THE INVESTIGATION OF HOSPITAL STAPHYLOCOCCUS

OUTBREAKS BY PHAGE TYPING

BY

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T A B L E O F C O N T E N T S

T A B L E S

The Figure follows page 93.

Acknowledgements

I am greatly indebted to Professor J. W. Howie for his invaluable advice and encouragement during the course of this work and for putting me in charge of the staphylococcus phage-typing in the Department of Bacteriology in the Western Infirmary, Glasgow. When it became clear that phage-typing could be done, I was glad to be encouraged to invite material from hospitals generally in the West of Scotland. In particular, however, I concentrated as much as possible upon places where good clinical and laboratory co-operation would give the work the best chance of being informative. This meant a good deal of personal reporting and visiting on my part, and a measure of tolerance on the part of those who were pressed to unearth the further details which gave real point to the use of phage typing. I should like to express my gratitude to colleagues who have contributed in this way to the investigations of the outbreaks described here. Their co-operation with me often entailed much additional work on their part. In particular I would mention the late Dr. H.S. Carter, Dr. A.D.T. Govan, Dr. J.G.P. Hutchison, Dr. Sheila McDonald, Mr.

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Introduction

The risk of acquiring infection has long been a hazard of hospital treatment. To-day, infection in hospitals due to Staphylococcus aureus is causing concern to both clinicians and bacteriologists. There are two reasons for this: the first, the ability of the organism to emerge in antibiotic-resistant forms; and the second, the tendency of some of these antibiotic-resistant strains to cause epidemics in hospitals, particularly in surgical and maternity units. The purpose of this study was to investigate by means of phage typing, the epidemiology of outbreaks of staphylococcus infection in hospitals. (The term "staphylococcus" as used in this study refers only to coagulase-positive members of the genus.)

This thesis begins with a short history of published studies of hospital infections followed by a description of the development of the technique of phage typing Staphylococcus aureus. Recent advances in knowledge of the epidemiology of hospital staphylococcus infections are then discussed in a review of the literature on the subject. My personal experiences in establishing a phage typing laboratory are related including some

of the difficulties encountered and the way in which they were

overcome.   Four illustrative outbreaks of hospital staphylococcus

infection are described.   The 4 outbreaks were chosen for detailed

study and description from among the material available to me

partly because they were episodes whose significance first became

apparent to me because of my vantage point in the phage-typing

laboratory.   I was able, in these 4 outbreaks, to generate by

personal reporting the kind of clinical interest and activity

which made it possible to demonstrate how the technique of phage

typing could be used to elucidate the epidemiology of the

infection and to prevent or control the development of further

sepsis.   Some interesting features of these outbreaks are

discussed together with their significance in relation to the

problem as a whole.   Finally, certain conclusions are drawn from

this work which it is hoped may be of value in preventing future

outbreaks of infection.

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CHAPTER I

THE HISTORY OF HOSPITAL INFECTIONS

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The History of Hospital Infections

For centuries, suppuration, pyaemia, septicaemia, and death, were expected sequels to surgical operations. Nevertheless, as early as 1782, Edward Alanson, surgeon to the Liverpool Infirmary, performed 35 consecutive amputations on unselected cases in the infirmary without the loss of a patient or any serious wound infection. Since, in these days, amputations were particularly hazardous operations, this series can be regarded as a monumental achievement. Alanson recognised the association of crowded insanitary hospitals and the development of suppuration and advocated the isolation of "all offensive, gangrenous or other putrid sores" and adequate ventilation of the wards. He also recommended that the clothing of patients admitted from infected places and the bedding of any patient with a "putrid" disease "should be baked in an oven constructed for the purpose by which all vermin and infection will be destroyed".

The association between infection and the hospital environment was noted by Oliver Wendell Holmes and Ignaz Semmelweiss in the middle of the nineteenth century. These

workers demonstrated epidemiologically the spread and sources of infection of puerperal fever — then the scourge of maternity wards. It was not until 1867, however, that the first light of understanding of the cause of putrefaction in wounds was shed by Lister. He applied the researches of Pasteur into the nature of fermentation to postulate that putrefaction in wounds might also be due to minute living organisms and advocated the practice of antiseptic surgery using carbolic acid to dress infected wounds (Lister, 1867a). He also suggested that dilute carbolic acid should be used to prevent the access of infection in simple incised wounds at operation (Lister, 1867b). So successful did the antiseptic treatment of wounds prove to be that Lister (1867b) was able to claim that "...... my wards, though in other respects under precisely the same circumstances as before, have completely changed their character; so that during the last nine months not a single instance of pyaemia, hospital gangrene or erysipelas has occurred in them".

The adoption of Lister's methods, and later the aseptic technique evolved by the German workers, Von Bergmann, Neubar, and Schimmelbusch in the years 1880 to 1893, caused a revolutionary

change in hospitals.   No longer were surgical wards haunted by

the dread of suppuration and hospital gangrene;   the era of safe

surgery had arrived.

During the twentieth century, however, with the

tremendous advances in medical science the problem of hospital

infection has again attracted attention.   In 1925, for example,

Meleney (1935) was disturbed to find that the sepsis rate in clean

operation wounds in a hospital in New York was as high as 15%.

In maternity units also, some workers described outbreaks of serious

infection among the newly born (McGuire,1903, Benians and Jones,

1929, Poole and Whittle,1935).   The main concern about the

problem, however, followed the introduction of penicillin in the

therapy of infections.   Unlike Streptococcus pyogenes, formerly

a serious cause of hospital infection but now invariably amenable

to treatment with penicillin, Staph. aureus soon revealed an

extraordinary ability to emerge in penicillin-resistant forms.

Reports from several workers showed clearly that the proportion of

penicillin-resistant staphylococci isolated in hospitals greatly

increased after the introduction of the antibiotic into general

use and that these strains were well established in many hospitals

(Barber, 1947; Barber and Rozwadowska-Dowsenko, 1948; Barber,

Hayhoe and Whitehead, 1949; Rountree and Thomson, 1949). Later,

as other antibiotics were developed and brought into use, hospital

strains of staphylococci rapidly emerged which were resistant to

some or all of them (Rountree, Barbour and Thomson, 1951;

Rountree and Thomson, 1952; Clark, Dalgleish and Gillespie, 1952;

Knight and Holzer, 1954). In order to study the epidemiology of

infections caused by these antibiotic-resistant staphylococci it

was necessary to be able to type them. Two methods of doing this

were in use by the late 1940's. The first was the serological

method first described by Cowan (1939) who used a slide-

agglutination technique with absorbed sera to distinguish three

main types of Staph. aureus. This method was later extended with

the recognition of more types by Christie and Keogh (1940) and

Hobbs (1948). Serological typing is still used by some workers —

for example, by Brodie and his colleagues in Dundee (Brodie, Kerr

and Sommerville, 1956) and Oeding in Norway (Oeding and Williams,

1958). It has been largely superseded, however, in general use

by the typing of strains of Staph. aureus by their susceptibility

to a series of bacteriophages. Oeding and Williams (1958)

have recently published an article in which the bacteriophage and
serological methods of typing staphylococci were compared in detail.
They found that the 3 major groups of phage types corresponded
broadly to the four groups defined among serotypes. A few
serotypes were associated with particular phage types but in
general there was little correlation between the individual types
recognised by the 2 techniques. However, consistent results in
the recognition of related strains were obtained with either
method. A far greater number of strains can be identified by
phage typing but the proportion of untypable strains is higher
than with serological typing. There is some variation in the
types identified by both methods but this has been assessed more
accurately in relation to phage typing. They conclude by
stating that although serological typing is technically simpler
and more rapid to perform it is less suited to the testing of
large numbers of strains than is phage typing.

CHAPTER II

THE DEVELOPMENT OF THE TECHNIQUE FOR

PHAGE TYPING Staphylococcus aureus

The Development of the Technique for

Phage Typing Staphylococcus aureus

In 1915, Twort described the phenomenon of spontaneous lysis in a culture of a white micrococcus obtained from calf lymph. He showed how the lysis could be transmitted to fresh cultures in filtrates from the original culture.   D'Herelle published his observations on the same phenomenon in 1917 followed later by three monographs which reported his detailed work on the subject. D'Herelle suggested the name "bacteriophage" for the lytic agent and held the view that it was a filtrable virus parasitic on bacterial cells.   The name of "bacteriophage" for the lytic agent has been widely adopted but is now generally contracted to "phage".

Williams and Timmins (1938) seem to have been the first workers to have used phages to distinguish between different strains of Staph. aureus.   They added loopfuls of 4 of the staphylococcal phages isolated by Burnet and Lush (1935) to different broth cultures of staphylococci.   They recorded whether cultures showed clearing or lessening of turbidity, and thus distinguished six strains of staphylococci by their different susceptibilities to the phages.

The present method of typing is based on the work of Fisk (1942). He made use of the fact that many strains of staphylococci are lysogenic to isolate phages from them by means of a cross-culture technique. This consisted of spreading a thin streak of one culture on an agar plate and spotting on to it drops of 4 different staphylococcal cultures. If either the basic strain or one of the drop cultures was lysogenic with a phage to which the other was susceptible, small areas of lysis or plaques could be seen in the drop area after incubation. The plaques were picked with needles into 0.5 or 1 ml. of water and propagated by culture with the susceptible strain until confluent lysis was obtained. Fisk's phage solutions were suspensions of areas of confluent lysis sterilised by the addition of zephiran germicide. The phages were tested on 24 different staphylococcal strains, and 24 phages which exhibited culture-strain specificity were thus identified. Fisk typed a number of staphylococcal strains by spotting drops of the phage solutions on to agar plates spread with the different cultures. After incubation the strains could be distinguished by their different patterns of phage reactions. Fisk noticed that strains from related sources were lysed by the

same phages whereas those from independent sources showed a wide variety of phage reactions. Later, in 1944, Fisk and Mordvin described a further study on the phage typing of staphylococci in which they investigated the epidemiological relationships of a number of strains.

Fisk's work was later extended by Wilson and Atkinson (1945) of the Central Public Health Laboratory, London — now an international centre for staphylococcal phage typing. Wilson and Atkinson modified Fisk's original technique and were able to set up a routine phage typing service for the investigation of epidemics of staphylococcal infection. They isolated phages by cross culture and also obtained new phages by adapting those already isolated to new propagating strains. The phages were propagated by serial passage in fluid medium and the resultant solutions were sterilised by filtration. Great care was taken to ensure the purity of the filtrates and each phage was twice repropagated from a single plaque. Phage filtrates of relatively high titre were obtained and typing was carried out at a critical dilution defined as the highest dilution producing confluent lysis of the propagating strain. In assessing results, Wilson and

Atkinson disregarded any reaction weaker than confluent lysis and were able to differentiate 21 types or subtypes of staphylococci most of which reacted in this way with only one phage filtrate.

Wahl and Lapeyre-Mensignac (1950) suggested another approach to the definition of types. They divided staphylococci into groups by their susceptibility to 5 major phages and further into subgroups by their reactions with 16 minor phages. They regarded reactions of 20 plaques or more as significant.

Further work has shown that neither of these methods of defining types is really satisfactory. That of Wilson and Atkinson had the disadvantage that even identical strains often differ from each other in the strength of their phage reactions and that regarding confluent lysis as the only significant reaction might lead to errors in interpretation: secondly, many strains are typable only with reactions weaker than confluent lysis and would under their scheme be regarded as untypable. The method proposed by Wahl and Lapeyre-Mensignac is rather complex and the division of phages into major and minor phages now seems of doubtful validity, especially in view of the stress which they laid on their major phage 68, which is now known to be a polyvalent phage with a wide

range of action.

The method of phage typing now widely used throughout the world is that described by Williams and Rippon in 1952, and evolved by them from the work of Wilson and Atkinson and later of Dr. V.D. Allison at the Central Public Health Laboratory, London. Williams and Rippon do not define rigid types or subgroups of staphylococci, although by their method most staphylococci fall into 3 main groups, which correspond broadly to Cowan's (1939) 3 serological groups. They prefer to identify strains by recording a list of the phages with which they give strong reactions. In this way numerous different patterns of phage reactions or "types" can be recognised within each group. Because this method of typing is the one used in this study it is necessary to describe the technique in detail, especially as workers who take it up seldom establish it in their laboratories without a good deal of trouble.

The Technique of Phage Typing of Staphylococcus aureus described by Williams and Rippon (1952).

21 phages are used routinely to type strains of Staph. aureus. They are divided into 3 main groups and one small

subsidiary group.   Table I gives a list of the phages and the

groups to which they belong.

In October 1958, phage 70 which is listed in Table I was

omitted from this basic set of typing phages and phage 187 (which

does not belong to any of the 4 phage groups) was introduced into

it.

Propagation of Phages

Phages are propagated by growing them with cultures of

the appropriate propagating strain of staphylococcus.   There are

two ways of doing this.   In the first a fluid medium is used.

The phage is added in suitable dilution to a bottle containing

$\frac{1}{3}$ of its volume of nutrient broth which has been freshly inoculated

with a $\frac{1}{100}$ dilution of a 2-hour broth culture of the propagating

strain.   It is usually necessary to add extra calcium to the

culture: this is done by adding a 1% solution (w/v) of calcium

chloride in distilled water to give a final concentration in the

medium of 200 μg. calcium per ml.   With some phages a concentration

of 400 μg. calcium per ml. is necessary.   The culture is incubated

at 37°C for 6 hours.   Frequently it can be seen that the culture

has lysed but sometimes phage is successfully propagated in the

TABLE I

The 21 Typing Phages

Group	Phages
I	29, 52, 52A, 79, 80
II	3A, 3B, 3C, 55, 71
III	6, 7, 42E, 47, 53 54, 70, 73, 75, 77
IV	42D

absence of visible lysis.   A preliminary titration is carried out

and if the phage titre is satisfactory, the culture is filtered

through either a Seitz E.K. filter pad or a Gradocol membrane

(average pore diameter 0.7 to 0.9μ).   The filtrate is then stored

at 4°C, at which it generally remains stable for about a year —

or longer with some filtrates.

The second method of propagation is on solid medium but

this has now been superseded by the first method described above.

Briefly, it consists of spreading an appropriate dilution of phage

over the surface of a nutrient agar plate which has been freshly

inoculated with a 4 to 6-hour broth culture of the propagating

strain.   The plates are incubated overnight at 30°C and in the

morning any areas of unlysed growth are cut out with a scalpel.

The plate is then frozen at -20°C and thereafter allowed to thaw

at room temperature.   The agar disintegrates and the resultant

fluid, which contains the phage, is pipetted off, titrated, and

filtered in the usual way.

Testing of Phage Filtrates

After filtration the titre of the phage filtrate is

checked again.   Titration is carried out by spotting, from a measured pipette, drops of 0.02 ml. of 10-fold dilutions of the phage filtrate in broth on to the surface of a nutrient agar plate previously flooded with the propagating strain.   After overnight incubation at 30°C the degree of lysis in each drop area is recorded.   The titre of the filtrate is defined as the highest dilution which just gives confluent lysis on the propagating strain (in practice semiconfluent lysis is used as the end point). This dilution is the one used in typing and is known as the Routine Test Dilution or R.T.D.   Phage filtrates must reach a titre of $\frac{1}{1,000}$ or higher before they are satisfactory for use in typing.

Phage filtrates of a satisfactory titre are next tested to ensure that they have undergone neither variation nor contamination.   This is done by checking their "lytic spectrum" — that is, the strength and range of their reactions on a series of 22 standard staphylococcal strains, 13 of which are standard propagating strains.   These reactions should remain constant for each individual phage, and any deviation from the standard pattern means that the filtrate must be discarded.   Fortunately this

rarely happens.

The Typing of Strains of Staphylococci

4-hour broth cultures of the staphylococcal strains being typed are flooded on to Difco dehydrated nutrient broth agar plates previously dried for $1\frac{1}{2}$ hours in an incubator. As in all phage-typing work, it is essential that the solid media used should contain only 1.0 to 1.2% shred agar. The plates used for typing are marked on the back with a grid of 25 squares and after the culture has been absorbed one drop of each phage filtrate is placed in the appropriate square. Special finely-drawn pipettes are used for this and the drops of phages are spotted on the plates in the order shown in table I. After incubation at 30°C overnight the plates are examined in a good light and all phage reactions are carefully recorded.

Staphylococci are first typed with the phages at their Routine Test Dilutions (R.T.D.) but if no reactions are observed they are retyped with the phage filtrates at 1,000 x R.T.D.

The Recording of Phage-Typing Results

Phage reactions are graded according to the degree of

lysis observed in each drop area.   The following symbols are used
to record reactions:-

++   =   more than 50 plaques   =   strong reaction

+   =   20 to 50 plaques   =   weak reaction

±   =   less than 20 plaques   =   minor reaction

Usually the phage type of a strain of staphylococcus is
reported as a list of the phages with which it gives strong or ++
reactions.   Sometimes weak or + reactions are also reported
although they are qualified by the letter "w".   Minor or ±
reactions are not normally reported except in so far as + following
a list of strong reactions indicates the presence of additional
minor reactions.   When the phages are used at 1,000 x R.T.D. the
reactions are recorded as before except that additional symbols
are used to draw a distinction between confluent lysis (++++) and
strong lysis with secondary growth (+++).   Reactions elicited
only with the phages at 1,000 x R.T.D. often present considerable
difficulty.   Unlike the results with the phages at R.T.D., cross
reactions between the phages of different groups are common and
the pattern of reactions is often very complex.   The main

disadvantage, however, is the inhibitory effect of the strong

filtrates on some staphylococcal strains. This inhibition may

give rise to areas of clearing indistinguishable from confluent

lysis or confluent lysis with secondary growth unless the filtrate

responsible is titrated on the culture. Unlike true phage

reactions, inhibition reactions never give rise to discrete

plaques on dilution. In routine practice titration of all

possible inhibition reactions is far too laborious and reliance

is placed on the quality of secondary growth and other character-

istics in attempting to distinguish them. Until recently

inhibition reactions were disregarded in assessing typing results

but it is now considered that they are significant because they

probably represent phage-staphylococcus reactions without phage

multiplication.

Interpretation of Phage Typing Results

Most staphylococci of human origin and association, when

typed by phages at R.T.D., fall into one of the 3 phage groups

I-III (table I) although some cross reactions between phages of

groups I and III are not infrequent. It has already been mentioned

that cross reactions are seen far more frequently with the phages

at 1,000 x R.T.D.   Within each phage group, many different

patterns of phage reactions are observed although, not surprisingly,

some patterns are far more common than others.   Many strains of

staphylococci react with a single phage but the majority react

with more than one.   Staphylococci of phage group III often react

with 5 or 6 or even more phages.

The main purpose of phage typing is to recognise whether

certain strains are identical or not and this is occasionally

quite difficult to assess on account of the normal variation

observed in typing results.   Thus strains from a single source,

especially if typed on different occasions, may differ by the loss

or gain of a strong reaction or more than one weak reaction.

Variations of this sort are more common with staphylococci of

phage group III than with those of phage groups I and II.   As a

general rule, 2 strains of staphylococci are regarded as different

if their phage patterns differ by 2 strong reactions;   the loss or

gain of weak or minor reactions is not usually regarded as

significant.   In practice strains of phage groups I and II would

probably be regarded as different on the basis of less than 2 strong

reactions but hard and fast rules on the interpretation of results

cannot be laid down: much depends on experience and knowledge of

the frequency distribution of phage types in the environment of an

investigation.

CHAPTER III

ICATION OF STAPHYLOCOCCAL INFECTION IN HOSPITALS

A REVIEW.

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THE INVESTIGATION OF STAPHYLOCOCCAL INFECTION IN HOSPITALS.

A REVIEW.

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The Investigation of Staphylococcal Infection
in Hospitals.   A Review.

A recent bibliography compiled by Dr. Dorothy Bocker of

the National Library of Medicine, Washington, listed approximately

500 articles on "Staphylococcal Infection" which had been published

since 1952.   Since there are probably at least as many articles

in the literature of the 6 years preceding 1952, it is necessary

to be selective rather than comprehensive in reviewing the subject.

The following account, therefore, deals mainly with investigations

into the epidemiology of staphylococcal infections in which phage

typing was used and which have materially increased our under-

standing of the many complexities of the subject.

Phage typing has shown that outbreaks of staphylococcal

infection in hospitals can usually be divided into 3 categories

(Anderson and Williams, 1956).   In the first category, most or

all of the infections are due to one phage type of staphylococcus.

Only one or 2 carriers of this strain can be found and it is

sometimes possible to demonstrate that one of them is responsible

for the spread of infection.   In the second type of outbreak

also, most of the infections are due to the same phage type of

staphylococcus but in this instance the epidemic strain is found

to be sidespread in the hospital or ward environment. In the

third type of outbreak, the infections are due to many different

strains of staphylococci and there is clearly no one common source.

Such outbreaks are usually attributed to a lowering of aseptic

standards and general hygiene.

Most infections in hospital to-day are due to antibiotic-

resistant staphylococci, and phage typing has shown that hospital

endemic strains belong predominantly to phage group III.

Penicillin-resistant staphylococci, when they first appeared,

belonged predominantly to phage group III but are now observed

quite frequently in phage group I — usually when they are

discovered as responsible for outbreaks of infection in maternity

units. To a lesser extent penicillin resistance is now also

appearing in phage group II staphylococci. The majority of

strains which are resistant to more than one antibiotic, however,

are found in phage group III. It is with strains of phage group

III, therefore, that we are concerned in considering the problem

of most hospital infections, although recently a phage group I

strain with some unusual properties (type 80) has been responsible

for some serious outbreaks of infection.   Type 80 is commonly

resistant to several antibiotics and this distinguishes it from

most other staphylococcal strains of phage group I.

Since antibiotic-resistant staphylococci are now

ubiquitous in the hospital environment it is not surprising that

they are carried in the noses of many of the hospital staff

(Rountree and Thomson, 1952; Duncan, Collins, Neelin and Roy,

1957; Hutchison, Green and Grimson, 1957).   A vast amount of

work has been undertaken in the study of the nasal carriage of

staphylococci.   The main relevant points which have emerged are

summarised below.

Although the staphylococcal nasal carriage rate among

the general population is about 50% (Gillespie, Devenish and Cowan,

1939; Rountree, Freeman and Barbour, 1954), the carriage rates

among hospital staff and in-patients are usually higher still.

Rountree and Barbour (1951) found that the nasal carriage rate

among trainee nurses rose from 52.6% to 71.4% within 5 weeks of their

entering the hospital wards and Shooter, Smith, Griffiths, Brown,

Williams, Rippon and Jevons (1958) found that 62% of the staff and

60% of patients who had spent 3 weeks or longer in a surgical ward

were nasal carriers. There is a tendency for people to be either persistent carriers or persistent non-carriers (Miles, Williams and Clayton-Cooper, 1944) although a considerable group of people are found who can be classified as temporary carriers and who may be more liable to acquire hospital staphylococci than the others (Hutchison, Green and Grimson, 1957). There is a close association between skin and nasal carriage of staphylococci (Miles, Williams and Clayton-Cooper, 1944) and in the majority of cases the same phage type of staphylococcus is carried on both skin and nose (Williams 1946). An association also exists between nasal and faecal carriage of antibiotic-resistant staphylococci in patients in hospital (Brodie, Kerr and Sommerville 1956).

Hospital staphylococcal infection is particularly troublesome in surgical and maternity units — doubtless because surgical wounds and newborn infants are especially susceptible to infection. A great deal of work has been done to elucidate the epidemiology of staphylococcal infection in both these situations and it is proposed to discuss this more fully in 2 separate sections.

I.   Staphylococcal Infection in Surgical Units

Surgical wounds may acquire infection either during

operation or, later, in the wards.   Some workers have found that

the operating theatre is the most frequent source of wound

infection — for example, Blowers, Mason, Wallace and Walton

(1955), Clarke (1957), Kinmouth, Hare, Tracy, Thomas, Marsh and

Jantet (1958).   Others have found that the majority of wound

infections are due to ward cross infection (Rountree, 1947;   Clarke,

Dalgleish and Gillespie, 1952;   Gillespie, 1957).

1.   Sources of Infection in Operating Theatres

Since nasal carriage of staphylococci is so common in

the adult population it follows that many of those present in

theatre during operations will harbour staphylococci in their noses.

Nevertheless it is clear that not all nasal carriers are necessarily

dangerous.   Hare and Thomas (1956) and Hare and Ridley (1958) have

shown that although in most carriers staphylococci are not readily

dislodged from the nose, contamination of carriers' skin and

clothing is frequent, and these sites may be important sources of

infection.   They also discovered that some carriers disseminate

large numbers of staphylococci into the surrounding atmosphere on movement — even when they wash their hands. This dissemination was not prevented by their changing into sterile clothing. There is no recorded outbreak of infection traced to a nasal carrier who was also shown to be a disseminator, but nasal carriers have been found to be responsible for some outbreaks. Devenish and Miles (1939) described an outbreak in which the source of infection was a surgeon who was a nasal and skin carrier of staphylococci. They showed how the organisms could be transmitted to the wounds through glove punctures and considered that permeable gown sleeves were another possible route for the spread of infection. A surgeon who was a nasal and skin carrier was implicated in another outbreak of wound infection described by Shooter, Griffiths, Cook and Williams (1957). The staphylococcus carried by the surgeon was the same phage type as those isolated from most of the infected wounds. A similar incident was also described by Blowers, Mason, Wallace and Walton (1955). In 2 other outbreaks of theatre-acquired infection the sources of the infection were traced to theatre nurses who were nasal carriers of the epidemic strain. Penikett, Knox and Liddell (1958) found that the

staphylococcus responsible for the sepsis was spread to the patients via "Terylene" sutures which had been contaminated by the nurse who arranged them. In the second outbreak Sompalinsky, Hermann, Oeding and Rippon (1957) showed that post-operative infections due to the epidemic strain ceased when the 2 assistant nurses who carried it were instructed in a stricter aseptic regime including the wearing of double masks and sterile gloves.

Although Lister 1867 (a) regarded air as a dangerous source of surgical infection, this view lost favour during the early part of the twentieth century. Interest in the air as a source of infection was revived, however, by the work of Bourdillon and Colebrook (1946). Using a slit sampler to measure the bacterial content of the air in dressing rooms for burns and major wounds, they found that large numbers of pathogenic organisms, including Staph. aureus, were liberated into the air during the changing of the dressings of large infected wounds. The degree of bacterial contamination of the air increased when the blankets and clothing of the patients were disturbed. They also showed that a system of forced ventilation supplying highly filtered air at about 10 changes per hour prevented an accumulation of airborne

bacteria and presented evidence that this played an important part

in reducing to a low level the incidence of added infection among

burned patients. They recommended that operating theatres should

be ventilated by a positive pressure or plenum system of ventilation

in which warm filtered air enters the theatre at a higher rate than

that at which it is extracted. A positive pressure is thus

created which prevents air contaminated with dust from the

hospital corridors from being sucked into the theatre. A "piston"

effect is created by arranging the input in the ceiling and the

extract at floor level. In 1955, Blowers, Mason, Wallace and

Walton described a serious outbreak of theatre-acquired wound

infection in a thoracic surgery unit. One phage type of

staphylococcus, the predominant cause of the infections, was wide-

spread in the hospital environment. The unit was closed and

reopened after the institution of numerous measures aimed at the

prevention and control of infection. The authors attributed the

resultant fall in the incidence of infection largely to improved

ventilation in the operating theatre, which caused a dramatic

reduction in the general bacterial content of the air with the

virtual elimination of <u>Staph. aureus</u> from the air sampled. They

regarded the isolation of infected patients, regular sterilisation

of hospital bedding, and the exclusion of blankets from the theatre

as other important factors in the reduction of the incidence of

sepsis.

A second outbreak of post-operative wound infection

attributed to inefficient ventilation in the operating theatre was

described by Shooter, Taylor, Ellis and Ross (1956).   In this

instance the infections were due to many different phage types of

staphylococci and high bacterial counts in the theatre air were

associated with a sepsis rate in clean wounds of 9%.   When the

ventilation was changed to produce a positive pressure in the

theatre with a cross draft over the operating table, the sepsis

rate fell to 1%.   Kinmouth, Hare, Tracy, Thomas, Marsh and Jantet

(1958), on the other hand, found that the introduction of a cross

draft over the operating table in a theatre already ventilated by

a plenum system reduced the bacterial content of the theatre air

but failed to reduce the rate of post-operative wound sepsis.

One difficulty in unreservedly accepting contaminated air as an

important source of wound infection is that none of these workers

has been able to demonstrate a high level of staphylococcus-

carrying particles in the air. The wounds are not likely,

therefore, to be contaminated by more than a very few staphylococci

from the air during their exposure at operation. There is, of

course, the possibility that each airborne particle carrying

staphylococci (which would be recorded as a single colony on a

slit sampling plate) might carry large numbers of the organisms,

but this seems, on the whole, to be unlikely. A plenum

ventilation system also prevents the accumulation of bacterial

aerosols which are rapidly cleared when they are set up by the

movement of those present in theatre. This may well be the most

important function of this sort of controlled ventilation system.

The possibility that staphylococci from the patient's

skin might contaminate the wound at operation has been considered

by some workers to be an important factor in wound infection.

Harrison and Cruickshank (1952) showed by phage typing staphylococci

from the skin and from the infected wounds that 4 of 16

staphylococcal wound infections were due to skin-autogenous

infection. They attributed a reduction in the incidence of post-

operative sepsis to changing the preoperative skin disinfectant

from acriflavine to tincture of iodine. Blowers (1957) described

similar investigations in a series of patients with wound
infections.   In half the patients the same phage type of
staphylococcus was obtained by repeated swabbing of the skin
preoperatively as that subsequently isolated from the wound
infections.   Kinmouth, Hare, Tracy, Thomas, Marsh and Jantet
(1958) found that acquisition of hospital staphylococci by patients
in the wards before operation was an important cause of infection
apparently acquired in the theatre.

2.   Sources of Infection in Surgical Wards

There are numerous possible sources of infection in
most surgical wards.   These include: blankets (Rountree, 1947;
Blowers, Mason, Wallace and Walton, 1955);   the dust and air of the
wards (Clarke, Dalgleish and Gillespie, 1952;   Shooter, Griffiths,
Cook and Williams, 1957);   the noses of the medical and nursing
staff (Rountree and Thomson, 1949 and 1952);   and infected lesions
and the noses of the patients (Clarke, Dalgleish and Gillespie,
1952;   Barber and Dutton, 1958;   Shooter, Smith, Griffiths, Brown,
Williams, Rippon and Jevons, 1958).   Unfortunately, it has proved
to be very difficult to demonstrate the sources and routes of

spread of staphylococci in ward cross infections. Nevertheless

many new facts have come to light in recent years and the

epidemiology of ward cross infection has been to some extent,

although not entirely, elucidated.

Rountree, in 1947, observing the high bacterial content

of ward blankets, investigated the effect of treating them with

the disinfectant Fixanol C and oil. She found that although the

numbers of bacteria in the blankets and released into the air

during bed-making were much reduced, there was no effect on the

cross-infection rate in wounds. The presence of some non-

pathogenic bacteria as well as Streptococcus pyogenes and Staph.

aureus was used as evidence of cross infection. (Here the word

"infection" is clearly used in the sense of transferred bacterial

contamination as distinct from clinical sepsis). Phage typing

showed that one episode of staphylococcal wound cross infection,

involving 8 patients in both the control ward and that in which

the treated blankets were in use, was probably due to 2 nurses who

were nasal carriers of the epidemic strain. Both nurses were

responsible for the dressing of wounds. It is interesting that

the strain responsible for this small outbreak could not be

discovered in the ward dust.   Similar findings with regard to the

effect on nasal and wound cross-infection rates with penicillin-

resistant staphylococci were reported by Clarke, Dalgleish, Parry

and Gillespie (1954).   In this instance oiling of the ward floor,

bed clothes, and screen covers had no effect on nasal and wound

cross-infection rates although a considerable reduction was

observed in the numbers of bacteria released into the air during

bed making.   These workers suggested that dust from bedclothes

played at most a minor part in the transfer of antibiotic-resistant

staphylococci to patients in the ward.

Nevertheless there is no doubt that ward blankets are

often heavily contaminated with hospital staphylococci (Blowers,

Mason, Wallace and Walton, 1955) and considerable research has been

done into methods of sterilising them.   Disinfection of woollen

blankets with quaternary ammonium compounds has been recommended

(Blowers and Wallace, 1955) and more recently the use of blankets

made of towelling, cotton weave or "Terylene", which can be boiled

without damage, has been advocated (Blowers, Potter and Wallace

1957).   Schwabacher, Salsbury and Fincham (1958) found that

provision of woollen blankets, freshly washed with a quaternary

ammonium compound, for each patient caused a reduction in the total

bacterial counts on settling plates and especially in the numbers

of an epidemic staphylococcal strain. They found also that the

use of cotton blankets caused a greater reduction in total

bacterial counts than that obtained by using "Terylene" blankets.

They claimed that no cross infection was observed during the trial

of cotton blankets, but since the experiment was carried out in a

side room containing only 3 beds, this finding is of doubtful

significance. They also stated that the use of freshly washed

and disinfected woollen blankets was associated with a reduction

in cross infection but no figures were given in support of this.

It is clear, then, that although blankets and the dust

and air of surgical wards are often contaminated with hospital

staphylococci, proof that they are often responsible for the cross

infection of patients is still lacking. An interesting point has

recently been raised by the finding of Pressley (1958) that

airborne dust (previously considered to be contaminated largely

from blanket fluff) consisted essentially of cellulose and not

woollen fibres, in wards where woollen blankets were used. The

dust was found to contain <u>Staph. aureus</u> which presumably was

acquired from a source other than the blankets. However, Pressley's

use of a "Terylene" filter for collecting the dust has been

criticised by Watson (1959) on the grounds that the "Terylene"

would repel any particle with the same electrostatic charge.

Watson states that it can be inferred from the results of Pressley's

experiments that wool particles have a charge similar to that of

the "Terylene" filter.

Much the same difficulties are found in assessing the

role of nasal carriers on the staff in the spread of infection in

surgical wards. The possibility is very difficult to rule out

that nasal carriage of staphylococci merely reflects rather than

causes the spread of staphylococci. A close correspondence

between strains of staphylococci isolated from patients' lesions

and from the noses of the staff was found by Rountree and Thomson

(1949 and 1952). They mention, however, that this would be found

whether the nasal carriers were reservoirs of infecting strains or had

merely acquired the strains from the same sources as the patients.

Nevertheless an instance has already been quoted in which Rountree

(1947) found evidence that 2 nurse nasal carriers were responsible

for infecting 8 patients whose wounds they had dressed. Gould

and Allan (1954) showed that there was a sharp fall in the number

of hospital staphylococcus infections when nasal carriage of

staphylococci among the staff was reduced by intra-nasal treatment

with 1% "Terramycin" cream. The incidence of infection rose when

the nasal carriage rate again rose after treatment was stopped.

This finding, if corroborated, would be striking evidence for the

importance of nasal carriers among the staff as a source of

infection. Nevertheless it is interesting that in this instance

the staphylococci isolated from blankets, dust, fomites and the

operating theatre were not the same phage types as those which

were epidemic in hospital infections, so that these sites could,

in this instance, be ruled out as possible sources of infection.

It has long been recognised that septic lesions are a

most important source of infection and Bourdillon and Colebrook

(1946) have shown that large numbers of bacteria are liberated

into the air when the dressing of a large infected wound is changed.

It is also a well accepted fact, at least among bacteriologists,

that infected patients should not be nursed in the same wards as

patients with "clean" wounds. Unhappily, few general hospitals

have isolation facilities nowadays and most surgical wards contain

at least one or two patients who are suffering from infections of

one kind or another.   Barber and Dutton (1958) have recently

described an outbreak of severe infection in a surgical ward in

which the epidemic strain was introduced by a patient who was

admitted while suffering from superficial septic lesions due to it.

In this instance, the epidemic strain was one widely recognised as

being of unusual infectivity and this fact may have been partly

responsible for the severity and extent of the outbreak.   It may

have been equally important in this episode that the cross-

infecting organisms were derived from active lesions.

It has already been mentioned that the nose and skin of

patients often become colonised with hospital staphylococci in the

wards and that this may be responsible for the development of

wound infection apparently acquired during operation (Kinmouth,

Hare, Tracy, Thomas, Marsh and Jantet, 1958).   Doubtless a

patient's nose and skin may also be colonised in the ward after

operation and give rise to autogenous infection with a hospital

organism;   in this case, of course, the colonisation of the patients

would in the first place be due to ward cross infection and the

fact that the wound is infected primarily from the patient's skin

rather than from a source in the hospital is to some extent irrelevant.

An article recently published has helped greatly to clarify the confused state of our knowledge of the mechanism of ward cross infection. This describes an investigation into the spread of staphylococci in a surgical ward undertaken on its reopening and continued over a period of 8 months (Shooter, Smith, Griffiths, Brown, Williams, Rippon and Jevons, 1958). The principal findings were as follows. On 9 occasions "broadcasts" of certain types of staphylococci into the air and dust of the ward were observed. Seven different phage types of staphylococci were associated with the 9 "broadcasts" and the 3 types which appeared in the air in the greatest numbers did not give rise to any secondary sepsis although they colonised the noses of several patients and members of the staff. Three strains of phage group III, all of which became broadcast, gave rise to 16 of the 24 ward infections observed. There can be little doubt that these strains were more infective than the many other types observed in the ward from time to time, which regardless of their ubiquity gave rise either to no sepsis or to sporadic infections only. It was not

always possible to be certain of the sources from which these
broadcasts of staphylococci emanated, but several were attributed
to patients with infected lesions.   These lesions were of a kind
which were particularly liable to disperse — for example, from
an infected tracheotomy wound, a urinary infection in an incontinent
patient, and a wound infection requiring frequent dressing.   In
5 "broadcasts" the strain was first isolated from the nose of a
patient or nurse.

The following conclusions may be drawn from the results
of this investigation.   Staphylococcal contamination of the air is
not a reliable index of the risk of ward cross infection and the
air itself is probably not a common source of infection.   One of
the most important factors in ward infection is the infectivity or
the ability to produce disease of any particular staphylococcal
strain which has access to the patients.   Patients with infected
lesions, especially those which cannot be kept covered, are important
sources from which staphylococci may be dispersed.   Nasal carriers
may often be responsible for introducing a strain into a ward
without necessarily being the immediate cause of its dispersal or
"broadcast".

II. Staphylococcal Infection in Maternity Units

Infection due to antibiotic-resistant staphylococci is endemic among the babies in most maternity units to-day. The infections are usually mild superficial lesions -- conjunctivitis, for example, or skin pustules, but sometimes the incidence of sepsis builds up to a high level (Barber, Hayhoe and Whitehead, 1949) with occasionally serious and even fatal infections (Beaven and Burry, 1956). Many investigations have been carried out to elucidate the epidemiology of neonatal sepsis, but the picture remains complex and confusing. Numerous reservoirs of staphylococci and possible routes of spread have been demonstrated, but it has proved as difficult to assess the relative importance of these in maternity units as in surgical wards. The following account describes some of the recent advances in our knowledge of the subject, and attempts to assess the situation with regard to staphylococcal epidemiology in neonatal nurseries as it is understood to-day.

In some hospitals babies are nursed beside their mothers in the post-natal wards, but in the majority the babies stay in

communal nurseries and it is in these that staphylococcal infection

has become a particular problem.   It has been shown that newborn

babies rapidly became colonised with hospital staphylococci, and

that by the first week or two of life nearly all carry the organism

in their noses (Cunliffe, 1949; Wallmark and Melin, 1954; Cook,

Parrish and Shooter, 1958).   The majority also harbour

staphylococci on their skin (Wysham, Mulhern, Navarre, LaVeck,

Kennan and Giedt, 1957) and on their umbilicus (Forfar, Balf,

Elias-Jones and Edmunds, 1953; Jellard, 1957).   It is clearly

important to know from what sources and by what means these

staphylococci spread to the infants, and to determine the factors

which may influence the development of infection.

Possible sources or reservoirs of staphylococci abound

in maternity units.   Firstly, the mothers may transmit their

staphylococci to their babies during breast feeding.   Barber,

Wilson, Rippon and Williams (1953) have shown that many of the

mothers acquire hospital staphylococci in their noses during their

stay in hospital.   Nevertheless these workers, and also Parker and

Kennedy (1949) and Rountree and Barbour (1950), found that the

infants only rarely acquired staphylococci from their mothers.

There is some evidence, indeed, from recent work that the infants
transmit staphylococci to their mothers (Cook, Parrish and Shooter,
1958; Munro and Markham, 1958).

The second possible reservoir of staphylococci is the
noses of the nurses.   Several workers have noted that the
strains of staphylococci which cause infections in the babies are
also present in the noses of many of the nurses (Allison and
Hobbs, 1947; Barber, Hayhoe and Whitehead, 1949; Rountree and
Barbour, 1950).   Allison and Hobbs (1947), Barber, Wilson,
Rippon and Williams (1953), and Barber and Burston (1955) have
suggested that babies commonly acquire staphylococci from their
nurses; and the observation by Rountree, Heseltine, Rheuben and
Shearmann (1956) that the neonatal infection rate in a nursery
fell simultaneously with the introduction of treatment of staff
nasal carriers with intra-nasal antibiotic cream, seems to support
this view.   On the other hand Parker and Kennedy (1949) and
Hutchison and Bowman (1957) found that cases of infection appeared
when no nasal carrier of the epidemic strain could be demonstrated
among the nurses.   Forfar and McCabe (1958) investigated the
effect of a strict gowning and masking regime on the staphylococcal

infection and carriage rates in a nursery with a high incidence of sepsis. They observed no reduction in the infant infection and colonisation rates, and concluded that direct transfer of staphylococci from the nose and mouth of attendants in the nursery is not important in infant infection. It should be pointed out, however, that in view of the findings of Hare and Thomas (1956), if any nurse nasal carrier in this experiment had been a disseminator of staphylococci, then strict gowning and masking could not be considered sufficient precautions to prevent the spread of the organisms. The third possible reservoir of staphylococci is the other infants in the nursery and many workers now believe that most infection is the result of infant-to-infant transmission — for example, Parker and Kennedy (1949), Hutchison and Bowman (1957), Wysham, Mulhern, Navarre, LaVeck, Kennan and Giedt (1957). Wentworth, Miller and Wentworth (1958) recently postulated an interesting view. They found evidence that although infant-to-infant transmission was responsible for epidemic spread of the infecting staphylococcus, the organisms were maintained in inter-epidemic periods by chronic nasal carriers on the staff who caused sporadic disease among the infants by direct contact.

Since the majority of babies are extensively colonised with staphylococci after the first few days of life they are obviously reservoirs from which the others may become infected — particularly in epidemic periods when the incidence of infection with a strain is high. The reappearance of an epidemic strain might well be due to the occasional transference of the strain to an infant from a chronic nurse nasal carrier.

There are several different routes by which staphylococci may be spread from infant to infant. Firstly, the nurses may transmit the organisms via their hands or gowns and, secondly, staphylococci may spread via contaminated air, dust or bedding. Staphylococci can occasionally be isolated from the hands or gowns of the nurses (Barber, Wilson, Rippon and Williams, 1953). The work of Cook, Parrish and Shooter (1958) suggests that although this may be the route of spread in some cases it is not responsible for the colonisation of most babies. These workers found that the use by the nurses of chlorhexidene hand cream, and of individual gowns for each infant, caused a small but significant reduction in the staphylococcus nasal carriage rate of the babies. The majority of infants continued to acquire staphylococci in their

noses, however, and they suggest that transmission in these cases must have followed a route other than direct contact from the nurses — possibly the air. Jellard (1957), showed that the infant umbilicus could be a prolific source of staphylococci, and Gillespie, Simpson and Tozer (1958) have confirmed the importance of this source of staphylococci by their observation that the application of dusting powder containing hexachlorophene to the umbilicus and surrounding skin greatly reduced staphylococcal colonisation and cross infection. Jellard also found evidence that babies' noses were colonised via the air. She noted that treatment of the umbilicus by triple dye caused a reduction in skin and nasal carriage of staphylococci and a fall in the staphylococcal contamination of the air suggesting that the organisms may spread from infant umbilicus via the air to another infant's nose. Rountree and Barbour (1950), Wallace and Duguid (1952), and Wysham, Mulhern, Navarre, LaVeck, Kennan and Giedt (1957) have shown that staphylococci are often present in the air of nurseries. Nevertheless the role of the air in the transmission of staphylococci in infant nurseries requires further elucidation. It would be interesting if work could be undertaken to assess if

improvement in nursery ventilation is followed by a reduction in the infant colonisation and sepsis rates.

Much the same difficulties complicate assessment of the significance of dust and bedding in the spread of staphylococci in nurseries. Dust has been shown to be often heavily contaminated with staphylococci (Rountree and Barbour, 1950; Hutchison and Bowman, 1957) but these workers also observed this in the absence of any significant sepsis. Barber, Wilson, Rippon and Williams (1953) on the other hand were unable to isolate any staphylococci from the dust of a nursery where strains of staphylococci were demonstrated to be spreading in the nursery environment. That blankets in neonatal nurseries are often heavily contaminated with staphylococci has been shown by Wysham, Mulhern, Navarre, LaVeck, Kennan and Giedt (1957) and Cook, Parrish and Shooter (1958). Cook and her colleagues found that sterile blankets often became contaminated before the babies acquired their nasal strains but pointed out that although blankets might be responsible for colonising the babies' noses they were not the primary source of infection. The possibility always remains that the contamination of dust and bedding may simply reflect the spread

of staphylococci in the environment: the role of contaminated

dust and bedding in the genesis of infection is still obscure.

Two papers have been published which throw light on some

of the problems of staphylococcal epidemiology in maternity units.

Both demonstrate the spread of staphylococci in nurseries in the

absence of severe sepsis. The first, that of Barber, Wilson

Rippon and Williams (1953), described how a strain, previously

shown to be capable of causing outbreaks of infant infection

(Barber, Hayhoe and Whitehead, 1949) could spread extensively in

the nursery without causing more than a sporadic case of mild

sepsis. The strain was the predominant staphylococcus in the

noses of both infants and nurses but was not isolated from bedding

or dust. In the second paper, Hutchison and Bowman (1957)

observed the spread of staphylococci in a nursery during 3 months,

and their findings correspond in many respects to those of Shooter,

Smith, Griffiths, Brown, Williams, Rippon and Jevons (1958) who

carried out a similar investigation in a surgical ward. Briefly,

Hutchison and Bowman found that different relatively predominant

strains of staphylococci waxed and waned from week to week with

undercurrents of minor strains appearing sporadically. A high

rate of colonisation by a strain could be found in the absence of infection due to it, although on the whole the incidence of infection by a strain was parallel to its carriage rate in infants' noses.   Strains sometimes colonised the infants' noses extensively although absent from those of the nurses, and it was concluded from this that, in infant colonisation and infection, staphylococci were usually transmitted from baby to baby and not from nurse to baby.   The dust of the nursery was found to be heavily contaminated with staphylococci and this was due almost entirely to dissemination from infants who acted as the culture medium.

It is clear from the foregoing account that the mechanism of infection in maternity units is still not entirely understood. Why, for instance, are staphylococci sometimes widespread in a nursery in the absence of significant sepsis?   The answer probably lies in the differing degrees of infectivity or the ability to produce disease of various staphylococcal strains.   Barber and Burston (1955), noting the absence of serious infections from a nursery until a nurse came on duty with a boil on her face, suggested that strains derived from an active lesion might be more virulent than those from healthy nasal carriers.   Beaven and

Burry (1956) found an increase in virulence in epidemic

staphylococci which resulted in the development of severe and

sometimes fatal infections.   They found that cross infection and

aerial contamination was promoted by overcrowding and postulated

that the more rapid passage of organisms which resulted might have

lead to an increase in virulence.   There remains a third

possibility — namely, that some strains of staphylococci may be

inherently more infective than others.   In the past 3 years

events have come to light which confirm that this is so.   The one

strain now recognised in countries all over the world as being of

unusual infectivity and especially liable to give rise to epidemics

in hospitals is phage type 80.   This unusual strain will now be

discussed in more detail, as it deserves.

Phage Type 80 — A Staphylococcal Strain
of Unusual Infectivity

In 1955 Rountree and Freeman described an epidemic due

to a new staphylococcal strain which reacted only with a newly

isolated phage numbered 80.   This strain was first observed in

1954 in a hospital in Sydney, where it caused an epidemic of

unusually severe skin lesions in both patients and staff. The

rate of nasal carriage of the strain was disproportionately low,

and this, together with the fact that the infections which it

caused among the staff appeared to be superimposed on the normal

stratum of antogenous infection, suggested that it possessed

enhanced virulence. The unusual severity of the lesions supported

this view. After its discovery in Sydney it was identified as the

cause of numerous epidemics throughout Australia and one in New

Zealand. It has since been reported in outbreaks of infection in

many other parts of the world — for example, in the United

Kingdom (Duthie, 1957; Gillespie and Alder, 1957), the United

States of America, where it is known as type 42B/52/81 with or

without 80, 44A, and 47C (Caswell, Schreck, Burnett, Carrington,

Learner, Steel, Tyson and Wright, 1958; Ravenholt, Wright and

Mulhern, 1957; Shaffer, Sylvester, Baldwin and Rhiens, 1957),

Canada (Bynoe, Elder and Comtois, 1956), New Zealand (Munro and

Markham, 1958), and Uganda (Hennessey and Miles, 1958).

In most outbreaks, type 80 has shown a clear predominance

as a cause of sepsis; and infections due to it are often unusually

severe (Gillespie and Alder, 1957; Bass, Stinebring, Willard and

Felton, 1958) although Munro and Markham (1958) found that this is
not always so.   In maternity units, type 80 has been the cause of
widespread infection among both babies and mothers — and in some
instances fatal infections in the babies have been described
(Fekety, Buchbinder, Shaffer, Goldberg, Price and Pyle, 1958;
Cooper and Keller, 1958).   In surgical units it has caused wound
infections and septic skin lesions in both patients and staff
(Caswell, Schreck, Burnett, Carrington, Learner, Steel, Tyson and
Wright, 1958; Duthie, 1957; Barber and Dutton, 1958).   The
ability of the strain to colonise the nose seems to have differed
from outbreak to outbreak.   Thus Duncan, Collins, Neelin and Roy
(1957) and Duthie (1957) found that it rapidly became widespread
in the noses of hospital staff, whereas others found that its
prevalence in the nose was low compared with its prevalence in
infections (Caswell, Schreck, Burnett, Carrington, Learner, Steel,
Tyson and Wright, 1958).   However, in a recently published review
of epidemic staphylococci, Williams (1959) reported that type 80
commonly generates a high rate of carriage, and often a high
incidence of skin lesions also among the hospital staff.   He
describes type 80 as "... a strain that has more recorded epidemics

to its credit than any other type; whose epidemics are, in our

experience, twice as extensive as the average of all other types."

Recently some American workers investigated the incidence

of sepsis in babies and mothers sent home from hospitals where type

80 was epidemic (Ravenholt, Wright and Mulhern, 1957; Wysham,

Mulhern, Navarre, LaVeck, Kennan and Giedt, 1957; Fekety,

Buchbinder, Shaffer, Goldberg, Price and Pyle, 1958). This

revealed that a considerable amount of infection develops in

babies and mothers only after their discharge from hospital.

Wentworth, Miller and Wentworth (1958) and Cooper and Keller (1958)

showed that type 80 might spread to the families of infants and

mothers recently discharged from a hospital. In this way the

strain might become, in the community at large, a cause of a kind

of infection which was mostly resistant to several antibiotics.

Rountree and Beard (1958) published an excellent

description of the effects of type 80 on the population both in

and outside hospitals in Australia during the 3 years since it

first made its appearance there. The strain was responsible for

70 of 86 major outbreaks of staphylococcal infection in maternity

hospitals and was the major cause of puerperal breast abscess in

mothers and of serious staphylococcal disease in both infants and older children. It was the predominant cause of infection among patients and staff in a large general hospital and there was evidence that it had also spread in the community at large. A marked increase in the number of cases of generalised staphylococcal infection admitted to a general hospital was almost entirely due to this strain and it was an important cause of fulminating staphylococcal pneumonia following Asian influenza. Rountree and Beard regard the strain as having high infectivity rather than high virulence because they found that although it appeared to cause more severe disease, the mortality rate in cases of generalised infection due to it was not significantly higher than in those due to other strains. They considered that the extensive spread of this phage-group I organism in the community was due both to its penicillin resistance and to its ability to invade the healthy skin — a property which is not a characteristic of the antibiotic-resistant strains of phage group III which normally predominate in hospital wards.

It is clear that this particular strain of staphylococcus is causing considerable concern to both clinician and bacteriologist.

It also offers the bacteriologist a challenge.   Type 80, because

of its unusual communicability and ability to produce disease,

provides a unique opportunity to investigate the epidemiology of

hospital staphylococcal infection and to apply the knowledge

acquired in these studies for the control of its further spread.

CHAPTER IV

PERSONAL EXPERIENCE OF PHAGE TYPING

a) Establishing a Phage-typing Laboratory

b) Local Distribution of Staphylococcal Strains

c) An Outbreak of Staphylococcal Infection in the
    Western Infirmary, Glasgow

d) An Outbreak of Staphylococcal Infection in Law
    Hospital, Lanarkshire

e) An Outbreak of Staphylococcal Infection in the
    Southern General Hospital, Glasgow

f) An Outbreak of Staphylococcal Infection in the
    Royal Maternity Hospital, Glasgow

PERSONAL EXPERIENCE OF PHAGE-TYPING

a) Establishing a Phage-typing Laboratory

The technique of phage typing staphylococci has been described in detail in Chapter II. Dr. R.E.O. Williams and Dr. Joan E. Rippon, who evolved the method now widely used, have taught the technique to other workers who have wanted to use it when studying staphylococcal epidemiology. When it was decided that a laboratory undertaking the phage typing of staphylococci should be established in the Western Infirmary, Mr. D.B. Colquhoun, the technician who has assisted in this work, and I each spent a week at the Staphylococcus Reference Laboratory in the Central Public Health Laboratory, Colindale, London, learning the technique from Dr. Williams and Dr. Rippon.

The technique is complex and numerous difficulties confront those embarking on the work for the first time, not all of which are apparent while one is working in the central laboratory at Colindale. In this laboratory one year's work was required to establish typing on a reliable basis.

The first few weeks of the work were spent in assembling

all the necessary equipment. Stocks of measured pipettes and finely drawn typing pipettes were prepared, petri dishes were marked, and the special medium for typing ("Difco" dehydrated nutrient broth agar) was obtained and made up. When the laboratory was stocked with all the necessary equipment the phage filtrates brought from London were examined and titrated. This, unfortunately, revealed that the majority were no longer at a satisfactory titre. Since we, like most laboratories (excepting some in the Public Health Laboratory Service in England) had to propagate the phages ourselves, we started attempting to raise the filtrates to satisfactory titres. This proved to be unexpectedly difficult. For phage propagation we had been advised to use "a good nutrient broth," but it soon became apparent that the nutrient broth satisfactory for routine bacteriological work in the Western Infirmary was unsuitable for propagating phage. The results were most erratic; with a very few phages, satisfactory titres were achieved after only one or two attempts at propagation, but with the majority there was little or no phage multiplication even after repeated attempts. The use of nutrient agar as a solid medium for propagation gave no better results. Finally, after

unsuccessful trials of various media, we obtained the recipe for

the nutrient broth used for phage propagation in the central

laboratory at Colindale. The basic difference between this medium

and the one used routinely in the Western Infirmary was that the

Colindale medium was made from fresh ox heart or muscle instead

of from horse heart. We made the medium ourselves so that

certain necessary precautions could be better observed. These

included the following points. The meat used must be fat free

and obtained fresh from the slaughterhouse; it is then infused

overnight with copper-free triple-distilled water. In

propagation, heating is kept to a minimum and care is taken in

adjusting the pH so that no alkali is added after the precipitation

and removal by filtration of the phosphates in the medium. The

broth should be made in a container free from traces of

contaminating copper and a covered stainless steel pan was

recommended for this. After all these precautions were carefully

observed the nutrient broth so prepared proved entirely successful.

We were warned that occasionally a batch might inexplicably give

poor results in propagation, but so far our medium has always

proved satisfactory. The majority of phages now reach a titre of

1 in 10,000 or higher on first propagation although a few of the more difficult phages rarely rise above a titre of 1 in 1,000 and may need more than one propagation to achieve this. Propagations have now become an entirely routine procedure and we have never been worried about our stocks of phages since using the medium prepared exactly as described above.

Another difficulty became apparent after we had overcome the problem of phage propagation when Mr. D.B. Colquhoun discovered that horse heart nutrient broth agar gave lower readings of phage titrations than did the typing medium ("Difco" dehydrated nutrient broth agar). It was also found that when the "Difco" medium was underlaid with peptone water agar — and this is recommended by the central laboratory, Colindale, in the interests of economy — better results were obtained than with the "Difco" medium alone. Mr. Colquhoun carried out further experiments which showed that titrations on peptone-water agar itself gave higher readings than on any other medium. It was clear that the same medium must be used for both titrations and typing, since any variation would mean that the phages used in typing were not at the correct routine test dilution (R.T.D.) on the typing medium. It was therefore

decided to use peptone water agar for both titrations and typing

and this has proved completely successful over a period of nearly

$3\frac{1}{2}$ years.   One possible objection to the use of this medium is

that some strains of staphylococci might require a richer medium

for adequate growth on the typing plates.   In practice, this has

been a very rare event and only 6 strains have failed to grow on

the medium.

The phage filtrates have proved to be remarkably stable

and most retain their titre over many months in storage at 4°C.

Although many phages require repropagation in about 8-12 months,

some have remained at a good titre for over 18 months.   One

constant problem is the prevention of contamination of stock phage

solutions.   These are stored as broth filtrates without any

preservative, and thus may be contaminated with moulds, and

sometimes bacteria, from time to time.   Moulds may be removed

by filtration but we prefer to discard any filtrate which is found

to contain one.   The danger of contamination has been reduced to

a minimum by very careful handling of the filtrates and by storing

them in a series of small screw-capped bottles instead of one

large one.   Titrations and dilutions for typing are made from one

bottle only, and if, as a result of repeated opening, it becomes

contaminated one of the other bottles may still be used. The

diluted filtrates used in typing are also kept in 5 ml. screw-

capped bottles, and although they are opened nearly every day, they

have proved remarkably free from contamination. Due to the volume

of work now undertaken, fresh dilutions are made up about every 2

to 3 months. The routine test dilutions are tested by spotting

each phage on its propagating strain approximately every 3 weeks,

to ensure that the phage still produces semi-confluent lysis.

The lytic spectra of the phages have also been very

constant. Variations have occasionally been observed elsewhere;

in America, for example, type 80 was lysed by additional phages

which had undergone mutation (Blair and Carr, 1958). The only

phage which we have found to vary is 42D which is one of the least

useful phages in the basic set and rarely lyses human staphylococcal

strains by itself. Our filtrates of 42D have shown a persistent

tendency to lyse some of the group III strains in the lytic spectrum.

Even after a successful propagation from fresh stocks of phage

and propagating strain, 42D has again shown this change on

repropagation after an interval of time. The explanation for this

change is unknown but 42D has been found by workers at the central

laboratory at Colindale to show an unusual tendency to variation

(Dr. Rippon — personal communication).

The method of recording phage reactions has been

slightly modified from that used in the central laboratory which

is described on page 18. Confluent lysis, whether obtained with

phage at R.T.D. or 1,000 x R.T.D., is designated as +++ but the

degree of secondary growth at 1,000 x R.T.D. is estimated and

expressed as the denominator of a fraction. In this way

reactions with maximal secondary growth are recorded as $\frac{+++}{4}$ and

those with minimal secondary growth as $\frac{+++}{1}$. Many of the reactions

with secondary growth are probably inhibition reactions but as

these are now regarded as significant phage reactions this does not

affect the interpretation of results. This system of recording

the amount of secondary growth is exceedingly useful as it permits

one to visualise in retrospect the appearance of the original

reaction. Semi-confluent lysis is recorded as ++(+); all other

reactions are designated by the method used in the central

laboratory. In June 1958 we introduced 2 new phages into the

routine typing set. These were designated "B" and "C"

and were isolated by Mr. Colquhoun from lysogenic cultures of strains which failed to react with any of the basic phages. Phages B and C have proved exceedingly valuable in identifying some important locally-distributed strains which would otherwise be untypable. Both these phages were sent down to the central laboratory in London for further testing with the result that phage C has now been incorporated in one of the extra "pool" of phages used there.

When all the difficulties had been encountered and over-come, the phage typing technique very quickly became a routine procedure. Considerable experience is necessary, however, in the reading of typing plates and particularly in the interpretation of results. This has gradually been built up over the months and in the 3 years since we began regular typing, we have phage typed more than 9,000 strains of staphylococci. A considerable proportion of these have been sent in from several hospitals in the west of Scotland and, in fact, the laboratory in the Western Infirmary has now become a local staphylococcal reference laboratory for those who care to call upon it for this service.

The Comparative Phage-typing Test 1957

(Report to The International Committee on Phage-typing
of Staphylococci by Dr. R.E.O. Williams.   Stockholm, 1958)

In October, 1957, an opportunity arose to test our phage typing methods, when the central laboratory at Colindale sent to all those undertaking phage typing, 33 staphylococcal strains for a comparative phage typing test.   The strains were typed in the usual way and a report was returned to the central laboratory at Colindale of the phage types of the strains with full details of every phage reaction obtained with each.   Twenty-nine phage typing laboratories took part in the test;   10 used phage filtrates supplied from the central laboratory and 19 propagated their own phages, although these had originally been obtained from the laboratory at Colindale.   The typing in the Western Infirmary was carried out with peptone-water agar but was repeated using the recommended "Difco" medium for comparison.   The results, however, were in very close agreement and the few differences which were noted were minor ones only.   Since it was the medium in routine use, the results on peptone-water agar were submitted for assessment in the test.

The Results of the Test

The analysis of the results obtained in the test was most interesting. The typing results of a laboratory were assessed by comparing the phage reactions obtained with each of the 33 test strains to a "modal" pattern. "Modal" patterns were defined as a list of the phage reactions obtained by the greatest number of laboratories. The typing results of each test strain were graded into 5 categories according to the following convention:-

Category 1.   Identical with "modal result".

Category 2.   Minor differences from "modal" pattern with 1 or more phages, which did not alter the report on the strain.

Category 3.   Minor differences with 1 or more phages which did result in alteration of the report.

Category 4.   One strong (++) difference with or without additional minor differences.

Category 5.   Two strong (++) differences with or without additional minor differences.

This can be interpreted as meaning that strains in category 5 would be regarded as significantly different from a strain of the "modal" pattern. Those in categories 3 and 4 although showing considerable variation do not necessarily differ significantly from the "modal result", whereas strains in categories 1 and 2 would definitely be considered the same as strains of the "modal" pattern.

The overall result of the survey enabled the following conclusions to be drawn.

1. The results from laboratories using phage prepared in the central laboratory showed less variation than those from laboratories propagating their own phages.

2. The results with strains of groups I and II were more homogeneous than those with strains of group III or group I/III.

3. Taken as a whole the results could be regarded as very satisfactory and confirmed the usefulness of the technique.

The results obtained in the Western Infirmary showed that our category grading was placed about the middle of the gradings of laboratories propagating their own phages. Table II

TABLE II

Category Grading of Strains Typed in the Western Infirmary for the Comparative Phage-typing Test, 1957

Number of strains typed	35[*]
No. of strains in Category 1	9
No. of strains in Category 2	4
No. of strains in Category 3	9
No. of strains in Category 4	9
No. of strains in Category 5	4
No. of strains in Categories 1 and 2	13
Average Category grading	2.86

[*]2 strains were typed at both R.T.D. and 1,000 x R.T.D. and the results have been assessed separately.

shows our grading results in detail.

Table II shows that although there were 18 strains in Categories 3 and 4, only 4 strains were in Category 5 which represents a significant deviation from the "modal" pattern. 13 strains showed no variation or only very minor differences from the "modal" result.

The individual performances of the phages used by the various laboratories were also assessed by recording the number of strong (++) reactions they gained or lost compared to the "modal" reactions. The overall results showed that the group III phages of most laboratories showed considerable variation compared to those of group I (with the exception of phage 79). Group II phages showed very little differences from "modal" results.

The results obtained in the Western Infirmary are shown in Table III. The results of this test of individual phage performances show that although the majority of phages showed no tendency to lose or gain strong reactions, phages 79, 7, 70, 73 and 75 were over-reactive and phage 47 was under-reactive. All these phages had correct lytic spectra and it was interesting that 42D, which had shown a distinct tendency to vary in its lytic

TABLE   III

Individual Performances of Phages Used by the Western
Infirmary Laboratory in the Comparative Phage-typing Test, 1957

Phage	No. of ++ reactions which should have been negative	No. of negative reactions which should have been ++	No. of strains whose modal phage reaction was negative	No. of strains whose modal phage reaction was ++
29	0	0	27	6
52	0	0	25	8
52A	1	0	24	8
79	3	0	29	3
80	0	0	20	10
3A	0	0	31	1
3B	0	0	30	2
3C	0	0	29	4
55	0	0	27	5
71	0	0	29	4
6	1	0	30	3
7	2	0	28	5
42E	0	0	25	6
47	0	3	28	5
53	0	1	27	4
54	0	0	26	6
70	3	0	30	2
73	3	0	29	3
75	3	0	27	5
77	0	0	30	3
42D	0	0	32	0

spectrum, gave no extra reactions.

The comparative phage typing test was most reassuring. Only 4 strains had shown a typing result which differed significantly from the "modal" pattern and the majority of phages had no tendency to gain or lose strong "modal" reactions. Although our results showed much more variation than those from the laboratories using phages prepared in the central laboratory, when compared with those from the other laboratories propagating their own phages, they were most satisfactory.

b)   Local Distribution of Staphylococcal Strains

In July 1958 and in June 1959 the percentage frequency

distribution was calculated of the phage types of staphylococci

isolated from septic lesions and examined in the Western Infirmary

during the 2 years from 1st June, 1957 to 31st May, 1958 and from

1st June, 1958 to 31st May, 1959.   8,231 strains of staphylococci

were phage typed in these 2 years but only 3,356 have been

included in the surveys — the remainder being omitted either

because they were not isolated from lesions or because their

origin was uncertain.   Staphylococcal strains from hospital

patients in surgical and general wards and in maternity units were

compared with those from outpatients.

Several hospitals in the west of Scotland submit

staphylococci to the Western Infirmary for phage typing and many

more were doing so during the second survey than in the previous

year.   The second survey, therefore, includes nearly twice as

many strains as the first.   Staphylococci from surgical and

general wards (the majority of which were in fact from surgical

wards) came from 3 hospitals where routine phage typing was

carried out on all staphylococci isolated (the Western Infirmary,

Glasgow, Law Hospital, Lanarkshire, and the Vale of Leven Hospital,

Alexandria), and from 8 hospitals from which batches of selected

strains were examined from time to time (Glasgow Royal Infirmary,

The Royal Hospital for Sick Children, Southern General Hospital,

Belvidere Hospital, Robroyston Hospital, and Ruchill Hospital, in

Glasgow, the Ayrshire Area Laboratory, and Gateside Hospital,

Greenock).   Most of the strains isolated in maternity units, on

the other hand, came from the Glasgow Royal Maternity Hospital

and its associated hospitals, the Ross Hospital, Paisley, and

Redlands Hospital, Glasgow.   However the Bellshill Maternity

Hospital, Thornhill Maternity Hospital, Johnstone, and the Rankine

Memorial Hospital, Greenock, also submitted strains from time to

time and these, together with strains isolated from cases of

puerperal breast abscess and infant infection after discharge from

hospital, have contributed to this part of the surveys.   In

general, therefore, the staphylococci from surgical and general

wards have been derived from a wider variety of sources than those

from maternity units.

The results of the 2 surveys are shown in tables IV and

V.   The staphylococci assessed have been divided into phage

Table IV

Percentage frequency distribution of phage types of Staphylococcus aureus examined in Western Infirmary, Glasgow

1st June, 1957 – 1st June, 1958

Group	Phage pattern	Septic lesions in hospital patients		Hospital outpatients
		Surgical & general	Maternity	
I	29, 29	3.2	7.5	(3.6)
	29/52	(0.7)	(0.5)	-
	52, 52	2	(1.8)	(1.3)
	52/52A, 52/52A	(0.2)	-	(0.4)
	52A, 52A	2.8	3.6	4.9
	79, 79	(0.7)	(1.8)	(0.9)
	52A/79, 52A/79	2.5	4.4	13.4
	80, 80	16.2	10.5	4.5
	52/52A/80	2.7	3.1	4.9
	Other Group I	2.9	4.9	5.4
	Total for Group	34	38.1	39.3
II	71	-	(1.8)	4.5
	3C/55/71	(0.7)	3.1	7.6
	3C/71	-	(0.3)	(1.3)
	Other Group II	5.9	7.7	17.4
	Total for Group	6.6	12.9	30.8
III	6/7/47/53/54/75, 6/7/47/54/75	2.8	(0.3)	-
	related patterns	7.5	(1.5)	(0.4)
	6/47, 6/47/54, 6/47/53/54, 6/47/53	1.8	(0.5)	-
	related patterns	4.8	(1.8)	-
	7/47/54/75/77, .../75, .../77	-	(0.3)	-
	related patterns	2	(1.5)	(3.1)
	42E, 42E	(0.3)	(0.3)	(0.4)
	related patterns	(0.2)	-	-
	47/53/75/77	-	(0.8)	-
	75/77	(0.5)	(1.3)	(0.4)
	75	(0.5)	(0.3)	-
	77	(0.9)	(1.8)	(0.9)
	related patterns	2.3	3.4	(0.4)
	53, 53	3.4	(1.5)	(0.4)
	Other Group III	13.4	12.9	9.4
	Total for Group	40.5	28.1	15.6
IV	Total	(0.5)	(0.3)	(0.9)
Mixed groups		9.8	11.1	6.3
Untypable strains		8.6	9.7	7.1
Total strains		561	388	224

TABLE V

Percentage frequency distribution of Phage Types examined
in Western Infirmary, Glasgow.   1st June 1958 - 1st June 1959.

Group	Phage pattern	Septic lesions in hospital patients		Hospital outpatients
		Surgical & general	Maternity	
I	29, 29	2.1	4.2	2.7
	29/52	(0.6)	1.4	(1.8)
	52, 52	1.8	1.3	2.4
	52/52A, 52/52A	-	-	-
	52A, 52A	(1.0)	1.6	2.4
	79, 79	(0.7)	1.6	(0.9)
	52A/79, 52A/79	3.8	5.1	12.6
	80, 80	23.3	7.8	4.4
	52/52A/80	2.7	4.9	(2.0)
	Other Group I	3.0	6.9	7.5
	Total for Group	43.3	42.6	43.3
II	71	1.2	2.2	(1.6)
	3C/55/71	(0.9)	1.3	5.5
	3C/71	-	-	(0.4)
	Other Group II	3.2	9	19.6
	Total for Group	5.4	12.5	27.2
III	6/7/47/53/54/75, 6/7/47/54/75	1.9	(0.5)	(0.9)
	related patterns	2.9	2.6	(1.3)
	6/47, 6/47/54. 6/47/53/54, 6/47/53	3.8	(1.1)	(0.7)
	related patterns	5.2	1.9	(0.4)
	7/47/54/75/77, .../75, .../77	1.6	(1.1)	(0.4)
	related patterns	(1.0)	2.3	(1.6)
	42E, 42E	(0.5)	(0.4)	(1.1)
	47/53/75/77	-	-	-
	75/77	(0.7)	-	-
	75	(0.5)	(0.4)	(0.2)
	77, 77	4.0	1.2	(0.2)
	related patterns	5.2	2.5	(0.7)
	53, 53	1.6	(1.1)	(1.1)
	Other Group III	4.0	7.1	4.6
	Total for Group	32.7	22.1	13.3
IV	Total	(1.0)	(0.8)	(0.2)
187		(0.3)	(0.4)	(0.4)
B		(0.1)	(0.4)	(0.2)
C		2.5	2.9	4.0
B/C		1.9	4.6	(1.1)
Mixed groups		3.2	8.2	4.4
Untypable strains		14.0	13.5	11.3
	Total strains	898	832	453

which had caused a small outbreak of infection. It is necessary, therefore, to know the epidemiological background of the hospitals where infections were under investigation to assess fully the significance of tables IV and V.

Tables IV and V show, firstly, that the group distribution of staphylococci varies among the 3 different kinds of patients. Thus phage group III strains predominated in surgical and general wards and phage group I strains predominated in maternity units. The higher incidence of phage group I strains in surgical and general wards in table V was almost entirely due to the extraordinary predominance of the highly epidemic phage group I strain — type 80. If allowance is made for this unusual strain, phage group III strains emerge clearly as the most frequent cause of infection in these wards. In outpatients, strains of phage group I and II were responsible for most of the infections — of which phage group III strains caused only a small proportion.

Secondly, tables IV and V show that phage types as well as phage groups varied in their distribution among different kinds of patient. The overall epidemiological picture of phage types

was of a pool of hospital strains which varied in the frequency with which they gave rise to disease. These strains could be classified broadly as epidemic, endemic or sporadic.

Strains were regarded as epidemic when they became a predominant cause of infection within one unit or hospital. One major epidemic strain produced extensive epidemics and there were several minor epidemic strains also which caused small scale outbreaks of infection. The endemic strains formed the larger part of the hospital staphylococcus pool. Although some from time to time emerged as minor epidemic strains the majority did not predominate but simply caused infection regularly but with varying frequency. There was a tendency for an individual strain to vary in its frequency distribution in the 2 kinds of hospital patient. Sporadic strains had no real epidemiological significance but appeared at random as a cause of occasional infection. When the epidemiological background of a unit or hospital was known, sporadic strains could be distinguished from endemic strains which were relatively uncommon.

Type 80 was the only example of a major epidemic strain and showed a remarkable ability to spread and rapidly to become

the major cause of infection in any kind of hospital unit. Its
incidence in maternity units was lower in 1958-1959 (table V) than
in the previous year and this was due to the type-80 epidemic in
the Royal Maternity Hospital during the first survey. In the
following year type 80 caused epidemics in several other maternity
units in the area and although a far greater number of specimens
were submitted for phage typing from the Royal Maternity Hospital
and its associated hospitals, type 80 was so predominant in the
infections originating in these other units that it outnumbered
all other strains as a cause of maternity hospital infection.

Several minor epidemic strains were observed during the
2 years of the surveys which although they did not cause wide-
spread infection, emerged as the predominant infecting strain in
a unit or in a hospital for varying periods of time. Examples
of minor epidemic strains in surgical and general wards were
type 6/47/53/54 in the surgical wards of Glasgow Royal Infirmary,
type 6/47/75 followed later by type 47/54/77 (1,000 x R.T.D.) in
the gynaecological wards of the Western Infirmary. Type 53 was
the predominant strain in infections in Ballochmyle Hospital,
Ayrshire, for a period during the first survey and this accounts

for its higher incidence in table IV than in table V. In the

same way the higher percentage frequency of type 77 in table V is

due to its emergence as a minor epidemic strain in the surgical

wards of the Western Infirmary in the last 2 months of the survey.

During the period of the first survey, the Royal Maternity

Hospital suffered an epidemic due to type 80, which necessitated

its closure and reopening after disinfection. Before the

epidemic specimens had not been taken routinely from every

infection there so that not all of the infecting strains were

available for phage typing and for several weeks after the

epidemic the infecting strains belonged to a wide variety of

phage types and it appeared that no staphylococcal pool had yet

become established. Later, maternity hospital endemic staphylo-

cocci emerged once more but showed little tendency to become

predominant and very few became minor epidemic strains. Two

things may have contributed to this: firstly the stricter

policy for the prevention of sepsis which was introduced after

the epidemic and secondly, the nursing of the infants beside

their mothers (instead of in a crowded infant nursery) in the

Ross Hospital, Paisley and, more recently in 2 of the 3 units

in the Royal Maternity Hospital. One interesting endemic strain,

however, became a minor epidemic strain during the second survey.

This was type B/C which in a period of 6 months caused most of

the infant infections in the A unit of the Royal Maternity

Hospital. This minor epidemic was of particular interest

because A unit was the only unit in the hospital where the

infants still spent much of their time in a communal nursery.

Tables IV and V show that most of the common endemic

staphylococci had a similar frequency distribution in both

surveys. Endemic strains with a high incidence in surgical and

general units were types 6/47/53/54 and 77, and their related

patterns, and types 52A/79 and 52/52A/80. Similarly, endemic

strains in maternity units were types 52A/79, 52/52A/80, 29 and

the related patterns of types 6/7/47/53/54/75 and 77. Other

common maternity hospital strains were type 29/7 and type

29/52/79/80 which, although not listed as individual phage types

in tables IV and V, are included in "mixed groups" and "other

group I" respectively. A few strains appeared to cause disease

readily in any kind of patient — for example, types 52/52A/80,

52A/79 and the related patterns of type 77. Type 52/52A/80,

however, is an unusual strain which merits further discussion.

Rountree and Beard (1958) noted a close epidemiological association between type 52/52A/80 and type 80 and this association has been observed in the type-80 epidemics investigated here. Type 52/52A/80 does not seem to possess the same epidemic properties as type 80 but it has appeared as a frequent cause of infection during and following epidemics due to type 80. There is evidence that in the laboratory type 80 can be transformed into type 52/52A/80 by the action of phage isolated from lysogenic cultures of type 52/52A/80 (Asheshov and Rippon, 1959; Rountree, 1959) and it is possible that this also happens in the field.

Although any coagulase-positive staphylococcus must be regarded as capable of producing disease the results of the surveys shown in tables IV and V suggest that different strains vary in their ability to do so. Hospital strains, moreover, show a tendency to flourish more readily in either surgical and general wards or in maternity units. This difference is more marked if the staphylococci are considered in relation to the phage groups to which they belong and has been commented upon by by Williams (1959) who states that it is more marked when only

strains which have caused outbreaks of infection are considered.

It is, of course, the epidemic strains which are of

particular interest and importance in the investigation of

outbreaks of hospital infection and several of these strains have

been described above.   Many of these epidemic strains gave rise

to small scale outbreaks of infection which occasioned no real

concern to the clinicians concerned but a few caused serious and

sometimes extensive outbreaks.   Of these outbreaks, four which

were of unusual interest and were investigated fully will now be

described in detail.

c)   <u>An Outbreak of Staphylococcal Postoperative</u>

<u>Wound Infection in the Western Infirmary, Glasgow</u>

(Published, jointly, in <u>The Lancet</u>, 1957, ii, 863)

This outbreak of postoperative sepsis occurred in a
surgical unit where Dr. Sheila McDonald and I were carrying out a
survey of wound infection.   The infections in the outbreak were
serious and 2 patients died.   Nevertheless the events which this
investigation revealed might have passed without notice if details
of every wound infection had not been recorded and if all
staphylococci isolated in the unit had not been submitted for
phage typing.   To emphasise that it may be difficult to detect
epidemics of wound infection and to find their source, the events
are described in the sequence in which they became known.

<u>Clinical Record</u>

The survey of postoperative sepsis was instituted to
determine the incidence and sources of infection in the general
surgical unit concerned.   The sepsis-rate was in fact very low,
but it rose suddenly when within 8 days four patients developed
postoperative infections.   Case 1 had a superficial wound

infection which was present at the time of first dressing on the 7th postoperative day.   Cases 2, 3, and 4 had deep wound abscesses which discharged on the 11th, 8th, and 15th postoperative days respectively.   These three wounds had appeared satisfactory at the time of first dressing.   The pus examined from these four infected cases yielded a pure growth of coagulase-positive staphylococci with a notably greyish-white pigmentation.   This cultural character was important, because it led to the discovery of a hitherto unrecognised case in the outbreak (case 5).

A colleague who had examined postmortem specimens from case 5 (of fatal peritonitis) commented on the unusually white appearance of the coagulase-positive staphylococci isolated from the peritoneal pus.   It was then discovered that the patient had recently had a gastroenterostomy in the unit whose outbreak we were investigating.

The postoperative course had been complicated by abdominal distension, vomiting, and pyrexia.   On the 6th postoperative day the patient collapsed with peripheral circulatory failure and a foul-smelling fatty fluid was discharged from his wound.   Despite administration of intravenous fluids and

erythromycin, he died later on the same day. At necropsy a collection of pus and clear yellow fluid was found in the peritoneal sac in the deep aspect of the surgical incision. There were also signs of generalised fibrinous peritonitis. There was no leakage from the anastomosis. Coagulase-positive staphylococci were obtained in pure culture from the peritoneal pus and isolated from the spleen and contents of jejunum and rectum. Histological sections showed clumps of gram-positive cocci in the exudate on the peritoneal surface of the intestine.

At this point it was realised that another patient (case 6) from the same unit had died a fortnight earlier in similar circumstances.

This patient developed severe abdominal distension after partial gastrectomy. His wound began to discharge, and coagulase-positive staphylococci, Escherichia coli, and enterococci were isolated from the pus. In spite of treatment his condition deteriorated; the possibility of a leak from the anastomosis was suspected, so he underwent a second operation. No leak was found, but there were signs of plastic peritonitis in the stages of resolution. No specimens were taken for bacteriological

examination.   He died a few hours later, and necropsy confirmed the findings recorded at the second operation.   Fortunately the staphylococci cultured from the wound of the first operation were available for further investigation.

In each case the site and character of the infection suggested that it had been acquired at operation, and review of the operating theatre lists showed that all the six infected patients had been operated on by surgeon A.   In operations undertaken by surgeon A during a period of 15 days (table VI) only two of his eight patients escaped staphylococcal wound infection. Two cases with which he assisted during this period also, remained free from infection.   It then came to light that surgeon A had been operating during this time with a small boil on his forearm. This lesion caused little pain or discomfort, and no systemic disturbance.   It measured about $\frac{1}{2}$ in. in diameter, and was on the ulnar aspect of his right forearm above the glove but where the gown sleeve might become wet.   While the boil was discharging, the surgeon had taken the precaution of covering it with a water-proof dressing.   When seen 3 weeks later the lesion was crusted over and almost, though not completely, healed.   From a broth-

TABLE VI

Sequence of events in an outbreak of postoperative
wound sepsis. The numbers assigned to the cases
reveal the order in which they become known

Day no.	State of boil on Surgeon A's arm	Surgeon A's operating-lists	Postoperative course
1	First noticed by surgeon	None	-
2	-	Case 6 Partial gastrectomy	Wound abscess; Staph. aureus type 52A/79
		Cholecystectomy	Uneventful
4	Discharged	Prostatectomy	Wound infection; coliforms
9	-	Case 6 Second operation	Patient died with peritonitis after operation
10	-	Case 2 Partial gastrectomy	Deep wound abscess; Staph. aureus type 52A/79
		Case 1 Polya - Billroth conversion	Superficial wound infection; Staph. aureus type 52A/79
		Case 4 Cholecystectomy	Deep wound abscess; Staph. aureus type
15	-	Case 5 Gastroenterostomy	Patient died on 6th postoperative day with peritonitis; Staph. aureus type 52A/79
		Case 3 Polya - Billroth conversion	Deep wound abscess; Staph. aureus type 52A/79
18	-	Laparotomy	Uneventful
24	First swab taken from almost healed lesion. Staph. aureus type 52A/79 (scanty growth)	Partial gastrectomy Cholecystectomy Removal of thyroid cyst	Uneventful Uneventful Uneventful

soaked swab rubbed over the area, a scanty growth of coagulase-

positive staphylococci was obtained.   A second swab taken 6 days

afterwards yielded a very scanty growth of the organism but

subsequent swabs were negative.   Routine nasal swabs taken from

surgeon A a month before the outbreak and twice during the

investigation did not yield coagulase-positive staphylococci.

The point of interest is that the presence of the boil and its

relation to the outbreak were discovered only because the recently

instituted wound-infection survey revealed a sudden change in the

previously low sepsis rate, and the phage typing disclosed an

epidemic type of staphylococcus whose origin was investigated with

a good deal of persistence.

The staphylococci isolated from each of the six patients

and from surgeon A's boil all had the characteristic greyish-white

colonial appearance already mentioned and were found to be the

same phage type — namely, 52A/79.   This strain had not been

isolated from any wound in the unit in the previous 6 months.

Nasal swabs from surgeons and theatre nurses showed that seven of

eleven carried coagulase-positive staphylococci.   Phage typing

showed these strains to be different from each other and from the

epidemic strain with one exception — namely, that one surgeon carried in his nose a strain of type 52A/79 which gave a well-marked golden pigment. This surgeon had no contact with any of the infected cases. While infected cases were still in the wards, one of the house-surgeons developed a boil on his neck. Several weeks later, when the incident was apparently ended, two patients developed superficial wound infections after first dressings. Type 52A/79 with greyish-white pigmentation was isolated from these infections. These three incidents, which were probably due to ward cross-infection, are the only evidence of subsequent spread of the epidemic strain in the unit. Three and a half months after the first operation the patient of case 1 developed a deep stitch abscess requiring operative treatment and, a year later, suffered a recrudescence of the same infection. This developed into a chronic wound sinus which was still discharging type 52A/79 in the pus 2 years after the first operation. It is clear that this patient, who had been regarded as the only case of superficial wound sepsis in the outbreak, also had a deep wound abscess. The patient of case 2 was readmitted for a repair of an incisional hernia 4 months after the original operation.

A wound abscess developed after this second operation, which was

not carried out by surgeon A.   A growth of staphylococci of type

52A/79 of greyish-white pigmentation was cultured from both of

these lesions.

Discussion

In the present outbreak unusually severe infections

developed in six patients after operations performed by a surgeon

who had a boil on his forearm.   Three patients had deep

abscesses, necessitating a long stay in hospital, and two died.

In one of the two fatal cases, the cause of death was

staphylococcal peritonitis.   The other patient died in similar

circumstances, and though the evidence was incomplete, there can

be little doubt that staphylococcal infection contributed to his

death.   It is interesting that this patient underwent operation

before the boil discharged, and that the other patients became

infected though the lesion was covered with an occlusive dressing.

The situation of the boil suggested that the route of

infection may have been by direct spread of the organism through

the surgeon's gown sleeves.   Gown sleeves often become wet above

the margin of the gloves — particularly during abdominal

operations. The possibility of inoculation through glove

punctures cannot of course be ruled out since it is probably that

the surgeon's hands were also contaminated with staphylococci.

Nevertheless the first hypothesis seems more likely to be the

correct one in this instance because only 2 of surgeon A's 8 cases

escaped infection during a 15 day period.

The danger of a surgeon operating while suffering from

a septic lesion was emphasised in The Medical Research Council

Memorandum no. 6 (1941). No reports, however, could be found

in the literature of any outbreaks with such an origin.

Coburn (1944), studying the epidemiology of Streptococcus

pyogenes, came to the conclusion that when this organism was

derived from subacute infections it might be more communicable

than when it was derived from a healthy mucous membrane. Barber

and Burston (1955) suggested that this might be true for coagulase-

positive staphylococci. Investigating staphylococcal cross-

infection in a maternity unit, they noted that, despite a high

nasal-carriage-rate among patients and staff, infections were few

and trivial until a nurse came on duty with a boil on her face.

Within a few days, one baby had acute mastitis — a much more

serious infection than any seen previously during the study —

and another had conjunctivitis. Gould (1957) found that the

incidence of superficial staphylococcal infection is higher among

members of hospital staff than among the general population.

There is little doubt that surgeons occasionally operate while

suffering from septic lesions, and outbreaks of this sort are

probably more common than is realised. Because of the mildness

of the associated systemic illness and also, perhaps, because the

introduction of antibiotic therapy has given rise to a certain

sense of complacency, few surgeons with skin infections are

willing to forgo operating. This outbreak emphasises the extreme

danger of this. Not only are lesions dangerous sources of

infection while they are actually discharging, but they may give

rise to infections before discharge and for many days thereafter.

d)   <u>An Outbreak of Staphylococcal Wound Infection</u>

<u>in Law Hospital, Lanarkshire</u>

(In press, jointly, <u>Lancet</u>)

In May 1958 in the surgical unit of Law Hospital, there was an epidemic of postoperative wound infection which illustrated two important features: the first, the danger of a surgeon operating while suffering from septic lesions, and the second, the extent to which the unusually infective <u>Staphylococcus aureus,</u> phage type 80, may spread among the patients when it is introduced into a surgical unit.

The Surgical Unit

The epidemic began in a surgical unit of 6 wards containing 180 beds in all.   The unit is staffed by 6 surgeons who carry out general surgical work including urology.   The wards are single-storey buildings connected by long airy corridors which have windows and doors opening on to the surrounding hospital grounds.   A newly built operating theatre serves the surgical as well as the gynaecological unit in the hospital.   The theatre is well designed and equipped and is

ventilated by a positive pressure ventilation system.

The Start of the Epidemic

Before the epidemic wound sepsis in the unit was infrequent, but not recorded. No one of the 6 surgeons appeared to have a significantly higher incidence than any other. In 1958, six weeks before the epidemic, routine phage typing of all staphylococci isolated from infected surgical wounds had been instituted. This revealed that several different strains of staphylococci, most of which belonged to phage group III, were responsible for the infections. At that time there was no evidence of an epidemic strain.

During May 1958, however, one surgeon, Mr. B, noticed a sudden rise in his sepsis rate in that 9 of 51 or 18% of his cases developed wound infections. Since most of the infections were deep wound abscesses it was thought that the infections must have been acquired at operation. At this point the surgeon stated that since the end of April he had been suffering from a series of boils affecting both axillae and that he had operated upon all the infected cases during the course of these infections.

Phage typing showed that all the infected cases were due to type 80, and this same type was isolated from one of surgeon B's axillary boils in May. There was therefore little doubt that surgeon B had infected these cases from his axillary boils during operation.

Shortly after this outbreak it was realised that there had been a smaller but similar outbreak of wound infection among surgeon B's cases in March, when 5 of 45 of his patients developed wound infection. At the end of February surgeon B had gone off duty with a septic finger. The infected patients had been operated upon when he returned to work when the lesion was scabbed over. Although no phage typing was being done in March 1958, the staphylococci from these infections and from surgeon B's finger had the antibiotic sensitivity pattern of the epidemic type 80 strain (i.e. resistant to penicillin and the tetracyclines, sensitive to chloramphenicol and erythromycin, and variable in sensitivity to streptomycin.) Later, in June, type 80 was isolated from one of the patients operated on in March who had a chronic discharging wound. This evidence therefore suggested that the March outbreak was also caused by type 80, in this instance

derived from surgeon B's scabbed-over septic finger and that his

axillary boils in May were due to the same staphylococcal type as

this earlier infection. It is interesting that in the interval

between episodes of sepsis, when he was in all probability still

harbouring the organism, surgeon B did not transmit it to his

patients.

Secondary Spread of type 80 Infection in the Surgical Unit

Shortly after the first small outbreak of infection in

March phage typing was begun. This showed that there had not

been any secondary spread of type 80 in the surgical wards at this

time. A widespread epidemic of wound sepsis, however, followed

the second appearance of the strain in surgeon B's cases in May

and a further 47 cases of wound infection due to type 80 appeared

during the succeeding 7 months. The first two secondary cases

of wound infection were found in May after the outbreak in surgeon

B's cases. They were apparently due to cross-infection since they

followed operations performed by different surgeons. Similarly,

in the secondary epidemic, wound infections were associated with

all 6 surgeons in the unit. Although the infections appeared

among patients in each of the surgical wards, two wards were more severely affected than the other four.

Table VII records the monthly incidence of wound infections due to type 80 and the proportion of the surgical wounds at risk which became infected.

It may be seen that after the introduction of type 80 in surgeon B's cases in May the sepsis rate of the unit in June and July was 5% and 4% respectively. In August, when various measures had been instituted in an attempt to reduce the number of infections, it fell to a low level and remained low during the next 4 months (from September to December). No type 80 infections appeared in January, 1959. The course of the epidemic in the surgical unit therefore extended over a period of 8 months and although the number of infected cases in each month was not large the morbidity among these patients was considerable. The figure shows the monthly incidence of all staphylococcal wound infections in relation to the incidence of those due to type 80 and of those due to other strains of staphylococci. In the first 4 months type 80 was clearly predominant as a cause of wound infection; but as the epidemic

TABLE VII

Number of Operations per Month followed

by Wound Infection due to Type 80

Month	Total no. of surgical operations	No. of operations followed by type 80 infection	% of wounds at risk which became infected with type 80
May	335	11	�
June	301	15	5
July	245	9	4
August	262	3	1
September	306	5	2
October	301	8	3
November	276	3	1
December	301	2	1

✗ The percentage of operation wounds in May becoming infected with type 80 was not calculated because all except 2 of the infections appeared in cases operated upon by surgeon B.
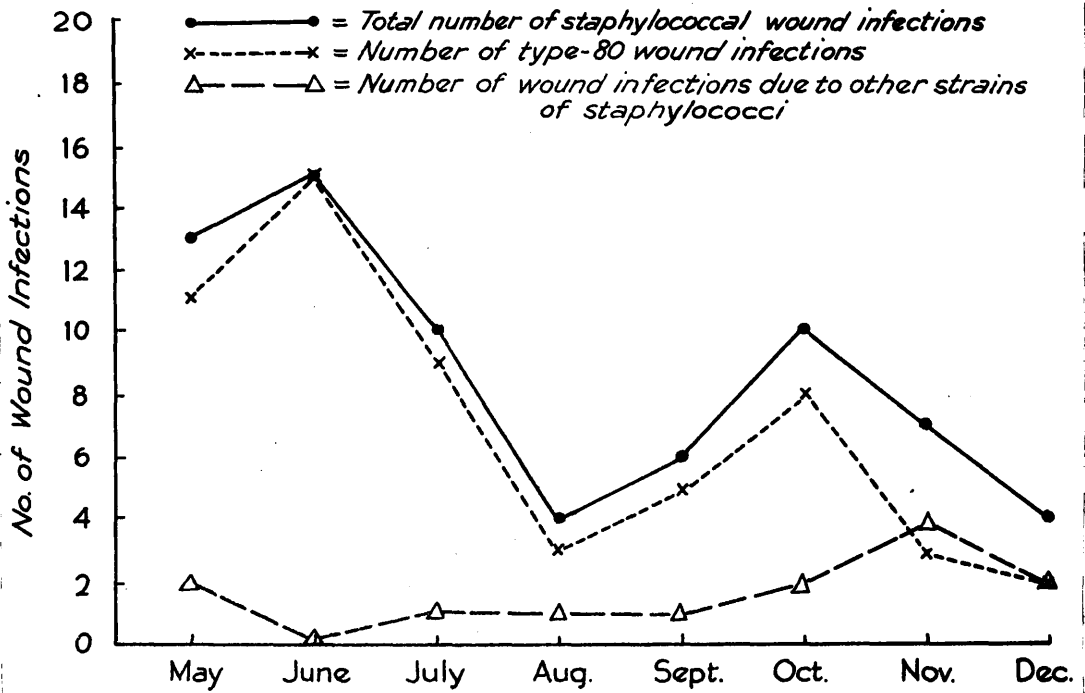
Figure. Monthly incidence of wound infections due to type 80 in relation to those due to other staphylococcal strains.

waned in the later months wound infections due to other strains of

Staph. aureus began to appear more frequently.

Most of the infections in the epidemic were wound

infections but type 80 also gave rise to other forms of septic

lesion in 11 patients.   Of 4 patients who had wound infections,

3 later suffered from boils, and one developed an abscess of the

thigh.   One patient whose wound was not infected also suffered

from boils.   Four patients had infections of the urinary tract:

three became infected after being catheterised and the fourth,

who developed the urinary infection pre-operatively, later

suffered from wound sepsis due to the same organism.   Type 80

was the cause of fatal parotitis and suppurative otitis media in

one elderly patient and was isolated from the stools of another

who had undergone prostatectomy and developed severe postoperative

diarrhoea.   Apart from surgeon B only one member of the hospital

staff is known to have become infected with type 80 during the

epidemic period.   This was a nurse in the outpatient department

who developed a septic finger.

Nine surgical patients who had infections due to type

80 died, but in 5 death was mainly due to other causes.   Although

type 80 materially contributed to the deaths of the remaining 4

patients their general condition had previously been poor and it

is probable that the supervention of any infections would have

hastened death.

Infections due to type 52/52A/80

The staphylococcal strain type 52/52A/80 has been

observed to be closely related to type 80 (Rountree and Beard

1958). During the present epidemic this strain was isolated from

4 surgical patients — from three who had wound infections and

a fourth who had parotitis. A nurse working in one of the

surgical wards also developed a septic finger due to the strain.

Type 80 in the Hospital Environment

In August, nasal swabs were taken from the entire

staff of the surgical wards. This included surgeons, anaesthetists,

nurses, orderlies and domestics. A total of 114 nasal swabs

were collected and 7 nurses were found to be carrying the epidemic

strain. Six of the nurses worked in the surgical wards but the

seventh was a theatre sister. Further inquiries however showed

that she could not have been responsible for the spread of the

epidemic strain because she had assisted at only 4 of the

operations which were followed by sepsis. The rather low carriage

rate (6%) of type 80 in the nursing staff in spite of ward

contamination may have been due to the rotation of the nurses

among other units. Three nurses were also found to carry the

related strain type 52/52A/80 in their noses. Samples were

taken from blankets and floor dust of the 2 wards which were most

affected by the epidemic and yielded strains of type 80.

The Source of the Epidemic Wound Infections

The most striking feature of the type 80 wound infections

in the secondary epidemic was that the majority were deep wound

abscesses and therefore appeared to have been acquired during

operation rather than in the wards postoperatively. There was

no demonstrable source of infection in the operating theatre.

Moreover, it was also used for gynaecological cases, among whom

there had been no type 80 infections; therefore it was unlikely

that the theatre itself, or any of the nursing staff there, could

be responsible for the spread of type 80.

The possibility remained that the patients were

themselves carrying the epidemic strain from the wards into the theatre. In the present epidemic no investigations were undertaken to estimate the staphylococcal skin and nasal carriage in patients before operation and there was therefore no direct evidence that this was a common route of infection. Nevertheless there was evidence which suggested that this was the probable explanation for the theatre-acquired infections which were an important feature of the secondary epidemic. Firstly, type 80 was known to have contaminated the ward environment and as all the wards contained cases of sepsis due to it there were obvious sources of infection within them; secondly, the wards with most cases of sepsis continued to show more new infections than the others; and thirdly, no source of infection could be found within the operating theatre. We learnt by chance of another way in which ward contamination could be brought into theatre from the wards. It was discovered that clean linen was returned to the wards in the same basket as that which had delivered soiled linen to the laundry. A swab was taken from one of these baskets and yielded a type 80 staphylococcus. Patients were sent to theatre dressed in socks, and in a "clean" gown (from

the soiled linen basket) which during operations was folded up under the patients' arms.   The gown, with its possible contamination, would therefore be placed only a few inches from the wound during abdominal operations.   The arrangements for delivery of clean laundry were altered as soon as this state of affairs was discovered and now linen is sent to and from the laundry in washable canvas hampers.

Measures taken for Control of the Epidemic

The first step was to rid the affected surgeon of his recurrent infections.   This proved to be extremely difficult. As he was a nasal carrier he began intra-nasal treatment with neomycin/bacitracin cream and was advised to wash with hexachlorophene soap both in hospital and at home.   After a short course of the intra-nasal antibiotic, his nasal swabs became negative and he resumed operating.   His boils, however, recurred while he was away on holiday and on returning he was once again unable to resume operating because of a boil on his finger due to type 80.   Further treatment with the intra-nasal antibiotic cream and the antiseptic soap was then carried out:

in addition his clothing was washed with a quaternary ammonium

disinfectant and all outer garments were dry cleaned (it was hoped

that the steam pressing would destroy any staphylococci

contaminating them). Despite these measures type 80 was isolated

from surgeon B's hands three weeks later although his boils were

then healed. Had one recurrence not coincided with his holiday

he would have been absent from duty for 3 months out of 6 with

recurrent boils. This history illustrates how difficult it is

to be certain of curing recurrent sepsis in any individual and

also the enormous inconvenience which may be caused to a surgeon

under these circumstances.

When it was realised that type 80 was causing a general

epidemic a very strict aseptic technique was begun in the wards

to avoid cross-infection during dressing rounds. All nasal

carriers of type 80 among the nursing staff of the surgical unit

were sent off duty and treated with neomycin/bacitracin cream.

Later, at the end of August, the surgeons were asked to use a

hand rinse of chlorhexidene in alcohol just before donning

surgical gloves. The efficacy of the hand rinse was demonstrated

on one occasion when we asked surgeon B to scrub up and don

surgical gloves for 2 hours — once with and once without the chlorhexidene hand rinse. Type 80 was isolated from his hands and the inside of his gloves when he omitted the hand rinse but no Staph. aureus was isolated when it was used.

These measures were followed by a sharp fall in the incidence of type-80 infections during and after August.

Discussion

This epidemic illustrates again the high incidence of postoperative sepsis which may result when a surgeon operates while suffering from a septic lesion. In the outbreak previously described a surgeon who operated while suffering from a boil on his forearm caused a small outbreak of severe wound infection involving 6 patients. In that instance the epidemic strain was type 52A/79 and no widespread epidemic followed in the surgical unit concerned. In the present outbreak the infecting strain was type 80, which, after its appearance in the surgeon's own cases, became the predominant cause of postoperative sepsis in the unit. There was evidence that a similar smaller outbreak, probably also due to type 80, had appeared 2 months earlier than

the major outbreak yet in this earlier outbreak there was no sign

of secondary spread of the organism.   It is noteworthy that

surgeon B did not infect his cases when he was carrying the

epidemic strain but was not suffering from sepsis due to it.

This provides further suggestive evidence of the possible increase

of danger from organisms derived from active lesions as distinct

from those carried on the healthy skin or nasopharynx.

The site of the surgeon's lesions in the present outbreak

was interesting.   Septic lesions on hands or forearms are an

obvious risk, but the danger of spread from a lesion in the

axilla may not be so apparent.   It is well known that the skin

surrounding discharging lesions is heavily contaminated with the

infecting organism.   Staphylococci from the axillae may spread

down the arm inside the sleeves of surgical gowns or everyday

clothing in sweat, air currents or by other means to contaminate

the forearm and hands.   Spread from there to the patients'

wounds may have been through glove punctures or wet gown sleeves

or possibly by dissemination into the air.   Colebrook and Ross

(1947) found that Streptococcus pyogenes from a scabbed lesion on

a surgeon's arm was disseminated into the air and this may

represent an important route for spread of organisms from a staphylococcal lesion also.

The history of recurrent sepsis in this particular surgeon emphasises the unsatisfactory state of treatment of this condition and also the inconvenience to both the surgeon and the hospital deprived of his services during the episodes of sepsis. Nevertheless it is clear that the danger of infecting wounds at operation is so great that no surgeon should ever operate while suffering from sepsis of hands or arms. Even in the absence of direct evidence boils anywhere on the body must be regarded as a surgical hazard of unknown magnitude and a surgeon who is suffering from this form of sepsis should first ascertain that his hands are not contaminated before operating and make use of hand rinses such as have been described.

Type 80 has been described as a strain which causes more extensive epidemics than any other staphylococcus and which often produces a high incidence of skin lesions (Williams 1959). In the present epidemic, however, the incidence of skin sepsis was relatively low and most of the infections were wound infections. Robertson (1958) has recommended that separate

containers be provided for clean and soiled linen and in the

present epidemic the isolation of type 80 from a ward laundry

basket, which was used for the transport of both clean and soiled

linen, emphasises the importance of this.   This obviously

dangerous and indefensible practice was being carried out at a

time when special precautions were being taken to avoid the

further spread of infection and illustrates the necessity of

supervising carefully all details of ward hygiene.

e)   <u>Two Outbreaks of Staphylococcal Infection</u>

<u>in the Southern General Hospital, Glasgow</u>

This report illustrates the difficulty in tracing the

epidemiology of staphylococcal infection in retrospect and without

full access to all the relevant information.   Nevertheless there

were some interesting features about the infections in this

hospital which were revealed by phage typing and the other

bacteriological investigations which were carried out.

In October 1957 I was asked to help in an investigation

into postoperative wound infection in the surgical unit of the

hospital.   The senior surgeon in the unit, surgeon C, was

particularly worried because a number of patients who had under-

gone cardiac and thyroidectomy operations had developed post-

operative infection and because 2 patients had died of severe

staphylococcal infection after cardiac operations.   It was

noticed that sepsis appeared more commonly after operations

performed in the newly built and theoretically plenum-ventilated

operating theatre than in those carried out in the old theatre

which had no controlled system of ventilation.

Fortunately all strains of <u>Staphylococcus aureus</u>

isolated in the hospital in the preceding year had been retained
and I suggested that all those isolated from infections in the
surgical unit be submitted for phage typing.   Phage typing was
also carried out on strains isolated from new infections as they
appeared.

Other investigations were carried out — for example:-

(1) Nasal swabs were taken on several occasions from
all surgeons and theatre nursing staff.

(2) Skin and glove swabs were taken from some of the
surgeons.

(3) Cultures were made from the inner surface of the
masks of the senior surgeon and theatre sister.

(4) Numerous sites in the theatre were sampled for
contamination with Staph. aureus.

(5) Some tests were performed to estimate the bacterial
content of the theatre air.

The last 2 investigations were carried out in the new
theatre where, in fact, most of the operations were performed.

Results

It soon became apparent that two epidemic strains of staphylococci were responsible for most of the surgical infections. These strains were (1) Type 3Bw/55vw/71 (Normally very weak phage reactions are not reported: however the minor reaction of this strain with phage 55 was so constant and so characteristic, that I decided to include it in the phage type report)   (2) Type 80.

The first strain, which belongs to phage group II, had appeared sporadically but persistently in wound infections in the preceding 8 months.   The second strain had caused a few sporadic infections during the preceding 7 months but had shown a dramatic rise in incidence towards the end of 1957.   Unlike the first strain it appeared in infections in patients throughout the hospital.

I.   Epidemiology of Infections due to Type 3Bw/55vw/71

Clinical Record

Phage group II staphylococci are a rare cause of wound infection and type 3Bw/55vw/71 is itself a very uncommon group II strain.   It was therefore surprising to find this strain

appearing so frequently in surgical infections.   It had been

discovered, however, that surgeon C was a persistent nasal carrier

of this particular staphylococcus and it seemed likely that he was

in some way transferring his nasal strain to cases during

operations.

Table VIII shows the monthly incidence of cases from

which type 3Bw/55vw/71 was isolated and also the surgeons who

operated upon them.   2 patients died of staphylococcal infection

following cardiac operations and in each, 2 strains of staphylococci

were responsible for the infections.

Case 1 was that of a patient who died in October 1956

after valvotomy and from whom 2 strains of staphylococci were

isolated.   One was a group III strain — the other a group II

strain which at the time of typing in 1956 differed in some of

its phage reactions from the very characteristic and constant

reactions of the strain which was epidemic in 1957.   It is

impossible to say whether this 1957 strain was a variant of the

original 1956 one or whether it was a different strain altogether.

The significant point is that, in 1956, surgeon C carried in his

nose a staphylococcus identical with that which was isolated from

Table VIII

Monthly Incidence of Infections due to Type 3Bw/55vw/71

Month	Case no.	Operation	Surgeon	Sites from which Type 3Bw/55vw/71 was isolated
October 1956	1	Valvotomy	C	Type 3B/3C/55/71 - blood culture (life) heart blood, spleen (post mortem). Also isolated = type 6/47/75 sputum, pleural fluid (life) pleural fluid, pericardium and lungs (post mortem)
February 1957	2	Oesophagectomy	C	Wound infection
April 1957	3	Thyroidectomy	C	Wound infection
	4	Thyroidectomy	C	Wound infection
May 1957	5	Valvotomy	C	Wound infection
	6	Appendicectomy	D	Wound infection
June 1957	7	Unknown	C	Wound infection
August 1957	8	Nephrectomy	E	Wound infection
September 1957	9	Valvotomy	C	Wound infection
October 1957	10	Thyroidectomy	C	Wound infection
	11	Operation for relief of coarctation of aorta	C	Wound infection (life) blood culture, pericardium, pleural cavity, spleen and lungs (post mortem). Also isolated = type 53w/77+ from blood culture, pleural fluid (life), pericardium and pleural cavity (post mortem)
	12	Valvotomy	C	Blood culture, nasal and throat swabs. Also isolated = type 71+ (1000 R.T.D.) from throat swab, blood culture, wound infection.
November 1957	13	Repair diaphragmatic hernia	C	Pleural cavity; later, type-80 also isolated.
	14	Splenectomy	C	Wound infection

this patient. 2 strains of staphylococci were isolated from each of 2 other patients who had undergone cardiac operations (cases 11 and 12). In case 12 the second strain was similar to but not identical with type 3Bw/55vw/71, and may have been a rather phage-resistant variant of it. In case 11, like case 1, the second staphylococcus isolated belonged to phage group III, but there is no evidence to indicate what the sources of these group III organisms were.

Table IX records the staphylococci isolated from surgeon C's nasal swabs and also from cultures of the inner surface of his mask and gloves. Numerous attempts were made to isolate staphylococci from surgeon C's gloves and skin, but the organism was found only on one occasion in his gloves.

Tables VIII and IX show that the majority (12 of 14) of the infections due to this unusual strain were in cases operated upon by surgeon C and that he carried this strain in his nose over a long period of time. Although he acquired the second epidemic strain, type 80, in his nose in November 1957, he continued to harbour type 3Bw/55vw/71 also — at least until 12th December 1957. No other member of the medical or nursing staff carried

TABLE IX

Staphylococcal Strains isolated from

Surgeon C's Nose, Mask and Gloves

Date	Site	Strain isolated
3.12.56	nose	type 3B/3C/55/71
29. 4.57	nose	type 3Bw/55vw/71
24.10.57	nose	type 3Bw/55vw/71
31.10.57	nose	type 3Bw/55vw/71
4.11.57	nose	type 80
11.11.57	nose	type 80
14.11.57	nose	type 3Bw/55vw/71
18.11.57	inner mask	type 3Bw/55vw/71
28.11.57	nose	type 80
9.12.57	(nose	type 80
	(inner mask	type 3Bw/55vw/71
12.12.57	(nose	type 80
	(inner mask	type 3Bw/55vw/71
16.12.57	gloves	type 80
9. 1.58	(nose	type 80
	(inner mask	type 42E/53/75 (1,000 x R.T.D.)

this strain except for one house surgeon from whom it was isolated on one occasion only in October 1957.

Discussion

There are two principal routes by which this surgeon's nasal strain may have been communicated to wounds at operation.

1. It could have been transmitted from the skin of the hands via glove punctures.

2. It could have spread by the air from mask, skin or clothing.

It is not known which of these routes was the more important. The sporadic nature of the infections suggests that the organisms passed only intermittently from surgeon C to the wound. Glove punctures are common and in most theatres about 30% of gloves have to be discarded after use for this reason. Despite repeated tests of surgeon C's skin and gloves his nasal strain was isolated from his gloves on only one occasion, in December 1957, when he was carrying type 80 in his nose. This shows, however, that the skin was occasionally contaminated with release of the organisms into the inside of the gloves. This is

in keeping with the sporadic nature of infections and with the fact that the infections tended to follow lengthy operations when glove punctures might be more frequent.

It is striking that positive cultures were obtained on several occasions from the inner surface of the mask. The masks used in the theatre did not have an impermeable layer of cellophane inserted between their folds, and it is therefore quite probable that contamination of the outer mask surface took place. Reference has already been made to the fact that there was an impression that infection was particularly troublesome in operations carried out in the new theatre. This theatre is modern in design. In theory it has a positive pressure system of controlled ventilation. Unfortunately this did not function as intended as a plenum ventilation system — because of the presence of a large hatch in one of the walls and because of inadequate thrust of the inlet fans — and air was drawn into the theatre through the doors. Air counts estimated on a slit sampler showed that the bacterial content of theatre air was higher than the desirable level but did not show a dangerous degree of bacterial contamination. The louvres of the input

vents in the ceiling, however, directed air straight down on to

the wound from above the surgeon's head and it is possible that

in this way staphylococcus-carrying particles could have been

dislodged from the surface of the surgeon's mask and carried into

the wound.

In the 2 cases not operated upon by surgeon C (cases 6

and 8), there was no evidence to indicate the source of the

infection and in the absence of known contact with either surgeon

C or a patient infected with the organism, this remains unknown.

II. Epidemiology of Infections due to Type 80

Clinical Record

During the 3 months from 1st November 1957 to 1st

February 1958, there was an epidemic of infections due to type 80

(which in this instance was resistant to penicillin and

streptomycin but sensitive to the other usual antibiotics) in

the surgical unit. Type 80 had first appeared several months

previously as a cause of sporadic surgical infection but it was

not until November 1957 that it became the predominant cause of

infection. Many of the patients developed septic lesions other

than wound infections;   these included boils, carbuncles,

infected ulcers, pustules, two cases of pneumonia and one of

abscess.   The monthly incidence of these lesions and of wound

infections is shown in table X.

Table X shows the sudden increase of type 80 infections

in November 1957.   During the following 3 months there were

20 cases of wound infections and 15 cases of other septic lesions.

The wound infections were not confined to the cases of any one

surgeon or to patients in any one ward.   One male ward, however,

was more severely affected than the others.   During the epidemic

period type 80 showed a clear predominance as the infecting

strain in the unit and was responsible for 62.5% of all wound

infections.

Sepsis due to type 80 was not confined to the surgical

unit, but affected patients throughout the hospital.   Information

is incomplete about these infections in other parts of the

hospital but it is known that at least 12 patients developed

septic lesions due to type 80.

Several members of the medical and nursing staff also

developed infections caused by the epidemic strain.   These

TABLE X

Monthly Incidence of Infections

due to Type 80 in Surgical Patients

Date	Wound Infections	Other Septic Lesions
1957		
March	0	1
April	0	1
May	0	0
June	0	1
July	1	0
August	3	1
September	1	1
October	1	1
November	7	6
December	4	4
1958		
January	9	5 (2 in patients with infected wounds due to type 80
	Total = 26	Total = 21

included two surgeons, who had boils on the finger and wrist respectively, and a surgical ward nurse who had a boil of the forearm. Two nurses in other departments suffered from septic fingers and the operating theatre orderly, who had been discovered to be a skin and nasal carrier of type 80 in October 1957, later developed recurrent boils of the face and neck. The epidemic strain also colonised the noses of several members of staff and patients. A close watch had been kept on staphylococcal nasal carriage in the theatre staff from the beginning of the investigation. This showed that the theatre orderly and surgeon C were the only persistent nasal carriers of type 80. Surgeon C first acquired type 80 in November and continued to carry it during the following 2 months. Three other members of the theatre staff were temporary carriers; these were the theatre sister and one of the surgeons who, on different occasions, each had a single nasal swab positive for type 80, and another surgeon from whose gloves the strain was once isolated although he was never a nasal carrier. Nasal carriage among the staff and patients in surgical wards was never investigated on a large scale. However nasal swabs taken in February from nurses and patients in the

most affected ward showed that 3 of 14 nurses and 5 of 41 patients

carried the epidemic strain.

Discussion

It was not possible in this outbreak to obtain enough

clinical details about the wound infections to determine whether

they had been acquired in the theatre or ward.   Nevertheless it

was obvious from the number of patients developing septic lesions

other than wound infection that ward cross-infection was on an

extensive scale.   That some ward nurses and patients acquired

the strain in their noses is further proof that type 80 was

spreading in the wards.   Patients with discharging lesions are

likely to be more dangerous sources of infection than nasal

carriers, and, since there were no isolation facilities for

infected patients, this doubtless contributed to further spread

of the epidemic strain in the environment of the wards.   Many

of the wound infections may have been acquired in this way —

either through contamination during wound dressing or by

colonisation of the patient prior to operation.

The members of the staff who developed septic lesions

due to type 80, with one exception, went off duty until the lesions

had healed and were therefore unlikely to have been responsible for

any of the infections.   The exception was the theatre orderly who

was a skin and nasal carrier of type 80 and who was discovered in

December to be suffering from recurrent boils of the face and neck.

It was realised that he might be a dangerous source of infection

in the operating theatre.   His duties included the loading and

unloading of dressing drums from the steriliser and he could have

contaminated the contents of the drum when handling them to close

the vents after sterilisation.   There was no evidence that type

80 had been spread widely in the environment of the operating

theatre.   Swabs taken from numerous sites in the theatre, and

settling plates exposed during operations, showed that staphylo-

coccal contamination was minimal;   and type 80 was isolated from

a sample of theatre dust on one occasion only.

It is unlikely in the type-80 outbreak that surgeon C

was an important source of infection.   Although he may possibly

have transmitted the epidemic strain to a few of his patients

type-80 wound infection frequently followed operations performed

by the other surgeons on the unit.

In this outbreak there were several possible sources of infection in both wards and theatre. Despite the considerable amount of ward cross-infection it was impossible to detect the major source or sources of infection and to trace the spread of type 80 in the unit concerned. This was partly because a great deal of the work was carried out in the absence of much relevant and necessary information — particularly with regard to conditions in the surgical unit. In this case the phage typing disclosed possible patterns of the spread of infection; but the full elucidation of the possibilities remains, as always, a matter requiring diligent inquiry by those in contact with the epidemic. Without this activity, phage typing of the many staphylococci submitted is tantalisingly suggestive but infuriatingly inconclusive. Such was the fate of this particular effort.

f)   An Outbreak of Staphylococcal Infection in

The Glasgow Royal Maternity Hospital

(Published, jointly, in The Lancet, 1958, ii, 1081)

This outbreak was due to type 80 and was characterised by a sudden and dramatic increase in the severity of infections among the babies.   With the co-operation of Dr. T.S. Wilson of the Public Health Department, Glasgow, a follow-up survey was conducted at the homes to which the babies and mothers were discharged.   This showed the extent of infection in the babies which was undetected at the time of their discharge from hospital.

The Hospital

The epidemic broke out in a maternity hospital with 120 beds divided into 3 separate units.   Babies normally stay beside their mother's beds in the post-natal wards but are taken to the nurseries, which are attached to each unit, for bathing or changing or if they are noisy.

The Sick Nursery

The hospital has a sick nursery which is run by paediatricians, and to which ill or premature babies from all 3

units are admitted.   Both before and during the epidemic there

appeared to be more infections in the sick nursery than in the

babies being nursed in the units.   This impression may have been

due, to some extent at any rate, to the routine bacteriological

investigations which are carried out on even the mildest

infections in the sick nursery.   For this reason, and also

because of the better case records kept there, the infections in

the sick nursery form the substance of the account of the epidemic

in the hospital.

Staphylococcal Infections before the Epidemic

Mild infections due to <u>Staphylococcus aureus</u> were common

in the sick nursery before the epidemic.   It was fortunate that

because the staphylococci isolated in the 5 months before the

outbreak had been phage typed, the strains which had been causing

these infections were known.   In practice, only about 85% of

these strains were actually submitted for typing but failure to

submit all strains was due to familiar human errors of one kind

or another and no selection was involved.

Phage typing showed that a variety of types had caused

these infections and although some strains were isolated from more

than one infection none was really predominant.   Type 80 was not

isolated in the hospital during this period.

The Epidemic

Type 80 was first isolated on 19th November 1957 from a

submandibular abscess in a baby transferred to the sick nursery

from one of the units.   Thereafter until the hospital closed

6 weeks later, on the 4th January 1958, type 80 caused 14 of the

18 infections appearing in the sick nursery.   During the epidemic

period the incidence of all staphylococcal infections in the

babies was 11%;   the figure for infection due to type 80 was 8%.

Severity of Infections due to type 80

The most noteworthy feature of the epidemic was the

high case incidence of serious infections.   In table XI the

infections during the epidemic period have been classified

according to severity.

"Minor" infections include skin pustules, conjunctivitis,

inflamed umbilicus, and mouth sores.   "Serious" infections

include abscesses, pneumonia and 1 case of osteitis.   Nine of

TABLE XI

Clinical Assessment of Infections in Sick Nursery During the

Epidemic Period (November 19, 1957, to January 4, 1958)

Minor		Serious[*]	
Type 80	Other strains	Type 80	Other strains
5	4	9 (5 fatal)	0

[*] 2 babies are included who had minor infections due to

type 80 and subsequently developed serious infections,

from which the organisms were not available for typing.

the 18 infections in the epidemic were serious infections; and

all the serious infections were due to type 80. This high

incidence of serious infection is especially significant since

there had been very few such cases in the 5 months preceding the

epidemic. Five of the 9 babies who had serious infections died.

Deaths associated with the Epidemic

Eight deaths in all were associated with the epidemic.

Complete bacteriological investigations were not possible in every

case. The first 6 cases had been nursed in the sick nursery;

cases 7 and 8 were nursed in the units.

Case 1. A male child who had severe cerebral birth injury died

on the 7th day of life, and type 80 was isolated from a blood-

culture taken just after death. Postmortem examination showed a

tentorial tear, cerebral haemorrhage, enteritis, and broncho-

pneumonia.

Case 2. A male child with cerebral contusion died on the second

day. Postmortem examination revealed tentorial bruising and

right lower lobe pneumonia. Type 80 was isolated from a post-

mortem specimen of lung.

Case 3. A premature female baby had a skin pustule on the 4th day from which type 80 was isolated. A scapular abscess developed but she made an apparent recovery and was discharged home on the 10th day. She died in another hospital 7 weeks after birth from bronchopneumonia; type 80 was isolated from the lungs at postmortem examination.

Case 4. A male baby developed a skin pustule due to type 80 on the 6th day and subsequently paronychia and osteitis. He died on the 11th day; permission for postmortem examination was refused.

Case 5. A premature female child developed conjunctivitis due to type 80 on the 5th day. She was transferred to another hospital on the 16th day and died on the 18th day. At postmortem examination death appeared to be due to enteritis and pneumonia. Type 80 was isolated in pure culture from the pleural fluid.

Case 6. A premature female baby developed septic spots on the 6th day from which Staph. aureus was isolated but not phage typed. She died on the 7th day and postmortem examination showed right upper lobe pneumonia. No bacteriological cultures were made but

histological sections of lung showed clusters of gram-positive cocci.

Case 7. A female child developed a skin pustule due to type 80 on the 9th day. She was transferred to another hospital on the 12th day with an axillary abscess due to type 80. After an apparent recovery she was discharged home but died 11 weeks after birth in a different hospital. Postmortem examination showed bronchopneumonia and type 80 was isolated from the lungs.

Case 8. A female baby suffered from septic spots on the skin but was discharged from hospital, apparently well, on the 8th day. She died a week later in another hospital from multiple abscesses and bronchopneumonia from which Staph. aureus type 29/7 (1,000 x R.T.D.) was isolated. This strain had caused a few sporadic infections in the hospital before the epidemic and was therefore probably acquired in the hospital.

Nasal Carriage of Staph. aureus

Staff.

When the hospital was closed, nasal swabs were taken from 475 members of the medical, nursing, administrative and

domestic staffs.   Thirty eight per cent were found to carry

Staph. aureus in their noses but only 0.6% (3 persons) harboured

the epidemic strain.   Of these 3, one was a maid who did not work

in the wards and 2 were nurses.   Both nurses had suffered from

boils during the epidemic but had gone off duty when the boils

appeared.   It was clear from their duties that they were

unlikely to have been responsible for the general spread of the

epidemic.   It was interesting to find that many nurses were

nasal carriers of the strains of staphylococci which had caused

infections before the epidemic started.

Babies.

Unfortunately nasal carriage of Staph. aureus in the

babies was not investigated on a large scale.   In the 5th week

of the epidemic nasal swabs were taken from 16 healthy babies in

the units.   Staph. aureus was isolated from the nose of 13

babies and 3 were found to carry type 80.   In relation to the

clear predominance of the epidemic strain in infant infections,

this was rather a low rate of nasal carriage in the infants.

Staphylococcal Contamination in Wards and Nurseries

When the hospital was closed numerous sites were sampled

for Staph. aureus: these included dust from floors, curtains,

screens, blankets, furniture, and equipment. Staph. aureus was

isolated from many of the sites tested but type 80 was found once

only — in a communal blanket used during changes of infants'

clothing in one of the unit nurseries. Several of the strains

which had caused sporadic infections before the epidemic were

isolated from sites in the nurseries. The failure to isolate the

epidemic strain, which had been so clearly predominant in

infections in the sick nursery, was unexpected.

Infections after Discharge Home

Babies.

While the hospital was closed, notifications were made

by health visitors of the public health department of infections

developing shortly after discharge from the hospital in babies

born in the last two weeks of the epidemic period. In this way,

it was discovered that 21 of 99 babies had developed infections

at home. Nearly all these infected babies had been nursed in

the units in the hospital.   With the exception of 1 case of

breast abscess all the infections were mild.   Eighteen of these

babies were visited at home about one month after their discharge

from hospital and swabs were taken from their nose, umbilicus and

lesion, and from the mother's nose.   Swabs were taken from the

lesions of a further 2 babies although nasal and umbilical swabs

were not obtained.

The strains of staphylococci which were isolated from

lesions in this investigation are shown in table XII.   Sixteen

lesions yielded cultures of Staph. aureus but only 4 were due to

type 80.   This is in striking contrast to the distinct

predominance of type 80 in infections in the hospital, but is in

accord with the type 80 nasal-carriage rate found in infants in

the hospital.   Strains other than type 80 which were isolated

from these lesions belonged to a variety of phage types;   but 10

of the 12 strains were penicillin-resistant indicating that they,

too, were probably acquired in hospital.

Nasal Carriage of Staph. aureus in Babies and Mothers

One month after discharge.

The results from the nasal swabs taken from babies and

TABLE XII

Staphylococci Isolated from Infections in Babies

One Month After Discharge from Hospital

No. of lesions swabbed	No. of lesions from which Staph. aureus was isolated			
	Total	Type 80	Other strains	
			Penicillin-resistant	Penicillin-sensitive
20	16	4	10	2

mothers in the survey are shown in table XIII. Seventeen of the 18 babies and 10 of the 16 mothers from whom nasal swabs were obtained were staphylococcal nasal carriers. Four babies harboured type 80; these were the same 4 babies who had infections due to type 80. Three mothers carried type 80 and in each case their baby was infected with the same strain.

Four months after discharge

Four months after the epidemic all babies were visited who were known either to have been infected with or to have been nasal carriers of the epidemic strain. In this second survey nasal swabs were again taken from mothers and babies and any history of infection in either was noted. The results are shown in table XIV.

The number of staphylococcal nasal carriers among both babies and mothers was much lower than in the previous survey one month after discharge. Thus 7 of 16 of the babies and 6 of 16 of the mothers were staphylococcal nasal carriers. Two babies and 3 mothers harboured type 80. Six babies and 4 mothers had a history of infection which clinically would be regarded as

TABLE XIII

Nasal Carriage of Staph. aureus in Infected Babies and their

Mothers one Month after Discharge from Hospital

No. visited	No. of staphylococcal nasal carriers		
	Total	Type 80	Other strains
Babies: 18	17	4	13
Mothers: 16	10	3	7

TABLE XIV

Nasal Carriage of Staph. aureus in Babies Colonised or Infected by

Type 80 and their Mothers Four Months after Discharge from Hospital

No. visited	No. of staphylococcal nasal carriers			No. with history of infection
	Total	Type 80	Other strains	
Babies: 16	7	2	5	6
Mothers: 16	6	3	3	4

staphylococcal but no bacteriological investigations had been
carried out on the lesions.

Mothers

No systematic attempt was made to investigate infection
in the mothers.   5 mothers were discovered by chance to have
developed infections due to the epidemic strain, type 80.   In
3 the infections were breast abscesses;   in one impetigo and
abscess of the hand;   and in the 5th recurrent boils of the skin
of the chest wall.   This last case was discovered in the survey
of infant infection carried out one month after discharge.   In
this survey another mother was found to have similar lesions due
to a different strain of Staph. aureus which was also the cause
of the baby's lesion.

The 4 mothers with a history of infection in the survey
4 months after discharge included the mother mentioned above who
had boils of the skin of the chest wall due to type 80.   She
still carried type 80 in her nose and in fact the boils had
persisted on her chest and neck until within 2 weeks of the later
survey.   The other infections discovered in this survey were

2 cases of breast abscesses, and one case of stye of the eye.   No

bacteriological investigations had been carried out in these cases.

Re-opening of the Hospital

On the 4th January 1958, the hospital was closed to new

admissions and by 10th January all patients had been transferred

from it.   The whole building was then thoroughly disinfected;

all wards, duty rooms, labour wards and operating theatres were

sprayed with 10% liquid formaldehyde and after a few days were

washed down with water to give a second fumigation.   All the

equipment in operating theatres and labour wards had been treated

with carbolic-acid solution before the formaldehyde fumigation.

The blankets, bed linen, clothing, curtains, and screens, were

sterilised with steam under pressure.   After 18 days the hospital

re-opened (22nd January).   No infections due to type 80 appeared

in the hospital during the six months following its re-opening.

Staphylococcal infections have been fairly common but they have

almost all been mild;   staphylococci of many phage types have

been isolated from them — no one strain being predominant.

The position with regard to infection in the hospital, therefore,

is virtually the same as it was before the epidemic.

Discussion

Outbreaks of staphylococcal infection in maternity hospitals due to <u>Staph. aureus</u> of phage-type 80 have now been reported from many different parts of the world. Some workers — for example, Rountree and Freeman (1955) and Gillespie and Alder (1957) — noted that the infections caused by type 80 were unusually severe and that its rate of colonisation of the noses of hospital staff was low; they therefore regarded the strain as unusually virulent. Munro and Markham (1958) on the other hand, described an outbreak in which minor infections were common and severe complications rare and in which the strain did not therefore appear to be unusually virulent. In the outbreak described the epidemic type 80 strain corresponded closely to the more virulent type of organism described by Rountree and Thomson and Gillespie and Alder. Clinically the epidemic was characterised by a sudden and alarming rise in the number of serious infections among the babies in the hospital concerned. Phage typing showed that the strain had not been present in the

hospital before the epidemic and that its appearance in infant infections coincided with this sudden increase in serious infections. There was no gradual build-up of infection due to the strain; it appeared quite suddenly as the predominant cause of infant infection and remained predominant until the hospital closed six weeks later. It was therefore clear that in this epidemic type 80 was of higher infectivity than other staphylococcal strains. Despite the fact that it caused 78% of the infections in the sick nursery (table XI) the rate of nasal carriage in the staff and of colonisation of the environment of wards and nurseries was extremely low. The latter was a most unexpected finding since it has been shown that as soon as infants were colonised or had open sepsis the infecting strains could be found in the ward dust (Hutchison and Bowman, 1957). It was most interesting that some of the strains of staphylococci which caused the mild infections before the epidemic were isolated from many sites in the hospital, as well as from the noses of many nurses. It is, of course, quite possible that the property of enhanced infectivity in a strain is not necessarily associated with the ability to colonise widely. In this

epidemic the less infective staphylococci appeared to have greater

powers of colonisation than the epidemic strain.

No vigorous attempt was made in the nurseries to control

the infections.   It is doubtful if this could have been effective

in view of the absence of satisfactory isolation facilities at the

time of the epidemic;   this was due to overcrowding which was

unusually great because the building was being altered.   When a

strain of staphylococcus becomes established as a major cause of

dangerous infection without colonising widely, it seems unlikely

that it could be eliminated by the measures usually recommended

which are mostly aimed at preventing widespread colonisation.

Although the closure of the hospital and its subsequent

disinfection were naturally unwelcome measures they were

successful in eliminating the epidemic strain from the hospital.

In the surveys on infants and mothers after discharge

an attempt was made to assess how far type 80 had spread outside

the hospital.   Despite considerable effort, it is probable that

only a part of the total picture was detected.   The nasal swabs

taken from infants after discharge showed a decline in the

staphylococcal nasal-carriage rate from 94% at one month (table XIII)

to 44% at 4 months (table XIV).   In the survey 4 months after

discharge only 2 babies and 3 mothers still carried type 80,

although infants were selected who were known to have been

involved in the epidemic.   There was therefore no evidence that

type 80 persisted longer in the nose than any other strain, and

the danger of its spreading widely in the general population as a

result of the epidemic appeared to be small.

It was interesting to find that type 80 did not show

such a clear predominance in infections at home as it had done

within the hospital.   This, of course, may simply be a

reflection of the strain's low powers of colonisation because its

prevalence in these infections, which was 25% (table XII),

corresponds closely to its prevalence in the infant staphylococcal

nasal carriers in hospital (23%).   But an unusually infective

staphylococcus would have been expected to cause disease more

frequently than normally pathogenic staphylococci, and why this

did not happen in babies discharged from hospital is not known.

The incidental discovery that penicillin-resistant strains other

than type 80 (which was resistant to penicillin and the tetra-

cyclines) were causing infections in infants at home, suggests

that even in the absence of the epidemic strain, hospital-acquired

staphylococci would still be giving rise to a considerable amount

of infection.   This raises two important points.   Firstly,

penicillin should never be used in these cases until the

antibiotic sensitivity of the infecting organism has been

determined.   Secondly, these infants and their mothers may

introduce antibiotic-resistant staphylococci into the general

population.

It is clear that follow-up surveys are essential to

determine the true extent of staphylococcal infection acquired

in maternity hospitals and this has been emphasised recently by

American workers (Ravenholt, Wright and Mulhern 1957, and Wysham,

Mulhern, Navarre, La Veck, Kennan and Giedt 1957).   Unfortunately

it is very difficult to carry out follow-up surveys in this

country.   In the outbreak described by Ravenholt and his

colleagues, inquiries were made by telephone about the subsequent

progress of babies and mothers — a method which would, of course,

be quite impractical in the United Kingdom.   Wysham and his

colleagues examined babies and mothers when they attended post

natal clinics .   This might be a practical method of follow-up

in this country, particularly if inquiries could also be made at child-welfare clinics. As things are, it is difficult for staff in maternity hospitals to be aware of the extent to which staphylococci acquired in hospital cause disease in babies and mothers after discharge. The surveys reported here show the possible extent of this kind of infection. It was also discovered that 3 infants died of staphylococcal disease after they had been discharged home apparently well.

It is very doubtful if these cases would have been traced to the hospital if, with the co-operation of other bacteriologists in the area, an especial effort had not been made to discover cases of infection in these babies. Because it is clearly important that maternity hospital staff have these cases brought to their notice it is suggested that serious staphylococcal infection appearing in infants after discharge be reported to the local health authority and to the hospital where they were born.

CHAPTER   V

OUTBREAKS   OF   STAPHYLOCOCCAL   INFECTION   IN   HOSPITAL.

A   DISCUSSION.

Outbreaks of Staphylococcal Infection in Hospitals.

A Discussion.

Staphylococcal infection is acknowledged as a major problem in many hospitals to-day. It is especially troublesome in surgical and maternity units — doubtless because patients with surgical wounds and newborn infants are more liable to develop infection than other patients. Two factors have largely been responsible for renewed interest in the centuries-old problem of hospital infection: first, the emergence of antibiotic-resistant strains of staphylococci and second, the appearance of epidemics of infection due to the organism in hospital wards.

This thesis describes the investigation of hospital staphylococcal outbreaks by phage-typing. The phage-typing technique has been described in detail. As a method of typing staphylococci it is laborious and time-consuming but once the initial difficulties have been overcome it is invaluable for investigating staphylococcal epidemiology. Numerous different types of staphylococci can be identified by phage-typing and although variation is found, this has been carefully analysed

(Williams and Rippon, 1952) and with experience, the significance

of the results can be assessed without great difficulty. Tables

IV and V show the percentage frequency of phage types isolated

from infections in different groups of patients and phage typed

at the Western Infirmary during the 2 years from June 1957 to

June 1958 and from June 1958 to June 1959. The results

demonstrate another way in which experience is of great value in

this work. The epidemiological significance of individual types

can be more easily assessed if the hospitals, units, lesions and

so on, with which they are commonly associated, are also known.

The importance of being familiar with the types causing infection

in a unit prior to the appearance of an epidemic can hardly be

over-emphasised. With information of this sort, an epidemic

can be recognised at an early stage and investigations can be

undertaken which may elucidate the source and mode of spread of

infection before the epidemic strain has become firmly established

in the unit concerned. It is in any event extremely difficult to

investigate epidemiology in retrospect. It may be unreasonable

to expect every hospital to phage type all staphylococci isolated

in its precincts, but a case can be made out for making facilities

of this sort available to all or most maternity hospitals.   In

the Royal Maternity Hospital, Glasgow, and its associated

hospitals, the Ross Hospital, Paisley, and Redlands Hospital,

Glasgow, routine phage typing is undertaken by the laboratory in

the Western Infirmary.   There is good evidence that, since the

1957-58 outbreak due to type 80, this service has helped to

prevent the development of further outbreaks.   In this respect,

the value of personal discussions between those doing phage typing

and those dealing with the investigations in the hospitals must be

emphasised.   In the four outbreaks described in this thesis this

sort of co-operation helped greatly to ensure that appropriate

epidemiological investigations and measures for controlling the

infections were instituted.   Of these four outbreaks, three

involved surgical patients and the fourth took place in a

maternity hospital.   This discussion deals with the principal

features of these four outbreaks and considers them in relation

to the general problem of outbreaks of infection in surgical and

in maternity units.

I. The Epidemiology of Outbreaks of
Staphylococcal Infection in Surgical Units

The epidemiology of infections due to <u>Staphylococcus</u> <u>aureus</u> in surgical units was studied by investigating individual outbreaks of infection as they became known in various hospitals. The principal features of the outbreaks described here were as follows:-

1.   <u>The Outbreak in the Western Infirmary, Glasgow.</u>

The source of this outbreak, which was due to type 52A/79, was a boil on a surgeon's forearm.   He was not a nasal carrier of the epidemic strain and the site of the lesion and the nature of the infections (all of which were deep wound abscesses) indicated that the route of infection was direct contact with the wound tissues through the wet sleeves of his gown.   There was an extremely high incidence of infection (6 among 8) in the cases operated upon by the surgeon while he was suffering from the boil and two of the infected patients died.   Although the epidemic strain did not subsequently become a predominant cause of infection in the unit there were three incidents of ward cross-

infection due to it.

2. **The Outbreak in Law Hospital, Lanarkshire.**

The first 9 cases of infection in this epidemic were due to a surgeon who operated while suffering from boils in the axillae which were due to type 80. There was some evidence that 2 months previously he had infected some of his cases from a scabbed over lesion on his finger and that this incident, also, was due to type 80. The route of infection from the axillary boils may have been from contamination of the skin of his hands and arms through glove punctures or wet gown sleeves but could possibly have been by dissemination of the organisms into the air. Although the surgeon was a nasal carrier of type 80 he did not infect his cases except when he himself was suffering from active sepsis. Subsequent to this, type 80 became epidemic as a widespread cause of wound infection in the unit. Most of the infections appeared to have been acquired during operation. It seemed likely that contamination in the wards of either the patients' skin or the gowns in which they were dressed for operation, was the source of these infections. A possible route

by which the gowns could become contaminated was discovered when

type 80 was isolated from a linen basket used for transporting

both clean and soiled linen to and from the laundry.

3. <u>The Outbreak in the Southern General Hospital, Glasgow.</u>

Two epidemic strains were responsible for the majority

of infections in the surgical unit of this hospital. The

source of the first strain, type 3Bw/55vw/71 was the nose of a

surgeon. The route of infection was probably either through

glove punctures from the skin of his hands or from dissemination

of organisms from his mask into the air. The infections due to

this strain had appeared sporadically over several months and

showed a marked tendency to follow long and serious operations.

The second epidemic strain was type 80 and nearly half the

infections it caused were septic lesions other than wound

infections and were clearly due to ward cross-infection. Due

to lack of necessary information it was impossible to determine

if the wound infections had been acquired in the theatre or in

the wards. There were sources of infection in both, because

the theatre orderly was suffering from recurrent furunculosis of

the face and neck, and septic cases were being nursed in the

wards among the other surgical patients several of whom — as

well as some of the nurses — were nasal carriers of type 80.

Staphylococcal wound infections appear in most if not

all surgical units.   Often the incidence of infection is low and

this sporadic sepsis does not as a rule give rise to concern

unless in individual cases when it may seriously delay recovery

or even endanger the patient's life.   Sometimes however the

incidence of infection rises steeply and instead of being

sporadic becomes epidemic.   It is this epidemic infection which,

to-day, is causing concern to both surgeons and bacteriologists.

The outbreaks which have been described illustrate some of the

ways in which this can happen.   The infections in the Southern

General Hospital which were due to type 3Bw/55vw/71 cannot be

correctly called epidemic because they appeared only sporadically

and over a considerable period of time.   Nevertheless they gave

rise to concern in several patients, and two died. The other

outbreaks were associated with a relatively high incidence of

of infection and in each, one phage type of staphylococcus was

responsible for most of the infections.   Outbreaks have been

reported, for example by Shooter, Taylor, Ellis and Ross (1956),
in which many different phage types had caused the infections but
most of the epidemics known to this laboratory have been
associated with one predominant phage type.

There are 3 main factors which may contribute to the
development of epidemic infection.   These are, firstly, the
susceptibility of the hosts, secondly, the sources and routes of
infection and thirdly the infectivity of the epidemic organism.
It is proposed to discuss the four illustrative epidemics which
have been described in relation to each of these factors.

1.   The Susceptibility of the Hosts.

Surgical wounds are highly susceptible to infection.
During an operation the body tissues inevitably undergo varying
degrees of trauma and haematomata or areas of relative ischaemia
may be left in the depth of the wound.   All this can, of course,
be minimised with expert surgical technique but it is nevertheless
likely that any wound constitutes a readly target for the
development of infection.   McDermott (1956) has suggested that,
because of advances in what surgeons now undertake, the hospital

population to-day is less able to combat infection than formerly

and that the present increase in hospital staphylococcal disease

is due to ".... this increased congregation of more susceptible

hosts". He mentions various surgical treatments which may lower

the body's defences to infection including such operations as

total gastrectomy and partial pulmonary resection.

In the outbreaks which are described here, there was,

with one exception, no evidence that the patients involved had

undergone unusually severe operations or had been subjected to

any other treatment which might render them more susceptible to

infection. The exception was the outbreak in the Southern

General Hospital due to type 3Bw/55vw/71 in which there was a

marked tendency for infection to follow cardiac and other long

and serious operations. There was evidence, however, that the

surgeon who was a nasal carrier of the infecting staphylococcus

might have transmitted this strain to his cases through glove

punctures from contamination of his hands or via wrongly directed

air currents due to the faulty ventilation of the theatre.

Gloves would be more liable to be punctured in the course of

long and difficult operations and it is possible that the

association of infection with unusually severe operations may have

been at least partly due to the increased opportunity offered for

the transmission of infection in these cases.   Probably increased

susceptibility of the hosts and increased opportunity for infection

both contributed to the development of infection in this outbreak.

Apart from this, the patients involved in the other outbreaks had

undergone the usual type of operation carried out in general

surgical units and there was no evidence that they were less able

to combat infection than any other patient. with a surgical wound.

It may be concluded, therefore, that there was, on the whole, no

evidence that undue susceptibility of the hospital population to

infection had been a major factor contributing to the development

of these four epidemics.

2.   The Sources and Routes of Infection

If they were not unusually susceptible to infection,

were the patients affected by these epidemics exposed to

particularly dangerous sources or routes of infection?   Surgical

wounds may become infected in the operating theatre or post-

operatively in the wards.   They are probably less susceptible to

infection in the wards than during operation, because the healing process, or the primary union, of a clean incised wound takes place very rapidly. Thus fibroblasts are active by the end of 12 hours and the wound edges are firmly sewn together by the 4th day (Boyd, 1947). During this period most surgical wounds would be firmly covered by an occlusive dressing unless they contained drainage tubes. It might be assumed from this that it is important to ensure only that the operating theatre is free from sources of staphylococci; but there are two reasons why conditions in the wards are of great importance also. Firstly, although theatre-acquired infections may be more common, many wounds undoubtedly became infected in the wards post-operatively. In the epidemics described here, although most of the infections were acquired at operation, in each instance some infections were due to postoperative contamination in the wards. In the Southern General Hospital, ward cross infection giving rise to various forms of septic lesion, was on a considerable scale. Secondly, the ward may be the source of infection although the wounds actually become contaminated at operation. The wards were almost certainly the source of many of the deep wound infections

which appeared in the later stages of the widespread outbreak in the surgical unit in Law Hospital.

Nevertheless, it is probable that a dangerous source of staphylococci will be more dangerous if it has access to wounds during operation. The principal sources of staphylococci in an operating theatre are the surgeons and nurses, the patients, and possibly the air. Of these sources, surgeons are probably the most important; their hands are in direct contact with the wound and organisms disseminated from their skin and clothing will be in close proximity to it. Devenish and Miles (1939) have shown how staphylococci from a surgeon's hands may be transmitted through glove punctures, and the frequency of these makes this an important and dangerous route of infection. This outbreak, together with that reported by Shooter, Griffiths, Cook and Williams (1957), shows that surgeons who are healthy nasal and skin carriers may infect a high proportion of their cases at operation. Although nurses in an operating theatre are not in close contact with the wound they may contaminate equipment used during the operation; and Penikett, Knox and Liddell (1958) have reported an outbreak due to a nurse who contaminated "Terylene" sutures with her nasal

staphylococcus. Blowers (1957) and Kinmouth, Hare, Tracy, Thomas, Marsh and Jantet (1958) have found evidence that infections are often due to staphylococci present on the patients' skin, and Kinmouth and his co-workers noted that these organisms were usually hospital strains which had been acquired in the wards prior to operation. Theatre air contaminated by dust from the hospital corridors due to faulty ventilation has been incriminated as a source of infection, and outbreaks of infection have been attributed to this by Blowers, Mason, Wallace and Walton (1955) and by Shooter, Taylor, Ellis and Ross (1956).

Two of the epidemics described here were due to surgeons operating while suffering from septic lesions and both were associated with a high incidence of infection among the cases at risk. It therefore appears that septic lesions on surgeons' hands or arms may be an exceptionally dangerous source of wound infection. There are two possible reasons for this. Firstly, staphylococci may be both more numerous and more infective when they are derived from an active lesion rather than from a healthy carrier, and secondly, direct planting of these organisms from the surgeons' hands or forearms into the exposed wound tissues may be

an exceptionally dangerous route of infection.   It was first

suggested by Barber and Burston (1955), who were investigating

staphylococcal epidemiology in a maternity unit, that

staphylococci from an active lesion were more dangerous than those

from a healthy nasopharynx.   The 2 epidemics described here lend

further support to this view.   Both the surgeons infected an

extremely high proportion of their cases while they were suffering

from boils;   moreover, the surgeon in the second outbreak did not

infect his cases when he had no sepsis himself, although he

continued to carry the strain in his nose.   In this instance

there was a marked association of sepsis in the surgeon with the

development of infection in his cases.   It is interesting to

compare these 2 outbreaks with the third which was due to a

surgeon who was a nasal carrier (and an intermittent skin carrier)

but who did not suffer from sepsis.   The infections were sporadic

and had appeared over a long period of time and they showed a

definite tendency to follow long and serious operations when the

patient's resistance to infection may have been lowered.   This

suggests that while a surgeon who is a healthy carrier may

occasionally infect his patients, he may be less likely to cause

a serious outbreak of wound infection than a surgeon who is suffering from active sepsis. However, serious outbreaks, which were due to surgeons who were healthy carriers, have been reported by Devenish and Miles (1939) and by Shooter, Griffiths, Cook and Williams (1957) although in the outbreak described by Devenish and Miles the surgeon had suffered from boils some months previously. The type of carrier who can cause outbreaks of this sort is probably rare and dangerous only when the staphylococci he carries have access to wounds during operation through the dangerous route of inoculation by direct contact. Nevertheless the possibility of a healthy carrier being a dangerous source of infection must be borne in mind. Even in the outbreak described here, although infections were only sporadic, the consequences in some of the patients were extremely serious.

It is obvious that the vast majority of nasal carriers among surgeons and members of the theatre staff are not sources of infection to others. In the course of the investigations recorded here many surgeons and nurses were proved to be nasal carriers of staphylococci which never caused infections in patients. Hare and Ridley (1958) estimated that about three-

fifths of a small group of nasal carriers had sufficient numbers

of staphylococci on their skin and clothing to make them capable

of acting as staphylococcal donors.   If these results are correct

and generally applicable, clearly the staphylococci disseminated

from healthy carriers seldom give rise to infection.   This might

be regarded as further evidence that most of the staphylococci

from the healthy nasopharynx are of relatively low infectivity

but further work is necessary on the dispersal of staphylococci

from carriers under operating-theatre conditions before it can be

assumed that such a high proportion of nasal carriers actually

disseminate organisms in theatre without causing infection in

their patients.

In the epidemic which followed the appearance of type 80

in the surgical unit in Law Hospital it seemed probable that

staphylococci acquired in the wards were being transmitted to the

wounds during operation from either the patients' skin or their

gowns.   There was little direct evidence for this beyond the

finding that the gowns in which the patients were clad had been

taken from a linen basket contaminated with the epidemic strain

and the fact that there was no possible source of infection in the

operating theatre which could be demonstrated except the patients themselves.   Kinmouth, Hare, Tracy, Thomas, Marsh and Jantet (1958) found that many patients became skin and nasal carriers of hospital staphylococci in the wards prior to operation.   Since it is unlikely that any method of pre-operative skin preparation can render the skin sterile, (Lancet, 1958) this may be an important mode of infection in an epidemic where one strain has become widespread and predominant in infections in the wards.   In the surgical wards in Law Hospital there were numerous sources in the wards from which type 80 could have been acquired.   The most important were probably the patients infected with type 80 who were being nursed alongside those admitted for operations in the usual way but the epidemic strain was also found in samples from ward dust and blankets.

The role of the theatre air as a source of staphylococci has aroused much interest in recent years.   It is obviously desirable that the air in operating theatres should be bacteriologically as clean as possible and that the system of ventilation should be able to remove rapidly any bacteria liberated into the air.   It is a little difficult to be convinced

the very few staphylococcus-carrying particles which it has been possible to demonstrate on a slit sampler in badly ventilated theatres can be regarded as a dangerous source of infection. Nevertheless, Shooter, Taylor, Ellis and Ross (1956) have described an outbreak which provides at least suggestive evidence that bad ventilation might sometimes be responsible for a high incidence of wound infection.

The only outbreak described here in which the theatre ventilation system may possibly have played a part was that due to the surgeon who was a nasal carrier. Staphylococci were regularly present on his mask and the vertical down-draught from the wrongly-directed input vents above his head may have transmitted the organisms into the wounds. If this were indeed so, the theatre air in this outbreak could be regarded as a route for conveying infection rather than the source of it.

It is often relatively easy to demonstrate the source and to deduce the probable route of infection acquired in the operating theatre. The investigation of the epidemiology of staphylococcal cross infection in the wards, on the other hand, is fraught with difficulties. This is largely due to the

profusion of possible sources of staphylococci in most surgical

wards — particularly under epidemic conditions — and the

virtual impossibility of demonstrating the routes by which the

organisms spread. Caswell, Schreck, Burnett, Carrington,

Learner, Steel, Tyson and Wright (1958) describing an epidemic of

ward cross infection in America due to type 42B/52/81 (which is

similar to the strain known as type 80 in this country)

considered that the most important means of spread of infection

was by direct contact with either staff or patients suffering from

active lesions or heavily contaminated hospital materials. They

found a low incidence of nasal carriage of the epidemic strain

among the staff (4.1%) and noted that outbreaks of infection in

some wards had been preceded by a cutaneous infection in a member

of the ward staff. They concluded that nasal carriers played an

insignificant role in the spread of the epidemic strain and that

infected hospital personnel were the most important source of

infection. The danger of members of staff carrying out ward

duties while suffering from active sepsis is apparent but

recently an outbreak has been described which emphasises that

patients also may be a dangerous source of infection if they are

nursed in an open ward while suffering from superficial skin sepsis. Barber and Dutton (1958) observed a serious outbreak of infection in a surgical ward which was traced to the admission of a patient who had a septic skin condition due to type 80. The epidemic strain was isolated from blankets, bed curtains, the ward air and also from the ward sister's nose. They point out that the carriage of the strain by the ward sister was probably a reflection of the spread of the strain rather than its cause, and suggest that superficial skin sepsis is a more dangerous source of hospital cross infection than are nasal carriers, whose role may be relatively unimportant. The study carried out by Shooter, Smith, Griffiths, Brown, Williams, Rippon and Jevons (1958) on the spread of staphylococci in a surgical ward showed that in several of the staphylococcal "broadcasts" which they observed the strains responsible were first introduced into the ward by a nasal carrier among the patients or nurses. Most often, however, the probable sources from which the staphylococci became widely dispersed were infected lesions — particularly when these were of a nature which would render adequate cover by dressings difficult. Although nasal carriers may occasionally

transmit their strain to others and may thus be responsible for sporadic infection, active lesions are probably the main sources of spread of epidemic infection.   There is little doubt that contaminated dust, blankets, bed screens, and other articles of ward equipment may act as secondary reservoirs in the spread of infection but the staphylococci which contaminate them must be maintained from other sources in the ward.   They could therefore perhaps be better described as routes rather than the sources of infection.

None of the hospitals whose epidemics are described in this thesis had isolation facilities for infected surgical patients. This meant that most of the surgical wards contained several patients with septic lesions being nursed with the other surgical patients admitted for operations in the usual way.   In an epidemic this, of course, results in the congregation of dangerous sources of the same staphylococcal strain among those who, because of their surgical wounds, are especially liable to develop staphylococcal infection.   This was particularly noticeable in the widespread epidemics due to type 80 in Law Hospital and in the Southern General Hospital where infections continued to appear more

frequently in some wards than others.   These more severely

affected wards each contained several patients infected with the

epidemic strain.   In general, when a strain became established

as the predominant cause of infection in a ward, one or two of the

nurses were found to be nasal carriers and it could often be

demonstrated in the ward environment.   It is, of course, almost

impossible under these conditions to demonstrate the actual

source which is responsible for the infections but this suggests

that these nurse nasal carriers simply reflected the spread of the

epidemic strain without necessarily being the cause of it.   In

some of the surgical wards in Law Hospital none of the nurses

were nasal carriers, and it was clear that in these wards the

epidemic was being sustained by infected patients who acted as

sources of infection to the others.

Apart from the surgeon in the Southern General Hospital

whose strain caused sporadic infections in his cases there was no

evidence that nasal carriers played any part in the spread of the

epidemics described.   Active lesions were found to be the most

important sources of staphylococcal infection and were especially

dangerous when organisms from them had access to wounds by direct

contact at operation.   Contamination with staphylococci acquired

in the wards pre-operatively from infected cases was probably

responsible for many of the wound infections which had apparently

become infected during operation.

3.   The Infectivity of the Epidemic Organism

The third factor which may influence the development

of epidemic staphylococcal infection is the infectivity of the

staphylococci themselves.   It is now known that individual

strains differ considerably in their ability to produce disease

and the results of the present study further confirm this.   In

making possible the identification of different strains of

staphylococci phage typing has been particularly valuable in

this respect.

Tables IV and V give details of the percentage frequency

of phage types isolated from infections in surgical and general

wards.   Most of these infections were in patients in surgical

wards.   It can be seen that type 80 was by far the most

important cause of infection: this was mainly due to its marked

tendency to become rapidly the predominant cause of infection in

any unit into which it became introduced.   This ability to cause

widespread infection is well seen in the outbreaks in Law Hospital
and the Southern General Hospital.   Type 80 has, in fact, been
the main problem in staphylococcal infections investigated by this
department over the past 2 years.   Williams (1959) in a review of
epidemic staphylococci points out that epidemics due to type 80
have been reported from many countries all over the world and that
at present we are witnessing its pandemic spread.   He also states
that type 80 is ".... a strain that has more recorded epidemics to
its credit than any other type; whose epidemics are, in our
experience, twice as extensive as the average of all other types".
Most of the epidemics reported in recent literature have troubled
maternity units but extensive outbreaks involving the patients in
surgical wards have been described by Duthie (1957) and Caswell,
Schreck, Burnett, Carrington, Learner, Steel, Tyson and Wright
(1958).   These workers noted a tendency for type 80 to cause
cutaneous lesions among patients and members of staff but whereas
Duthie observed a high nasal carriage rate, Caswell and his
co-workers found that this was relatively low.   In the epidemics
described here, a high incidence of septic lesions was observed
in the Southern General Hospital where many patients and some

members of staff developed this kind of infection, but in Law

Hospital infections other than wound infections were relatively

rare.   If a staphylococcal strain produces an outbreak of

superficial skin infections in a hospital, it is evident that it

causes disease more readily than most other staphylococci and can

probably be regarded as being unusually infective.   However,

even in Law Hospital where this tendency was not marked, type 80

behaved as a dangerous organism with a particular propensity for

epidemic spread.   Although Williams (1959) has observed that

epidemics with type 80 commonly generate a high carriage rate

this has not been a characteristic of outbreaks investigated

here.

Several workers have reported that type 80 tends to

cause more severe disease than is usually seen with most strains

of staphylococci and it has therefore been regarded as unusually

virulent.   This seems to have been most apparent in outbreaks

in maternity units (Rountree and Freeman, 1955; Gillespie and

Alder, 1957; Bass, Stinebring, Willard and Felton, 1958) and may

be due to the greater susceptibility of newborn infants.

Although Duthie (1957) describes the surgical infections as

"severe" it is not clear whether he regards wound infection per se as a severe form of sepsis or the wound infections in this particular epidemic as being unusually severe of their kind. Caswell and his co-workers state that type 80 was the cuase of the severe infections in their hospital but give no convincing clinical facts to support this statement.   In the outbreaks reported in this thesis there was no real evidence that the individual lesions were unusually severe.   Four patients died in the outbreak in Law Hospital, and in each, infection with type 80 played a part;   but the patients' general condition was poor and, on the whole, the organism did not appear to cause more serious disease than any other staphylococcus although it did seem to cause disease more readily.   Rountree and Beard (1958) have noted that although type 80 caused an increased amount of severe disease in the 3 years since it first appeared in Australia, the case mortality rate in infections due to it was no higher than with other staphylococcal strains.   They prefer to call type 80 highly infective rather than highly virulent.   This description is therefore more appropriate to the organism in the epidemics described here than "highly virulent".

Type 80 is a particularly dangerous cause of epidemic

staphylococcal infection but it must be emphasised that other

strains can, and frequently do, give rise to outbreaks of

infection.   Staphylococcal strains of phage group III have been

the cause of several outbreaks in surgical wards (Blowers, Mason,

Wallace and Walton, 1955; Gillespie, 1957; Shooter, Griffiths,

Cook and Williams, 1957; Williams, 1959).   Tables IV and V

show that phage group III strains caused many infections in

the surgical and general wards from which strains were submitted

to the Western Infirmary for phage typing.   Although they have

not given rise to any epidemics as widespread as those due to

type 80 these strains have been a major cause of wound infection

in surgical units.   Shooter, Smith, Griffiths, Brown, Williams,

Rippon and Jevons (1958) found that phage group III strains

formed a high proportion of the staphylococci present in the

environment of surgical wards and caused, from time to time,

small scale outbreaks of infection.   This picture is probably

typical of most surgical wards unless they are experiencing an

epidemic due to a strain of increased infectivity.   Shooter and

his co-workers also found evidence that staphylococcal strains

differed greatly in their ability to cause disease.   Although 186

different phage types were isolated from the ward under investigation

only 13 gave rise to disease and only 3 of these caused infections

in more than one patient.   Probably any staphylococcus which is

coagulase-positive is capable of producing disease but it seems

certain from these observations that different strains vary

greatly in their ability to do so.   Many different grades of

infectivity may exist among staphylococci, ranging from the

highly infective organisms — of which type 80 is an extreme

example — through some of the more dangerous phage group III

strains and others which appear less frequently in infections,

to the strains which very rarely cause disease.   This gradation

in degrees of infectivity among the staphylococci responsible for

infections in surgical and general wards can be seen in tables IV

and V and has been discussed in Chapter IV (b).   It is unlikely

that any staphylococcus can be regarded as of little or no

importance as a cause of infection and incapable of producing

an outbreak of sepsis.   Type 52A/79 is not a common cause of

epidemic infection in surgical units yet when it had access to

surgical wounds from a dangerous source in which its natural

infectivity may have been increased (in this instance an active lesion on a surgeon's forearm) it produced an outbreak of serious wound infection. The other epidemic strain — type 3Bw/55vw/71 — which was responsible for a number of infections in the Southern General Hospital, had been hitherto virtually unknown as a cause of hospital infection. But when it became transmitted to wounds during operation from a healthy carrier who was a surgeon, it gave rise to serious infection in several patients and undoubtedly contributed to the death of 2 of them.

It can be concluded that some strains of staphylococci have a higher infectivity or ability to produce disease than others and so are more likely to produce epidemics of hospital infection. Type 80 is an extreme example of this kind of organism and the outbreaks described here give evidence of its unusual abilities to spread and to give rise to disease more readily than other strains. Other strains may, however, have their natural infectivity enhanced by being derived from an active lesion (which therefore constitutes an exceptionally dangerous source of infection). Staphylococci which very rarely cause infection in the normal course of events may nevertheless do

so when they are transmitted to a surgical wound at operation,

although there is no evidence that their infectivity is in any way

increased.   Possibly the dangerous direct route of inoculation is

partly responsible for this.

No staphylococcal strain, given exceptional means and

oppurtunity, can be ignored as a possible cause of outbreaks of

surgical infection although some strains have inherent properties

of infectivity which make them more dangerous as potential causes

of epidemic infection.

The Control of Outbreaks of Staphylococcal
Infection in Surgical Units

It is probably unrealistic to attempt to abolish

staphylococcal infection from surgical wards.   Since at least

half of both patients and members of the staff carry

staphylococci in their noses, a few sporadic infections from time

to time would not be surprising.   However the incidence of

infection should and probably could be kept to a very low level —

1% or less in clean surgical wounds.   Most hospital staphylococci

are resistant to at least one and usually to several antibiotics,

and it is clear, therefore, that the excessive use of these drugs, far from providing an answer to the problem, will merely result in the appearance of more and more resistant strains. Planned control of or even a thoughtful self-discipline in their use might help to prevent the frequent emergence of strains resistant to several antibiotics. Of itself, this would render serious infections more amenable to therapy, but alone it would be unlikely to prevent outbreaks of infection. The control of infection must ultimately depend on the elimination of sources and the blocking of routes of infection.

The elimination of dangerous sources of infection is the most urgent problem in surgical units. Strict observance of the aseptic technique in the operating theatre and in the dressing of surgical wounds in the wards is vital. Unfortunately there is reason to believe that with the advent of antibiotic therapy, and loose thinking on the subject, aseptic routine is not carried out so rigidly as before. In the epidemics described here 2 surgeons were discovered to have operated while suffering from boils of the arms. This, of course, is a gross breach of the aseptic technique; yet it came twice to notice in

a relatively short period of time — and a time, moreover, when

wound infections were under investigation in the units concerned.

The suspicion is inescapable that this serious lapse is probably

more often allowed than is ever realised or discovered. Nurses,

also, sometimes continue to carry out theatre and ward duties

with septic lesions of their hands, arms and face — perhaps

without being aware of the dangers to which they expose their

patients. Errors of this sort should never be allowed. Members

of the hospital staff should always and at once be relieved of

duties in operating theatre or wards if they are suffering from

active sepsis, and they ought not to return until the lesion is

completely healed.

Although any source of infection is probably more

dangerous if it has access to wounds during operation, measures

are also necessary to rid the wards of the more important

sources of infection. If staphylococcal infection is spreading

in a ward, it is obviously essential to isolate those suffering

from the disease from those who are susceptible to it.

Isolation is an accepted principle in the prevention of infectious

disease and it ought therefore to be applied to staphylococcal

disease in hospital. Few hospital authorities or clinicians have faced up to this: most recognise that staphylococcal infection is a problem in many surgical wards but few have made any provision for the isolation of septic cases. Until infected cases can be segregated from the other patients, staphylococcal infection is bound to continue. Lack of isolation facilities is particularly serious when an epidemic breaks out and is undoubtedly an important way of keeping the infecting strain active as a major cause of infection. If these dangerous sources of infection were denied access to the operating theatre or wards, most outbreaks of infection would probably be prevented or soon cut short.

It has been stated here that most nasal carriers are unimportant as sources of epidemic infection. They cannot of course be ignored, as there is no doubt that some of them infect patients from time to time, and occasionally on an extensive scale (Devenish and Miles, 1939; Shooter, Griffiths, Cook and Williams, 1957). In an epidemic, carriers of the epidemic strain should be relieved of duty and an attempt must be made to abolish the strain from their noses. Although it is sometimes

difficult to do this, the results obtained by Gould and Allan

(1954) and Gould (1957) suggest that the intra-nasal application

of antibiotic cream may be effective — at least as a temporary

measure. The member of staff who is a persistent carrier of an

epidemic strain, and who does not respond to treatment, presents

a particularly difficult problem. It is probably reasonable to

allow such people to resume duties unless there is definite

evidence that they are infecting patients. Apart from a small

outbreak described by Rountree in 1947, there is little published

or other evidence that nasal carriers have caused widespread

infection in a ward but it is certain that they have occasionally

done so in the operating theatre. The outbreaks described by

Devenish and Miles and Shooter and his co-workers suggest that

infection of this sort might be prevented if surgical gloves

could be made of some material less prone to punctures than that

at present in use, and if surgeons wore impermeable oversleeves

over their ordinary gowns. The institution of hand rinses in

antiseptics, such as chlorhexidene in alcohol, before donning

gloves might also help to prevent staphylococci from being

transmitted to the wound from the surgeon's hands in this way.

Recently, several measures have been recommended to prevent staphylococci from reaching the patients' wounds. These include the provision of wound dressing rooms separate from the wards, a plenum ventilation system in theatre supplying filtered air, the sterilisation of woollen blankets by quaternary ammonium compound disinfectants, (or by boiling blankets made of cotton weave, towelling or "Terylene") and the oiling of floors, damp dusting, vacuum sweeping and adequate ventilation of surgical wards. It is most desirable, of course, that surgical units should have facilities of this kind but as considerable expenditure would be involved if they were introduced on a large scale, this is unlikely to happen in the near future. The observations of Clarke, Dalgleish, Parry and Gillespie (1954) that oiling of the floor, bed clothes and screen covers had no effect on the nasal and wound cross infection rates, and of Kinmouth, Hare, Tracy, Thomas, Marsh and Jantet (1958) that positive-pressure ventilation in a theatre with a cross draught over the table failed to reduce post-operative sepsis, indicate that by themselves these measures will not prevent outbreaks of infection. There is at present a tendency to overlook the point

that these sites are only secondary reservoirs of staphylococci

which must be maintained by other sources. The original sources

from which staphylococci in the hospital environment must be

derived are infected lesions and carriers. I believe that the

principal and most dangerous sources of infection are active

lesions and that if these were rigidly excluded from theatre and

wards, the problem of hospital infection in surgical units would

largely be solved. Clearly, if outbreaks of surgical infection

are to be entirely prevented, extra precautions are necessary to

ensure that carriers do not infect wounds during operations —

and measures which might achieve this have been described —

but the approach which is most likely to yield dramatic results

in the first instance, is the isolation of all active lesions

due to staphylococci from wards and theatre. If these dangerous

sources of staphylococci are ignored, measures directed solely at

controlling spread from the secondary reservoirs are unlikely to

succeed. The application to surgical units of the first

principle of the control of infectious disease — namely the

isolation of those with the disease from those susceptible to

it — would probably prevent the most highly infective

staphylococcus from establishing itself as a cause of epidemic

infection.

II. The Epidemiology of Outbreaks of
Staphylococcal Infection in Maternity Units

Staphylococcal infection among the babies in maternity

units is probably even more troublesome than in surgical units.

Mild infections are common in the nurseries of most maternity

hospitals, but from time to time outbreaks of infection have

disastrous consequences. The outbreak of this sort in the

Glasgow Royal Maternity Hospital was investigated more completely

than is often possible because phage-typing facilities were

available and were being systematically used for some months

before the epidemic began. The epidemic has already been

described in detail in this thesis and it is proposed to discuss

the results of the investigations in relation to the general

problem of outbreaks of staphylococcal infection in maternity

hospitals.

The main features of the epidemic were as follows:-

As in most maternity hospitals, mild staphylococcal

infections among the babies were not uncommon before the epidemic.
They had been due to many different phage types of staphylococci,
however, none of which was really predominant.   The epidemic began
when type 80 suddenly appeared as the predominant infecting
organism;   this was associated with a sharp increase in the number
of serious infections which led to the hospital being closed 6
weeks after the first appearance of the epidemic strain.
Investigations carried out just before and just after the closure
of the hospital showed that the nasal carriage rate of type 80
among a small group of babies was low compared to its incidence
in infections and that, although staphylococci were present in
numerous sites throughout the hospital, contamination of the
hospital environment with type 80 was minimal.   The epidemic
strain also exhibited very low powers of colonisation in the
noses of members of the staff.   However, many of the strains
isolated from sporadic infections before the epidemic were found
to have colonised widely.

Inquiries at the homes of some of the babies and mothers
revealed a number of infections due to staphylococci acquired in
the hospital which had appeared after their discharge home.

Type 80 showed no tendency to persist unduly in the noses of the babies and mothers. Three infants died of staphylococcal infection after discharge home from hospital: in 2 cases the infecting strain was type 80, in the third it was a hospital staphylococcus of a different phage type. Infection with type 80 probably contributed to the deaths of 4 other infants.

In the discussion of the epidemiology of outbreaks of staphylococcal infection in surgical units, three factors were considered as possibly responsible for the development of epidemic infection. These were, firstly, the susceptibility of the hosts, secondly the sources and routes of infection, and thirdly the infectivity of the infecting organism. It is proposed to discuss the maternity hospital epidemic in relation to each of these factors.

1. <u>The Susceptibility of the Hosts</u>

Newborn babies are particularly susceptible to staphylococcal infection, which usually takes the form of such minor lesions as skin pustules, conjunctivitis, and inflamed umbilicus but may sometimes be more serious disease — for

example: abscess, osteitis, and pneumonia. The infant's body

cannot of course be protected like a surgical wound by a firm

occlusive dressing, and infection may appear anywhere upon it,

although sites subjected to the minor trauma of rubbing or chafing

are more often affected (Gillespie, Simpson and Tozer, 1958).

Newborn infants are, in any case, probably less able than adults

to combat bacterial invasion perhaps because they have not yet

developed an adequate immunological defence mechanism.

In this epidemic the sick and premature infants in the

sick nursery appeared to be more affected than the healthy babies

in the units. This was probably partly due to the inadequacy of

the records concerning the latter and to the practice carried out

in the sick nursery but not in the units of taking routine

bacteriological specimens from even mild infections. The

infants in the sick nursery may have been more susceptible to

epidemic infection because their physical condition made them

less able to combat infection than the healthy babies, and also

because the crowding of infants together into one nursery

provides a fertile soil for the spread of infection. Infants

in the units are nursed beside their mothers in the lying-in

wards although they normally spend some time each day in the unit

nurseries for bathing and changing or if they are noisy.   These

facts may explain why the infants in the sick nursery appear to

be more affected by the epidemic but they do not alone explain'

why the epidemic broke out.   Under normal conditions there are

always ill and premature babies in the sick nursery and for

several weeks preceding the epidemic there had been some over-

crowding there.   The infants at this time were certainly

exposed to staphylococci yet infections were mild and sporadic.

It can be concluded, therefore, that although the hosts may have

been particularly susceptible to staphylococcal infection,

another factor was primarily responsible for determining the

outbreak of epidemic infection.

2.   The Sources and Routes of Infection

        The investigation of the sources of infection in

infant nurseries is probably even more difficult than in a

surgical ward.   Staphylococci abound in the environment of

most infant nurseries: they contaminate the air, dust, blankets,

and articles of equipment, and they are often present in the

noses of the nursing staff. It has been shown that, in addition
to this, nearly all infants born in hospital become colonised
within a few days of birth and harbour the organisms in their
nose, on their umbilicus and on other areas of the skin surface
(Gillespie, Simpson and Tozer, 1958). With this profusion of
possible sources of staphylococci it is extremely difficult to
determine the actual source or sources which are the most
important in the spread of infection. A considerable amount of
work has been carried out to elucidate this and the following
conclusions may be drawn from it. Nurse nasal carriers are
often responsible for the introduction of a staphylococcal strain
into a nursery (Jellard, 1957) but subsequent spread is usually
from baby to baby (Parker and Kennedy, 1949; Hutchison and
Bowman, 1957). The most important source of staphylococci in
an infant who has become colonised is probably the umbilicus
(Jellard, 1957; Gillespie, Simpson and Tozer, 1958) where
staphylococci may multiply as in an open wound and which may
therefore be a prolific source from which infection is readily
disseminated into the air. The air may be an important route
by which the organisms spread from infant to infant (Jellard, 1957)

although contact via the nurses' hands is probably responsible in

a small number of cases (Cook, Parrish and Shooter, 1958).

Blankets and bedding, however, appear to play little part in the

spread of staphylococci among the infants (Gillespie, Simpson and

Tozer, 1958).

In the epidemic described here type 80 appeared for the

first time in an infection in a baby in one of the units.   The

infant was later transferred to the sick nursery.   Thereafter

type 80 became the predominant cause of infection throughout the

hospital.   It was quite clear that the epidemic was spreading

from infant to infant and that nasal carriers among the nurses

could not be held responsible for the infections.   Nor had there

been any extensive contamination of the hospital environment which

might also have contributed to the spread of infection.   The

predominance of type 80 as a cause of infection would result, of

course, in the congregation of sources of this one strain among

the infants in the nurseries: in addition the epidemic strain

was known to have colonised about one third of the healthy babies

who must therefore also be regarded as possible sources of

infection.   There is evidence that in surgical wards the most

important sources of staphylococci are active lesions rather than healthy carriers. This conclusion may not apply to maternity wards to the same extent. There is, of course, a possible reason for this in that the neonatal umbilicus, which is probably one of the most dangerous sources of staphylococci in a nursery, can reasonably be regarded as an open wound where staphylococci are able to multiply without necessarily causing overt signs of infection. Newborn infants whose umbilical stumps become colonised may therefore be compared to adult patients with infected surgical wounds. In this epidemic although some of the infections were superficial — for example: skin pustules, conjunctivitis, and inflamed umbilicus, from all of which organisms may readily be disseminated, many were of a more serious nature and took the form of abscesses. Abscesses, however, can be described as "closed" lesions (in contrast to the former more superficial infections which constitute "open" lesions) and are unlikely to be sources of infection unless they are actually discharging. In practice, infants with infections of this kind were usually transferred to another hospital for further treatment before this happened and so were

unlikely to have acted as sources of infection to the other infants. The babies who suffered from pneumonia on the other hand may well have been responsible for disseminating the organisms into the air and thus for spreading the infection to others.

There are numerous routes, of course, by which staphylococci may spread from infant to infant. These include the air, the nurses' hands or gowns as they handle the infants, bed linen, or the communal equipment used in the nurseries for bathing and changing. It was impossible to demonstrate which of these routes might have been the most important in the spread of the epidemic but the fact that type 80 was isolated from only 1 sheet, although numerous samples were taken from linen, bedding, dust and equipment generally, suggests that the epidemic spread principally by some other route. There was in fact no evidence that this epidemic was due to spread from a particularly dangerous source of infection. It seemed probable that the dominant factor was the high infectivity of the epidemic staphylococcus.

3.   The Infectivity of the Epidemic Organism

The epidemic is a striking illustration of how dangerous

an unusually infective staphylococcus may be when it appears among

the highly susceptible population of a maternity unit.   The

epidemic strain was type 80, whose special properties have already

been discussed in relation to infection in surgical wards.   It

has been responsible for numerous outbreaks of infection in

maternity units in recent years (Williams, 1959) and in many

instances the severity of the infections has been a prominant

feature (Rountree and Freeman, 1955; Gillespie and Alder, 1957;

Bass, Stinebring, Willard and Felton, 1958).   Type 80 is quite

clearly a strain which is particularly liable to cause extensive

epidemics of infection and may often be responsible for unusually

severe disease but some reports suggest that it does not always

have these characteristics.   Thus Munro and Markham (1958)

described an outbreak in which nearly all the infections were

mild, and Gillespie, Simpson and Tozer (1958) described a nursery

in which type 80 was present as a minor cause of mild infection.

The outbreak described here, however, shows the tendency of

type 80 to produce unusually severe disease.   Williams (1959) has

stated that staphylococcal strains of phage group I are particularly

prone to colonise the noses of the hospital staff and to spread

widely in the environment and that type 80 commonly generates a

high rate of nasal carriage among the members of the hospital

staff.   The extremely low rate of nasal carriage among the staff

and colonisation of the hospital environment generally was one of

the most remarkable features, however, of this epidemic.   The

explanation for this is unknown.   It may have been a special

property inherent in the particular type 80 strain which became

epidemic in this hospital, or it may have been that the shortness

of the epidemic period (6 weeks) allowed insufficient time for

the strain to become established in the unit.   This latter

explanation is unlikely because the epidemic strain had been

established as the predominant cause of infection for the 6 weeks

preceding the closure of the hospital.   The more probable reason

for the low rate of colonisation is that it was due to some

individual characteristic of the strain and this has been

observed previously in outbreaks described by Rountree and

Freeman (1955) and Gillespie and Alder (1957).   It was

interesting that both the nurses who carried type 80 in their

noses had suffered from attacks of boils.   Duthie (1957) noticed

a marked tendency for nasal carriers of type 80 to develop super-

ficial septic lesions and this, of course, affords further proof

of the strain's ability to produce disease more readily than

other staphylococci.

Tables IV and V show that type 80 was the most important

cause of infection in the maternity units from which strains were

submitted to the Western Infirmary for phage typing.   This is

largely due to its appearance in some of these maternity units as

a cause of epidemic infection.   Other strains of staphylococci

can also be responsible for outbreaks of infection in maternity

units and although type 80 is probably more dangerous than most

other strains it must not be regarded as the only staphylococcus

which need occasion concern.   Extensive outbreaks due to other

phage types have been described by Barber, Hayhoe and Whitehead

(1949) and Colbeck (1949).   Tables IV and V show that, unlike

what is found in surgical units in which phage group III strains

are the most common cause of infection, phage group I strains

predominate in maternity hospitals.   It is probable that phage

group I strains constitute a high proportion of the staphylococci

which are normally present in most maternity hospitals and some of which may, from time to time, cause small scale outbreaks of infection. The picture of a few relatively predominant strains waxing and waning from week to week with undercurrents of minor strains was revealed by the investigations of Hutchison and Bowman (1957) into staphylococcal epidemiology in a maternity unit.

In the epidemic described in this thesis, some staphylococci which had colonised extensively had caused very few infections in the preceding months and it was clear that they were of relatively low infectivity. Others appeared to be slightly more infective because they had caused a higher proportion of infections than the former strains. It was plain, in fact, that as in surgical units individual strains of staphylococci differed among themselves considerably in their ability to produce disease and that this was not necessarily related to their ability to colonise.

It is interesting that phage group I strains should flourish more readily in maternity units than in surgical wards. This has been noted and discussed by Williams (1959) in a recent review of epidemic staphylococci. On the whole, it is unlikely

that different strains have been selected in the 2 types of unit

as a result of the use of different antibiotics, for as far as can

be ascertained, the same antibiotics are commonly used in both.

The reason may lie in some as yet unknown property which enables

some strains to cause infection more readily among the infants in

maternity units than among the adult patients in surgical wards.

The difference in the types of staphylococci which frequently

cause infection in maternity units on the one hand and surgical

wards on the other hand is not particularly clear cut and several

strains are fairly common in both.   Nevertheless the difference

exists and the possible reasons for it afford interesting

speculation.

One strain which seems capable of causing disease in

either kind of unit is, of course, type 80.   Although more

outbreaks have been reported from maternity units (Williams, 1959)

it can spread just as extensively in surgical units (Caswell,

Schreck, Burnett, Carrington, Learner, Steel, Tyson and Wright,

1958).   There is little doubt that the newborn infant is

particularly susceptible to infection by staphylococci and that

an unusually infective organism, such as type 80, more often

results in serious and fatal infection when it becomes epidemic

in a maternity hospital. In this outbreak there was no evidence

that a particularly dangerous source played any part in spreading

infection and the special properties of type 80 appeared to be

the main factor in determining the development of the epidemic.

The Control of Outbreaks of Staphylococcal

Infection in Maternity Units

The control of infection among the infants in maternity

units presents a far more difficult problem than that in surgical

units. Conditions in most maternity hospitals to-day make

control of infection virtually impossible to achieve. Probably

the single most important factor responsible for the frequency of

staphylococcal infections among the newborn is the crowding

together of the infants in small nurseries or beside their mothers

in an open ward (when they usually still spend a considerable

amount of time in a communal nursery). The newborn infant is

particularly susceptible to infection with staphylococci and as

most become colonised by the organism within a few days of birth

it is not surprising that infection is so common in maternity

hospitals. The investigations reported here on infection in

babies shortly after their discharge home from hospital, indicate
that the true incidence of hospital-acquired staphylococcal
disease is much higher than is realised from a study only of the
infections observed inside the hospital. The very high incidence
of infection which was revealed by these investigations cannot be
regarded with complacency. Nor can the fact that some of the
infections may be serious and even fatal be ignored. Three
babies were discovered to have died from staphylococcal sepsis
after their discharge from hospital: in 2 cases the infecting
strain was type 80 but the third child died of infection with a
strain which had caused sporadic disease in the hospital but had
never appeared to be particularly infective.

It is difficult to see how infants can be protected
from the staphylococci which are ubiquitous in maternity
hospitals except by the provision of single rooms where they can
be nursed alongside and by their mothers. Unfortunately few
hospitals have this sort of accommodation at present and until
it is available on a large scale the incidence of staphylococcal
infection is likely to remain high.

Attempts to prevent infants from becoming colonised by

staphylococci are almost certainly doomed to failure when they are

being nursed in the conditions pertaining in most hospitals to-day.

Various measures have been recommended in an attempt to reduce

cross infection and colonisation in infant nurseries.   These

consist for the most part of either the application of antiseptics

to what are considered to be the principal sources of infection or

precautions in the handling of infants to avoid the transfer of

organisms from one to the other.   A strict aseptic technique is

of course desirable but is difficult to carry out when a large

number of infants require frequent attention from a few nurses.

The work by Cook, Parrish and Shooter (1958) and Forfar and McCabe

(1958) suggests that most infants become colonised by a route

other than via the nurses' hands.   The most realistic approach

would appear to be to prevent the organisms from reaching and

disseminating from the most important sources of infection.   The

reasons for believing that the umbilical cord may be an important

source of staphylococci have been discussed and good results have

been reported from the application of antiseptics to it in an

effort to reduce cross infection and colonisation.   Jellard (1957)

used triple dye for this and noted a reduction in skin and nasal

carriage rates and Gillespie, Simpson and Tozer (1958) reported

similar results with a fall in the incidence of sepsis after

dusting the cord with powder containing hexachlorophene.   The

study by Gillespie and his co-workers however makes it clear that

this alone will not prevent more than half the infants from

becoming colonised by about the 6th day of life.   Measures like

this may prevent a considerable amount of infection and should

probably be instituted in most nurseries but it must be admitted

that they are unlikely to have much effect on an epidemic due to

a highly infective organism of the sort described here.   When a

strain like type 80 becomes introduced and established as a major

cause of infection then more stringent precautions are necessary.

If prompt action were taken to isolate all infected cases and

carriers of the organism at the outset it might be possible to

break the circle of infection.   This of course can be done only

when phage typing facilities are immediately available.   The

severity of the infections described here indicates that action

of this sort ought to be contemplated if an organism known to be

highly infective makes its appearance.   It may be that not all

epidemics due to type 80 are attended by such serious consequences

as this one, but the risk does not seem to be worth taking and it should be emphasised that it is often extremely difficult to ascertain the number and severity of infections unless inquiries are extended beyond the hospital where the infants were born. Unless prompt action — as outlined above — is taken, it may become necessary to close the hospital. This is always a most unwelcome measure but is preferable to risking infant deaths from infection.

Under present conditions it seems likely that staphylococcal infection will remain a problem in maternity units. Until single rooms can be provided for each baby and mother the dangerous circle of infection from infant to infant will continue, and outbreaks of infection will appear from time to time when a more than usually infective organism becomes established in the nurseries. We are to-day facing the question whether the benefits of confinement in hospital are outweighed by the greatly increased risk of serious infection.

Strenuous efforts should and must be made to ensure that our hospitals do not constitute a danger to the patients, particularly those in maternity units and in surgical wards.

Now that the staphylococcus seems likely to remain unconquered by

any new antibiotic which may be introduced it becomes imperative

that we take measures to protect patients from infection with

this organism . This study suggests that more could be done

to prevent hospital staphylococcal infection than is being done

at present. Staphylococcal disease in hospital is an infectious

disease: much harm has arisen from the failure to regard it and

treat it as such.

Summary

1. ... of phage typing Staphylococcus aureus has been described in detail together with some of the difficulties which are encountered in the setting up of a phage typing laboratory.

2. Differences in the percentage frequency distribution of phage types isolated from infections in surgical and general wards, in maternity units, and in outpatients are discussed.

3. Phage typing was used to investigate in some detail the epidemiological incidence of staphylococcal infection in 3 surgical units and in a maternity hospital.

4. In the surgical units, most cases of wound infection had been acquired in the operating theatre, but in one outbreak there was some evidence that contamination with staphylococci of the wards prior to operation was probably responsible for a number of these.

Summary

1. The method of phage typing Staphylococcus aureus has been

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    surgical units and in a maternity hospital.

4. In the surgical units, most cases of wound infection had

    been acquired in the operating theatre, but in one outbreak

    there was some evidence that contamination with staphylococci

    in the wards prior to operation was probably responsible for

    a number of these.

5. The development of outbreaks of infection was found to be

    determined either by the infectivity of the infecting

    organism, by the wounds being exposed to an unusually

dangerous source of organisms in which their natural
infectivity is increased, or by the organisms having access
to the wounds by a particularly dangerous route of
inoculation.

6. Type 80 is a staphylococcal strain of exceptional infectivity.
    It showed a marked tendency to establish itself rapidly as a
    predominant cause of widespread infections.   In one outbreak
    it caused frequent septic lesions other than wound infections.
    It did not cause unusually severe infections in the surgical
    units.

7. Active lesions were the most dangerous sources of
    staphylococci, and there was evidence that organisms derived
    from them were more infective than those from healthy
    carriers.   The presence of infected patients in the wards
    was considered to have been an important factor in the
    spread of the epidemics.

8. Wounds are particularly susceptible to infection during
    operation and direct contact with organisms from a surgeon's
    hands is probably the most dangerous route of infection.

9. Most outbreaks of wound infection could be prevented if all

those suffering from active lesions, whether patients or members of staff, were isolated from the operating theatre and wards.

10. In the epidemic in the maternity hospital, the main sources of infection were the infants themselves and the infection spread from infant to infant.

11. Newborn infants, particularly if they are ill or premature, are unusually susceptible to staphylococcal infection, but the epidemic was primarily determined not by this, but by the appearance of the highly infective type 80 among them.

12. Type 80 in the maternity hospital showed a marked ability to cause severe and sometimes fatal disease and to spread rapidly as the predominant infecting strain. The high case incidence of severe disease was probably due to the greater susceptibility of neonatal infants to staphylococcal infection as compared to adults. It had low powers of colonisation — in the noses of the nurses and in the hospital environment generally.

13. A considerable amount of infection due to staphylococci acquired in the maternity hospital was discovered only

after the infants had been discharged home.

14. Conditions in most maternity hospitals, where babies are

congregated into small nurseries or open wards, are held to

be largely responsible for the high incidence of staphylo-

coccal disease there and for the appearance of outbreaks of

of infection from time to time.

15. The spread of staphylococci from infant to infant and the

consequent danger of the outbreak of serious infection could

probably be prevented if babies were nursed beside their

mothers in separate rooms.

16. Hospital staphylococcal outbreaks could be prevented by

using the methods by which we successfully control other

infectious diseases.

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