collated by the infection control team.

LABORATORY RECORDS

These are an important source of information but even under the best conditions cannot be expected to reveal all infections, and it is often difficult, from the information provided with specimens to distinguish between clinical infection and carriage. Nevertheless, these records must be scrutinized daily by a senior member of the laboratory staff, who should draw the attention of the infection control team to significant results. These should also be recorded on some form of visual display that relates them to the location within the hospital of the patients suspected of being infected.

CLINICAL RECORDS

A regular system can be established whereby clinicians or senior nurses record all patients thought to be suffering from a microbial disease, whether or not this is thought to have been acquired in the hospital. For this purpose, standard definitions of the diseases to be recorded must be agreed upon beforehand and explained to the staff.

High priority should be given to the collation of clinical and laboratory data about infections, but how this is done will depend on local circumstances. Clinical information may be transmitted to the infection control team on forms, obtained by periodic visits to wards, or a combination of these may be used. If forms are employed a brief notification of all infections is sent to the team, and the field worker visits the ward to collect fuller information of either (1) all infections or (2) significantly grouped infections, according to the availability of resources. The main weakness of such methods is incomplete reporting by ward staff. Alternatively, the field worker may visit all departments regularly to collect information. If good personal relationships with ward staff have been built up this system works well, and the visits to wards
can be used also for monitoring and educational activities. When it is impracticable for the field worker to visit all departments at frequent intervals the team must establish a system of priorities between wards. Visits made only when ward staff request them are unlikely to result in adequate surveillance.

The regular collection of information from these sources should give early information of outbreaks of infection. It is also of some value for the retrospective assessment of long-term changes in the pattern of infection in individual hospital departments. These must, however, be interpreted cautiously because infection rates vary greatly in different classes of patients and in patients subjected to different procedures. Sequential comparisons are valid only if these factors are known to be constant.

Comparisons between crude sepsis rates in different departments and different hospitals are misleading. If made, they should be computed for comparable patients submitted to similar procedures, but this is usually impracticable as a continuous routine. Periodic cross-sectional surveys of all patients in a hospital or group of hospitals may yield valuable information if it is possible to collect and analyse sufficiently detailed information about their clinical background, but this must be performed on very large populations by a specially trained team.

CONTINUOUS MICROBIOLOGICAL MONITORING OF PATIENTS

The majority of patients in certain hospital departments are already very ill, and the clinical consequences of added infection are difficult to evaluate. In these cases it may be necessary to rely mainly on laboratory evidence to detect potentially dangerous situations. Some form of continuous microbiological monitoring of the patients may be required. If the laboratory is to be able to devote sufficient resources to this time-consuming activity, the number of departments in which monitoring is carried out must be kept as small as possible and the sampling programme must be selective (see p. 41, Patients under continuous microbiological monitoring).
In this chapter knowledge of the methods used in clinical microbiology is assumed but special methods used in the investigation of hospital infection, and for purposes of surveillance and monitoring, are considered in some detail.

**DIAGNOSTIC METHODS**

**Collection and transport of specimens**

Collection and transport of specimens may expose hospital staff to infection from both the patient and the specimen. Badly collected specimens constitute a hazard to laboratory workers. Persons who collect blood samples should be instructed to avoid forcible expulsion of blood through needles and in certain instances to wear gloves. Soiling of the outside of containers must be avoided. All samples for microbiological examination, and indeed all samples for transmission to the laboratory, must be enclosed in impervious containers; the laboratory request forms must not be placed in these containers. A special “danger” coding system should be instituted to identify specimens from patients known to be, or suspected of being, infected with highly pathogenic agents, especially hepatitis B virus. On their arrival in the laboratory, all specimens should be sorted in a designated laboratory area — never the office — by specially trained staff.

The laboratory usually provides the containers into which samples from patients are taken; in any case, the microbiologist must ensure that these are appropriate, sterile, and do not constitute a hazard to laboratory staff. They should be of such dimensions that material (especially faeces and sputum) can be placed in them without contaminating the outside. A national standard for specimen containers is desirable. The containers must not leak. Screw-capped containers with an effective liner are to be preferred; plastic “snap-on” lids are dangerous to open.

Every effort should be made to ensure that containers are free from antimicrobial substances. Some rubber bottle liners have inhibitory properties. Certain batches of cotton fibre, and man-made fibres that have been sterilized by irradiation or toxic gases, have a strong antibacterial action; this is also
sometimes true of wooden and plastic materials used in the construction of swabs. These effects can be partly or wholly counteracted by boiling fibres in phosphate-buffered saline, by impregnating swabs with powdered charcoal, or by dipping swabs in horse serum before autoclaving; serum-dipped swabs may inhibit viruses but swabs dipped in bovine serum albumen do not. Some transport media (see below) tend to neutralize the inhibitory action of swabs.

The necessity of avoiding delay in transporting specimens to the laboratory is relative and can be partly circumvented by the use of transport media or, in some cases, by refrigeration. Transport media of the Stuart type are, in general, effective for the preservation of most bacteria on swabs from wounds and mucous membranes and are recommended for most purposes. Very rapid transfer to the laboratory is, in any case, necessary if the maximum yield of non-sporing Gram-negative anaerobes is to be obtained; alternatively, pre-reduced media can be seeded at the bedside. Blood cultures may be collected directly into bottles of medium, or a tube containing sodium polyanethol sulphonate may be used; the latter procedure has the advantage that several tubes of appropriate culture media can be seeded in the laboratory and that moderate delay in transfer to the laboratory is not so serious a matter. If a 24-hour laboratory service is not provided the former method is to be preferred. The microbiologist should recommend a suitable technique for preliminary disinfection of the skin, and train ward staff in its use.

Cultures of urine must be semiquantitative; the significance of the results obtained is related directly to the care taken in collecting samples and the conditions under which they are transported to the laboratory. Catheterization to obtain a sample of urine for routine diagnostic purposes is now unacceptable; suprapubic puncture may be used in selected cases but some form of "clean-catch" or "mid-stream" sampling is the most common routine method.

The clinical significance of counts obtained in this way is dependent on the skill and care exercised by ward staff in collecting the specimens. The technique to be used should be specified by the microbiologist and described in a clearly worded instruction sheet; alternatively, a colleague from the laboratory could take responsibility for the initial training of all staff in its use. Whenever possible, samples should reach the laboratory within an hour or so of collection; if this is impracticable they should be refrigerated immediately after collection and sent to the laboratory in batches every few hours. If transit time is likely to exceed 1 hour some form of immediate culture such as the "dip-slide" should be used.

Isolation and identification of pathogens

The laboratory should be able to isolate and recognize all or most of the organisms listed in Table 1 or should have access to facilities for this purpose elsewhere. Precise identification is more important for some classes of organism than for others. It is essential for the main bacterial pathogens, particularly those that may be communicable such as \textit{S. aureus}, the groupable $\beta$-haemolytic streptococci, pneumococci, and enterococci, the pathogenic clostridia, \textit{Corynebacterium diphtheriae}, the enterobacteria (at least to generic level), the species of \textit{Proteus}, and the common serotypes of \textit{Salmonella} and \textit{Shigella}. The serotypes
of *Escherichia coli* that are frequently associated with infantile enteritis, *P. aeruginosa*, *P. cepacia*, and *F. meningosepticum* should be recognized also. It is much less important for the patient or for epidemiological purposes to devote efforts to subclassification within the following groups, although this may be of scientific interest: other nonhaemolytic streptococci, anaerobic cocci, Gram-negative nonsporing bacilli, *Candida*, moulds. Laboratory workers should, however, always be alert to the appearance of similar but unidentified micro-organisms in specimens from more than one patient.

Some facilities for the diagnosis of viral infections are essential although it may not be possible to provide many of these locally. The service that will be used constantly, and which should be decentralized as far as possible, is for recognition of cases and carriers of hepatitis B. Rapid electronmicroscopic detection of viruses in the faeces in infantile diarrhoea is now assuming practical importance. Occasional, but readily available, access to diagnostic services for smallpox, vaccinia, and influenza are essential, and for other virus diseases an advantage. The services of a specialized mycological laboratory for the diagnosis of systemic mycoses are highly desirable.

Much of the diagnosis of bacterial infection will be performed on general purpose nonselective media, but this will be efficient only if experienced “front-line” technical staff is available. A reliable system for anaerobic culture must be available and kept in constant use. Whether a good “conventional” anaerobic culture (preferably in an atmosphere of hydrogen with added carbon dioxide, obtained either from cylinders or from commercially available sachets such as Gaspak\(^a\) or Gaskit\(^b\)) gives optimal results for the isolation of nonsporing Gram-negative anaerobes, or whether special anaerobic cabinets give significantly better results, is still subject to controversy.

Diagnostic microbiology should be decentralized as much as possible to ensure close and continuous contact with the clinical staff, but not so far that a comprehensive service cannot be provided; the laboratory unit must be of sufficient size to warrant the provision of adequate senior staff, preferably under the direction of a medical graduate. In very large hospital laboratories subdivision of work along technical lines of demarcation may tend to obscure the laboratory’s view of the situation in individual hospital departments and, indeed, of the individual patient. This may be counteracted by an active chief microbiologist and an efficient field worker. An alternative arrangement for laboratory organization is to form teams responsible for the diagnostic needs of sections of the hospital.

The laboratory must aim to provide as rapid a diagnostic service as possible, making full use of an agreed scheme of provisional reporting (always to be followed later by a definitive report). This scheme must be fully explained to the clinicians. Microscopic examinations are often of great value in establishing a rapid presumptive diagnosis — cerebrospinal fluid in suspected meningitis or wound exudate in suspected gas gangrene, for example. They may have additional advantages in illuminating the results of culture of, for example, urine

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\(^a\) Manufactured by Becton Dickinson Co., Cockeysville, MD 21030, USA.

\(^b\) Manufactured by Oxoid Ltd, Basingstoke, RG24 0PW, England.
and sputum. For these reasons, some laboratories provide a preservative fluid
and ask that a portion of suitable specimens be placed in it immediately after
collection. Many hospitals expect clinicians to perform simple laboratory
examinations during the night; in general, the results of these are not satisfac­
tory. A laboratory “on-call” system should be provided whenever possible.

In addition to traditional methods of rapid diagnosis, such as direct microscopi,
many entirely new techniques are now under development or trial, and
some of them will undoubtedly soon become part of the normal laboratory
routine (see Table 4).$^{a}$

<table>
<thead>
<tr>
<th>Method</th>
<th>Example of application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electronmicroscopy</td>
<td>Recognition of morphologically characteristic viruses (in skin lesions or faeces, for example)</td>
</tr>
<tr>
<td>Immune electronmicroscopy</td>
<td></td>
</tr>
<tr>
<td>Immunofluorescence</td>
<td>Visualization of many different viruses, bacteria, fungi, or parasitic agents in tissues, body fluids, or secretions</td>
</tr>
<tr>
<td>Counter-immunoelectrophoresis</td>
<td>Detection of viral (e.g., HBV), bacterial (e.g., pneumococcal, meningococcal), and fungal (yeast) antigens in body fluids or secretions</td>
</tr>
<tr>
<td>Radioimmunoassay</td>
<td>Detection of antigens (e.g., HBs) in serum</td>
</tr>
<tr>
<td>Gas chromatography</td>
<td>Detection of substances characteristic of certain infections in body fluids; identification of bacteria (e.g., anaerobes)</td>
</tr>
<tr>
<td>Nephelometry, pH change, radiometry, electrical impedance, bioluminescence, microcalorimetry</td>
<td>Detection (and sometimes partial characterization) of micro-organisms in normally sterile fluids, screening for bacterial populations of more than a given density (e.g., in the urine), or antibiotic-sensitivity testing</td>
</tr>
</tbody>
</table>

**DETECTION OF CARRIERS**

Isolation of a micro-organism from the body surface or from a secretion
does not necessarily indicate that it is “resident” at the site sampled; it may be
a contaminant from an external source or from another site in the same person.
The significance of a particular finding may, therefore, depend on the site sam­
ped, the number of micro-organisms present, and whether the finding can be
repeated. Such decisions are not always easy to make.

**In epidemiological investigations**

When investigating incidents or suspected incidents of infection it may be
necessary to search for carriers of the causative organism among contact

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$^{a}$ Table 4 is not an exhaustive list because progress in this field is rapid.
patients and staff. Large numbers of specimens may have to be processed in a short time, and the detection of small numbers of the organism may be of significance. When an appropriate medium is available it may be used exclusively. The organisms most commonly sought will be (1) *S. aureus*, groupable \( \beta \)-haemolytic streptococci, *P. aeruginosa*, and various enterobacteria in investigations of sepsis; and (2) salmonellas, shigellas, enteropathogenic *E. coli* (and possibly certain viruses in future) in investigations of diarrhoea.

The sites most often sampled include the anterior nares, the throat, various skin areas, and the lower bowel. Swabs moistened with broth or physiological saline are preferred for nasal swabbing; either may be used for the skin but broth containing the detergent Triton X100 is preferable for quantitative studies on normal skin. In sampling the intestinal flora, rectal swabs have the advantage of rapidity and the certainty that the sample comes from the indicated person, but isolations may be irregular and somewhat dependent on the skill of the operator; they should not be used in the search for enteric carriers. Faecal specimens give higher isolation rates but obtaining them may delay the obtaining of the result and there are possibilities for cross-contamination and substitution during collection.

(a) *Sampling for Staphylococcus aureus.* Nose swabs should be collected from all contacts, and swabs must be taken from any wound, discharge, skin sore or rash; small areas of mild atopic eczema should be carefully sought and sampled. Even so, a few carriers will be missed; in adults, these will be mainly perineal skin carriers who have negative nose swabs. The total perineal carrier rate is around 10%, and the frequency of “independent” perineal carriage 2-4%. It is usually impracticable to collect perineal swabs from all contacts, but this should be done in key suspects. If this is impossible tests for dispersion of staphylococci into the air may be performed or the subject may be required to take a bath in a large plastic bag, after which the water is examined by membrane filtration. Hand swabs often yield small numbers of staphylococci that have been transiently acquired from external sources; for this reason the hand is seldom swabbed unless a lesion is present. However, repeated isolation of the same staphylococcal strain from the hand in the absence of nasal carriage may sometimes indicate that the subject is a perineal carrier. Throat carriage is much less common than nasal carriage except, according to some observers, in young infants. When investigating outbreaks of staphylococcal sepsis among newborn infants both nose and skin swabs should be taken from all contacts; the umbilicus is the preferred skin site.

Quantitative studies of skin flora may be needed, not only in studies of the epidemiology of *S. aureus* infection but also in more general investigations of the transfer of infection between persons. Various “contact” methods may be used such as applying an agar surface or even a moistened velvet pad to the skin. The results provide a “map” for the location of skin areas contaminated with the organism sought but do not give an accurate measure of the numbers present because bacteria are irregularly distributed on the skin as “micro-colonies”. Nevertheless, contact sampling provides a striking visual demonstration of micro-organisms on the skin and is therefore often of considerable educative value. “Streaking” the fingers across an agar surface may provide a
useful semiquantitative method for assessing the effects of skin disinfectants. A truer quantitative result can be obtained by elution of skin flora in fluid. For example, the fluid (preferably Triton X100 broth) is placed in a cylinder applied to the skin; after a standard scrub with a small brush or a glass rod, the fluid is removed and counts are made by surface inoculation, pour-plate, or membrane filtration methods. With appropriate media these methods are applicable to quantitative studies of any constituent of the skin flora. Semiquantitative studies of the flora of the anterior nares can be made by elution of bacteria from nasal swabs.

It is sometimes valuable to measure the ability of a carrier to disperse S. aureus or other skin flora into the air. Dispersers and nondispersers are not distinct classes, thus some form of quantitative estimation is essential. This can be done by placing the subject in a standard cubicle and requiring him to perform an agreed physical activity, such as stationary walking for 1 min or undressing; a measured volume of air is sampled by slit sampler or settle-plates are exposed. The site of dispersion can be revealed by repeating the tests with particular areas of the body, e.g., the bathing-trunk area, enclosed in a tight-fitting plastic garment. Semiquantitative tests for dispersion by patients in single-bedded rooms can be made by sampling the air while a usual standard bed-making operation is performed.

(b) Sampling for groupable β-haemolytic streptococci. To detect group A streptococci swabs of throat and nose and of any wound, discharge, or skin lesion must be taken. Throat carriers generally exceed nose carriers in number, but nose carriers may have negative throat swabs and are epidemiologically very important because they usually disperse the organism profusely. The presence of group A streptococci in saliva has also been taken as an evidence of infectivity, but the number of streptococci in saliva is often small and the effect of delay in transporting salivary swabs on the result of culture is considerable; direct sampling by pipette and immediate seeding of plates has been recommended.

Healing lesions of streptococcal pyoderma must always be sampled with a moistened swab; dry crusts should be raised with a needle-point before sampling. In investigations of neonatal and puerperal sepsis it is essential that, in addition to nose and throat swabs of adult contacts, swabs of the umbilicus of all contact infants be taken. Outbreaks of surgical and puerperal sepsis have been traced to peri-anal carriage of group A streptococci by a member of the hospital staff. These carriers gave negative nose and throat swabs. Peri-anal carriers of streptococci have been detected by the unexpected isolation of the causative strain from a hand swab of a supposed noncarrier and there is reason to believe that they would be detected by aerial dispersion tests, as used for S. aureus.

In investigations of group B streptococcal infection in newborn infants a vaginal swab from the mother should always be examined, but the normal carrier rate for pregnant women has been variously reported as between 10% and 25%. Anal carriage is said to exceed vaginal carriage in frequency. Throat-carrier rates have been less extensively investigated but figures in the region of 5% have been obtained. Considerable skin, umbilical, and throat carriage by
healthy newborn infants in hospital is to be expected; immediately after birth, swabs of the external ear canals are said to give the greatest number of isolations. The intra-hospital spread of group B streptococci in other classes of patients has been little investigated.

(c) **Sampling for Pseudomonas aeruginosa.** This organism may be present in the bowel contents of some 15—30% of hospital patients but the infection of contacts from this source does not appear to be common. Its presence in wounds, burns, tracheostomy, and ileostomy stomata, and in the respiratory tract is probably of greater significance and should always be sought. Bowel carriage by staff is less frequent and probably not of great significance. The presence of the organism on the hands of staff members is common but usually transient, though washing cannot always be relied upon to remove all pseudomonads from the hands. Long-term hand carriage of a single strain is detected occasionally, particularly in members of the domestic staff and others whose hands are moist for long periods of time; it is often associated with chronic infection round the nails.

(d) **Sampling for clostridia.** *Clostridium welchii* is present in the faeces of virtually all persons; the detection of faecal carriers is, therefore, of no particular epidemiological significance. In studies of the epidemiology of hospital-acquired gas gangrene, therefore, the assistance of a typing method would be required if faecal and lesion isolates are to be compared. *C. welchii* is often present in small numbers on the skin, and its distribution is of some epidemiological significance. Greater numbers can be isolated by “stripping” the skin with adhesive tape than by use of moistened swabs.

**In routine screening programmes**

(a) **Staff.** The examination of specimens from healthy members of the staff who are not suspected of being responsible for infections among the patients is seldom of immediate value as a preventive measure, but its occasional performance for educational purposes may be useful. In the past it was common practice to examine for group A streptococci throat swabs from all members of the staff on their first joining the maternity department. To be effective this would have to be repeated very frequently, possibly weekly. The practice has now ceased in most hospitals. In the 1950s widespread screening of nurses for the nasal carriage of *S. aureus* was performed. The number of carriers discovered made a policy of general exclusion impracticable, and topical antibiotic treatment, often with a short period of exclusion, was given either to all carriers or to carriers of certain categories of resistant strains. This caused much disturbance to the work of the hospital and probably did little good; when actively pursued it appeared to reduce the total carriage rate but often increased the frequency of highly resistant strains. The present opinion is that, in general, nurses are considerably less important than patients as sources of staphylococcal infection and that carriers should be sought only when the source of specific infections is under investigation.
The screening of kitchen staff for intestinal pathogens is still widely practised but it is seldom possible to do this often enough to detect and eliminate a significant proportion of excreters of salmonellae and shigellae; most episodes of excretion last for only a few weeks. Whether the initial screening of kitchen workers for typhoid carriage is worth while is difficult to say; many hospitals favour a selective policy, screening only those who have resided in a country where enteric fever is common or whose past history suggests that they may have had this disease. Bacteriological examinations of members of the hospital staff on return from visits to tropical and subtropical countries may be considered.

In all, more importance is attached to the use of the hospital's occupational health service to detect persons likely to have an infectious disease, or to be carriers, than to routine screening.

(b) Patients on admission to hospital. At various times, screening of new entrants (usually children or parturient women) for group A streptococci, diphtheria bacilli, or enteropathogens has been practised. The interval of time between admission and the receipt of the result greatly reduces the benefit to be expected from such programmes, and they are now seldom performed. If accompanied by a brief “holding” period in an isolation unit, a selective programme for the rapid screening of certain categories of ward entrant may have some advantages.

ENVIRONMENTAL SAMPLING

Objectives

Sampling of the environment may be required for one of three reasons: (1) to detect reservoirs of microbes that may be of significance in a current episode of infection, (2) to monitor infection control procedures, and (3) for educational purposes.

In the first case our objective is to detect a particular microbial strain, but its detection does not lead automatically to the conclusion that infection from this contaminated source was responsible for the outbreak. It is common experience to find a number of alternative environmental “sources”, and their respective importance can be assessed only by careful enquiry to establish that infection from one source and no other could have reached a susceptible site in all, or most, of the infected patients.

In the second case we use the detection of microbes to reveal that an essential procedure has not been performed effectively. We may detect this failure in terms of the total number of organisms isolated, of the presence of potentially pathogenic organisms, or of the survival of a test organism. In general, however, we recommend the use of bacteriological methods to monitor procedures only when no other suitable method is available.

The educational value of routine environmental sampling is a matter of opinion. Periodic bacteriological “inspections” by an outside team are no substitute for an active educational programme generated in the hospital; they
should never be made by a team connected with the manufacturer of a particular disinfectant or other commercial product. Nevertheless, a selective programme of "educational" sampling linked to formal instruction in infection control techniques is valuable, but only if planned so that bacteriological results can be related directly to specific technical lapses or outbreaks of infection.

Air

Of the many methods available the two in most common use both depend on the deposition of bacteria-carrying particles on to the surface of an agar medium (the choice of which, whether selective or not, must be given careful consideration — see p.33; Special methods for the isolation of potential pathogens in epidemiological studies: *Staphylococcus aureus*) and counting the number of colonies that develop after incubation; the presence of one colony is taken to indicate the deposition of one bacteria-carrying particle. Airborne particles may be impacted on to the plate by means of a slit-sampler or other technique and the number of colonies can then be related to the volume of air sampled. Alternatively, the particles can be allowed to fall on to the surface of a plate of medium. Since most of the airborne particles that carry staphylococci and streptococci are skin scales within a narrow range of sizes (equivalent to a sphere of diameter 15—25 µm), a direct relation can be established between the settling rate of bacteria-carrying particles on to an agar surface and the number of particles per unit volume of air. The following approximate formula, number of bacteria-carrying particles settling on 1 m² of medium per min = number of such particles per 0.3 m³, is thus an easy way of converting settle-plate counts of nearly all bacteria that cause septic infections into air counts.

Volumes of air up to 0.6 m³ per min can be passed through a slit-sampler but under most conditions lower rates of flow (0.03—0.2 m³ per min) are more appropriate for total bacterial counts in ordinary rooms. For counting the number of *S. aureus*-carrying particles in the air of patients' rooms a flow rate of 0.6 m³ per min, with a total exposure time of 1 h, is appropriate. To obtain countable numbers of *S. aureus* on a 15-cm diameter settle plate exposure periods of about 8 h in patients' rooms are necessary. The period of exposure can be reduced if several plates are exposed in the same ward area; a suspended carrier for several plates is convenient.

High total air counts generally reflect physical activity, population density, and grossly poor ventilation, all of which can be as easily detected by observation. A clear relation between total air count and risk of infection in hospital rooms has never been demonstrated, and there is little purpose in making regular measurements of this.

Ventilation rates and the direction of air flow in operating theatres are easily measured by physical means, but even when these are adequate total air counts may vary over a considerable range, and high counts are usually attributable to the presence of too many people in the theatre and to excessive movements of persons. Thus, although total air counts are not a measure of the efficiency of ventilation, they do detect unsatisfactory conditions in
the theatre. Studies in a number of operating theatres have suggested that there is a general relationship between total air count and the risk of infection; when counts were in the range 700–1800 per m$^3$ there was a significant risk of airborne infection, and when they were under 180 per m$^3$ the risk appeared to be slight. In some Scandinavian studies, however, where the numbers were much below 180 per m$^3$, the rate of hospital-acquired infection was still about 9%. Counts of the order of 2 per m$^3$ can be achieved through directed air-flow ventilation, but the effect of this on sepsis rates is uncertain.

Recommended standards in the United Kingdom are that air delivered into the theatre by the ventilation system should contain not more than 1 colony-forming unit of *C. welchii* or *S. aureus* per 30 m$^3$ and not more than 35 bacteria-carrying particles per m$^3$. Total air counts, measured over a 5-min period in the theatre during surgical operations, should not exceed 180 per m$^3$.

The detection of *S. aureus* in the air of patients' rooms and operating theatres reflects the amount of dispersion of this organism by individuals. It is a useful method of discovering the presence of potentially dangerous dispersers, but not as a routine procedure. The admission of a single heavy disperser to a multibeded hospital room may cause a 10-fold increase in the air-count of *S. aureus* and this would be easily detectable on settle-plates. In well ventilated operating theatres, however, a slit-sampler would be necessary to detect all but the heaviest dispersers. Regular monitoring of theatres to detect dispersers of *S. aureus* among the surgical team is not widely practised; when a member of the team falls under suspicion individual tests for carriage and dispersion are appropriate.

**Surfaces**

Unlike air, which is freely mixed and therefore uniformly contaminated, surfaces tend to be irregularly contaminated, and the results of bacteriological tests on them are difficult to evaluate. Routine sampling of general surfaces such as floors, walls, and articles of furniture not in direct contact with patients or staff give results that can seldom be related to defined risks of infection. If it is done quantitative or semiquantitative measurements of contamination per unit area of surface must be made, and the area must be sufficiently large to minimize the effect of irregular contamination.

Tests for the presence of specific pathogens on surfaces may serve a limited purpose. When a definite incident of infection has occurred they may draw attention to a technical lapse, e.g., in the hygiene of cleaning equipment and the control of disinfectant solutions. The chance of associating environmental contamination with a specific defect in technique is greatest when the pathogen is a Gram-negative bacillus; with Gram-positive cocci it is usually impossible to distinguish between contamination by the aerial and contact routes. Detection of clostridia on surfaces often causes confusion and embarrassment; the number of *C. welchii* spores in outside air makes it almost inevitable that surfaces should be contaminated. Even in the operating theatre the skill of the

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microbiologist in isolating this organism often defeats the efforts of the most efficient cleaning team.

**Equipment and materials**

The infection-control committee will have laid down in detail the hospital's policy for ensuring as far as possible that items of equipment and other materials that come into contact with patients are microbiologically safe, and the microbiologist will have given advice at this stage. His role in monitoring the implementation of this policy is limited, but important.

One category of items will require to have been sterilized; some of these will be disposable and have been sterilized by the manufacturer; others will be sterilized in the hospital, either by heat or a combination of heat and chemical treatment. A separate category of items will be disinfected (i.e., rendered free from vegetative organisms) by heat or by chemical means.

The following general principles are applicable to both sterilization and disinfection.

(a) Heat is preferable to chemical treatment whenever the nature of the item makes this possible.

(b) Heating should, whenever possible, be performed in a programmed machine rather than in one that is operated manually.

(c) Physical or chemical monitoring of the process, whether of heat or chemical treatment, is preferable to bacteriological testing because the results are immediately available.

The use of bacteriological monitoring will, therefore, be confined to (1) processes for which adequate physical or chemical monitoring is not practicable and (2) initial and periodic subsequent checking of processes that are being regularly monitored physically or chemically. Examining supposedly sterilized or disinfected items for surviving bacteria is an uncertain means of ensuring that they have been adequately treated; the examination of quite large samples from a batch or load will reveal only gross errors in the process. Tests for the destruction of a large population of a test bacterium are more informative. These are usually performed by impregnating a strip of paper or coating a strip of metal (or capillaries) with a known number of spores or vegetative bacteria. These strips are so placed within the load that they will be subjected to the least stringent conditions possible, and may be assembled into “test pieces” that simulate the objects being treated. In some countries the bacterial strains appropriate for use as biological indicators have been specified (see below).

Bacteriological monitoring may be used in the following circumstances.

(a) Heat sterilization (autoclaving, hot-air sterilization) is routinely controlled by temperature measurements and the use of heat-sensitive chemicals. There is general agreement that bacteriological tests should be performed on commissioning a new sterilizer, after engineering modifications, or if the nature of the load is greatly changed. In some countries additional tests with biological indicators are performed periodically on autoclaves with the object of
detecting technical errors that may not have been revealed by routine physical control. In Scandinavia and the United Kingdom paper strips impregnated with spores of *Bacillus stearothermophilus* (No. NCTC 10003, for example) are used for testing autoclaves. Centrally prepared and officially recognized preparations are available for use as biological indicators in Scandinavia; dehydrated preparations of *B. subtilis* spores are used for testing hot-air sterilization because the amount of moisture in the bacterial cell is decisive for the outcome of the sterilizing process.

(b) **Sterilization by subatmospheric steam and formol** can be monitored physically by the physical parameters revealed by the temperature and pressure curves but the curves are more difficult to interpret than those of steam autoclaves. Test pieces made to simulate the narrow-bore equipment often sterilized by this means and impregnated with endospores of, for example, *B. stearothermophilus* or *B. subtilis* should be included with each load as a routine.

(c) **Disinfection by subatmospheric steam** may be similarly monitored by the inclusion of test pieces, but these should be impregnated with a heat-resistant strain of enterococci.

(d) **Hot-water disinfection** is used for such items as infant feeds, tableware, laundry, and bedpans and also for the “make-safe” treatment of surgical instruments and anaesthetic equipment before they are cleaned. Where possible, programmed appliances, or at least a recording thermometer, should be used; without these, reliance has to be placed on the careful recording of time and temperature of exposure by a responsible operator. Initial and subsequent periodical monitoring, using test pieces impregnated with *S. faecalis*, is recommended.

(e) **Sterilization by ethylene oxide.** This method should be used only in large centres where skilled supervisory staff is available. Its dangers, and its incompatibility with gamma irradiation, should be remembered. Each load must be monitored bacteriologically. In the United Kingdom, 10 test pieces, each contaminated with at least $10^6$ spores of *B. subtilis* (No. NCTC 10073, for example) evenly distributed through the load, must be sterilized.

(f) **Chemical disinfection of heat-sensitive equipment.** A variety of chemical treatments have been advocated but none is entirely satisfactory, particularly if the equipment is complex in design and includes narrow-bore tubing. Any treatment is likely to fail unless the equipment has first been adequately cleaned. For respiratory machines and certain types of endoscope nebulized ethanol, hydrogen peroxide (with chemical detection of residual disinfectant), formol vapour, and aqueous glutaraldehyde or peracetic acid have all been recommended. Periodic bacterial monitoring is desirable in any circumstance.

(g) **In-use testing of general-purpose disinfectants.** Many commonly used general disinfectants tend to deteriorate or to be inactivated by organic matter or plastics. Contaminating Gram-negative bacilli may multiply in some fluids and be disseminated when these are applied to surfaces. Regular sampling of disinfectant solutions kept at use-dilution is strongly recommended.
(h) *Sampling of foods and toilet and pharmaceutical products.* A number of other substances that experience has shown to be contaminated from time to time may need to be sampled. These include human milk, baby foods prepared by manufacturers whose products are not centrally monitored, liquid soaps and other detergents, and certain pharmaceutical products. The actual sampling problem is a matter for local decision.

**SPECIAL METHODS FOR THE ISOLATION OF POTENTIAL PATHOGENS IN EPIDEMIOLOGICAL STUDIES**

**Staphylococcus aureus**

Many experienced workers use blood-agar plates for the isolation of *S. aureus* from carrier sites, relying on the appearance of colonies for recognition. Others use phenolphthalein-phosphate agar to detect phosphatase-producing colonies, which become pink after brief exposure to ammonia vapour. The colonies must be subcultured very quickly because the colour soon fades. For very heavily contaminated material one or other variety of Baird-Parker's egg-yolk tellurite medium, with or without the addition of polymyxin (75 µg per ml), is useful. Salt agar (7–10% w/v), with or without mannitol, is also used, but is somewhat less selective. Cooked-meat broth containing NaCl 10% (w/v) is a good enrichment medium.

*S. aureus* is difficult to recognize on blood-agar plates exposed to the air because it usually constitutes no more than 1% of the mainly coccal flora and its colonies develop rather slowly at first. Poor yields are obtained on all the selective media, especially when a slit sampler is used; the jet of air causes local dehydration of the medium with concentration of the inhibitory agents. Phenolphthalein-phosphate agar with the addition of 10% horse serum is recommended.

**Groupable β-haemolytic streptococci**

These may be isolated from swabs of the respiratory tract on blood-agar plates, preferably layered. The blood must never be human. Horse-blood agar gives good haemolysis but technicians must be familiar with the differences between colonies of streptococci and *Haemophilus parainfluenzae*; sheep-blood agar gives poorer haemolysis but *H. parainfluenzae* is inhibited. Haemolysis is improved by anaerobic incubation, and this is recommended. Crystal-violet blood agar (about 1 in 500 000) can be used for respiratory tract swabs; in swabs from streptococcal pyoderma, in which staphylococci also are often present in large numbers, its use greatly increases the isolation rate of group A streptococci. The use of 4% agar is often of value if a contaminating Gram-negative flora is expected. Media with a more "broad-spectrum" selective action include blood agar containing neomycin or nalidixic acid or a combination of polymyxin, neomycin, and fusidic acid. All of these media are appropriate for the isolation of other clinically significant haemolytic streptococci.
Enterobacteria

Except for Salmonella and Shigella, enterobacteria are generally distinguished from one another by the appearances of their colonies on a general purpose bile-salt medium such as MacConkey's agar with or without the addition of a sugar. Representatives of each recognizable type of colony are subcultured for subsequent identification by means of a series of biochemical tests. The absence of selective or indicator media for most individual species of enterobacteria places a limit on quantitative information about their distribution in the body flora and the environment. A little information can be obtained by subculture from colonies appearing in the zone of inhibition around antibiotic-containing discs on primary culture plates.

Pseudomonas aeruginosa

Usually, this organism is easily recognized when present in large numbers on plates of nonselective media but some strains are non-pigmented and colonies are atypical. For its isolation from the environment a choice of selective media is available; most of these media incorporate cetrimide (about 0.3% w/v). To this may be added nalidixic acid (0.02% cetrimide + nalidixic acid 15 µg/ml), nitrofurantoin, or a mixture of novobiocin, penicillin, and cyclohexamide according to the composition of the expected contaminating flora. An alternative selective indicator system is cetrimide in King's B medium incubated strictly at 37°C and then examined under ultraviolet light; most fluorescent colonies that develop under these conditions are of P. aeruginosa. Enrichment media include cetrimide broth preferably incubated at 41°C.

Clostridia

Egg-yolk agar containing 100 µg per ml of neomycin is suitable for isolating and enumerating C. welchii from air, dust, and surface swabs. For rapid recognition “half-antitoxin” plates are useful. The plate is first dried, then 3—4 drops of C. welchii a-antitoxin are spread over half the plate. If the clostridium is C. welchii or C. bifermantans-sordellii opacity around the lecithinase-producing colonies is inhibited on the half of the plate containing antitoxin.

The isolation of C. tetani from environmental swabs and materials often presents difficulties. Multiple primary cultures should be set up. These should include at least two tubes of cooked-meat broth from which the air has been driven by immersion in boiling water. After seeding the cooled material (at the bottom of the tube by means of a pipette, and without air bubbles), half the tubes should be heated at 80°C for 10 min. Plates of freshly poured blood agar, some containing neomycin, should be seeded, but only on one segment of each plate. Plate cultures should be examined after 1 and 2 days for a spreading edge of fine growth. Enrichment broths should be subcultured, each to a single segment of a separate blood agar plate, daily for 4 days. Repeated serial subculture from the edge of the spreading growth may be necessary to obtain pure cultures. An alternative method is to subculture on to blood agar containing 40—60 units of commercial tetanus antitoxin per ml, on which tetanus bacilli form discrete colonies.
PRINCIPLES

These methods are used to subdivide groups of otherwise indistinguishable micro-organisms — usually members of one species — on the basis of differences in a single class of characters, e.g., the presence of certain antigens, susceptibility to bacteriophages, production of, or sensitivity to, bacteriocines. When organisms differ in this way they are assumed to be epidemiologically distinct; it is thus possible to eliminate infections or sources of infection that are not relevant in the incident under investigation. When organisms belong to the same type (or have the same typing pattern) we take this as evidence of epidemiological relatedness. Neither assumption is always true, and the strength of the evidence for or against the relatedness of strains depends on two characteristics of the typing system used.

(1) Discrimination. This is the ability of the system to divide organisms into a large number of types, no one of which is common. The discriminatory power of a typing system is inversely proportional to the frequency of the most common type in the total population of the species. Uncritical use of typing systems with low powers of discrimination may result in erroneous attribution of infections to sources from which they did not emanate. Similarly, if a high proportion of untypable strains is found the typing system will have little value.

(2) Reproducibility. Lack of reproducibility has the opposite effect; unless it is recognized it may result in epidemiologically related isolates being considered “different”. A totally reproducible typing system probably does not exist. In addition to genetic changes, phenotypic variations may occur in clones of organisms in the natural environment, and in some typing methods there are also uncontrollable technical variables. In general, typing systems based on the possession of one of a series of alternative antigens (e.g., pneumococcal type polysaccharides) appear to be more stable than methods in which pattern reactions are obtained (e.g., phage and bacteriocine methods). Nevertheless, the limits of variation, and the frequency with which variation occurs, can be established empirically by studying large groups of epidemiologically related isolates, as has been done for staphylococcus phage-typing. The size of the difference in pattern necessary to establish a given probability that two strains are indeed “different” can then be determined. The use of such a “difference rule” naturally has the effect of reducing the discriminatory power of the method. Unfortunately, some phage-typing and bacteriocine-typing methods have not been fully evaluated for reproducibility under field conditions.

PROVISION OF TYPING FACILITIES

There is little doubt that the typing of certain organisms, e.g., S. aureus, has in the past been greatly over-used in some large centres where facilities were freely available. Typing is a waste of laboratory resources unless performed with clear epidemiological objectives. Typing is required:
(1) in outbreaks or suspected outbreaks of infection to define the extent of the outbreak, detect symptomlessly infected contacts, and reveal environmental reservoirs of the causative microbe;

(2) in continuous studies in defined situations to determine how often infections are spread in different ways and to evaluate preventive measures;

(3) in continuous monitoring of phage patterns appearing in special wards, such as orthopaedic, obstetric, and intensive care units, in order to be able to react early when there is a trend towards accumulation of identical patterns.

In the first instance results are required quickly but the need for typing is intermittent, and the use of an easy, even if not very discriminatory, method may be acceptable. In the second, speed is unimportant, the workload is often large and long-continued, and highly discriminatory methods may be required. In the third, there is a continuous requirement for speedy typing of several different micro-organisms, and it may therefore be necessary to choose very simple methods.

To cover all eventualities the hospital microbiologist would require facilities for typing many different micro-organisms, but a number of these would be used infrequently. The resources needed to maintain even a few typing systems in one laboratory are considerable and are unlikely to be available except at the largest centres. The individual microbiologist is in a difficult position unless typing resources can be organized regionally or nationally, but overcentralization at national typing laboratories may lead to loss of epidemiological interest.

In general, typing should be done as near to the individual hospital as possible, and schemes for area and regional diversification and cooperation should be encouraged. The extent to which these are practicable depends on the size of the area expected to yield a worthwhile workload for the test and on the availability of typing reagents.

Lack of supplies of essential reagents is the chief obstacle to extending the availability of typing facilities. Numerous examples of this are quoted below. Commercial manufacturers of diagnostic reagents are unlikely to increase their range of products greatly. Increased support from national governments is therefore essential if typing facilities for all the more important hospital pathogens are to be provided wherever they are needed. This support should, in the first instance, take the form of establishing national typing centres for the respective micro-organisms when these do not already exist. National centres concerned with the more common pathogens should be equipped and staffed for the manufacture of typing reagents, which should be distributed, in a form in which they can be used easily, to selected laboratories that will provide an area or regional typing service. Centres concerned with less common organisms should be responsible for providing a comprehensive and speedy typing service for the whole country.

Available methods of typing

Notes on methods used for typing bacteria of importance in hospital infection are given below.
(a) **Staphylococcus aureus**

**Phage typing.** Internationally standardized system for typing human strains; discrimination good; limits of reproducibility well defined ("two major differences" rule). Phages available through national representatives; local devolution of typing practicable if liquid phage is supplied from a national centre.

**Serological typing by slide-agglutination.** Method 1 (Pillet): types defined on presence of a single “type-determining” antigen; method 2 (Oeding): strains characterized by pattern of antigens detected with factor sera. Both methods are used in Europe but no serious attempt has been made to compare them. In definite outbreaks of infection both give results in general conformity with those of phage typing. Antisera are not available commercially, and few countries have national sources of supply.

**Antibiotyping.** Much used by clinical microbiologists but little evaluated; poor “over-all” discrimination and only a minority of strains with unique resistance patterns can, therefore, be recognized. Many resistance determinants on separate plasmids; these tend to be lost singly, so reproducibility is not good. Frequency of interstrain transfer of resistance determinants under field conditions not known.

"**Resistogram**" typing by sensitivity to empirically selected chemicals. Most of the markers are resistances to heavy metals; some of these are plasmid-determined and may be lost. Reagents easily available.

(b) **Coagulase-negative staphylococci and micrococci**

Primary subdivision by biotyping, but species not yet clearly defined. At least two phage-typing systems for "S. epidermidis" exist; phages tend to be difficult to propagate and maintain; at least 30% of strains are untypable.

(c) **Group A streptococci**

**T typing.** Slide agglutination of trypsinized suspensions. Some monospecific reactions, which are reproducible, and some pattern reactions, which are less so. Percentage typability high but discrimination only moderate. Sera available commercially and suitable for most studies of hospital epidemics.

**M typing.** Precipitation reaction between hot-acid extract of streptococcus and antiserum. Monospecific reactions: discriminating and reproducible but typability seldom exceeds 50% of all strains. Sera difficult to make and not generally available.

(d) **Group B streptococci**

Precipitation reaction with hot-acid extract; only 5 types, and discrimination therefore poor. Sera not difficult to make but not generally available.

(e) **Streptococcus faecalis**

Precipitation reaction with hot-acid extract; 11 types. Sera not difficult to make but not generally available. Have seldom been used in epidemiological studies.
(f) **Pneumococci**

Capsular typing: reproducible; discrimination adequate for most purposes in hospital epidemiology. Two sets of type numbers, the Danish and the American. Only one source of typing sera in Europe.

(g) **Enterobacteria**

In general, the enterobacterial groups are characterized by their biochemical characteristics and are most conveniently subdivided or “typed” by means of their antigenic structure. Many of these serotyping systems are highly discriminating. Therefore, if antisera are available serotyping is the preferred method. Phage and bacteriocine methods are used for the subdivision of certain common serotypes. Antibiotyping of enterobacteria and many other Gram-negative bacilli is a poor method of studying the spread of bacterial strains among patients because plasmid resistance determinants are rapidly transferred from strain to strain. On the other hand, the study of the spread of identifiable plasmids in the flora of patients (“plasmid epidemiology”) may provide valuable information about the consequence of particular policies of antibiotic administration.

*Escherichia coli.* Comprehensive and highly discriminating serological system based on detection of O, K, and H antigens. Full range of sera available in a few national centres; “short sets” of O antisera locally prepared by interested workers. “Resistogram” typing has been advocated but is not highly discriminatory.

*Salmonella, Shigella, and enteropathogenic types of Escherichia coli.* Sera available from national centres and commercially; “short sets” widely used in local laboratories. Phage or bacteriocine methods of subdividing common serotypes (e.g., phage typing and biotyping for *Salmonella typhimurium* and certain other salmonellae, phage and bacteriocine typing for *Shigella sonnei*, and phage typing for *Shigella flexneri* at national or local centres).

*Proteus mirabilis and P. vulgaris.* Combined serological typing system (O + H) for these two species; highly discriminating but sera not widely available. Alternatively there are several phage-typing systems and at least one bacteriocine-typing method; these appear to be less discriminating but may be adequate for epidemiological purposes. Dienes’ method may be appropriate for the examination of small sets of cultures.

*Proteus rettgeri and Providencia.* Separate serological typing system, with additional biotyping and phage-typing methods.

*Klebsiella-Serratia-Enterobacter.* Separate serological system for each.

*Klebsiella.* Biotyping not highly discriminatory; capsular typing sufficiently discriminating for epidemiological studies, except of the “respiratory” biotypes. Full sets of antisera not widely available. Alternative phage-typing and bacteriocine-typing systems have not been fully evaluated for discrimination and reproducibility in the field.

*Serratia and Enterobacter.* O and H typing systems; bacteriocine-typing and phage typing for *Serratia.*
(h) *Pseudomonas aeruginosa*

*Serological typing.* At least 5 "national" typing systems with different designations for essentially the same types, some 12–18 in number; an international numbering system is pending. Reproducibility very good; discrimination poor because 2–3 types are common. Sera easy to make; available commercially.

*Bacteriocine typing.* Two rather similar "active" methods (those of Wahba and Gillies & Govan) based on the production of pyocines by the strains to be typed. Widely used in local centres, where rapidity of results and ready availability of reagents is an advantage. Type designation dependent on exact reproduction of typing pattern, and this is not invariable. Discrimination poor; nevertheless, useful for early recognition of outbreaks. Several variants and elaborations of these methods have been described. "Passive" bacteriocine-typing methods, in which phage-free and bacteria-free preparations of bacteriocines are used as reagents, are under development.

*Phage-typing.* Several sets of phages have been described; these are easy to prepare but are not widely available outside national centres. Reproducibility less good than with *Staphylococcus* phage-typing but acceptable results obtained by use of a "three-major-differences" rule in interpretation. This considerably reduces discrimination.

*Combined typing methods.* The "hierarchical" application of two typing methods increases discrimination; thus, serological typing may be followed by phage typing, the latter being of value to subdivide strains within common serotypes.

(i) *Clostridium welchii.*

Serological typing systems are being developed.
CHAPTER 6

INVESTIGATION AND CONTROL OF OUTBREAKS OF INFECTION

Only a small proportion of hospital-acquired infections form part of definite outbreaks, and these must be recognized promptly. The onset of some outbreaks is acute and these cannot escape attention but others can be easily missed, particularly if cases are few and scattered, have varying symptomatology, and are spread over a number of days. A good surveillance system (see chapter 4) should reveal the more definite outbreaks of infection but in certain departments the appearance of a potentially dangerous situation may be difficult to detect on clinical grounds alone; greater reliance must then be placed on microbiological monitoring of patients (see p. 41).

ACTION TO DEFINE AN OUTBREAK OF CLINICAL INFECTION

It is important that microbial isolates from early cases should be available for re-examination when the existence of an outbreak is suspected. The laboratory must therefore arrange for short-term storage of all isolates from ill patients or staff of potentially communicable pathogens such as S. aureus, groupable streptococci, enteric pathogens, P. aeruginosa, and possibly of other Gram-negative bacilli. The isolates can conveniently be stored on agar slopes in a series of boxes, one for each week. As soon as an outbreak is suspected the relevant set of isolates is assembled for typing, either in the laboratory or at some other designated centre.

The infection control team must begin to accumulate epidemiological information at the earliest possible time, and should certainly not wait until the typing results are available. All the information must be written down when it is obtained, preferably on a standard form; it should include, for all affected persons, the date of admission and of onset of symptoms, location in the hospital, and circumstances in common. The team should prepare a preliminary assessment of the probable time and place of infections and possible sources and routes of infection. This should be presented immediately to the chairman of the infection control committee, who will decide whether to call a meeting of part or all of that committee.
BACTERIOLOGICAL INVESTIGATIONS OF THE EXTENT OF THE OUTBREAK
AND THE SOURCE OF INFECTION

These investigations should be started as soon as the preliminary assessment of the outbreak has been made. Their nature will depend upon the results of this assessment, and they will be concentrated on persons and objects in the supposed place of infection, though this may not be clearly established until later in the investigation. It is, therefore, wise to collect at an early stage all specimens that could conceivably be needed, and to store those not examined immediately. According to the circumstances of the outbreak and the nature of the causative microbe, attention will be focused on human carriers (in staphylococcal and streptococcal sepsis) and on utensils, apparatus, or fluids (in explosive outbreaks of sepsis due to Gram-negative rods). The reservations stated in chapter 5 about the significance of isolating various pathogens from the environment in association with infected persons must be borne in mind. In investigating outbreaks we need supporting epidemiological evidence that infected patients had significant contact with the infected object or substance. Similarly, not all carriers of the infecting strain are likely sources of the infection; some may be fellow-victims.

BRINGING THE OUTBREAK TO AN END

Ending the outbreak is, according to circumstances, a matter of (1) effectively treating or removing to isolation infected persons (whether cases or carriers), (2) destroying micro-organisms that are environmental sources of infection, and (3) detecting specific technical lapses in hospital procedure. The role of the laboratory is mainly to perform clearance tests on infected persons and limited environmental testing as indicated in chapter 5.

PATIENTS UNDER CONTINUOUS MICROBIOLOGICAL MONITORING

A small proportion of patients, mainly in certain special departments such as an intensive care unit, may be continuously monitored for the appearance of potentially dangerous micro-organisms. The number of body sites examined will usually be limited by practical considerations; sites likely to reveal an immediate hazard to the patient will be chosen – tracheostomy stomata, respiratory secretions, and cannulation sites, etc. The objectives are to reveal (1) an undue frequency of infection or contamination at the sites and (2) dissemination of particular strains of micro-organism among the patients.

Many of the micro-organisms isolated will belong to common species, and the second of these objectives will be attained only if prompt typing of these organisms is possible. In the absence of these facilities some help may be obtained from a comparison of spectra of resistance to antimicrobial agents.

When a potential pathogen is being disseminated it will often not be possible to remove the infected persons from the unit, or even to isolate all of them effectively, and elimination of the pathogen from the patients may prove
difficult. The main value of continuous monitoring, therefore, is in directing attention to technical lapses and to undetected environmental sources of infection in the unit. Regular monitoring of the more important environmental sites should be part of the hospital's general infection control programme; this activity should be intensified and broadened whenever it appears that an undesirable situation has arisen in a particular unit.

REPORTING

A full account of all outbreaks should be prepared by the infection control team and discussed at the next meeting of the infection control committee.
CHAPTER 7
THE INFECTION CONTROL PROCESS

The infection control committee of a hospital is responsible for codifying infection prevention practice in the hospital, and the microbiologist should be prepared to give advice to the committee on all of the major topics where decisions are required. In doing so, his attitude must at all times be realistic; if he makes recommendations that his clinical colleagues know to be impracticable they are unlikely to be accepted and he is not likely to be asked for further information. The primary function of the hospital is to provide medical and surgical treatment, and the temptation to take unnecessarily elaborate precautions must be resisted. The art of designing an effective infection control policy is to arrive at an optimal "mix" of precautions that can, in fact, be implemented with the available material resources and staff, and to convince all concerned that it is both practicable and worthwhile.

This section briefly indicates some of the areas where advice may be sought from the microbiologist and gives some broad indications of the principles on which decisions should be taken.

DESIGNING AND EQUIPPING HOSPITAL BUILDINGS

When a new hospital is being planned a great deal of advice will probably be available from central sources, and the role of the local microbiologist will be to make detailed comments on the implications of the plan for hygiene. When modifications of an existing hospital are proposed the microbiologist may be called upon to produce evidence in support of particular improvements or modifications to operating suites, kitchens, etc., the addition of special departments such as intensive-care and renal units, or the provision of specific equipment in wards — bedpan washers or disposable bedpans, dish-washers, etc.

SAFE PROCEDURES

Sterilization and disinfection

The first task is to make a comprehensive list of all objects and materials that need to be treated in order to destroy potentially pathogenic micro-organisms
and to decide which method is appropriate for each organism, where and by whom the procedure will be performed, and what methods will be used to monitor it (see p. 27). Factors to be taken into consideration include (1) whether absolute sterility is required or whether a disinfection process, in which only vegetative bacteria and viruses are destroyed, is sufficient; (2) whether the object or material can be sterilized or disinfected by heat; and (3) if that is not the case what chemical disinfection process is acceptable.

In large hospitals centralized units for heat sterilization of equipment are being provided with increasing frequency; they have numerous advantages. Local circumstances determine the size and function of these units. It is usual practice for sterilization of surgical instruments and linen needed in operating theatres to be carried out in the theatre block, preferably in a “theatre sterile supply unit”. Standard items of sterile equipment, packs of dressings, and instruments — often in the form of “kits” for common procedures — may be provided for wards and departments other than operating theatres from a “central sterile supply department”. One such department can conveniently supply several neighbouring hospitals.

It is undesirable that either type of sterile supply department should be responsible for disinfection of equipment or apparatus, and there is a case for establishing in each major section of a large hospital, whenever possible, “decontamination units” for the treatment of medical and nursing equipment such as respirators, oxygen tents, baby incubators, aspiration bottles, tubing, and so on.

The destruction of micro-organisms by chemical agents is often uncertain and usually difficult to monitor. Chemicals should seldom, if ever, be used when sterilization is the objective or heat treatment is possible. Ethylene oxide is not suitable for use in most ordinary hospitals; most heat-sensitive objects can be disinfected with low-temperature steam or sterilized with low-temperature steam and formaldehyde.

There is general agreement that all communally used objects that come into contact with the mucous membranes of patients and certain categories of objects (e.g., laundry) that merely touch their skin should undergo some form of disinfection. Whether, and under what circumstances, it is necessary to disinfect general surfaces in hospital rooms (e.g., walls, floors, furniture) is subject to controversy. However, it would seem reasonable to restrict this activity to surfaces likely to be touched frequently by the hands of patients or staff, and to disinfect other surfaces (e.g., floors) only when they have been manifestly contaminated with human secretions.

Total disinfection of surfaces in a room previously occupied by an infectious patient (“terminal disinfection”) is practised rarely, and for very few diseases only. In those circumstances, gaseous formaldehyde is liberated in the sealed room under conditions of high humidity. For a wider range of infections terminal disinfection by spraying a liquid disinfectant is more frequently practised, but the choice of disinfectant does not appear to be based on any clear principle.

Misuse of liquid disinfectants can introduce additional infection hazards. Gram-negative organisms may multiply in disinfectant solutions that are too weak or deteriorated or inactivated. Only experienced staff should be entrusted
with the task of making up disinfectant solutions. Where chemical tests for strength are available (as for phenolic and chlorine-containing compounds) these should be used. Regular bacteriological monitoring of disinfectant solutions kept at use-dilution is essential.

A "disinfectant policy" should therefore be instituted to (1) state the legitimate uses of chemical disinfectants and designate appropriate substances and strengths for each; (2) arrange for the preparation and correct dilution into clean containers at frequent intervals of these substances; (3) instruct the users of disinfectants in correct procedures; and (4) set up a programme of regular in-use bacteriological tests for disinfectant solutions.

Cleaning

Good "domestic" cleaning of hospital premises is best monitored visually (see p. 31), and bacteriological tests should seldom be needed. Cleaning is probably all that is required for rooms (including operating theatres) after they have been occupied by most classes of infected persons; for exceptions to this see the previous section, p. 43.

Preliminary cleaning of contaminated instruments and equipment is an essential step before chemical disinfection. This may be less important for objects that are to be disinfected or sterilized by heat but is nevertheless desirable on general grounds. A "make-safe" disinfection should be carried out with a chemical agent that is little affected by the presence of organic matter, a suitable phenolic compound, for example, in order to reduce the possibility of infection being transmitted to the cleaning staff.

Specific ward procedures

Methods to be employed in certain procedures that carry a risk of infection for the patient or staff should be laid down by the infection control committee and written instruction sheets should be prepared for each procedure. Subjects for consideration by the committee include (1) aseptic technique for wound dressing, (2) catheterization and closed bladder drainage, (3) intravenous injection or cannulation, (4) lumbar puncture, (5) pre-operative skin preparation, and (6) collection of specimens for laboratory examination. Hand-washing procedures should also be outlined.

Operating theatres

Aspects of operating theatre practice relevant to the prevention of infection include the following.

(a) Design and ventilation

The initial aim is to provide physical and aerial separation of the theatre suite from the rest of the hospital, a sequence of increasingly clean zones from the entrance to the operating and sterilizing areas, and facilities for the removal of "dirty" materials without contaminating clean areas, and to introduce sufficient air into clean areas to dilute airborne contaminants generated there and
to maintain a constant flow of air away from these areas. As we have seen (see p. 31), this is routinely monitored by physical means supplemented with occasional bacteriological tests.

(b) Discipline

This includes limiting the numbers of persons in the theatre, strict separation of those admitted into "scrubbed" and "unscrubbed" groups with defined duties, restricting physical activity to a minimum, banning from the theatre any anaesthetist or member of the "scrubbed" team suffering from a septic skin lesion or upper respiratory-tract infection, requiring theatre personnel to remove their outer clothing and to change their shoes before entering the theatre, and giving patients freshly laundered clothing and blankets immediately before transport to the theatre.

(c) Cleaning the theatre

Upward facing surfaces may become heavily contaminated during operations as a result of settlement of bacteria dispersed from the skin and clothing of people in the theatre; however, the chance that bacteria might be transferred from these surfaces to operation wounds or to sterile equipment is extremely small. Surfaces should not be allowed to become visibly dirty, and it is advisable to mop the floors with water and a detergent after every operating session; a floor-scrubbing machine is suitable for use at the end of the day. For shelves and ledges frequent damp dusting is appropriate; the operating lamp should be cleaned (not oiled) daily.

When the floor or another surface is known to be contaminated with pus or other infective material the contaminated area should be disinfected with an appropriate (e.g., phenolic) disinfectant at the recommended use-dilution. Walls and other vertical surfaces, if undamaged, acquire very few bacteria, even if left uncleared for many weeks. They should, however, be washed at least once every 3 months or at shorter intervals if that is required to prevent the deposition of visible dirt. Exposed plaster where paint has peeled off can, if moist, become heavily colonized by bacteria; cleaning and disinfecting will not reduce the numbers of bacteria on such areas, and the damaged wall must be promptly resurfaced with paint or other wall finish.

(d) Hand-decontamination and use of gloves

The wearing of rubber gloves by the surgeon and other "scrubbed" members of the operating team is a valuable aseptic measure, minimizing the risk of direct contact contamination of wounds and sterile equipment. However, some contamination can occur through torn gloves or through invisible small holes that appear in about 20% of gloves during use, and also through moisture on sleeves of cotton gowns; gloves are commonly not worn by eye surgeons. For these reasons the scrubbed team should use an antiseptic skin preparation before operating.

Effective preparations are (1) certain detergent antiseptic solutions containing, for example, 4% chlorhexidine or 10% povidone iodine applied vigorously to fingers, hands, and forearms for 2–3 minutes with running water and no brush, followed by rinsing and drying; or (2) 10 ml of 95% ethanol or isopropanol with 1% glycerol and, for greater activity, 0.5% chlorhexidine (or
another effective additional antiseptic) but no water, rubbed vigorously on to fingers, hands, and forearms until they are dry. Repeated use of these agents has a cumulative effect due partly to residues of antiseptic left on the skin, which prevent the build-up of bacterial flora on the gloved hand even during long operations.

A detergent must be used to remove blood, pus, faeces, or other physical contaminants, and the under surfaces of finger nails should be cleaned, when necessary, with a scraper. Hands must be washed with an antiseptic detergent preparation, and fresh gloves and gown must be put on when a visible tear appears in a glove. If gloves are sterilized and re-used they must be tested for holes by inflation under water. Rings should, if possible, be removed before preparation of the hands.

(e) Pre-operative skin preparation

The skin of the operation site should be washed with soap and water, shaved with a safety razor (if necessary), and covered with a sterile towel in the ward on the day of operation. Great care must be taken to avoid cuts or abrasions; preferably, shaving should not be done on the day before the operation because exudate from minute lesions can become heavily colonized with bacteria overnight. Soap and water for shaving should be applied with sterile gauze.

In the operating theatre an effective antiseptic solution (70% ethanol containing either 0.5% chlorhexidine digluconate or 1% iodine, for example) is liberally applied with friction over and well beyond the operation site for 3–4 minutes, care being taken to cover the whole area. The antiseptic is usually applied on a gauze swab held in forceps but a larger reduction in skin bacteria can be obtained by rubbing the antiseptic into the operation site with a gloved hand, for which purpose a second glove is worn over the operating glove. For emergency operations a single pre-operative cleansing and disinfection in the theatre must suffice, but in elective high-risk operations two or three preliminary preparations of the patient in the ward with detergent antiseptic solution (containing 4% chlorhexidine, for example), starting on the day before the operation, followed by disinfection of the operation site in the theatre with an alcoholic antiseptic solution (0.5% chlorhexidine in 70% ethanol, for example) are desirable and produce a higher degree of disinfection.

Before operations on skin likely to be heavily contaminated with spores of Clostridium tetani or C. welchii (e.g., the hands of farm workers and gardeners with ingrained dirt) or the thighs of patients with poor arterial supply, application for half an hour of a compress soaked in 10% polyvidone iodine solution is useful. The usual short skin cleansing procedures do not destroy bacterial spores but a large proportion of accessible spores are destroyed by a polyvidone iodine compress in 30 minutes; some may also be removed with dead skin scales by vigorous washing with detergent and, when necessary, grease-solvent jellies.

Protective clothing

The various items of protective clothing worn by hospital staff are established by tradition but often do not effectively serve the purposes for which
they were designed. The most useful function of the microbiologist is to con­
vince others of this.

(1) Garments made of conventional materials do not significantly reduce
the amount of airborne contamination from the wearer’s skin. Impervious gar­
ments are uncomfortable at normal operating theatre temperatures.

(2) If changed frequently (e.g., between procedures on different patients)
these garments have a limited function in preventing the transfer of light con­
tamination from one patient to another, but if the garment becomes heavily
contaminated micro-organisms pass through it on to underlying skin or gar­
ments, and a freshly donned gown may be contaminated.

(3) Daily changing of outer garments probably does little to prevent
patient-to-patient spread of infection unless an impervious apron is used to
cover the parts of the garment that come into contact with the patient. This
should be donned for defined procedures and discarded afterwards.

(4) There are good reasons for covering the hair, but the cover must be
complete, close-fitting, and preferably impervious.

(5) Simple paper masks have a limited function in deflecting large-sized
particles expelled from the mouth away from an operation wound but individ­
ual makes of mask should be separately assessed. More efficient masks for
special purposes are obtainable.

Isolation

If the government of the country has not already done so, the hospital
infection control committee must prepare a list of the microbial diseases that
are considered to be transmissible and for which isolation within the hospital,
or transfer to an infectious-diseases unit, is mandatory.

Isolation facilities within the hospital will be needed to prevent the spread
of infection to other patients (“source isolation”) and to protect susceptible
patients (“protective isolation”). Isolation in single rooms does little to prevent
infection by the aerial route unless mechanical ventilation is provided; ideally
this should be by negative pressure for source isolation and by positive pressure
for protective isolation. Isolation rooms with facilities for both types of venti­
cation can be built and these can be used at different times for source and pro­
tective isolation. An air-lock must be provided in rooms for source isolation,
whether of the single-purpose or dual-purpose type. Infection by the faecal-oral
route in multibedded rooms can be prevented by strictly applied nursing tech­
niques, but this is easier in single-bedded rooms with separate toilet facilities.

It is very unlikely that sufficient facilities (or staff) will be available for the
isolation of all patients for whom this would be an advantage. Thus, scarce
source isolation facilities may be conserved by classification of patients into
those requiring (1) single rooms with mechanical ventilation and separate
toilet facilities, (2) single rooms with separate toilet facilities, (3) the remain­
der, for whom less than optimal arrangements must be made.

A considerable proportion of the hospital population would probably
benefit from protective isolation, but it is impracticable to provide it for them.

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It would be reasonable to select for protective isolation patients whose resistance to infection is seriously, but temporarily, impaired, and whose life is likely to be significantly prolonged by treatment. The alternatives for protective isolation are (1) single rooms with positive-pressure ventilation, (2) rooms with laminar flow of air, (3) plastic enclosures ("isolators") in open wards, and (4) ultra-clean (usually multibedded but not mechanically ventilated) wards. Their relative efficacy has not yet been evaluated.

Use of antimicrobial agents

The microbiologist has a clearly established role as adviser to the clinician on the sensitivity to antimicrobial agents of the patient's infecting organism and on the choice of a suitable agent for treatment; very often he assumes the additional role of expert on the pharmacokinetics of antimicrobial action. The clinician may, however, have to take decisions about appropriate treatment for severe infections before the causative organism has been isolated or before sensitivity tests have been completed. The microbiologist should accumulate data about the resistance of common pathogens to antimicrobial agents and should issue regular (e.g., quarterly) summaries to the clinicians. This information is very helpful in choosing a drug likely to be active against the bacterium known, or thought, to be responsible for a severe infection.

The infection control committee should be encouraged to concern itself with the more general problem of the pattern of usage of antimicrobial agents in the hospital as a whole, that is to say, in the development of an agreed antibiotic policy. This must be done tactfully because it may appear to limit the clinician's freedom to do his best for the individual patient. The objectives of the policy are (1) to reduce the total amount of antimicrobial treatment given in the hospital; (2) to prevent the administration of an agent to patients infected with, or carrying, bacteria resistant to it; (3) to reduce the use of certain agents or restrict their use to specific classes of patients; and (4) to diversify the pattern of usage where two or more agents are equally effective for a specific purpose.

The reduction of unnecessary antimicrobial therapy is a matter for individual clinicians, but the microbiologist can support this by providing speedy and accurate sensitivity tests and by being prepared (and competent) to give advice on treatment for particular patients, by making available information about the current resistance situation in the hospital, and by encouraging the committee to produce periodic statements about the appropriate use of individual antimicrobial agents.

Reasons for restricting or reserving the use of particular antimicrobial agents include (1) the recent appearance of resistance to it in a common pathogen, (2) the hope that a sharp reduction in the use of an agent might restore its usefulness when resistance has become common, (3) the knowledge that resistant variants of micro-organisms are rapidly selected in patients receiving the agent, and (4) the fact that an important pathogen is almost invariably sensitive to a particular agent. Reasons (1) and (2) might be grounds for a

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\(^d\) i.e., antibiotics and chemotherapeutic agents.
severe, but possibly temporary, reduction in use of an antimicrobial agent for all purposes combined with an attempt to remove or isolate carriers of the resistant strain. Reasons (3) and (4) are appropriate for restricting, for as long as the policy proves effective, the use of the agent to severe infections with sensitive organisms when other antimicrobial agents are likely to be inactive, and to “blind” therapy when this is unavoidable. The committee’s policy on the restriction and reservation of antimicrobial agents should be communicated to all clinicians in writing, and appropriate modifications to it circulated with (quarterly) reports on sensitivity.

The health of hospital staff

A good occupational health service for the hospital staff is an important means of preventing their becoming infected from patients and of being unsuspected sources of infection for patients. Therefore, the infection control committee will collaborate closely with the authority responsible for providing this service.

(a) Pre-employment medical examination

All categories of hospital worker must be given a pre-employment medical examination. The aim should be to detect pulmonary tuberculosis and to elicit a past history suggestive of enteric fever in persons coming from countries where the disease is common, or a history of recent diarrhoeal disease or jaundice, chronic skin disease (especially eczema), recurrent skin sepsis, or discharge from the ear. Appropriate laboratory tests may be requested when the history of an individual suggests the necessity for this, but not for all staff.

(b) Immunization

Tuberculin-sensitivity tests should be performed on all new entrants to the hospital service and BCG vaccination offered to all nonreactors. As a minimum, vaccination against smallpox and poliomyelitis should be offered. Rubella vaccination is recommended for females in the appropriate age group who do not give serological evidence of previous infection.

(c) Self protection

All untrained entrants who will come into contact with patients should be given elementary training in how to avoid becoming infected.

(d) Reporting illness

All hospital employees must report to the occupational health service when they suffer from certain specific diseases (e.g., tuberculosis, jaundice, infected wounds or other surface lesions, diarrhoea) or when they return to work after recovering from these infections. When they join the staff they should be given a clearly worded leaflet setting out the symptoms that should lead them to report, and this should be reinforced by verbal explanations. Voluntary reporting of significant illnesses will be effective only if the terms of service do not impose severe economic disadvantage on those who cooperate.

Reports of significance must be communicated speedily to the infection control team and appropriate microbiological tests performed.
(e) Surveillance

Routine microbiological screening of staff will seldom be performed (see p. 27). However, in the case of personnel taking sickness leave it is wise to arrange for routine checking of certificates that state the nature of the illness responsible for their absence from work, if it is the practice to require these. When significant diseases or symptoms are mentioned the infection control team should be informed. Special surveillance programmes will be required for staff particularly at risk for certain infections such as tuberculosis and hepatitis.
Formal instruction in the prevention of hospital-acquired infection is, or should be, part of the normal education of professional groups such as medical graduates and nurses and is thus not a direct responsibility of the hospital administration. Experience in most countries indicates, however, that members of these groups enter hospital with inadequate training in this respect. The infection control committee of the hospital should therefore consider the desirability of organizing regular induction courses for professional recruits at which the hospital’s infection control practice is explained. Nonprofessional workers such as domestic and kitchen staff often enter hospital service without any previous training in hygiene, and the committee must take responsibility for remedying this situation. Basic rules of conduct should be drawn up, and these must be explained to all recruits on their joining the staff. In addition, simple courses of instruction specifically oriented to the work of respective groups should be conducted regularly.

Members of the infection control team must expect to take an active part in these formal educational activities. In addition, they have an important direct role in the in-service training of staff. This should be an informal activity, and is better organized on a departmental than a staff category basis. If the correct relationship between the team and the staff of departments has been established the periodic visits of the field worker or the infection control officer to departments for purposes of surveillance and monitoring can be used as occasions for instruction and exchanges of views on relevant matters. The team will have established its role as educators when it is regularly consulted by members of the staff of any department faced with a problem of hospital infection or wishing to obtain information about how best to prevent this.
SELECTED BIBLIOGRAPHY

INTRODUCTION AND CHAPTERS 1 AND 2

General


Council of Europe; Committee of Ministers. Resolution 72 (31) on hospital hygiene, 1972.


Infections caused by specific groups of micro-organisms

1. *Staphylococci*


2. *Streptococci*


3. *Pseudomonas*


4. *Anaerobic bacteria*


5. *Other*


**CHAPTERS 3 AND 4**

**Organization for control of infection, and surveillance**


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CHAPTER 5

Laboratory methods

1. Collection and transport of specimens


2. Rapid and automated diagnostic methods


3. Sampling of carrier sites

(For carriage of S. aureus, streptococci and P. aeruginosa, see Wilson & Miles (1975),


Parker, M.T. Post-graduate medical journal, 53 (in press).


4. Air sampling


For complete reference see under General heading, p. 53.
5. Sampling of surfaces


6. Equipment and materials (see also Sterilization and disinfection)

**Bacteriological monitoring of sterilization**


**Disinfectants**


Methods of culture

1. Basal media


2. *Staphylococcus aureus*


3. *Streptococci*


4. *Pseudomonas aeruginosa*


5. Anaerobes

Typing methods

1. *Staphylococcus aureus*: phage typing


2. *Staphylococcus aureus*: serotyping


3. *Staphylococcus aureus*: “resistogram” typing


4. *Other staphylococci and micrococci*: biotyping


5. *Staphylococcus epidermidis*: phage typing


6. *Streptococci*: group A (M and T typing)


7. *Streptococci*: group B


8. *Streptococcus faecalis*


Serological typing methods for enterobacteria


1. “Resistogram” typing of *Escherichia coli*

2. *Klebsiella*

3. *Serratia*: bacteriocine typing

4. *Proteus*: bacteriocine typing

5. *Proteus*: bacteriophage typing

6. *Proteus*: Dienes typing

7. *Pseudomonas aeruginosa*: serological typing

8. *Pseudomonas aeruginosa*: bacteriocine typing

9. *Pseudomonas aeruginosa*: phage typing
10. *Clostridium welchii*: serotyping


CHAPTER 7

Sterilization and disinfection (general)


Heat sterilization


Low-temperature steam and formaldehyde


Ethylene oxide


Central sterile supply


Disinfection of respirators


Chemical disinfectants


Soaps


Terminal disinfection of rooms with formaldehyde

Cleaning

Maurer, I.M. *Hospital hygiene*. London, Edward Arnold, 1974 (general).

Operating theatres

*Guidelines for the construction, maintenance and surveillance of ventilation systems in hospitals*. Aarau, Swiss Hospital Institute, 1975 (Bulletin No. 4).


Isolation


Antibiotic policy


Annex I

REVIEW MEETING ON THE APPLICATION OF LABORATORY METHODS TO HOSPITAL INFECTIONS
Copenhagen, 15–17 April 1975

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Annex 2

WORKING GROUP ON THE ROLE OF THE LABORATORY IN THE PREVENTION AND CONTROL OF HOSPITAL-ASSOCIATED INFECTIONS
Bucharest, 3 — 7 May 1976

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