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Airborne staphylococci in the surgical ward

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The exposure of hospital patients to airborne staphylococci has commonly been estimated by collecting the bacteria from relatively large volumes of air over rather short periods with the use of one or other form of slit-sampler (Report, 1948). The design of the slit sampler was determined largely by the need to collect particles down to about 1–2 μ in diameter, for which collection by sedimentation on to exposed culture plates is very inefficient (Bourdillon, Lidwell & Thomas, 1941), and it therefore employs a high velocity jet of air impinging on the culture plate. While the slit sampler is a very efficient instrument for collecting airborne particles, it has proved difficult to modify it to give really long-period sampling because of the drying effect of the air-stream on the agar plates. Recently it has been shown that only a very small proportion of the staphylococci in the air of hospital wards are associated with particles less than 4 μ in diameter (Noble, Lidwell & Kingston, 1963) and that the median equivalent particle diameter for airborne staphylococci is about 14 μ. For such particles the deficiency of sedimentation as a method of collection is small: the settling rate of 14 μ particles is such that the number contained in 1 ft.^{3} of air is approximately equal to the number that settle on 1 ft.^{2} in 1 min. Since with settling plates it is simple to obtain an integrated sample over a considerable number of hours, it seemed worth exploring the use of this method to monitor the staphylococcal content of the air in hospital wards, as has also been reported by Alder & Gillespie (1964). This paper describes a study in a small surgical ward in which an attempt was made to recognize the sources of the airborne staphylococci and to use the method to study cross-contamination between the separate rooms of the ward.

MATERIALS AND METHODS

Almost all the work reported here was done in a 14-bed surgical ward at St Mary's Hospital London between February 1964 and September 1965; the ward is divided into 4 rooms (Fig. 1) and is used mainly for men and women undergoing thoracic and cardiac surgery. The ward has natural window ventilation; the corridor between the rooms leads to a stairway and the stack effect in this generates a flow of air along the corridor and out of the bedrooms in almost all weathers.

A much shorter study was made in a 22-bed open 'Nightingale' ward, using 4 settling plates placed in the 4 quarters of the ward.

Bacteriological methods

Air sampling

Six-inch diameter Petri dishes of nutrient agar containing 5 % horse serum and 0·01 % phenolphthalein phosphate were exposed on brackets fixed to the wall about 5–6 ft. from the floor. During an initial period of 2 months, 3 plates were used to cover the 24 hr.; subsequently 2 plates were each exposed for 12 hr. and later still, when it was found that the counts on the night and day plate were very

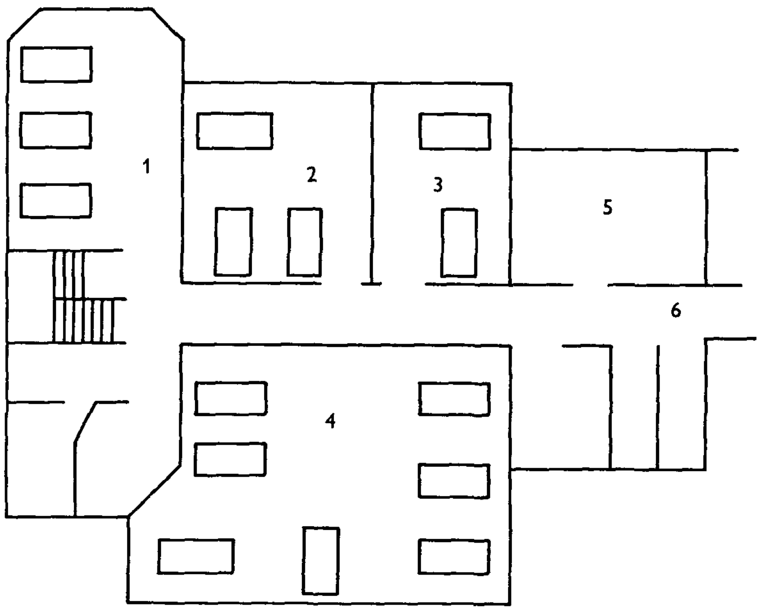

Fig. 1. Diagram plan of ward studied. Rooms 1–4 are bedrooms, 5 is the ward office and 6 is a corridor.

Table 1. *Settling plate counts from different periods of day*

	Period of exposure	*S. aureus* (c.f.u./0·2 ft.^{2}/hr.)
24 Feb.–1 April 1964	6.0 a.m. to 3.0 p.m.	0·99
	3.0 p.m. to 9.0 p.m.	0·75
	9.0 p.m. to 6.0 a.m.	0·66
3 May–25 Sept. 1964	3.0 a.m. to 3.0 p.m.	0·22
	3·0 p.m. to 3.0 a.m.	0·23

Note: By chance there was a very considerable broadcast of staphylococci during the earlier months.

similar (Table 1) a single plate was exposed from 3.0 a.m. to 3.0 p.m. each day (except Saturday and Sunday). For a great part of the survey, plates were also exposed in the ward office to detect dispersal from staff.

The plates were incubated at 37° C. for about 20 hr. and then examined after exposure to ammonia vapour. Colonies showing a bright pink colour were counted

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and a sample of them was subcultured for coagulase testing; during most of the study a maximum of 2 or 3 colonies were picked at random from each plate. Coagulase-positive staphylococci were tested for sensitivity to tetracycline, using a 10 μg. disk, and for phage type, using the phages recommended by the International Subcommittee (see Parker, 1962) together with three experimental phages D, 77 Ad (now 84) and B 5 (now 85).

The term *Staphylococcus aureus* is used for coagulase-positive staphylococci but where 'staphylococci' are referred to without qualification, it is *S. aureus* that is meant.

Carrier surveys

All the 307 patients entering the ward had nasal swabs taken and examined for staphylococci on admission and subsequently once a week; for the first few months the patients also had swabs taken from the skin of the front of the chest. The nursing and medical staff of the ward had hand swabs examined weekly. Nasal swabs from the staff were examined during only the first 2 months.

RESULTS

Numbers of Staphylococcus aureus *in the air*

The air counts from all the 4 rooms of the ward for the whole study have been pooled and their distribution is shown in Fig. 2. The counts are plotted logarithmically with a 'probability' scale for the abscissa. The fact that the points fall so close to a straight line indicates that the logarithms of the counts are effectively normally distributed. The median count was 2·6 colony forming units (c.f.u.)/ft.^{2}/24 hr.; 20 % of counts exceeded 11, and 10 % exceeded 24 c.f.u./ft.^{2}/24 hr. The volume of air inhaled by a normal adult in 24 hr. is about 480 ft.^{3}; the median number of staphylococcal particles inhaled by the patients in the ward (on the volume: settling count ratio already noted) was therefore about 4 in 24 hr., with 100 being inhaled on some 3 % of days.

Broadcasts of staphylococci

The day-to-day variation in the air counts was considerable (Fig. 3). At most times the number of staphylococci recovered from the air was less than 25 c.f.u./ft.^{2}/24 hr. but there were 32 periods during which the air count in one or other of the rooms was 50 c.f.u./ft.^{2}/24 hr. or more (Table 2). In most cases the staphylococci found during such 'broadcasts' were almost all of one phage type: in 19 of the 29 shown in Fig. 4, 80 % or more were of one type. Of the total of 32 incidents, 29 appeared to represent dispersal of a single staphylococcus type, 2 were probably made up of two simultaneous dispersals. In the last the peak in the air count was constituted by 4 different types and is not therefore considered further as a 'broadcast'.

Many of the broadcasts lasted only 2 or 3 days and there was little correlation between duration and the number of staphylococci recovered from the air (Fig. 5).

It was possible to recognize a single person, patient or staff, as the probable

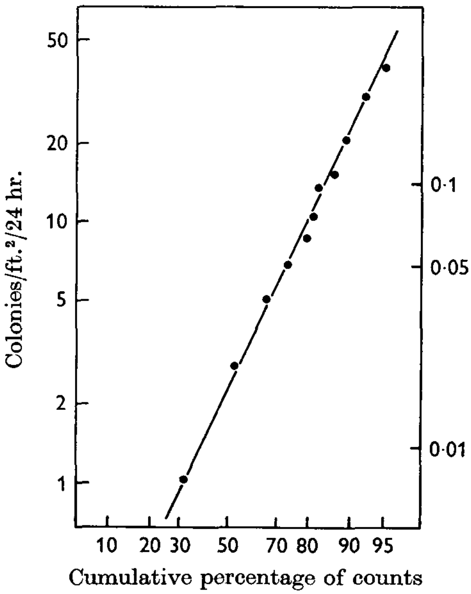

Fig. 2

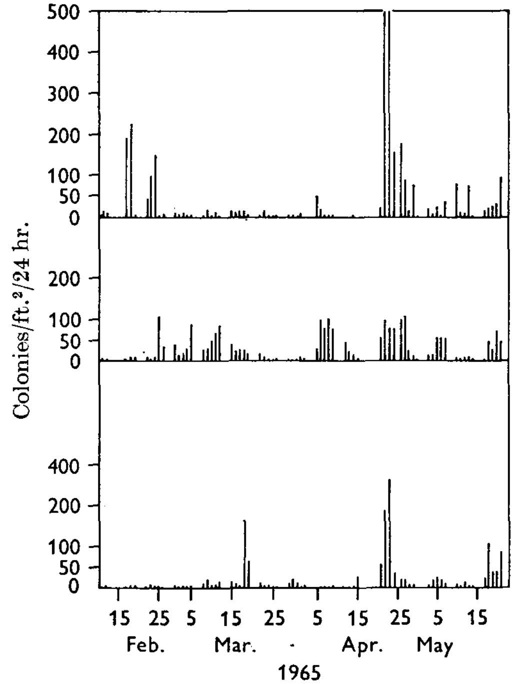

Fig. 3

Fig. 2. Frequency distribution of counts of *Staphylococcus aureus* in the air of the ward (from Williams, 1966; reproduced by kind permission of the Editor of *Bacteriological Reviews*).

Fig. 3. Daily air counts in 3 of the 4 rooms in the ward (from Williams, 1966; reproduced by kind permission of the Editor of *Bacteriological Reviews*).

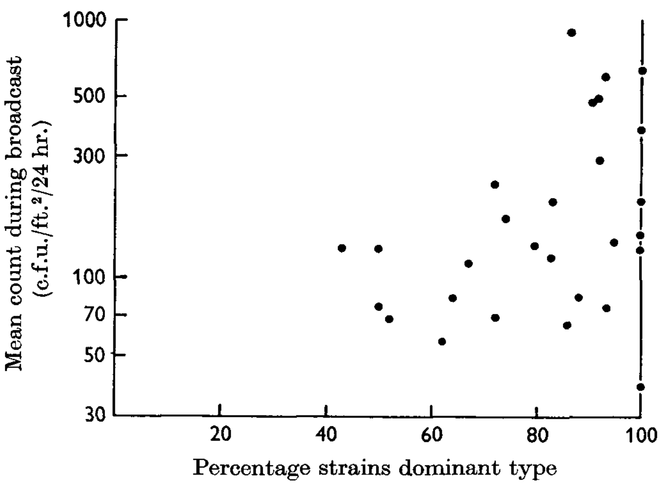

Fig. 4. The prevalence of single phage types of staphylococci during broadcasts (3 broadcasts in which fewer than 5 strains were typed have been omitted)

Table 2. Broadcasts of staphylococci

No.	Duration (days)	Type	Tetracycline resistance	Dominant type: No./no. typed	Dominant type: Mean c.f.u./ft.²/24 hr.	Source of broadcast
1	24	29	S	49/54	375	P/N (W)
2	8	80	ND	5/6	165	P/N
3	8	3C/55/71	S	12/12	37	P/N
4	8	6/47/53/54/75/83A	R	14/15	71	P/N
5	5	83A/+	R	12/12	365	P/NW
6	2	*NT*	S	8/9	98	Not found
7a	2	52/7/47/75+	S	4/8	64	Not found
7b		85	R	3/8	55	Not found
8	2	*77*	S	7/14	39	Not found
9	1	52/52A/80/81	S	10/10	125	P/N
10	17	47/53/54/75/83A/81	S	46/62	123	P/N
11	5	6/7/47/53/54/75/+	S	7/8	84	St/N
12	3	*NT*	ND	12/23	72	(Several possible carriers)
13	3	*NT*	S	5/7	67	(2 possible carriers)
14	2	*NT* (Inh)	R	5/5	240	P/Sp
15	9	75/77	R	7/11	35	P/N
16a	1	*NT* (Inh)	R	1/2	80	P/N
16b		75/77	R	1/2	80	P/N
17	2	6/47/53/54/75/77	S	3/3	113	St/N
18	15	81	R	22/24	260	P/N
19	2	*29*	ND	6/6	145	Not found
20	15	81	R	14/22	53	P and St/N
21	2	*NT*	S	5/7	161	P/N
22	9	80/81/+	R	16/20	93	P and St/N
23	9	85	R	14/16	784	Not found
24	3	81	R	5/6	97	St: several/N
25	9	85	R	13/14	656	P/N
26	3	77/+	S	4/6	75	P/N (W)
27	1	85	R	2/2	1000	P/N
28	29	85	R	40/40	622	P/N (W)
29	8	*(29)*	S	11/12	450	P/N
30	3	4 types	—	6 typed	—	—
31	11	(29)	S	21/22	164	P/N
32	3	52A/6/42E/47/54/75/83A/81/+	S	6/7	55	P/N

Broadcasts 11 and 17; 14 and 16*a*; 15 and 16*b*; 21, 29 and 31; 25, 27, and 28 were each due to single persons; one doctor was probably involved in broadcasts 20 and 24, having been infected during broadcast 18.

Under source: P, patient; St, staff member; N, nasal carrier; W, wound infection; (W), wound infection developing during the course of the broadcast; Sp, sputum infection.

source for 22 of the 33 distinguishable broadcasts, and for 3 others there were 2 or more alternative sources in the ward. Recognition of the sources was often facilitated by the fact that the airborne staphylococci did not appear to spread to any great extent from one room to another (see below). It is possible that members of the staff would have been implicated more often if they had been examined for carriage more effectively, but it was noticeable that, in the broadcasts for which staff were thought to be responsible, staphylococci of the relevant type were found in substantial numbers in all the rooms of the ward and in the ward office (e.g. broadcasts 11 and 17). In only 8 cases was no source definitely recognized and in 2 of these there were actually some nasal carriers present in the ward but the evidence implicating them as the source of the broadcast was poor.

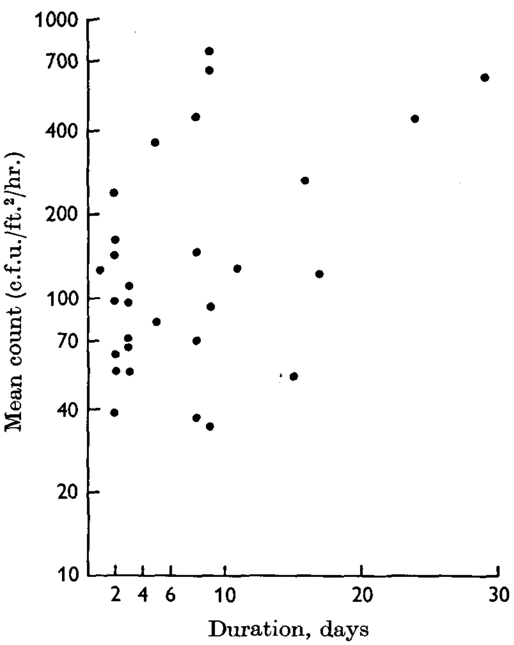

Fig. 5

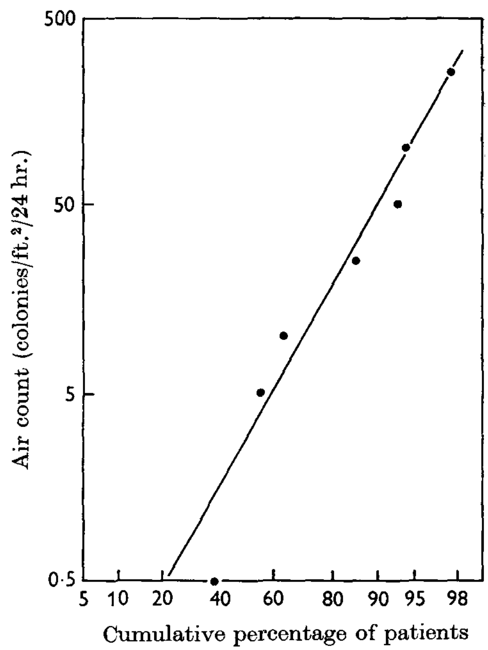

Fig. 6

Fig. 5. Relation of staphylococcal air count during broadcast to duration of broadcast.

Fig. 6. Air counts generated by patients admitted as nasal carriers of staphylococci (from Williams, 1966; reproduced by kind permission of the Editor of *Bacteriological Reviews*).

The broadcasts of tetracycline-resistant staphylococci had a tendency to be greater than those of sensitive strains (Table 2), in that the median values of the mean counts were 150 and 100 respectively.

Twenty of the presumed dispersers were patients and 15 of the 20 were symptomless nasal carriers of the staphylococcus and had no infected lesion of any sort; in none of the remaining 5 was there good reason to think that the infected lesion was the source of the airborne staphylococci. None had a pressure sore. Six individuals (4 patients and 2 doctors) were each involved in more than 1 broadcast and were

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between them concerned in 14 of the total of 33 broadcasts. Six of the 16 patients thought to be responsible for broadcasts had acquired their staphylococci in hospital, as had both doctors; 12 of the patients dispersed staphylococci that they carried on admission to hospital and for which there was no indication of acquisition during a previous hospital admission.

During the whole study 85 patients were found, at first examination after admission, to be nasal carriers of a strain of *S. aureus* for which there was no known source already present in the ward. Staphylococci of the same phage type were found in the air of the ward during the ward stay of 53 of these patients; the mean air counts recorded during their stay in the ward are shown in Fig. 6. About 10% of the patients generated air counts that averaged more than 50 c.f.u./ft.^{2}/24 hr.

In order to assess the sources of airborne staphylococci, the possible sources for each of the various types isolated in each of the 64 weeks were scrutinized; a carrier was recognized among the patients present in the ward for about 30% of the isolates.

Table 3. *Spread of staphylococci between rooms*

Count in rooms not source of broadcast as % of count in source room	No. of broadcasts	Mean count in source rooms (c.f.u./ft.^{2}/24 hr.)
< 1	8	55, 75, 80, 125, 161, 164, 260, 1000
1–5	5	123, 240, 375, 450, 622
6–10	5	71, 80, 165, 365, 656
11–15	2	35, 37

Incidents during which there were carriers of the broadcast type in non-source rooms are excluded

Spread of airborne staphylococci between the rooms

The simultaneous air sampling in all 4 rooms of the ward enables us to make some assessment of the transfer of airborne bacteria from one room to another.

Of the 33 broadcasts there were 20 in which a single patient was presumed to be the source. The mean count of the index staphylococcus in the 3 rooms other than that harbouring the source is shown in Table 3. In over half the incidents the count in the 'recipient' rooms was 5% or less of that in the 'source' room. Further examination of the records did not reveal any consistent differences between the individual rooms.

In the open surgical ward there was much less difference between the counts on the 4 plates that were exposed: when a high count was observed on one plate, the count on the plate 20 ft. distant averaged 26%, and that on the plate 70 ft. distant averaged 11% of the 'high-count' plate.

Acquisition of the nasal carrier state

The rate of acquisition of *S. aureus* in the nose during hospital stay has frequently been documented and has been suggested as one index of the efficiency with which a hospital layout can protect patients from cross-infection (Parker, John, Emond & Machacek, 1965; Williams, 1966; Lidwell *et al.* 1966). In our ward 6·2% of patients were found to harbour tetracycline-resistant staphylococci at first swabbing (0–6 days after admission to the ward); the patients examined after 4 weeks' stay in the ward had a rate of 13·2 % (Fig. 7). The carriage rate for tetracycline-resistant strains on admission is certainly higher than would be found in the normal population because many of the patients had had previous admissions to hospital. It is of some interest that the carrier rate for all staphylococci declined from 31·3 to 26·4 % during the 5 weeks.

Analyses of the potential sources of infection for the 53 patients who acquired typable staphylococci in the nose have been cited elsewhere (Williams, 1966); they showed that staphylococci of the relevant type had been present in the air before the acquisition in 34 cases (64 %).

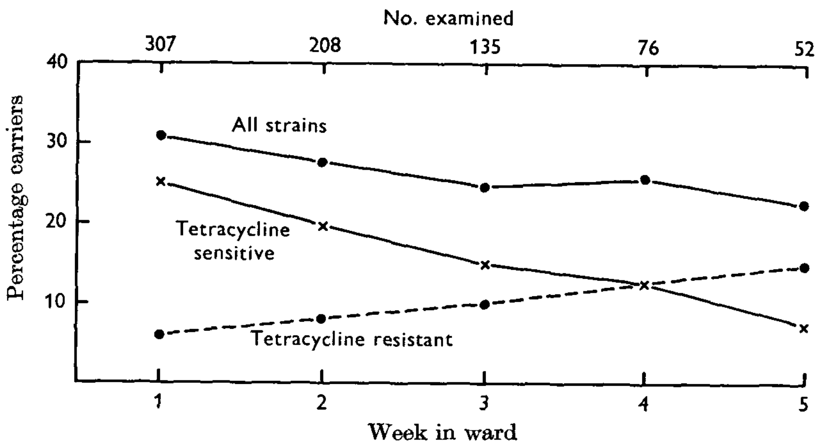

Fig. 7. Nasal carrier rates for *Staphylococcus aureus* after varying periods of stay in the ward. Patients swabbed in week 1 had been in the ward 1–6 days, those swabbed in week 2, 7–13 days, etc.

It has not proved possible to relate the acquisition to the air counts in the ward rooms because patients were moved from one room to another very frequently.

During the survey 4 patients developed wound sepsis due to staphylococci that they apparently acquired while in the hospital. None of these acquisitions occurred during a recognized broadcast and in only one case had the staphylococcus been found in the air prior to the appearance of the wound infection. One other patient who as a carrier was the source of an extensive broadcast (1 in Table 2), developed wound infection with his own strain late in the incident.

DISCUSSION

One of the biggest problems facing those who are concerned with the prevention of cross-infection in a hospital is to find simple ways of predicting trouble; and one of the biggest problems facing those who are asked to advise on the 'hygienic' design of hospital wards is to discover ways in which the efficiency of any particular design can be assessed. Bacterial air sampling seems to have some attractions as an index that might be helpful in attacking both these problems.

There is good evidence that on some occasions, individuals who shed large numbers of *S. aureus* into the environment are the sources of epidemics of infection (e.g. Shooter *et al.* 1958; Blowers, Mason, Wallace & Walton, 1955; Murley, 1965). However most of the dispersers that we recognize among patients in surgical wards seem to be remarkably harmless; in the present study none of the recognized dispersers gave rise to any clinically infected lesions in other people and, more significantly because of the greater number exposed, only one of the 8 very heavy dispersers recorded by Noble (1962) produced an epidemic. In Noble's study this was probably because most of the heaviest dispersers harboured staphylococci lacking in 'virulence' or 'communicability', for the one carrier who caused an epidemic was the only one who had a staphylococcus resistant to penicillin and tetracycline —a pattern very commonly seen in strains that cause epidemics (see Williams, Blowers, Garrod & Shooter, 1966). In the present study the danger of the heavy dispersers was difficult to assess because of the small number of patients exposed to each disperser; half the broadcast strains were tetracycline-resistant, and several of them belonged to phage types known to cause epidemics.

Alder & Gillespie (1964) have suggested that routine examination of ward air, with methods similar to those adopted here, may be useful in indicating potentially dangerous dispersers. Our own results, here and in previous work (Shooter *et al.* 1958; Noble, 1962) suggest that a count of all staphylococci would not be useful because so many dispersers shed what appear to be quite harmless staphylococci. The method might well be useful if it could be made selective for the more virulent staphylococci, but before it is adopted for this purpose we need to have some measure of the frequency with which heavy dispersers of virulent staphylococci recognized in this way subsequently give rise to infections, and what proportion of clinical infections are due to such dispersers.

I have discussed elsewhere (Williams, 1966) the reasons for thinking that the airborne route makes an important contribution to the spread of staphylococci within hospitals and that the non-symptomatic nasal carriage that commonly results is important as the continuing reservoir of hospital staphylococci. One of the desirable features of a ward design should therefore be its contribution to reduction of the airborne spread of staphylococci. This can be detected by air sampling and from this aspect, the frequency of relatively harmless dispersers is an advantage, since it means that there is generally a good supply of staphylococci whose spread can be determined.

For either of these purposes, the use of sedimentation plates seems to have a considerable advantage over the use of mechanical air samplers and, in a long term experiment, few disadvantages.

The rather low rate at which our patients acquired staphylococci in the nose is of interest. It may be compared with the much higher rates recorded in earlier studies at St Bartholomew's Hospital (Williams *et al.* 1962; Noble, Williams, Jevons & Shooter, 1964) where the patients were nursed in open wards, and in recent studies (unpublished) at the Queen Elizabeth II Hospital, Welwyn, where the wards are divided into bays opening widely off a corridor. Recent studies in a subdivided ward at St Bartholomew's Hospital, like the ward studied here used for patients having thoracic surgery (Lidwell *et al.* 1966), have shown a low acquisition rate similar to ours. In both wards there was a fairly high usage of antibiotics, but, presumably because the subdivision has reduced the rate of transfer of the staphylococci in some way, this has not had the effect of increasing the carrier rate in the way that it did in the patients nursed in open wards (Noble *et al.* 1964).

SUMMARY

The air of a subdivided surgical ward was sampled by the exposure of culture plates for 12 hr. periods 5 days a week.

A number of 'broadcasts' of airborne *Staphylococcus aureus* were observed; many of these were of very short duration. A single person could be recognized as responsible for 22 of the 33 broadcasts; in all cases dispersal seemed to be from carrier sites rather than from infected lesions.

There was little spread of the staphylococci between the 4 rooms of the ward. The frequency of nasal carriage of tetracycline-resistant *S. aureus* increased from 6·2 % in patients examined during their 1st week to 13·2 % in those examined in their 4th week in the ward; the rate for all *S. aureus* declined from 31·3 to 26·4 %.

It is suggested that the long-period exposure of culture plates for the collection of airborne staphylococci may be useful in monitoring some aspects of hospital hygiene.

I am very grateful to Miss B. A. Wimble and Mrs S. Edser for technical assistance; to Sister Jessie Munro and her staff for their support and help in the ward, and to Mr L. L. Bromley for the permission and encouragement to study the patients under his care. The work was supported by a generous grant from the Endowment Funds of St Mary's Hospital.

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