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Studies of the effectiveness of an isolation ward

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Isolation wards have been provided in great variety in general hospitals in the last few years, but there have been relatively few reports of any attempts to measure the effectiveness of the isolation provided. In 1965, a 14-room isolation ward was constructed at St Mary's Hospital in what had previously served as bedrooms for domestic staff and, for structural reasons, each room was provided with an individual ventilation plant. Since this provides a system that is both simple and economical in building costs, it seemed desirable to carry out some bacteriological tests to discover whether it was effective.

WARD LAY-OUT AND ORGANIZATION

The isolation ward

As will be seen from figure 1, the 14 bedrooms open off one long corridor, the service rooms in the centre dividing the patient rooms into two groups. The ward is situated on the fifth floor of the hospital and, being above the level of most of the surrounding buildings, is exposed to moderate wind pressures.

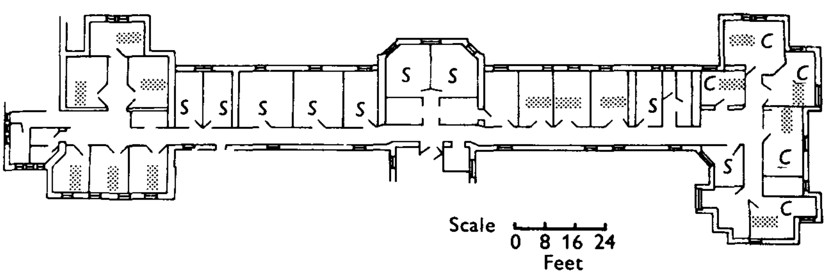

Fig. 1. Plan of the isolation ward. Bedrooms marked *C* have a ducted cool air supply as well as the individual room ventilator. *S* = service rooms, including offices and kitchen.

The ventilation system. Warmed air, passed through a Vokes automatic roll filter, is supplied under slight pressure to the corridor. In the corridor wall of each bedroom is fitted an individual ventilator unit (Pl. 1A, B), comprising a fan with a capacity of 150–180 ft^3/min., a two-stage 3 kW. heater controlled by a room thermostat, and a washable nylon filter with an efficiency rating of 90 % against particles down to 5 μ. All the servicing of the unit is carried out from the corridor side, and the filter is readily removable for cleaning; in practice this has been found necessary every 3–4 months.

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The ventilator units provide about six air changes per hour with a slight positive pressure within the bedrooms. Ordinarily the air is discharged through a gap left at the top or bottom of the window; it would certainly have been preferable to fit non-return louvres since, on windy days, there can be a definite inward air current. When the door is opened the room air discharges into the corridor, which must thus become contaminated. Contaminated air should not, however, enter the bedrooms since the input is taken through the filter and there should be no flow from corridor to room through the doorway. It was thought that this system had an advantage over the supply of air under pressure to the corridor with infiltration to the bedrooms because it would have been difficult to retain an adequate positive pressure in a corridor with windows down one side, and because the corridor air must always be at risk of contamination from patients and staff using it. Individual room ventilating units were much simpler and cheaper to install than a ducted air supply system to all rooms. The rooms at the south-west corner of the ward (marked *C* in Fig. 1) are, however, provided with a supplementary supply of cooled and filtered fresh air through ducts.

The patients. The ward is used mainly for patients with open septic lesions; occasionally patients with generalized infection are admitted, as are a few who are in need of protective isolation because of immunosuppressive or cytotoxic treatment. This last use is, in principle, undesirable, but is preferable to the nursing of such patients in open wards that have no separate isolation rooms.

Nursing organization and technique. The nursing complement of the ward numbers 14, including one ward sister, two or three staff nurses and one trained State-enrolled nurse. Each nurse looks after patients in several different rooms. When on duty all the nursing and domestic staff wear plastic aprons, which are wiped down with 2·5 % Roccal after the performance of any treatment or after close contact with a patient's bed. Disposable plastic gloves are worn during the performance of wound dressings and other treatments. Soiled dressings are enclosed in plastic bags before removal from the bedroom for destruction. Masks are not ordinarily worn while on duty in the ward. The staff wear easily cleaned shoes that are not worn elsewhere; plastic overshoes are provided for visitors and there are disinfectant-soaked mats at the entry to the ward corridors, though, in the light of more recent investigations (Subcommittee on Aseptic Methods in Operating Theatres, Report, 1968), this is probably not of great value.

Cleaning techniques. The ward was carefully designed to facilitate cleaning; most of the equipment needed is kept in a locker in each bedroom.

Bed linen is changed daily or more often, and all the blankets and pillows from a bed are changed and sterilized after each patient's discharge. All linen is enclosed in a plastic bag, which is firmly closed, before being removed from the bedroom. Mattresses, which have plastic covers, are washed *in situ*.

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METHODS

Bacteriological methods

Nasal swabs were taken from all patients, generally within 24 hr. of admission and again on one day in each week. These were plated on blood agar and examined for coagulase-positive staphylococci (*Staphylococcus aureus*) after 18 hr. incubation at 37° C. Coagulase-negative strains were not studied further and the word 'Staphylococcus', when used in this paper, refers to *S. aureus*. All strains of *S. aureus* were submitted to phage typing.

Nasal swabs from the nurses and other ward staff were examined in the same way once weekly.

Records were obtained from the hospital diagnostic laboratory of all infected lesions; staphylococci isolated from such lesions are phage typed as a routine.

The staphylococcal content of the air was determined by the exposure of culture plates with an inside diameter of 13·8 cm. for 12 or 24 hr. The plates were ordinarily placed on a window ledge or shelf, or on top of the ventilator unit, about 1–1·5 m. above the floor.

During the greater part of the investigation the air was sampled only when one of the patients in the ward was thought to be an active disperser of staphylococci; in these circumstances plates were exposed for 12 hr. in the disperser's room, the corridor, and a number of the nearby rooms. During a 6-week period early in 1968, plates were exposed for 24 hr. on 5 days a week in each bedroom, at the two ends of the corridor and in the service areas of the ward. During the first period, the air was sampled on a culture medium containing tryptone, yeast extract and serum with phenolphthalein phosphate as indicator (TY medium of Harding & Williams, 1969), and the plates were incubated aerobically at 37° C. overnight; colonies of *S. aureus*, detected after exposure to ammonia vapour, were subcultured for coagulase testing and for phage typing. During the second period the culture medium had in addition 1 % glucose and the plates were incubated anaerobically at 41° C. for 24 hr. (medium TYG of Harding & Williams, 1969). During the first period a maximum of about five colonies were chosen at random for phage typing; during the second period up to eight colonies were selected from plates with this number or more.

Air-flow determinations

Smoke tests to demonstrate the direction of the air flow through the doors of the bedrooms were carried out once a week during the period November 1966 to April 1967. Titanium tetrachloride was used as a source of the smoke (Williams, Blowers, Garrod & Shooter, 1966).

RESULTS

Pattern of air flow

The direction of air flow through the partly opened doorways of the bedrooms was determined on 20 days between November 1966 and April 1967. A total of 264 tests were made. In 171 (65 %) the air-flow was outward, from room to corridor, as planned. In 61 (23 %) the flow was indeterminate or different at the top

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and bottom of the doorway. In only 32 (12 %) was there a clear inward flow from corridor to bedroom. One room showed inward flow on five of 20 occasions and two others on four of 19 and 20 occasions respectively. On only one day was there an inward flow in as many as four roms. It has to be stressed that, for these tests, the room doors were partly open; they were ordinarily kept shut all the time except when someone was entering or leaving the room, so that even if the test showed corridor-to-room flow, this can only have happened intermittently.

Table 1. *Numbers of colonies of* Staphylococcus aureus *from ward air*

	No. of colonies per 24 hr. plate (0·36 m.² hr.)							
	0	1–	5–	11–	21–	51–	101+	Total
Occupied patient rooms								
No. with 0 type	98	—	—	—	—	—	—	98
No. with 1 type	—	77	11	13	10	18	20	149
No. with 2 types	—	24	15	3	8	1	4	55
No. with 3 types	—	0	3	3	1	1	0	8
No. with 4 types	—	0	0	0	0	0	1	1
Total	98	101	29	19	19	20	25	311
Service areas								
No. with 0 type	84	—	—	—	—	—	—	84
No. with 1 type	—	84	10	5	1	1	0	101
No. with 2 types	—	37	12	4	1	1	0	55
No. with 3 types	—	8	12	3	0	0	0	23
No. with 4 types	—	3	6	2	0	0	0	11
No. with 5 types	—	—	5	1	0	0	0	6
No. with 6 types	—	—	1	0	0	0	0	1
Total	84	132	46	15	2	2	0	281
Empty bedrooms								
Total	73	14	0	0	0	0	0	87
Grand total	255	247	75	34	21	22	25	679

Staphylococci in the ward air

The results from the first part of the study, in which the air was sampled rather sporadically, were analysed separately from those of the short period of comprehensive sampling, but differences between the two periods were very small and it will suffice to combine them for presentation.

A total of 311 plates were exposed in bedrooms occupied by patients (Table 1); only 98 (31 %) yielded no colonies of *S. aureus*; 101 (33 %) had 1–4 colonies and 25 (8 %) had more than 100, the highest count being about 800. The median count, determined graphically, was 4·6 colonies of *S. aureus* per plate exposed for 24 hr., or 13 col./m.² hr. In the service areas approximately the same proportion of plates yielded no *S. aureus* but on average the counts were lower than in the bedrooms, and no plate yielded more than 100 colonies; the median count was 2·5 col. per 24 hr. plate (7 col./m.² hr.).

Only one of the plates from occupied bedrooms yielded more than three different phage types of staphylococcus and on 149 (70 %) of the 213 positive plates all the

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colonies examined were of one type. In contrast, in the service areas only 52 % of the positive plates yielded a single type and 9 % of the plates yielded colonies of four or more distinct types. The rarity with which we found multiple types on the plates with very high staphylococcal counts is doubtless partly an artifact, deriving from the fact that we never picked more than 8 colonies for typing.

In considering the sources of the staphylococci recovered from the air, the different types isolated were scrutinized separately. Thus if a culture plate yielded 10 colonies of *S. aureus* and, of the 5 typed, 4 proved to be of one type and one of another, the results were treated as if we had had one air sample with 8 colonies and a second sample with 2. On this basis the 424 positive plates shown in Table 1 yielded the 667 'strains' considered in Table 2.

Table 2. *Numbers and apparent sources of* Staphylococcus aureus *from ward air*

	No. of single strains				
		On plates with (colonies/24 hr. or 0·36 m.^{2} hr.)*			
	Total	1–	6–	21–	101+
Occupied bedrooms, total	291	183	47	37	24
S. aureus of type carried					
By patient in room	127	36	31	37	23
By patient in other room	99	88	10	0	1
By patient in other room or staff	1	1	0	0	0
By staff, not patient	22	20	2	0	0
Source not found	38	38	4	0	0
Service areas, total	362	327	31	4	0
S. aureus of type carried					
By patient in ward	195	163	28	4	0
By patient or staff	8	8	0	0	0
By staff, not patient	35	33	2	0	0
Source not found	124	123	1	0	0
Empty bedrooms, total	14	14	0	0	0
S. aureus of type carried by patient in ward	11	11	0	0	0

* About half the plates were exposed for only 12 hr.; the counts on these plates have been doubled for entry into this Table.

In all but one of the cases where the number of colonies found on plates exposed in bedrooms was more than 20, the staphylococci were of the same type as that harboured by the patient in the room. The one example of major cross-contamination was observed on the first day of the study and was quite possibly due to retrograde spread of air, from a neighbouring room in which there was a patient who was a very active disperser, along the cool-air ventilation duct. Subsequently a filter was installed in the duct to prevent this occurrence.

With low counts, the staphylococci seemed very frequently to have been derived from a patient in another room. Similarly, staphylococci on plates exposed in service areas were, in half the cases, of a type harboured by one of the patients

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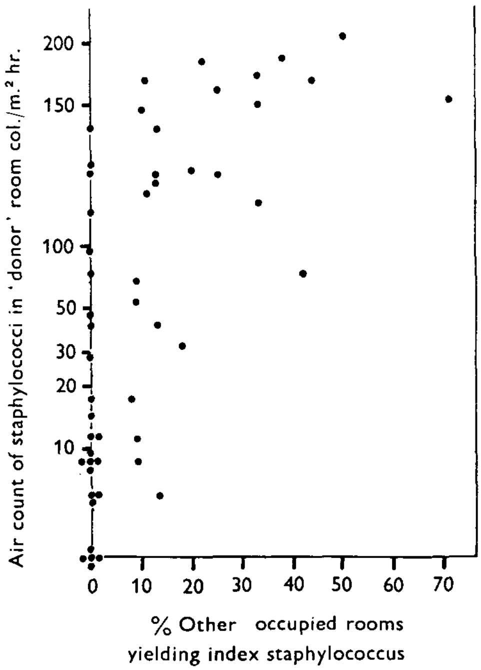
present in the ward at the time. Strains of types carried by members of the staff were found both in bedrooms and in service areas but not very frequently, nor ever in large numbers.

During the study there were 15 patients in the ward who at some time dispersed staphylococci to give air counts in their rooms in excess of 20 col. per plate in 24 hr.; it is these patients who were responsible for most of the spread to other rooms (Figs. 2, 3).



Fig, 2

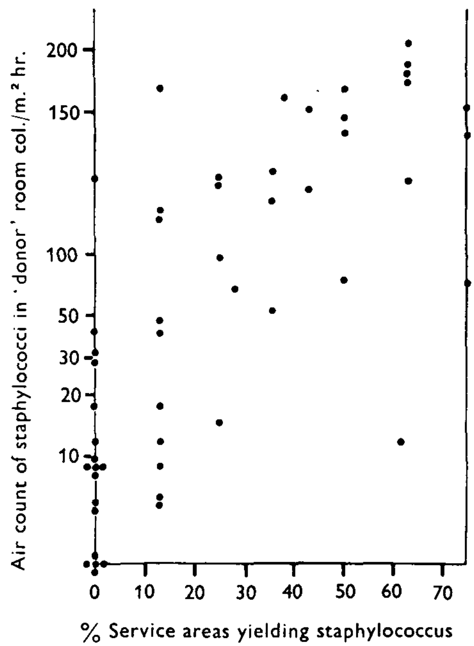


Fig. 3

Fig. 2. Spread of staphylococci from one bedroom to another.

Fig. 3. Spread of staphylococci from bedrooms to service areas.

In Fig. 4 an attempt is made to measure the degree of protection against air-borne staphylococci provided by the ward design. Line *A* gives the cumulative distribution of staphylococcal air counts generated by carriers within their bed-rooms. Line *B* gives the distribution of counts from other bedrooms for staphylo-cocci of the types being dispersed by the carriers. The counts in the recipient rooms appear to be about 1/500th of those in the donor rooms. This is much less than was found in a partially subdivided ward in this hospital (Williams, 1967).

In an attempt to track the mode of spread from one patient room to another, we compared the frequency of cross-contamination of air from rooms occupied by carriers who shed *S. aureus* into the air of their own rooms to other rooms at the two ends of the corridor (cf. Fig. 1). For this analysis, which was based entirely on the second period of air sampling (cf. p. 651), we excluded all occasions when the same phage type of staphylococcus was known to be harboured by more than one patient. Since there were commonly two or more dispersers, of different types,

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present at one time the 'number of plates examined' quoted in Table 3 includes, as separate 'plates', the successive examinations of the same plate for different types of staphylococci. Cross-contamination was certainly most frequent in nearby rooms, and these observations would be compatible with the idea that it was leakage of air from the corridor that accounted for the staphylococci found in the air of the bedrooms. Presumably, however, the opportunities for transfer by personnel would also be greater between nearby than between distant rooms.

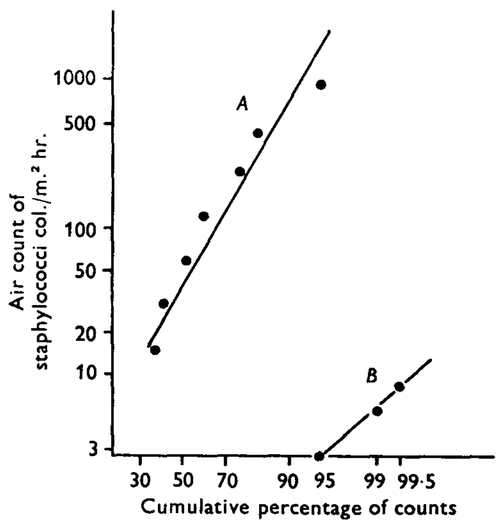

Fig. 4. Comparison of air counts in dispersers' rooms (upper line) with count for same staphylococci in other rooms (lower line).

Table 3. *Spread from rooms occupied by* Staphylococcus aureus *shedders*

	Plates examined	Percentage yielding *S. aureus* of patient's type
Occupied bedrooms		
At the same end of corridor	106	29·3
At other end of corridor	129	17·1
Corridor or 'sluice'		
At the same end of corridor	46	74·0
At other end of corridor	47	25·6

* For this table, 'shedders' were defined as patients who were nasal carriers of *S. aureus*, and whose staphylococci were found in the air of their own room and at least one other room or ward area.

Acquisition of Staphylococcus aureus *by patients*

There was no change in the mean nasal carrier rate for *S. aureus* with increasing length of stay in the ward (Table 4), such as has been observed in open surgical wards (e.g. Williams *et al.* 1959). Unfortunately the staphylococci were not all tested for antibiotic sensitivity so we cannot judge whether there was an increase

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in the carrier rate for resistant strains (cf. Lidwell, Polakoff, Jevons & Parker, 1966).

Thirteen patients appeared to acquire staphylococci in the nose during their stay in the ward; two patients seemed to acquire two strains each and one acquired three strains so that the total number of apparent acquisitions was 17. In 11 cases of the 17 a staphylococcus was found in the nose of a patient who had two previous swabs that yielded either no staphylococci, or cocci of a different phage type ('probable acquisitions'); in the rest there was only one negative or different culture ('possible acquisitions'). In all 13 cases for which the sensitivity results were available the new strain was sensitive to tetracycline.

Table 4. *Nasal carrier rates for* Staphylococcus aureus

Week of swabbing	No. patients examined	Percentage carrying *S. aureus*
1	197	38·1
2	117	33·3
3	90	32·2
4	60	31·7
5	41	41·5
6	30	36·7
7	24	33·3
8	20	35·0
9, 10	27	37·0

The 17 apparent acquisitions were observed among the 409 second or subsequent examinations of the patients; they represent a rate of 4·2 per 100 patient weeks at risk. The 11 more certain acquisitions represent a rate of 2·7 per 100 patient weeks.

Five of the 11 probable acquisitions were with staphylococci of a phage type known to be carried by another patient present in the ward and one was of a type found in the ward air but not in any person; for the six possible acquisitions the corresponding figures were 1 and 1. No source was known for eight acquisitions, and one of the 'probably acquired' strains was untypable. Thus acquisitions from recognized sources totalled 6, a rate of 1·3 per 100 patient weeks at risk, and acquisitions with no recognized source were 11, or 2·8 per 100 patient weeks.

There were five patients who appeared to acquire *S. aureus* in a wound during their stay in the ward and a further five patients who possibly acquired *S. aureus* in a wound. The staphylococci from two of the former were of a type not known to have been present in the ward previously; those from the remaining three were of the same type as had been present in the patient's own nose for some time previously. Two of the last three patients were active dispersers of their staphylococci; the third was one of the patients who had acquired the staphylococcus in her nose during her stay in the ward. One of the five patients for whom the evidence of ward-acquired infection was scanty was infected with a staphylococcus that was probably the same type as a strain carried by a ward orderly. No carriers were found as possible sources for two strains and the remaining two were lost before they could be typed.

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DISCUSSION

The main object of providing separate rooms for isolation nursing is to reduce the risk of airborne transfer of infection from one room to another, though doubtless this form of isolation also reduces the risk of transfer on fomites and probably has an important psychological effect in reminding staff of the perennial need for strict aseptic precautions. The study reported here was limited to the spread of staphylococci because there is evidence that these bacteria are conveyed between patients by the air, at least to set up nasal carriage, and because the necessary bacteriological techniques have been well developed.

The air sampling revealed low counts of *Staphylococcus aureus* in the patients' rooms: the median was about 4·6 per plate in 24 hr. or about 13 col./m.^{2} hr. This is not very different from the figure observed in a subdivided surgical ward in this hospital (Williams, 1967) but is lower than the figure from open surgical wards, where counts of 40 col./m.^{2} hr. have been observed. The mean nasal carrier rate among the patients was no lower than observed in previous studies so that lack of sources for dispersal cannot be the explanation of the low air counts.

There was some spread of staphylococci from one room to another, and it is presumed that this was by way of the air, although it is impossible to exclude that some may have been transferred on the person of members of the staff moving from room to room. Nevertheless the average count of staphylococci in the air of 'recipient' rooms seemed to be only about 1/500th of that in the room containing the patient dispersing the cocci.

Lidwell *et al.* (1966) have examined the relationship between the number of staphylococci inhaled and the acquisition of the nasal carrier state and have shown that the slope of the dose-response curve is very low, that is that a very substantial reduction in the dose inhaled is needed to effect much reduction in the acquisition rate. Our estimates of acquisition in the nose were not entirely satisfactory, but they indicate a rate between 2·7 and 4·2 per 100 patient weeks at risk, which is substantially less than the rates of about 9 per 100 patient weeks observed in a series of medical wards (Public Health Laboratory Service, Report, 1965) and in the wards at the Queen Elizabeth II Hospital, Welwyn Garden City (Lidwell *et al.*, in preparation) and may be compared with the rate of 3·4 per 100 patient weeks recorded in a subdivided surgical ward by Lidwell *et al.* (1966), the 5·9 per 100 patient weeks observed in a subdivided ward at St Mary's Hospital (Williams, 1967) or the 6·3 per 100 patient weeks observed by Parker, John, Emond & Machacek (1965) in a fully subdivided isolation hospital ward. The fact that the staphylococci that were acquired were all, in so far as they were tested, sensitive to tetracycline, suggests that a large proportion of the acquisitions may have been spurious in the sense used by Parker *et al.*

SUMMARY

Studies were made of a 14-room isolation ward in which the bedrooms were provided with individual ventilation units to provide a slight positive pressure within the rooms. Airborne staphylococci were detected with sedimentation plates.

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The median count of *Staphylococcus aureus* in the occupied bedrooms was 4·6 col. per 14 cm. plate exposed for 24 hr. or 13 col./m.^{2} hr. When the air count was high virtually all the staphylococci proved to be of the phage type harboured by the patient in the room; with low counts a substantial proportion were apparently derived from patients in other rooms.

The apparent rate of acquisition of *S. aureus* in the nose of the patients was between 2·7 and 4·2 per 100 patient weeks at risk. This is substantially lower than has commonly been observed in open wards.

We are very grateful to Miss M. A. Adams, Sister in charge of the Almroth-Wright isolation Ward, and all her staff for all their help and co-operation during this study, which was supported by funds provided to St Mary's Hospital by the Ministry of Health for clinical research.

The reconstruction of the ward was designed by Mr A. Stableford, Group Engineer to St Mary's Hospital; the ventilation units were designed and supplied by White Bays and White Ltd., London.

REFERENCES

Harding, L. & Williams, R. E. O. (1969). Selection of *Staphylococcus aureus* in cultures from air samples. *J. Hyg., Camb.* **67**, 35.

Lidwell, O. M., Polakoff, S., Jevons, M. P. & Parker, M. T. (1966). Staphylococcal infection in thoracic surgery: experience in a subdivided ward. *J. Hyg., Camb.* **64**, 321.

Parker, M. T., John, M., Emond, R. T. D. & Machacek, K. A. (1965). Acquisition of *Staphylococcus aureus* by patients in cubicles. *Br. med. J.* i, 1101.

Public Health Laboratory Service. Report (1965). Infections acquired in medical wards. *J. Hyg., Camb.* **63**, 457.

Sub-Committee on Aseptic Methods in Operating Theatres, M.R.C. Committee on Hospital Infection. Report (1968). Aseptic methods in the operating suite. *Lancet* i, 705.

Williams, R. E. O. (1967). Airborne staphylococci in the surgical ward. *J. Hyg., Camb.* **65**, 207.

Williams, R. E. O., Blowers, R., Garrod, L. P. & Shooter, R. A. (1966). *Hospital infection.* London: Lloyd-Luke.

Williams, R. E. O., Jevons, M. P., Shooter, R. A., Hunter, C. J. W., Girling, J. A., Griffiths, J. D. & Taylor, G. W. (1959). Nasal staphylococci and sepsis in hospital patients. *Br. med. J.* ii, 658.

EXPLANATION OF PLATE

A. The ventilation unit, bedroom side.
B. The ventilation unit, corridor side.

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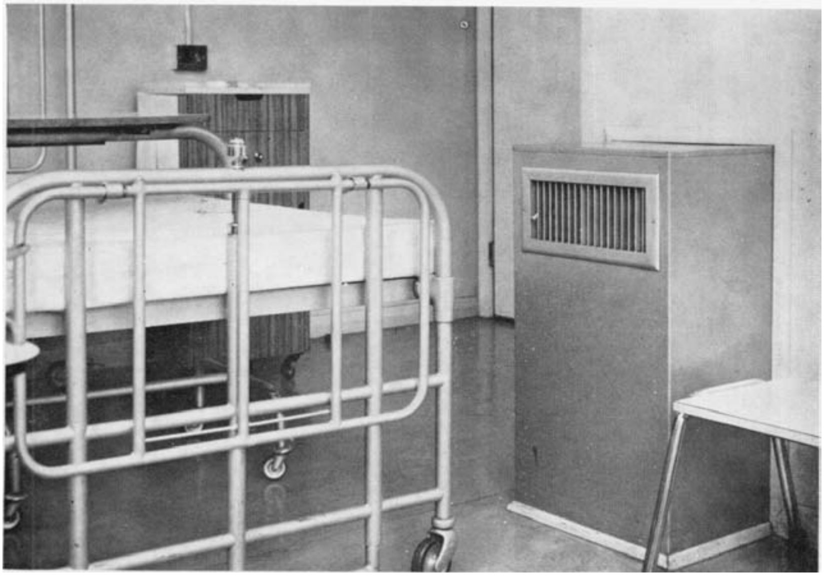

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B

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