J. Hyg., Camb. (1973), **71**, 787
Printed in Great Britain

Dispersal and transfer of *Staphylococcus aureus* in an isolation ward for burned patients

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(*Received* 9 *April* 1973)

SUMMARY

The dispersal of *Staphylococcus aureus* from burned patients, the relation between nasal carriage by the staff and exposure to airborne *Staph. aureus*, and the transfer of *Staph. aureus*-carrying particles within the ward have been studied. The dispersal of *Staph. aureus* from burned patients was correlated to the size of the burn wound. The median values varied from 21 c.f.u./m.^{2}/hr. for patients with small burns to 453 c.f.u./m.^{2}/hr. for extensively burned patients. The size of the dispersed particles appeared to be smaller than that usually found in hospital wards. Carriage of nasal strains by the staff was correlated to the air counts; the number of patient sources did not seem to be of great importance. The transfer of *Staph. aureus* within the ward was at least 6 to 20 times that which would have been expected if transfer was due to air movement only.

INTRODUCTION

In a previous epidemiological investigation from an isolation ward for burned patients it was shown that in spite of the design of the ward there was a considerable amount of cross-infection with *Staphylococcus aureus* (Hambraeus, 1973).

In order to estimate the role of airborne transfer of infection, studies with an airborne particle tracer were carried out in the ward. According to this investigation, the airborne transfer of particles from room to room was small (Hambraeus & Sanderson, 1972). However, as burned patients are sometimes heavy dispersers of bacteria, even a small amount of airborne room-to-room transfer might give high air counts in the receiving rooms. The size of the bacteria-carrying particles is another factor that influences the airborne room-to-room transport of bacteria. In the earlier particle tracer investigation a particle with a sedimentation rate of 0·3 m./min. was used, as this is the median value found for airborne particles carrying *Staph. aureus* in hospital wards (Noble, Lidwell & Kingston, 1963). The median sedimentation rate for *Staph. aureus*-carrying particles in a burns ward might differ from this. In addition to transfer of staphylococci from one room to another by air movement, there might also be a contribution to the air counts in the room by carriers among the staff. Another possibility is transport of staphylococci by nurses' clothing. The importance of this will be reported in a separate paper.

The aim of the present investigation was to study the dispersal of *Staph. aureus* from burned patients and the transfer of staphylococci within the ward. The results obtained in this investigation are compared with those of the particle tracer experiments. The influence of high air counts on the nasal carrier rate in the staff has also been studied and an attempt made to evaluate the importance of staphylococcal carriers among the staff as a source of airborne staphylococci.

MATERIALS AND METHODS

Ward design

The design of the ward and its ventilation have been described in detail in an earlier paper (Hambraeus & Sanderson, 1972). The ward is entered via an air-lock with double doors. A corridor runs down the middle of the ward. There are five bedrooms of similar dimensions and a sixth larger room containing an airbed. All these have individual air-locks and they are situated along one side of the corridor. On the other side of the corridor are service rooms and the bathroom. Only burned patients were admitted to the ward. The number of permanent staff working in the ward per week was 25, doctors and night staff included. Protective gowns and masks were used when treating the patients in their rooms. The patients generally did not leave their rooms except for bathing or operations. Weekly reports on the patients occupying the rooms and on bathing and operating schedules were made by the secretary of the ward.

Bacteriology

From the patients specimens were taken from the nose, throat, skin, perineum and wound on admission and thereafter once a week. Weekly specimens from nose and throat were taken from the staff. Deoxyribonuclease-producing staphylococci were classified as *Staph. aureus* (Di Salvo, 1958) and one representative of each morphologically distinguishable type was phage typed (Blair & Williams, 1961). The staphylococcal content of the air was determined by the exposure of settle plates with an inside diameter of 13·5 cm. The medium used was blood agar containing 2 μg./ml. of nalidixic acid to prevent swarming of *Proteus*. The plates were placed three in the corridor and one in each bedroom, 3–5 days a week. From five to nine colonies of *Staph. aureus* found on settle plates in the corridor together with 25% of colonies (up to a maximum of eight colonies per plate) from settle plates in the bedrooms were phage typed. Strains were assumed to be distributed in the sample in the same ratio as in the colonies that were phage typed. For the determination of the size of the colony-forming units an Andersen sampler (Andersen, 1958) was used.

Methods of calculation

The results of the air count observations in different situations have been presented by plotting the cumulative distribution of the counts on log probability

Table 1. *Number of plates exposed in bedrooms of patients with burns of different extent*

(Median values of staphylococcal dispersal.)

Burned area II + III°	No. of patients	Total no. of plates	Median no.* (c.f.u./m.²/hr.)
⩽ 5 %	12	80	21
6–15 %	17	176	50
16–30 %	15	166	141
> 30 %	11	112	453
Total no.	55	534	—

* The coefficient of variation of each of these values is approximately 20 %.

paper. It has then been assumed that the error of an estimation is largely the Poisson variance. For the Poisson function the values which delimit 50 % probabilities of falling into the lower or upper class are approximately 0·7 above the actual digital value when these are small numbers. It is these limits which have been used when plotting the cumulative distribution.* In all cases it seemed reasonable to draw straight lines through the points plotted in this way, i.e. the distributions were approximately log-normal. The best straight lines were assessed by eye.

RESULTS

The correlation between the extent of the burn and dispersal of Staph. aureus

The individual dispersal of *Staph. aureus* from patients whose burns were colonized with *Staph. aureus* admitted to the ward from February 1969 to September 1971 was determined. Only periods when a patient was treated alone in a bedroom have been analysed. This means that in some cases the period analysed does not consist of consecutive weeks. The patients were divided into four groups according to the extent of the burn. The material is presented in Table 1. Fig. 1 shows the distribution of the air counts of *Staph. aureus* within the four patient groups; 37·5 % of all plates exposed in bedrooms of patients with small burns yielded no staphylococci, the corresponding figure for patients with extensive burns being 4·5 %. The median values varied from 21 c.f.u./m.²/hr. for the least burned patient up to over 450 c.f.u./m.²/hr. for those with the most extensive burns. The maximum dispersal generally occurred during the week of wound colonization or the following week. This was usually the first or second week of the stay in the ward. In most cases the maximum dispersal period did not last for more than one week, except for extensively burned patients, who had longer periods of maximum dispersion. The decrease in dispersal took place whether the patient had been operated upon or not. However, operation always seemed to diminish the dispersal. In three patients a new period of dispersal was noticed late

* This method of plotting the cumulative distribution has been suggested by Dr O. M. Lidwell.

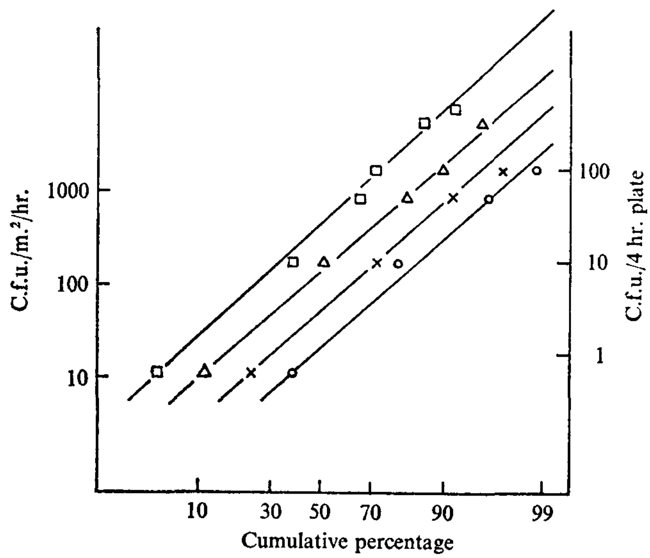

Fig. 1. Dispersal of *Staph. aureus* in relation to burned area. ○, ⩽ 5 % burned area; ×, 6–15 % burned area; △, 16–30 % burned area; □, > 30 % burned area.

Table 2. *Size distribution of* Staphylococcus aureus-*carrying particles according to Andersen sampler*

Week of treatment	No. samples	No. patients	Mean no. *S. aureus*/m.³	% *Staph. aureus* on different stages of the sampler: 1	2	3	4	5	6*	Median particle size (µm.)
1	8	6	339	15·7	22·2	17·6	21·7	18·0	4·8	4·0
2	8	7	78	15·9	16·6	19·0	18·3	25·2	4·9	3·5
3	7	5	81	29·0	16·7	18·3	15·1	17·7	3·2	5·0
> 4	11	6	44	24·9	25·6	12·5	17·6	17·6	1·8	5·6

* Size distribution on stages: 1, ⩾ 9·2 µm.; 2, 9·2–5·5 µm.; 3, 5·5–3·3 µm.; 4, 3·3–2 µm.; 5, 2–1 µm.; 6, < 1 µm.

in the treatment period. This period occurred the same week or the week after the wound was infected with a new staphylococcal strain.

The size distribution of the *Staph. aureus*-carrying particles dispersed was investigated with an Andersen sampler. Thirty-four samples were taken from 19 patients. As far as possible the samples were taken during a period of dispersal, i.e. when the settle plates had shown about 10 c.f.u. in a 4 hr. exposure. The burned area was 15 % or more in all but two cases. Table 2 shows the mean number of *Staph. aureus* per m.³ and the distribution of *Staph. aureus* in the different stages.

The counts found in different weeks of treatment are given. As could be expected, the mean value of *Staph. aureus*/m.³ was highest in samples taken the first week.

The apparent median particle size was much below that suggested by other observations in hospital wards; e.g. Noble, Lidwell & Kingston (1963) found a median particle size of 13–16 µm. The particle size also seems to have been smaller

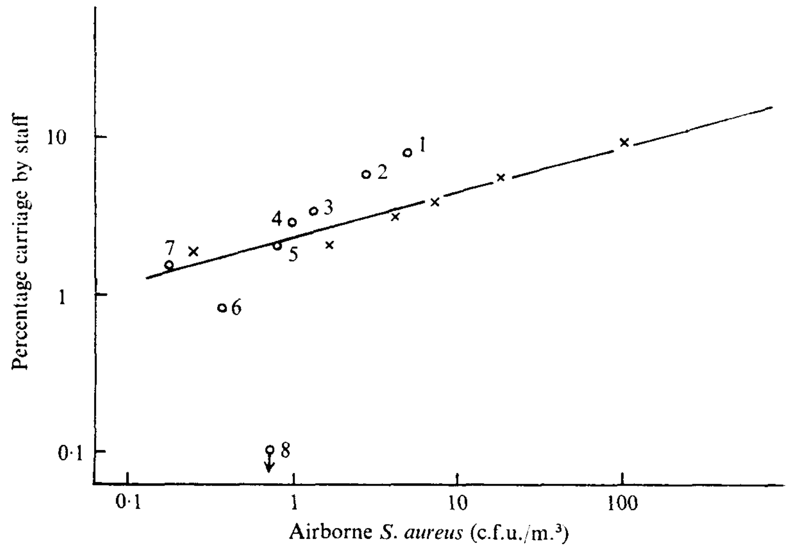

Fig. 2. Relation between nasal carriage by staff and exposure to airborne *Staph. aureus*. Logarithmic scales for both coordinates. Exposure to airborne *Staph. aureus*: mean count/m.³/week assuming a sedimentation rate of 0·3 m./min. (= c.f.u. per 4 hr. plate). The line refers to all strains of *Staph. aureus*. The relationship between exposure and carriage is also given for 8 'epidemic' strains. 1, 84 III (methicillin resistant); 2, NT88; 3, 52/52A/80/81 Complex; 4, 3A II; 5, 53/77/84/85 III; 6, 84/85 III; 7, NT52A/42E/47/53/75/77/88 I + III; 8, 84/85 III (not carried by any member of the staff). 6 and 8 are two strains with the same phage pattern occurring during two separate periods.

early during treatment when the rate of dispersal was greater. The Andersen sampler has been said to be inadequate for collecting larger particles (May, 1964) but a few parallel measurements made in these rooms by Lidwell with the size grading sampler (Lidwell, 1959) also suggested that the particle size was smaller, at least when dispersal was vigorous.

Nasal carriage of Staph. aureus *by the staff*

On an average, six members of the staff per week were nasal carriers of *Staph. aureus*. Over a period of 130 weeks the nasal carrier rate as a function of airborne *Staph. aureus* was studied. This was done in the following way. The mean number of airborne *Staph. aureus* (c.f.u./m.³) of each different phage type found in the bedrooms was calculated for each week from the sedimentation plates, assuming a settle rate of 0·3 m./min. and the number of staff and patients from whom the appropriate type was isolated was recorded. Non-typable staphylococci were excluded. A median of five different phage types was found per week. The sources of airborne staphylococci were: patients only on 296 occasions; staff only on 36 occasions; patients and staff on 181 occasions. No source was found on 128 occasions. The median value of the weekly means was 0·67 c.f.u./m.³ for phage types for which the only known source was patients, 0·06 c.f.u./m.³ for those for which staff carriers were the only source, 1·56 c.f.u./m.³ when both patients and

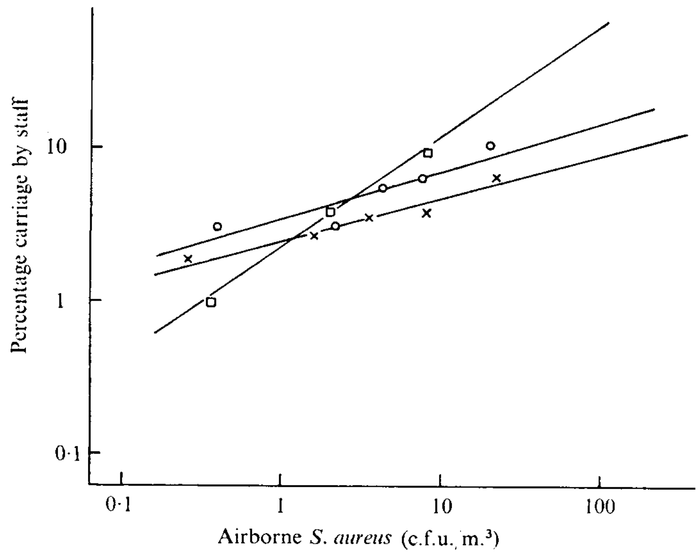

Fig. 3. Relation between nasal carriage of 'epidemic' strains and exposure to airborne *Staph. aureus* for 1, 2 and 3 patient sources. ×, 1 patient source; ○, 2 patient sources; □, 3 patient sources.

staff were possible sources and 0·17 c.f.u./m.^{3} when there was no recognized source. The proportion of the staff who were carriers of a particular strain is shown in Fig. 2 as a function of the number of that strain per m.^{3}/week for those weeks on which the strain was carried by at least one patient. Nasal carriage was more common when the strain was extensively dispersed. The slope of the line relating the logarithm of the percentage carriage to the logarithm of the extent of airborne dispersal is about 0·30.

An attempt was made to see whether 'epidemic' strains, i.e. those which were present in at least two patients' burns for 6 consecutive weeks or more, differed from the others and whether carriage of the strain by more than one patient showed any effect. The median values for the weekly counts of airborne *Staph. aureus* and the corresponding mean value of the weekly carriage rate for eight such epidemic strains are also shown in the figure. While there was some indication that staff carriage of these strains in relation to the extent of air dispersal was more frequent than with other strains (nos. 1 and 2 in Fig. 2) the effect was not consistent.

The observations recorded with these strains have also been examined in connexion with the number of patient carriers present in any one week, and the results are shown in Fig. 3. Again there is some suggestion that nasal carriage by staff was greater when there were more patient carriers, but this also is not consistent.

The transfer of airborne Staph. aureus *within the ward*

The transfer of staphylococci from a source room to the corridor and to other rooms in the ward was investigated in the following way.

Those occasions were selected when there was a patient dispersing 180 c.f.u./

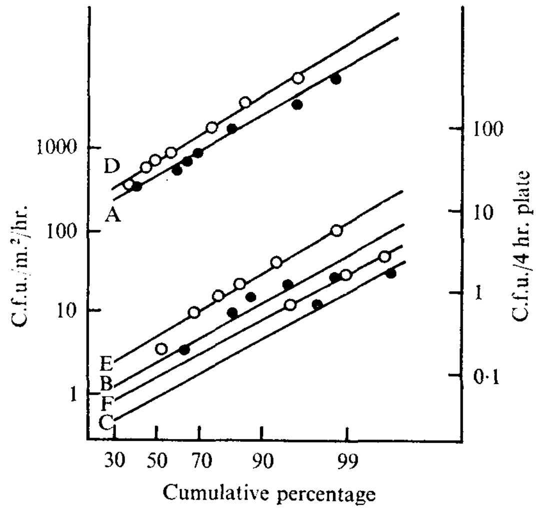

Fig. 4. Comparison of air counts of *Staph. aureus* in dispersers' rooms with counts of the same staphylococci in the corridor and other rooms. Lines A, B and C refer to source room, corridor and receiving rooms respectively, when no staff carriers were present. Lines D, E and F refer to source room, corridor and receiving rooms when staff carriers were present.

m.^{2}/hr. (10 c.f.u./4 hr. plate) or more of a type of *Staph. aureus* which was not isolated from any other patient in the ward. Parallel counts of the number of this type found on settle plates in the source room, i.e. that housing the patient, corridor and other bedrooms were made. If more than one type was dispersed at the same time the different types were considered separately. Days on which the patient was transported from his room into the passage were excluded. Those occasions when the patient was the only source within the ward and those when there were carriers of the phage type among the staff also have been analysed separately. Over a 3-year period 74 occasions without carriers among the staff and 74 occasions with staff carriers were found.

Fig. 4 shows the cumulative distribution of the air counts of the dispersed *Staph. aureus* for the two different circumstances. Lines A, B and C represent source room, corridor and receiving room respectively when no staff carriers were present. Lines D, E and F represent the counts from the same places when staff carriers were present. Median values have been taken from these lines. These were 447 c.f.u./m.^{2}/hr. for source rooms, 2·5 c.f.u./m.^{2}/hr. for the corridor, and 0·9 c.f.u./m.^{2}/hr. for receiving rooms when there were no staff carriers and 708 c.f.u./m.^{2}/hr., 5·0 c.f.u./m.^{2}/hr. and 1·6 c.f.u./m.^{2}/hr. for the same places when staff carriers were present. Although the air counts were slightly higher when staff carriers were present, the ratios of the median values between the three places were similar for both conditions.

Arithmetic mean values were also calculated for the same data. These will be more sensitive to isolated high counts on individual plates. However, if the distribution of the individual dispersion was similar, the ratios between these mean values should be similar to the ratios of the medians. The median and arithmetic

Table 3. *Airborne transfer in the ward*

Situation	Median value (c.f.u./m.²/hr.)	Arithmetic mean value (c.f.u./m.²/hr.)	Ratio source room values to other sites: Transfer of *Staph. aureus*		Tracer particle transfer		
			Median values	Arithmetic mean values	Correct ventilation	Worst ventilation	Average ventilation
A. No staff carriers							
Source room	447	1119	—	—	—	—	—
Corridor	2·5	5·2	179*	215*	$1·5\times10^{3}$*	188*	287*
Receiving room	0·9	0·6	497†	$1·9\times10^{3}$†	$3·4\times10^{5}$†	$4·4\times10^{4}$†	$4·3\times10^{4}$†
B. With staff carriers							
Source room	708	1498	—	—	—	—	—
Corridor	5·0	11·2	142*	134*	—	—	—
Receiving room	1·6	1·2	443†	$1·2\times10^{3}$†	—	—	—

The particle transfer figures for correct ventilation and the worst conditions are those given in a previous paper (Hambraeus & Sanderson, 1972). The average values have been deduced from the proportion of different ventilation conditions observed in the ward (Hambraeus & Sanderson, 1972).

* The ratio concentration in source room/concentration in corridor.

† The ratio concentration in source room/concentration in receiving room.

mean values together with the ratios of the values in the source room to those in the corridor and receiving rooms are given in Table 3. The values for particle tracer transfer (Hambraeus & Sanderson, 1972) are also included for comparison. These values have also been adjusted to allow for the proportion of times when the ventilation system was not functioning correctly (average ventilation). As shown in the table the values for transfer of *Staph. aureus* from source room to corridor are close to those for tracer particles with average ventilation conditions. For transfer from source room to receiving room, however, the ratios source room to receiving room are between 90 and 20 times less than those for tracer particles (average ventilation) depending on whether the median or arithmetic mean values for the counts of *Staph. aureus* are employed.

DISCUSSION

An earlier paper (Hambraeus, 1973) describes the finding that burned patients sometimes disperse large numbers of staphylococci.

This investigation has shown that dispersal is correlated with the extent of the burned area. The median value of dispersal for patients with a burned area of less than 5 % was 21 c.f.u./m.²/hr. and for patients with a burned area of over 30 % it was 453 c.f.u./m.²/hr.

Like air counts found in dermatological wards (Selwyn, 1965), these are very high compared with air counts in ordinary hospital wards where heavy dispersers are seldom found (Noble, 1962; Williams, 1966; Williams & Harding, 1969;

Edmunds, 1970; Lidwell, Polakoff, Davies & Hewitt, 1970; Ayliffe, Collins, Lowbury & Wall, 1971). The correlation of the air counts with the burned area clearly indicates that the burn wound is the most important source of dispersed *Staph. aureus*.

The high air counts of *Staph. aureus*-carrying particles in the ward naturally influenced the rate of nasal carriage of the dispersed *Staph. aureus* among the staff. The slope of the line relating the logarithm of the percentage carriage to the logarithm of the extent of airborne dispersal was about 0·30. If this can be interpreted as the extent to which the staff acquire nasal strains as a result of airborne dispersal by infected patients, it is of some interest to note that the slope is similar to that reported for nasal acquisition of *Staph. aureus* by patients in hospital wards (Lidwell *et al.* 1966, 1970, 1971).

The contribution to the air counts by the staff seemed to be very small; this might of course be partly an artifact as only a small proportion of the *Staph. aureus* found on settle plates in the bedrooms were phage typed. However, it was of the same range as that reported by Edmunds (1970) and settle plates exposed in the corridor and in other areas of the ward never indicated the presence of a disperser among the staff.

The size distribution of the airborne particles carrying *Staph. aureus* was investigated with an Andersen sampler. During periods of dispersion the particles were almost evenly distributed over the five upper stages of the Andersen sampler. The median equivalent particle diameter was 4–5·6 μm., which is less than that found in other wards (Noble *et al.* 1963). Although the Andersen sampler is not completely adequate for sampling larger particles parallel measurements with the Lidwell size grading sampler also indicated that the airborne particles found in the ward were often small.

The transfer of staphylococci in the ward has been compared with the transfer of a particle tracer in an earlier paper (Hambraeus & Sanderson, 1972). These experiments, however, were carried out with a particle size larger than that found for airborne particles in the ward. The contribution of particle sedimentation to the total rate of ventilation in bedroom and corridor and hence its effect on the transfer ratios is given in that paper (loc. cit. p. 306). The effect of smaller particle size and hence lower sedimentation rate can be estimated by reducing the contribution this makes to these ventilation rates; sedimentation in the air-lock is only a minor factor. Elimination of all sedimentation reduces these values by a maximum of 60 %. If we assume a reduction to about 50 % this would seem to be at least as much as is likely for the airborne particle carrying *Staph. aureus* in this unit. The values of the transfer ratios to corridor and receiving room for average ventilation conditions (Table 3) will then be reduced to 144 (one half) and $1{\cdot}1 \times 10^4$ (one quarter) respectively. This is in agreement with experiments with the same particle tracer in a general hospital which showed that transfer of tracer gas between patient rooms situated close to one another was only about three times greater than that of the particles (Foord, 1972).

The transfer of airborne staphylococci within the ward (Table 3) shows reasonable correspondence with the tracer experiments for transfer from the source room to the corridor, i.e. the results obtained are consonant with the assumption that the airborne particles are carried out into the corridor by air movement. Transfer from the corridor to other bedrooms is, however, as is shown by the overall transfer from source room to receiving room, very much greater than in the case of the particles. Even if allowance is made for the possible effect of a smaller particle size the difference appears to be between 6 and 20 times. This strongly suggests that the apparent transfer from the corridor into these rooms is not due to simple air movement alone. The most likely possibility is that the nurses' clothing becomes contaminated when dealing with an infected patient and that particles are dispersed from this clothing when she enters another patient's room. This would not affect transfer from source room into the corridor as the high levels of air contamination produced in the corridor probably mask this dispersal. Strong evidence that the nurses carry staphylococci from room to room on their clothes in spite of the fact that they put on protective clothing before entering a patient's room, and that these staphylococci are dispersed into the air of the room will be presented in a following paper.

This investigation was supported by grants from the Swedish Delegation for Applied Medical Defence Research.

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