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Nasal acquisition of *Staphylococcus aureus* in a subdivided and mechanically ventilated ward: endemic prevalence of a single staphylococcal strain

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SUMMARY

An investigation was made of nasal acquisition of *Staphylococcus aureus* and of staphylococcal wound sepsis in a hospital ward divided into two sections and provided with mechanical ventilation, so that there was no transfer of air from one of the sections to the other. Although the strains of *S. aureus* found in the air, and those colonizing the noses of patients, in the protected section could seldom be related to patients nursed elsewhere in the ward, the mechanical ventilation did not lead to any significant reduction in the degree of contamination of the air or in the rate of nasal acquisition of *S. aureus*.

Even in the protected section, nearly 20 % of the strains of *S. aureus* recovered from the air could not be related to known nasal carriers. Since this proportion was nearly as great as that found in the absence of directed air-flow, it seems probable that these strains were derived either from undetected sources within the section or were dispersed from the clothes of persons who entered it.

Nearly one-third of the nasal acquisitions in the ward could not be related to known nasal carriers, but about one-half of these (16 %) were probably 'spurious' and half of the remainder (8 %) could be related to strains recovered from patients' lesions or drawsheets, leaving no more than 8 % unaccounted for. A short investigation in which both drawsheet and perineal samples were examined showed that drawsheet samples did not give a reliable indication of perineal carriage unassociated with nasal carriage.

During the period of the investigation, a single strain of *S. aureus* that was resistant to a wide range of antibiotics established itself in the ward. The most notable character of this strain was the profuse dispersion of it by carriers. As a consequence, staphylococcal wound sepsis increased, with nearly three-quarters of

the infections attributable to this strain, and nasal carrier rates increased with length of stay in the ward, over 20 % of patients who stayed 5–6 weeks acquiring the strain.

INTRODUCTION

In an attempt to reduce the incidence of wound sepsis, part of which we thought might be due to pre-operative acquisition of hospital strains of *Staphylococcus aureus*, a male surgical ward was divided into two parts by a wood and glass

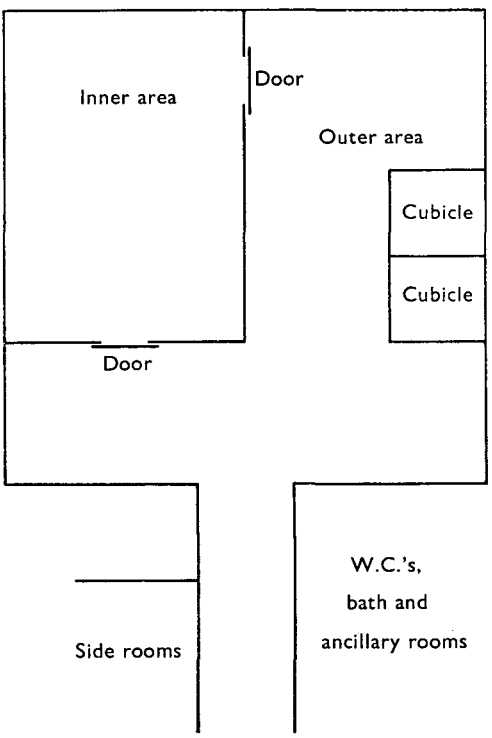

Fig. 1. Schematic plan of the ward.

partition reaching from floor to ceiling (Shooter *et al.* 1963). As far as possible, patients were admitted to the inner part before operation and transferred to the outer area after operation (see Fig. 1). Nasal acquisition of tetracycline resistant strains occurred twice as often among patients in the 'post-operative' (outer) area as among those in the 'pre-operative' (inner) area. However, the natural air movements in the ward resulted in substantial exposure of patients in the inner area to airborne strains dispersed by patients in the outer area and, in fact, about half of the nasal acquisitions by patients in the inner area that could be referred to particular patient sources appeared to be derived from patients in the outer area.

Later, we tried to prevent airborne transfer of staphylococci between the two parts of the ward by means of mechanical ventilation, first of the inner area only and later of both sections of the ward. We now report the results of the following experiments.

(1) To prevent the airborne transfer of staphylococci from the outer area to the inner, mechanical ventilation of the inner area was installed with an input of filtered fresh air, equivalent to about 10 air changes per hour, introduced through ceiling diffusers. The excess air escaped into the outer area of the ward around the edges of the floors and through grilles beside them. Even when the doors between the two parts of the ward were opened the direction of air flow was consistently outwards from the inner ventilated section. Observations were carried out with this arrangement from March 1963 until December 1964, and during this time the plant was out of action only for four periods each of less than 24 hr.

(2) Any apparent effects of this combination of ventilation and subdivision might, however, be attributable to the provision of a positive ventilation system in the inner area rather than to the separation of the two parts of the ward. The ventilation plant was therefore extended so that a separate supply of filtered fresh air was provided at approximately ten air changes per hour to each part of the ward. An air outlet, via a disused chimney, carried part of the input to the inner area directly out of the building but a substantial fraction escaped, as previously, into the outer area of the ward. Observations were made from February 1966 until June 1967, but during this period the ward was closed for cleaning for 4 weeks and part or all of the ventilating plant was out of action on eight occasions for periods of between 1 hr. and 1 day.

During both periods of observation we studied the carriage of *S. aureus* by patients and staff and the occurrence of staphylococcal sepsis. In 1962, several different strains of *S. aureus* had spread among the patients but no one of them was prevalent in the ward for long. Early in the present experiments, however, a new strain of *S. aureus* was introduced into the ward and became established in both parts. It was lysed by phages 84 and 85, or occasionally only by one of these two phages, and was resistent to penicillin, tetracycline, erythromycin and neomycin. The widespread dissemination of this strain among patients in both parts of the ward, especially during 1966–7, so confused the identification of sources for nasal acquisition as to make evaluation of the effects of the ventilation arrangements of doubtful significance.

METHODS

Patients

Patients were admitted to both parts of the ward but those admitted with sepsis, known to have been hospital in-patients within the previous 12 months or not expected to undergo operations, were placed in the outer area. As far as possible patients infected with or carrying tetracycline-resistant strains of *S. aureus* were transferred to the isolation cubicles or to the side rooms off the entrance corridor. The same staff attended all patients, and patients in isolation were generally not barrier-nursed. Staff found to be carrying tetracycline-resistant strains were treated with Soframycin nasal spray, given hexachlorophane soap to use and kept off duty until clear. Dusting powder, containing 0·33% hexachlorophane, was used extensively on the skin of patients.

Patients nursed in the inner area had to pass through the outer area in order to

use their own separate bathroom and W.C. but they were instructed not to linger or talk with patients in the outer area.

Bacteriology

A nasal swab was taken from each patient as soon as possible after admission, usually within 24 hr., and thereafter weekly on a fixed day of the week. Swabs were taken from operation wounds at first dressing and subsequently on any sign of sepsis, and also from other septic lesions not arising in operation wounds. Weekly nasal swabs were taken from the ward nurses and from as many of the medical and auxillary staff as possible. One representative of each colonially distinguishable type of *S. aureus* was selected for further examination. During 1966–7, impression plates were taken from patients' under bed-sheet (drawsheet) in the area in contact with the perineum, and perineal swabs were obtained during limited periods totalling about 9 weeks. Up to ten colonies of *S. aureus* from each plate were examined.

Air samples were taken weekly on the fixed swabbing day by impingement onto phenolphthalein phosphate serum agar using a slit sampler. The duration of sampling was 1 hr. and the volume of air sampled was 108 ft.^{3} (about 3 m.^{3}). Up to ten colonies of *S. aureus* from each plate were examined.

All cultures of coagulase-positive staphylococci were classified as *S. aureus* and were phage typed and tested for resistance to penicillin and tetracycline.

Sepsis

Wounds that on examination showed visible pus were recorded as septic. Wounds from which pathogenic organisms were cultured but where there was no visible pus were recorded as colonized. Sepsis was also suspected when pus cells were seen in the Gram film and a pathogenic organism was found on culture; the wound was then re-examined for signs of visible pus.

Method of analysis

Measurements of the nasal carrier rate and the rate of acquisition of new strains of *S. aureus*, and determinations of the probable source of infection or colonization, were in general made by methods described previously (Lidwell *et al.* 1966). In this investigation, however, the collection of weekly nasal swabs and air samples on the same day reduced the number of assumptions that had to be made about the carriage state in the intervening periods.

RESULTS

Airborne Staphylococcus aureus

Table 1 shows the results of the air sampling in the two periods of investigation (1963–4 and 1966–7). Possible sources for the strains isolated were looked for among patients and staff carriers detected on the same day or, if no swab had been obtained from one of the staff on that day, in the previous or subsequent week. Untypable strains were always recorded as derived from unknown sources even if

a carrier of an untypable strain was present in the ward. Untypable strains comprised about 40 % of those strains without identifiable source.

Although the total number of airborne *S. aureus*, varying from 56–106/1000 ft.^{3} (28 m.^{3}) for the two parts of the ward during the two periods of observation, were substantially lower than those observed in open wards in the hospital in previous

Table 1. *Source and numbers of* Staphylococcus aureus *isolated from the air*

Sampling position	Strain	Source of strain	No. of colonies of coagulase-positive staphylococci/1000 ft.^{3} of air sampled: In 1963–4	In 1966–7
Inner	Any other than 84/85	Inner	13·2 (8·7)	7·5 (5·0)
		Outer	1·3 (0·5)	2·6 (1·6)
		Outer (+cubicles and side)	3·0 (0·9)	2·8 (1·3)
		Staff	5·6 (0·3)	2·8 (0·2)
		Ambiguous	6·2	3·8
		Not known	8·8	6·5
		Total (all origins)	36·8	23·4
	84/85	All origins	19·9	39·4
	All	Overall total	56·7	62·8
Outer	Any other than 84/85	Inner	5·1 (3·4)	2·2 (1·5)
		Outer	21·5 (7·9)	4·1 (2·6)
		Outer (+cubicles and side)	26·1 (7·7)	5·7 (2·6)
		Staff	9·6 (0·6)	2·4 (0·2)
		Ambiguous	23·8	2·8
		Not known	23·7	6·9
		Total (all origins)	88·3	20·0
	84/85	All origins	17·3	46·2
	All	Overall total	105·6	66·2
Any	84/85	All origins	18·5 (16·8)	42·5 (14·7)
Any	Tetracycline resistant *not* 84/85	*All origins	2·4 (2·4)	2·4 (1·4)
Any	Any other than 84/85	*All origins	52·7 (2·2)	17·6 (1·0)
Vol. sampled in each position			29,800 ft.^{3}	6800 ft.^{3}

'Not known' includes untypable strains.

Figures in parentheses give the count derived from a single source carrier (i.e. the number of colonies/1000 ft.^{3} of air divided by the average number of carriers present in the position and of the type specified: see Table 6).

* Excluding 'no possible source identifiable' but including untypable strains. (As the 1963–4 records do not differentiate between these two categories of strains, the number of untypable strains for the period was estimated as 40 % of the aggregate of untypables and strains without identifiable source—the proportion observed during the period 1966–7.)

years, i.e. about 200/1000 ft.^{3} (Noble, 1962), they differed little from the counts observed during the period after the partition had been erected but before any mechanical ventilation was introduced, i.e. 70–80/1000 ft.^{3} (Shooter *et al.* 1963).

The 84/85 strain accounted for about 26 % of airborne *S. aureus* in 1963–4 and by 1966–7 this had risen to 71 %. Owing to the widespread dissemination of the strain there was usually more than one carrier present at any given time so that the

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sources from which the air strains were derived could often not be identified. In allotting the airborne staphylococci to probable sources in various parts of the ward, we therefore excluded this strain from consideration.

During 1963–4 the distribution of other strains from positively identified patient-sources conformed with the air-flow pattern. Staphylococci found in the air were much more often referable to sources in the same area than to sources elsewhere in the ward. But whereas less than one-tenth (ratio $1{\cdot}3/(13{\cdot}2+1{\cdot}3)$) of such strains recovered in the inner area appeared to be derived from sources in the outer area, nearly one-fifth (ratio $5{\cdot}1/(21{\cdot}5+5{\cdot}1)$) of those recovered in the outer area were related to sources in the inner area. The origin of the small number of strains found in the air of the inner area for which no sources other than patients in the outer area could be discovered is not known. It seems unlikely that they were due to reverse air flow. Carriers of these strains in the inner ward or among the staff may have escaped detection, especially if they carried the organisms only in small numbers or on sites that were not examined. Alternatively, the strains may have been brought into the area on the clothes of the nurses and then dispersed into the air (Speers *et al.* 1969).

The distribution of airborne staphylococci attributable to single source carriers (shown in parentheses in Table 1) was in general similar to that for staphylococci attributable to all known sources.

After the installation of mechanical ventilation in both parts of the ward in 1966 the sources of the air strains recovered in the two parts of the ward were more evenly distributed, in each area between one-quarter and one-third apparently originating from sources in the other area. The total count of airborne staphylococci was also nearly equal in the two areas. During 1963–4 the count in the unventilated outer section had been nearly twice that in the inner area.

There was a considerable difference between the number of airborne staphylococci dispersed by single carriers of the 84/85 strain and of other strains of staphylococci. In 1963–4, single carriers of the 84/85 strain contributed on average 16·8 staphylococci/1000 ft.^{3} to the air of the ward, but single carriers of all other staphylococci contributed only 2·2/1000 ft.^{3} of air and single carriers of tetracycline-resistant staphylococci other than the 84/85 strain contributed only 2·4/1000 ft.^{3} of air. A similar difference was observed in 1966–7.

Excluding the 84/85 strains, no source could be identified for 24% of the air-strains recovered in 1963–4 and 33% of those recovered in 1966–7. These figures may be compared with 23% of airborne strains without identifiable sources in the unventilated divided ward (Shooter *et al.* 1963). Since the introduction of positive ventilation in place of the previous general inflow of air from outside the ward led to no reduction in the proportion of airborne strains without an identifiable source it seems unlikely that any significant proportion of these were brought into the ward by air currents from other parts of the hospital.

As there was more than one possible source for 20% of the air strains other than 84/85 only about 50% of these strains could be related to probable sources of dispersion. In 1966–7 when 67% of the strains were 84/85 types this resulted in identified unique sources for little more than 16% of all air strains.

Nasal acquisition of Staphylococcus aureus

The overall rates for apparent nasal acquisition, lying between 36 and 71/1000 patient weeks (Table 2), were appreciably lower than those reported for the ward divided but unventilated (100 and 120/1000 patient weeks in the inner and

Table 2. *Sources and rates of nasal acquisitions of* Staphylococcus aureus *by patients*

Position at time of acquisition	Strain	Position of source	No. of strains acquired/1000 patient weeks in the ward: In 1963–4	In 1966–7
Inner	Any other than 84/85	Inner	3·5 (2·3)	—
		Outer	1·2 (0·4)	—
		Staff	4·7 (0·3)	—
		Ambiguous	5·9	—
		Not known	12·9	—
		Total (all origins)	28·2	44
	84/85	All origins	8·2	27
	All	Overall total	36·4	71
Outer	Any other than 84/85	Inner	0·9 (0·6)	—
		Outer	7·7 (2·8)	—
		Staff	10·5 (0·7)	—
		Ambiguous	5·7	—
		Not known	25·9	—
		Total (all origins)	50·7	25
	84/85	All origins	6·7	33
	All	Overall total	57·4	58
Any	84/85	All origins	8·4 (7·6)	33 (11·4)
Any	Tetracycline resistant *not* 84/85	*All origins	2·7 (2·7)	5 (3·0)
Any	Any other than 84/85	*All origins	29·3 (1·2)	21 (1·1)
Patient weeks recorded			2375	1134

'Outer' does *not* include cubicles or side rooms.
Figures in parentheses give the rate of acquisition from a single source carrier (see Table 1).
* Excluding 'no source identifiable' but including untypable (see Table 1).

outer areas respectively; Shooter *et al.* 1963) and in 1963–4 they were lower in the inner ventilated area than in the outer area. Even including acquisition of the 84/85 strain, acquisition of tetracycline resistant strains was also lower in 1963–4 than during the preceding study; in 1966–7, however, when over half of all apparent acquisitions were of the 84/85 strain, the rate was essentially similar to that observed in the outer area of the unventilated divided ward.

The widespread dissemination of the 84/85 strain during 1966–7 and the preponderance of acquisitions of this strain had the result that only six of the 75 apparent nasal acquisitions observed during this year could be related to particular carriers in identified situations during the week preceding the apparent nasal

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acquisition. It was therefore not profitable to attempt any analysis of the location of sources of nasal acquisition during this period.

Examination of the results for the period 1963–4 shows that when the source was identifiable it was usually in the same area of the ward as the recipient, and that staff carriers were generally individually weak sources, although since they were numerous an appreciable proportion of all nasal acquisitions appeared to be derived from them.

Drawsheet samples and perineal swabs

As in previous analyses of this type, a substantial proportion of apparent acquisitions could not be related to any known source in the ward. Some of these acquisitions were certainly spurious, since examination of repeated nasal swabbings of the same individual shows that intermittent recovery is not uncommon (Parker, John, Emond & Machacek, 1965). There are also more antibiotic sensitive strains among these 'acquisitions' without apparent source than among acquisitions from known sources, a fact which correlates with the greater frequency of sensitive strains in nasal swabs taken from patients on admission compared with those from patients who have been in hospital for some time. Even when allowance is made for this (see Lidwell *et al.* 1966), there are still appreciable numbers of apparent nasal acquisitions including some of antibiotic resistant strains without any known source. Some people carry *S. aureus* on the skin of the perineum but not in the nose, and it has been suggested that perineal carriage may dispose towards greater dispersal of the organisms carried, so that these individuals might be more potent sources of cross-infection than plain nasal carriers (Hare & Ridley, 1958). It seemed possible that the widespread dissemination of the 84/85 strain observed in the present investigation was associated with perineal carriage. Regular perineal swabbing of patients was possible only during a short period of the investigation, but the drawsheet of each patient was sampled weekly during 1966 and 1967.

Table 3 shows an analysis of the 23 apparent acquisitions during 1966 and 1967, excluding seven acquisitions of untypable staphylococci, for which there was no known source among nasal carriers in the ward. These acquisitions were divided into two fractions (see Lidwell *et al.* 1966) with a distribution of antibiotic sensitivities similar to that found in staphylococci in admission swabs (line 2) and that for acquisitions from known sources (line 3). This suggested that 11·6 of the 23 acquisitions were 'real'. However, the inclusion of staphylococci isolated from drawsheets and lesions as possible sources produced sources for nine of the 23 acquisitions (line 4). The antibiotic sensitivity distribution of the remaining 14 (lines 5, 6) was such as to suggest that eight of them were possibly spurious in the sense described above, leaving six or no more than 8% of the original total as probably genuine acquisitions without any identified source (line 7). The contribution of the drawsheet impression samples to this was, however, small since in only two instances did a drawsheet sample identify a possible source that was not already indicated by a lesion swab.

The relationship between nasal carriage and drawsheet samples is shown in Table 4. Of 173 nasal carriers, excluding carriers of 84/85, only 22% yielded

Table 3. *Acquisitions without identifiable sources* (1966–7)

Acquisitions	No. of acquisitions with the following antibiotic sensitivity pattern: S	P	T	All sensitivities
1. Without nasal source	8	5	10	23 (31 %)
2. By admission swab sensitivity distribution	6·6	4·0	0·8	23 { 11·4
3. Leaving 'probably real' (known source, sensty. distribution)	0·5	2·3	8·8	11·6 (16 %)
4. Acquisition related to drawsheet or lesion sources	3	1	5	23 { 9*
5. Leaving without any identifiable source	5	4	5	14 (19 %)
6. Without identifiable source, by admission sensitivity	4·6	2·8	0·6	14 { 8·0
7. Leaving 'probably real' without any identifiable source	0·2	1·2	4·6	6·0 (8 %)
8.† Acquisitions related to drawsheet or lesion sources, by admission sensitivity	1·9	1·2	0·2	9 { 3·3
9.† Leaving 'probably real', from drawsheet or lesion source	0·2	1·1	4·3	5·7

S = Sensitive to penicillin and tetracycline; P = resistant to penicillin, sensitive to tetracycline; T = resistant to tetracycline.

* Of these nine, seven could be related to lesions and eight to drawsheets, six were related to drawsheet and lesion simultaneously. A part of these drawsheet/lesion acquisitions may also be spurious and due to missed nasal admission positives (see lines 8, 9).

† Applying the method of distribution according to antibiotic sensitivities, it is probable that no more than six of the nine acquisitions (line 4) were 'real'.

Note: lines 6 and 8 add to give line 2; lines 7 and 9 add to give line 3.

Table 4. *Isolation of* S. aureus *from drawsheets of patients and its relation to nasal carriage by the patient in the bed*

S. aureus in nasal swab	Examined	Drawsheets yielding *S. aureus*: 84/85 strain	Not 84/85 strain: Same as nasal strain	Not 84/85 strain: Different from nasal strain	Without *S. aureus*
Present: 84/85 strain	72	42 (58)*	—	0	30
Present: other strain	173	8 (5)	38 (22)	3 (2)	124
Absent	843	57 (7)	—	27 (3)	759

* In parentheses, percentage in nasal carriage class with positive drawsheet culture.

drawsheet samples positive for the same strain and 6 % were positive for a strain that differed from that carried in the nose. In conformity, however, with the greater dissemination of the 84/85 strain, this strain was recovered from 58 % of drawsheet samples from nasal carriers of the strain. Nearly 7 % of drawsheet samples from non-nasal carriers also yielded colonies of the 84/85 strain while only 3 % showed colonies of other strains.

The results obtained on the limited number of occasions when nasal, perineal and drawsheet samples were obtained at the same time are analysed in Table 5. Although the strains isolated from two or more sites were usually identical, the drawsheet samples gave a poor indication of perineal carriage. There were 30 occasions on which *S. aureus* was isolated from the drawsheet, but the same strain was not isolated either from the nose or the perineum on 12 of these occasions; the same strain was isolated from perineum and drawsheet on nine occasions, but on four of them the patient was a nasal carrier, so that unsuspected carriage was detected on only five occasions. The drawsheet culture was negative for the strain carried in the perineum eight of 17 times, and six of 11 times in patients who were not nasal carriers. Thus, nearly half of the positive drawsheet cultures appear to have been 'false', and half of the perineal carriers were missed.

Table 5. *Simultaneous culture for* Staphylococcus aureus *of samples from drawsheet, perineum and nose*

(No isolation was made from any site from 122 of the 185 sets of samples.)

	Number of occasions						
	Drawsheet +				Drawsheet −		
	Perineum +		Perineum −		Perineum +		Perineum −
Strain isolated*	N +	N −	N +	N −	N +	N −	N −
84/85	2	4	7	7	0	2	6
Other	2	2†	3‡	3	2	3	20
Total	4	6	10	10	2	5	26

\+ = *S. aureus* isolated; − = *S. aureus* not isolated; N = nasal swab.
* Except where indicated, strains isolated from two or more sites were identical.
† One pair: drawsheet, strain 84/85; perineum, other strain.
‡ One pair: drawsheet, other strain; N, strain 84/85.

Nasal carriage and length of stay in hospital

The changes in nasal carriage of coagulase-positive staphylococci with the length of time the patients have been in the hospital show interesting variations from place to place and at different times, and it seems that they may be a good index of the epidemiological situation in a ward (Lidwell *et al.* 1966). It is much easier to measure these changes than to carry out an analysis of individual sources of cross-infection such as had been given in the earlier sections of this paper. Only coagulase and antibiotic sensitivity testing is required and much less detailed patient records are needed. In Fig. 2 we present the results obtained in the ward under study both before and after the introduction of mechanical ventilation and show also, for comparison, the situation in an undivided unventilated ward in another part of the same hospital. The intrusion of the 84/85 strain is clearly seen. In the earliest years the overall carriage rate in both wards increased with length of stay. Carriage of strains sensitive to all antiobiotics or resistant to penicillin only showed little change with duration of stay while carriage of strains resistant to

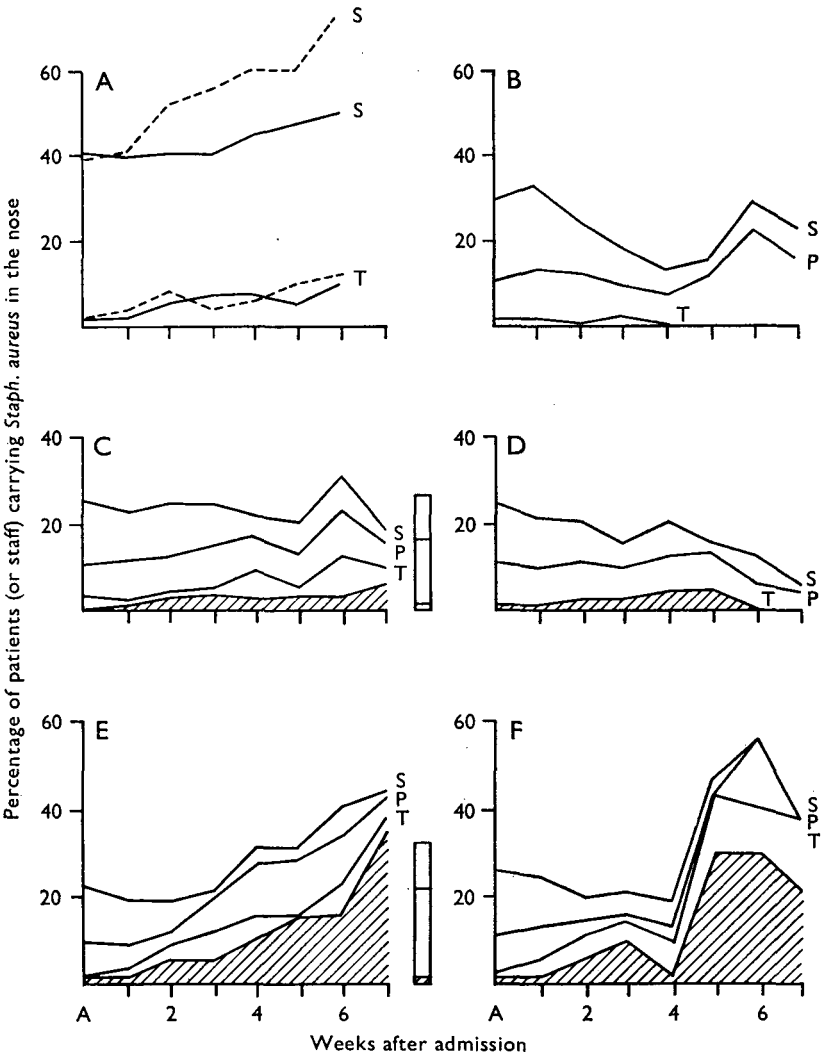

Fig. 2. Changes in nasal carriage of *S. aureus* during hospital stay. The top line, labelled S in each section, shows the percentage of patients carrying *S. aureus* in the nose after varying length of stay in the ward. The line P shows the percentage carrying strains resistant to penicillin or tetracycline or both and the lower line T the percentage carrying tetracycline resistant strains, the hatched areas indicating the part due to carriage of the 84/85 strain. (A) Year 1961. Full lines refer to the divided unventilated ward, broken lines to an undivided unventilated ward elsewhere in the hospital. (B) Year 1966. Patients in the same undivided unventilated ward. (C) Year 1963–4. Patients in the outer area of the divided ward. The inner area only was mechanically ventilated. (D) Year 1963–4. Patients in the ventilated inner area of the divided ward. (E) Year 1966–7. Patients in the outer area of the divided ward. Both areas were mechanically ventilated. (F) Year 1966–7. Patients in the inner area of the divided ward. The histograms between (C) and (D) and between (E) and (F) show the average rate of nasal carriage by members of the staff working in the divided ward.

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tetracycline and other antibiotics increased. This has been a general experience in open hospital wards (Lidwell *et al.* 1966). However, experience in some subdivided wards in recent years has shown situations in which carriage of sensitive staphylococci was reduced during hospital stay and there was little countervailing increase in resistant strains. It seems likely that this change is due partly to a more effective use of antibiotics but it may also reflect a reduction in the opportunities for cross-infection in the situations described or a change in the disseminating abilities of the prevalent strains of staphylococci.

The results given in Fig. 2 show that in this hospital, in the undivided unventilated ward as well as in the ward under study, there has been during recent years a loss of sensitive strains during stay in hospital without any significant increase in the carriage of multiple resistant strains. In 1966 and 1967, however, this was true in the divided ward only for strains other than 84/85; this strain spread so effectively that there was an overall increase in the nasal carriage rate with length of stay in the ward entirely attributable to acquisition of this strain. There is some slight evidence that acquisition was delayed in the inner area compared with the experience of the outer section.

Table 6. *Average numbers of carriers of coagulase-positive staphylococci present*

	1963–4	1966–7
Unambiguously located (strains other than 84/85)		
In inner area	1·51	(1·5)
In outer area	2·72	(1·6)
All patients		
Strains other than 84/85	7·24	3·88
84/85	0·93	2·28
Tetracycline resistant strains other than 84/85	0·55	1·08
Staff		
Strains other than 84/85	16·95	14·70
84/85	0·17	0·60
Tetracycline resistant strains other than 84/85	0·44	0·60

Nasal acquisition and the numbers of airborne staphylococci

The potential value of ventilation systems designed to reduce the exposure to airborne bacteria depends not only on the proportion of cross-infection attributable, directly or indirectly, to airborne micro-organisms but also on the relationship between the numbers of airborne organisms to which the patient is exposed and the risk of infection which this represents. Nasal carriage of *S. aureus* is not in itself a disease but is the principal reservoir of the organism. The exchange of different strains between patient and patient and between patient and staff is then the mechanism by which particular strains, especially those resistant to antibiotics that are less often used in the normal population, maintain themselves endemically in the hospital environment. Examination of the data presented in Tables 2 and 3 together with the figure for the numbers of possible source carriers given in Table 6 shows that the chance and rate of nasal acquisition is related to both the airborne counts and to the number of possible sources. Neither relationship is, however, very close and, as in the two other situations in which we have

made a similar analysis (Lidwell *et al.* 1966, and unpublished data from a partially subdivided modern ward at the Queen Elizabeth II Hospital, Welwyn), there is a better correspondence between the rate of acquisition per possible source carrier, and the exposure to airborne staphylococci per source carrier in the same relationship to the recipient. The exposure per source carrier and the rate of acquisition per source carrier are given in Tables 2 and 3, in brackets, and the relationship between them is exhibited on a log. scale in Fig. 3. As observed previously the relationship, for the figures from the 1963–4 observations on strains other than 84/85, can be represented by a straight line with a slope substantially less than unity. For the present observations this slope, about 0·6, is appreciably greater

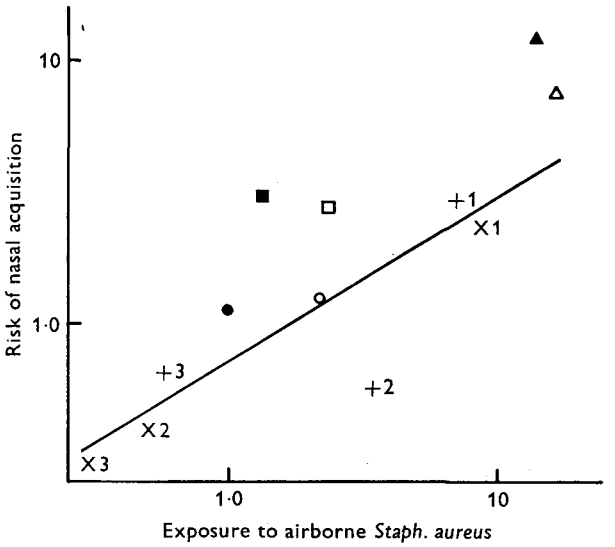

Fig. 3. Relation between the risk of nasal acquisition and the exposure of airborne *S. aureus*. Logarithmic scales for both co-ordinates. Risk of nasal acquisition: per potential source (carrier) per 1000 patient weeks. Exposure to airborne *S. aureus*: colony count/carrier/1000 ft.^{3} (28 m.^{3}) of air sampled. Line drawn with slope of 0·60. ×, Acquisitions by patients in the inner area, all strains except 84/85. +, Acquisitions by patients in the outer area, all strains except 84/85. (1) Acquisitions from patients in the same area. (2) Acquisitions from patients in the other area. (3) Acquisitions from staff carriers. ○, Average rate of acquisition and exposure to *S. aureus* for all strains other than 84/85 by all patients from all sources. □, Average rate of acquisition and exposure for tetracycline resistant strains other than 84/85 by all patients from all sources. △, Average rate of acquisition of and exposure to the 84/85 strain for all patients from all sources. The symbols ●, ■, ▲ give the comparable figures for the period 1966–7 when detailed source breakdown was impracticable.

than in the other two situations, 0·20 and 0·25 respectively, but the accuracy of these estimates is not high, especially in the present situation. A relatively consistent relationship of this kind lends force to the contention that the airborne route is the most important one with respect to nasal acquisition. The low values of the slope imply that reduction in the airborne transport of staphylococci, e.g. by ventilation systems, will produce a much less than proportionate reduction in the

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rate of nasal acquisition. A tenfold reduction would, in the evidence presented here, lead to a reduction of the order of about threefold, or rather over $1\frac{1}{2}$-fold and rather less than twofold in the other two situations referred to.

Points are also shown on the figure for the average acquisition rates for both observation periods, for tetracycline resistant strains other than 84/85, and for 84/85 strains. The average figures for 1966–7 are between 40 and 50 % higher than those for 1963–4 but no detailed breakdown by sources was possible, as has been explained earlier. We have no explanation, other than the inherent variability of this kind of observational data, to account for this. In each year the tetracycline resistant strains were acquired about twice as frequently as the average of all strains for a given level of exposure. The 84/85 strain was similar to other tetracycline resistant strains in this respect, i.e. the great capacity this strain showed for spreading did not appear to be due to any greater colonizing potential but entirely to the much greater extent to which carriers dispersed it into their environment.

It must be pointed out that the limited effect of reduction in airborne staphylococci on nasal acquisition consequent on the below unity slope of the relationship as shown in Fig. 3 applies to each epidemiologically distinguishable strain separately, the effects of different strains would appear to be additive, i.e. any environmental measure which reduced the airborne levels by reducing the number of possible sources would be expected in this respect to produce a proportionate reduction in the rate of nasal acquisition.

Wound colonization and sepsis

Table 7 shows the figures for the two periods of observation. The rapid rise in the proportion of sepsis due to the 84/85 strain is at once apparent although the overall difference between the two periods is negligible. The rates during both periods (7·6 and 7·8 % respectively) were, however, substantially higher than in the divided unventilated ward (5·4 %; Shooter *et al.* 1963), or in the undivided ward the year previously (3·8 %; Williams *et al.* 1962).

Table 7. *Wound colonization and sepsis due to* Staphylococcus aureus

	1963–4	1966–7
Number of wounds examined	485	475
Percentage colonized with *S. aureus*	11·4	13·0
Percentage septic with *S. aureus* (all strains)	7·6	7·8
Percentage septic with 84/85 strain	1·6	5·7
Percentage septic without *S. aureus*	2·3	3·2
Total wound sepsis (%)	9·9	11·0

There have been some changes in the character of the surgery performed in this ward over the years but this had not been great, and application of the rates given in the second of the above references to the operation list for 1966–7 leads to an expected sepsis rate of only 4·7 %. Examination of the distribution of sepsis due to the 84/85 strain over the different types of operation does not suggest any associa-

tion with any particular types of operation. The widespread dissemination of this strain has, therefore, been accompanied by a significant overall rise in wound sepsis. There was also no significant difference in the incidence of sepsis between patients nursed in the two different ward areas.

DISCUSSION

The changes that take place in the nasal carriage of *S. aureus* by patients during successive weeks of their stay in hospital are now somewhat different from those observed over 7 years ago. At that time, it was the general experience that the total carrier rate of patients increased progressively during their stay in hospital. This was due to the acquisition by many patients of multiple-antibiotic resistant 'hospital' staphylococci with little corresponding loss of sensitive strains or of strains resistant only to penicillin. In a number of hospitals the more sensitive strains are now lost more quickly than formerly, and this is probably attributable to changes in the pattern of antibiotic usage, and particularly to giving penicillin in large dosage. The fact that in some hospital wards the rate of acquisition of multi-antibiotic resistant staphylococci has decreased, so that the total effect is a falling carrier rate during stay in hospital, may be attributable to hygienic improvements and to avoiding giving ineffective antibiotics to patients infected or colonized with resistant strains.

The introduction of the 84/85 strain into our ward interrupted this comfortable progress. The great potential of this strain for spreading seems to depend on its being dispersed by carriers some ten times more profusely than any other strain encountered. In addition to having a rather wide range of antibiotic resistance, it may also possess some other undetected character that enables it to multiply to higher levels in colonized sites, thereby increasing the number of organisms dispersed into the environment from them. Some part of the wider dispersal of the strain might also arise from better survival in the environment, including the air, but we have no evidence of this either. Clinically the strain does not seem to present any special characteristics, except that like most 'hospital' strains belonging to phage group III it seldom causes boils in patients or staff. By the end of the second period of observation, however, nearly 75% of all cases of staphylococcal sepsis were due to it, and the total staphylococcal wound sepsis rate in the ward had probably risen by 50%. In this changing epidemiological situation it was clearly very difficult to assess any effects due to sequential changes in the environment such as ventilation. In spite of the advent of the 84/85 strain the total count of airborne coagulase-positive staphylococci in the air of the ward did not rise significantly above the level to which it had fallen in the immediately preceding period, and nasal acquisition of new strains also remained low, except for substantial acquisition of the 84/85 strain following several weeks in the ward. It is clear, however, that mechanical ventilation with fresh air at as high a rate as ten air changes/hr. in the ward was ineffective in controlling the spread of this epidemic strain and led to no reduction in the incidence of sepsis in surgical wounds. A similar conclusion was reached by Whyte, Howie & Eakin (1969) who found no

difference between the rates of nasal acquisition and sepsis in a 'race-track' type ward (internal concentric corridor) mechanically ventilated at 7–8 air changes/hr. and those experienced in two open Nightingale type wards.

The widespread dispersion of the 84/85 strain also complicated attempts to investigate in greater detail the possible origins of new strains appearing in the noses of patients that could not be traced to other patients or staff carriers. It was thought that impression plates from the drawsheets might reveal undetected perineal carriers as sources of this acqusition. In fact, very few additional sources were recognized by this procedure, but the systematic study of swabs from all lesions enabled all but 8 % of the nasal acquisitions to be plausibly accounted for. A smaller study in which perineal swabs as well as drawsheet impressions and nasal swabs were taken at the same time showed, however, that the drawsheet cultures were a very unreliable indicator of perineal carriage.

Finally it was possible from the data obtained during the first part of the study, before the 84/85 strain became too widespread, to examine the relationship between exposure to airborne *S. aureus* and the chance of nasal acquisition of the strain. In conformity with observations reported elsewhere, the risk of acquisition of a single strain increased less than any increase in airborne exposure to it. This effect was somewhat less pronounced than in two other situations in which similar studies had been made, but it is possible that the differences reflect no more than the substantial error inherent in the estimates. Considered on an absolute scale, the risk of acquisition for an equivalent dose was similar to that found in another divided surgical ward (Lidwell *et al.* 1966) and of the order of half that in a general medical ward (unpublished). In all the three situations, the risk of acquisition of a resistant strain, including the 84/85 strain, was of the order of twice that found for all strains, predominantly those sensitive to all antibiotics or resistant to penicillin only.

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