With one exception, the minor cases have obtained rapid relief of pain and healing of the ulcer has been accelerated.

The major cases have generally derived great benefit from the treatment. All showed initial improvement. With maintenance treatment some have been completely free of ulceration during several months of observations. Others have had minor ulceration but are greatly improved. Only one has shown a tendency to relapse during treatment.

The special cases have likewise shown a good response.

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SPREAD OF STAPHYLOCOCCI IN A SURGICAL WARD

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In the summer of 1956 a surgical unit at St. Bartholomew's Hospital suffered a severe outbreak of staphylococcal infection in which staphylococci of a single phage type caused 31 infections in two months. The staphylococcus appeared to be spread in part by a member of the surgical team who was a carrier, but there was also evidence of spread within the ward (Shooter, Griffiths, Cook, and Williams, 1957). The large number of staphylococci found in the air and on the bedclothes in the ward raised the question of the importance of air-borne transfer in the spread of infection within the ward, and of the value of measuring air and dust contamination with staphylococci in the prediction of outbreaks of infection.

The male ward of the unit was redecorated in September, 1956, and the opportunity was thus presented of observing the recolonization of a clean ward by

staphylococci, and possibly of tracing the source of staphylococci isolated from the air and from objects in the ward.

This study of the natural history of *Staphylococcus aureus* had not proceeded far when we observed the first example of the wide dissemination of a single phage type of staphylococcus, without, however, the occurrence of any wound sepsis. The study continued for eight months (until May 31, 1957), during which we observed nine waves of staphylococcal "broadcast," in each of which the numbers of staphylococci of one phage type reached an unusually high level (0.1 bacteria-carrying particle per cu. ft. (3.5 particles per cubic metre) of air) and, in most cases, comprised 60-80% of the staphylococci found in the air at the time. Of the nine staphylococcal broadcasts, only three were associated with clinical infection in more than one patient. These observations lend colour to the idea that some staphylococci are less virulent than others, and also that some patients shed staphylococci more freely than their neighbours.

In this paper we record, first, the extent to which patients acquired staphylococcal infection of wounds and other parts, and to which patients and nurses became nasal carriers during their stay in the ward. We also describe the extent of staphylococcal contamination of inanimate objects—particularly bedclothes and bed-curtains—and the air. Second, we describe the staphylococcal broadcasts and discuss their probable genesis and observed effect.

By means of phage-typing it is now possible to recognize many separate and distinct types of *Staph. aureus* that are ordinarily quite stable. With an organism as common as *Staph. aureus* some typing method of this sort is essential for a study of the epidemiology of infections. The usefulness of the method is emphasized by the fact that some 186 apparently distinct types of staphylococci were recognized during our eight months' study.

A possible source of confusion was introduced into our investigation of the spread of infection by the decision, prompted by experience in the summer outbreak, to isolate in a side-room any patients infected with staphylococci thought to be particularly virulent, which in the event proved to be those resistant to both penicillin and tetracycline.

The Investigation

The study was made in a male surgical ward. The work of the unit consisted of general surgery with a considerable proportion of abdominal and rectal operations. The ward had 22 beds, spaced about 6 ft. (1.8 m.) apart, with three more beds in two side-rooms. There were cotton curtains, suspended from rails 7 ft. (2.1 m.) high, that could be pulled out to surround each bed. Wound dressings were done in the ward by a no-touch technique. Patients infected with what were thought to be dangerous staphylococci were nursed in one of the two side-rooms. Special nurses were not employed, but a strict barrier-nursing routine, including the wearing of gowns, was followed.

A variety of minor steps were taken which it was hoped would help to check the spread of staphylococci. All the bedding from the patients who were nursed in isolation was disinfected with formaldehyde before being sent to the laundry. Curtains in the ward were changed once every four to five weeks. The floors were

wax-polished and swept with a vacuum cleaner. No dressing cloths were used on the top of dressing trolleys, which were wiped with 0.2% sodium hypochlorite solution between each dressing. Hypochlorite was also used for disinfecting the bath after each patient, for the urinals, for wash-basins, and for lavatory seats, which were wiped three times a day instead of being polished. Soiled dressings were put immediately into a bin with a pedal-operated lid, and the unused contents of sterile opened dressing packets were put to one side for resterilization. In a previous study staphylococci had been isolated from unused materials (and from a dressing-trolley cloth) at the end of a dressing, and if not removed there was a temptation to use the lately sterile dressings for miscellaneous tasks. For a similar reason cloth urinal covers were replaced by disposable paper covers.

Bacteriological Methods

Swabs were taken from wounds routinely at first dressing and subsequently if infection was suspected on clinical grounds. Specimens of sputum and urine were examined as thought necessary. Nasal swabs were taken from the medical and nursing staff and the ward cleaners and kitchen staff weekly, and from patients on admission and weekly thereafter.

On week-days during the first three and a half months of the study samples were taken from bedclothes, bed-curtains, dressing-trolley tops, baths, basins, lavatories, etc., a total of 877 examinations being made. The sweep-plate method (see Blowers and Wallace, 1955) was used for fabrics; swabs were used for other objects. Air was examined with a slit sampler on one day in each week: on average about 180 cu. ft. (5.1 cubic metres) was sampled. During May a new slit-sampler was introduced and it was possible to take air samples daily; the total volume examined each week was 150–240 cu. ft. (4.25–6.8 cubic metres).

Blood agar was used for the cultivation of specimens from persons and articles; for the air samples we employed serum agar containing phenolphthalein phosphate (Barber and Kuper, 1951) as an indicator medium.

From all cultures, colonies resembling *Staph. aureus* were tested for coagulase, and coagulase-positive strains were submitted for phage-typing. Strains from people and objects in the ward were also tested for antibiotic sensitivity.

Staphylococci were tested for phage sensitivity and classified into a number of types by means of the methods and rules already described (Williams and Rippon, 1952; Anderson and Williams, 1956). The "types" quoted are lists of the phages to which the strain was sensitive; types that could be determined only with strong phage filtrates are printed in italic. The suffix "w" indicates weak reactions, and "+" indicates additional minor reactions.

Some 15 types were each isolated from many different sources; these types were reasonably well defined and distinguished from each other, and from other strains encountered. There were a great many other phage patterns that were seen only once or on a few occasions; with these it is less easy to be sure how many distinct types were present, but we estimate that there were at least 186.

Records.—In addition to conventional records and a wound-book for recording the state of operation wounds (see Shooter, Taylor, Ellis, and Ross, 1956) a record was made each day of the position of patients' beds in the ward, of operations and wound dressings, and of what was known of the distribution of staphylococci.

Chemotherapy.—Of the 311 patients admitted to the ward during the period of this investigation, 128 received one or more antibiotics, but no routine pre-operative chemotherapy was given, except for operations on the small and large intestine. Of the 128 patients, 82 were given sulphonamides, 78 penicillin, 17 streptomycin (usually by mouth), 8 neomycin (by mouth), 5 erythromycin, and 3 tetracycline;

novobiocin and E.129 for two patients, and nitrofurantoin ("furadantin") and nystatin each for one patient.

Results

Staphylococcal Infection of Clean Wounds

During the study 311 patients were admitted to the ward, and 195 underwent operations involving cutting skin or mucosa; many of these operations were on the gastrointestinal tract. Sixteen operations were into infected regions: these comprised 11 haemorrhoidectomies, 3 other operations on the anal canal, 1 suture of a perforated duodenal ulcer in which the incision was contaminated at the time of operation, and 1 hemiglossectomy. There were thus 179 clean cases for analysis, and, as shown in Table I, 26 (14.5%) developed clinical signs of infection. From 8 (4.5%) of the wounds *Staph. aureus* was isolated.

TABLE I.—Fate of 179 Clean Operation Wounds

Clinical	Bacteriological	No. of Wounds
No sepsis	(Not all examined)	153
Sepsis	<i>Staph. aureus</i> isolated	8 (7)*
"	No <i>Staph. aureus</i> ; Gram-negative bacilli isolated	7 (3)
"	No <i>Staph. aureus</i> ; no specific organism recorded	8 (5)
"	Not examined	3 (1)
Total with sepsis		26 (16)

* Figures in parentheses indicate number of infections thought to have been acquired in the ward.

Sixteen of the 26 cases of sepsis and 7 of the 8 staphylococcal cases seemed to be due to ward infection. The decision to call a wound septic was a clinical one, and was founded on the presence of visible pus. Infection was considered to be probably acquired in the theatre rather than the ward when pus was found in the depths of the wound within a few days of operation, or when signs of infection were present at or before the first post-operative dressing.

Other Infections due to Staphylococci.—Six patients developed infections of the chest from which staphylococci were isolated; 4 developed staphylococcal infections of the skin, ear, or conjunctiva; one a staphylococcal urinary infection; and one a staphylococcal enterocolitis. Three patients were admitted with burns which became infected; one patient was admitted with a septic hand and another with a carbuncle, both due to staphylococci.

Staphylococci Responsible for Infection

Of the 311 patients admitted, 2 already had staphylococcal sepsis on admission and 17 (5.5%) developed staphylococcal wound sepsis or some other staphylococcal infection while in the ward. One of the patients with wound sepsis had been infected in the operating theatre. Of the remaining 16 patients, several had more than one focus of infection, so that there were 24 separate instances of staphylococcal disease acquired in the ward.

The phage types of the infecting staphylococci are shown in Table II. Of the 186 different phage types of staphylococci present at one time or another, only 13 caused disease, only 10 gave rise to ward infections, and only 3 were responsible for disease in more than one patient. These three types were all of phage-group III, and all were resistant to penicillin, streptomycin, and tetracycline.

The two patients admitted with septic lesions and the one infected in the theatre were infected with different types from those infected in the ward, and in no case did their type spread to other patients.

First Stages in the Return of Staphylococci to the Ward

Before giving an account of the sources of the infections just detailed it may be of interest to recount how the ward became recolonized with staphylococci at the beginning of our study.

When the ward reopened on the morning of September 25, 1956, members of the staff provided the only recognized

TABLE II.—Phage-types of *Staphylococci* Causing Clinical Infections

Phage Type	Antibiotic Sensitivity*			No. of Septic Lesions		Total No. of Patients with Septic Lesions	No. of Persons (Patients and Staff) Becoming Nasal Carriers
	Penicillin	Tetracycline	Streptomycin	Post-operative Wound Infection Acquired in Ward	Other Infections		
47/53/75/77 ..	—	—	—	1 abd. wound of prostatectomy	(Septic blister on same patient) 1 burn	3	6
6/42E/47/75w ..	—	—	—	0	1 chest (and tracheotomy in same patient) 1 conjunctivitis (1 otitis), 1 burn, 1 varicose ulcer	3	9
75/77	—	—	—	2 abd.-perineal exc. rectum† 1 gastrectomy (1 abd.-perineal exc. rectum†)	(Chest in all 3; enterocolitis in 1)	3	4
75/77	—	+	+	1 orchidopexy	1 burn	1	12
3C/55/71+ ..	+	+	..	0	1 chest	1	2
3C/55/71 ..	+	+	..	0	(Urinary tract, same patient)	1	1
7/47/53/54/75/77 ..	—	—	—	1 abd.-perineal exc. rectum	0	1	3
6/47/53/75 ..	—	+	—	1 ileal bladder, several wounds	0	1	2
29/80/42E ..	—	+	..	0	1 chest	1	2
80/6/7/47/53/54 ..	—	+	..	0	1 otitis	1	2

* + = Sensitive. — = Resistant to the antibiotic. .. = Not tested.

† 1 patient had an abdomino-perineal excision of rectum infected first with the 75/77-resistant and later with the 75/77-sensitive.

Note.—One thyroidectomy wound was infected in the operating theatre with a type 80 strain. One patient was admitted with a tenosynovitis due to type 55, and one with a carbuncle due to type 3B/55/71. All three strains were penicillin-sensitive. Lesions indicated within parentheses were in patients appearing elsewhere in the table with other lesions.

source of staphylococci. Twenty-one were examined, and 10 were found to be nasal carriers; of these not more than two carried the same type. In the afternoon they were joined by three patients, one of whom was a nasal carrier. During the day 185 cu. ft. (5.24 cubic metres) of air was examined but *Staph. aureus* was not found, and none was isolated from blankets on three empty beds or from two bed-curtains.

On the second day two more patients, both nasal carriers of *Staph. aureus*, were admitted. No staphylococci were isolated from bedding, curtains, bath, or wash-basin, but a lavatory seat yielded a staphylococcus of the type carried by one of the patients.

On the third day two more patients arrived, both staphylococcal carriers. Of 21 sweep plates and swabs from bedding, curtains, and toilet fittings, three yielded *Staph. aureus*. One of the positive cultures was from a drawsheet, and was the same type as that carried by the occupant of the bed; one was from a curtain with the type carried by the person taking the sweep, and the third was from a lavatory seat, this time with a different patient's staphylococcus.

By the end of the first week there were 12 patients in the ward, six being nasal carriers of different types of staphylococci. Re-examination of the staff showed that seven of the 21 were carriers of six different types. The air yielded 14 colonies of staphylococci of nine different types, of which seven were carried by patients and two were carried by the staff.

By the end of the second week there were 21 patients, 11 being carriers of 10 different types, and of the 23 members of the staff 13 were carriers, with not more than two carrying any one type. The air sample yielded 14 staphylococcal colonies, 11 of which were types carried by patients and one a type carried by a nurse; the source of two could not be traced.

Reservoirs of Infection

The sources from which patients could be infected included infected lesions, both septic and silently infected, carrier sites, inanimate objects, and air. We attempted to assess the load of infection under each of these headings, and in this section we describe the results obtained in the whole eight-months survey.

Infected Lesions.—The incidence of sepsis has already been discussed, and from this it is clear that at any one time there might be between 0 and 6 patients in the ward with some staphylococcal sepsis. We cannot indicate the incidence of prevalence of simple colonization of wounds, because, in the ordinary way, swabs were taken only when wounds appeared unhealthy.

Nasal Carriers.—The results of the examinations for nasal carriage conformed with what has been found elsewhere.

Some 39% of patients swabbed during their first week in hospital carried *Staph. aureus* in the nose; the proportion tended to rise with increasing stay, so that about 60% of those swabbed in the third or later week were positive. Altogether 839 nasal swabs were examined from 96 members of the nursing, medical, and lay staff who worked in the ward at one time or another; 523 (62%) yielded *Staph. aureus*. Most of the carriers retained one type of staphylococcus at successive examinations, but, of the 96, 12 had two different phage types in successive cultures, three had three types, and one had four types.

Inanimate Sources

Staph. aureus was isolated from 284 of the 877 articles examined. In general the results reflected the carriage state of the person in contact with the article, or the general predominance of one type of staphylococcus in the ward at the time.

Staphylococci were isolated on 72 occasions from articles of bedding. These staphylococci were thought to be of the same phage type as those of the occupant of the bed on 27 occasions, of another patient in the ward at that time 31 times, and of a member of the staff 9 times; in 5 cases the source was not traced. Of the 18 drawsheets examined 12 yielded *Staph. aureus*: 9 strains were of the same type as that of the occupant of the bed and the other 3 were all of a type that was very widely spread in the ward at the time, apparently by a carrier with an ileostomy. Of the six negative drawsheets, five were from beds whose occupants were not nasal or faecal carriers of staphylococci.

Of 219 examinations of bed curtains 63 were positive for *Staph. aureus*: 19 of the strains were of the same type as that of an adjacent patient, 28 the same as that of another patient in the ward at the time, 12 were types carried by the staff, and 4 were not traced. Of samples of dust examined, 15 contained types traceable to patients, and one a type traceable to the staff. The speed with which contamination occurred was illustrated by one patient, a nasal and faecal carrier of staphylococci, who had contaminated his pillow, drawsheet, and bed-curtain within 24 hours of his admission to the ward.

Thus, in the circumstances of the ward that we studied, environmental contamination is more often attributable to patients than to staff. As time went by it became clear that under some circumstances some patients could shed staphylococci in great numbers. The presence of such patients was reflected in the results of air sampling.

Isolation of Staphylococci from the Air

After the first month of the study the air samples revealed the presence of an average of about 0.25 staphylococcus-carrying particle per cu. ft. (8.8 per cubic metre) of air.

But examination of the Chart shows immediately that such an average has little meaning: one of the most striking observations of the whole study has been the occurrence of successive waves of staphylococcal broadcast. Six major peaks in the air count were observed, and when the types of the air staphylococci were taken into account nine broadcasts could be recognized. During the first three and a half months, while routine sampling of articles was carried out, it was clear that they too showed this changing prevalence of different types, and it was in fact the close correlation of the types of staphylococci in the air with the types of those on articles that led us to give up routine sampling of the latter.

The fact that the staphylococcal broadcasts shown in the figure do not coincide with high general bacterial counts indicates that they were not due simply to occasional sampling at the time of some special disturbance—for example, bedmaking.

Spread of Staphylococci

A study was made of the genesis of the staphylococcal broadcasts just mentioned. Three typical examples are first described in some detail.

Spread of Type 6/42E/47/75w

This type (No. 8 in Chart) first appeared on January 18, 1957, in a patient's nose on the day after his admission, and it was subsequently isolated from his stool; he probably acquired it when a patient in another ward. As the strain was resistant to tetracycline the patient was isolated in a side-room on January 21, remaining there until March 15. The bedding and articles in the side-room became heavily contaminated, and the patient himself developed conjunctivitis and otitis media. He was undergoing deep x-ray therapy and had no wound to infect.

A staphylococcus of this type next appeared on February 25 in the nose of a patient in an adjoining side-room. This patient was ambulant, and as he distributed newspapers he moved freely through the ward, though not, officially, into the isolated side-room in which the first patient to carry the strain was nursed.

On April 3 a strain of type 6/42E/47/75w was isolated from a varicose ulcer of a patient who had been in the ward since February 4; how long before April it was present is unknown, as the ulcer had escaped swabbing. It was subsequently found at weekly intervals until the patient's discharge on May 16.

Also on April 3, staphylococci of the same type were isolated from a burn of a patient who had had the strain for the first time in his nose on April 1. This patient left on April 7. On the next day (April 8) type 6/42E/47/75w was isolated from the noses of four other patients; it was carried in the nose by one more patient in the next week. During the course of the following week three of these patients were discharged, and one was isolated in a side-room and his nose treated with neomycin cream. The type was not isolated again from patients apart from the varicose ulcer.

From the air the strain was isolated in small numbers in samples taken on March 19 and 26. On April 2, at about the time when the strain infected the burn, the air contamination increased to about 0.17 colony per cu. ft. (6 per cubic metre) of air. The count was 0.03 and 0.02 colony per cu. ft. (1.05 and 0.7 per cubic metre) respectively on April 8 and May 3, and none was found thereafter.

Type 47/53/75/77

We could not trace the way in which this strain (No. 1 in Chart) entered the ward. It was first isolated on

Results of weekly air sampling. ⊕ = Specified type present in the air. ⊗ = Type present at 0.1 colony per cu. ft. (3.5 per cubic metre) or more; the actual count is indicated by the hatching in the column above. ● = Cases of infection occurring in the ward. Numerals refer to the incidents of broadcasting detailed in Table III. Sampling was ordinarily carried out on one day in each week, but samples were taken on two days in the week of March 7, and as the type distribution differed considerably the results of both are entered.

October 22 from a bed-curtain and subsequently on October 31 from a towel in the sterilizing room, and on November 2 from two bedspreads. One of the two beds was empty and the other was occupied by a patient who was not carrying or infected with staphylococci.

The strain was first isolated from a person on November 5 when it was recovered from an anal wound of a patient admitted unconscious on November 2. On November 5 it was also isolated from a nasal swab of a patient admitted on November 3 and from another patient with extensive burns. This last patient had been in the ward between November 1 and 2, but thereafter remained isolated in a side-room until his discharge on November 12. On November 8 type 47/53/75/77 was found to be infecting the tracheotomy wound and sputum of the patient admitted unconscious on November 2, who was then moved to isolation in the second side-room, where he stayed until he died on November 10.

At this stage there were indications that further spread of the strain was beginning, and by November 12 three more patients, all of whom had had a different type before, carried type 47/53/75/77 in their noses. It had infected one more patient's wound, and by the time this patient was isolated on November 16 it had produced a septic blister on him. The patient was discharged on December 3, and, after the remaining two carriers in the ward had lost the type from their noses, it disappeared.

The various incidents were reflected in air counts. No colonies were found on October 29; on November 5 the count was 0.03 colony per cu. ft. (1.05 per cubic metre), on November 12 it was 0.20 (7.6), on November 20 less than 0.01 (0.35), and none was found on November 27.

Type 79w

This penicillin-resistant tetracycline-sensitive staphylococcus (Nos. 4 and 5 in Chart) colonized the noses of 15 members of the staff and 42 patients, and was found on articles and in the air, but was not responsible for any sepsis. It was apparently brought into the ward by a nurse, who, although a heavy carrier, did not appear to shed the strain freely. She was in the ward from September 24 until December 4, but in that period her staphylococci were not isolated from any article, and only two colonies were isolated from air. On November 19 the nurse was joined by another carrier of the same type, but this girl too was presumably not a heavy shedder.

The most likely source for the brisk spread of the type, which began in the second half of December, was a patient admitted on November 24 who had acquired the strain in his nose by December 3. This patient had a septic wound, but swabs on December 10 and January 2 failed to show staphylococci. Because of the infection the wound was dressed at intervals of two to four hours from December 8 to 11, and until January 4 twice daily. Staphylococci of type 79w were present on the patient's bedding, and the upheaval which the frequent dressings necessitated presumably threw them into the air. By the end of December this type had colonized four nurses' and nine patients' noses, and had been isolated on 21 occasions from bedding and curtains at both sides and both ends of the ward. Two colonies (less than 0.01 per cu. ft.—less than 0.35 per cubic metre) were isolated on November 27. Thereafter the air counts were 0.12 colony per cu. ft. (4.24 per cubic metre) on December 18 and 0.11 per cu. ft. (3.88 per cubic metre) on December 24.

By the time the patient was discharged on January 2 this staphylococcus was plainly well entrenched, and it stayed as a common type in the ward for the next three months. In this time it colonized the noses of 11 more members of the staff and 20 patients, and it was isolated from three wounds, none of which, however, was regarded clinically as being infected.

Between January 1 and April 8, 2,290 cu. ft. (64.5 cubic metres) of air were examined. From this amount 1,006 colonies of staphylococci were isolated and 390 were typed: 147 belonged to 79w. There was one peak period from February 11 to February 21 when 391 colonies of staphylococci were isolated from 410 cu. ft. (11.6 cubic metres) of air. Of these colonies 108 were typed, 81 belonging to type 79w. The reason for this rise was not found.

At the beginning of April five patients carried this type in their noses: by the middle of the month they had been discharged, and until the end of the investigation the only carriers left were four nurses. With patients eliminated there was very little aerial shedding, and after April 8 only an occasional colony was isolated from the air (5 colonies from 1,531 cu. ft.—43.4 cubic metres).

Summary of Staphylococcal Broadcasts

In Table III we have summarized the information about the nine staphylococcal broadcasts that can be distinguished

TABLE III.—Details of Nine Incidents of Staphylococcal Broadcast

Key to Chart	Type	Date of		Source from which First Isolated	Source from which Probably Dispersed	Wounds at Risk During Period of Dispersal		No. Patients Developing Septic Lesions	No. Becoming Nasal Carriers	
		1st Isolation	Last Isolation			Total Wounds at Risk	Average No. of Dressings per Day		Patients	Staff
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1	47/53/75/77	Oct. 22	Dec. 11	Bed curtain	Sputum of unconscious pt.	15	8	3	6	0
2	7/47/53/54/75/77	Nov. 19	" 21	Nose of pt.; already in ward air	Urinary infection	18	8	1	3	0
3	" 73 "**	Oct. 3	See 6	Nose of pt.	Ileostomy (though evidence for infection not good)	24	8	0 (doubtful infection of ileostomy)†	3	0
4	79w	Sept. 24	" 5	Nose of nurse	Nose of pt.; frequent bedmaking; wound not adequately swabbed	13	6	0†	15	7
5	79w	See 4	May 31	See 4	Not known. (? Unrecognized infection of wound)	30	7	0	27 new	8 new
6	" 73 "	" 3	Apr. 2	" 3	Not known	27	7	0	4	0
7	77	Mar. 7	" 2	Air	Not known; never found on patient or staff	18	7	0	0	0
8	6/42E/47/75w	Jan. 18	May 13	Nose of pt.; ? acquired in another ward	Burns of different pt.	20	8	3	9	0
9‡	75/77 tet. sens.	Apr. 23	Later than May 31	Nose of pt.; ? acquired in ward or earlier	Frequent dressings and bedmaking of same pt.	23	7	1	13	1
	75/77 tet. res.	Mar. 11	May 13	Patient from another ward	—			3	3	0

* Type "73" included a number of strains with rather variable patterns of phage reactions, lysis by phase 73 used at a strong concentration being the most characteristic reaction.

† At least three wounds became colonized but not septic.

‡ The drug sensitivity of the strains from the air was not determined.

in the air sampling records given in the Chart. Four of the seven different staphylococcal types were apparently introduced by nasal carriers, in two cases probably infected in other wards of the hospital. The origin of the other types is not known, though the first two in Table III (47/53/75/77 and 7/47/53/54/75/77) were probably derived from elsewhere in the hospital.

It is more difficult to specify the source of the broadcasting into the air of the ward, and several of the entries in column 6 of Table III are open to some doubt. With the exception of type 77 there were always nasal carriers of the strain in the ward at the material time, but we cannot tell whether they, or some patient with an unrecognized subclinical infection of a wound, was responsible for spread in the incidents given as "not known" in column 6. It was of interest, however, that there was only one instance in which the staphylococci were probably dispersed by the person who introduced the strain into the ward.

When the phage types listed in Table III are compared with those that were observed causing sepsis (Table II) it is immediately clear that a wide dispersal of a single type might be quite unrelated to sepsis. In comparing the different types, however, it needs to be remembered that the patients infected with tetracycline-resistant strains (incidents 1, 2, 8, and 9) were nursed in isolation. Had they been nursed in the open ward the degree of dispersal might have been as great as in incidents 5, 6, and 7.

There was also a wide variation in the extent to which different staphylococci colonized noses: type 79w colonized many noses of patients and staff, while type "73" colonized only seven noses, and this despite the fact that both types were present in the air in large numbers and over a considerable period.

An additional indication that some people shed staphylococci more freely than others was provided by a comparison of the types carried by people with the types found on articles or in the air. From people 152 different types were isolated, but only 44 types were isolated from articles. Again, the 946 air staphylococci typed belonged to 71 different phage types, but only 25 of these types occurred three or more times.

Discussion

In the summer of 1956, at a time when numerous cases of staphylococcal sepsis were occurring in the ward, *Staph. aureus* of the epidemic type was found widely spread in the air and on bedclothes, bed-curtains, and the like (Shooter *et al.*, 1957). This observation raised several questions. Did the heavy air contamination represent spread from one or more especially active dispersers, or did it merely reflect the number of infected patients in the ward? Was the staphylococcus actually spread to new hosts by way of the air, or was the aerial contamination merely a by-product of spread by other routes? Could the counts of *Staph. aureus* in the ward air be used to measure the risk that infection might spread among the patients? Did the spread of one particular type of staphylococcus reflect the chance presence of a dangerous disperser of that type, or was the staphylococcus a specially virulent one?

Eight months' further study of the ward that suffered the 1956 epidemic could not be expected to answer these queries completely, but it has served to clarify some of the issues.

To us the most striking feature of our survey has been the occurrence of successive waves of staphylococcal broadcast due to different staphylococci and each apparently due to a different patient. A succession of different types infecting the patients in a ward has been noted in maternity units—for example, Hutchison and Bowman (1957) and Baldwin, Rheins, Sylvester, and Shaffer (1957)—but in our study it was the succession of environmental broadcasts that was so striking. There was no obvious relation between the degree of environmental contamination in these broadcasts and the development of sepsis in the susceptible

wounds in the ward except that no staphylococcus spread to wounds without some evidence of broadcast to air and articles. It was clear that extensive contamination of the air and environment could result from dispersal from a single person. We still do not know whether, when staphylococci spread to other wounds, they spread through the air, though it is reasonable to think that this was the course by which the noses of staff and patients were colonized.

That some people shed staphylococci more readily than others also seemed clear. On some occasions this shedding could be related to the sort of wound that they had, or the frequency with which it was dressed. While the lack of correlation between the level of aerial contamination and the incidence of sepsis indicates that air sampling cannot be used alone to predict outbreaks of wound infection, it can be used to detect persons who are likely to disperse bacteria. By more extensive studies it ought to be possible to define circumstances in which potential dispersal should be assumed without need for individual testing, and such studies would also show how common are the healthy heavy dispersers described by Hare and Thomas (1956).

Although the failure of some of the types of *Staph. aureus* to cause secondary cases of sepsis may have been due to a lack of truly susceptible wounds in the ward at the time, this seems unlikely, and it is more reasonable to think that the strains that spread were the more virulent strains. Until recently there was no good evidence that virulence varied greatly among coagulase-positive staphylococci. During the last few years, however, epidemics of infection in maternity units due to staphylococci of phage-type 80 (and the same or closely related strains reported in American literature as 52/42B/42C/44A/80/81, etc.) have demonstrated unequivocally that such variations exist.

As a tentative hypothesis we may distinguish three different ways in which surgical patients may be infected by staphylococci, apart, that is, from the case where a particular dangerous carrier is concerned (see McDonald and Timbury, 1957).

At the time of operation patients may be susceptible to infection by staphylococci of many different phage types, as seemed to be the case in the unit reported by Shooter *et al.* (1956); this susceptibility might be due to a depression of resistance, or simply to the fact that the organisms can be deposited deeply in the tissues.

In the ward, patients are clearly exposed to a great number of different staphylococci—both those that they carry themselves and those carried by other people. Most of these staphylococci are probably of relatively low virulence, and perhaps patients become infected with them only when subjected to a large dose, so that in the ordinary way the incidence of infection is an index of the standard of asepsis attained.

From time to time a ward may be invaded by staphylococci that are more virulent, such as some strains of type 80, or the types like 75/77, 47/53/75/77, and 6/42E/47/75w that we encountered. It is unlikely that these strains are spread any more easily than less virulent staphylococci, but there seems little doubt that they cause infection more easily and that conventional nursing techniques will not entirely control them.

Of the 24 infections that we observed 16 were due to three types of staphylococci, and the remaining eight were due to seven different types. The low incidence of these "sporadic" infections may well be attributable to the adequacy of the equipment and staffing of the ward.

We believe that, in our ward, barrier nursing in a side-room of patients with the more virulent strains was an effective method of isolation. Furthermore, we believe that, by isolating patients infected with these few strains, we prevented widespread infection. Again, the effectiveness of this measure may have been due to the favourable circumstances. Under less propitious conditions both the sporadic infections might be more common, so that some of the

staphylococci that appeared avirulent to us could infect wounds, and also the simple form of isolation might not suffice to prevent the spread of the virulent strains. Only trial will tell.

Summary

During an eight-months survey, 311 patients were admitted to a general surgical ward and 17 (5.5%) developed staphylococcal wound sepsis or some other staphylococcal infection (for example, pneumonia, urinary infection, entero-colitis) while in the ward. Only one of the eight cases of wound sepsis was attributable to infection in the operating theatre.

The reservoirs of staphylococci in nasal carriers and in inanimate objects and the air were examined regularly, and staphylococci from all these sources, as well as from patients' wounds, were examined for bacteriophage type.

Some 186 different types of *Staph. aureus* were recognized, but only 13 of these caused disease, and only three were responsible for disease in more than one patient.

The air and dust sampling revealed nine occasions when staphylococci of a single phage type reached the level of 0.1 particle per cu. ft. (3.5 per cubic metre) of air. These nine broadcasts were due to seven different types of staphylococci; the three types that were present in the air in the greatest numbers failed to cause any manifest secondary infections. This, and the fact that there were so many types of staphylococci that never caused sepsis, suggested that some staphylococci were more "virulent" than others.

Several of the staphylococcal broadcasts could be attributed to patients with infected lesions who were peculiarly apt to disperse, such as an infected tracheotomy wound, infected urine in an incontinent patient, an infected wound requiring very frequent redressing.

Patients infected with tetracycline-resistant staphylococci were, when possible, barrier-nursed in a side-room. This appeared to be effective in limiting the spread of their infection. Ten patients (with four different types) were nursed in isolation, and only one secondary case appeared in the ward.

We are indebted to Mr. C. Naunton Morgan and Mr. D. F. Ellison Nash for permission to make these observations in their ward. Our thanks are also due to the Medical Research Council for a grant in support of the work, and to Miss P. M. Davies and Miss Anne Deacon for laboratory assistance.

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The Nuffield Provincial Hospitals Trust has approved a grant of £7,500 spread over three years to assist in the establishment of a sheltered workshop, for long-stay patients with chronic psychotic illnesses, at Cheadle Royal Hospital, Cheshire. The project will be under the direction of the senior medical hospital staff. The Trust is also providing £1,500 for an investigation into the cost of mental illness.

LONG-TERM RESULTS OF VAGOTOMY AND GASTRO-ENTEROSTOMY IN CHRONIC DUODENAL ULCERATION A COMPARISON WITH GASTRECTOMY

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In 1950 one of us (H. B.) initiated an investigation into the results of vagal-nerve section in the treatment of chronic duodenal ulceration. Mr. A. V. Pollock was invited to undertake this work. Some 1,300 cases were collected from teaching and non-teaching hospitals in this country. This series included 489 cases treated by vagotomy and gastro-enterostomy (Pollock, 1952). It was decided to file the names and addresses of these patients and to use them as the basis of a long-term study. In 1955 Mr. John Lloyd Davies undertook a review of these cases, and his results were published (Lloyd Davies, 1956). Of the initial cases, permission to study was granted in 198, and these formed the basis of his report. We have now, two years later, made a further study of these cases, and we have been able to add a further 103 of the original series. We now therefore report on 301 cases, the earliest being seven years after operation and the latest nine.

This review has been made by questionnaire and personal interview. The series included 69 war pensioners, but, while they have been included for the purpose of assessing the proved recurrence rate, they have been omitted in our studies of post-operative symptomatology. In another group of 103 cases the follow-up study was made on our behalf by the department of surgery concerned. In assessing the post-operative picture with regard to symptoms, we have chosen to limit ourselves to a series of 130 cases which we have ourselves investigated.

Of this series of 301 cases, only six are untraced and 13 have died from causes known to have no connexion with peptic ulceration, leaving 282 cases followed to seven to nine years after operation.

Analysis of the Post-operative State

Mortality.—One of us (H. B.) used this operation in 1949 and 1950 but stopped using it then because its results were unknown. We did, however, come to use it again when the results of Mr. Lloyd Davies's work became known, and we have used it in all cases of duodenal ulceration needing surgical treatment since that time. We can report a series of approximately 100 cases without a death. Other workers have reported a very low mortality from this operation. Crile (1952) recorded 0.4% mortality in 445 patients and Hoerr (1953) a mortality of 0.5%.

Recurrence Rate.—The proved recurrence rate, as shown by perforation, haemorrhage, or operation, has been found to be 4.25%. As is discussed below, this figure must be considered in the light of evidence of a high incidence of incomplete nerve section.

Nutritional State.—One feature of this operation is that the patients are able to eat meals of normal size. It is not