also reduce the opportunities for contact infection either by infected patients or by staff. Not only are patients with identified sepsis or other forms of nosocomical infection individually nursed but some increasingly common and potentially dangerous manoeuvres, hitherto often carried out in open wards, can now be performed in isolation. From the social point of view – and this was one of the original aims – some pre-operative patients are spared the traumatic scenes which may occur in large wards.

It still remains extremely difficult to measure the advantages of improved hospital design in terms of the increased safety of patients, because the causes of infection are multifactorial and individual patient susceptibility varies so widely. Although there was a considerable reduction in acquired post-operative staphylococcal infection in the new unit it was not possible to identify precisely how this was achieved. It occurred at a time when a wide range of phage types of organisms had also become common in hospital and it seems clear that these strains were less communicable or less virulent than 'type 84/85' which was endemic in the old open-type ward but not in the new. Controlled ventilation in separate rooms may have diminished the total load of staphylococci in the dust and in the air of the new unit but we could not say how frequently, or whether, air-borne transmission affected particular infection incidents. Finally the new unit with its special type of accommodation abolished the age-old problem of overcrowding which was such a prominent feature, on receiving days, of many of the older open-type wards. Hard architectural fact had succeeded when many years of advice and caution had signally failed.

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## *101 Use of gas and particle tracers in the study of infection transmission*

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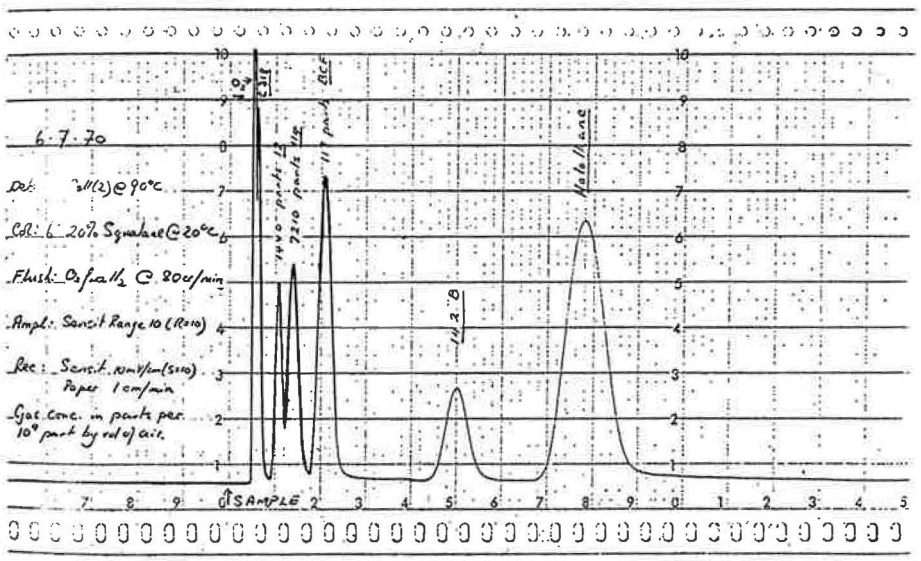
One important factor in the spread of airborne infection must be the movement of the air itself i.e. the ventilation, although an exact correlation of it with the risk of infection has yet to be found. As part of an infection survey in a hospital ward we made a detailed study by physical methods of the movements of the air and of the transport of particles by this means. A description is given of the methods employed.

For air-transfer measurements a gas tracer was used. Baird (1969) and others have used nitrous oxide in conjunction with an infra-red gas analyser to measure air transfers within hospitals. However, nitrous oxide may be liberated into the air of hospitals as a consequence of its use as an anaesthetic, and for use over a large area the method is too insensitive and the range over which the tracer can be estimated is too small. Lundquist (1970) described a method of using radioactive krypton which has sufficient sensitivity; but it is considered undesirable to use radioactive material within an occupied area.

We have developed a method of using an electron-capture detector to measure tracers chosen from the family of halogenated hydrocarbons (Foord and Lidwell, in preparation). Its sensitivity is similar to that of radioactive gas tracer methods and its range is probably greater.

Several tracers can be used simultaneously; they are separated from the oxygen of the air and from each other by means of a chromatographic column. Three tracers – freon 12, freon 114 and B.C.F. – were chosen and found to be sufficiently separated on a 2 m column of 20% squalane without too much delay for quick sequential sampling. The response from the detector cell is amplified and reversed,



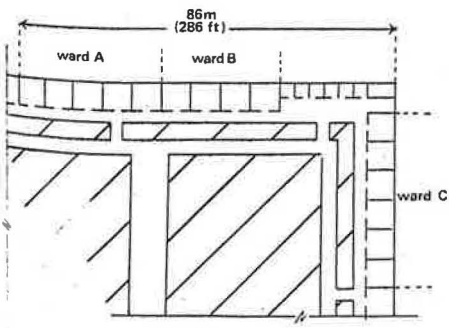




Fig. 1. Recording from gas chromatographic/electron capture gas tracer system. The recording includes several other electron capturing gases in addition to the three tracers: freon 12, freon 114 and BCF. The paper speed was 1 cm/min.

Fig. 2. Plan of hospital wards.

so that a recording made by a flat bed recorder have a peak for each tracer present together with an oxygen peak which is undelayed by this column (Figure 1). The delay time of each peak is characteristic of the particular tracer gas and in used as the means of identification. Because of the difficulty of determining the peak area in the field, the peak height was calibrated before use of the instrument by means of a known diluted mixture of the tracer gases kept under pressure.

The equipment was installed centrally and pipework connections were made from it to selected sampling positions so that air could be sucked from these positions back for analysis at a central point. The tracer gases, liquified under pressure, were supplied in cylinders mounted on trolleys and positioned at selected source points. The vapour pressure of the gas was sufficient for its own dispersal via a flowmeter and an air mixing fan. Dispersion was usually continuous until constant equilibrium concentrations were recorded at all the sampling sites. The air transfer was calculated from these measurements. However, air transfer measurements are not the whole story. Airborne infection is likely to be by means of bacteria-carrying particles which although wholly dependent upon air movement for their transport are unable to follow air streams exactly because of the effects of gravity and inertia due to motion upon the particle mass. A more accurate picture of the transfer of airborne bacteria, especially where long distance or recirculation with filters is involved, may be obtained by the use of a particle tracer.

Observations of bacteria-carrying particles should reveal the most relevant information, but the use of naturally occurring and easily typed organisms such as *Staphylococcus aureus* (e.g. Williams and Harding, 1969) has many statistical limitations, and there are many reasons for avoiding the use of artificially dispersed bacteria. A method in which fluorescent particles are observed by ultraviolet light is perhaps the most widely used particles tracer system but its value in the hospital environment is limited by the occurrence of particles from materials washed in particular detergents which also fluoresce in ultraviolet light.

Foord and Lidwell (1972) devised a very effective particle tracer system making use of crystals of potassium iodide. To simulate bacteria-carrying particles of mean size 13 $\mu$m diameter and mean settling rate of 0,3 m/min. with potassium iodide whose density is some three times greater, particles of mean size 7 $\mu$m diameter were generated with a spinning disc (May, 1949). After dispersal, the particles were collected from the air on to membrane filters either by suction or sedimentation. For detection, the filters were soaked in an acidic solution of palladium chloride which made each crystal appear as a larger brown spot. A low-powered microscope enabled these to be counted and an assessment of the particle concentration to be made.

Normally the particles were dispersed from a source position for a limited period of time to form a cloud. An integrated sample was collected over a measured interval of time on to filters attached to the pipe network described above, so that the one central pump was used to control the whole area. For sampling low concentrations of particles a centripetal sampler was made which enables large volumes of air to be effectively sampled without all the air passing through the membrane filter. The air turns a sharp corner and the momentum of the particles is sufficient to separate them from the main air stream and throw them into a central cone which has an airflow of perhaps 3% of the total and deposits all the particles upon the filter. Volumes of 0,1 $m^3$/min. were sampled at each site in this way without the need to provide a high powered suction system.

*Table 1 Air transfer between rooms within the same ward measured by a gas tracer method*

| ward | no. of rooms | median transfer index* from source in another room ($\times 10^{-5}$ sec/m³) | median concentration in recipient room/concentration in source room ($\times 10^{-5}$) | mean outflow from each room to corridor (m³/sec) | (cu.ft/min) | total outflow from ward rooms (m3/sec) |
|---|---|---|---|---|---|---|
| A | 5 | 7.5 | 1.7 | 0.121 | 257 | 0.605 |
| B | 4 | 354 | 92 | 0.058 | 123 | 0.231 |
| C | 6 | 510 | 106 | 0.013 | 28 | 0.078 |

The rooms concerned had a volume of about 140 m³ (5000 cu.ft) and a mean ventilation rate, depending upon which ward, of between 5.5 and 6.5 air changes per hour. This gave an effective ventilation of 0.21 to 0.26 m³/sec (450-550 cu.ft/min) and a transfer index from a source to the room in which it was situated of 3.8 to 4.8 sec/m³

* Lidwell 1960.

*Table 2 Air transfer between rooms of different wards measured by a gas tracer method*

| ward containing source | recipient ward | median transfer index from source ($\times 10^{-5}$ sec/m³) | median concentration in recipient room/concentration in source room ($\times 10^{-5}$) |
|---|---|---|---|
| A | B | 138 | 31.5 |
| B | C | 66 | 17.2 |
| A | C | 21 | 4.8 |
| B | A | 6.6 | 1.7 |
| C | B | 4.2 | 0.9 |
| C | A | no significant transfers observed | |

The minimum detectable transfer varies with the characteristics of the method. The maximum detectable transfer used in above results is 192 $\times 10^{-5}$ sec/m³ and the median values are obtained by graphical means assuming that in the extrapolated region the logarithmic distributions of each situation are normal with similar standard errors.

*Table 3 Particle transfer relative to corresponding air transfer*

| situation | median $\frac{\text{particle transfer}}{\text{gas transfer}} \times 100$ (%) |
|---|---|
| transfer within source room | 73 |
| transfer within same ward | 21 |
| transfer between wards | 9 |

The fewer number of observations made do not allow further separation of the groups as in the case of air transfer measurements

Transfers within and between three subdivided wards of a new fully mechanically ventilated hospital were measured by these methods. The three wards A, B and C were adjacent to each other with 6-bed patient rooms round the perimeter (Figure 2). An excess of air normally flowed from each room of the wards into the corridor and out into the core of the building, so that the doors in the corridor greatly influenced the air movement. Table 1 shows the air transfer between rooms within each ward together with the volume of air leaving the rooms when all the doors in the corridor were open – the most prevalent situation. The transfer between rooms of different wards is shown in table 2. From these it can be seen that the greater rate of airflow out from the rooms of Ward A, and to a lesser degree from those of Ward B, was reflected both in a much better degree of air isolation of the rooms of Ward A both within the ward itself and from the other two wards and in more transfer into Ward B from Ward A and into Ward C from Wards A

and B. Comparison of results obtained by the two methods allows the validity of the gas tracer for determining bacterial air transfer to be assessed. Table 3 gives the relative particle transfer resulting from a given air transfer in different situations. As might be expected, those transfers with a high transfer index i.e. involving shorter transit times, resulted in a lower loss of the particles being transported.

Finally, the actual and relative transfers found from these results together with the isolation they represent may be compared with findings from a concurrent bacteriological survey, and will probably reveal much concerning the relative importance of the airborne route of infection in this particular situation.

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# *102 Some aspects of the dispersal of* Staphylococcus aureus *in hospital wards*

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## INTRODUCTION

In spite of numerous and extensive investigations there are many aspects of the spread of staphylococcal strains among hospital patients that remain obscure. This is so both in regard to the conditions determining nasal colonisation or wound infection and to the ways in which the organisms are actually transported from patient to patient in the hospital environment. Some studies (Lidwell et al. 1966, 1970, 1971) have shown an apparent correlation between the numbers of airborne staphylococci in the particular immediate environment and the chance of nasal colonisation with that strain. It is not however certain whether this is a truly causal relationship or whether the air samples are merely indicators of environmental contamination.

Since there are many individuals at any time among the population of the hospital, or that part of it under observation, who are carriers of coagulase positive staphylococci either in the nose, on the skin or in infected lesions any attempt to trace in detail the routes of dispersion is dependent on the ability to differentiate between different strains of the microorganism and to recognize these when isolated from different situations. The phage typing systems in use, especially when supplemented with the results of antibiotic sensitivity testing, have a high discriminatory power but the inability to distinguish between two strains, allowing for the inherent