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# Nasal acquisition of *Staphylococcus aureus* in partly divided wards

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## SUMMARY

The spread of coagulase-positive staphylococci has been studied in a modern hospital in which most of the patients were nursed in 4-bed rooms separated from a common corridor only by low dividing walls. Acquisition of new nasal strains from patients in other bedrooms was nearly as easy as from patients in the neighbouring beds. There was no indication that subdivision of this type hindered the spread of nasal strains as compared with open wards of the 'Nightingale' pattern.

## INTRODUCTION

In recent years most newly built hospital wards have been subdivided in one way or another. This has been done for aesthetic, management or hygienic reasons and it is not known to what extent, if any, the different forms of subdivision may affect the risk to a patient of acquiring an infection. As part of an extended study of this question a survey of nasal carriage and acquisition of *Staphylococcus aureus* in two medical wards of the Queen Elizabeth II Hospital, Welwyn Garden City, was carried out during the two years 1965–6.

## METHODS

### *Organization*

Both the wards studied contained 29 beds distributed in six 4-bed rooms and five 1-bed rooms (Fig. 1). The latter were proper rooms completely separate from the rest of the ward, but the 4-bed rooms had only three complete walls, the fourth side being open to the corridor except for low dividing walls, about 3 ft. high, on each side of the entrance from the ward corridor.

Bacteriological samples were taken and the patient records kept by a nurse

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investigator appointed for the purpose. The samples were examined and primary isolations made by an experienced laboratory technician also appointed for the purpose. Both worked at the hospital under the general direction of the hospital clinical pathologist. Strains of *Staphylococcus aureus* were sent to the Central Public Health Laboratory for phage typing.

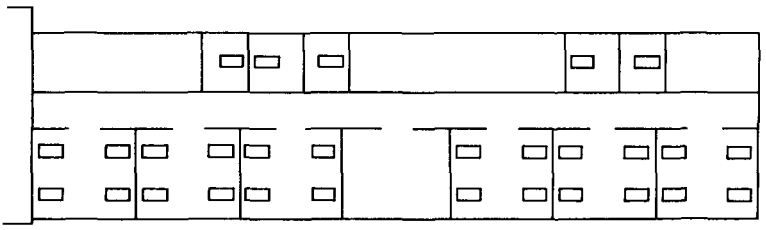

Fig. 1. Plan of one of the wards (the other was a mirror image on the same floor of the building on the left-hand side of the central area).

### *Observations in the wards*

*Nasal swabbing*

Both nostrils were sampled with one dry swab, two circular excursions being made around each nasal vestibule.

*Patients.* A nasal swab was taken as soon as possible after the patient was admitted to the ward. If this was not done within 3 days of admission the patient was considered not to have had an admission swab. Subsequently a swab was taken from each patient on a set day every week. A patient was defined as anyone who spent a night in a hospital bed.

*Staff.* A nasal swab was taken weekly on a set day whenever possible. Staff regularly absent on the swabbing day were swabbed on another convenient day with the object of spacing the swabbing evenly. Anyone working in the ward more than 6 hr. a week was considered to be staff.

*Air sampling*

On the day on which the weekly nasal swabs were taken from the patients, $5\frac{1}{2}$ in. diameter (14 cm) Petri dishes filled with phenolphthalein-phosphate serum agar were exposed in each ward. Four Petri dishes were exposed for 8 hr. during the day and four more for 16 hr. during the following night. The four rooms examined each week were selected from the 11 rooms in each ward according to a randomized scheme, two being 1-bed and two 4-bed rooms.

*General information*

Records were made daily of the bed position of individual patients in the wards, of their mobility (i.e. whether confined to bed, up for toilet purposes only or fully ambulant) and of antibiotic treatment.

*Analysis*

Assessment of acquisition of new strains of *Staphylococcus aureus* in the noses of the patients was made in the same way and using similar conventions to those employed in previous studies (Lidwell *et al.* 1966). An attempt was also made to assess the effect of such factors as the age, sex, disease and nasal carriage state of the patient, as well as antibiotic treatment and environmental circumstances, on the nasal acquisition rate. Since many of these factors are intercorrelated the data were examined using a stepwise multiregression analysis programme, BMD 02R (Biomedical Series, 1965). The unit of data for this analysis was the patient-week of exposure in the ward. In earlier studies the interval between admission and the first weekly nasal swab had been regarded as equivalent to a full week for purposes of analysis, although it is in fact variable and averaged only $3\frac{1}{2}$ days. Separate analyses were performed in the present instance recording the above interval as either equivalent to a whole week or as equivalent to only one-half a week's exposure in the ward. The computations were carried out at the Medical Research Council's Computer Unit.

## RESULTS

*Nasal carriage rates*

The nasal carriage state of the patients after varying length of stay in the ward is shown in Fig. 2. Both the overall carriage rate and in particular carriage of strains resistant to tetracycline increased with time in the ward.

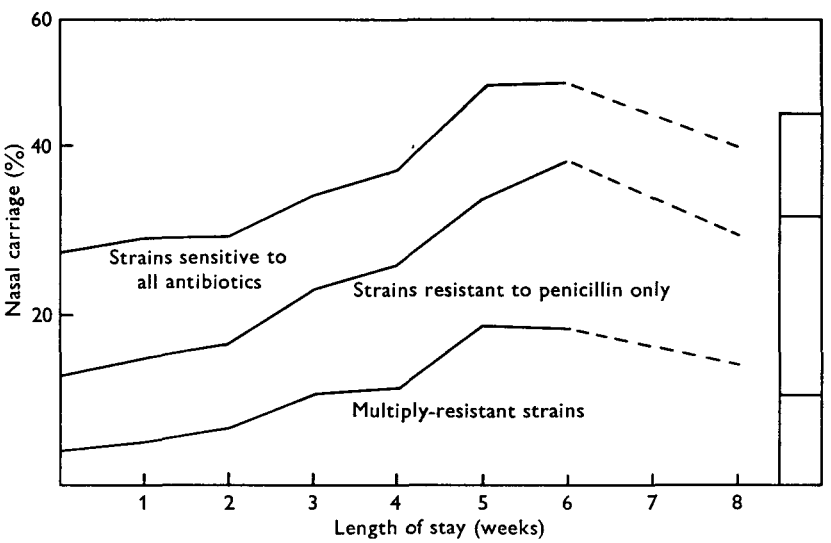


Fig. 2. Change in nasal carriage of *Staph. aureus* during hospital stay. The top line shows the percentage of patients carrying *Staph. aureus* in their noses after varying lengths of stay in the ward. The bottom line shows the percentage carrying strains resistant to tetracycline. The middle line shows the percentage carrying strains resistant to penicillin together with the small proportion carrying strains sensitive to penicillin but resistant to tetracycline. The histogram shows the average rate of nasal carriage by members of the staff.



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*Distribution of airborne* Staphylococcus aureus

The results of the air sampling are shown in Table 1. As the air samples were taken on the same day as the patients noses were swabbed the carriage state of each patient at this time was known. Each colony isolated from an air-sampling plate, or each group of colonies indistinguishable by phage typing, was then considered in relation to the strains carried by the patients and the staff. About 16 % of the colonies isolated could not be related to any known source in the ward. In the case of rather more than 50 % of colonies there was more than one possible

Table 1. *Number and sources of airborne strains of* Staphylococcus aureus

| Probable source | No. settling per 1000 sq.ft. min. | | No. of possible sources | | | No. settling per possible source per 1000 sq.ft. min. | |
|---|---|---|---|---|---|---|---|
| | | | | Carriers | | | |
| | All strains | T strains | Persons | All strains | T strains | All strains | T strains |
| Patient(s) in same room or bay | | | | | | | |
| Single rooms | 48·2 | 3·9 | 1·0 | 0·4 | 0·1 | 120 | 39 |
| 4-Bed bays | 15·6 | 1·5 | 3·56 | 1·2 | 0·3 | 12·9 | 5·0 |
| Patient(s) in other rooms or bays | 16·6 | 9·0 | 22·3 | 7·0 | 1·7 | 2·4 | 5·3 |
| Staff carriers | 9·0 | 4·0 | — | 10·3 | 2·5 | 0·9 | 1·6 |
| No known source | 8·7 | 3·7 | — | — | — | — | — |
| Total | 55·1 | 18·6 | — | 19·0 | 4·4 | 3·1 | 4·2 |

T strains = strains resistant to tetracycline.

The numbers of possible sources are average over the period of observations.

In forming the totals the values for the 4-bed bays and the single rooms have been weighted in proportion to the number of patient-weeks of experience in the different locations.

1000 sq.ft./min. = 93 $m^2$/min.

source. In compiling the table these have been allocated to the different sources in the same proportion as the distribution of those from unambiguously located possible sources. The much larger number of colonies found in the single rooms, and probably originating from a patient carrier in that room (48·2/1000 sq.ft. min.), compared with that found in the 4-bed bays, probably originating from patient carriers in beds in the same bay (15·6), is a reflexion of the much smaller air volume into which the organisms were dispersed in the single rooms. The central three columns in Table 1 show the spatial distribution of the carriers who could have acted as sources for the strains found in the air samples. The fractional figures arise from averaging the numbers over the period of observation; that is, the average bed occupancy in the 4-bed bays was 89 %, hence the average number of persons in these bays was $4 \times 0{\cdot}89 = 3{\cdot}56$ (single rooms were included only when they were occupied). Since the average carrier state among the patients was a little over 30 % for all strains and about 8 % for strains resistant to tetracycline, calculation then gives the average number of carriers shown in the different situations, e.g. 30 % of 22·3 $\simeq$ 7·0 (small differences arise from the different rates of

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carriage found among patients nursed in the different rooms of the ward). The actual number of staff was variable and records were only kept of the numbers of nasal carriers. Dividing the numbers of colonies found in the air samples by the number of possible sources from which it might be presumed they had derived produced the figures given in the last two columns of the table; e.g. the number of colonies of strains resistant to tetracycline probably arising from patient carriers being nursed in beds in other parts of the ward than that where the sample was taken was 9·0/1000 sq.ft. min. There were, on average, 1·7 nasal carriers of such strains among the patients in beds in other parts of the ward. The average number of colonies of these strains reaching the sampling position from a single patient carrier in other parts of the ward was then 9·0/1·7 = 5·3/1000 sq.ft. min. Overall, a patient in a 4-bed bay was exposed to airborne staphylococci from a carrier in the same room in numbers about 5 times as great as from a carrier in another part of the ward. The dispersal of tetracycline strains, however, appeared to be more uniform throughout the ward area.

The exposure of a patient in a single room to airborne staphylococci from patient carriers elsewhere in the ward (not given separately in the table) was actually greater than that of patients in the 4-bed bays. The day-time numbers of *Staph. aureus* in the air were about twice the night-time values.

*Nasal acquisition of* Staphylococcus aureus

The rates of acquisition of new strains of *Staph. aureus* are given in Table 2. Of the 257 apparent acquisitions on which the table is based, 91 (35%) could not be related to known sources in the ward, although 18 of these were with strains identical with strains present at the same time in the other of the two wards studied. Thus 73 (28%) apparent acquisitions were without any known possible source.

Table 2. *Rates of nasal acquisition of* Staphylococcus aureus

| | Acquisition rate per 1000 patient-weeks | | No. of possible sources (carriers) | | Acquisition rate per possible source per 1000 patient-weeks | |
|---|---|---|---|---|---|---|
| Probable source | All strains | T strains | All strains | T strains | All strains | T strains |
| Other patients in same bay | 3·4 | 1·3 | 0·8 | 0·2 | 4·3 | 6·5 |
| Patients in other rooms or bays | 22·0 | 11·0 | 7·0 | 1·7 | 3·2 | 6·5 |
| Staff carriers | 24·6 | 10·7 | 10·3 | 2·5 | 2·4 | 4·3 |
| All known possible sources | 50·0 | 22·9 | 18·0 | 4·4 | 2·8 | 5·2 |
| No known source | 27·3 | 6·3 | — | — | — | — |
| Probably real | 6·9 | 3·3 | — | — | — | — |
| Probably spurious | 20·4 | 3·0 | — | — | — | — |
| Total | 77·4 | 29·0 | — | — | — | — |

The total experience comprised 3327 patient-weeks, of which 2750 was in 4-bed bays (the interval between the admission swabs and the 1st regular weekly swab has been counted as a full week). There were 257 apparent acquisitions.

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When the distribution of antibiotic sensitivity among the apparent acquisitions without sources is considered (see Lidwell *et al.* 1966) it seems probable that no more than 23 represent genuine acquisitions of new strains and that the remaining 50 are probably spurious, due to failure to isolate the strain on the previous swabbing. Overall, for 81 acquisitions there was more than one possible source. These have been allocated in compiling the table in the same way as was done for air strains in Table 1. The central two columns in the table show, in the same way as the corresponding columns in Table 1, the spatial distribution of carriers from whom the acquisitions might have derived. Since a patient cannot be the source of his own acquisition the number of possible sources is less than those given for the airborne samples, e.g. there can be no source in the same room for a patient in a single room and only three at most in the same bay for a patient in a 4-bed bay. The actual figures for bed occupance bring this down to $3{\cdot}56-1 = 2{\cdot}56$ and the average number of carriers who could have been sources becomes $1{\cdot}2(2{\cdot}56/3{\cdot}65) = 0{\cdot}86$ (rounding-off errors account for the difference from the more accurate figure of 0·8 given in Table 2). The corresponding value for those carrying tetracycline-resistant strains is similarly given by $0{\cdot}3$ $(2{\cdot}56/3{\cdot}56) = 0{\cdot}2$. The figures in the last two columns are then derived, as in Table 1, by dividing the acquisition rates by the number of carriers from whom acquisitions of the kind could have arisen. For example, the rate of acquisition, all strains, probably arising from nasal carriers among the staff, was 24·6/1000 patient-weeks, and the average number of staff carriers was 10·3. Hence the acquisition rate from a single staff carrier was $24{\cdot}6/10{\cdot}3 = 2{\cdot}4$/1000 patient-weeks. It is clear that acquisition from a patient carrier in another part of the ward, 3·2/1000 patient-weeks, was almost as likely as when the carrier was in the same 4-bed bay, 4·3/1000 patient-weeks.

Patients in the single rooms acquired strains from other patients at almost the same rate as patients in the other parts of the ward (23·9/1000 weeks compared with 24·1/1000 weeks). These figures are not shown in the table.

*Exposure to airborne staphylococci and risk of nasal acquisition*

When the rates of nasal acquisition from single sources (shown in the two right-hand columns of Table 2) are plotted against exposure to airborne *Staph. aureus* derived from individual source carriers a consistent relationship is obtained (Fig. 3). As in the previous studies in which this method of analysis was employed (Lidwell *et al.* 1966; Lidwell *et al.* 1970) the overall risk of nasal acquisition increases much less than proportionally to the increase in exposure and is considerably greater for a given airborne exposure in the case of the tetracycline-resistant strains. The slope of the line drawn in the Fig. 3 is 0·22, compared with 0·20 and 0·6 in the two studies referred to above, and the ratio of the rates of acquisition of tetracycline-resistant strains to that for all strains at similar levels of airborne exposure is 1·7, compared with 2·7 and rather over 2.

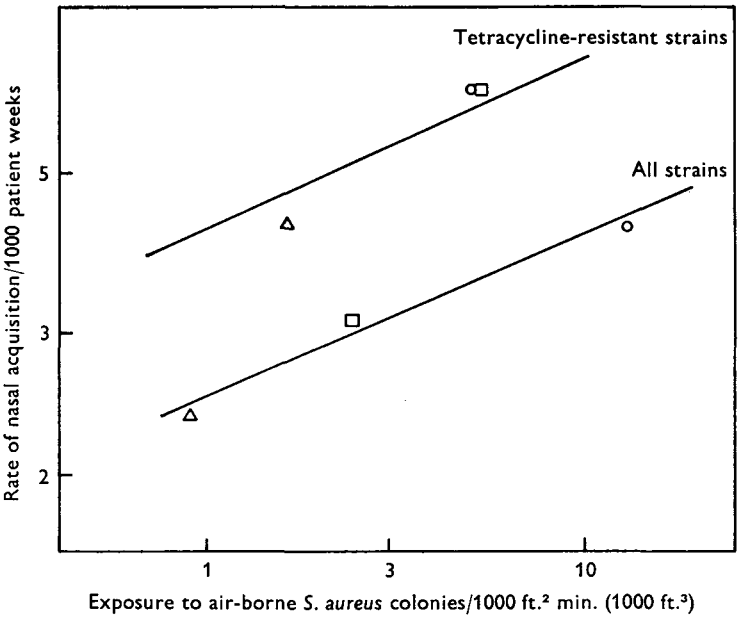


Fig. 3. Relation between risk of nasal acquisition and exposure to airborne *Staph. aureus*. Logarithmic scales for both coordinates. Risk of nasal acquisition: per potential source (carrier) per 1000 patient-weeks. Exposure to airborne *Staph. aureus*: colony count per carrier per 1000 sq. ft (93 m.²) minutes of exposed settling plates – approximately equivalent to 1000 cu. ft. (29 m.³) of air. ○, Acquisitions from other patients in the same bay; □, acquisitions from other patients in other parts of the ward; △, acquisitions from staff carriers. The lower line refers to all strains of *Staph. aureus*, the upper line to those strains resistant to tetracycline.

*Effect of patient and environmental factors on nasal carriage and acquisition*

The following factors were considered in relation to nasal carriage and nasal acquisition of *Staph. aureus*, and where no assessment of the effect of any one of them is given in the tables it implies that this was not significant, i.e. it did not reach its estimated standard error. The factors were: age, sex, diagnosis, nasal-carriage state (for effect on acquisition of new strains), antibiotic treatment, week of stay in ward, mobility, nursed in a 1-bed room, and week preceding death (for patients who died in hospital). The diagnostic groups considered were (*a*) diseases of the heart and circulatory system, (*b*) diseases of the respiratory system, (*c*) diseases involving the stomach and duodenum, (*d*) diseases of the cerebral vascular system, (*e*) disorders of the urogenital system, (*f*) skin conditions, (*g*) neoplasm, (*h*) diabetes, (*i*) rheumatoid arthritis, (*j*) other conditions not comprised in any of the above groups. Table 3 shows the differences in nasal carriage rates in relation to some of the above factors. Carriage rates for tetracycline-resistant strains but not for all strains together were clearly higher in the elderly, in those receiving antibiotics and during the week preceding death. There were also substantial differences, especially in relation to tetracycline-resistant strains, for some diagnostic groups, although the number of individuals involved was sometimes rather small. The effects of length of stay in the ward have already been presented in Fig. 2.

A similar examination of the rates of nasal acquisition is presented in Table 4. The rates are greater for the elderly and very much greater with regard to acquisition of tetracycline-resistant strains among patients receiving antibiotics. It is clear that the elderly, for example, often stay longer in the ward and may be liable to receive antibiotics more often than younger patients. The multiregression analysis was undertaken in order to determine which of the effects apparent in the simple analysis represented independent influences. This is particularly relevant

Table 3. *Association of various factors with the mean nasal-carriage rate*

| Factor | Reference group | Relative carriage rate: All strains | Relative carriage rate: T strains |
|---|---|---|---|
| Age | | | |
| Under 40 | 40–60 | 1·1 | 1·2 |
| Over 60 | 40–60 | 1·1 | 2·5 |
| Sex, female | Males | 1·0 | 0·9 |
| Diagnosis | | | |
| A | All patients | 1·1–1·8 | 1·2–3·0 |
| B | All patients | 0·9–1·2 | 0·8–1·3 |
| C | All patients | 0·2 | 0·8 |
| Received penicillin | Received no antibiotics | 0·9 | 2·1 |
| Received antibiotic other than penicillin | Received no antibiotics | 0·9 | 2·5 |
| In single room | In 4-bed bay | 1·2 | 1·4 |
| Week before death | All patients | 1·2 | 2·3 |

The figures are the ratio of the carriage rates in the 'factor' groups to those in the reference groups.

Diagnostic set A includes skin conditions (41), diabetes (48), disorders of the urogenital system (108) and diseases of the cerebrovascular system (535). Set B includes respiratory diseases (510), diseases of the stomach and duodenum (124), neoplasm (286) and diseases of the heart and circulatory system (885), together with conditions not specifically classified (1181). Set C was rheumatoid arthritis (132). The numbers in parentheses give the patient-weeks experience for each group. The diagnoses are here listed in order of decreasing carriage rate of T (tetracycline-resistant) strains. The range of values given for the relative carriage rates is the spread for the several diagnoses included in the particular set.

Table 4. *Association of various factors with the nasal-acquisition rate*

| Factor | Reference group | Relative acquisition rate: All strains | Relative acquisition rate: T strains |
|---|---|---|---|
| Age, over 60 | Under 60 | 1·4 | 1·6 |
| Received penicillin | Received no antibiotics | 1·0 (0·6) | 2·6 |
| Received other antibiotic | Received no antibiotics | 1·3 (0·5) | 3·9 |
| In single room | In 4-bed bay | 1·1 | 1·3 |
| Confined to bed | All patients | 0·9 | — |
| Fully ambulant | All patients | 1·0 | — |
| Week before death | All patients | 0·8 | 1·0 |

The figures are the ratio of the nasal acquisition rates in the 'factor' groups to those in the reference groups.

The figures in parentheses are the relative acquisition rates for strains sensitive to all antibiotics or resistant to penicillin only.

to the comparison of cross-infection in hospitals of differing layout and construction as it will be essential to take into account any differences in the patients or their treatment that can be shown to influence their acquisition of new nasal strains of *Staph. aureus*.

Table 5. *Factors influencing the rate of nasal acquisition of* Staphylococcus aureus: *coefficients of the multiregression analysis*

| | | Probable sources | | | | | |
|---|---|---|---|---|---|---|---|
| | | All known sources | | Other patient carriers | | No known source | |
| Factor | Proportion (%) | S+P strains | T strains | S+P strains | T strains | S+P strains | T strains |
| Age | | | | | | | |
| Under 60 | 57 | **25** | **42** | 6 | 3 | (−1) | 6 |
| Over 60 | 43 | 11 | **32** | (4) | (2) | (−2) | (4) |
| Diagnostic group | | | | | | | |
| Heart and circulation | 25 | — | — | (−6) | — | — | (−5) |
| Respiratory | 15 | — | — | — | **12** | — | — |
| Cerebro-vascular | 16 | (12) | — | — | — | **17** | — |
| Neoplasm | 8 | **34** | — | — | — | — | — |
| Others (except skin conditions and unclassified) | 12 | — | (−14) | (−7) | — | — | — |
| In single room | 13 | — | — | 12 | — | (11) | — |
| Non-carrier | 68 | — | — | — | — | — | — |
| Received no antibiotics | 43 | (10) | (−12) | 10 | — | **19** | — |
| Received antibiotics (other than penicillin) | 15 | — | **20** | — | 5 | — | **12** |
| Carrier | 32 | — | — | — | — | — | — |
| Received no antibiotics | 21 | — | −27 | — | — | — | — |
| Received antibiotics (other than penicillin) | 7 | (−18) | — | — | — | — | 13 |
| 1st week in ward | 35 | — | −14 | — | — | **29** | — |
| Mean acquisition rate | — | 27 | 23 | 9 | 5 | 21 | 7 |
| Multiple correlation coefficient | — | 0·18 | 0·19 | 0·12 | 0·10 | 0·19 | 0·11 |
| No. of acquisitions | [257] | 88 | 77 | 28 | 17 | 70 | 22 |

The figures in the table, apart from the last three rows and the first two columns, are the coefficients of the linear regression equation giving the nasal acquisition rate per 1000 patient-weeks. The values in bold figures exceed three times their standard errors while the values in parentheses lie between 1 and 2 times their standard error. A dash indicates that the regression analysis terminated without involving the factor concerned, none of those omitted attaining a regression coefficient equal to or greater than its standard error if included in the analysis.

S+P strains are those sensitive to all antibiotics or resistant to penicillin only. T strains are those resistant to tetracycline. The strains were only tested against penicillin and tetracycline.

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The results of the computer analysis are given in Table 5. The second column shows the proportion of the population (each patient-week record is a separate unit) to whom the factor in the first column relates, e.g. 57 % of the patient-week records related to patients under 60; the 32 % with positive nasal swabs (carriers) included 7 % who had received an antibiotic, other than penicillin, at some time during the preceding week. The rate of acquisition among elderly patients was greater than among patients under 60, independently of the effect of other factors. The difference is equivalent to a rate of acquisition between $1\frac{1}{2}$ and 2 times greater. The substantial increase in the rate of acquisition during the first week of stay in the ward of strains sensitive to all antibiotics or resistant to penicillin only, which could not be related to any known source, confirms the impression that a high proportion of these were spurious. No improvement in the overall correlation was obtained by treating the interval between admission and the first weekly swab as a half rather than a whole week of patient stay. The figures given in Table 5 and elsewhere are therefore based on the earlier practice of treating the interval between admission swab and first regular weekly swab as equivalent to the intervals between weekly swabs and recording these as 'weeks'. Nasal carriers not receiving antibiotics were much less likely and non-carriers receiving antibiotics were much more likely to acquire resistant strains. The only other notable factor apparently affecting the rate of nasal acquisition was the increase in this rate among cancer patients with regard to strains fully sensitive to antibiotics or resistant to penicillin only.

## DISCUSSION

The increase in nasal carriage rates with length of stay in the ward, the fairly high rates of acquisition of new strains, over three times that found in the divided thoracic surgery ward (Lidwell *et al.* 1966), and the relatively small differences between the risk of acquisition from a carrier in a nearby bed, i.e. in the same 4-bed bay, or from one in a more remote part of the ward are all characteristics common to the pattern of nasal acquisition with *Staph. aureus* in open wards of the 'Nightingale' pattern.

This confirms the belief that the partial subdivision of a ward, as in the Queen Elizabeth II Hospital, is without effect on the spread of infection.

The nursing of patients in single rooms opening off the general ward area and not mechanically ventilated also appears to have had no detectable effect on the spread of staphylococci to these patients.

The multiregression analysis of factors that might affect the rates of nasal acquisition did not produce any substantial additional information but confirmed that age and antibiotic treatment are the most important factors so far discovered.

Our thanks are due to the patients and staff of the hospital, to Mrs Vick, Mrs Grinrod and Mrs Peirce who collected the bacteriological specimens and recorded patient and staff data, and to the North West Metropolitan Regional Hospital Board for their co-operation and financial support from their research funds.

## REFERENCES

BIOMEDICAL SERIES (1965). Health Sciences Computing Facility, University of California, Los Angeles.

LIDWELL, O. M., POLAKOFF, S., JEVONS, M. P., PARKER, M. T., SHOOTER, R. A. FRENCH, V. I. & DUNKERLEY, D. R. (1966). Staphylococcal infection in thoracic surgery: experience in a subdivided ward. *Journal of Hygiene* **64**, 321.

LIDWELL, O. M., POLAKOFF, S., DAVIES, J., HEWITT, J. H., SHOOTER, R. A., WALKER, K. A., GAYA, H. & TAYLOR, G. W. (1970). Nasal acquisition of *Staphylococcus aureus* in a subdivided and mechanically ventilated ward: endemic prevalence of a single staphylococcal strain. *Journal of Hygiene* **68**, 417.