ISOLATION FOR THE CONTROL OF STAPHYLOCOCCAL INFECTION IN SURGICAL WARDS

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In a study of the natural history of staphylococcal infection we have observed a total of 3,986 patients treated in one or other of three surgical wards at St. Bartholomew's Hospital during the past five years. It was soon apparent that one factor of great importance in the causation of sepsis was the difference that exists between the pathogenic activities of different strains of *Staphylococcus aureus* (Shooter *et al.*, 1958). We also found that those of our patients whose noses were colonized with staphylococci during their stay in the ward suffered a much higher sepsis rate than those who remained non-carriers (Williams *et al.*, 1959).

From the start of our investigations in two of the wards, A and B, we had, on empirical grounds, isolated patients infected with tetracycline-resistant staphylococci in side-wards whenever possible. The observation that relatively few strains of staphylococci had epidemic propensities supported the idea that isolation of the carriers of dangerous strains might reduce the incidence of sepsis, and in 1959 four isolation cubicles were constructed in one of the wards (B). This enabled the isolation policy to be pursued with greater ease and completeness.

We have now tried to assess the value of our isolation policy in preventing post-operative wound sepsis and in controlling the spread of staphylococci generally. Most of the analyses are based on the records from wards B and C, but results for ward A, which was studied only in the earlier part of our investigation, are included when possible. We also report here the results of a comparison of the use of cotton blankets in place of wool in one ward (B).

Materials and Methods

The Wards.—The general arrangement of the wards (A, B, and C) was described in our previous papers. All three were general male surgical wards, but there were especially large numbers of patients undergoing rectal surgery in ward A, vascular surgery in ward B, and urinary tract surgery in ward C. All three wards had a total of three beds in two side-wards, and in addition ward B had, from July, 1959, four beds in four single

"cubicles" built into the ward. These cubicles were constructed of wood and glass and the walls reached from floor to ceiling. Each had a wash-basin, and an extract-fan was fitted in the window so that air from the cubicle did not return to the ward; the exhaust fans were run continuously, and the cubicle door was kept closed whenever the patient in the cubicle needed isolation. The side-wards did not have controlled ventilation, but were 25 feet (7.5 metres) from the main ward along a corridor.

Nursing Routine.—In wards A and B all patients who were infected with or were carriers of tetracycline-resistant staphylococci were nursed in isolation whenever there was a bed available in a side-ward or a cubicle. Since admission to isolation depended on the results of bacteriological examination, there was inevitably a delay between the time when a patient became infected and the time he was transferred to isolation. In ward C infected patients were not isolated. Strict non-touch dressing techniques were used in all the wards; gowns were worn when nursing patients in isolation in ward A but not in ward B. Cleaning equipment used in the isolation rooms was not used in the main ward. Woollen blankets, when soiled, were laundered after the discharge of a patient who was known to have an infected lesion and, otherwise, at irregular intervals. The cotton blankets introduced into ward B were laundered after the discharge of each patient and, in addition, at monthly intervals for long-stay patients.

Bacteriological Routine.—Nasal swabs were taken from patients on the day of admission or as soon after as possible; thereafter all the patients in the ward had their noses swabbed on one day each week. Bacteriological examination was made of material from all septic lesions, suspected chest infections, and so forth. During the latter four years swabs were also taken from healthy wounds at the time of the first post-operative dressing. All cultures were examined for staphylococci, and coagulase-positive strains were tested for antibiotic sensitivity and phage type. The air of the wards was examined for staphylococci with slit-samplers, the usual volume examined being 216 cubic feet (5.8 cubic metres) collected over a two-hour period on each of three days in the week. Bedding and curtains were sampled by

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the sweep-plate method as necessary. Nasal swabs from the ward staff were examined as a routine only during the first eight months of the study.

Definition of Sepsis.—Wounds were regarded as "septic" only if there was visible pus; the sepsis was attributed to staphylococci if these bacteria were isolated from a septic wound. The term "other sepsis" is used to cover all other clinically recognizable infective complications; most of the infections referred to were in the chest. Infections of the urinary tract have not been considered, because urine samples were not received from all patients.

Chemoprophylaxis.—During one six-month period neomycin nasal prophylaxis was used in ward B, a small amount of 1% neomycin or later "naseptin" cream being administered to all patients twice daily, and soap containing 2% hexachlorophene was used for washing. This period has been excluded from all analyses, except when mentioned specifically.

Calendar of Experiments.—Fig. 1 shows the periods during which the various investigations were carried out in the wards. For brevity we refer to A and B as the "isolation" wards and C as the "non-isolation" ward.

FIG. 1.—Diagram showing periods during which the three wards were under the various investigations.

Effect of Introducing Cotton Blankets.—As will be seen from Fig. 1, ward B was supplied with cotton blankets in October, 1958. There was surprisingly little difference between the wool- and cotton-blanket periods in the frequency with which the blankets in use on the beds yielded staphylococci, in the numbers of staphylococci found in air samples, in the frequency with which patients acquired staphylococci in the nose, or in the incidence of staphylococcal sepsis (Table I). Nor do the figures for the cotton-blanket period in B show any notable difference from those derived from ward C, which used wool blankets throughout. In all the

TABLE I.—Effect of Cotton Blankets

	Ward A Cotton Blankets	Ward B Wool Blankets	Ward C Wool Blankets
No. weeks of survey/ .. patients	41 386	20 181	119 1,604
No. of blankets	230	52	127
Percentage of blankets sampled at random yielding staphylococci	49	58	46
Airborne staphylococci (cols. per c.ft.)	0.15	0.12	0.18
Patients acquiring staphylococci in nose, percentage of all admissions	20.5	18.8	16.7
Staphylococcal post-operative sepsis, as percentage of all operations	3.5	3.9	4.5

subsequent analyses the results from the wool and cotton periods have been taken together.

Methods of Analysis

We have had to use a number of different methods to measure the effectiveness of our isolation policy in preventing the spread of infection.

(1) **Direct Comparison of Total Sepsis Rates in the Isolation and Non-isolation Wards.**—This is the simplest method, but it has the disadvantage that there were substantial differences in the operations commonly performed on the patients in the different wards, and the different operations had very different sepsis rates. This difficulty can be partially overcome either by confining the analysis to the group of operations performed in reasonable numbers in both units or by some method of statistical "standardization" to allow for the differing distribution of operations in the two wards.

(2) **Carrier Rates.**—The acquisition of hospital staphylococci in the nose is another measure of the extent to which cross-infection occurs with a ward.

(3) **Source of Staphylococci Causing Sepsis.**—We have tried to separate those cases of sepsis that appeared to result from cross-infection from those apparently due to self-infection and to compare the experience of the wards in this respect. This separation could be done simply by counting the number of cases due to "epidemic types" of staphylococci, or by trying to determine the most probable source of infection for each individual case of sepsis.

(4) **Spread from Recognized Carriers.**—A completely different approach was to measure the extent to which carriers of recognized types of staphylococci spread their strains to other patients in the ward and to compare spread from patients nursed in the open ward with that from patients nursed in isolation.

Method 4

The analysis was confined to types of staphylococci that seemed able to spread in the ward, shown by their isolation from two or more patients within a period of 14 days. Each staphylococcal type was then considered separately, and for each day of the period during which it was present in the ward we noted whether (a) all carriers and infected patients were being nursed in isolation, or (b) some were present in the open ward. We also recorded the number of patients who were found to have acquired the specific staphylococcus on each day of observation. The figures from all the different staphylococcus types and for the three wards were summated. We could thus express the number of acquisitions of staphylococci on days when all the known sources of the specific types were in isolation as a ratio to the total number of days on which there were such carriers in the isolation rooms and not in the open ward, and so compare the frequency of spread in the various circumstances.

A number of assumptions and conventions had to be adopted; most are concerned with the interpolation needed because after admission the patients had nasal swabs taken at weekly intervals. The conventions are illustrated in Fig. 2.

Patients were assumed to be infected from the day midway between a negative and a positive culture provided the interval between the cultures was not more than seven days; and from a positive culture to the day of discharge from the ward provided this was not more than seven days after the day of the culture (patients A and B in Fig. 2). Patients not swabbed on admission were also regarded as infected from the day

FIG. 2.—Diagram showing the conventions adopted for estimating cross-infection rates. Horizontal lines show the period for which the patient was in hospital. Square blocks represent cultural results: above line from the nose, below line from lesion. Stippled blocks represent cultures yielding *Staph. aureus*. Horizontal stippled bands show period during which patient was assumed to be infected.

midway between admission and the day of the first culture (B, nasal cultures). A few patients whose nasal swabs taken on admission yielded a staphylococcus currently epidemic in the ward were regarded as the victims of cross-infection unless the strain belonged to a type known to be common in the normal population. Half-days of carriage were counted as whole days.

A few patients had single cultures taken from their wounds; if these yielded staphylococci the wound was regarded as infected for the seven-day period centred on the day of the culture (patients C and D). No patient was regarded as suffering more than one "acquisition" with a particular type—that is, for this purpose the lesions in patients B and C of Fig. 2 were assumed to be infected from the patients' own noses.

The date taken for the acquisition of a staphylococcus, for correlation with the state of the ward at the time, is the day on which the strain is presumed to have been acquired—that is, day four in patient B of Fig. 2. There were sometimes a few days during the period of prevalence of a particular staphylococcus type when no carriers were known to be present in the ward. Patients becoming infected during such periods are entered separately in Tables VII and VIII. An epidemic was regarded as continuing over these periods when the staphylococcus was not shown to be present in the ward only if one or more of the patients known to have been infected during the earlier part of the epidemic was still present.

Incidence of Sepsis

Of the 2,555 patients included in the analysis, 1,677 had surgical operations; 100 (6%) of the operation wounds showed post-operative sepsis, in 72 cases (4.3% of all wounds) due to *Staph. aureus*. An additional 20 wounds (1.2%) were found to be colonized with staphylococci but were not diseased.

Of 72 wounds with post-operative staphylococcal sepsis, only five showed signs of the sepsis within five days of the operation; in 27 sepsis was first recognized between 6 and 10 days after operation, and in the remaining 40 it was not seen until 11 days after operation. Of the 72 wounds, 62 yielded staphylococci from their first post-operative swab and 10 are known to have been free of staphylococci at the first swabbing.

Sepsis in Relation to Nasal Carriage

Table II shows the relation of staphylococcal sepsis—wound infection and other septic lesions—to the patients' carrier state. It is based on patients in wards B and C, and includes the records of some of the patients analysed in our previous report (Williams *et al.*, 1959). Analysis of the available records from ward A shows close similarity. There was a striking difference between the frequency of staphylococcal wound sepsis in patients who were never nasal carriers (1.3%) and those who entered the ward as non-carriers and became carriers while in the ward (11.9%) or who changed their type of staphylococcus while in the ward (12.4%). The rate for the permanent carriers was intermediate (3.4%). "Other" staphylococcal sepsis was also more frequent in the patients who acquired staphylococci in the ward.

There were 38 cases of staphylococcal wound sepsis in nasal carriers with staphylococci of the same type isolated from nose and lesion. Twenty of these patients were nasal carriers of the lesion type six or more days before the sepsis developed, and a further eight were found to be nasal carriers between one and five days before the appearance of sepsis. In only 4 of the 38 was the staphylococcus not isolated from the nose until more than five days after the appearance of sepsis.

Table II also shows, however, that the patients who acquired staphylococci in their noses in the ward had more non-staphylococcal sepsis than the non-carriers. We therefore sought other differences between those who acquired staphylococci in the ward and those who did not. The most striking difference was in length of stay in the ward (Table III): the mean stay for the

TABLE II.—Relation of Wound and Other Sepsis to Nasal Staphylococcal Carrier State (Wards B and C)

Carrier State	No. of Patients	Percentage Developing			
		Staphylococcal Sepsis		Non-staphylococcal Sepsis	
		Wound	Other	Wound	Other
Patients having operations:					
Never carrier	758	1.3	0.3	0.9	1.3
Non-carrier on admission, acquired staphylococcus in ward	235	11.9	6.0	4.3	4.3
Carrier on admission, changed staphylococcus in ward	121	12.4	7.4	3.3	0.8
Carrier on admission, no change	563	3.4	2.7	1.2	1.8
Subtotal	1,677	4.3	2.4	1.7	1.8
Patients not having operations*	878	0.1†	0.8	0	0.2
Total	2,555	2.8	1.8	0.95	1.3

* 57% of these patients had only one nasal swab examined.

† Patient admitted with traumatic lesion.

Excluded from this table are 137 patients from whom no nasal swab was obtained and 484 patients who were in ward B during the period of the type 53/77 epidemic and subsequent neomycin prophylaxis.

TABLE III.—Length of Stay in Hospital in Relation to Carrier State (Wards B and C)

Carrier State	Percentage of Patients in Various Carrier Categories among those whose Total Stay in Hospital was:				Mean Stay (Days)
	1-10 Days	11-20 Days	21-30 Days	31+ Days	
Never carriers	56.0	46.0	36.5	22.5	11.6
Carrier on admission, no change of strain	38.5	33.0	20.5	18.5	11.6
Changed strain or acquired staphylococcus in hospital	5.5	21.0	43.0	59.0	22.0
Total patients	897	747	223	157	

This table is based on those patients who had no sepsis.

patients who acquired nasal staphylococci while in the ward was 22.0 days compared with 11.6 days for those who remained non-carriers. The mean stay in hospital for patients with non-staphylococcal sepsis was also longer than for those who had no sepsis, and it seems likely that the prolonged stay in the ward of the patients with non-staphylococcal sepsis resulted in some of them becoming nasal carriers of ward staphylococci. It is interesting to note that only 32% of the 44 patients with non-staphylococcal sepsis acquired their ward staphylococcus before the onset of sepsis, compared with 57% of 84 of the patients with staphylococcal sepsis ($d=25$, $SEd=9.3$).

Sepsis in Relation to Age and Type of Operation

Sepsis was more frequent in the older patients (Table IV) and in those having certain operations, especially genito-urinary surgery and operations on ischaemic limbs (see Table V). The effect of age may, in part at least, reflect the slower rate of healing in old age, with consequent increase in exposure to infection.

TABLE IV.—Sepsis in Relation to Age (Wards B and C)

Age (Years)	No. of Patients having Operations	Percentage Developing Wound Sepsis		Percentage Developing Other Sepsis		Percentage Acquiring Nasal Staphylococci while in Ward
		Staphylococcal	Non-staphylococcal	Staphylococcal	Non-staphylococcal	
1-30	286	1.1	1.4	1.1	1.1	14.5
31-50	482	2.7	1.5	2.1	1.9	16.7
51-70	748	6.1	1.9	3.3	2.3	25.7
71+	161	6.3	1.9	1.2	1.2	26.6

Assessment of Value of Isolation

Functioning of the Isolation Rooms

The isolation cubicles in ward B were planned so that air from the cubicle should never return into the open ward. The success achieved in this was assessed in three ways. Smoke tests carried out on several occasions showed that when the fans were working and the doors only slightly open there was no flow out of the cubicles into the ward. This was confirmed by liberation of nitrous oxide into a cubicle with subsequent sampling outside, using the equipment described by Lidwell (1960). When the door was widely opened there was some reflux from the cubicle into the ward.

Bacteriological testing by means of simultaneous air-sampling in main ward and isolation cubicle was not entirely satisfactory. Thus on 3 out of 10 occasions staphylococci of the same type as in the cubicle were found in the ward air, but it was not possible to exclude the possibility of undetected carriers in the main ward. On a further four occasions high air counts were obtained in the cubicles by shaking the patient's blankets; despite concentrations up to 53 staphylococci per cubic foot (1,870 per cubic metre) in the cubicle, no staphylococci of the particular type were found in the main ward.

In wards A and B the side-wards along the corridor were also used for isolation. These had no mechanical ventilation, but the structure of the building had the effect, in ward A, of providing a steady outflow of air from the main ward. The ventilation pattern in the side-rooms of ward B was variable and there must sometimes have been reflux of air from these rooms into the main ward; the side-rooms were not, however, often used for the isolation of infected patients after the construction of the cubicles in the ward.

Some difficulty was experienced at first in persuading patients to remain in the isolation cubicles in ward B with the doors closed, for they could see the other patients in the ward around them but could not converse with them. On one occasion at least we believe that cross-infection from an isolated patient was attributable to the patient having switched the fan off. This was at a time when we had a rapidly spreading epidemic of staphylococci of type 53/77 which led us to attempt control by neomycin prophylaxis. The period of this epidemic and of the neomycin prophylaxis is omitted from the subsequent analyses because early in the epidemic there were too many infected patients for isolation to be practicable.

Sepsis Rates

The incidence of post-operative wound infection in ward B (excluding the 53/77 epidemic just mentioned and the period during which neomycin prophylaxis was in use) was 3.8%; that in the non-isolation ward (C) was 4.5%. As we have already indicated, a simple direct comparison is not satisfactory because of the differing nature of the operations. Table V presents the results in more detail. The operations entered in the top half of the table were performed in reasonable numbers in both wards; those below were done in much larger

TABLE V.—Incidence of Staphylococcal Sepsis in Isolation Ward (B) and Non-isolation Ward (C)

	No. of Operations Performed		Percentage Wound Sepsis		Percentage Other Sepsis*	
	B	C	B	C	B	C
Gastrectomy ..	57	39	1.8	5.1	7.0	2.6
Appendectomy ..	39	58	0	0	0	1.7
Repair of hernia ..	110	151	0	6.0	0	0.7
Neck and head ..	33	39	3.0	0	3.0	2.6
Recto-anal ..	35	55	2.9	3.7	0	1.8
Nephrectomy ..	10	35	40.0	26.5	0	0
Miscellaneous abdominal ..	47	83	4.3	7.2	6.4	4.8
Total ..	331	460	2.7	6.1	2.7	1.95
Varicose vein† ..	52	58	1.9	0	1.9	0
Minor limb ..	84	55	3.6	0	1.2	1.8
Major limb and arterial graft ..	72	2	12.5	50	8.3	0
Genito-urinary operations ..	55	320	9.0	4.7	1.8	2.8
Other operations‡	114	112	0	0.9	2.6	0.9
Grand total	708	1,007	3.8	4.5	2.8	1.1

* "Other" sepsis includes chest sepsis, boils, etc.; infections of urinary tract are excluded altogether.

† The mean stay in hospital for varicose-vein operation is 9.7 days in the isolation ward, but only 4.8 days in the non-isolation ward.

‡ Other operations were as follows: lumbar sympathectomy (B, 58; C, 3), cervical sympathectomy (B, 9; C, 0), eye operations (B, 0; C, 62), mastectomy (B, 5; C, 4), cholecystectomy (B, 15; C, 17), thyroidectomy (B, 9; C, 5), thoracic operation (B, 6; C, 0), mixed operations (B, 12; C, 21).

numbers in one of the wards than in the other, or were, like minor limb operations, different in nature; or, as in the case of operations on varicose veins, there was a major difference in the routine of post-operative management. For the common list of operations the sepsis rate was 2.7% in the isolation ward and 6.1% in the non-isolation ward; this difference is not statistically significant ($SEd=3.6$).

There was no striking difference between the two wards in the incidence of other staphylococcal sepsis.

Carrier Rates

Of the patients swabbed on admission to ward B (isolation) 1.9% were carrying tetracycline-resistant staphylococci in the nose compared with 3.2% of the patients admitted to the non-isolation ward C. In both wards the patients acquired staphylococci in their noses,

but the rate of acquisition was much slower in ward B than in ward C (Fig. 3): among patients who had been in the ward six weeks the proportion carrying tetracycline-resistant strains was 11% in ward B and 23% in ward C. A similar analysis for the other ward (A), which had been studied earlier and which had only side-ward isolation rooms, showed a rate of acquisition of resistant staphylococci very similar to that of ward B.

FIG. 3.—Nasal carrier rates for staphylococci for patients in the wards. Non-carriers=Patients with no *Staph. aureus* in nose; R/PT strains=Staphylococci resistant to penicillin and tetracycline.

Presumed Source of Infection

There was an indication that epidemic spread of staphylococci was less in ward B than in ward C (Table VI). Thus there were fewer epidemics due to tetracycline-resistant staphylococci, a lower proportion of all the septic lesions were due to "epidemic" types of staphylococci—that is, strains causing more than two cases of sepsis in one episode—and a rather higher proportion of the sepsis was attributable to staphylococci carried by the patient on admission. The numbers of cases or incidents on which these proportions are based are, however, rather small, so that by themselves they would have little significance.

The second isolation ward (A) was in several respects intermediate between wards B and C (Table VI).

Cross-infection from Particular Patients

For this analysis we have used the records of all three wards and have not distinguished side-ward from cubicle isolation. Since even in the isolation wards there were often days when patients harbouring tetracycline-

resistant strains were actually present in the open ward, many of the "non-isolation" days in fact refer to the isolation wards. Furthermore, since the analysis was based on all episodes in which a particular type of staphylococcus infected two or more patients, regardless of its tetracycline-resistance, some of the incidents concern staphylococci for which isolation was not considered.

Comparison of Wounds and Nasal Carriers as Source of Infection

It was first necessary to discover whether nasal carriers were more or less liable to give rise to cross-infection than patients with septic lesions. The results of an analysis based simply on cross-infection from patients in the open ward are presented in Table VII. There was a steep increase in the frequency with which patients acquired the staphylococci in the ward with the number of carriers present to serve as sources. Patients with septic lesions gave rise to cross-infections only slightly more often than nasal carriers.

The material was re-analysed to see whether antibiotic-resistant staphylococci behaved differently, and to see whether patients with severe septic lesions were any more active in generating cross-infection than all those with lesions. In neither case was any noteworthy difference from the figures of Table VII detected.

From these results it seemed justifiable to treat nasal carriers and septic lesions as equivalent for the measurement of cross-infection from patients in isolation.

TABLE VI.—Sources of Staphylococcal Infection

	Isolation				Non-isolation C	
	B		A			
Frequency of epidemic incidents per month of observation ..	0.3		0.4		0.4	
Frequency of incidents due to strains resistant to penicillin and tetracycline ..	0.1		0.3		0.3	
Percentage of all septic lesions due to:						
Tetracycline-resistant staphylococci	52		30		89	
"Epidemic" types of staphylococci	38		43		66	
	No.	%	No.	%	No.	%
Wound sepsis due to staphylococci:						
Carried on admission ..	4	15	9	26	3	7
Acquired in ward:						
Probably first in nose ..	6	37	8	65	15	42
First in lesion ..	4		14		4	
Wound sepsis in patients not carriers of wound strain:						
Due to "epidemic" staphylococci	4	15	1	3	11	24
Due to "non-epidemic" staphylococci ..	8	30	2	6	11	24
Source not known ..	1		—		1	
Total patients with wound sepsis	27		34		45	

TABLE VII.—Nasal Carriers and Septic Lesions as Sources of Cross-infection (Wards A, B, and C)

	Sources of Infection in Ward								
	No Known* Source	Carriers Only			1 Lesion Only	1 Lesion + Carriers			2 Lesions + Carriers
		1	2	3+		1	2	3+	
Total days' experience ..	793	1,242	487	375	168	267	181	149	130
No. patients acquiring infection in ward:									
Nasal carriage only ..	41	70	38	45	10	19	26	21	21
Septic lesion, not carrier ..	8	10	6	3	2	1	1	1	0
Lesion and carriage ..	9	9	7	8	2	4	3	8	5
Total acquisitions ..	58	89	51	56	14	24	30	30	26
Acquisitions per 100 days ..	7.3	7.2	10.5	15.0	8.3	9.0	16.6	20.0	20.0

* In this table "no known source" includes days when patients in isolation carried the strain, but there was no known source in the main ward.

It will be noted that the cross-infection rate on days when no sources were known to be present in the ward was practically the same as that on days when there was one known source (Table VII). These days with no known source were all from the middle of recognized incidents, and we presume that there must in fact have been some unrecognized source of infection present. Investigations of perineal carriage made during one epidemic revealed the existence of a number of patients with staphylococci on the skin but not in the nose. These would have been missed by our routine examinations, but might well have been important as a source of cross-infection.

Cross-infection from Patients in Isolation

With sources of the specific staphylococci present in the open ward the acquisition rate for other patients in the ward was 10.5 per 100 days: when all the recognized sources of infection were in isolation it was 7.3 (Table VIII). When there were no known sources of infection in the ward (as in the previous analysis on occasional days during the run of a particular type episode) the rate was 7.3. This again suggests that there may often have been an unrecognized source of infection in the ward on these days.

TABLE VIII.—Cross-infection from Patients in Isolation (Wards A, B, and C)

	Source of Infection			
	None Known	In Main Ward	In Isolation	In Main Ward and Isolation
Total days' experience	478	2,730	315	269
No. of patients in open ward acquiring infection:				
Nasal carriage only	23	225	18	25
Septic lesion, no carriage	5	22	3	2
Lesion and carriage	7	45	2	1
Total acquisitions	35	292	23	28
Acquisitions per 100 days	7.3	10.5	7.3	9.8

Analyses from the three wards taken separately gave very similar figures.

Table VIII omits the period of one staphylococcal epidemic due to phage type 53/77. This strain was introduced by an unrecognized carrier transferred from another ward and had a very great tendency to spread and colonize the nose. It is certain that the isolation rules were not properly followed at the time when the first recognized patient was segregated, and several secondary cases arose. It subsequently became impossible to isolate all the known carriers, and neomycin nasal cream and hexachlorophene soap were therefore given to all patients in the ward; this regime continued for various reasons for a total of six months (Fig. 1). If the period of the type 53/77 outbreak were included in Table VIII the figure for acquisition from isolated patients would be increased from 7.3 to 9.5 per 100 days; those for sources in main ward, or main ward and isolation, would become 10.5 and 11.5 respectively.

In Table VIII there are recorded 23 infections acquired at a time when the only known sources were in isolation. For nine of these cases a carrier had been present in the main ward one to five days before the presumed date of acquisition, so the infection may have been acquired in the ward but remained unrecognized for a longer period than allowed for by our conventions. There was no known carrier within the previous seven days for the remaining 14, but six of them were part

of an outbreak due to type 52/55 and occurred within a few days of each other; the staphylococcus was found in the air of the main ward even when all the carriers were in isolation, so that it is possible there was an undetected carrier among the patients or staff.

Cross-infection in Relation to Proximity to a Carrier

Using methods of analysis similar to those employed for testing the effect of isolation, we tried to find out whether cross-infection was commoner in patients nursed in beds close to a carrier. No clear relation could be demonstrated (Table IX), but the regression coefficients of acquisition rate on bed-spacing are all negative, as would be expected if the closer patients were at greater risk, though none of them is statistically

TABLE IX.—Effect of Distance from Carrier on Cross-infection

No. of Bed Spaces between Patient Acquiring Infection and Nearest Carrier	Acquisition Rate per 1,000 Patient Days with		
	1 Carrier in Ward	2 or More Carriers or Patients with Lesions	Any Type of Source
1	6.3 (8)	9.3 (38)	8.6 (46)
2	4.1 (7)	8.6 (32)	7.2 (39)
3	8.2 (15)	3.4 (9)	5.3 (24)
4	6.7 (11)	7.8 (11)	7.2 (22)
5 and 6	4.1 (7)	8.5 (6)	5.3 (13)

Numbers in parentheses = No. of acquisitions.

N.B.—Owing to the layout of the ward, no patient could be more than six bed spaces away from any other patient.

significant. The results are consistent with the notion that the most remote patients experience as much as half the acquisition rate of the patients nursed adjacent to a carrier. It is interesting to note that, in a few experiments in which a tracer gas was liberated at one point in the ward, samplers at the far end of the ward (which because of the ward layout is equivalent to six bed spaces distant) collected about half the quantity of tracer collected 6–8 ft. (1.8–2.4 m.) from the point of liberation. Such a reduction in transfer has, however, a limited effect on cross-infection because so few patients are as much as five or six beds away from one another.

Neomycin and Hexachlorophene Prophylaxis

Neomycin and hexachlorophene prophylaxis for all patients admitted to ward B was started in April, 1960, because of the widely spreading epidemic due to a staphylococcus of phage type 53/77 and the lack of sufficient isolation accommodation. The prophylaxis was continued until October, 1960. The wound sepsis rate during the whole period April to October was 5.6% (on 356 operations). Eight of the 20 cases of sepsis were due to type 53/77, so that the sepsis rate for other types was about 3.5%—that is, the same as the overall rate for the non-neomycin period. Moreover, the sepsis rate on 96 operations performed after the end of the 53/77 epidemic in mid-May was as high as 7.3%. The introduction of the neomycin and hexachlorophene prophylaxis appeared to eliminate the type 53/77 staphylococcus and terminate that epidemic. However, during the subsequent period it had no detectable effect in reducing the total post-operative sepsis rate; it is, however, curious that of the seven septic wounds occurring in patients on prophylaxis, four were infected with staphylococci sensitive to penicillin and tetracycline.

Of 92 patients under neomycin prophylaxis after the end of the 53/77 epidemic, 37 (40%) were at some time nasal carriers of staphylococci. This may be compared with 55% for similar patients not given chemoprophylaxis.

Discussion

On the face of it the results of our attempt to control staphylococcal cross-infection by isolation are disappointing: a post-operative wound-infection rate of 3.8% in a ward in which all patients known to be harbouring tetracycline-resistant strains were isolated, compared with a rate of 4.5% in a ward where no isolation was practised. But we need to consider not only whether the isolation was actually effective in restraining the spread of staphylococci but also how much we could have hoped to achieve by our isolation methods at their best, and the extent to which a similar system could ever be applied in a general hospital routine.

The effect of an alteration in technique is necessarily difficult to establish by comparing the experience of patients in only two wards, and none of our conclusions can be more than tentative. Apart from the difference in isolation policy between the wards, there may have been other unrecognized differences in management which affected our results. This proviso has to be borne in mind in all our comparisons between the wards when we attribute the observed differences to the isolation policy.

There was one important difference, which we can allow for—namely, the different operations performed on the patients in the two wards. There were 331 operations on patients in the isolation ward and 460 on patients in the non-isolation ward having one or other of seven common operations. The sepsis rate on these operations was 6.1% in the non-isolation ward and 2.7% in the isolation ward. The sepsis rate to be “expected” in the isolation ward, calculated by applying to each group of operations the rate observed in the non-isolation ward, was 5.1%. Though not statistically significant, the figures suggest a halving of the sepsis rate.

In the isolation ward the operations excluded from the common list had a higher-than-average sepsis rate (4.7%). If we assume that the sepsis had been reduced among these operations by the same proportion as among the common operations, the sepsis rate in a control ward with a similar distribution of operations and with the conditions of our non-isolation ward might have been about 8.2% (58/708). If these rather tenuous assumptions are accepted we can estimate that the isolation policy may have prevented 31 cases of sepsis.

One also needs to ask how much an isolation policy could have achieved. Four of 26 cases of sepsis in the isolation ward were due to staphylococci carried by the patient on admission (information on one further patient is lacking); this is equivalent to a sepsis rate of 0.6%, which could certainly not be prevented by isolation. A further eight cases were due to staphylococci not isolated from any other septic lesion; in so far as these were derived from known carriers, they were mostly tetracycline-sensitive, so that the sources of these cross-infections would not have qualified for isolation under our rules. On these grounds the incidence of “unavoidable” sepsis might have reached 1.8% of the 708 patients; this is about half the sepsis actually observed.

An alternative approach is to consider what might have happened if we had been able to isolate effectively all patients harbouring “epidemic strains” of staphylococci—that is, those giving two or more cases of sepsis

—from the time of admission to the ward. Elimination of all cross-infection with epidemic strains would have prevented 11 of the 27 cases of sepsis in ward B, again reducing the sepsis rate from 3.8% to 2.3%.

In sum, then, the records suggest that if the ward had not followed an isolation policy at all there might have been 58 cases of wound sepsis, and if it had been completely successful in preventing cross-infection from patient to patient there might have been only 16. The observed number was 27.

A part of the sepsis regarded as unavoidable in the previous analysis is due to the patients' own staphylococci. Part is probably also due to cross-infection in the operating-theatre, though very few of our patients developed their sepsis with the signs of fever soon after operation and deep pus that are characteristic of theatre infections; in over half the cases the appearance of sepsis was delayed for more than 10 days. Nevertheless we cannot exclude infection in the operating-theatre or soon afterwards as quite unimportant. Some cases of infection may also be due to infection from the medical and nursing staff in the wards. These were outside our investigation, but the small proportion of acquisitions by patients at times in our epidemics when we knew of no carrier or lesion among patients (58/378, Table VII) does not point to a large reservoir in the staff.

That the isolation rooms were probably reasonably effective in preventing the escape of staphylococci from patients nursed in them is shown not only by the tracer experiments but also by the fact that when all known infected patients were in isolation the cross-infection rate was reduced to the same level as that found during periods in the middle of epidemics when there were no known carriers present in the ward. One must presume that the residual cross-infection is attributable to undetected carriers present in the ward.

Although our observations were not continued long enough to provide unequivocal results, it seems that the isolation rooms with ventilation, when properly used, were probably effective in limiting the spread of staphylococci from patients nursed within them, and this was as true of the isolation rooms within the ward as of the side-wards. If confirmed this is important, since isolation rooms within an open ward are sometimes the only facilities available. We have the strong impression that some of our “escapes” from isolation resulted from the switching off of the exhaust fan; this certainly allowed the contaminated air from within the room to reach the main ward.

The main difficulty of an isolation policy became clear during our study; it is the difficulty, in many epidemics of ward infection, of detecting carriers who serve as reservoirs from which the spread is maintained. We could detect hardly any difference between carriers and patients with septic lesions as sources of cross-infection, and, though there might be greater differences in other circumstances, it seems to us inescapable that a control policy based simply on the isolation of patients with septic lesions must often fail. To detect all the dangerous carriers by swabbing is an expensive procedure and will frequently give the information too late—as it often did in our own wards. The implication seems to be that, unless we prefer to protect patients against the acquisition of staphylococci in their nose by chemoprophylaxis, hospitals ought to be constructed so as to isolate as many as possible of the patients from

one another, and in particular to protect newly admitted patients from exposure to those who have been in hospital long enough to acquire hospital staphylococci.

Summary

The natural history of staphylococcal infection was studied in three male surgical wards, in two of which an attempt was made to isolate all patients known to carry or be infected with tetracycline-resistant staphylococci. One of the wards was provided with four exhaust-ventilated cubicles for isolation purposes.

The introduction of cotton blankets, washed at frequent intervals, into one of the wards had no detectable effect.

Patients who acquired staphylococci in their nose during their stay in hospital developed staphylococcal sepsis more than five times as often as those who did not. In most cases the nasal colonization preceded the sepsis. The patients who acquired staphylococci also had a higher incidence of non-staphylococcal sepsis, but this appeared to be associated with prolonged stay in hospital.

The post-operative sepsis rates were compared in patients having operations performed with comparable frequency in one of the isolation wards, and in the non-isolation ward. The rates were 2.7 and 6.1% respectively; the difference of 3.4% does not reach the level of statistical significance.

Patients in the isolation wards became nasal carriers of tetracycline-resistant staphylococci more slowly than those in the non-isolation ward.

There was some evidence that epidemic spread of staphylococci was less in the isolation wards than in the non-isolation ward.

When individual sources of infection were considered, it was found that nasal carriers were almost as important in generating cross-infection as patients with septic lesions. When all patients known to be sources of infection in the ward were isolated the incidence of cross-infection was apparently reduced. The exact magnitude of the reduction is difficult to determine because of the almost certain presence of undetected sources of infection in the ward.

The limitations of any study of this sort based on three wards is stressed, but, taken at their face value, the results suggest that the isolation policy might have reduced the sepsis rate by about one-half. The demonstrable importance of nasal carriers as sources of cross-infection implies that such an isolation policy can be applied only if continuous bacteriological surveillance is available. Since this is seldom practicable, the conclusion is reached that, to prevent the transfer of staphylococcal infection, hospitals need to be constructed so as to isolate as many patients as possible from one another.

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SPREAD OF A MARKER ORGANISM IN A HOSPITAL WARD

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In an earlier study (Rubbo, Pressley, Stratford, and Dixon, 1960) it was suggested that air-borne bacteria were dispersed in hospital wards either as free organisms or in association with fibre nuclei arising from personal clothing or bedclothing. The present study is a continuation of this work. Here an attempt has been made to follow the spread of a marker organism in a hospital ward when its source, time of entry, and concentration in the ward are known. These conditions were met by introducing *Staphylococcus citreus* into a bacteriologically clean ward and subsequently tracing its movement in that ward over a period of two days. In this way it was possible to compare the degree of environmental contamination which may arise when different types of textiles act as reservoirs of infection. At the same time the dispersion of naturally introduced *Staph. aureus* was followed, and it was found that the movement of this organism closely paralleled that of the marker organism.

The main points which emerge from the present study are: (1) contaminated woollen blankets do not disperse organisms more freely than similarly contaminated cotton blankets; (2) contaminated blankets, either woollen or cotton, disperse their organisms most effectively when covered by cotton counterpanes (quilt or bed-covers); and (3) the degree of airborne contamination of textiles depends largely on the presence of counterpanes and the manner in which they are handled.

Materials and Methods

Marker Organism

Staph. citreus was selected as a marker organism for several reasons. First, the background count arising from sources other than those produced experimentally was extremely low and could be disregarded in all calculations. Secondly, the same selective medium could be used for *Staph. aureus* and *Staph. citreus*; thus the differentiation of the two species on pigmentation was not difficult. Thirdly, the survival time of *Staph. citreus* was quite adequate to cover the two-day period of our ward experiments. Finally, it was innocuous to patients and laboratory personnel.